MSBA 7004
Operations Analytics

Class 3-2: Process Flow Analysis (III-2)

Inventory & Little's Law

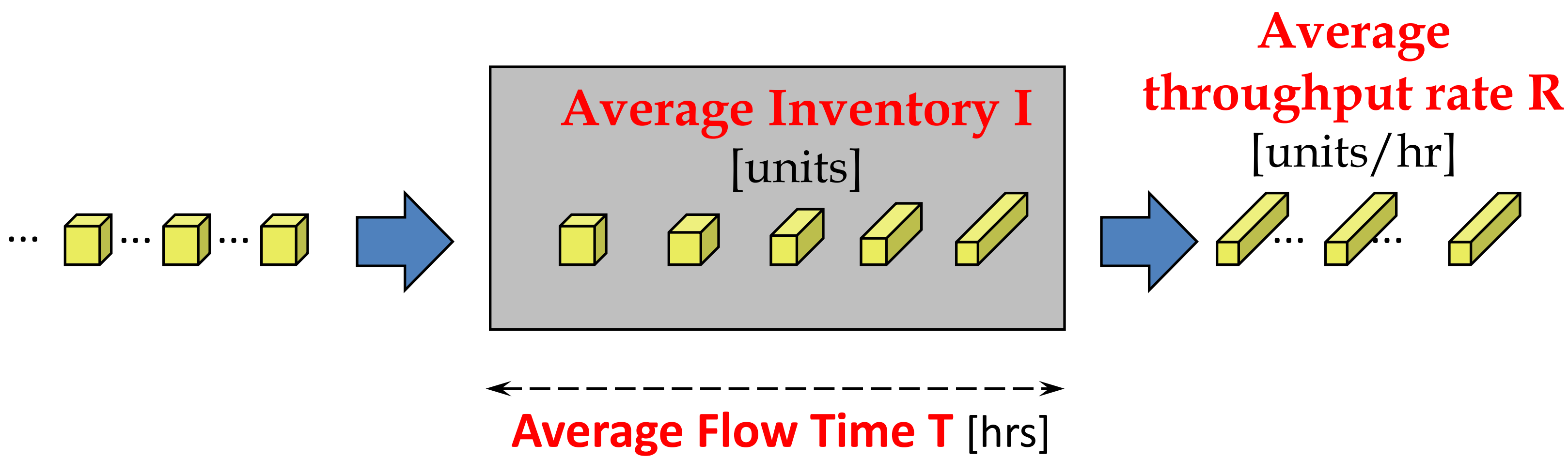
2023

Steps for Process Flow Analysis

- Process Mapping: Standard/Linear/Swim Lane/Gantt Chart
- Bottleneck Analysis: Identify *"flow units"*, "theoretical flow time", "bottleneck resource", "capacity rate"
- Short-run analysis (inventory build-up diagram)
- Long-run analysis (Little's Law)

Little's Law

- Establishes a relationship between **average** inventory, **average** throughput rate, and **average** flow time

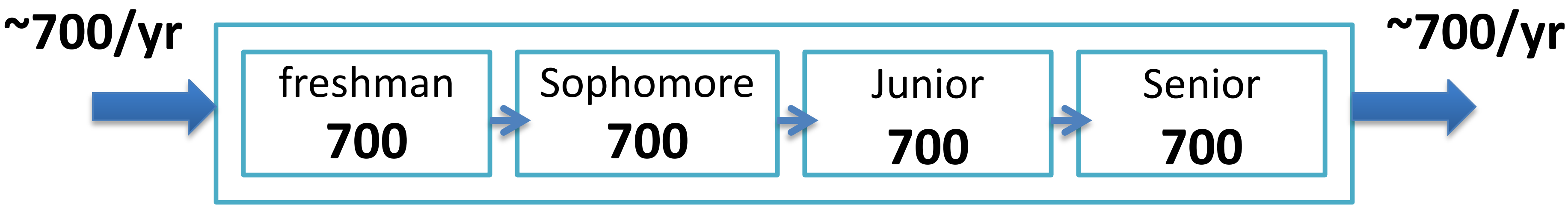


Little’s Law

- Throughput rate: 700 undergrads/year
- Flow time: 4 years
- Total # undergrads in HKU FBE?

