



ΧΑΡΟΚΟΠΕΙΟ ΠΑΝΕΠΙΣΤΗΜΙΟ  
HAROKOPIO UNIVERSITY

# Supply Chain Management

Αναπληρ. Καθηγήτρια Κλεοπάτρα Μπαρδάκη

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# Διδάσκοντες

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# Σκοπός

Σκοπός του μαθήματος είναι οι φοιτητές να αποκτήσουν γνώση και εμπειρία σε θέματα διαχείρισης της εφοδιαστικής αλυσίδας. Δίνεται έμφαση στη **χρήση των τεχνολογιών πληροφορικής και επικοινωνιών (ΤΠΕ)** για τη βελτίωση και τον **ψηφιακό μετασχηματισμό** των διαδικασιών και την **υποστήριξη λήψης αποφάσεων** στην εφοδιαστική αλυσίδα.

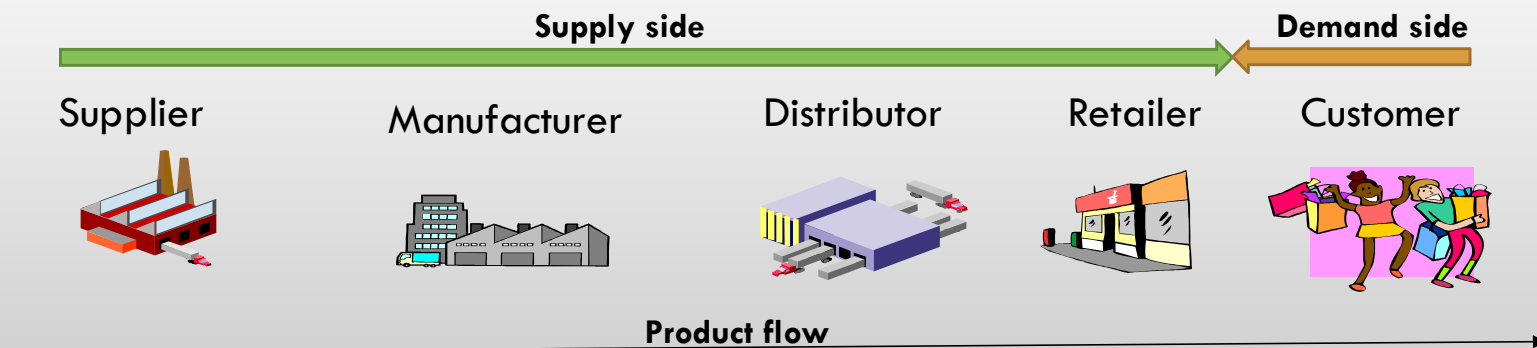
# Αξιολόγηση

- ❑ Εξετάσεις (65%)
- ❑ Μελέτη + Κατανόηση άρθρου (paper) (35%)
  - ❑ 1 άτομο ανά άρθρο

