Universität
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Department of Business Administration

Services & Operations Management

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Module Overview

1. Operations strategy
2. **Process analytics**
3. Quality management: SPC
4. Platform management
5. Sports management

Learning Goals

After this lecture you should be able

- to analyze business processes
- to detect process inefficiencies
- to improve process efficiency
- to determine throughput and cycle times
- to determine process capacity and utilization
- to identify bottlenecks
- to apply Little’s Law

Throughput Time vs. Cycle Time

Case 1

Tunnel

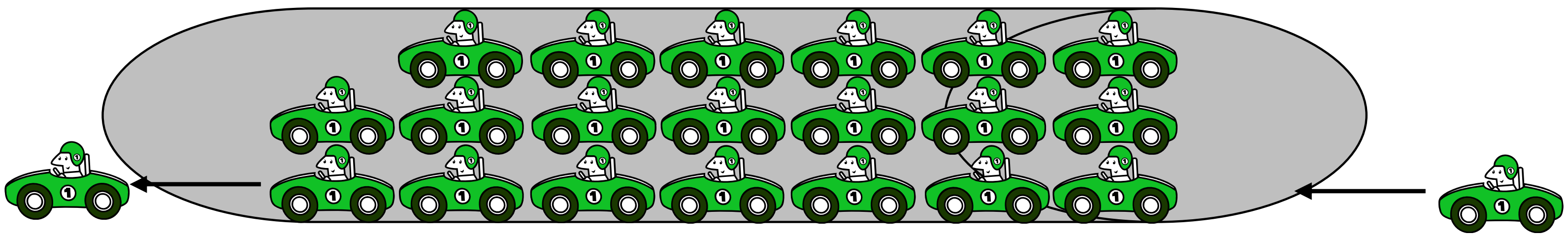
Production rate = 0.05 cars/min

Throughput time = 40 min
Number of cars in tunnel = 2

Cycle time = 20 min

Case 2

Production rate = 0.5 cars/min



Throughput time = 40 min
Number of cars in tunnel = 20

Cycle time = 2 min

Throughput Time vs. Cycle Time

Throughput Time

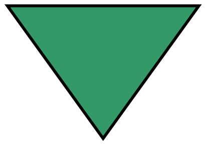
- Period required for a product to pass through the production process
- **Question:** How long is the period between the entry of a car into the tunnel and the exit of the same car out of the tunnel?

Cycle Time

- Period between completion of successive products
- Equals the reciprocal value of the production rate
- **Question:** How long is the period between the exit of a car out of the tunnel and the exit of the next car?

Process Flow Charts (Symbols)

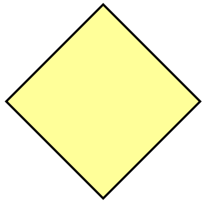
- Holding
  - Raw Materials (RM)
  - Work-in-Process (WIP)
  - Finished Goods Inventory



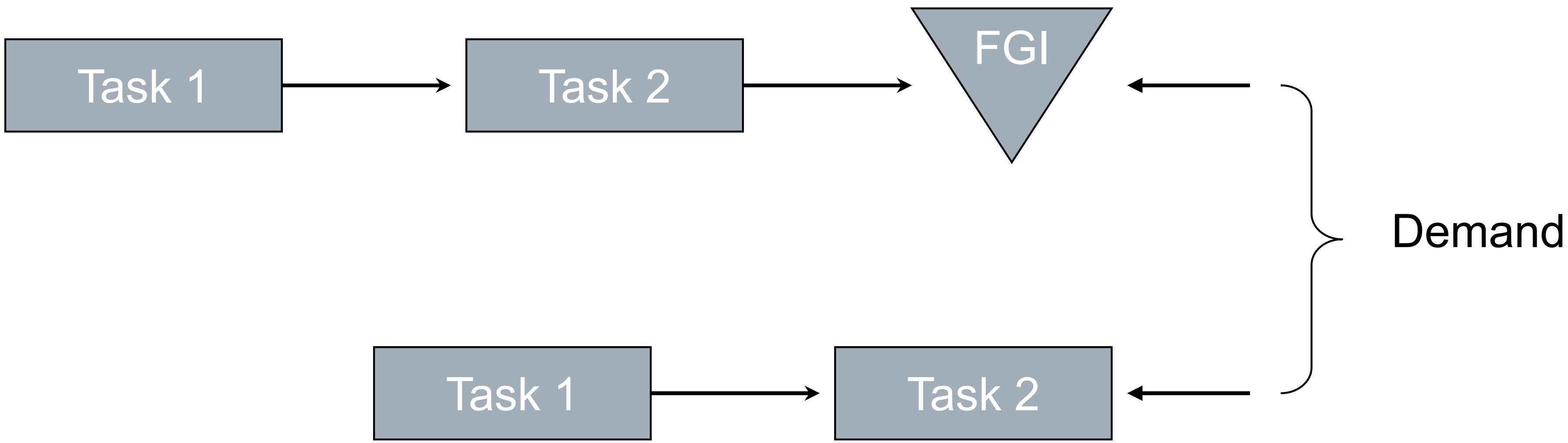
- Flow of Material or Work

- Processing Step

- Decision Point



Make-to-Stock vs. Make-to-Order



If demand is satisfied by FGI then the system is ***make-to-stock***, otherwise it is a ***make-to order*** system

Capacity

- Capacity (per unit of time) = maximum possible output (per unit of time)
  - Examples
    - Steel mill can produce 1’000 tons of steel per week
    - Insurance company can process 125 claims per hour

- Capacity can be determined for every processing step or task and for the entire process

- Process Capacity is determined by the bottleneck

Capacity for a Batch Process

- Batch produces 72 units
- Setup Time is 1 hr.
- Run Time is 5 hrs.

Setup Time	Run Time	Setup Time	Run Time
1hr.	5 hrs.	1hr.	5 hrs.

- **Capacity of Batch** = Units per Batch / Cycle Time = (72 Units per Batch) / ((1+5) hrs. per Batch) = 12 Units per hr.

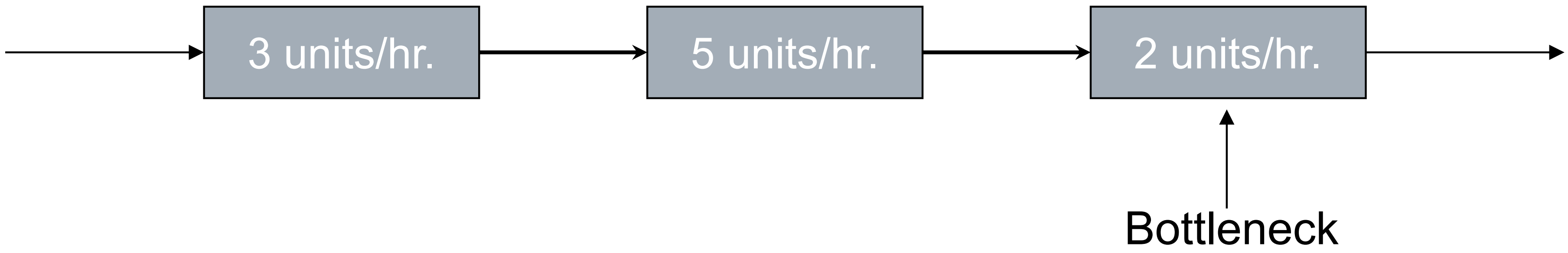
Utilization

- **Utilization** = (Realized Output per Unit of Time / Capacity per Unit of Time) x 100%

- Example
  - As before
  - Batch produces 140 units per day
  - Production time is 14 hrs. per day
  - Utilization = [140 units per day / (12 units per hr. x 14 hrs. per day)] x 100% = 83.33%

Bottleneck

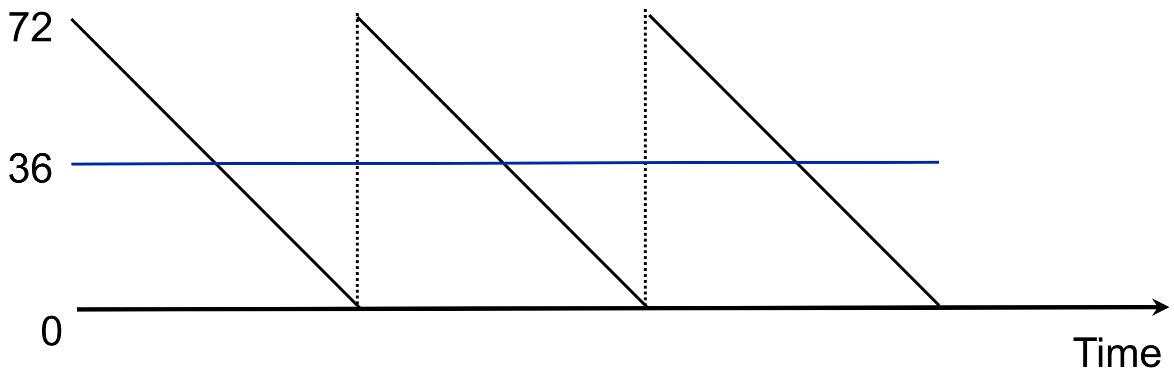
- **Bottleneck of a process** is the resource which limits process capacity
- Bottlenecks define the management focus for process improvements!
- Example



Stock

- **Average Stock** = ½ Batch

- Example
  - A batch consisting of 72 units is produced every 6 hrs.
  - Demand = Production = 72/6 = 12 units/hr.
  - What is the average stock?



