Micron Educator Hub

An application of Little's Law in Micron’s supply chain

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Little’s Law – goal and objectives

Goal

- Participants will be able to understand basic concepts of Little’s Law and how it applies to the manufacturing industry at large, and specifically to the semiconductor industry.

Objectives

- Understand Little’s Law as a fundamental theory in supply chain management
- Explain how Little’s Law is used to determine optimal throughput rates
- Describe how varying the throughput time can affect the inventory level
- Explore examples of the practical business use at Micron

Little's Law – target audience

- Individuals interested in a career in supply chain and interested in how data driven supply chain works.
- Interns, NCGs (New College Grads), and new employees in supply chain roles need to understand these concepts
- Examples of critical target audience roles at Micron that utilize these concepts:
  - Supply Chain Engineer
  - Supply Chain Optimization Engineer
  - Inventory Optimization Engineer
  - Operations Research Engineer
  - Product Operation
  - Capacity Planner
  - Strategic Planner
  - Data Scientist working on Supply Chain domain

Pro tip

Everyone interviewing at Micron can use this presentation to prepare for the interview by learning foundational information about memory. Check out the candidate guides for Engineering, Technician and Business roles.

- Micron engineering candidate guide
- Micron technician candidate guide
- Micron business candidate guide

Data disclaimer

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Little’s Law

Little's Law

John goes to a coffee shop

Input variables

- **Service rate** – 30 seconds per customer (2 customers per minute)
- **Population** – Infinite
- **Arrival rate** – 2 customers per minute (for demonstration purpose)

John's position in the queue

9th

08:00:00

8 7 6 5 4 3 2 1

Little's Law

John goes to a coffee shop

John's position in the queue

8th

08:00:30

9  7 6 5 4 3 2 1

Little’s Law

John goes to a coffee shop

John’s position in the queue

7th

08:01:00

9 8  6 5 4 3 2 1

Little’s Law

John goes to a coffee shop

John’s position in the queue

6th

08:01:30

9 8 7  5 4 3 2 1

Little’s Law

John goes to a coffee shop

John’s position in the queue

5th

08:02:00

9 8 7 6 4 3 2 1

Little’s Law

John goes to a coffee shop

John’s position in the queue

4th

08:02:30

9 8 7 6 5  3 2 1

Little's Law

John goes to a coffee shop

John's position in the queue

3rd

08:03:00

9 8 7 6 5 4  2 1

Little’s Law

John goes to a coffee shop

John’s position in the queue

2nd

08:03:30

9 8 7 6 5 4 3  1

Little's Law

John goes to a coffee shop

John is currently being served

08:04:00

9 8 7 6 5 4 3 2

Little’s Law

John goes to a coffee shop

John exits the system

08:04:30

9 8 7 6 5 4 3 2 1

Little’s Law

John goes to a coffee shop

Metrics

- **Average queue length** – 9 customers
- **Time taken by John in the system** – 4 minutes 30 seconds
- **Service rate** – 30 seconds per customer (2 customers per minute)

John exits the system

08:04:30

Relationship drawn

Average queue length (9 customers) **= Time in the system** (4.5 minutes) **X Service rate** (2 customers per minute)

Little’s Law

- Little's Law is a fundamental principle in queuing theory and inventory management
- Here is how the Little’s law equation can be applied in the service industry as derived from the coffee shop scenario

Average queue length = Average time in queue × Service rate

Mapping to production

Little’s Law application at Micron

- Throughput time = 10 weeks
- Throughput rate = 7,000 wafers per week

What is the expected WIP inventory?

$$WIP = 10\ weeks \times 7{,}000\ \frac{wafers}{week} = 70{,}000\ wafers$$

Coffee shop scenario	Micron application
Queue length	WIP Inventory
Time in queue	Throughput time
Service rate	Throughput rate

