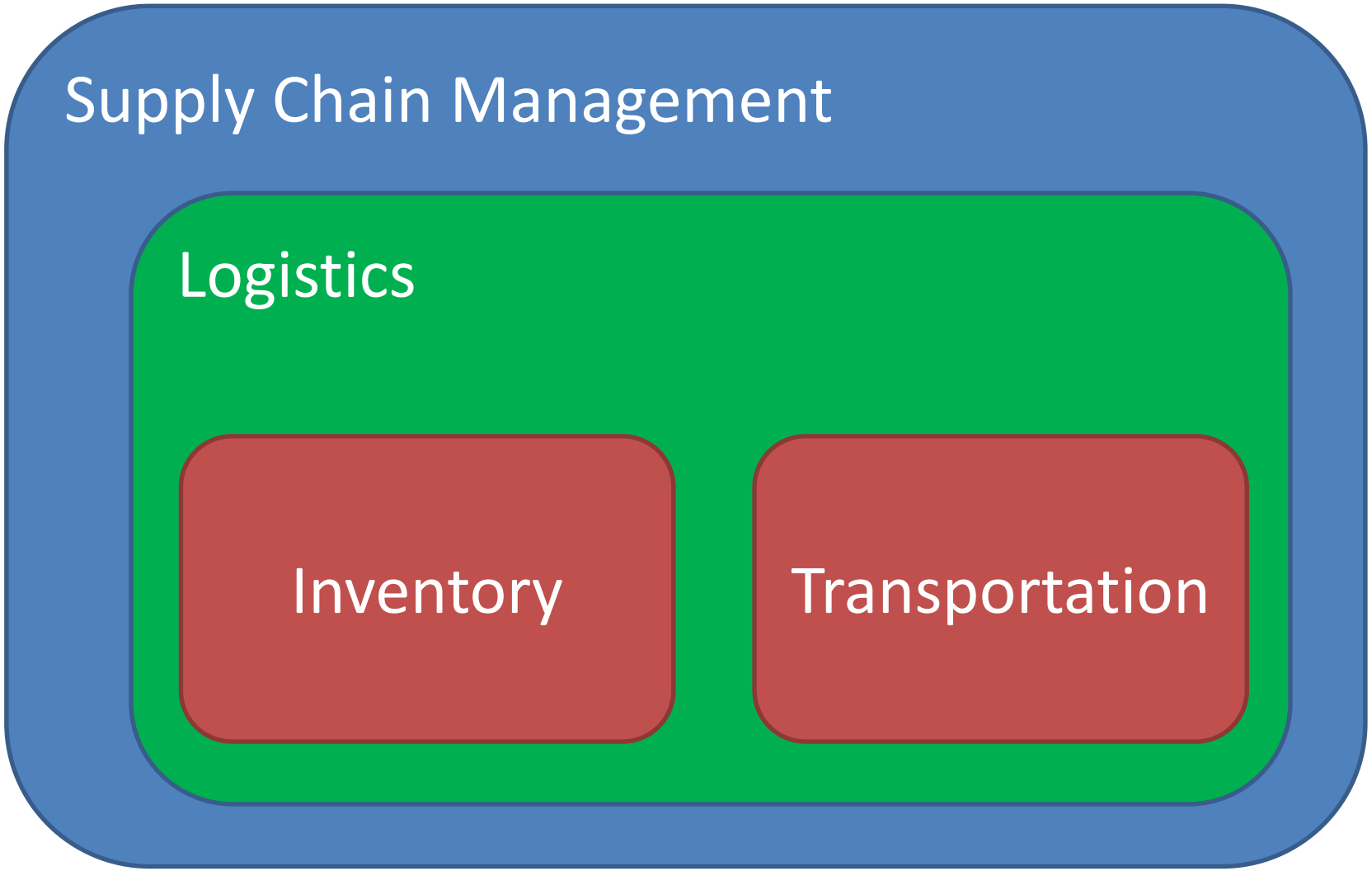
Inventory Management

Summer 2025

Prof. Dr. Stefan Minner
Logistics & Supply Chain Management
TUM School of Management


Supply Chain Management
Logistics
Inventory
Transportation

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Learning objectives

- Understand inventory management as an integral part of logistics and supply chain management solutions

- Know the strategies, concepts and methodologies for an effective working capital management

- Apply and develop quantitative decision support for real world inventory management in different industries

- Obtain knowledge for successful project and research work

Literature

No obligatory books, the course material will cover the exam material.

Main texts

- Vandeput, N. (2020). Inventory Optimization: Models and Simulations, de Gruyter
- Silver, E.A., Pyke, D.F., and Thomas, D.J. (2016), Inventory and Production Management in Supply Chains, 4th ed., CRC Press
- Muckstadt, J.A., Sapra, A., (2010), Principles of Inventory Management, Springer
- Axsäter, S. (2015), Inventory control, 3rd ed., Springer

Additional texts

- Zipkin, P.H. (2000), Foundations of inventory management, McGraw-Hill
- Makridakis et al. (1998), Forecasting: Methods and Applications, Wiley
- Chopra (2018), Supply Chain Management: Strategy, Planning, and Operation, 7th ed., Pearson.