Little's Law

- Little's Law explains the relation between Work-in-Process (*WIP*), Throughput Time (*W*) and Production Rate (λ):

Work-in-Process = (Throughput Time) x (Production Rate)

or

$$\boldsymbol{WIP = W\lambda}$$

- Each variable is fully determined by the other 2 variables!

Little’s Law: Example 1

- A bakery produces pretzels at a rate of 10‘000 per hour
- It takes 6 minutes until the pretzels have cooled after coming out of the oven
- How many pretzels must the cooling-down area hold?

Example 1: Solution

- Apply Little's Law:
  - $WIP = W\lambda$
  - We want to calculate *WIP* = Work-in-Process
  - We know
    - *W* = throughput time
    - λ = production rate
  - Filling in gives
    - *WIP* = (0.1 h) x (10‘000 pretzels/h) = 1‘000 pretzels
  - The cooling-down area must hold 1‘000 pretzels

Little's Law: Example 2

- The PACU (post-anesthesia care unit) receives 10 patients per hour
- Patients stay 5 hours in the PACU
- How many beds should the PACU have?
- How does the answer change if the process is not deterministic but stochastic and the values are averages?

Example 2: Solution (1/2)

- Apply Little's Law:
  - $WIP = W\lambda$
  - We want to calculate WIP = Work-in-Process
  - We know
    - W = throughput time
    - λ = production rate
  - Filling in gives
    - WIP = (5 h) x (10 patients/h) = 50 patients
  - The PACU must have 50 beds

Example 2: Solution (2/2)

- How does the answer change if the process is not deterministic but stochastic and the values are averages?
  - Since Little’s Law calculates average values for stochastic processes there will be 50 patients on average in the PACU, often more but often also less.
  - Therefore, 50 beds would not be enough because about half of the time there will be more than 50 patients in the PACU.

Little’s Law: Example 3

- No patient should stay more than 3 hours in the clinic
- There are 30 patients in the waiting room
- What is the required cycle time?
- If every physician can treat 2.5 patients per hour how many physicians are required?
- What changes if treatment times are stochastic?

Example 3: Solution (1/2)

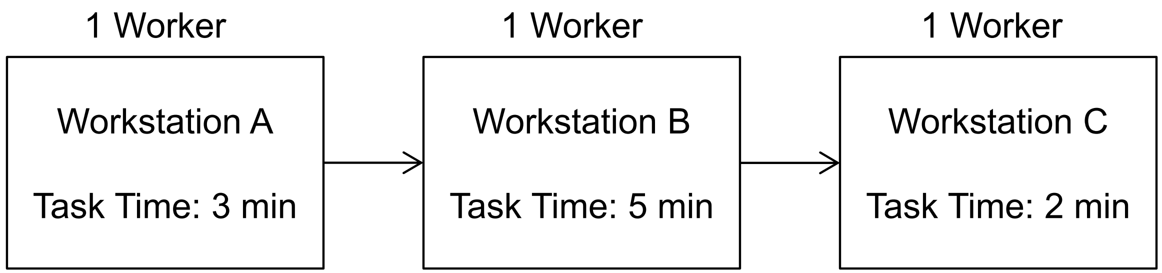
- Apply Little's Law:
  - $WIP = W\lambda$
  - We want to calculate cycle time
    - *Cycle time* = $1/\lambda$
  - We know
    - W = throughput time = 3 h
    - WIP = Work-in-process
  - Filling in gives
    - $\lambda = WIP/W$ = 30 patients/3 h = 10 patients/h
  - The cycle time must not exceed 6 minutes

Example 3: Solution (2/2)

- If every physician can treat 2.5 patients per hour how many physicians are required?
  - *(Number of physicians)x(2.5 patients/h) = 10*
  - *=> 4 physicians are required*

- What changes if treatment times are stochastic?
  - Since Little’s Law calculates average values for stochastic processes the results would be average values.
  - In the stochastic case, an average cycle time of 6 minutes would not be enough to guarantee that no patient must stay more than 3 hours in the clinic
  - More than 4 physicians would be required.

Process 1: Three Step Process (Sequential)

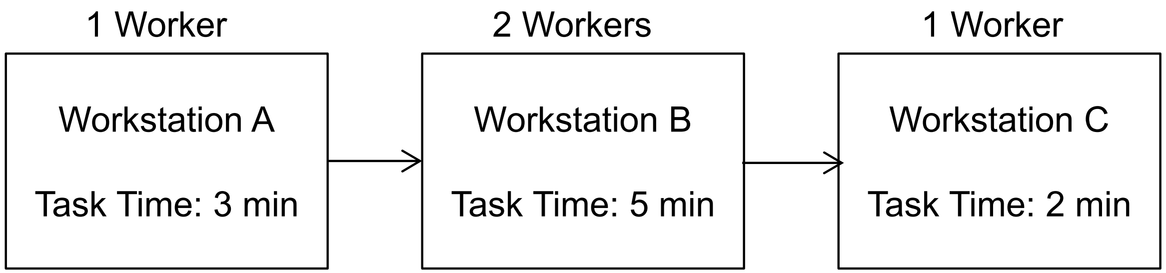


- Where is the bottleneck?
- Calculate cycle time, capacity and throughput time of the entire process!
- Calculate the utilization of each step!
- Calculate the average utilization of the entire process!

Process 1: Solution

- Workstation B is the bottleneck (longest Task Time).
- The cycle time of the entire process is 5 minutes.
- Capacity is 12 units per hour.
- The minimum throughput time for a rush order is the sum of the task times of all 3 workstations.
- Utilization is 60% for Workstation A, 100% for Workstation B (bottleneck) and 40% for Workstation C
- (Average) Utilization is (60% + 100% + 40%)/3 = 66.67%.

Process 2: Process 1 with an Additional Worker



- Where is the bottleneck?
- Calculate cycle time, capacity and throughput time of the entire process!
- Calculate the utilization of each step!
- Calculate the average utilization of the entire process!

Process 2: Solution (1/2)

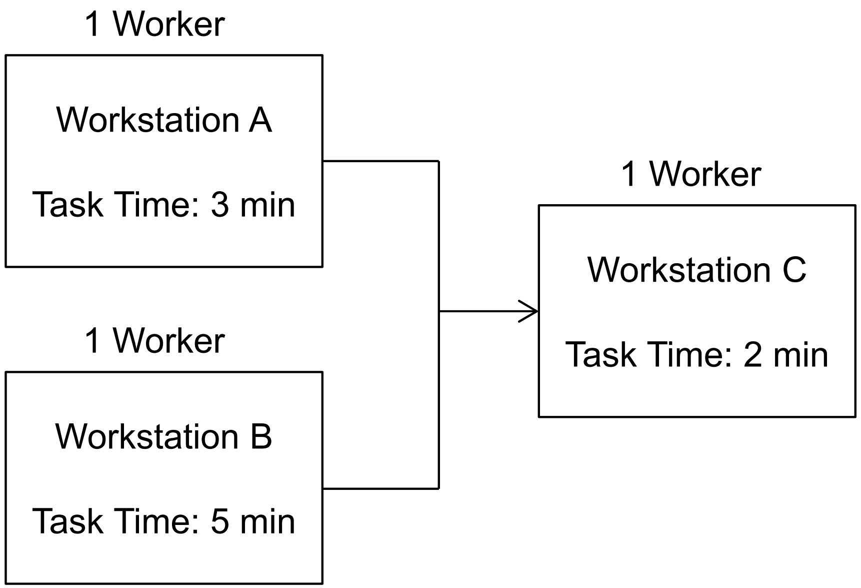
- Adding a second worker to Workstation B reduces the cycle time at Workstation B to 2.5 minutes.
- Workstation A becomes the new bottleneck and the cycle time of the entire process is 3 minutes. Capacity is 20 units per hour.
- Minimum throughput time remains unchanged if the product or service can only be processed by one worker at a time (e.g., processing an insurance claim from the beginning until the end by one worker)
- Minimum throughput time reduces to 7.5 minutes if both workers simultaneously process the same product or service (e.g., loading a truck)

Process 2: Solution (2/2)

- Utilization is 100% for Workstation A, 83% for each of the 2 workers on Workstation B and 67% for Workstation C

- Average Utilization is now (1x100% + 2x83% + 1x67%)/4 = 83.33%.