WIP – Work in progress

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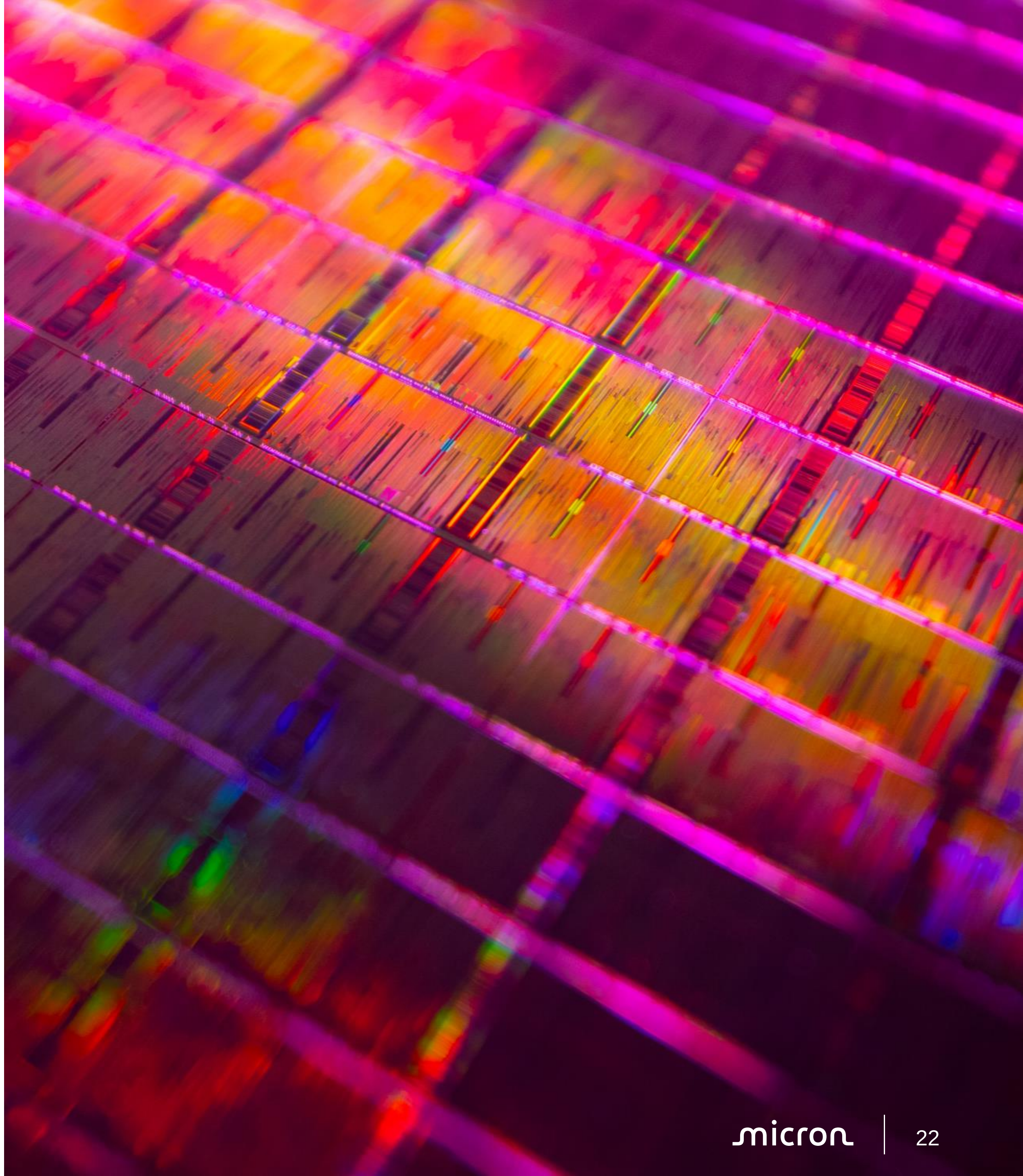


Factors that affect time in queue or throughput time

Service Industry

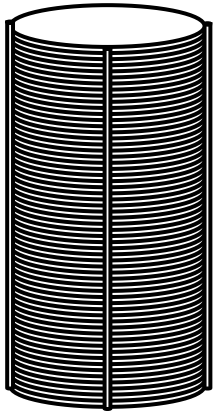
Queue length

- 9 people takes 4:30 minutes
- 20 people takes 10 minutes
- 100 people takes 50 minutes

Service Industry Strategies

Improve service rate by

- Increasing the number of servers to reduce the wait time
- Giving training to the servers
- Automating service



Semiconductor Industry

WIP is the work or product in progress

- Reduce WIP (work in progress) by reducing throughput time by increasing throughput rate
- 1 wafer takes 10 weeks throughput time
- 1 wafer has 700 steps

Semiconductor Industry Strategies

Reduce WIP by

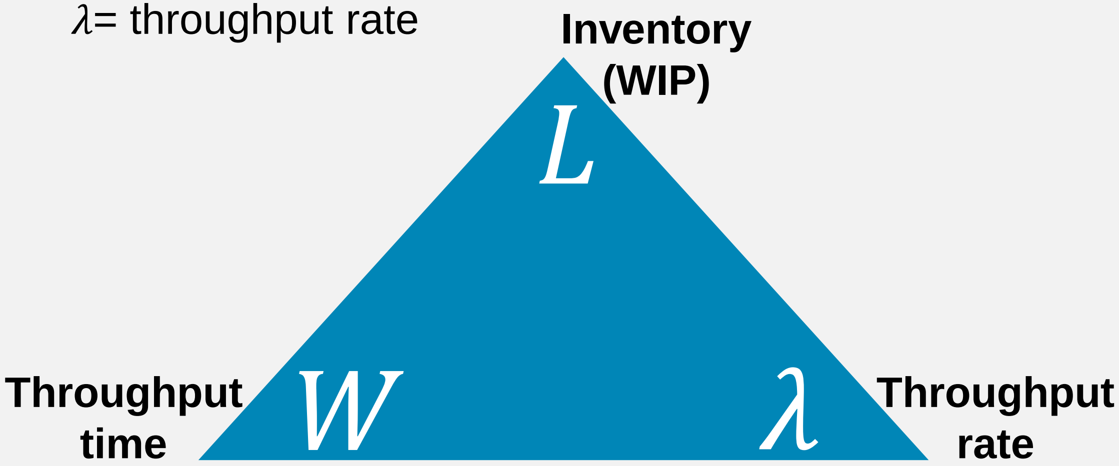
- Increasing the number of tools
- Minimizing downtime of existing tools
- Reducing process time in each tool
- Removing a step in the process
- Automating production

