Operations & Business Process Management

Prof. Apurva Jain
MSIS 503

Contents

Where are we…(flow of the class)

What is the flow?: Flow-units, Resources, Activities,

What are the symptoms?: Cost, Time, Quality

Activities
Which tasks to automate?
Which activities add value?
- scorecard
- value/waste

Flow-units
How many flow-units?
How to manage a variety of units?
- forecasting models
- errors, software
- improvement ideas

Resources
What type of resources?
How many resources?



HBO’s problem

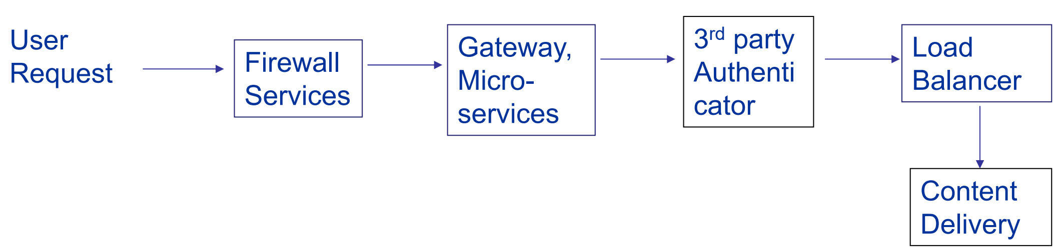
- On Sunday night, HBO clocked a record-breaking audience for the season four premiere of Game of Thrones, bringing in 6.6m viewers, the network’s biggest audience since The Sopranos finale. There seemed to be just as many complaints on Twitter that HBO Go, the channel’s streaming service, had crashed due to the high demand of people trying to watch the show at the same time, something that also happened just a few weeks ago during the True Detective finale.
- The season 7 premiere of “Game of Thrones” drew a record audience of 16.1 million viewers (10.1 million on linear and the rest from DVR and streaming).
- Season 8 of Game of Thrones kicked off with a bang the other night, adding new viewers to its existing audience as 17.4 million viewers tuned in across multiple platforms to watch the premiere. It was the most-watched GoT episode ever.
- The final episode of “Game of Thrones” brought in a series record of 19.3 million viewers. The finale, titled “The Iron Throne,” broke the record set by last weekend’s episode, “The Bells,” for which 18.4 million viewers tuned in.
- With that demand came issues for various HBO digital platforms. According to the Hollywood Reporter, HBO.com crashed during the premiere and HBO Go experienced outages in Latin America.

What may be the reasons for these crashes?

Space for discussion notes

What may be the reasons for streaming delays and crashes?

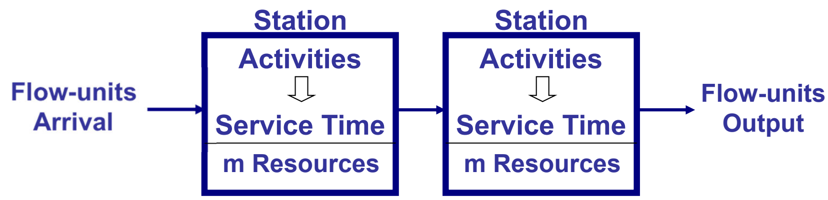
HBO Flow



Ensuring balanced capacity across different stations/resource-types is necessary.

- *How do we measure capacity?*
- *Why do we see lack of balance?*

Capacity terminology



A station is an assignment of a set of activities to a resource-type.

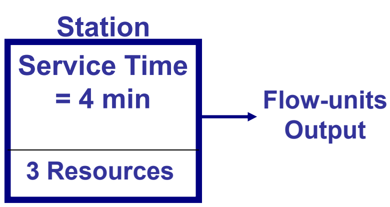
We will define following measures:

Defining service rate

Defining station or resource-type's capacity

Defining process capacity and bottleneck

Defining Capacity



A resource-type's (station's) capacity is the *Maximum* number of flow-units it can output in one unit of time. Capacity is expressed as a steady-state **rate** (number of flow-units per time-unit).

Define service time = Time for one resource to perform activities on one flow-unit.
One resource's capacity = service rate = 1/service time

If there are "m" resources of same resource-type then
Resource-type (station) capacity = m* one resource's capacity

In the above example:
One resource's capacity = service rate =

Resource-type capacity = station capacity =

To convert from "per min." to "per hour," multiply by 60.

Defining capacity

A resource-type's (station's) capacity is the *Maximum* number of flow-units it can output in one unit of time. Capacity is expressed as a steady-state **rate** (number of flow-units per time-unit).

Define service time = Time for one resource to perform activities on one flow-unit.
One resource's capacity = service rate = 1/service time

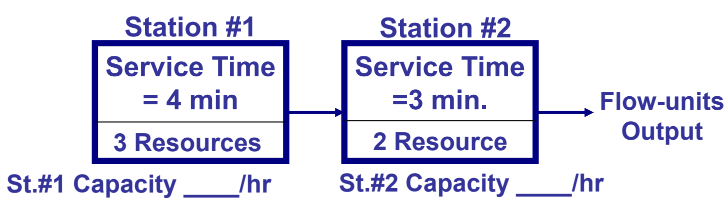
If there are "m" resources of same resource-type then
Resource-type (station) capacity = m* one resource's capacity

In the above example:
One resource's capacity = service rate = (1/4) per min = (1/4)*60 per hr = 15/hr

Resource-type capacity = station capacity = 3 * 15/hr = 45/hr

To convert from "per min." to "per hour," multiply by 60.

Defining Process Capacity



Process Capacity is Minimum of all resource-type (station) capacities.
In the above example: process capacity =

Performance of a flow is constrained by the resource-type with minimum capacity.

This resource-type is called: Bottleneck.

In the above example: bottleneck is the resource-type on station 2.