Process 3: Three Step Process (Parallel Sub Assembly)



- Where is the bottleneck?
- Calculate throughput time, cycle time and capacity of the entire process!
- Calculate the utilization of each step!
- Calculate the average utilization of the entire process!

Process 3: Solution

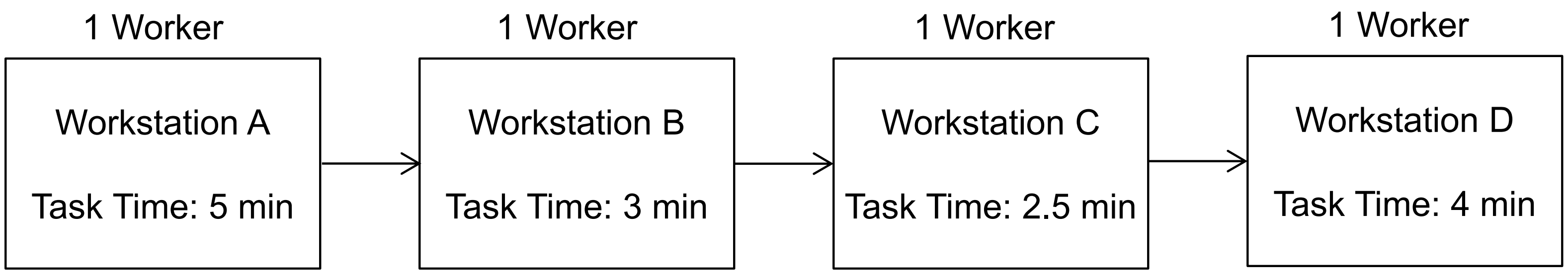
- Process 3 is identical to Process 1, except that steps A and B are done in parallel.

- Throughput time reduces to Max $\{$Task Time A; Task Time B$\}$ + Task Time C = Max $\{3; 5\}$ + 2 = 7.

- Cycle time and capacity remain unchanged.

- Utilization also remains unchanged.

Process 4: Four Step Process

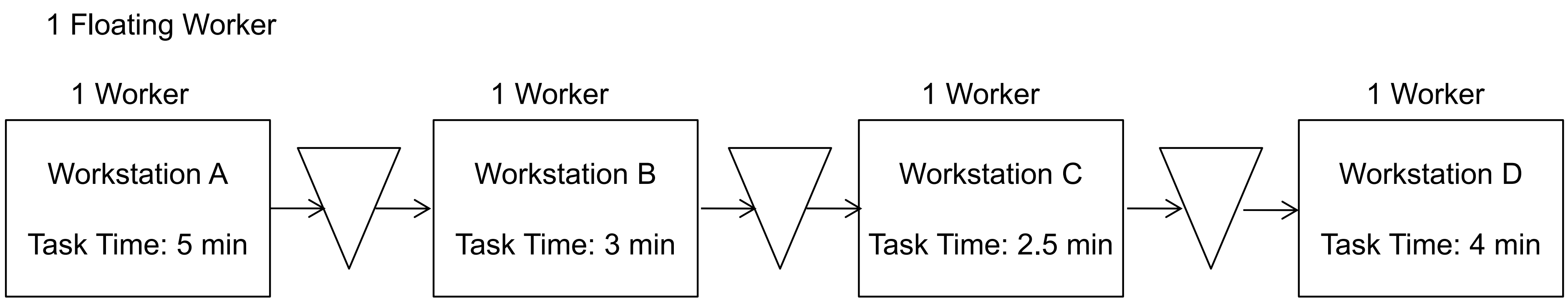


- Where is the bottleneck?
- Calculate cycle time, capacity and throughput time of the entire process!
- Calculate the utilization of each step!
- Calculate the average utilization of the entire process!

Process 4: Solution

- Workstation A is the bottleneck (longest task time).
- Cycle time is 5 minutes, capacity is 12 units per hour.
- Minimum throughput time is the sum of the task times of the 4 workstations = 14.5 minutes.
- Utilization is 100% for Workstation A, 60% for Workstation B, 50% for Workstation C and 80% for Workstation D.
- Average utilization is (100% + 60% + 50% + 80%)/4 = 72.50%.

Process 5: Four Step Process with Cross Training



- The fifth worker (floating worker) is cross-trained, i.e. she/he can work on all workstations.
- There are no transportation costs/times between the workstations.
- Where is the bottleneck?
- Calculate cycle time, capacity and throughput time of the entire process!
- Calculate the utilization of each step!
- Calculate the average utilization of the entire process!

Process 5: Solution (1/2)

- The floating worker will start to work at Workstation A (the original bottleneck). If the floating worker stayed at Workstation A, Workstation D would become the new bottleneck. But, since the floating worker is not fully occupied at Workstation A, she/he will move back and forth between Workstation A and D. This brings the cycle time on the A/D pair down to (Task Time A + Task Time D)/Number of workers = (5 + 4)/3 = 3.

- The Workstation pair A/D and Workstation B will be the bottleneck.

- Cycle time is 3 minutes and capacity is 20 units per hour.

- If the workers can simultaneously work on a product/service, minimum throughput time will be reduced by the floating worker to (Task Time A + Task Time B + Task Time C + Task Time D)/2 = (5 + 3 + 2.5 +4)/2 = 7.25 because the floating worker would be used successively on Workstations A, B, C and D for a priority order.

Process 5: Solution (2/2)

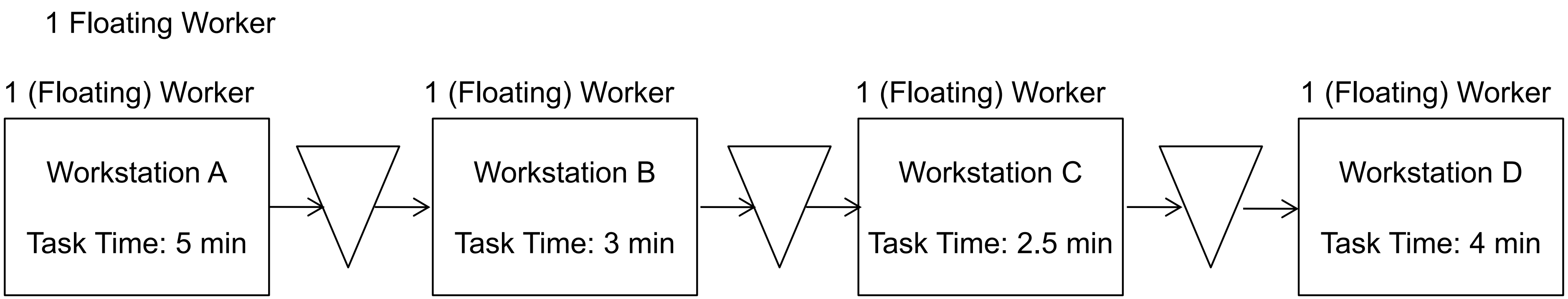
- If the workers cannot work simultaneously on a product/service on each workstation, minimum throughput time will remain unchanged.

- Utilization is 100% for Workstation A, 100% for Workstation B, 83% for Workstation C and 100% for Workstation D.

- Average utilization of the 4 Workstations is (1x100% + 1x100% + 1x83% + 1x100%)/4 = 95.83%.

- Labor utilization of the 5 workers (including the floating worker) is (4x100% + 1x83%)/5 = 96.67%.

Process 6: Four Step Process: All Cross Trained



- Now, all five workers are cross-trained, i.e., they can work on all workstations.
- There are no transportation costs/times between the workstations.
- Where is the bottleneck?
- Calculate throughput time, cycle time and capacity of the entire process!
- Calculate the utilization of each step!
- Calculate the average utilization of the entire process!