Little's Law applications

1) Management strategy and control

Only two out of the three of the following determine a strategy. The third is implicitly determined.

L= average inventory
W= throughput time
λ= throughput rate



- Example: λ= demand (projected), W= goal (set), L= means of monitoring W
- Any other combination is also possible

2) Inventory Management

Turnover Ratio

$$\frac{1}{W} = \frac{\lambda}{L}$$

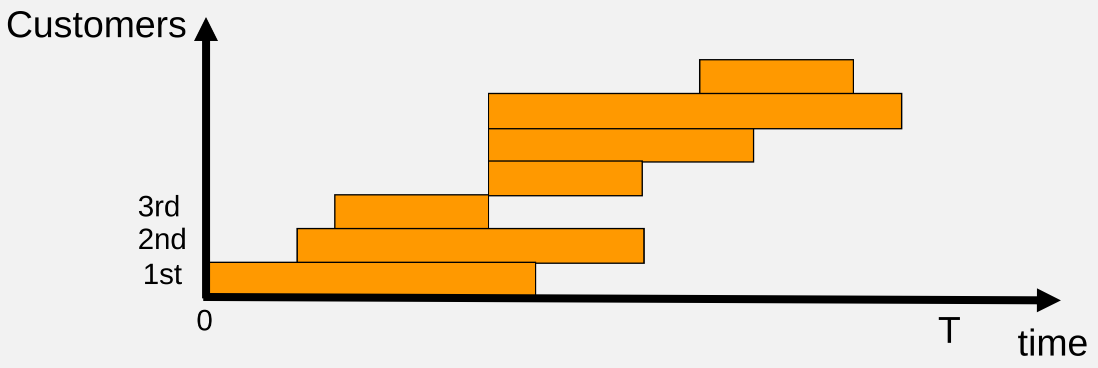
L= average inventory
W= average time in inventory
λ= average throughput rate

- We may have a target turnover ratio which can be achieved by tweaking the value of L for a given projected λ
- We may have a target value for L which can be achieved by tweaking the value of W for a given projected λ

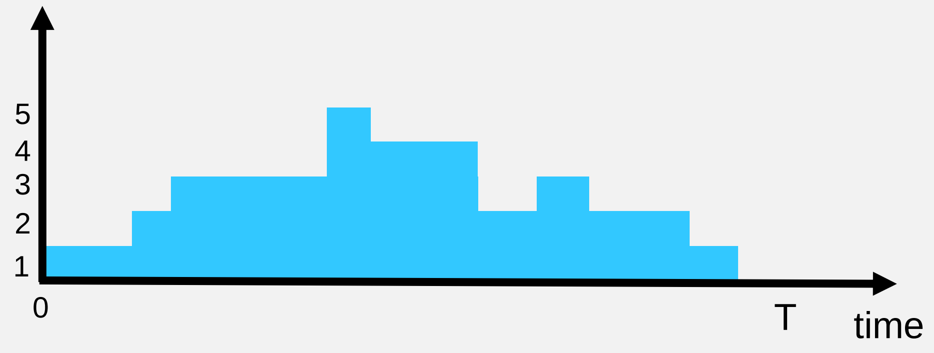
Graphical representation of a service industry example

N customers are served by the system during a cycle. A customer is represented by a rectangle of unit height, whose length equals the time the customer spends in the system.

Representation of each customer arrival and their respective service times



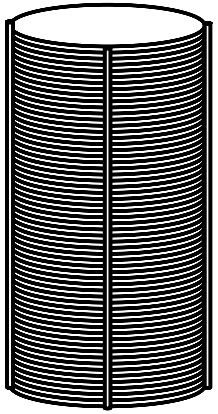
Representation of the queue length at any point in time



- S = shaded area (units: customer × hours), measures total waiting time
- $W = \frac{S}{N}$, divides waiting among customers (average waiting time or time in the system)
- $L = \frac{S}{T}$, divides waiting over time (average number of customers at any point of time or average queue length)
- $\lambda = \frac{N}{T}$, average number of customers served or service rate
- Therefore, $L = \lambda W$

Little's Law: Service vs. Semiconductor Industry

Average queue length = Average time in queue × Service rate



Average Inventory (WIP) = Average time a product is in the system × Rate of production