Organizational

- **Lectures**
  - All materials provided on Moodle
  - Slides, Excel sheets, Python codes

- **Exercise Sessions**
  - Exercise sheets are uploaded to be discussed on predefined sessions.
  - Students are expected to present solutions and discuss them in these sessions.
  - Please prepare the solutions in this way before coming to the session.
  - Exercises which were not prepared **will not be discussed.**

- **Trial Exam:** An additional exercise session with a sample exam

- **Q&A:** Final session to clarify remaining questions

- **Final exam:** July 16, 2025, 11:30am - 1pm, open book and computer format, 3 out of 4 questions

1. Introduction

Silver et al. (2017), Chapter 1-2

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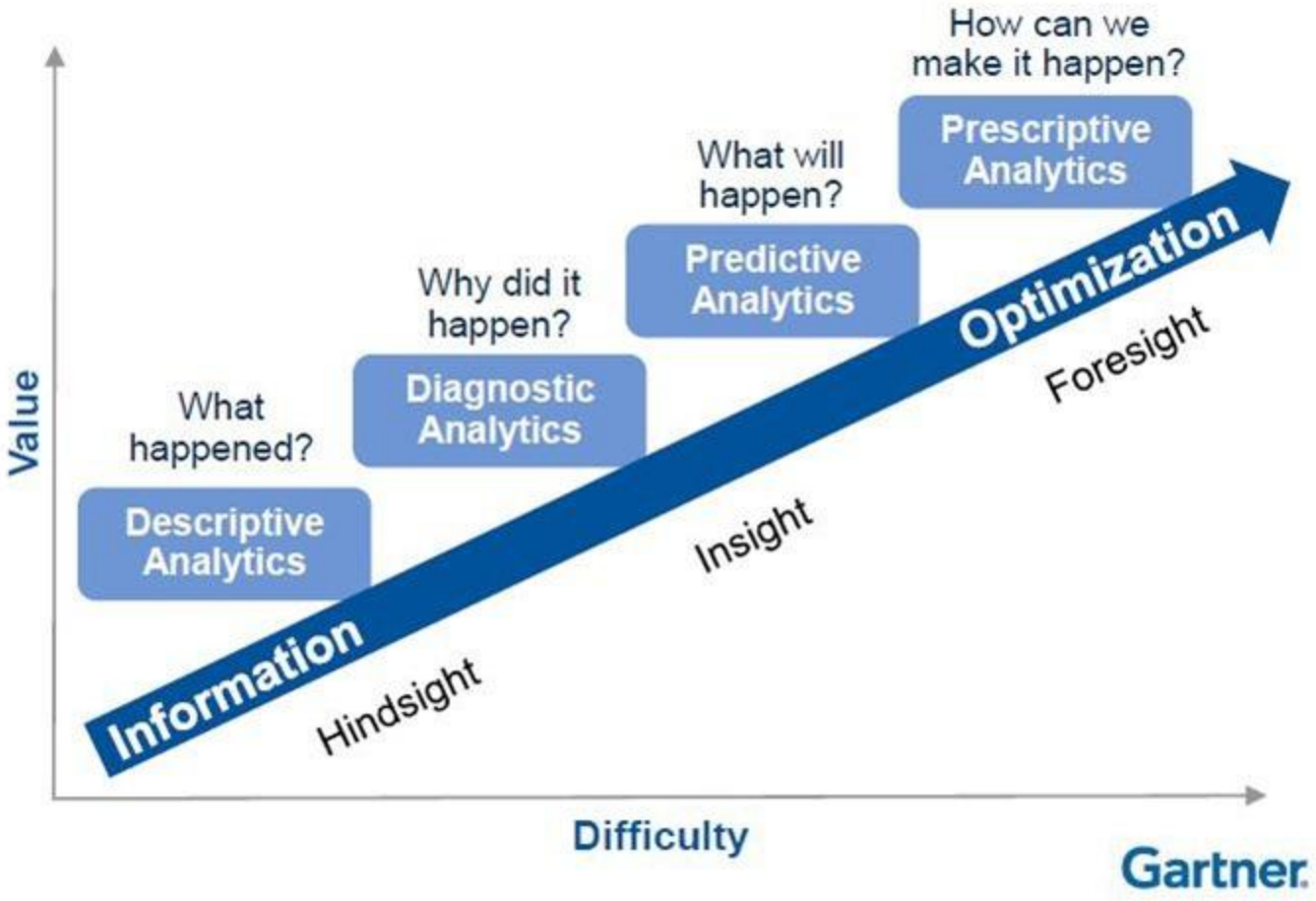
Gartner Analytics Trends



Business News

295 views | Apr 4, 2019, 08:00am

Zero Waste: Z5 Inventory For Healthcare

Mary Juetten Contributor
Entrepreneurs

Last month I wrote a tiny rant about he
ironically, I heard about Carl Natensted
of Z5 Inventory, founded and headquarte
Inventory went live with the first version
management application in 2014. Their m
control and greater access to medical servi
that?