Total # Undergrads = (700/year) * (4 years) = 2800

(average) inventory = **(average) throughput rate** * **(average) flow time**



I = R * T

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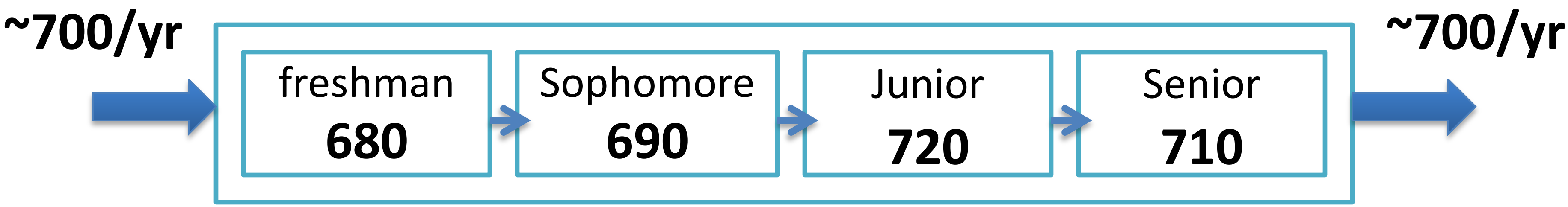
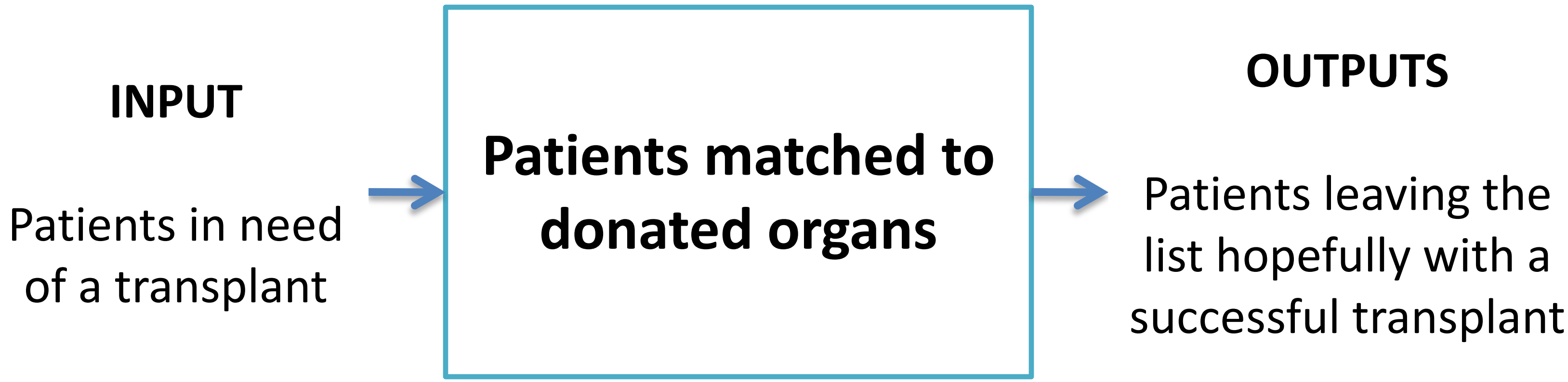
(average) inventory — (average) throughput rate — (average) flow time



I = R * T

Little’s Law: Example 1

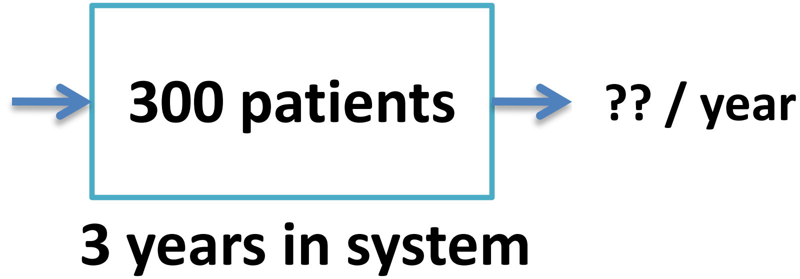
- Patients waiting for an organ transplant are placed on a list until a suitable organ is available. We can think of this as a process. Why?