Defining process capacity

Flow-units Arrival → **Station #1** [Service Time = 4 min | 3 Resources] → **Station #2** [Service Time =3 min. | 2 Resource] → Flow-units Output

St.#1 Capacity _3*(1/4)*60=45_/hr **St.#2 Capacity _2*(1/3)*60=40_/hr**

Process Capacity is Minimum of all resource-type (station) capacities.
In the above example: process capacity = **Min (45,40) = 40/hr**
Cycle time is the time between two consecutive units of output.

Performance of a flow is constrained by the resource-type with minimum capacity.

This resource-type is called: Bottleneck.

In the above example: bottleneck is the resource-type on station 2.

Example: Identifying Bottleneck

Station #1 [Service Time = 5 min. | 4 Resources] → **Station #2** [Service Time = 4 min. | 5 Resource] → Flow-units Output

St.#1 Capacity ____/hr **St.#2 Capacity ____/hr**

Process Capacity is Minimum of all resource-type (station) capacities.
In the above example: process capacity =

bottleneck =

Example: Identifying bottleneck

Station #1
Service Time = 5 min.
4 Resources

Station #2
Service Time = 4 min.
5 Resources

Flow-units Output

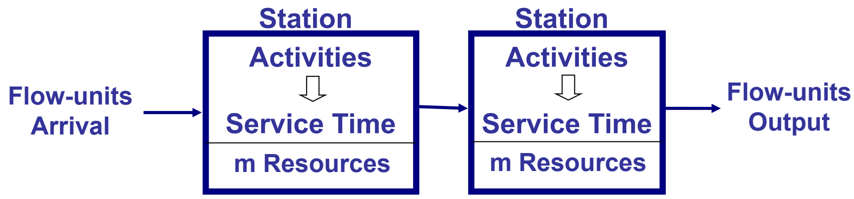
St.#1 Capacity _4*(1/5)*60=48/hr

St.#2 Capacity _5*(1/4)*60=75/hr

Process Capacity is the Minimum of all resource-type (station) capacities.
In the above example: process capacity = Min (48,75) = 48/hr

bottleneck = Station 1

Summary of flow terminology

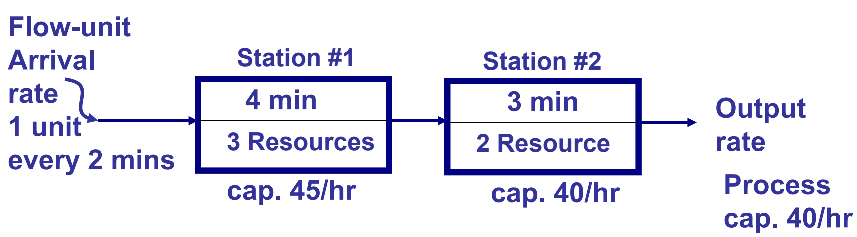


A station is an assignment of a set of activities to a resource-type. There may be multiple resources of that type.

We have defined following concepts:
service rate
station or resource-type's capacity
process capacity and bottleneck

In next few slides, we will add:
Output rate and Utilization
Lead time and WIP (Little's Law)
Balance

Define Utilization



Arrival rate expresses the number of flow-units entering the process per time-unit.
Output rate expresses the number of flow-units exiting the process per time-unit.
Throughput (Th) or Output rate = Min (Arrival rate, Process capacity)
Utilization of resource-type on a station = output rate / resource-type capacity

In the above example:
Arrival rate = 1 unit every 2 min. = (1/2) unit per min. = (60*1/2 = 30) unit per hr

Throughput(Th) or Output rate =

Utilization of station 1 resource-type =

Utilization of station 2 resource-type =

Define Utilization

Flow-unit Arrival rate 1 unit every 2 mins → Station #1 (4 min, 3 Resources, cap. 45/hr) → Station #2 (3 min, 2 Resource, cap. 40/hr) → Output rate

Process cap. 40/hr

Arrival rate expresses the number of flow-units entering the process per time-unit.
Output rate expresses the number of flow-units exiting the process per time-unit.
Throughput (Th) or Output rate = Min (Arrival rate, Process capacity)
Utilization of resource-type on a station = output rate / resource-type capacity

In the above example:
Arrival rate = 1 unit every 2 min. = (1/2) unit per min. = (60*1/2 = 30) unit per hr

Throughput(Th) or Output rate = Min (30/hr, 40/hr) = 30/hr

Utilization of station 1 resource-type = 30/45 = 0.6667 = 66.67%

Utilization of station 2 resource-type = 30/40 = 0.75 = 75%

Define Lead Time & WIP

Flow-unit Arrival rate 1 unit every 2 mins → Station #1 (4 min, 3 Resources, cap. 45/hr) → Station #2 (3 min, 2 Resource, cap. 40/hr) → Output rate

Process cap. 40/hr

Lead time (LT) represents the time a flow-unit spends in the flow from arrival to output.
Work-in-Process (WIP) refers to the average number of flow-units in the flow.

Min Lead time = Min. time a flow-unit spends in system=

How many* flow-units are in the flow (WIP, number)?=

*time-average: average of many random observations.

Little's Law: WIP = Th * LT

Between any two boundaries of flow:
Number in flow = flow-rate * Time in flow

Define Lead Time & WIP

Flow-unit Arrival rate
1 unit every 2 mins

Station #1	Station #2
4 min	3 min
3 Resources	2 Resource
cap. 45/hr	cap. 40/hr

Output rate

Process cap. 40/hr

Lead time (LT) represents the time a flow-unit spends in the flow from arrival to output.
Work-in-Process (WIP) refers to the average number of flow-units in the flow.