# άρθρα πέρυσι

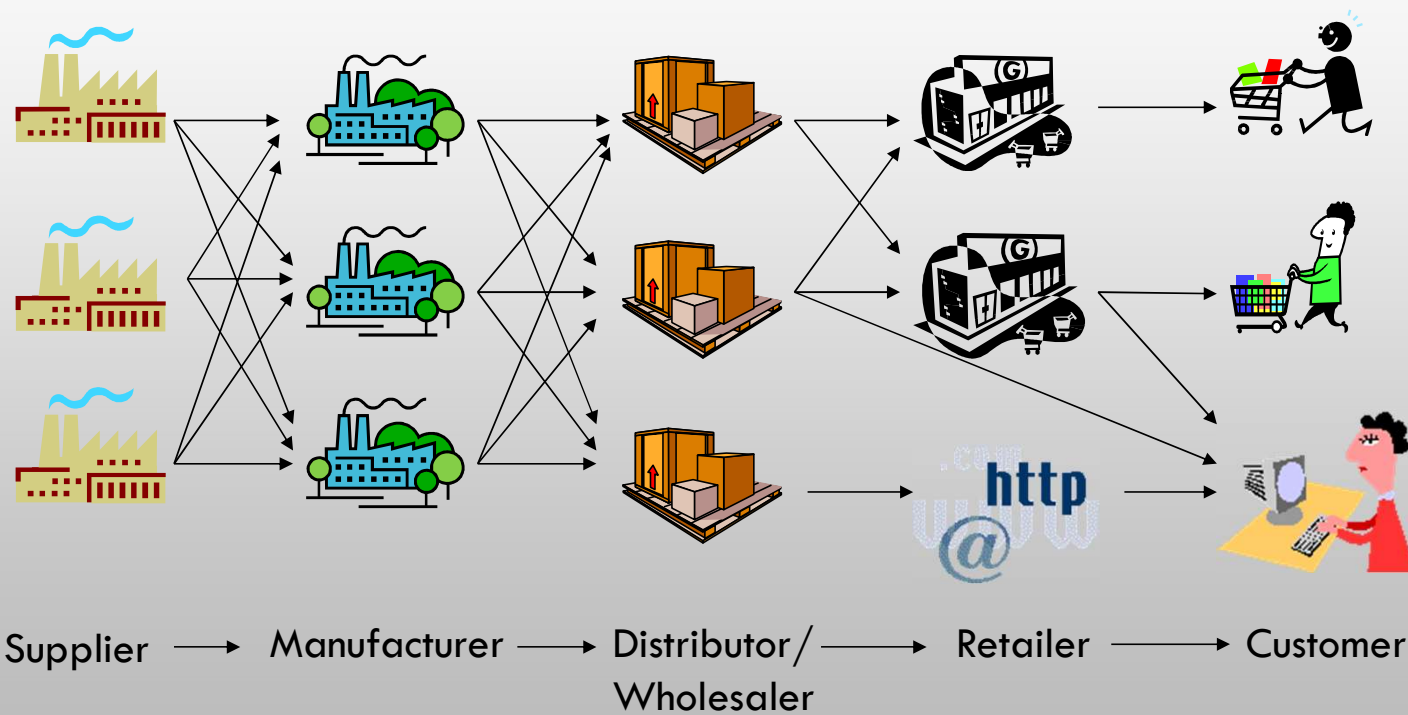
- ❑ Digital twin for sustainable manufacturing supply chains: Current trends, future perspectives, and an implementation framework
- ❑ Stock visibility for retail using an RFID robot
- ❑ .....

# A Typical Supply Chain



In a basic supply chain, raw materials are procured from suppliers and product items are produced at the manufacturers' factories, shipped to warehouses and distributions centers, and then shipped to retailers to reach the customers.

# Supply Network



# Supply Chain Flows



A SC is dynamic and the supply chain stages are connected through the flow of products, information, and funds. These flows often occur in both directions and may be managed by one of the stages or an intermediary.

# Supply Chain's Objective

**SC Main Objective: Maximization of the overall Value generated**

**SC Value:** the difference between what the final product is worth to the customer and the costs the supply chain incurs in filling the customer's request.

In other words, **SC Value = SC Profitability/ Surplus**, namely the difference between the revenue generated from the customer and the overall cost across the supply chain.

SC value ought to be shared across all supply chain stages and intermediaries and it should be measured across the entire value chain and not in terms of the profits at an individual stage. The focus on profitability at individual stages may lead to a reduction in the overall supply chain profits.



# Supply Chain Management

Successful, Profitable SC Management achieves:

right **Product/ Service**,

for the right **Customer**,

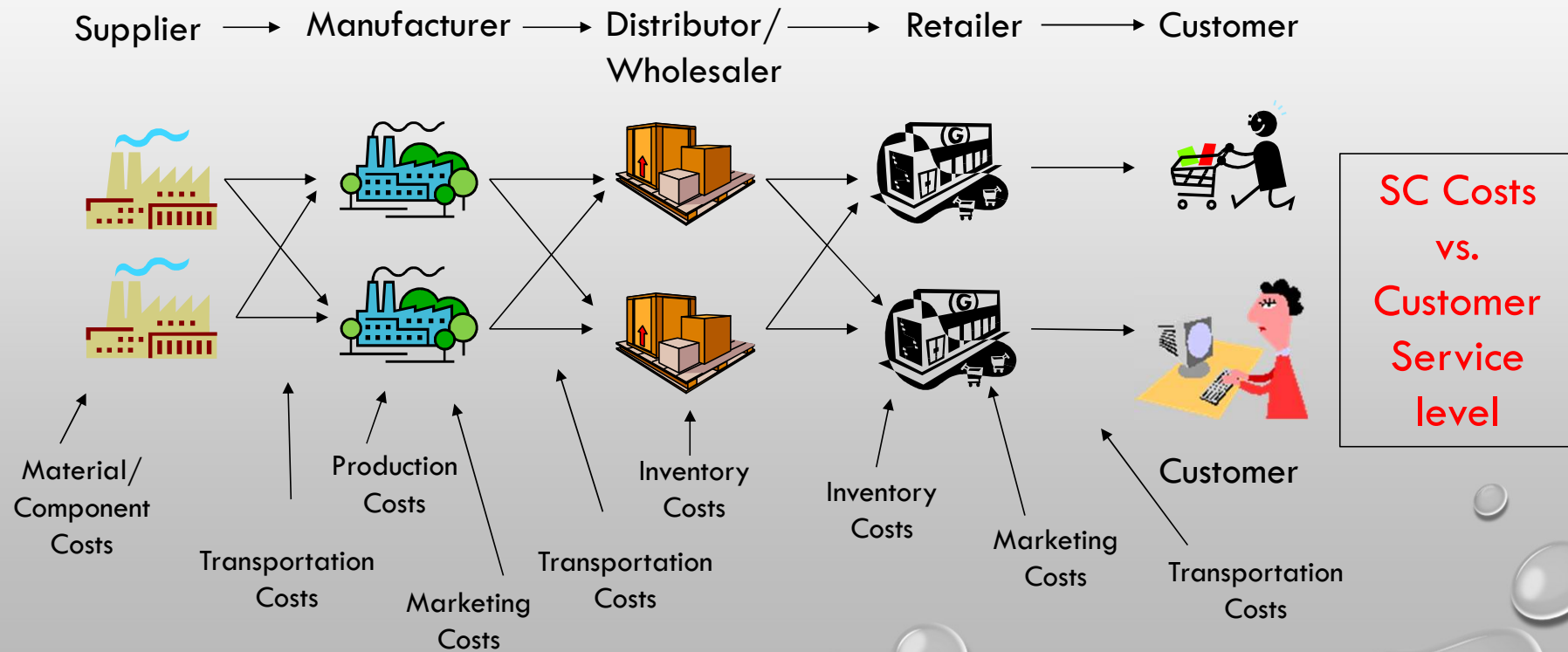
at the right **Quantity**,

the right **Location**, and

at the right **Price**.



# Supply Chain Management



# The Value Chain Processes Strategy

*Product development strategy* specifies the portfolio of new products that a company aims to develop.

*Marketing and sales strategy* specifies how the market will be segmented and how the product will be positioned, priced, and promoted.

*Operations + Distribution + Service strategy* = **Supply Chain strategy**

# Supply Chain Strategy

*Supply chain (SC) Strategy* determines

- ✓ the nature of material procurement, transportation of materials, manufacture of product or operation to provide the service,
- ✓ distribution of product to the customer, follow up customer service and
- ✓ whether these processes will be performed in-house or outsourced.

SC strategy specifies which processes should perform particularly well + the role of each supply chain entity.

Examples:

- ✓ Dell's retail direct strategy where orders are processed direct from customers and the computers are built based on customers specification.
- ✓ Amazon decides to operate its own warehouses.
- ✓ Walmart mandates its suppliers to put RFID tags on pallets and cases of products, in order to improve inventory accuracy.