Little's Law: Example 1

Question (a)

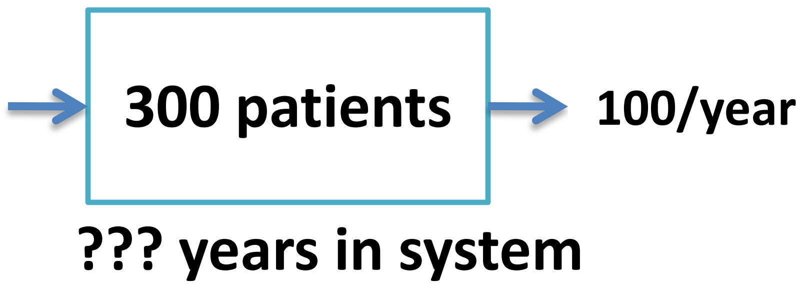
- On average, there are 300 people waiting for an organ transplant
- On average, patients wait on the list for 3 years
- Assume that no patients die during the wait
- How many transplants are performed per year?



I = R * T

Inventory I = 300 patients
Flow Time T = 3 years
Throughput Rate
R = I/T = 100 patients / year

Little’s Law: Example 1



I = R * T

Inventory I = 300 patients
Throughput R= 100 patients/year
Flow Time
T = I/R = 3 years

Question (b)

- On average, there are 300 people waiting for an organ transplant
- On average, 100 transplants are performed per year
- Assume that no patients die during the wait
- How long do patients stay on the list?

Little's Law: Example 2

- It takes 6 days for Copper Ltd. to ship copper from inland China to the terminal at Hong Kong. After a container arrives at Hong Kong terminal, it waits for 3 addition days to be shipped oversea.

INPUT
Copper

Road Transportation
6 days

Wait at the Terminal
3 days

OUTPUT

Little's Law: Example 2

On average, the holding cost for copper is $50 per ton per day (no matter the copper is at the terminal or on the road). Copper Ltd. ships 10,000 ton every month. How much Copper Ltd. spends on holding the copper every month?

Answer:

I=R*T=10,000(ton/month)*(6+3days)/30(days/month)

= 3000 (ton)