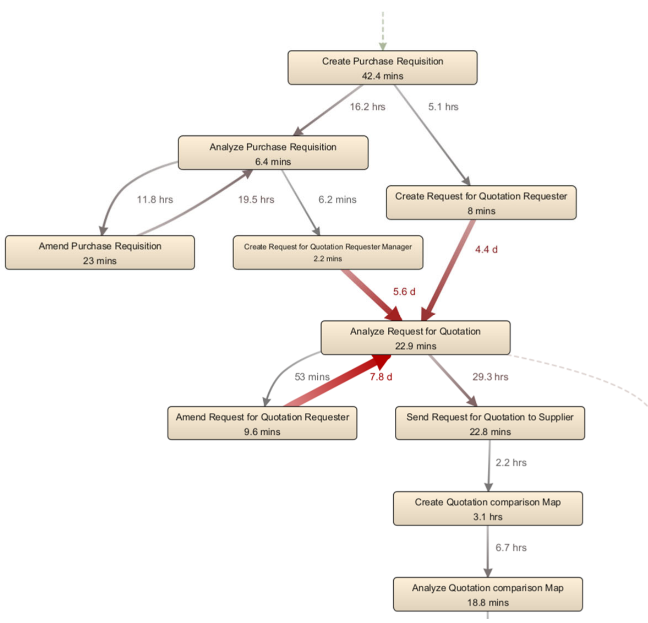
Min Lead time = Min. time a flow-unit spends in system= 4+3=7 min

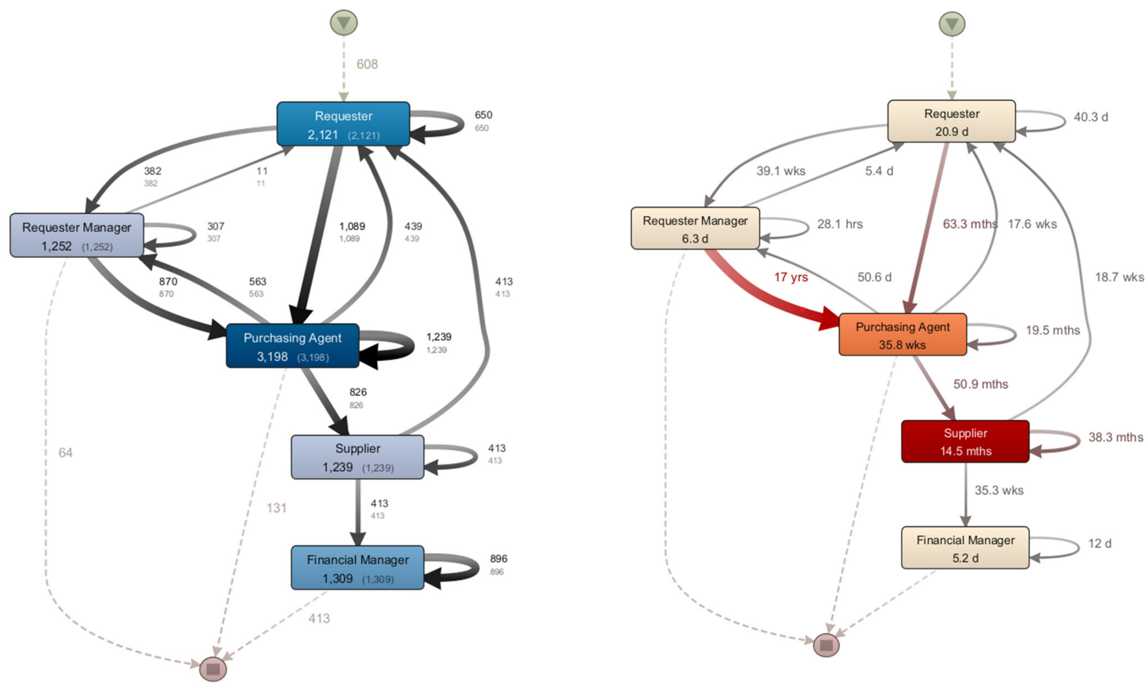
How many* flow-units are in the flow (WIP, number)?= 30/hr*7min =
= 30/hr*(7/60)hr=3.5

*time-average: average of many random observations.

Little's Law: WIP = Th * LT

Between any two boundaries of flow:
Number in flow = flow-rate * Time in flow





How to solve problems

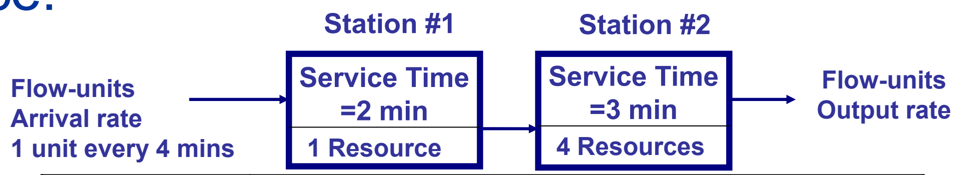
Read the text of the problem and list all resource-type or stations and determine service time for each resource-type. Identify the flow-unit and note if any information about arrival rate is given. If there are multiple types of flow-units, determine average service times for each resource-type.

Compute resource-type capacities and process capacities. Identify bottleneck. If asked, compute utilizations.

Note if any redistribution of work or flexibility of resources is possible to get closer to a balanced line.

Practice problem:
In a data center, requests for a specific type of job arrive once every four minutes. Each request is first handled by a single data-processing server where it takes 2 minutes and then goes to one of a set of four computation-server resources where it takes 3 minutes. Compute process capacity, utilizations and WIP. How can we increase process capacity?

Practice:



Capacity	Station#1____________, St.#2________________ Process Capacity____________ How to improve?
Output Rate(Th)	Arrival rate________________, Output rate_______________
Utilizations	Station#1____________, St.#2________________
Lead Time (LT)	Min_____________
WIP	_________________________________

Process capacity for the example on the previous slide is (units per hour):

20

30

60

80

Deeper Dive: Bottleneck Analysis

- Batches of flow-units flow through the process

  → Treat a batch as a flow-unit and compute service times for the batch

- Multiple-types of flow-units take different service times at a station

  → Combine different types of flow-units into one "Average" unit by taking a weighted average of service times at each station. Weights are equal to %age of each type of flow-unit in total.