Hornby faces another year of losses on supply woes

Maker of toy trains still suffering from long-running backlog issues

ns can do more with data

ckchain, arti
es IBM's Jon
- be mo

FORWARD THINKING

Oracle updates Supply Chain communication

By Supply Chain Quarterly Staff | March 21, 2019

s plans for inventory robots

obotics to add the compa
under a pilot progra
or inventory and

Inventory-management startup Radar raises $16M

3/29/2019

Radar, a startup that uses computer vision and radio frequency identification to automate retailers' inventory management, recently raised $16 million. The company expects to deploy its system with three customers this year.

Impressions

Motivation

Top inventory management
- Increase service levels
- Reduce costs
- Academic roots!

Inventory Management Software
- SAP APO
- ORACLE NetSuite
- SAS
- ZoHo Inventory
- Asset Panda
- SlimStock
- ….

Impact, U.S., Nov. 2018
- 10% of GDP in inventories (2 billion US$)
- Increasing
- For every 1$ of sales, 1.35$ of inventory

- Not only commercial sales!

Consulting statements

Eight ways to reduce your inventory:

1. Reduce demand variability
2. Improve forecast accuracy
3. Re-examine service levels
4. Address capacity issues
5. Reduce order sizes
6. Reduce manufacturing lot sizes
7. Reduce lead times
8. Reconfigure the supply chain