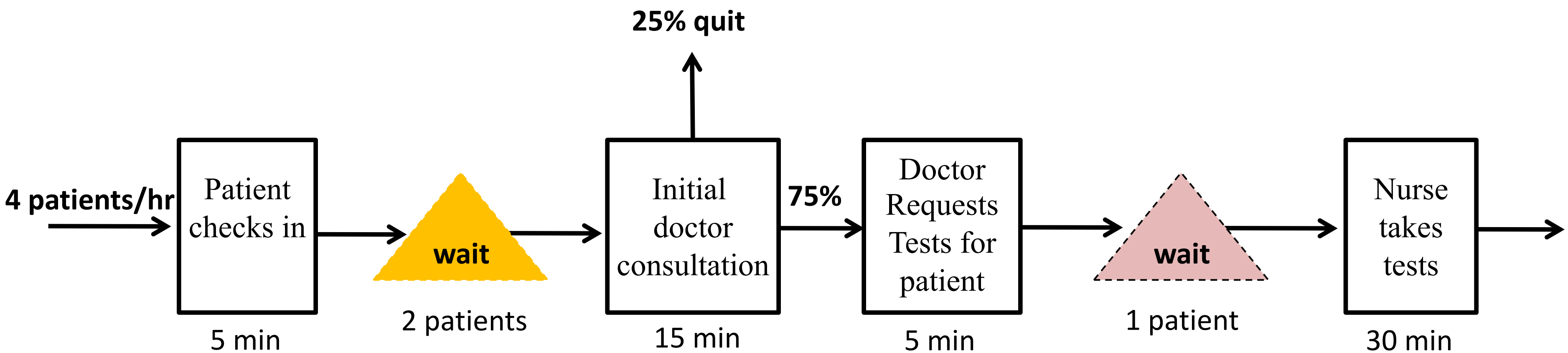
So the holding cost for each month is

3000(ton)*50($/ton/day)*30(days/month)=4,500,000$/m

Key: Apply Little's Law on the correct process

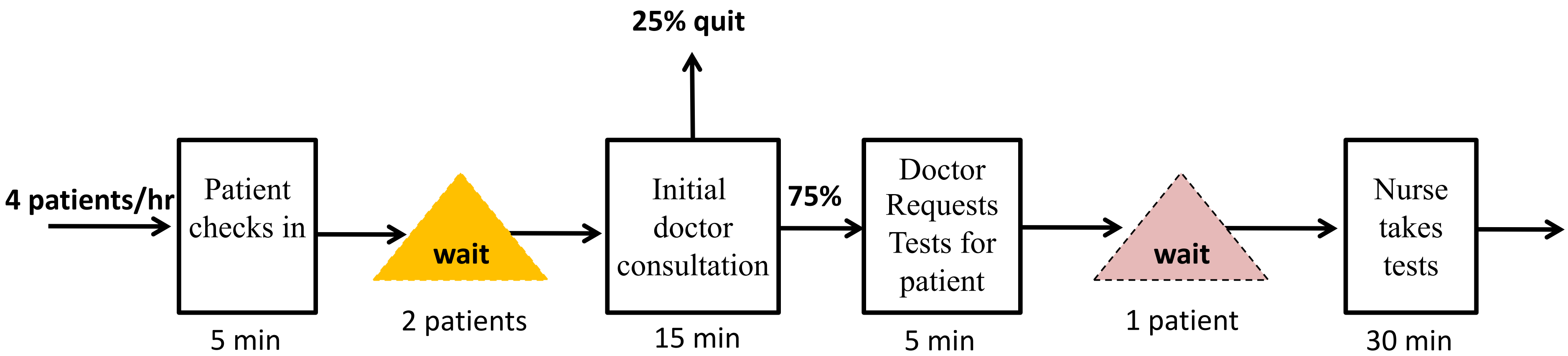
Interpretation of Inventory: "A flow unit is either being processed or waiting for process" implies that both "activity" and "buffer" can hold inventory.

Little's Law: Example 3



Assumption: Input 4 patients/hr and each stage has enough resources to handle the input.
Average flow time of the patients?

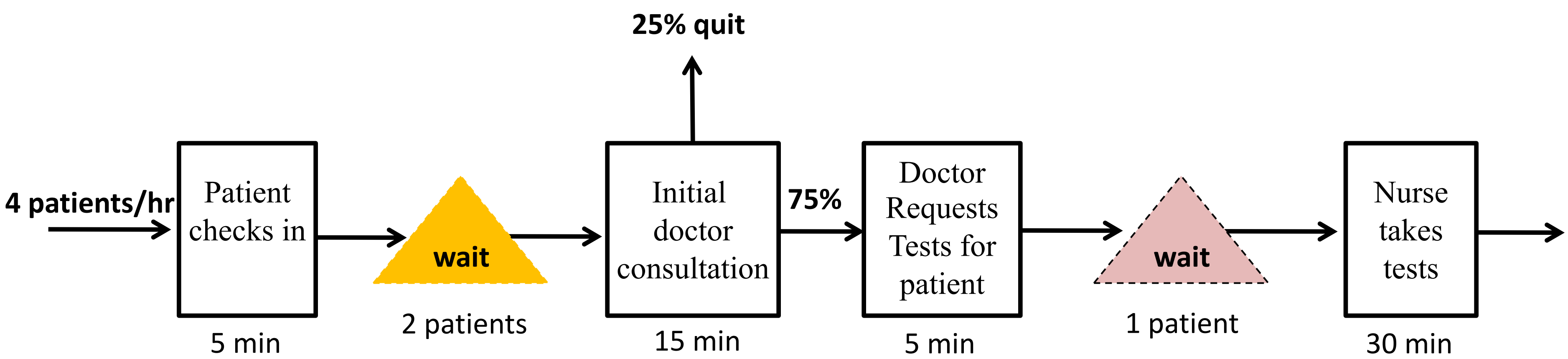
Little's Law: Example 3



1. Total flow time
   - Quit: 5min + 2 patients/(4 patients/hr) + 15min = 5+30+15 min = 50 min
   - Continue: 50 min + 5 min + 1 patient/(4 patients/hr *0.75) + 30 min = 105 min
2. Average flow time:

   25%*50 min + 75%*105 min = 91.25 min

Little's Law: Example 3



Average flow time T = I/R.

R = 4 patients/hr.