- A resource splits its time between different stations

  → Compute service time as the total time a resource spends on a flow-unit across all different stations.

- A flow-unit exits the flow before finishing the process

  → For the remainder of the process steps, consider this flow-unit's service time to be 0.

Practice:

Flow-units Arrival rate 1 unit every 4 mins → **Station #1** [Service Time =2 min | 1 Resource] → **Station #2** [Service Time =3 min | 4 Resources] → **Flow-units Output rate**

Capacity	**Station#1=1*(60/2)=30/hr, St.#2= 4*(60/3)=80/hr** **Process Capacity_ Min (30,80) = 30 / hr___**
Output Rate(Th)	**Arrival rate= (1/4) / min = (60/4) or 15 / hr,** **Output rate__ Min (15,30) = 15 / hr__**
Utilizations	**Station#1_15/30 = 50%, St.#2 _15/80 = 18.75%___**
Lead Time (LT)	**Min__2 min + 3 min = 5 min__**
WIP	**_____Th*LT = 15 /hr * (5/60) hr = 1.25____**

How do we improve process capacity?

Practice:

Flow-units Arrival rate 1 unit every 4 mins → **Station #1** [Service Time =2 min | 1 Resource] → **Station #2** [Service Time =3 min | 4 Resources] → Flow-units Output rate

Capacity	Station#1=1*(60/2)=30/hr, St.#2= 4*(60/3)=80/hr Process Capacity_ Min (30,80) = 30 / hr___
Output Rate(Th)	Arrival rate= (1/4) / min = (60/4) or 15 / hr, Output rate__ Min (15,30) = 15 / hr__
Utilizations	Station#1_15/30 = 50%, St.#2 _15/80 = 18.75%___
Lead Time (LT)	Min__2 min + 3 min = 5 min__
WIP	_____Th*LT = 15 /hr * (5/60) hr = 1.25____

Improve Process capacity by shifting one resource from ST.#2 to St.#1.
It will give a balanced line and a process capacity of 60/hr

A Moment of Reflection

- **Do you know where is the bottleneck in your workflow / supply chain?**

"A word to the wise, Harry. At this morning's meeting you were referred to as 'the bottleneck'."

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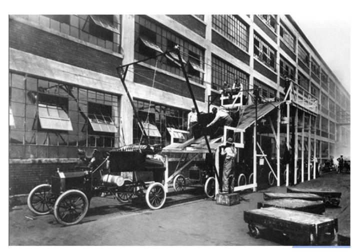
Ford's problem

- The Model T made its debut in 1908 with a purchase price of $825.00. Over ten thousand were sold in its first year, establishing a new record.
- It took 12.5 hours to put together a car. Each car was assembled by one worker.
- Ford needed to figure out how to increase production
- …
- Four years later, production and sales soared. The price dropped to $575.00.

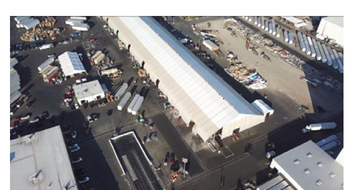


Tesla's problem

- Musk is asked why it's producing just 2,000 Model 3s a week, as opposed to the 5,000 a week he promised at launch. (Wired, Apr 2018)

- "Our Model 3 production plan includes periods of planned downtime in both Fremont and Gigafactory 1," a Tesla spokesperson said. "These periods are used to improve automation and systematically address bottlenecks in order to increase production rates."

- A billionaire business owner sleeping on a sofa above a factory floor: admirable behavior or a sign of desperation?



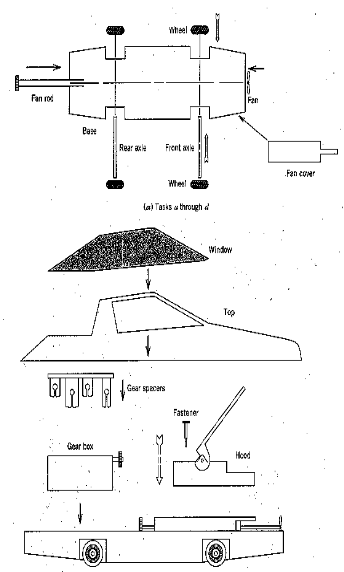
An example: toy car assembly

Activity	Description	Time (min)
a	Insert front wheels	0.1
b	Insert gear assembly	1.0
c	Insert rear wheels	0.7
d	Insert engine	0.5
e	Attach top	0.2

Target output rate: 50/hr

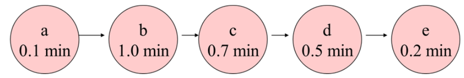
Engineering constraints:

a 0.1 min → b 1.0 min → c 0.7 min → d 0.5 min → e 0.2 min



With each additional task assigned to a resource, there is a reduction in the efficiency which can be modeled as an increase in activity times.

An example: toy car assembly



Design a line with two resources, that is, allocate activities to resources to create stations. What is the process capacity?

What are the station utilizations?

What is the minimum lead time? How many cars are in the process (WIP)?

Toy car line design

Option 1: First station a,b Second station c,d,e
Option 2: First station a,b,c Second station d,e

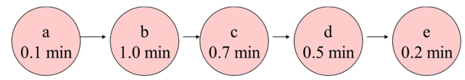
Option 1

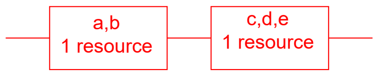
Option 2

I have another idea.

I just like the color yellow.