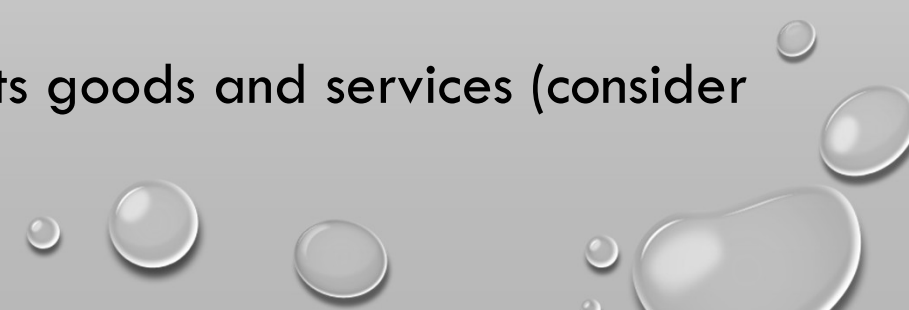


# Supply Chain Performance Drivers

1. *Facilities/ Υποδομές*: physical locations in the SC where product is stored, assembled, or fabricated.
2. *Inventory/ Απόθεμα*: all raw materials, work in process, and finished goods within a SC.
3. *Transportation*: moving inventory from point to point in the SC via many combinations of modes and routes.



## Supply Chain Performance Drivers

- 4. *Information*: data and data analysis concerning facilities, inventory, transportation, costs, prices, and customers throughout the SC (consider Big Data, data analytics)
  - 5. *Sourcing*: who performs each SC activity such as production, storage, transportation, or the management of information -> in-house or outsource activities
  - 6. *Pricing*: how much a firm charges for its goods and services (consider differential pricing, dynamic pricing)
- 

# Information

the most critical SC driver

enables coordination and collaboration between SC partners

huge effect on SC decisions (consider data inaccuracies e.g.  
faulty demand forecasts)

Information -> Information technology

# Information-related Metrics

Information Quality

Forecast horizon

Frequency of forecast update

Forecast error

Seasonal factors

Variance from plan

Ratio of demand variability to order variability

# INVENTORY: WHAT

- Raw material
  - ☒ not processed yet
- Work-in-process
  - ☒ Under processing, not completed
- Maintenance/repair/operating (MRO)
  - ☒ Necessary for maintenance and repair of equipment
- Finished goods
  - ☒ Completed product awaiting for shipment

# INVENTORY: WHAT

- We need inventory to handle mismatch between supply and demand.
- major source of cost, great influence on responsiveness
- Significant impact on material flow time: time elapsed between the point at which material enters the SC to the point at which it exits.
  - ✓ Throughput: rate at which sales occur
  - ✓ Inventory (I) = Throughput (D) \* Flow time (T)
  - ✓ Managers aspire reduced flow time -> reduced inventory