https://www.industryweek.com/companies-amp-executives/12-ways-reduce-inventories

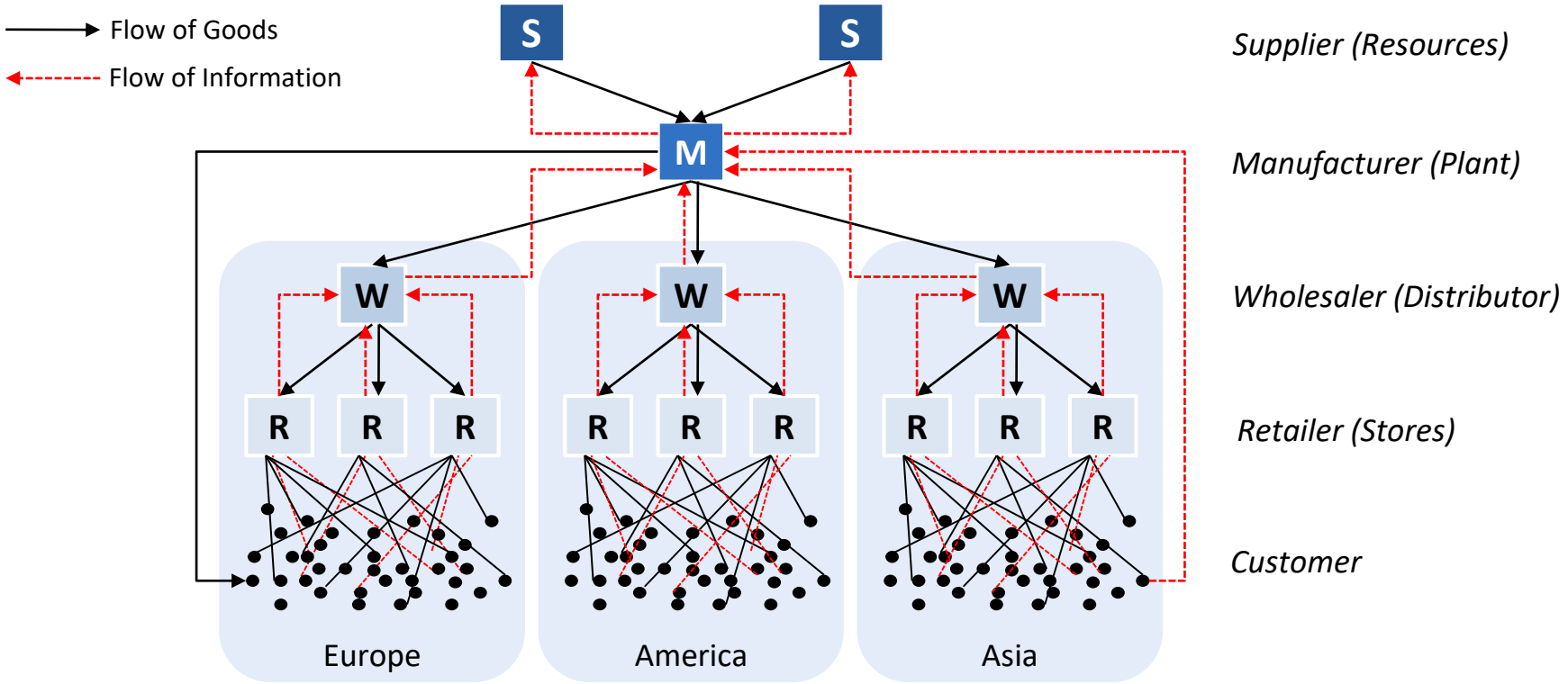
Motivation: balance sheets

All numbers in millions

Source: https://finance.yahoo.com

Company:	Wal-Mart Inc.		Boeing Co.		Siemens AG		Google Inc.	
Period 2020/21	Jan-21		Dec-20		Sep-20		Dec-20	
Assets								
Current Assets								
Cash And Cash Equivalent	17,741	7.03%	7,752	5.10%	14,041	11.33%	26,465	8.28%
Short Term Investments	0	0.00%	17,838	11.73%	2,680	2.16%	110,229	34.49%
Net Receivables	6,516	2.58%	10,051	6.61%	26,046	21.02%	31,384	9.82%
Inventory	**44,949**	**17.80%**	**81,715**	**53.71%**	**7,795**	**6.29%**	**728**	**0.23%**
Other Current Assets	20,861	8.26%	4,286	2.82%	2,406	1.94%	5,490	1.72%
Total Current Assets	**90,067**		**121,642**		**52,968**		**174,296**	
Net Property Plant and Equipment	109,848	43.50%	11,820	7.77%	10,250	8.27%	96,960	30.34%
Goodwill	28,983	11.48%	10,924	7.18%	20,449	16.50%	22,620	7.08%
Long-Term Investments	0	0.00%	1,016	0.67%	10,155	8.20%	20,703	6.48%
Accounts Receivable, Long Term	0	0.00%	1,936	1.27%	0	0.00%	0	0.00%
Loans Receivable, Long Term	0	0.00%	0	0.00%	0	0.00%	0	0.00%
Deferred Tax Assets, Long Term	0	0.00%	86	0.06%	0	0.00%	1,084	0.34%
Other Long-Term Assets	23,598	9.35%	4,712	3.10%	30,075	24.27%	3,953	1.24%
Total Assets	**252,496**		**152,136**		**123,897**		**319,616**	

The flow of goods and information



→ The right flow of goods decreases inventories and increases service levels.

→ The right flow of information is needed for the right flow of goods.

Inventory management in a nutshell

Main questions:

- Frequency of stock reviews and order decisions
- When should an order be placed?
- How much should be ordered?

Recent developments and research

- Digitalization: Data-driven inventory management
- Non-stationary demands in inventory management
- Behavioral inventory management – human judgments

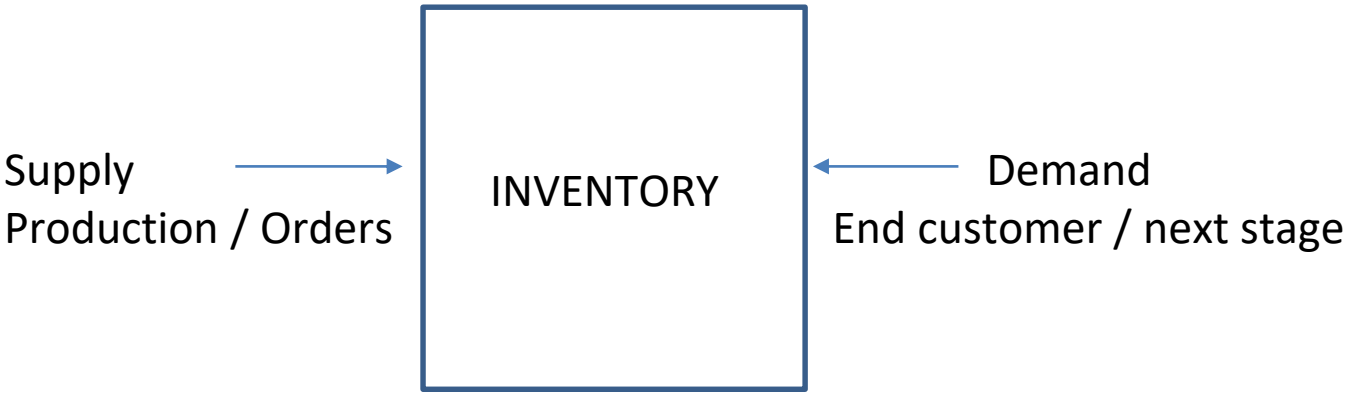
Applications and challenges

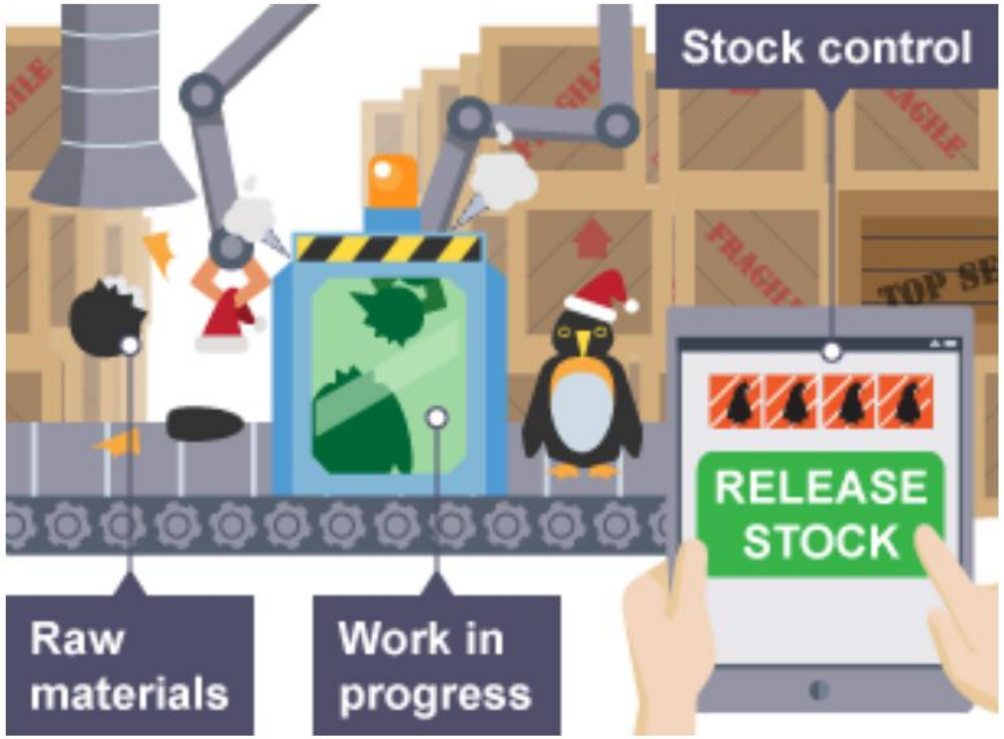
- Manufacturing parts and consumer goods
- Perishable items
- Spare parts
- Reverse logistics
- Health-Care operations
- Disruption risk and multiple suppliers
- Marketing-Operations interface