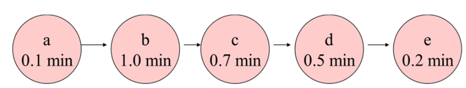
An example: toy car assembly



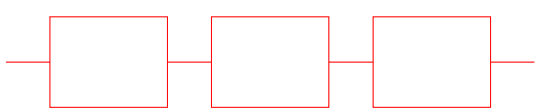


With two resources, what is the process capacity?
Tasks a,b on station 1: Service time = 0.1+1=1.1,
Station 1 capacity = (1/1.1)*60=54.44 per hr
Tasks c,d,e on station 2: Service time = 0.7+0.5+0.2=1.4,
Station 2 capacity = (1/1.4)*60=42.86 per hr
Process Capacity = Minimum of station capacities = 42.86 per hr. Station 2 is bottleneck.
What are the station utilizations?
Station 1 utilization=output rate 42.86 per hr/station cap.54.44 per hr = 0.7873 = 78.73%
Station 2 utilization = output rate 42.86 per hr / station cap. 42.86 per hr = 1 = 100%
What is the minimum lead time? How many cars are in the process (WIP)?
Minimum lead time = 1.1+1.4 = 2.5 min
WIP = output rate 42.86 per hr * lead time 2.5/60 hr = 1.79

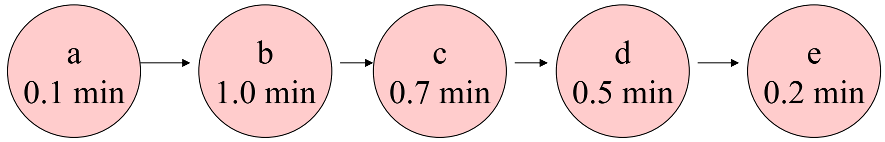
An example: toy car assembly



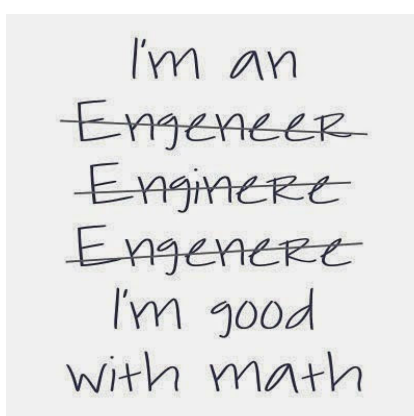
With three resources, design a line. What is the process capacity?



An example: toy car assembly



With three resources, what is the process capacity?
Tasks a,b on station 1: Service time = 0.1+1=1.1,
Station 1 capacity = (1/1.1)*60=54.44 per hr
Tasks c on station 2: Service time = 0.7,
Station 2 capacity = (1/0.7)*60=85.71 per hr
Tasks d,e on station 2: Service time = 0.5+0.2=0.7,
Station 3 capacity = (1/0.7)*60=85.71 per hr
Process Capacity = Minimum of station capacities = 54.44 per hr. Station 1 is bottleneck.
To meet the target of 50/hr, we need at least three resources.



Line Flow Design: Optimization

Given a sequence of tasks and estimated times
and
the precedence relationship between these tasks
and
a target output rate or number of stations

Minimize the maximum amount of work assigned to any station,
subject to:
Each task is assigned to exactly one station,
No task is assigned to an earlier station than any of its predecessors;
→ Algorithms and optimization software is commercially available.

However, if there is significant uncertainty in task times, real-sized problems are difficult to solve.

In most practical settings, rather than designing a line flow from scratch, we have an existing flow and want to improve it. This requires us to think about the concept of *Balance* which we now introduce.

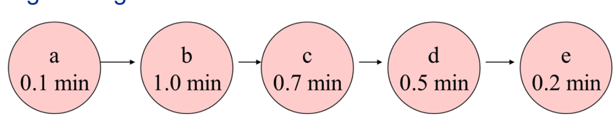
Excel Optimization: Line Balancing

Activity	Description	Time (min)
a	Insert front wheels	0.1
b	Insert gear assembly	1.0
c	Insert rear wheels	0.7
d	Insert engine	0.5
e	Attach top	0.2

Activity	Duration	Predecessors
a	0.1	None
b	1	a
c	0.7	b
d	0.5	c
e	0.2	d

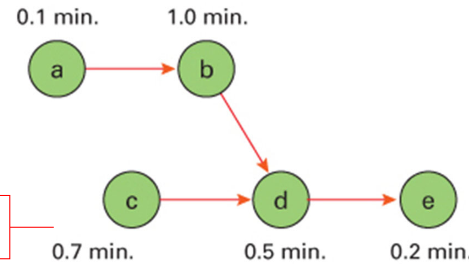
Target output rate: 50/hr

Engineering constraints:



How can resequencing help? Balance.

An engineering redesign allows us to change precedence relationship as shown in the new figure. With three resources, what is the process capacity?

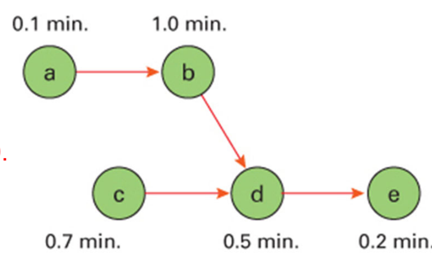


What will be the process capacity if we can *somehow* fully balance the line?

Model 3 door hanging, as well as truck and hood, is being assembled in a different way than what we saw earlier.
-FT Alphaville

How can resequencing help? Balance.

An engineering redesign allows us to change precedence relationship as shown in the new figure. With three resources, what is the process capacity?