## EXAMPLE

Χρόνος συναρμολόγησης μηχανής (flow time): 5 ώρες

Throughput: 30 μηχανές/ώρα

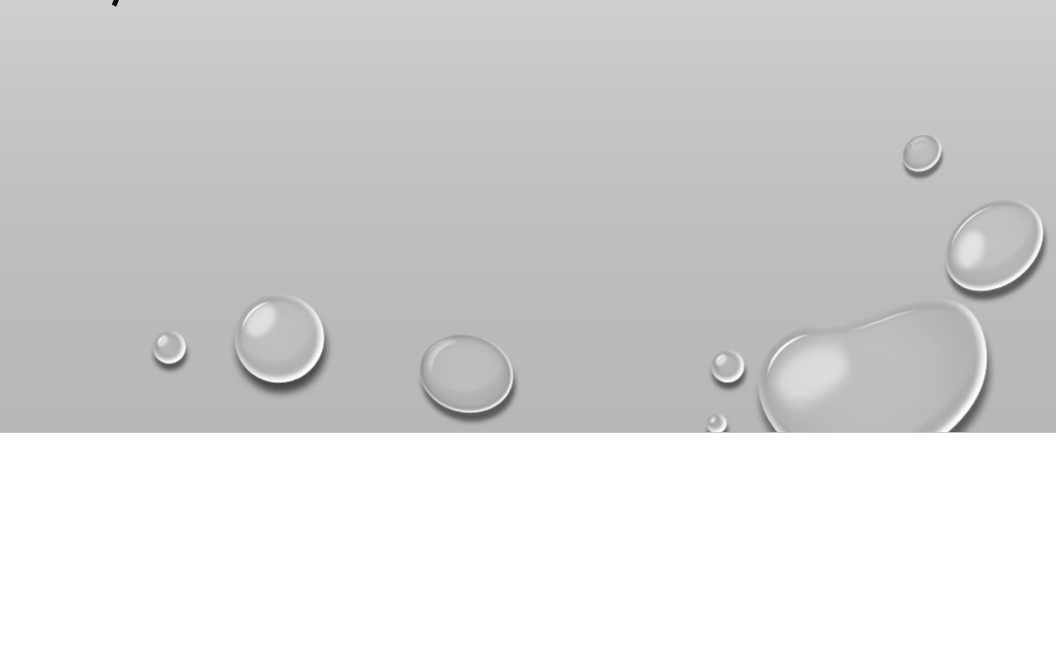
Απόθεμα =  $30 * 5 = 150$  μηχανές

Αν θέλω να μειώσω το απόθεμα μου στο μισό, χρειάζεται να βελτιώσω σημαντικά το χρόνο συναρμολόγησης (flow time). Δεν πειράζω τη ζήτηση.

Πως να βελτιώσω το χρόνο συναρμολόγησης;



# INVENTORY: WHERE

- Suppliers and Manufacturers
  - Warehouses and Distribution centers
  - Retailers (sales floor, backroom)
- 

# INVENTORY: WHY?

- Overcome *demand and supply uncertainty*
- Prevent *stock-out* incidents.
- Take advantage of quantity discounts -> *Economies of scale*.
- *Hedge against inflation and price changes*.
- Satisfy demand during *lead time* between supply chain stages
- Overcome production capacity limitations (e.g. stock products during spring to satisfy high demand in the summer)

# INVENTORY-RELATED DECISIONS

*Cycle inventory*: average amount of inventory used to satisfy demand between receipts of supplier shipments.

- ✓ High cycle inventory -> high inventory holding cost vs. low cycle inventory with more frequent orders (ordering + shipping costs)

*Safety inventory*: inventory held in case demand exceeds expectations

- ✓ Inventory holding cost or lost-sales cost

*Seasonal inventory*: inventory built up to counter predictable demand variability

- ✓ Inventory carrying cost vs. flexible production cost

*Product availability level*: fraction of demand satisfied on time from available inventory

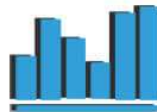
## A MANAGER MONITORS INVENTORY-RELATED METRICS:



**Average  
Inventory  
Formula**

**(Beginning Inventory + Ending Inventory)**

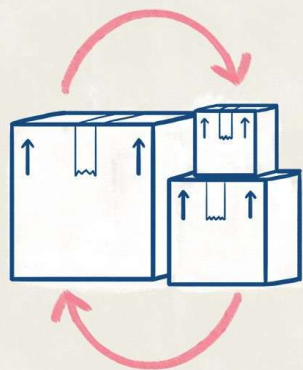
**2**



Έτσι λαμβάνω υπόψη  
και ενδεχόμενες  
πτώσεις ή κορυφώσεις  
που έγιναν μέσα στην  
περίοδο που εξετάζω

## A MANAGER MONITORS INVENTORY-RELATED METRICS:

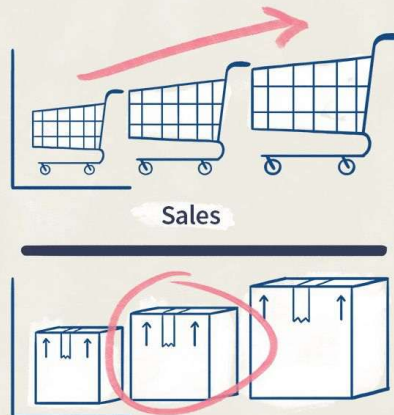
### What Is Inventory Turnover?



#### Inventory Turnover

The ratio showing how many times a company has sold and replaced inventory during a given period.