WIP – Work in progress

Little's Law

Mapping to the production context

For production scenario

Average queue length ≡ average inventory (WIP)

Average time in the system ≡ throughput time (time spent by a product within the system)

Service rate ≡ throughput rate (rate of production)

Therefore, the resultant relationship is

Little's Law

Average inventory (WIP) = throughput time x throughput rate

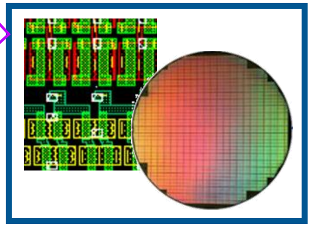
WIP – Work in progress

Semiconductor memory manufacturing stages of production

Stages of Production

1. Front End (wafer / die bank)

Start Material: Silicon is purified and formed into wafers (outside Micron).

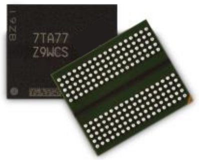


Wafer-Level Fabrication: Electronic devices (transistors, resistors, capacitors, etc.) are fabricated on the silicon wafers, and are then interconnected together into complete circuits.

Probe: Each die is tested for functionality, failing die are flagged. Failure data (bins) is collected for yield improvement.
Param: Wafer-level electrical data is collected to characterize and improve the process.

2. Back End

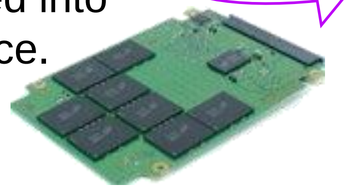
Packaging: Die that pass Probe are separated from the wafer and assembled into packages.



Final Test and Burn-In: Packaged parts are tested for functionality. Some parts are given additional tests under harsh conditions to verify reliability.

3. Finished goods

Module Assembly and Testing: Some DRAM packaged parts are placed into modules and further tested for functionality and reliability.



System/SSD Testing: NAND packaged parts may be placed into SSDs or Composite drives and further tested for performance.

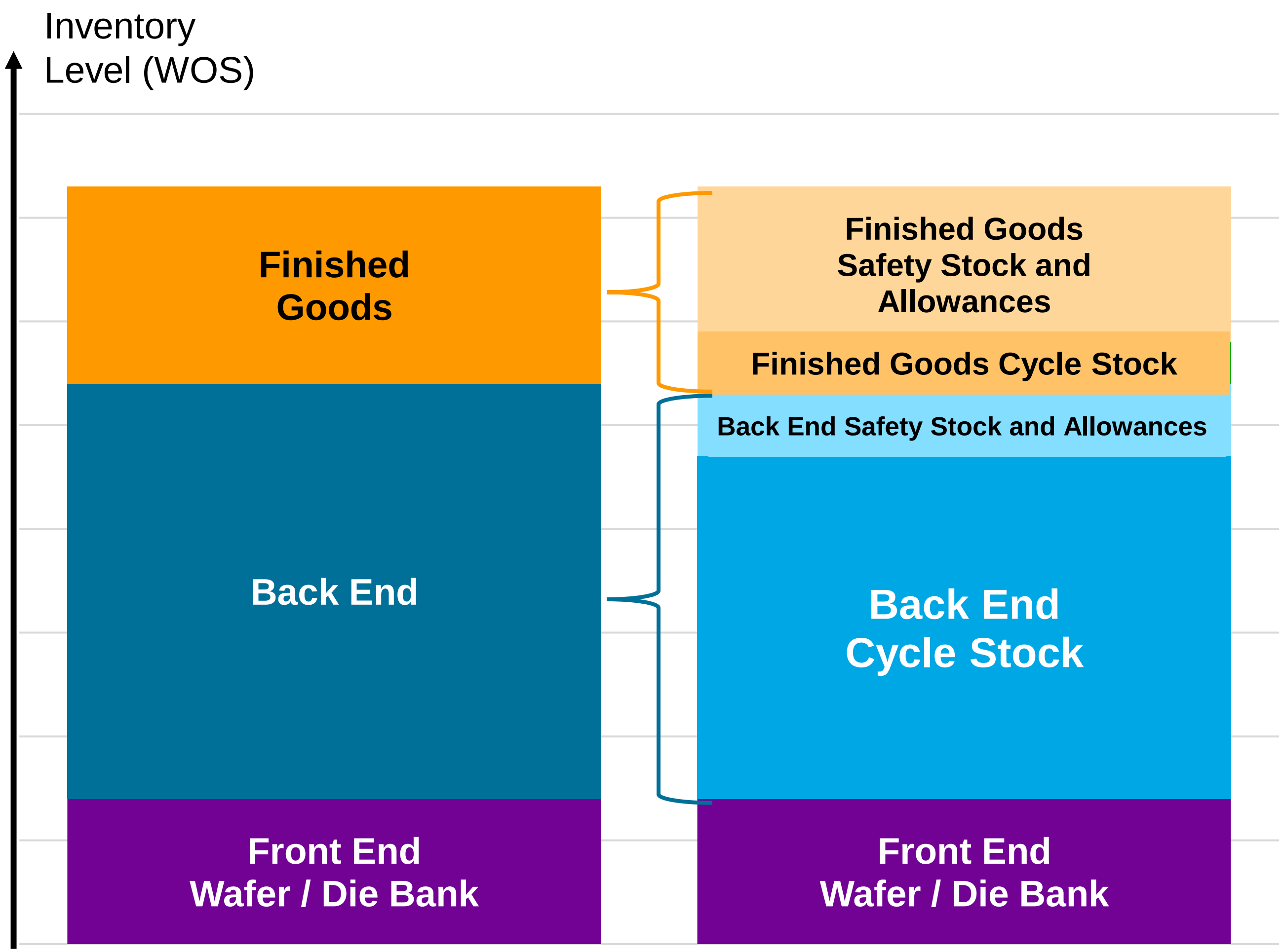
Customer!