Tasks a,c on station 1: Service time = 0.1+0.7=0.
Station 1 capacity = (1/0.8)*60=75 per hr
Tasks b on station 2: Service time = 1,
Station 2 capacity = (1/1)*60=60 per hr
Tasks d,e on station 2: Service time = 0.5+0.2=0.7,
Station 3 capacity = (1/0.7)*60=85.71 per hr
Process Capacity = Minimum of station capacities = 60 per hr. Station 2 is bottleneck.
Resequencing allows us to achieve better balance.
This is more than 54.44 per hr we had before the engineering change.

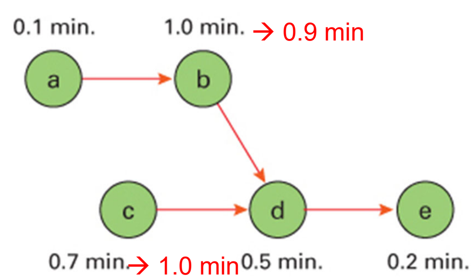
What will be the process capacity if we can *somehow* fully balance the line?

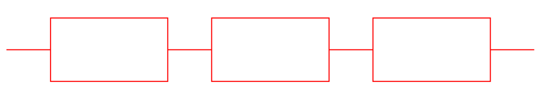
In a fully balanced three station line, if we can somehow full balance then that means that the utilizations and therefore station capacities will be equal. Because we have one resource at each station, equal capacities mean equal service time at each station. Because total work on a flow unit is 2.5 min, dividing it equally between three stations will give a service time of 2.5/3 at each station. Each station capacity and process capacity will be equal (1/(2.5/3))*60= 72 per hr.

Why is automation not helping?: Robots vs. Humans

It turns out that estimation of b task time was inflated and the task time for c must account for extra rework due to quality issue.
Other times remain the same.

What should we do?

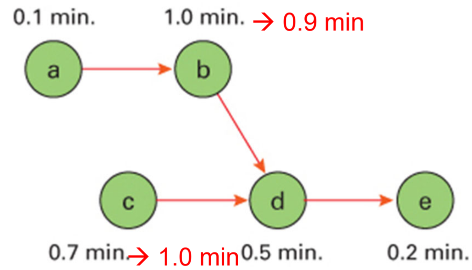




Why is automation not helping?: Robots vs. Humans

It turns out that estimation of b task time was inflated and the task time for c must account for extra rework due to quality issue. Other times remain the same.

What should we do?



Change the line design to have tasks a,b on station 1, task c on station 2 and tasks d,e on station 3.

Without the change the process capacity will decrease.

However, such quick change requires A great degree of flexibility. We can expect that from flexible human resources but not from automated dedicated robots.

Characteristics Needed for Automation

A scorecard for selecting candidate tasks for automation

Automation Fit		**Level of Effort**		**Value Created**	
Feature	*Score*	*Feature*	*Score*	*Feature*	*Score*
Consistency		Development hours		Hours Saved	
Complexity		Development Cost		Dollars Saved	
Documentation				Revenue Impact	
Discretion/ Expertise Required				Other value	
Homogeneity of data required					

Should we add any other feature to our scorecard?

Ref: MIT Sloan Journal

Boeing & Aerospace | Business

Boeing abandons its failed fuselage robots on the 777X, handing the job back to machinists

Nov. 13, 2019 at 7:10 pm | *Updated Nov. 15, 2019 at 12:37 pm*

Boeing is abandoning robotic production machinery, known as Fuselage Automated Upright Build, or FAUB, used to add fasteners on 777 fuselages. (Gail Hanusa / Boeing)

CIO

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Contributing writer

8 big IT failures of 2023

Define Balance

Define Balance: Equal station capacities across different resource-types

For a given set of resources and activities, a balanced flow will provide the most process capacity. Theoretically, the maximum process capacity of a balanced flow can be calculated as the capacity of a single station with all the activities and resources on the same station.

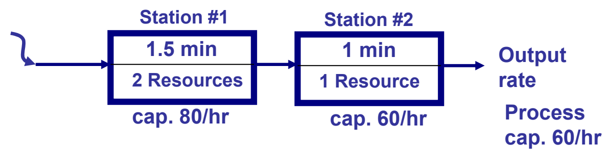
In practice, it may not be possible to balance the flow fully. We can get closer by (1) Identifying the Bottleneck, (2) Helping it by

- Add capacity at the right place in the right amount
- Re-allocate activities between stations
- Re-assign/share resources between stations

Flexible resources help in two important ways. They make it easier to reallocate activities and share resources between stations. They make it easier to change the flow design when activity times or demand volumes change.

Define Balance

Define Balance: Equal capacity across different resource-types



Improve Existing Flow:

Identify the Bottleneck: Station 2

Elevate the Bottleneck:

- Add capacity at the right place in the right amount

We can add another resource to station 2 which will make station 1 bottleneck and increase process capacity to 80/hr. Adding new resources is expensive and the flow would still be unbalanced. Alternatively, we can invest in technology to bring station 2 capacity to 80/hr, balancing the line.

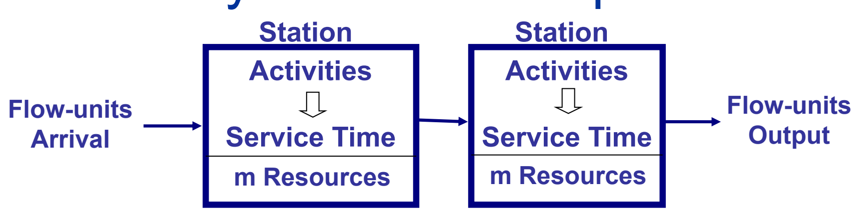
- Re-allocate activities between stations

We can take x min of service time from station 2 and give it to station 1, making station 1 capacity 2*(1/(1.5+x))*60 per hr and station 2 capacity 1*(1/(1-x))*60 per hr. To balance the line, we can make the two capacities equal and solve for x, giving x=0.5/3 and new process capacity as 72/hr. Because the flow is fully balanced now, this is the most we can get from the flow. Another way to get to 72/hr is to simply imagine a flow with all work (2.5 min) and all resources (3) on one station. This will give us the balanced capacity as 3*(1/2.5)*60=72/hr but will not tell us the distribution of work at each station needed to get us the balanced capacity.