=

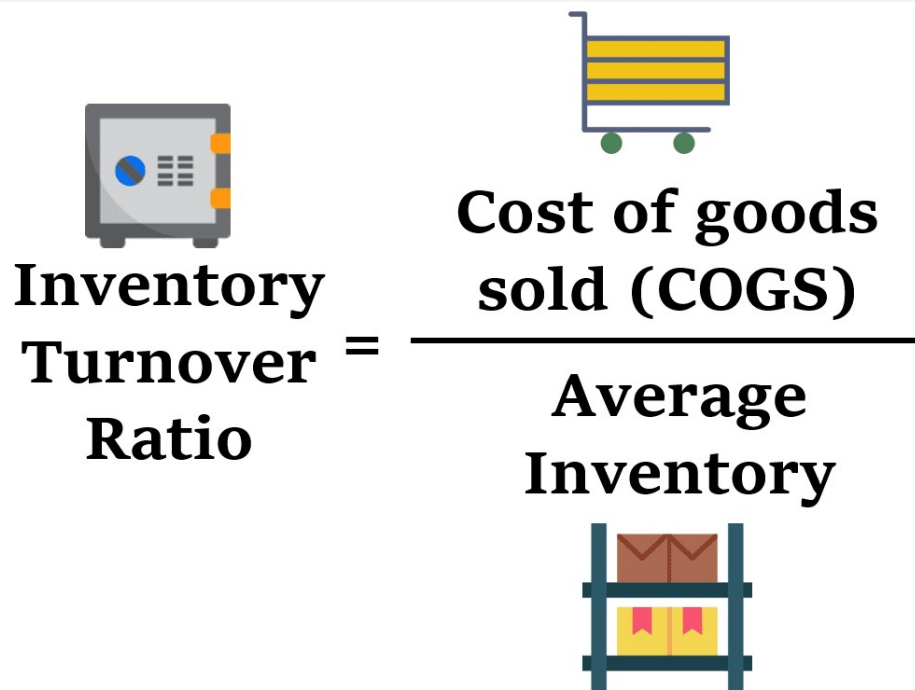


#### Average Inventory

A calculation that estimates the value or number of a particular good or set of goods during two or more specified time periods.

Inventory turnover:  
πόσες φορές η  
εταιρεία έχει διαθέσει  
το αποθεμα της μέσα  
σε μια χρονική  
περίοδο

A MANAGER MONITORS INVENTORY-RELATED METRICS:



The equation for the Inventory Turnover Ratio is presented within a white rectangular box. On the left side of the box, the text 'Inventory Turnover Ratio' is displayed in a bold, black, serif font. Above this text is a small icon of a grey safe with a blue dial and orange handles. To the right of the text is an equals sign, followed by a horizontal fraction bar. Above the fraction bar is the text 'Cost of goods sold (COGS)' in a bold, black, serif font, with a small icon of a yellow shopping cart above it. Below the fraction bar is the text 'Average Inventory' in a bold, black, serif font, with a small icon of a blue pallet with yellow boxes above it.

$$\text{Inventory Turnover Ratio} = \frac{\text{Cost of goods sold (COGS)}}{\text{Average Inventory}}$$

Inventory  
turnover period:  
 $365 / \text{Inventory Turnover}$



# INVENTORY MANAGEMENT GOAL

Strike a balance between

Customer Service level

Inventory Costs ([Inventory Investment](#))