Process 6: Solution (1/2)

- With all 5 workers cross-trained, they can all move around freely to break any and all bottlenecks. Indeed, in the simulation they move in tandem from step to step, filling up the succeeding inventory buffer, before moving to the next step.

- The resulting process is equal to a batch process with a batch size of 5 units.

- Throughput time for each unit is (Task Time Ax5)/5 + (Task Time Bx5)/5 + (Task Time Cx5)/5 + (Task Time Dx5)/5 = 14.5.

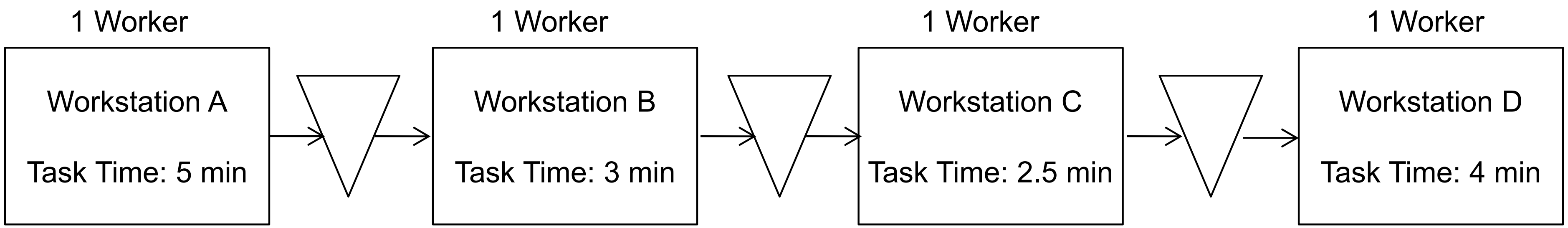
Process 6: Solution (2/2)

- Process cycle time is (Task Time A + Task Time B + Task Time C + Task Time D)/5 = 14.5/5 = 2.9 minutes.

- Capacity is 60/2.9 = 20.7 units per hour.

- Utilization is 100%. All workers are busy all the time.

Process 7a: Four Step Process with Inventories

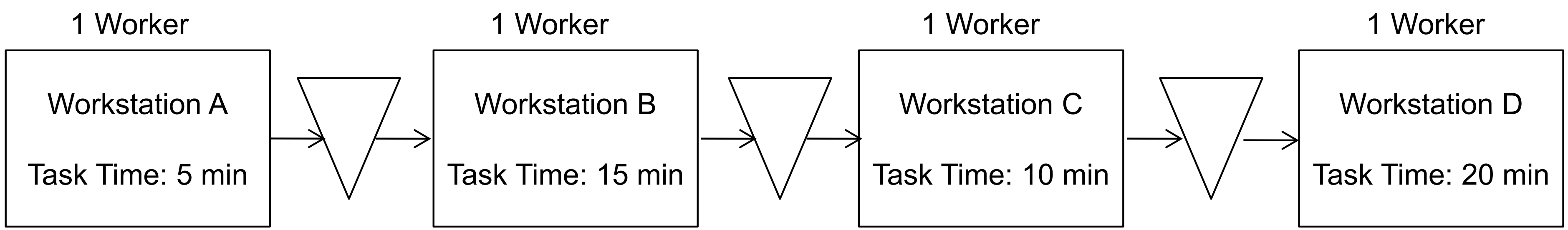


- Each inventory can hold up to 5 units.
- Which of the inventories will fill up?

Process 7a: Solution

- If we introduce inventories, they will remain empty because Workstation A is the bottleneck.
- Workstation A releases products at a rate of one unit every 5 minutes, and the products then go smoothly through the rest of the process.

Process 7b: Four Step Process with Inventories

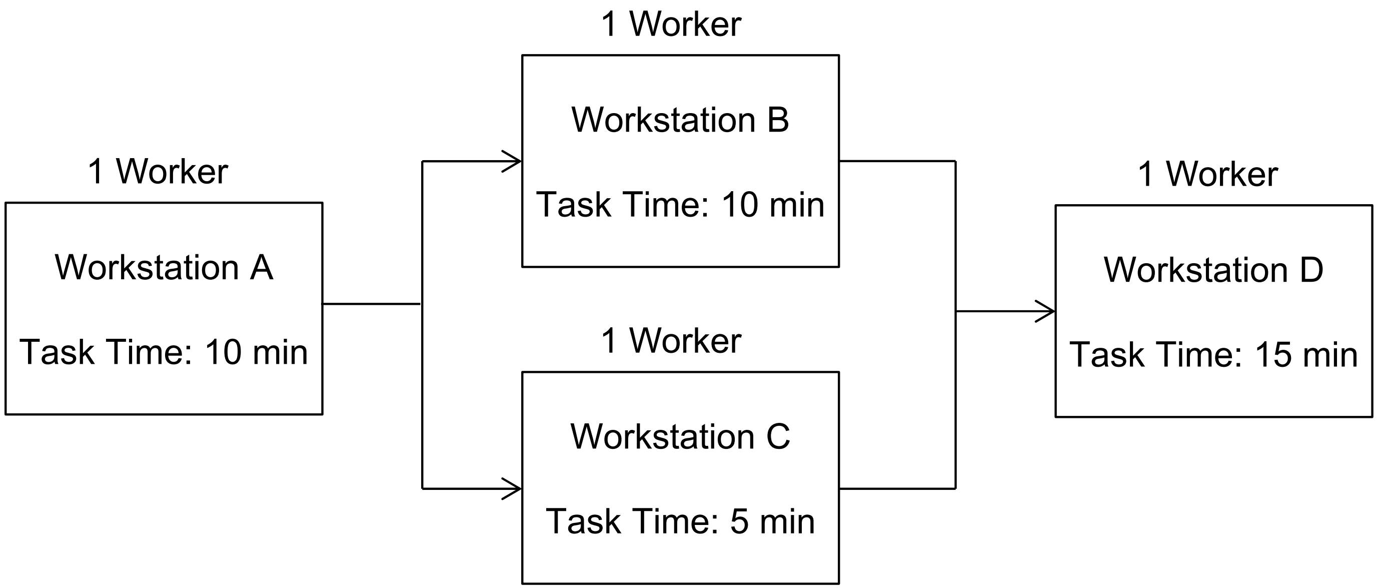


- Each inventory can hold up to 5 units.
- Which of the inventories will fill up?
- How will throughput time be affected?

Process 7b: Solution

- Inventory will accumulate whenever a workstation is followed by a slower workstation.
- Accordingly, inventory will accumulate between A and B and between C and D.
- Once the buffer between C and D is full, C will be blocked. At that point, inventory between B and C will accumulate.
- After a while, all inventories will be full.
- Little’s Law shows that throughput time will increase, if process cycle time remains constant and WIP increases.

Process 8: Sub-Assembly: Symmetrical

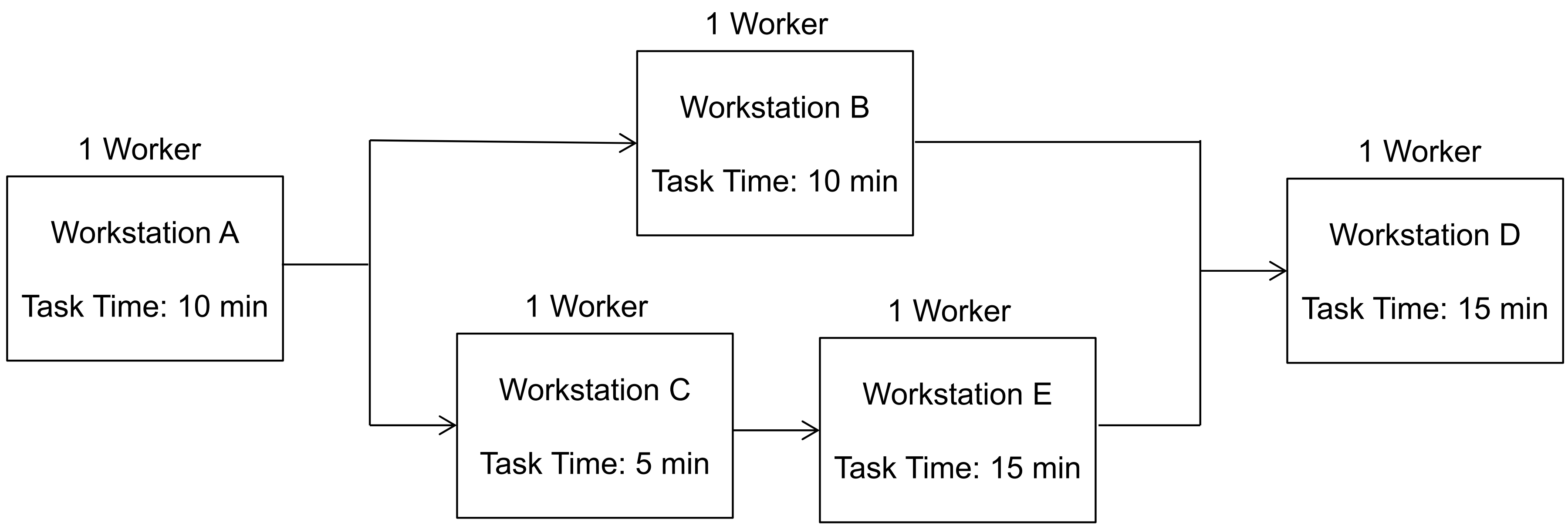


- Where is the bottleneck?
- Calculate throughput time and cycle time of the entire process!
- Calculate the average utilization of the entire process!

