

# Matching Supply with Demand: An Introduction to Operations Management

## Solutions to End-of-Chapter Problems

(last revised February 25, 2008; make sure to visit [www.cachon-terwiesch.net](http://www.cachon-terwiesch.net) for the latest updates, excel files, ppt files and other information)

### Chapter 4

#### **Q4.1. Empty System Labor Utilization**

(a) Time to complete 100 units:

#1 The process will take  $10+6+16\text{minutes}=32$  minutes to produce the first unit.

#2 We know from problem xyz that resource 2 is the bottleneck and the process capacity is 0.1666 units per minute

#3 Time to finish 100 units

$$= 32 \text{ minutes} + \frac{99 \text{ units}}{0.1666 \text{ units/min}} = 626 \text{ minutes}$$

(b) + (c) + (d) Use Exhibit for Labor computations

#1 Capacities are:

Resource 1:  $2/10 \text{ units/ minute}=0.2 \text{ units/minute}$

Resource 2:  $1/6 \text{ units/ minute}=0.1666 \text{ units/minute}$

Resource 3:  $3/16 \text{ units/ minute}=0.1875 \text{ units/minute}$

Resource 2 is the bottleneck and the process capacity is 0.1666 units/minute

#2 Since there is unlimited demand, the flow rate is determined by the capacity and thereby 0.1666 units/minute; this corresponds to a cycle time of 6 minutes/unit

$$\text{\#3 Cost of direct labor} = \frac{6 * 10\$/h}{60 * 0.1666 \text{units/h}} = 6\$/\text{unit}$$

#4 Compute the idle time of each worker for each unit:

Idle time for workers at resource 1 =  $6\text{min/unit} * 2 - 10 \text{ min/unit} = 2 \text{ min/unit}$

Idle time for worker at resource 2 =  $6\text{min/unit} * 1 - 6\text{min/unit} = 0 \text{ min/unit}$

Idle time for workers at resource 3 =  $6\text{min/unit} * 3 - 16\text{min/unit} = 2 \text{ min/unit}$

#5 Labor content =  $10+6+16 \text{ min/unit}=32\text{min/unit}$

$$\text{\#6 Average labor utilization} = \frac{32}{32 + 4} = 0.8888$$

#### Q4.2. Assign tasks to workers

(a)

Worker	Task(s)	Processing Time (sec)	Capacity (units per hour)
1	1	30	120
2	2	25	144
3	3,4	75	48
4	5,6	45	80

The capacity of the current line is restricted by the capacity of the step with the longest processing time. Therefore, capacity =  $1 / 75 \text{ sec} = 48 \text{ units per hour}$ .

(b)

Worker	Task(s)	Processing Time (sec)	Capacity (units per hour)
1	1,2	55	65.45
2	3	35	102.86
3	4	40	90
4	5,6	45	80

Therefore, capacity of the revised line =  $1 / 55 \text{ sec} = 65.45 \text{ units per hour}$ .

(a) No matter how you organize the tasks, maximum capacity of the line is *65.45 units per hour*, i.e. at a cycle time of 55 seconds.

#### Q4.3. Power Toys

(a) Since every resource has exactly one worker assigned to it, the bottleneck is the assembly station with the highest processing time (#3)

(b) Capacity =  $1 / 90 \text{ sec} = 40 \text{ units per hour}$

(c) Direct labor cost = Labor cost per hour / flow rate  
 $= 9 \times 15 \text{ $/h} / 40 \text{ trucks per hour} = 3.38 \text{ $/truck}$

(d) Direct labor cost in work cell =  $(75+85+90+65+70+55+80+65+80) \text{ sec/truck} \times \$15/\text{hr}$   
 $= 2.77 \text{ $/truck}$

(e) Utilization = flow rate / capacity  $85 \text{ sec} / 90 \text{ sec} = 94.4\%$

(f)

Worker	Station(s)	Processing Time (sec)	Capacity (units per hour)
1	1	75	48
2	2	85	42.35
3	3	90	40
4	4,5	135	26.67
5	6,7	135	26.67
6	8,9	145	24.83

(g) Capacity =  $1 / 145 \text{ units/second} = 24.83 \text{ toy-trucks per hour}$