- Re-assign/share resources between stations

Instead of shifting work away from the bottleneck, we can also consider the possibility of moving part of a resource away from the non-bottleneck station and add it to the bottleneck, by asking the resource to share her time between two stations. This can be analyzed by modeling fractional resources at each station.

Summary of flow concepts



A station is an assignment of a set of activities to a resource-type.

After discussing the capacity terminology - service rate, resource-type capacity, LT, WIP, process capacity, arrival and output rates, utilization – we used the Tesla example to explain the Line Flow Design problem (Lina Balancing optimization).

In most practical settings, rather than optimizing the line flow, we look for possible improvements. We introduced the concept of *Balance* that helps generate ideas for improvement.

If service times are uncertain initially, line design changes often. For that we need flexible resources. We used the Tesla story to highlight the value of resource flexibility.

Operations & Business Process Management

Prof. Apurva Jain
MSIS 503

Contents

Flow Improvement through Bottleneck/Balance Ideas

Flow Optimization in Designing the Flow:
- How much capacity and where?: Line Balancing Optimization
  Assign activities to resources to achieve a target process capacity while meeting precedence constraints.

- How much capacity and when?: Scheduling of Shift optimization
  Given a certain resource availability and varying demand patterns, what is the best time to deploy the resources?

Improve Existing Flow:

Identify the Bottleneck
- Compute each resource-type's capacity
- Guess based on the location of the backlog/inventory

Exploit the Bottleneck
- Make sure the Bottleneck is fully utilized (never idle)
- Subordinate everything else to the bottleneck

Elevate the Bottleneck
- Reduce Service Times
- Add capacity at the right place in the right amount
- Re-allocate activities between stations
- Re-assign/share resources between stations

A Broad View of Different Flow Planning Systems

Serve to a schedule:
Customers arrive at a schedule; optimize your resource plans to meet that schedule. Workforce planning and scheduling software.

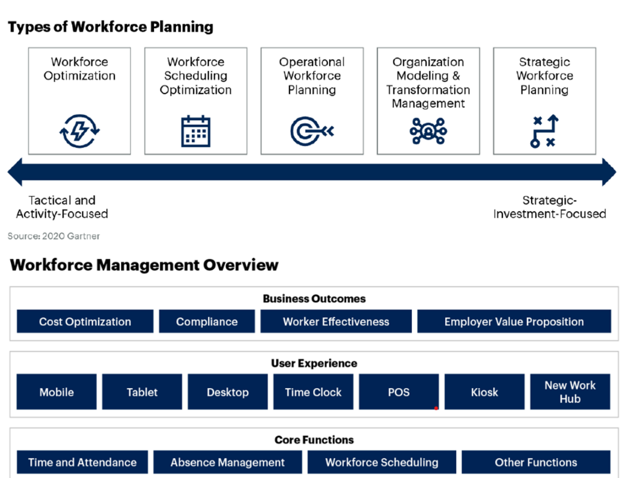
Serve to a rate:
Forecast a demand rate, determine capacity at each step, and satisfy demands as they arrive. Queueing optimization.

Build to a rate:
Determine a production rate that can meet the forecasted demand, optimize the flow design, build inventory, and utilize it to satisfy demand. Line balancing optimization.

Build to a schedule:
Negotiate/forecast/set due dates, optimize a resource plan, revise and update. S&OP and MRP software. [Also, ref: Project Management]

Workforce Planning Systems

By 2025, 50% of large enterprises with hourly workers and variable demand for labor will use automation to drive workforce scheduling decisions.



Source: Gartner

S&OP, MRP Software Vendors

Modeling and Optimization

Optimization Modeling Platforms

AIMMS, AMPL, FICO, IBM, Portfolio Decisions, River Logic, SAS

Optimization Solvers

Conopt, FICO Xpress, Gurobi, IBM CPLEX, SAS/OR,* Knitro

Optimization Applications

Marketing, supply chain, pricing, logistics, strategic planning, government, operations and many more

Source: Gartner

Bottlenecks Are Everywhere

It seems like an obvious idea and an easy-to-spot problem. Then why do we still have bottlenecks?

- Demand and supply conditions change all the time. Without a regular process improvement initiative, imbalances will occur.
- Historical decisions lock in a capacity that is hard to change. Technological solutions may help to either divert demand or to find new sources of capacity.
- Different steps may have different owners who may not have the right incentive to share information or add capacity.

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Improvement Ideas

- Forecast the arrival rate during peak periods; plan capacity for this peak workload.
- Consider all steps and resource-types in the flow to find the bottleneck and estimate the process capacity.
- If the bottleneck is not in our control, we must share information with the right station and collaborate with them. (More about this later in the class).
- Make sure that the bottleneck is never starved; it should always have work to do.
- Devise a plan to help the bottleneck. Adding more capacity may take time and is usually costly. Automation like RPA is a relatively cheaper way to reduce service times.
- If possible, shift resources from other locations that may peak at different times.
- Cross-training resources to share their time at the bottleneck increases bottleneck resources. Also, explore shifting some of the bottleneck activities to other stations.
- Effective use of current resources may require solving optimization problems to assign resources and determine their shift schedules.