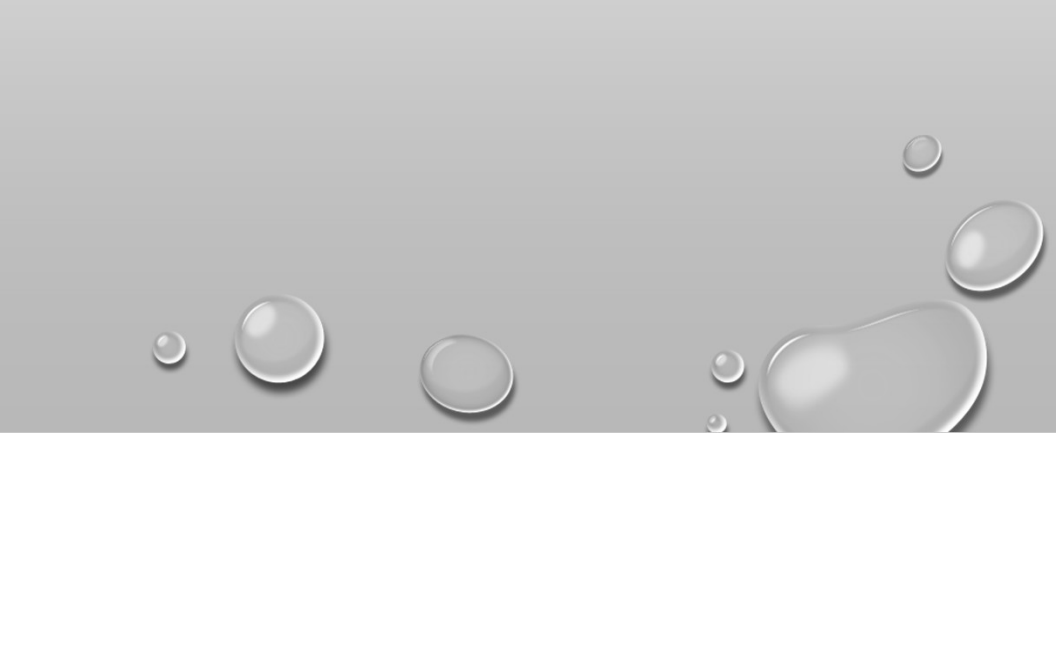


# INVENTORY POLICY

How much to order

When to order

Optimal Order Quantity



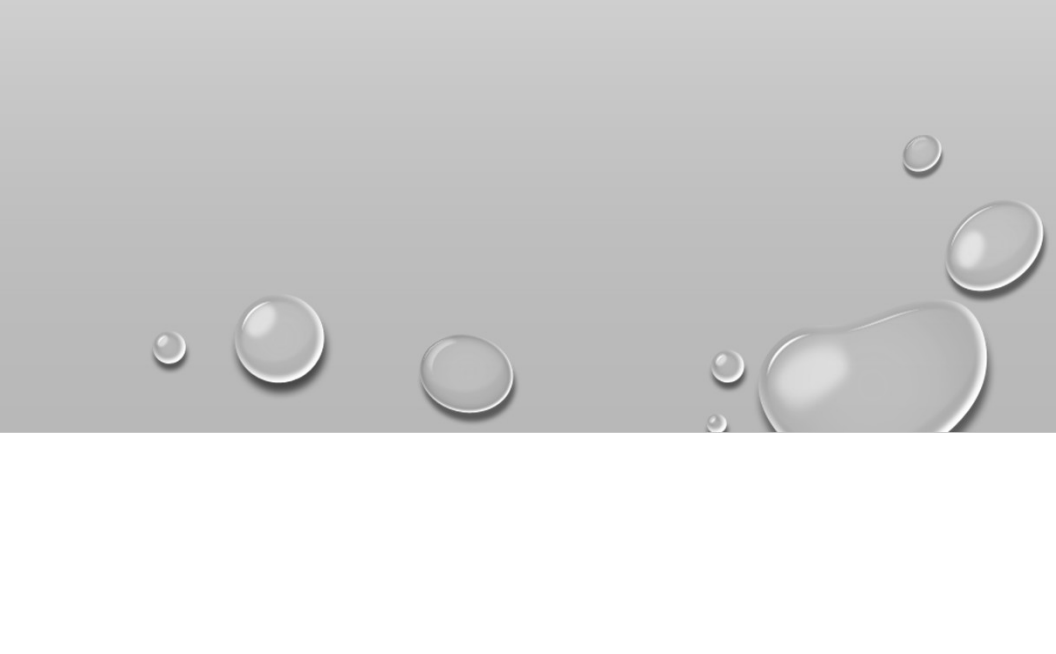


# INVENTORY POLICY

How much to order

When to order

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ΧΑΡΟΚΟΠΕΙΟ ΠΑΝΕΠΙΣΤΗΜΙΟ  
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# ***Demand Forecasting in SCM***

# WHAT IS FORECASTING?

Procedure to predict future events.

- ✓ Historical data + mathematical model
- ✓ Intuition (e.g. this new version of the game will sell 30% more than the old one.)
- ✓ Managers' judgement
- ✓ Combination of the above.





# DEMAND FORECASTING IN SC: WHY?

Effective supply chain planning depends on demand forecasting of the firm's products and services.

Essential for all strategic and planning business decisions (production, supplies, inventory, human resources, facilities etc.