Types of inventory

A typical semiconductor company accumulates inventory in three stages:

- Finished Goods
- Back End manufacturing
- Front End (Wafer / Die bank)

Total inventory at each stage = safety stock target + cycle stock (except for Front End which is automated and supply driven, hence no safety stock)



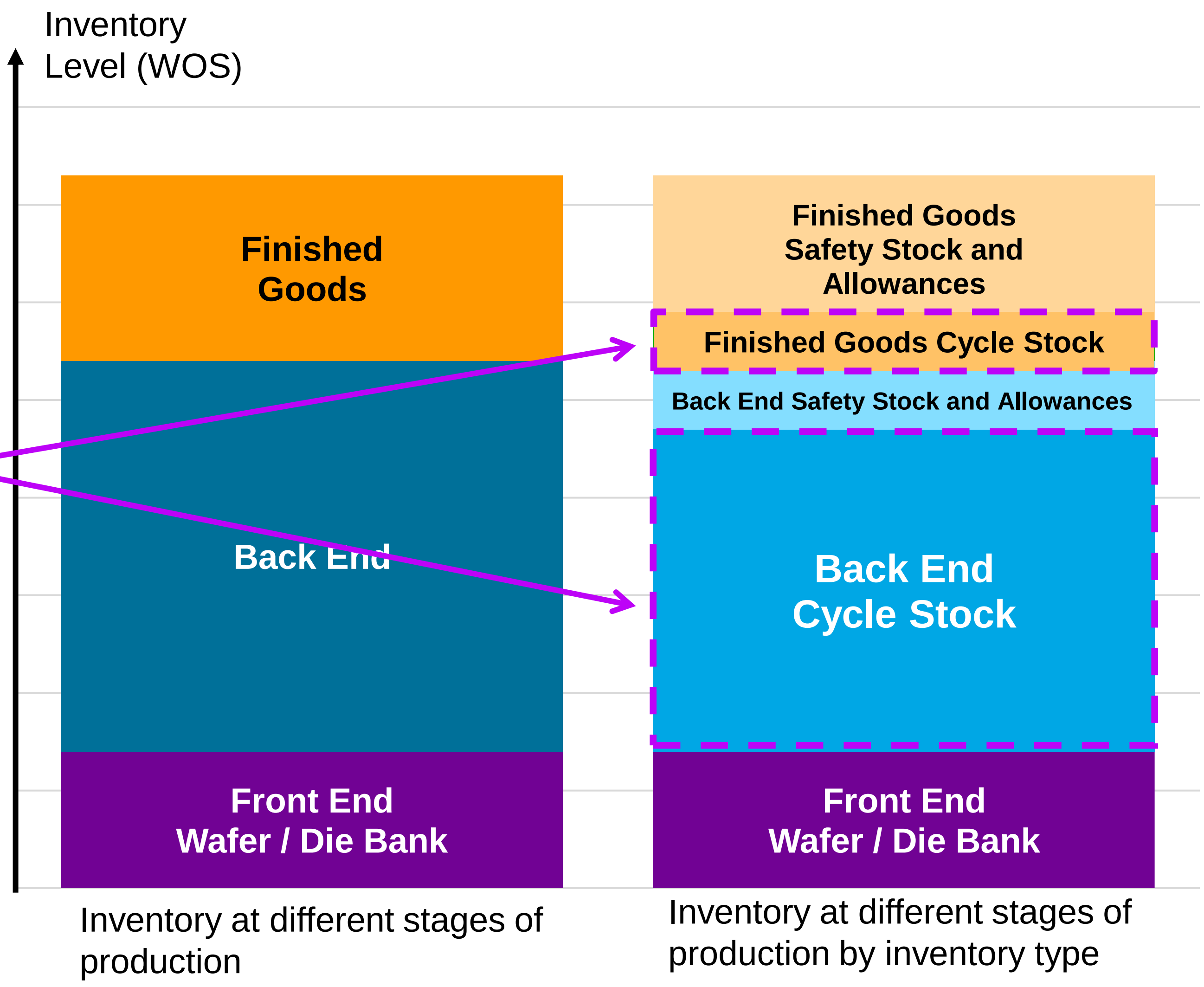
Inventory at different stages of production