Types of inventory

Locations

- Finished goods inventory
- Work in process
- Raw materials





Purpose of inventory

- **Cycle stock**
  Amount of inventory that is planned to be used in a certain cycle
- **Congestion stock**
  Inventory piled up because e.g. a machine is disrupted
- **Safety stock**
  Inventory kept to account for supply and demand uncertainty
- **Anticipation inventories**
  Extra inventory to anticipate on e.g. a peak in demand
- **Pipeline inventories**
  Finished goods that have not yet reached the customers
- **Decoupling stock**
  Inventory buffer between different stages of the supply chain

Performance measures

Strategic

- Annual inventory turnover ratio: (cost of goods sold in year) / (average inventory)

Operational

- **Quantity measures**
  - Days of supply: total inventory value / average daily sales value
- **Cost measures**
  - Ordering cost
  - Inventory holding cost
  - Backorder and lost sales penalty cost
- **Service measures**
  - Availability – *α-service*
  - Fill rate (item, product, customer order) – *β-service*
  - Cycle service level: probability of no stock-out during an order cycle

Calculation example

$$\text{Annual turnover ratio} = \frac{Avg.\,COGS^{*}}{Avg.\,Inventory}$$

$$\text{Inventory days} = \frac{365}{Annual\ turnover\ ratio}$$

2020 All numbers in billions	**Average COGS***	**Average Inventory**	**Annual turnover ratio**	**Inventory days**
BASF	40.2	10.0	4.0	90.8
Bayer	14.9	11.0	1.4	269.2
BMW	67.7	14.9	4.5	80.3
Daimler	110.5	26.4	4.2	87.4
Siemens	33.9	7.8	4.3	84.0

*COGS = Cost Of Goods Sold

Cost categories

Ordering cost

- Administration of order, transportation cost
- Setup cost (change tools, opportunity cost for capacity loss)
- Handling cost

Inventory holding cost

- Cost of capital (opportunity cost)
- Payments for renting warehouse space, insurance, warehouse operations

Backorder and lost sales penalty cost

- How to estimate?

Period	Demand	Begin Inv = Order_t + End Inv_t-1	Order	End Inv = Begin Inv_t - Demand_t	Fulfilled Frequency (Alpha Lv)	Fulfilled Quantity (Beta Lv)
1	15	50		35	Y	15
2	15	35		20	Y	15
3	15	20		5	Y	15
4	18	5		-13	N	5
5	4	37	50	33	Y	4
6	6	33		27	Y	6
7	6	27		21	Y	6
8	10	21		11	Y	10
9	7	11		4	Y	7
10	10	54	50	44	Y	10
11	15	44		29	Y	15
12	12	29		17	Y	12
13	7	17		10	Y	7
14	15	10		-5	N	10
15	9	45	50	36	Y	9
16	7	36		29	Y	7
17	12	29		17	Y	12
18	12	17		5	Y	12
19	8	55	50	47	Y	8
20	8	47		39	Y	8
Total	**211**				**18**	**193**

"availability" (α-service):
fraction of time with positive stock on hand

$$\frac{18}{20} = 90.0\%$$

"fill-rate" (β-service):
fraction of demand that can be satisfied immediately

$$\frac{193}{211} \approx 91.4\%$$

Cycle service level:
Fraction of order cycles without a stock-out

$$\frac{2}{4} = 50.0\%$$

Calculating inventory holding cost (illustrative example)

Average Inventory (Investment) Value

- €32,000

Annual Inventory Costs

- Storage € 800
- Handling € 400
- Obsolescence € 600
- Damage €800
- Administration € 600
- Total € 3,200

Inventory Costs divided by Average Inventory Value:

- € 3,200 / €32,000 = **10%**

Summary

- Opportunity Cost of Capital: 8%
- Insurance: 5%

- **Total: 23%**

ABC / XYZ Analyses

ABC Analysis

- Categorization of items with high, middle, low importance

XYZ Analysis

- Categorization of items for which good, medium or bad forecasts can be obtained