#### Q4.4. 12 tasks to 4 workers

(a)

Worker	Task(s)	Processing Time (sec)	Capacity (units per hour)
1	1,2,3	70	51.43
2	4,5,6	55	65.45
3	7,8,9	85	42.35
4	10,11,12	60	60

(a) Capacity =  $1 / 85 \text{ sec} = 42.35 \text{ units per hour}$

(b) Direct labor content =  $(70+55+85+60) \text{ sec} = 270 \text{ sec/unit or } 4.5 \text{ min/unit}$

(c) Labor utilization = labor content / (labor content + total idle time)  
 $= 270 \text{ sec} / (270 + 15 + 30 + 0 + 25 \text{ sec}) = 79.41\%$

(d) Note that we are facing a machine paced line, thus the first unit will take  $4 \times 85$  seconds to go through the empty system. Flow Time =  $4 \times 85 \text{ sec} + 99 / (1 / 85 \text{ sec}) = 8755 \text{ sec or } 145.92 \text{ min or } 2.43 \text{ hrs}$

(e) There are multiple ways to achieve this capacity. This table shows only one example.

Worker	Task(s)	Processing Time (sec)	Capacity (units per hour)
1	1,2	55	65.45
2	3,4,5	50	51.43
3	6,7	70	51.43
4	8,9	35	102.86
5	10,11,12	60	60

Capacity =  $1 / 70 \text{ units/sec} = 51.43 \text{ units per hour}$

(f) There are multiple ways to achieve this capacity. This table shows only one example.

Worker	Task(s)	Processing Time (sec)	Capacity (units per hour)
1	1,2	55	65.45
2	3,4,6	55	65.45
3	5,8,10	55	65.45
4	7	50	72
5	9,11,12	55	65.45

Capacity =  $1 / 55 \text{ units/sec} = 65.45 \text{ units per hour}$

(g) We have to achieve a cycle time of  $3600/72=50$  seconds/unit. The following task allocation includes a lot of idle time, but is the only way to achieve the cycle time, given the constraints we face.

Worker	Task(s)	Processing Time (sec)
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1	1	30
2	2,3	40
3	4,5	35
4	6	20
5	7	50
6	8,9	40
7	10,11	40
8	12	20

Therefore, a *minimum of 8 workers* are required to achieve a capacity of 72 units per hour.

#### Q4.5. Geneva Watch

(a) *Station E* is the bottleneck with a process capacity of 1 unit every 75 seconds.

(b) Capacity =  $1 / 75 \text{ sec} = 48 \text{ watches per hour}$

(c) Direct labor content =  $68 + 60 + 70 + 58 + 75 + 64 = 395 \text{ sec}$

(d) Utilization =  $60 \text{ sec} / 75 \text{ sec} = 80\%$

(e) Idle time =  $(75 - 70) \text{ sec} / 75 \text{ sec} * 60 \text{ min per hour} = 4 \text{ min per hour}$ ; as an alternative computation, we can observe that the worker has 5 seconds idle time per cycle (i.e. per unit) and that there are 48 cycles (units) per hour. Thus, the idle time over the course of an hour is 240 seconds=4 minutes.

(f) Time to produce 193 watches = time for the first watch + time for the remaining 192 watches =  $6 * 75 \text{ seconds} + 192 * 75 \text{ seconds} = 14,850 \text{ seconds} = 4\text{h}7\text{min}30\text{sec}$ . Production begins at 8:00, so 193 watches will be completed by 12:07:30

#### Q4.6. Yoggo Soft Drink

a. Bottling machine capacity: 1 bottles/second

Lid machine capacity: 0.333 bottles/sec

Two labeling machines capacity:  $10/25=0.4$  bottles/sec

Packaging machine capacity: 0.25 bottles/sec

So the process capacity is going to be  $0.25\text{bottles/sec}=0.25*3600=900 \text{ bottles/hour}$

b. The packaging machine

c. It has no effect on the capacity since it is not the bottleneck

d. Process capacity = 90 boxes/ hour, implied utilization=process capacity/demand rate= $0.666=66\%$