Inventory at different stages of production by inventory type

WIP – Work in progress
WOS – Weeks of Stock

Types of inventory

Little's Law typically is applicable to the cycle stock (WIP occurring during production process)



WIP – Work in progress
WOS – Weeks of Stock

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Study of cycle stock

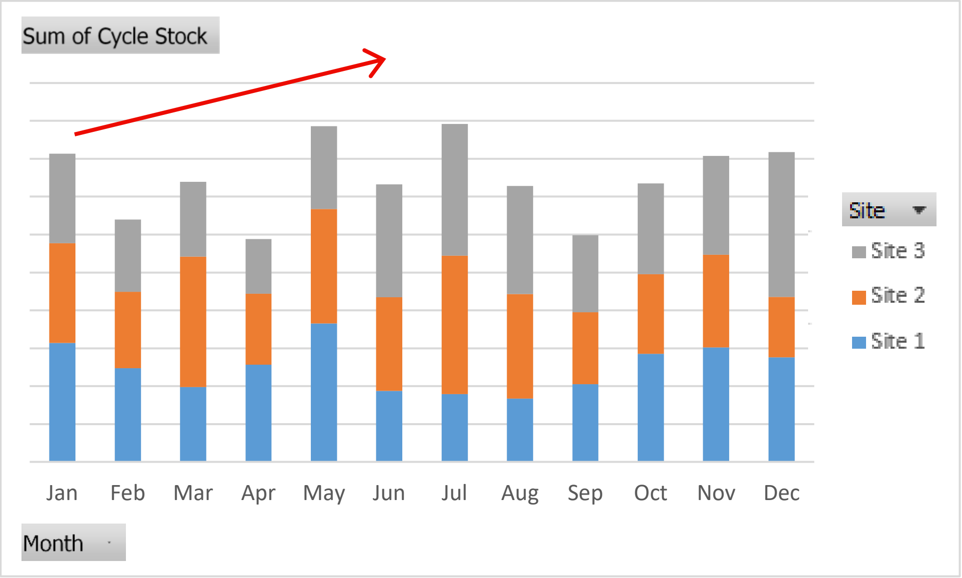
Product group X comprises of products A, B, C, D, and E

3 Production Sites: Site 1, 2, and 3

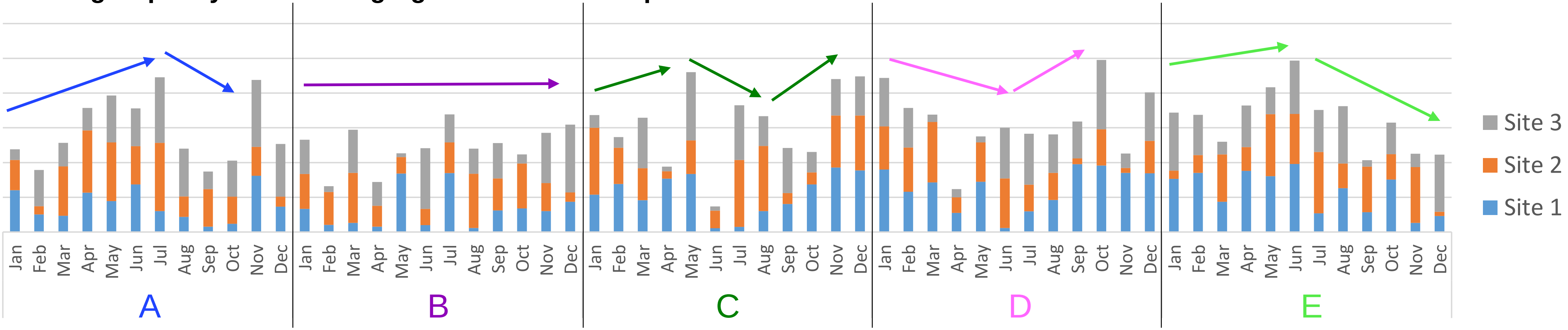
Purpose of analysis: identify expected directional changes in product group X

- Is overall product group inventory increasing or decreasing?
- Which product contributes most to the inventory change? Why? (Little's Law helps in answering)