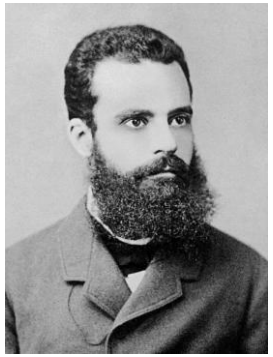
Combining ABC and XYZ

- 3 x 3 matrix
- Goal: Segmentation by ABC and XYZ to determine which products to focus on

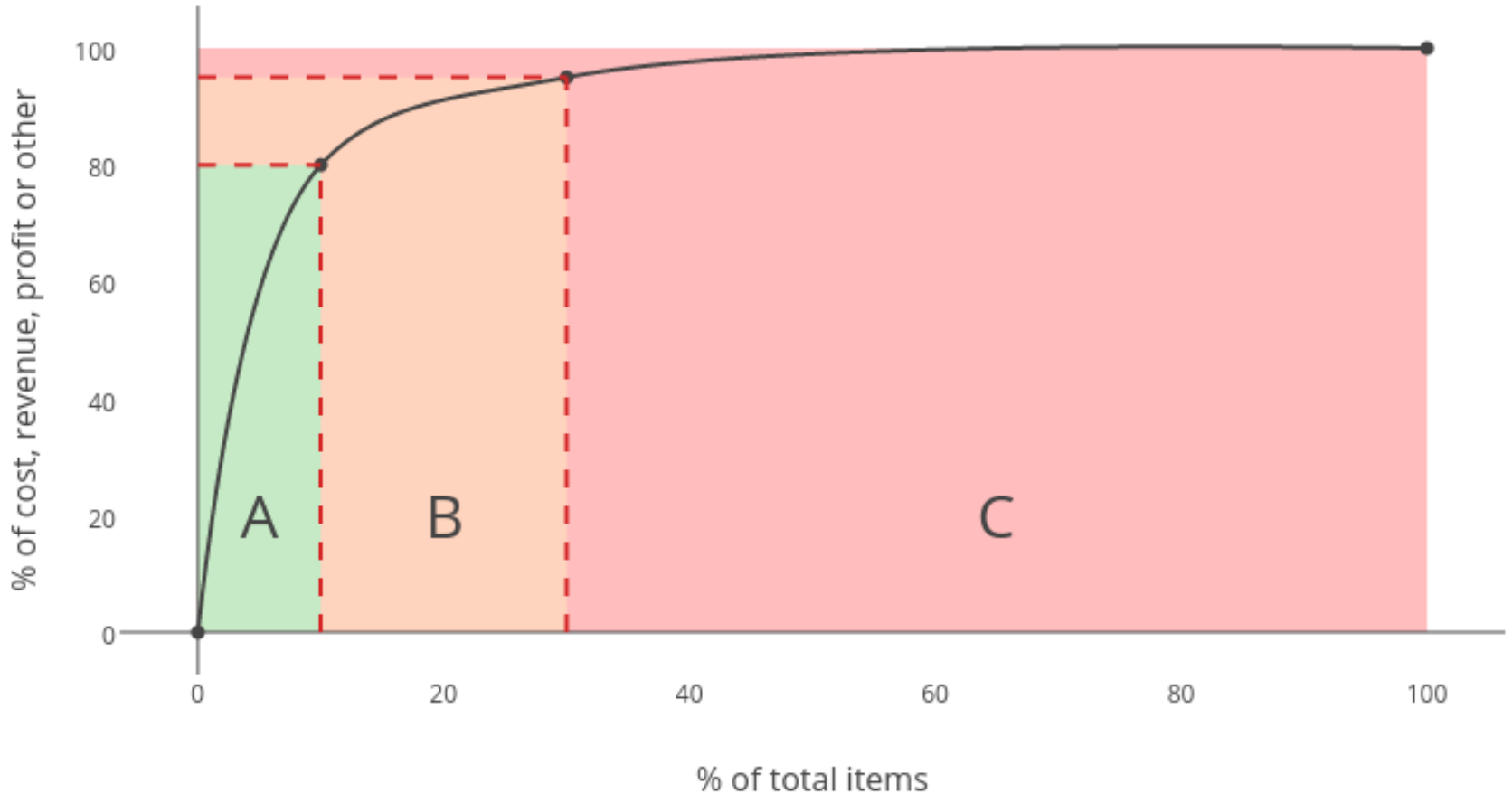
ABC-Analysis

Rank all items based on “importance”
- Consumption value
- Revenue
- Profit

Pareto principle:
A small number of items account for a large part of profit (e.g. 80/20)