I = I1 + I2 + I3 + I4 + I5 + I6 = 5/60 hr*4patients/hr + 2 + 15/60 hr*4patients/hr + 5/60 hr*3 patients/hr + 1 + 30/60 hr*3 patients/hr = 1/3 + 2 + 1 + ¼ + 1 + 3/2

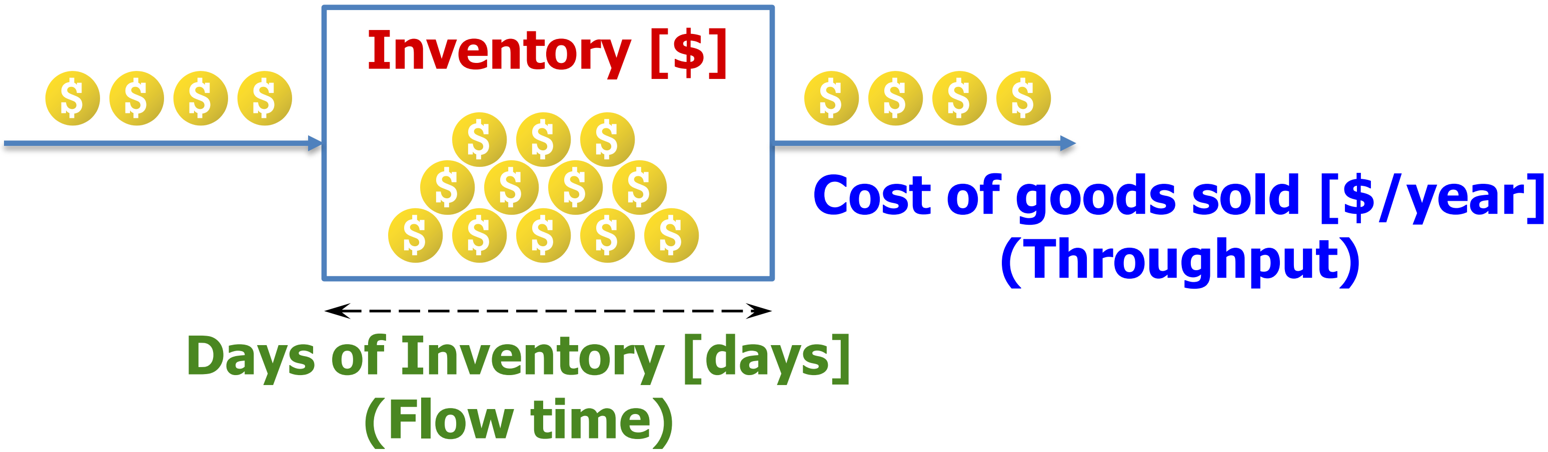
T = 91.25 minutes.

Inventory Turnover
(Link financial and operations measure)

- ***Inventory Turnover*** (or ***turns***) (how frequent turning inventory)
  = [Cost of goods sold] / [Average inventory investment]
  = [$ value of cost of output] / [$ value of average inventory]
  = R / I
  = 1 / T

- Why are higher inventory turns good?
  - "Selling your goods faster".
- How to increase inventory turns, i.e., how to turn "stock" into "flow"?
- The flow time (i.e., T) when expressed in days is also referred to ***days in inventory***
  - measures the average number of days the company holds its inventory before selling it

Days of Inventory & Inventory Turnover



By Little's Law,

$$\text{Days of Inventory} = \frac{365 \times \textbf{Inventory}}{\textbf{Cost of goods sold (Throughput)}}$$

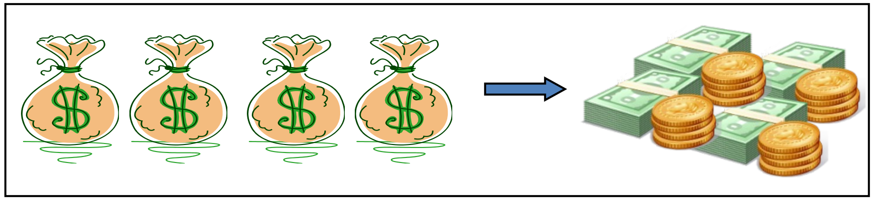
$$\text{Inventory Turnover} = \frac{\textbf{Cost of goods sold (Throughput)}}{\textbf{Inventory}}$$

This measures the velocity of moving inventory.

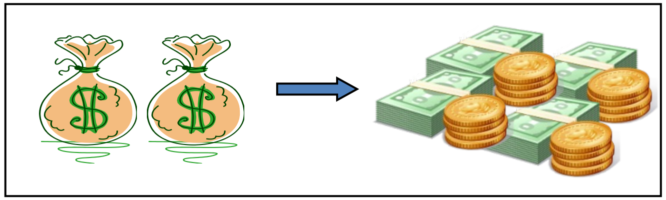
The Importance of Inventory Turnover

	Inventory Turnover	Increasing Inventory Turns (Velocity)
Dell	5-8 times more than competitors	Dell's business model Assemble to order
Toyota	Spare parts inventory 10 times faster than competitors	Just-in-time Components are received from suppliers only when they are needed. Not order in advance.
Wal-Mart	Year 2018: 8.5 Turns (Target was slightly less than 6)	Cross docking
Progressive Insurance	Claims processed in hours instead of days	Immediate response claims handling