#### Q4.7. Atlas Inc

- The bottleneck is the worker with the highest processing time (across activities), which is Worker 2 (60 seconds)
- Capacity of the line is decided by the processing time of the bottleneck step. Hence we have Capacity =  $1 / 60 \text{ sec} = 60 \text{ units/hour}$
- Utilization is given by Flow Rate/ Capacity. Hence, we have Utilization =  $45 \text{ sec} / 60 \text{ sec} = 75\%$ .
- As we are facing an empty system, the first unit would take  $(50+60+30+45+40)=225$  seconds to go through the system. Hence, Flow time =  $225 + (100-1)*60 = 102.75$  minutes
- Labor Utilization is given by Labor Content / ( Labor Content + Idle Time). Total Labor Content can be calculated as  $(50+60+30+45+40)=225$  seconds. Idle time for each worker can be calculated as processing time of bottleneck - processing time of worker. Hence, we have Labor Utilization =  $225 / (225+10+30+15+20) = 75\%$ .
- Direct Labor Cost = Labor Cost per Hour / Flow Rate =  $5 * \$15 / 60 = \$1.25/\text{unit}$
- Again, there are multiple configurations that minimize completion time, but in all of these the processing time of the bottleneck resource is 55 seconds. Hence maximum achievable capacity is  $1 / 55 \text{ sec} = 65.5 \text{ units/hour}$ .
- Direct Labor Cost =  $(30+20+35+25+30+45+40) \text{ sec} * \$15/\text{hour} = \$0.9375/\text{unit}$
- The bottleneck is worker 3, and process capacity is given by  $1 / 75 \text{ sec} = 48 \text{ units/hour}$

#### Q4.8. Glove Design

- Cutting has a process capacity of  $1 \text{ glove} / 2 \text{ minutes} * 60 \text{ minutes} = 30 \text{ gloves/hour}$ .  
Dyeing has a process capacity of  $1 \text{ glove} / 4 \text{ minutes} * 60 \text{ minutes} = 15 \text{ gloves/hour}$ .  
Stitching has a process capacity of  $1 \text{ glove} / 3 \text{ minutes} * 60 \text{ minutes} = 20 \text{ gloves/hour}$ .  
Packaging has a process capacity of  $1 \text{ glove} / 5 \text{ minutes} * 60 \text{ minutes} = 12 \text{ gloves/hour}$ .  
Therefore, the capacity is **a. 12 gloves/hour**.
- The first statement is incorrect because packaging is the bottleneck. The second statement is incorrect because in a machine-paced line or conveyor belt, the unit spends the same amount of time at each station as the bottleneck. The fourth statement is incorrect because cutting is not the bottleneck. **c. By reducing packaging time the process capacity increases** is correct because packaging is the bottleneck.
- If the demand is 10 gloves/hour, then the implied utilization at packaging =  $10/12 =$  **d. 83.3%**.
- A glove spends 5 minutes in each of 4 stations, so the flow time =  $5*4 =$  **c. 20 minutes**.

#### Q4.9. Worker Paced

a. We know that Step 4 is the bottleneck and has a process capacity = to the capacity of the entire process because the utilization = 100%. We are given the fact that the process capacity = 36 units/hour, and Step 5 has a utilization of 40%. Therefore, the capacity of Step 5 =  $36/0.4 = \mathbf{d. 90 \text{ units per hour.}}$

b. The step with the highest utilization is the bottleneck, or **d. Step 4.**

c. The step with the highest utilization has the highest process capacity. Step 1 has a process capacity of  $36/(4/30) = 270$  units/hour. Step 2 has a process capacity of  $36/(4/15) = 135$  units/hour. Step 3 has a process capacity of  $36/(4/5) = 45$  units/hour. Step 4 has a process capacity of 36 units/hour. Step 5 has a process capacity of  $36/(2/5) = 90$  units/hour. Therefore, the step with the highest capacity is **a. Step 1.**

d. There are 5 workers per hour to make 36 units. The wages per hour, then =  $5 * \$36 = \$180$  in labor costs to make 36 units. Therefore, the direct cost of labor per unit =  $\$180/36 = \mathbf{a. \$5 \text{ per unit.}}$