Key points and takeaways

- Capacity Terminology and calculations: Service rate, Resource-type & process capacity, LT, WIP, Output rate (throughput), Utilization
- In a repetitive flow, capacity is determined by considering line design decisions about assigning tasks to stations. This is called a Line Balancing problem as we saw in the Tesla example.
- Balance is achieved when all stations have equal capacity; this is when the flow achieves the maximum possible process capacity.
- Adding resources at the right place, relaxing engineering constraints, reallocating work between resource-types and sharing resources between stations are all ideas to move in the direction of a balanced flow.
- Resource flexibility helps balance the flow and is very important to deal with dynamically changing contexts such as Tesla.
- Flow optimization and improvement is a feature of Manufacturing and Workforce planning systems. Excel based optimization and other tools are available.
- Balance-based Improvement ideas

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There is usually a bottleneck in the flow; look for it. This will help you avoid under-capacity problems, cut costs by balancing flow, and make right capacity decisions.

Contents

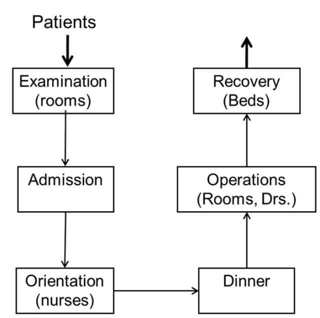
1. Identify Flow
2. Automate Workflow
3. Forecast Demand
   - 3.1 Time Series: Exponential Smoothing, MAD
   - 3.2 Trend & Seasonality
   - 3.3 Forecasting Software
4. Balance Capacity
   - 4.1 Capacity Definitions
     - Service rate, Resource-type & process capacity, LT, WIP, Output rate, Utilization
   - 4.2 Balance
     - Tesla example, Define Balance
     - Resource Flexibility
   - 4.3 Software / Applications
     - Different vendors and capabilities
     - Improvement ideas

Next: Quiz 2 due

5. Mitigate Variability's Impact

Example: Hospital capacity calculations

Resource-type Exam room:
6 rooms, 20 minutes per patient



Exam room capacity:

Example: Hospital capacity calculations

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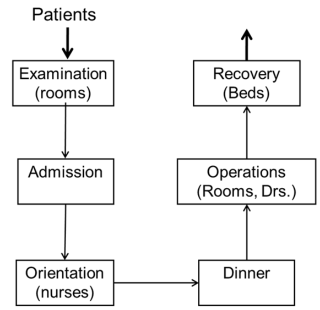


Exam room capacity:

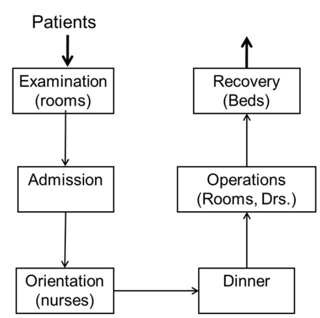
Service time for one flow-unit = 20 minutes

Capacity =6*(1/20) per minute
= 6*(1/20)*60 per hour = 18 per hour

Example: Hospital capacity calculations

Operations:
5 rooms, 10 surgeons
45 minutes for simple operations
90 minutes for complex operations
1 complex operation for every 3 normal ones
Rooms: 8 hours per day,
Doctors: 5 hours – coffee break (30 min)

Operating load varies from 30-36 operations per day. As a result each surgeon performed 3 or 4 operations per day.



Operating Rooms Capacity:

Doctors Capacity:

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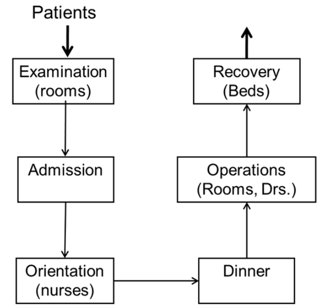

Operating Rooms Capacity:
Service time for one average flow-unit = (3/4)*45+(1/4)*90 =56.25 minutes
Capacity = 5*(1/56.25)*60*8 per day = 42.67 per day

Doctors Capacity:
Capacity = 10*(1/56.25)*60*4.5 per day = 48 per day

Practice Example: Lab Investment

A lab in Seattle area tests the biological samples sent to it by several cancer hospitals around the country. The testing process consists of three steps: sample preparing, testing and centrifuging. The current data is as following:
step 1: service time 5 min, number of resources 3
step 2: service time 4 min, number of resources 2
step 3: service time 7.5 min, number of resources 3

The lab has secured an investment of $3million and decided to invest all of it to increase capacity. Investment of $1 mil at step 1 can increase service rate by 0.5 samples per hr. $1 mil. investment at step 2 will increase the service rate by 7.5 samples per hr. $1 mil. investment at step 3 will increase the service rate by 3 samples per hr. Change in service rate at each step is proportional to the amount of investment.

The firm thinks there is a lot of demand in the market and therefore wishes to increase its process capacity as much as possible. How much investment would you recommend at each step?

If the fixed cost per day (8 hours) is $675 and for each sample, lab's cost is $5 and revenue is $10, what is the increase in profit per day?

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The firm thinks there is a lot of demand in the market and therefore wishes to increase its process capacity as much as possible. How much investment would you recommend at each step?

If the fixed cost per day (8 hours) is $675 and for each sample, lab's cost is $50 and revenue is $100, what is the increase in profit per day?

Current: Step 1 capacity = 3*(60/5) = 36 per hr; Step 2: 2*(60/4) = 30 per hr; step 3: 3*(60/7.5)=24 per hr; process cap = 24 per hr = 24*8 = 192 per day

Invest x at step 1, y at step 2 and 3-x-y at step 3. To maximize process capacity, we should balance it. Therefore, we look for x and y that will:
36+1.5*x = 30+15*y = 24+9*(3-x-y) which gives us: 1.5 x -15 y = -6 and 10.5 x+ 9 y = 15.
Solving these gives: x=1,y = 0.5, 3-x-y=1.5

The process is balanced with each step capacity = 37.5 per hr = 37.5*8 = 300 per day

Increase in samples served per day = 300-192 = 108 per hour. Increase in profit per day = ($100-$50)*108 = $5400 per day