Measuring Inventory Cost: Inventory Turns



Money as inventory Money as goods sold



Money as inventory Money as goods sold

(Annual) Inventory Turns = (Annual) COGS / Inventory

Days of Inventory = 365 / Inventory Turns

	Target	Wal-Mart
Inventory Turns (2018 data)	5.90 (62 days)	8.53 (43 days)
Per-unit Inventory Cost	0.68%	0.47%
(assuming annual interest rate of 4% or 0.011% daily)		

Operations in Finance:

Walmart Income statement and balance sheet

Fiscal year is February-January. All values USD Millions.	2021	2020	2019
Sales/Revenue	559,151	523,964	514,405
Sales Growth	6.72%	1.86%	2.90%
Cost of Goods Sold (COGS) incl. D&A	420,315	394,605	385,301
COGS excluding D&A	409,163	383,618	374,623
Depreciation & Amortization Expense	11,152	10,987	10,678
Depreciation	11,152	10,987	10,678
COGS Growth	6.52%	2.41%	3.19%
Gross Income	138,836	129,359	129,104
Gross Income Growth	7.33%	0.20%	2.05%
Gross Profit Margin	24.83%	-	-
Net Income	13,510	14,881	6,670
Net Income Growth	-9.21%	123.10%	-32.37%
Net Margin	2.42%	-	-

Operations in Finance:
Walmart Income statement and balance sheet

Fiscal year is February-January. All values USD Millions.	2021	2020	2019
Cash & Short Term Investments	17,741	9,465	7,756
Cash Only	17,741	9,465	7,756
Cash & Short Term Investments Growth	87.44%	22.03%	14.80%
Cash & ST Investments / Total Assets	7.03%	4.00%	3.54%
Total Accounts Receivable	6,516	6,284	6,283
Accounts Receivables, Net	6,516	6,284	6,283
Accounts Receivables, Gross	6,516	6,284	6,283
Bad Debt/Doubtful Accounts	-	-	-
Accounts Receivable Growth	3.69%	0.02%	11.92%
Accounts Receivable Turnover	85.81	83.38	81.87
Inventories	44,949	44,435	44,269

Little’s Law: Example - Retail

($ in billions)	Target (1/30/2020)	Wal-Mart (1/30/2020)
Net Sales	$78.11	$523.96
Cost of Goods Sold	$54.86/year	$394.61/year
Net Income	$3.28	$14.88
Inventories	$9.50	$44.44
Months of Inventory	9.50/54.86*12 = 2.08 month => 5.8/yr	44.44/394.61*12 = 1.35 month => 8.58/yr

If Wal-Mart carried the same months of inventory as Target, its inventories would be

$$I = R \times T = (394.61/12)*2.08 = 68.40$$

This would tie up about $23.96 billion extra in inventory.

Little's Law and Business Functions

	Performance Measures	**Effects seen in**
Inventory	Use of Working Capital	Balance Sheet
Throughput **R**ate	Rate of Revenue Generation	Income Statement
Flow **T**ime	Responsiveness Lead time	Operations Marketing

Little’s Law: Example - Burgerville

Customer Flow: Burgerville is a regional restaurant chain. At a typical location, 1,080 customer per day visit the restaurant. (The restaurant is open 12 hours/day). On average there are 36 customers in the restaurant.

- How long does the average customer spend in the restaurant?