Product group X aggregated cycle stock



Product group X cycle stock segregated at individual product level



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Application examples

Translating throughput time to WIP targets

Little’s Law

Utilized to determine target WIP levels

Little’s Law Formula

$$WIP = Througput\ time\ x\ Throughput\ rate$$

Targets

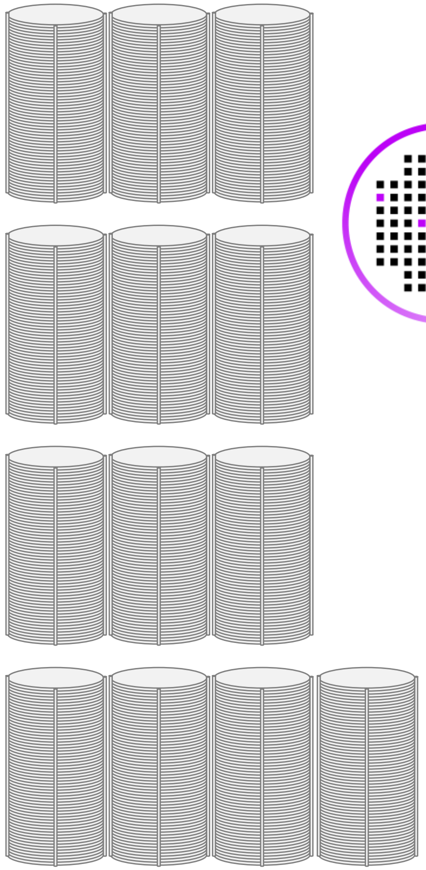
- How much WIP should we have in our fab?
  - What should be the target throughput time?
  - What should be the target pace?

WIP - Work in Progress

Semiconductor scenario use for Little's Law

- The business quarterly demand is 13,000 wafers
- Note: A business quarter is 13 weeks

- Each wafer has 700 steps to complete
- Production time for each wafer is 10 weeks



700 Steps Total
✓ 1
✓ 2
✓ 3
✓ …
✓ …
✓ …
✓ 698
✓ 699
✓ 700

Week	M	T	W	Th	F	Sa	Su
1							
2							
3							
4							
5							
7							
8							
9							
10							

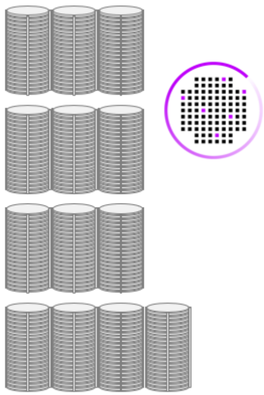
Step 1

10 weeks

Step 700

What is the expected target WIP?

Quarterly Demand =
13,000 wafers

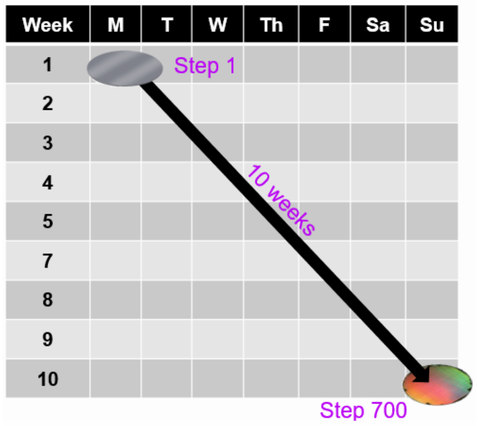


Business quarter = **13** weeks

Steps per wafer =
700 steps

700 Steps	
✓	1
✓	2
✓	3
✓	…

Production time (Throughput Time) =
10 weeks per wafer



What is the expected target WIP?

$$Target\ throughput\ rate\ per\ week = 13{,}000\ wafers/13\ weeks = 1{,}000\ wafers/week$$

$$WIP = Throughput\ rate \times Throughput\ time = 1{,}000\ wafers/week \times 10\ weeks = 10{,}000\ wafers$$

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Is the target throughput rate being met?

Tuesday: 70,000 steps were completed.

week	M	T	W	Th	F	Sa	Su
Target Throughput rate= 1,000 wafers/week		**70,000 Steps**					

What is the Weekly Throughput for Tuesday?

$$Throughput\ rate\ (day) = \frac{70{,}000\ steps/day}{700\ steps/wafer} = 100\ wafers/day$$

$$Throughput\ rate\ (weekly) = 7\ days\ x\ 100\ wafers/day = 700\ wafers/week$$

Is the target throughput rate being met?

Tuesday: 70,000 steps were completed.

week	M	T	W	Th	F	Sa	Su
Target Throughput rate= 1,000 wafers/week		**70,000 Steps**					

Is Tuesday's pace ahead or behind the target?

(assume each step has equal contribution to wafer processing and WIP is evenly distributed)

$$700\ wafers/week < 1{,}000\ wafers/week$$

$$Tuesday\ is\ behind\ the\ target\ throughput\ rate$$

Little’s Law

$$Throughput\ Time = \frac{WIP}{Throughput\ Rate} = \frac{WIP}{Pace} = \frac{WIP}{Moves\ /\ Step\ QTY}$$

- Constant: Step quantity
- Dynamic: Moves and WIP
  - More moves and less WIP = lower throughput time
  - More moves and more WIP = similar throughput time
  - Less moves and more WIP = higher throughput time
  - Less moves and less WIP = similar throughput time

Moves are the main indicator of throughput performance

Other expressions for throughput time

$$\frac{Step\ QTY}{Moves/WIP}\ or\ \frac{Step\ QTY}{WIP\ Turns}$$

Moves – Total number of steps in unit of time
Step QTY – Total number of steps needed to complete a unit
WIP – Work in progress
WIP turns – Moves/WIP

Conclusion:
Little’s Law shows that throughput time and WIP are good ways to monitor the efficiency of the fab.