Vilfredo Pareto
1848-1923
Italian economist



Example ABC-Analysis based on value

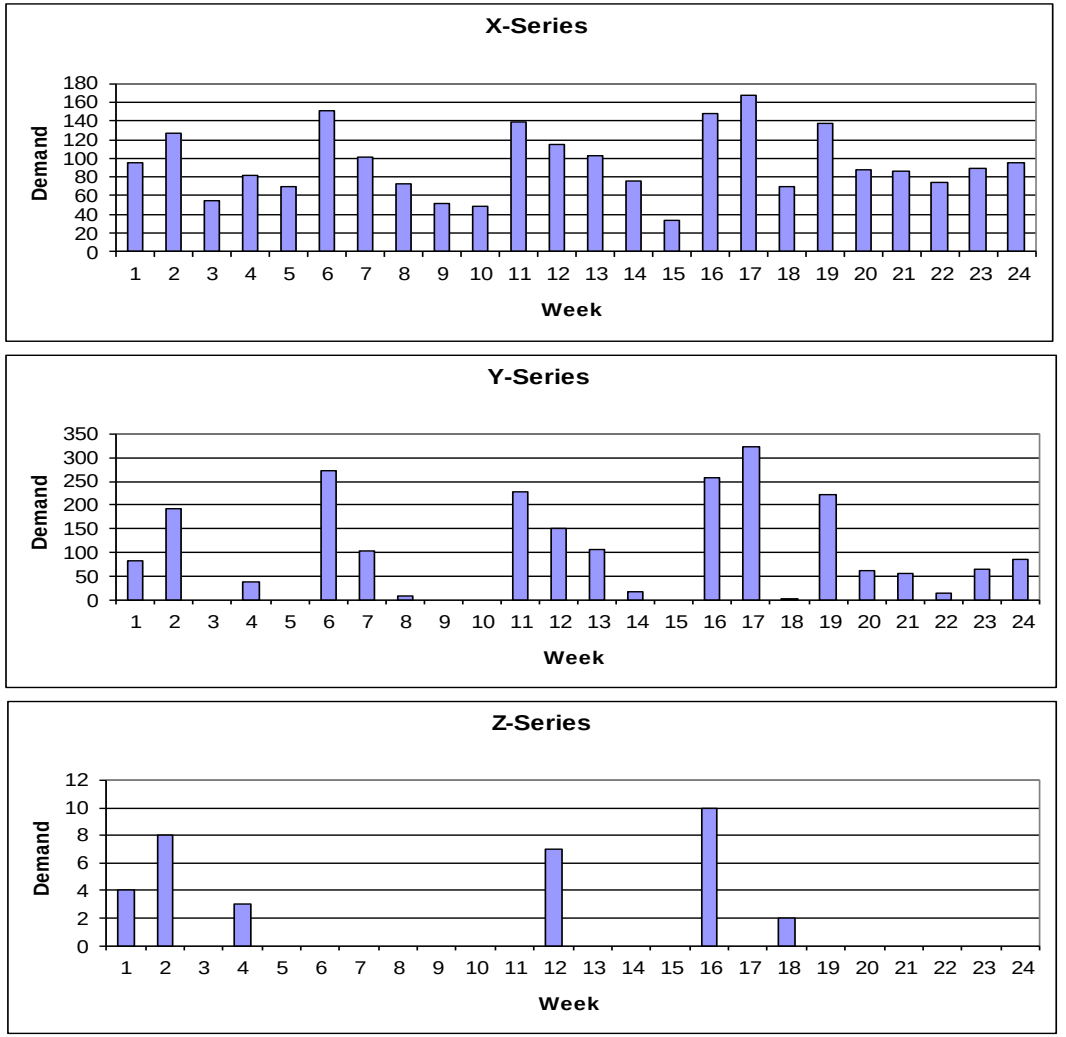
Item	Value (T €)	%	Cumulative %	Classification	Proportion of items	Proportion of value
7	34000	46.7	46.7	**Class A** (e.g., engine, gear drive)	20%	81%
1	25000	34.3	81.0			
9	4500	6.2	87.2	**Class B** (e.g., plastic parts, metal sheets)	40%	17.5%
5	3360	4.6	91.8			
2	2200	3	94.8			
6	1950	2.7	97.5			
3	640	0.9	98.4	**Class C** (e.g., glue, bolts)	40%	2.5%
4	560	0.8	99.2			
10	480	0.6	99.8			
8	120	0.3	100			

Source: Jonsson (2008), p. 426, Domschke (2005), p. 139.

XYZ-Analysis

Ranking on **demand pattern / forecast requirements**
Example:

- **X: regular demand**
  - Few periods without demand
  - Coefficient of variation ≤ 0.5
  - *Normal distribution*
- **Y: irregular demand**
  - Small fraction of periods without demand
  - Coefficient of variation > 0.5
  - *Negative binomial distribution*
- **Z: sporadic demand**
  - Large fraction of periods without demand
  - *Compound Poisson demand models*



Example XYZ based on coefficient of variation

t	1	2	3	4	5	6	7	8	9	10
Product 1	95	127	55	81	70	151	101	73	51	48
Product 2	83	192	0	36	0	271	102	9	0	0
Product 3	4	8	0	3	0	0	0	0	0	0

t	11	12	13	14	15	16	17	18	19	20
Product 1	139	115	102	75	33	148	167	70	137	88
Product 2	229	151	107	18	0	258	324	2	223	61
Product 3	0	7	0	0	0	10	0	2	0	0

	Mean	Standard deviation	Coefficient of variation	Classification
Product 1	96.30	38.57	0.40	X
Product 2	103.30	109.44	1.06	Y
Product 3	1.70	3.11	1.83	Z

$$cv = \frac{\sigma}{\mu}$$

Inventory with Service Levels

Problem

- Service parts criticality
- Volatile demand
- ABC classification
- Inadequate inventory policy

Approach

- Extended classification : XYZ
- Service level oriented inventory policy
- Different, **class specific models**