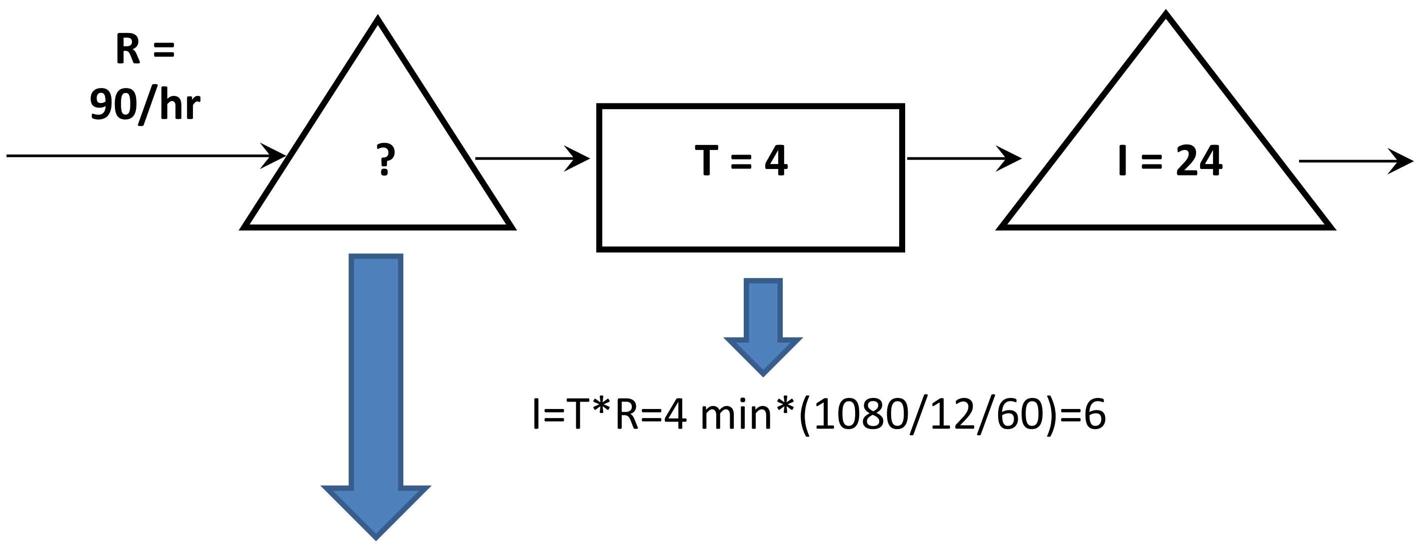
  36/(1080/12)=0.4 hours = 24 minutes

- What is the hourly inventory turnover?

  1/0.4 hours= 2.5/hour

Extending the Example

- Customers in the restaurant are either waiting to place their order, being served or eating. Being served takes 4 minutes and on average 24 of the 36 customers are eating. How long does the average customers wait in line?



I=36-6-24=6 customers waiting in line on average
T=I/R=6 / (90/hr) = 4 minutes

More Burgerville

Workforce Turnover

- 2005: Only 3% of hourly workers sign up for healthcare.
- 2006: Offer more generous healthcare benefit. Today 98% of Burgerville's 579 eligible hourly employees are enrolled.
- “Turnover in 2006 plunged to 54%, from 128% in 2005. That's a big deal when it costs an average of $1,700 to replace and train a restaurant worker, according to People Report.”

  -- “Burger Chain’s Health-Care Recipe,” *WSJ* Aug. 31, 2009

Question: What is the benefit of offering better healthcare benefit?

What is the annual cost savings in hiring?

More Burgerville: Using Little's Law for financial analysis

- 2005: Only 3% of hourly workers sign up for healthcare.
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Year	Annual Turnover	T = 1/Turns (years)	I (Hourly employees)	R = I/T (hires/year)	Cost @ $1,700/hire ($/year)
2005	1.28		579		
2006	0.54		579		