Process 8: Solution

- The bottleneck is D.
- Minimum throughput time is Task Time A + Max {Task Time B; Task Time C} + Task Time D = 10 + Max {10; 5} + 15 = 35 minutes.
- Process cycle time is 15 minutes.
- Utilization is (2x67% + 1x33% + 1x100%)/4 = 67.67%.

Process 9: Sub-Assembly: Asymmetrical

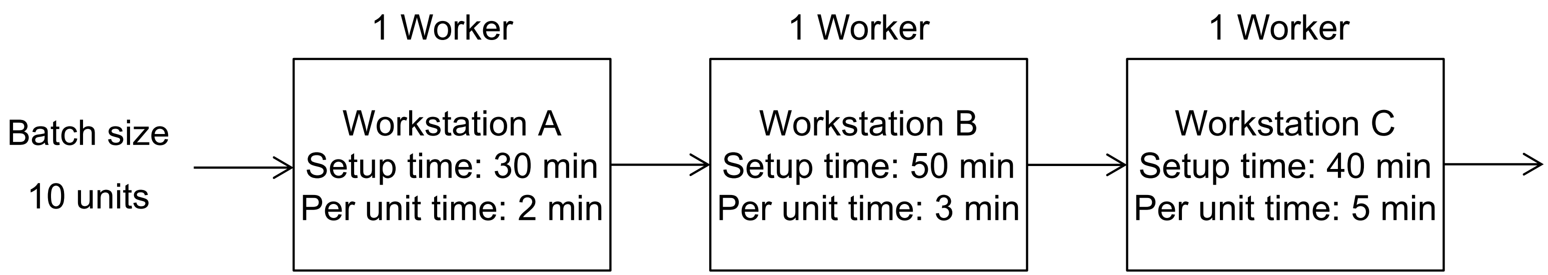


- Where is the bottleneck?
- Calculate throughput time and cycle time of the entire process!
- Calculate the average utilization of the entire process!

Process 9: Solution

- Minimum throughput time is Task Time A + Max {Task Time B; Task Time C + Task Time E} + Task Time D = 10 + Max {10; 5 + 15} + 15 = 45 minutes.
- Bottlenecks are D and E.
- Process cycle time is 15 minutes.
- Utilization is (2x67% + 1x33% + 2x100%)/5 = 73.33%

Process 10a: Batch Processing

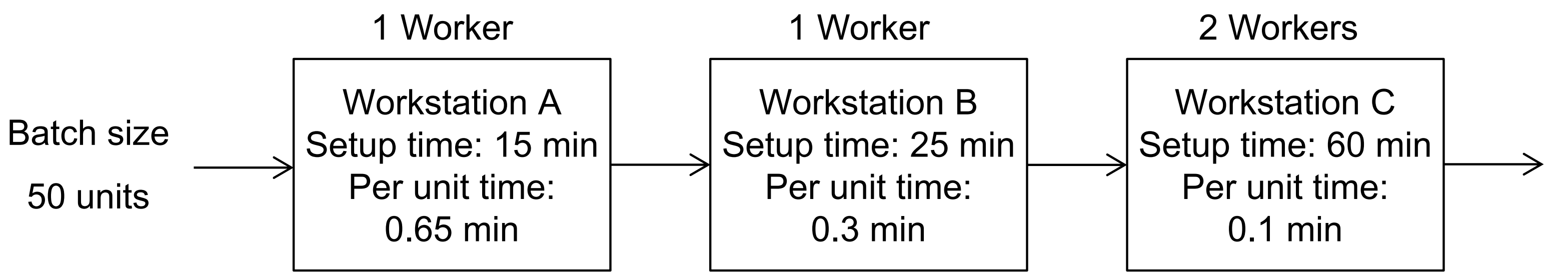


- Where is the bottleneck?
- Calculate cycle time and capacity of the entire process!
- How does a change of the batch size affect the bottleneck?

Process 10a: Solution

- If only 10-unit batches are produced, the cycle time of A is 30 + 2x10 = 50 minutes, the cycle time of B is 50 + 3x10 = 80 minutes, and the cycle time of C is 40 + 5x10 = 90 minutes.
- The bottleneck is C and process cycle time is 90 minutes for 10-unit batches.
- Capacity is 60/90 = 2/3 batches (or 20/3 units) per hour.
- Even if the batch size changes, A will never be the bottleneck because both its setup time and run time per unit are less than B and C.
- Let y be the batch size at which the bottleneck moves from B to C, then the calculation is 50 + 3y = 40 + 5y → y = 5.
- If the batch size is smaller (larger) than 5, B (C) is the bottleneck.

Process 10b: Batch Production



- The second worker at Workstation C helps to reduce setup time and unit time to 50%.
- Calculate the throughput time for one batch!
- Where is the bottleneck?
- Calculate cycle time and capacity of the entire process!
- At what batch sizes does the bottleneck change?

Process 10b: Solution

- Throughput time is 15 + (0.65x50) + 25 + (0.3x50) + [60 + (0.1x50)]/2 = 120 minutes.

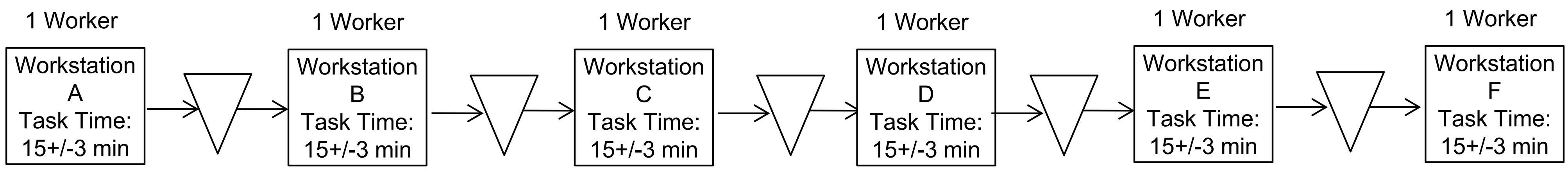
- At a batch size of 50 units, cycle times are
  - A = 15 + (0.65x50) = 47.5 minutes.
  - B = 25 + (0.3x50) = 40 minutes
  - C = [60 + (0.1x50)]/2 = 32.5 minutes.

- A is the bottleneck and process cycle time is 47.5 minutes for 50-unit batches.

- Capacity is 60/47.5 = 1.26 batches (or 63.2 units) per hour.

- If the batch size is reduced, the bottleneck moves from
  - A to B: 15 + 0.65y = 25 + 0.3y → y = 28.6.
  - B to C: 25 + 0.3z = (60 + 0.1z)/2 → z = 20.