Pace plot for visualizing performance

Pace plot shows actual pace performance vs. target pace

Target pace

- Calculation is based on demand and step QTY

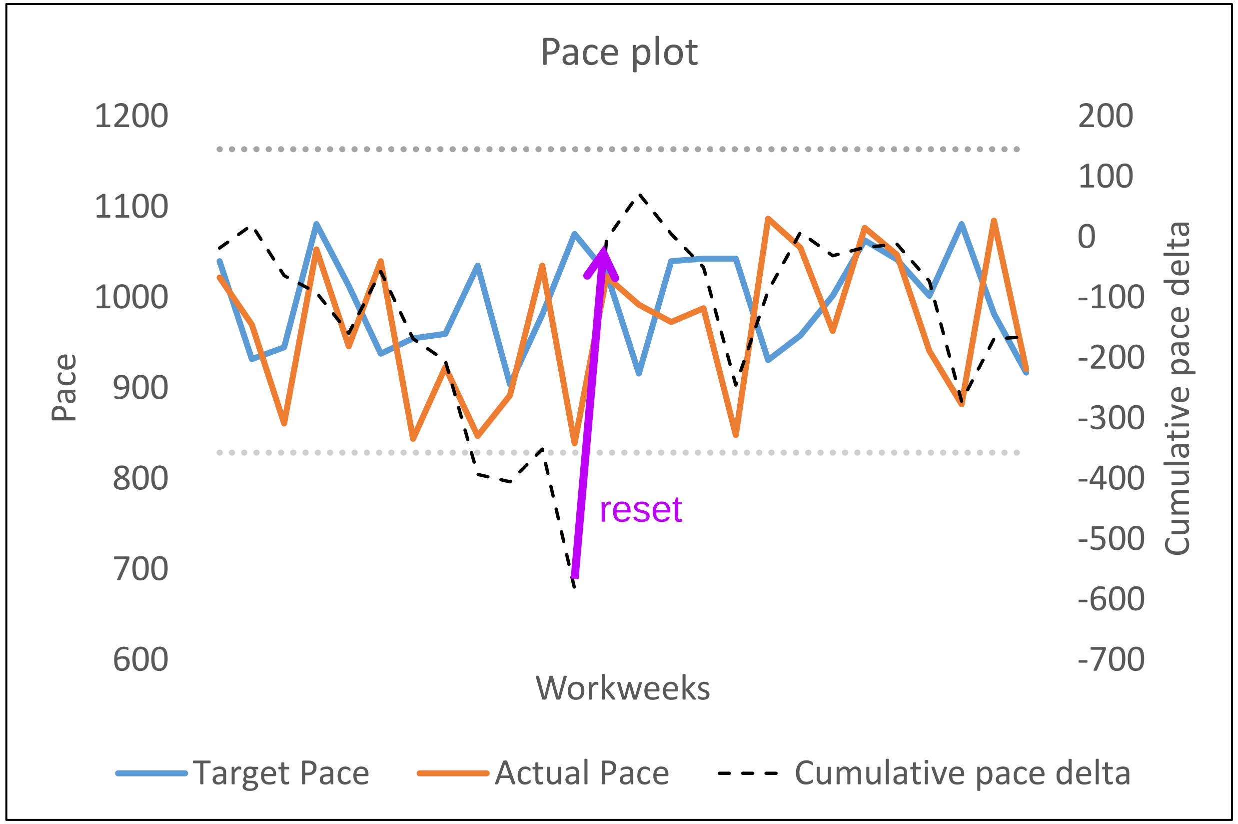
Actual pace

- Actual pace based on actual number of steps performed and step QTY

Pace delta

- $Actual\ pace - Target\ pace$

- Cumulative pace delta (CPD) = Cumulative sum of pace delta
- If CPD falls behind, the fab will not be able to meet its wafer ships commitment. The target wafer ships will need to be adjusted and the CPD will then be reset to zero.



- Control limit for changes: +/-3 sigma

Glossary

Glossary

Term or acronym	Definition/description
Cycle stock	Inventory that is used during the production process
Safety stock	Inventory kept to prevent stockouts due to variability in demand or supply
Throughput time	The average time a product spends within the system from the start until it is completed
Throughput rate	The rate at which products are completed and exit the system
Turnover ratio	The throughput rate divided by the average inventory
WIP	Work in Progress; product that is currently being processed in the production system
WOS	Weeks of Stock; inventory level measured in terms of the number of weeks it would take to deplete the stock at the current usage rate.

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