More Burgerville: Using Little's Law for financial analysis

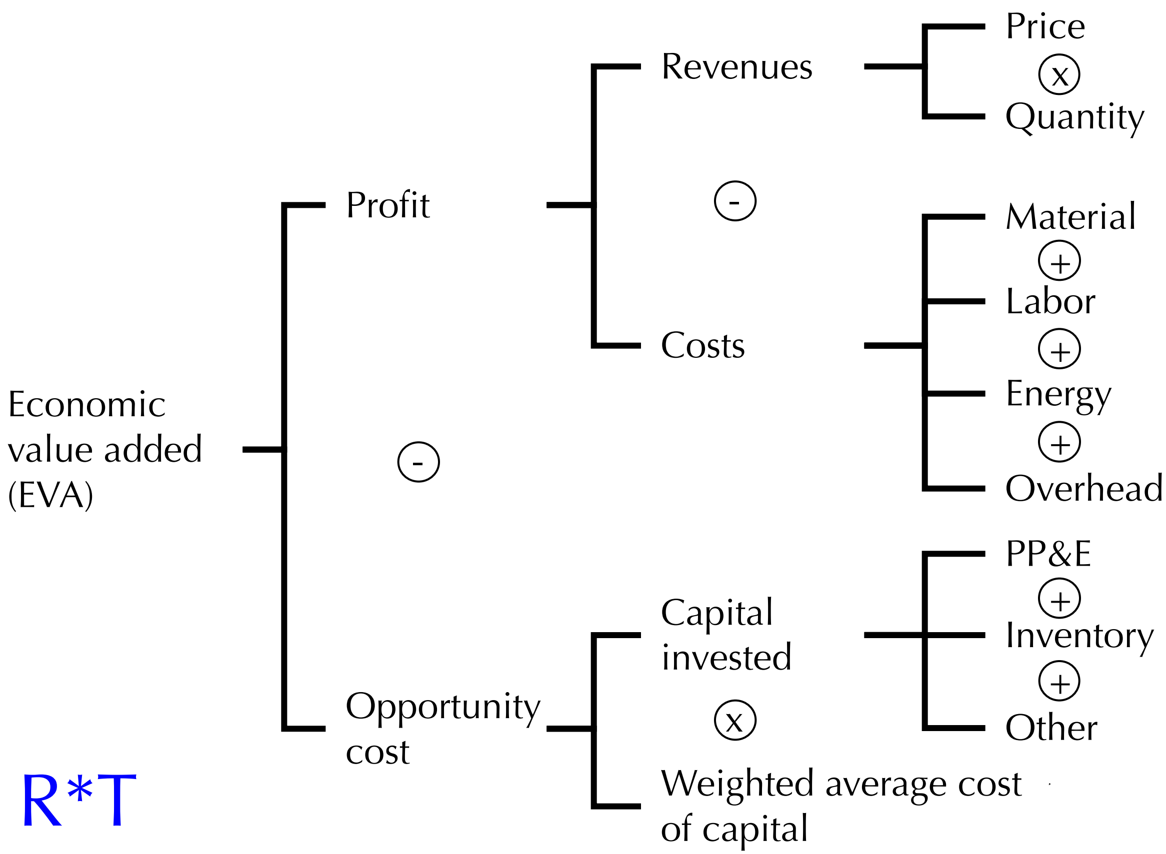
Year	Annual Turnover	T = 1/Turns (years)	I (Hourly employees)	R = I/T (hires/year)	Cost @ $1,700/hire ($/year)
2005	1.28	0.781	579	741.12	$1,259,904
2006	0.54	1.852	579	312.66	$531,522

- **Benefits**: Saving of $728,382/year in hiring costs
- **Costs**:
- **Additional benefits**: Higher quality of services; Higher productivity
- **Additional costs**: They might have to improve coverage for salaried employees.

Little's Law: Implications

- Given two operational measures, one can always compute the third, for any activity/buffer in a process.
  - **Throughput rate**, **flow time**, and **inventory** are related
- As a manager you can only control two. The third is determined by your choices of the first two.
- It is useful to connect the information on a balance sheet (stock) and income statement (flow) with flow time.

The business imperative: creating economic value



Improvement levers

1. Increase price
2. Improve quality
3. Increase throughput
4. Reduce costs
5. Reduce capital intensity
6. Reduce inventory

Reduce time

I = R*T

Financial metrics ⟷ **Operational metrics**

PP&E: Property, Plant, and Equipment (long-term assets)

Capital Intensity: Total Asset/Total Revenue

Process Analysis: Improving Performance

- Reducing cycle time increases capacity rate, so increases productivity;
- Reducing flow time increases inventory turnover, so reduces inventory cost.

Process Analysis (III): Recap

- Capacity rate versus throughput rate (**Utilization**)
- “Short-run” versus “long-run” averages
- Input and output rates vary over time resulting in
  - Excess capacity
  - Inventory build-ups
- **Inventory build-up diagrams** are useful tools, but
  - Average can be misleading; need to be carefully calculated
- **Little’s Law** helps make the connection between average flow measures

Interpretation of Process Measures In Production and Service

	Production Process	Service Process
Flow Unit	Materials	Customers
Input Rate	Raw material releasing rate	Customer arrival rate
Output Rate (Throughput rate)	Finished goods output rate	Customers departure rate (service completion rate)
Flow Time	Time required to turn materials into a product	Time that a customer is being served
Inventory	Amount of work-in-process	Number of customers being served
Capacity	Maximum output rate	Maximum service completion rate
Utilization	Equipment Utilization	Proportion of busy time of a nurse/operator/clerk