Process 11: Stochastic Process

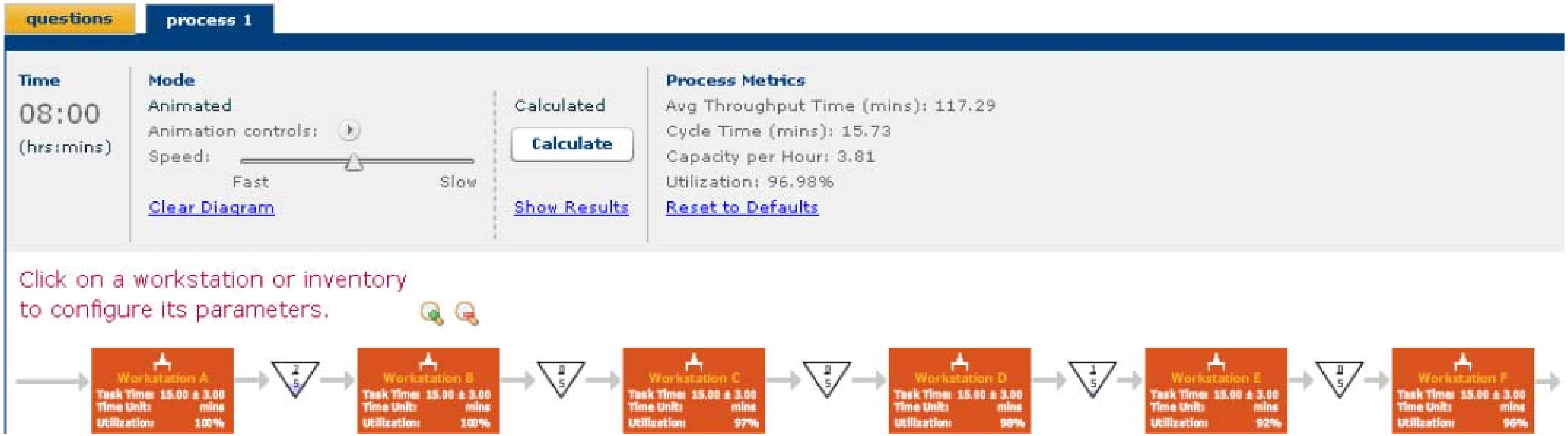


- Now, the task time of each workstation is no longer deterministic, but equally distributed between 12 and 18 minutes.
- Identify the bottleneck!
- Calculate expected throughput time!
- Calculate cycle time, capacity and utilization of the entire process!

Process 11: Solution

- Now, the bottleneck is no longer constant, but may change continuously.
- The fastest possible throughput time is 6x12=72 minutes
- The expected throughput time is much longer. It is not only longer than the sum of the expected task times of all workstations (6x15 = 90) because of the additional waiting time in the buffers (inventories), but also longer than the sum of the longest possible task times of the workstations (6x18 = 108) due to blocking once the buffers are full.
- Expected throughput time, cycle time, capacity and utilization cannot be calculated analytically.
- On the next slide you will find the simulation results.

Process 11: Simulation Results

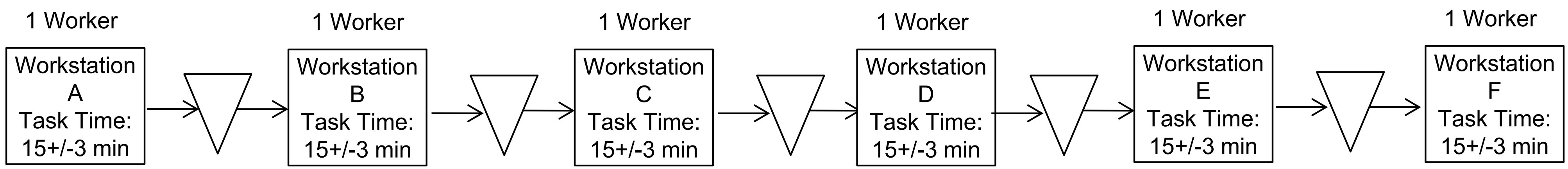


- In this simulation, average throughput time is 117.29 minutes, average cycle time is 15.73 minutes, average capacity is 3.81 per hour and average utilization is 96.98%.

- Little's Law can be used to calculate average inventory (WIP): Work-in-Process (WIP) = (Throughput time) x (Production rate) = (Throughput time) x 1/(Cycle time) = 117.29 x 1/15.73 = 7.456

Source
: Operations Management Simulation: Process Analytics (HBP No. 3291)

Process 12: Stochastic Process: Inventories



- If you could add inventories with a combined total capacity of 16, where would you locate them?

Process 12: Solution (1/2)

- In the presence of variability, inventory increases capacity because it helps to feed the workstation after the buffer (thus preventing starving) and, as long as the buffer is not full, it prevents the workstation before it from being blocked.

- If we could add 1 inventory buffer, we would place it in the middle.

- General rule: In the presence of variability, it is best to divide the entire process into equally long sub-processes.

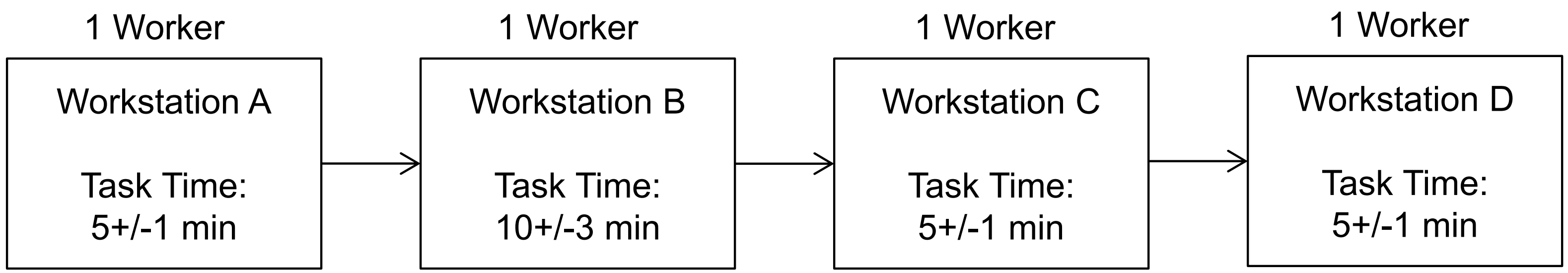
- If we had 2 inventory buffers, we would place 1 between B and C and 1 between D and E

- Moreover: There are decreasing marginal returns on each unit of buffer capacity. Adding a second buffer unit does not improve capacity as much as the first buffer unit.

Process 12: Solution (2/2)

- Applying both principles (dividing the entire process into equally long sub-processes and decreasing marginal returns on each additional unit of buffer capacity) the optimal allocation of 16 units of buffer capacity is
  - 3 units between A and B
  - 3 units between B and C
  - 4 units between C and D
  - 3 units between D and E
  - 3 units between E and F

Process 13a: Four Step Stochastic Process

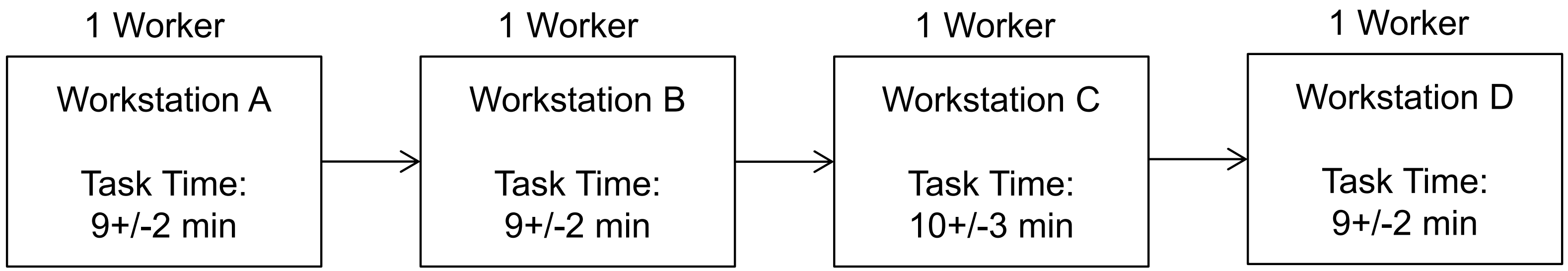


- Identify the bottleneck and calculate process capacity!

Process 13a: Solution

- Average capacity of process 13a is 6 units per hour.
- B is always the bottleneck because the shortest possible task time of B is higher than the longest possible task times of all other workstations of process 13a.
- Possible task times of C and D in process 13a overlap. However, this overlap remains irrelevant because C is fed by B at best every 7 minutes and therefore will never be blocked by D.

Process 13b: Four Step Stochastic Process



- Compare the capacity of this process with the capacity of process 13a!

Process 13b: Solution

- Workstation B of process 13a has a higher utilization than Workstation C of process 13b, because the task times of Workstation B of process 13a do not overlap with the task times of A, C and D of process 13a.

- Therefore, Workstation B of process 13a has a utilization of 100%, it is never blocked and never has to starve.

- The task times of Workstation C of process 13b, on the other hand, overlap with the task times of A, B and D of process 13b. Due to this overlap Workstation C of process 13b may be blocked or may have to starve.