Article		AX	BX	CX	AY	BY	CY	AZ	BZ	CZ
SL Old		100 %	97.4 %	100 %	89.5 %	100 %	39.0 %	76.5 %	100 %	90.5 %
SL New		100 %	100 %	98.8 %	100 %	100 %	92.7 %	100 %	100 %	85.7 %
Deviation	SS	-25 %	-29 %	-40 %	+100 %	+150 %	+233 %	+100 %	0 %	0 %
	SL	0 %	+2.6 %	-1.2 %	+10.5 %	0 %	+53.7 %	+23.5 %	0 %	-4.8 %

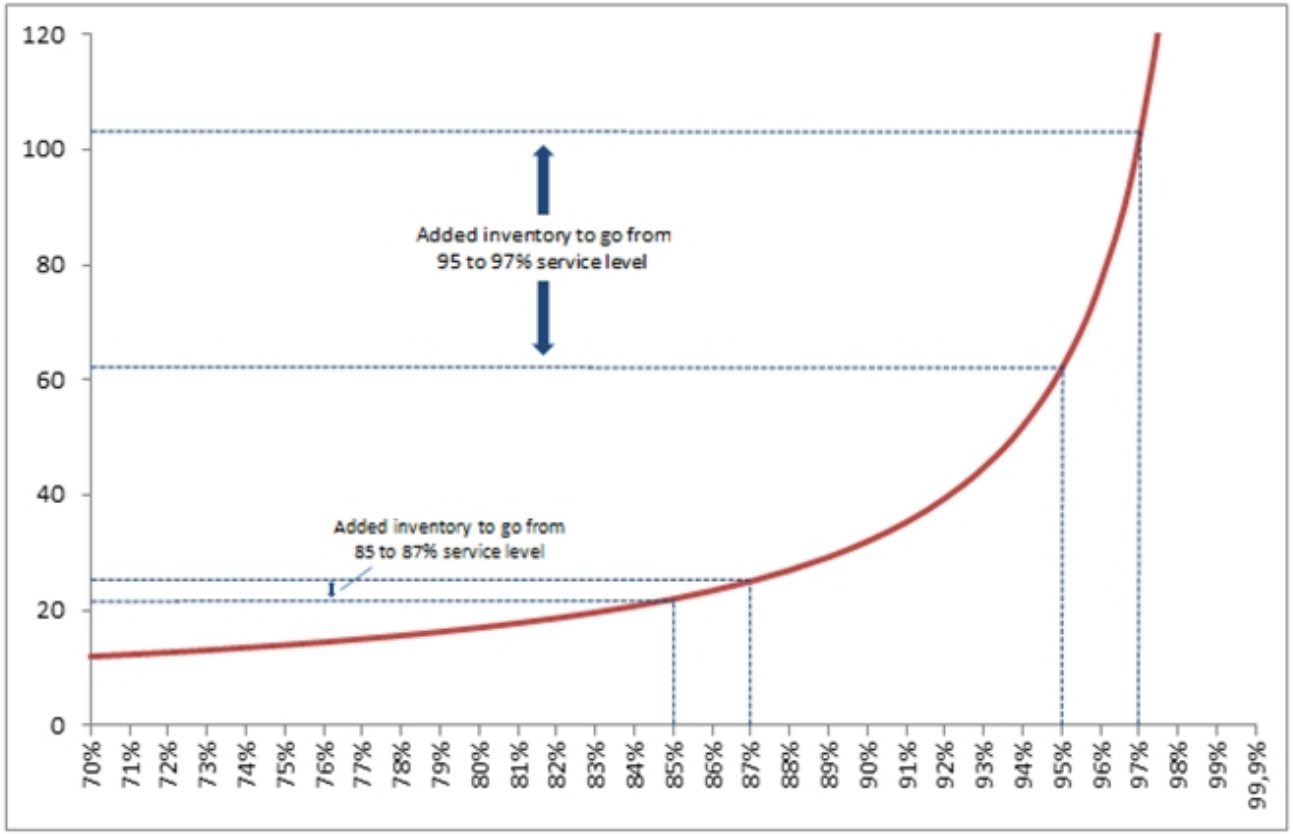
Service levels

ABC groups the **importance** of different items
XYZ groups their **demand patterns and forecastability**

Classical view: Service level A > B > C

But: achieving a certain service level requires more safety stock for Z than for Y than for X

	A	B	C
X	high value, high predictability continuous demand	medium value, high predictability continuous demand	low value, high predictability continuous demand
Y	high value, medium predictability fluctuating demand	medium value, medium predictability fluctuating demand	low value, medium predictability fluctuating demand
Z	high value, low predictability irregular demand	medium value, low predictability irregular demand	low value, low predictability irregular demand



Modern view: cost analysis per item

Pros and cons of ABC and XYZ Analysis

Pro:

- Categorization of a lot of stock keeping units (SKUs) into three clear groups
- Simple application
- Easy graphical visualization

Con:

- Why three groups? Why these group sizes?
- What to classify on? (ABC: value/revenue/profit? XYZ: CV/forecast accuracy?)
- Are C-parts also less important from an **inventory** perspective?

State-of-the-art research: **machine learning SKU classification**