Process 14a: Six Step Stochastic Process

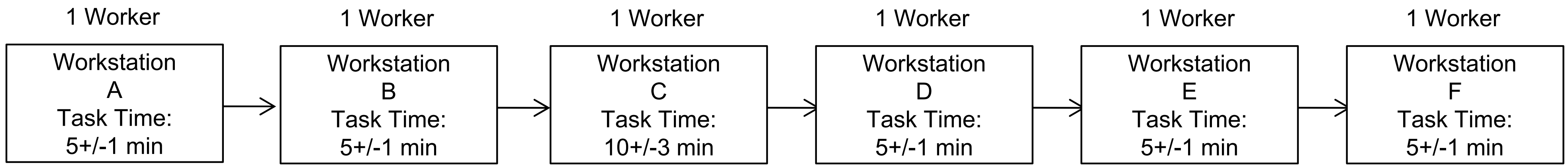
1 Worker	1 Worker	1 Worker	1 Worker	1 Worker	1 Worker
Workstation A Task Time: 9+/-2 min	→ Workstation B Task Time: 9+/-2 min	→ Workstation C Task Time: 10+/-3 min	→ Workstation D Task Time: 9+/-2 min	→ Workstation E Task Time: 9+/-2 min	→ Workstation F Task Time: 9+/-2 min

- Compare the output of this process with the output of process 13b!

Process 14a: Solution

- Process 14a has a lower average output than process 13b, because the problems caused by overlaps increase with the number of workstations.

Process 14b: Six Step Stochastic Process

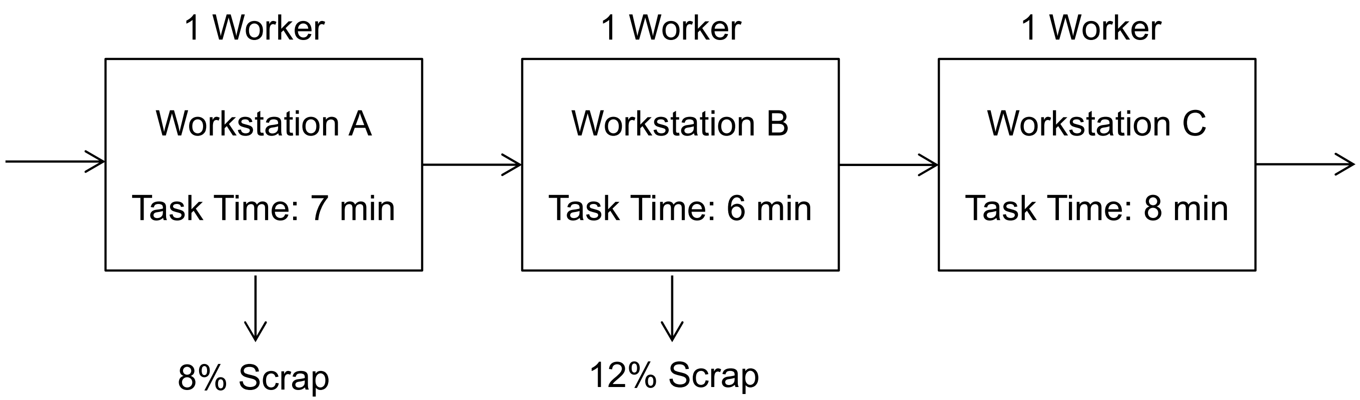


- Compare the output of process 14b with the output of process 14a!

Process 14b: Solution

- Process 14b has a higher average output than process 14a, because process 14b has, other than process 14a, no overlaps between the bottleneck and the other workstations.

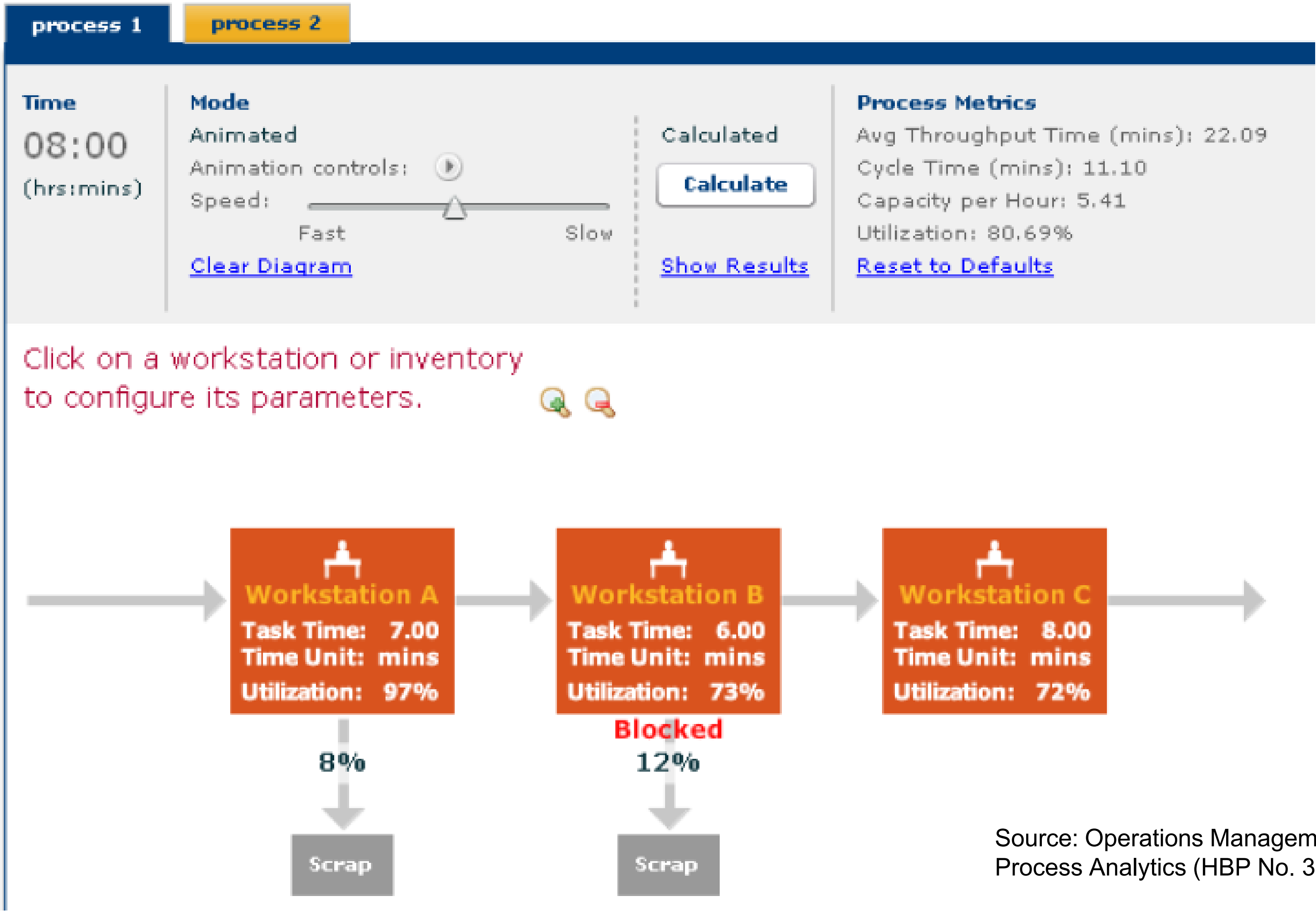
Process 15: Three Step Process with Scrap



- Now, Workstations A and B do no longer produce defect-free, but may occasionally produce scrap.
- Identify the bottleneck and calculate process capacity!

Process 15: Analysis

- If we simply compare the capacity of each of the three workstations with their expected inputs, we get for
  - A = 60/7 = 8.57, no input from predecessor
  - B = 60/6 = 10, expected input from A = 8.57x92% = 7.9
  - C = 60/8 = 7.5, expected input from B = 7.9x88% = 6.94.
- Thus, B and C have enough capacity to process their inputs and A is the bottleneck.
- Because of the scrap, expected process capacity would be 6.94 units per hour.
- However, the simulation results on the next slide show that this is not correct!

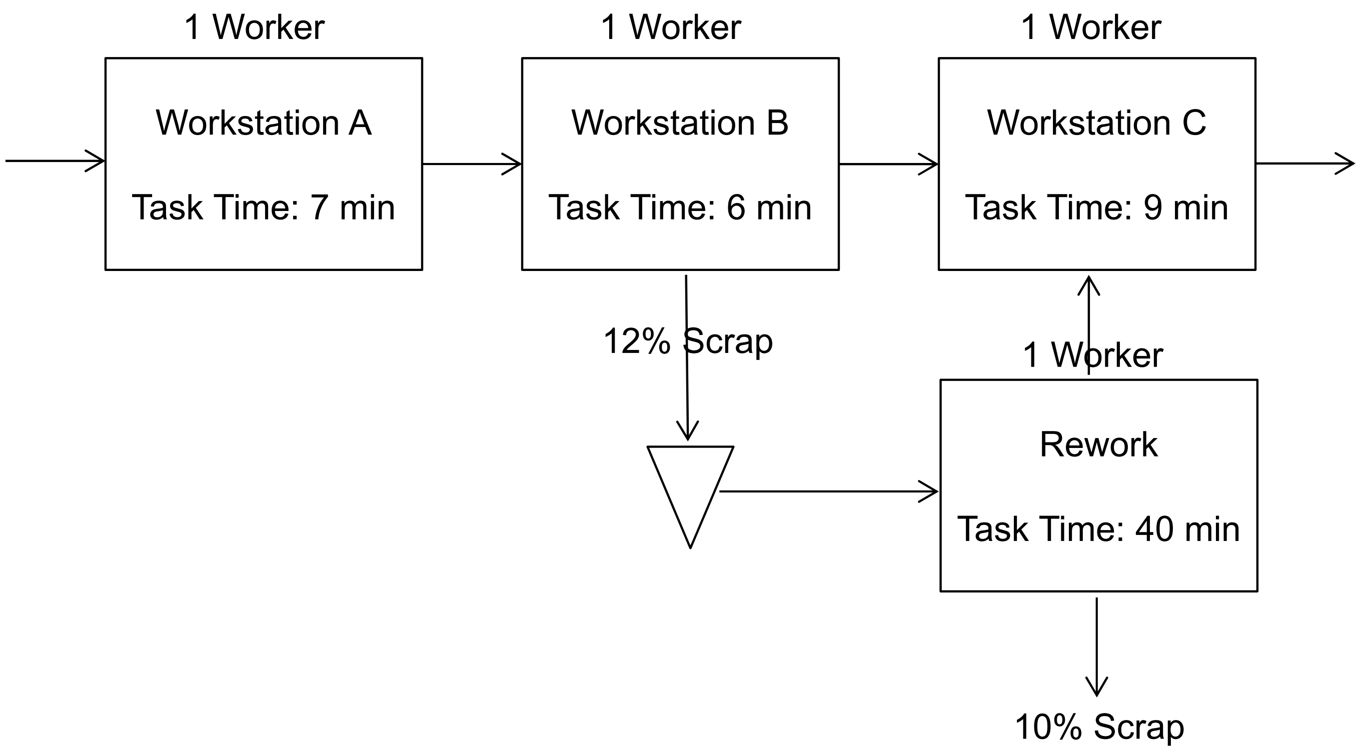


Source: Operations Management Simulation:
Process Analytics (HBP No. 3291)

Process 15: Solution

- Actual (average) capacity is lower than 6.94, because scrap is not distributed evenly (defects are random vs. exactly 1 in 8 and 1 in 12).
- If A and B do not produce scrap for a while, C will become the bottleneck.
- If C becomes the bottleneck, B and/or A will be blocked and the (average) capacity of the entire process decreases.

Process 16: Three Step Process with Scrap and Rework



- Now, the defects can be reworked.
- Identify the bottleneck and calculate process capacity!

Process 16: Analysis

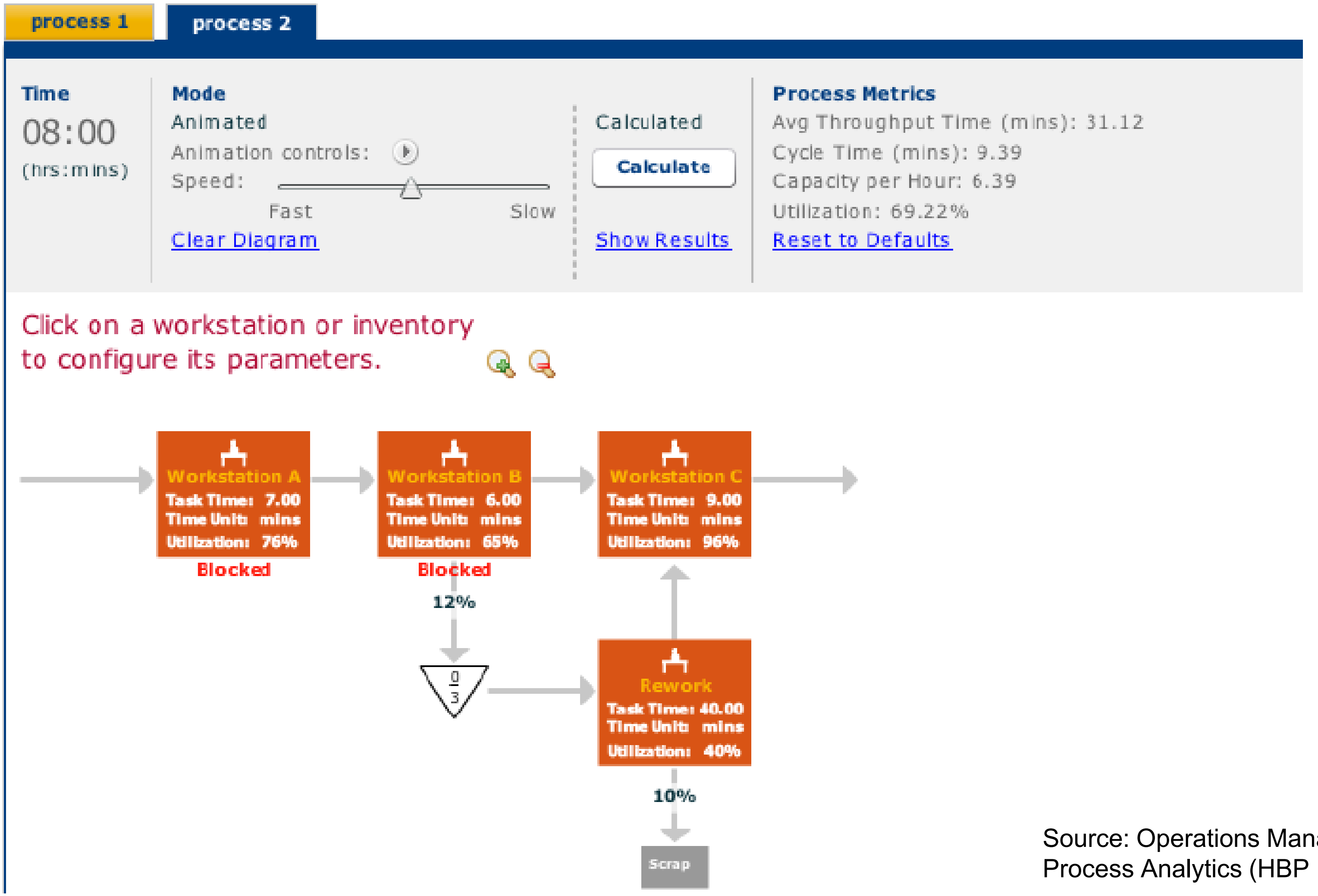
- With Rework, the calculations become more complicated, but the basic logic remains the same.

- Comparing the capacity of each workstation with their expected inputs gives us for
  - A = 60/7 = 8.57, no input from predecessor
  - B = 60/6 = 10, expected input from A = 8.57 (no scrap on Workstation A)
  - Rework = 60/40 = 1.5, expected input from B = 8.57x12% = 1.03
  - C = 60/9 = 6.67, expected input from B + expected input from Rework = (8.57x88%) + (1.03x90%) = 8.47.

- Based on this calculation, C would be the bottleneck and expected process capacity would be 6.67 units per hour.

- However, the simulation results on the next slide show that this is not correct!

Process 16: Simulation



Source: Operations Management Simulation: Process Analytics (HBP No. 3291)

Process 16: Solution

- Actual process capacity is much lower than 6.67 units per hour, because defects are random.
- A is often blocked by the bottleneck. Therefore, its utilization is only 76%. Consequently, actual capacity of A is only 76%x8.57 = 6.5.
- The actual utilization of Workstation B is 65%. Consequently, B produces (on average) only 6.5 units per hour.
- Accordingly, Rework produces 12%x6.5 = 0.78 units per hour.
- Total (average) output is 90%x0.78 + 88%x6.5 = 6.4 units per hour.