Key for push and pull processes:

- ✓ Pull processes: act in response to customer demand -> demand forecast to determine the available inventory level of material/ parts to produce the ordered products.
  - ✓ Push processes: act in anticipation of customer demand -> demand forecast to plan distribution, production etc.
- 



## DEMAND FORECASTING IN SC: WHY?

Demand Driven leaders have:

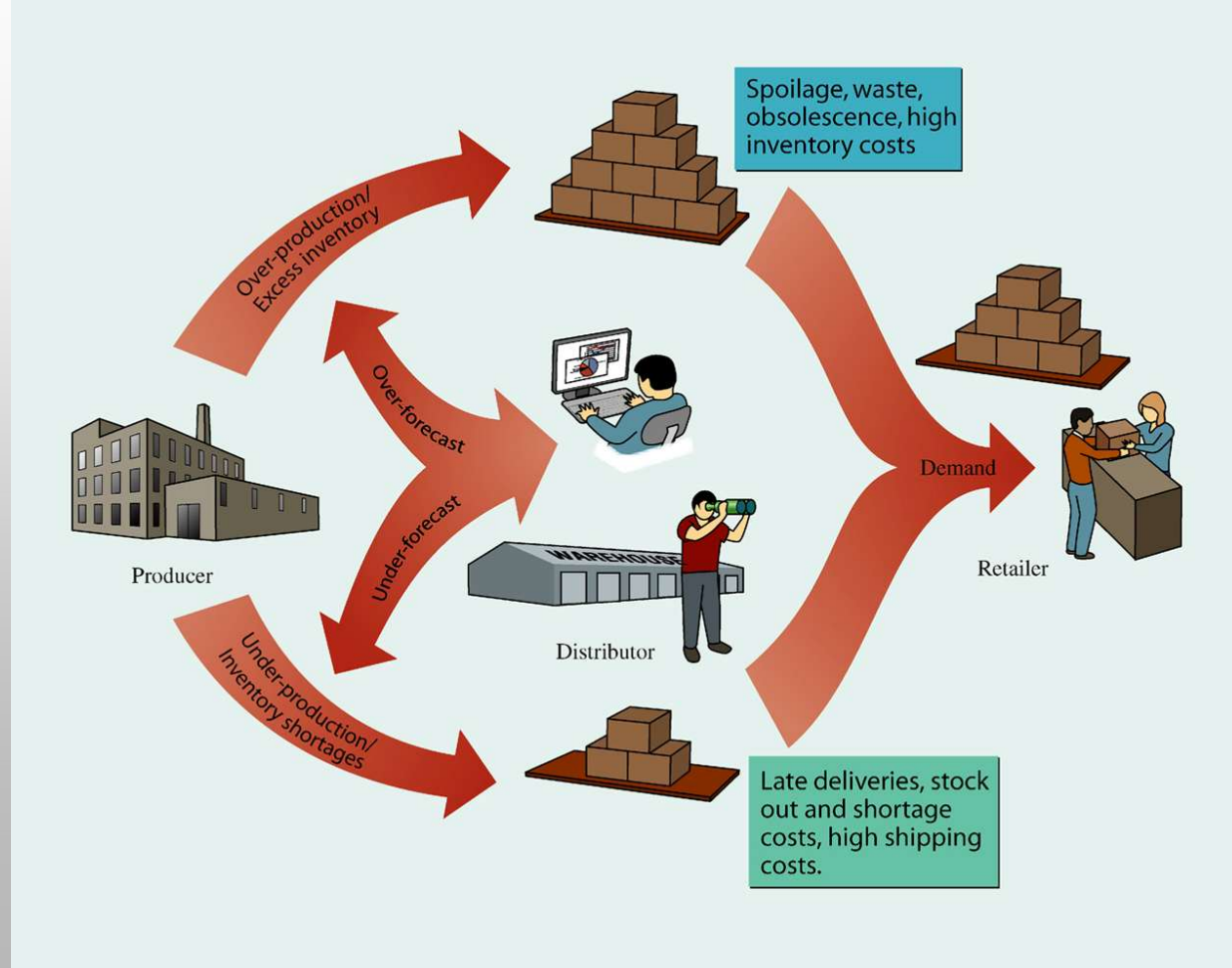
15% less inventory

17% stronger order fulfillment

Which translates to: 60% better profit margins



# EFFECT OF INACCURATE DEMAND FORECASTING IN



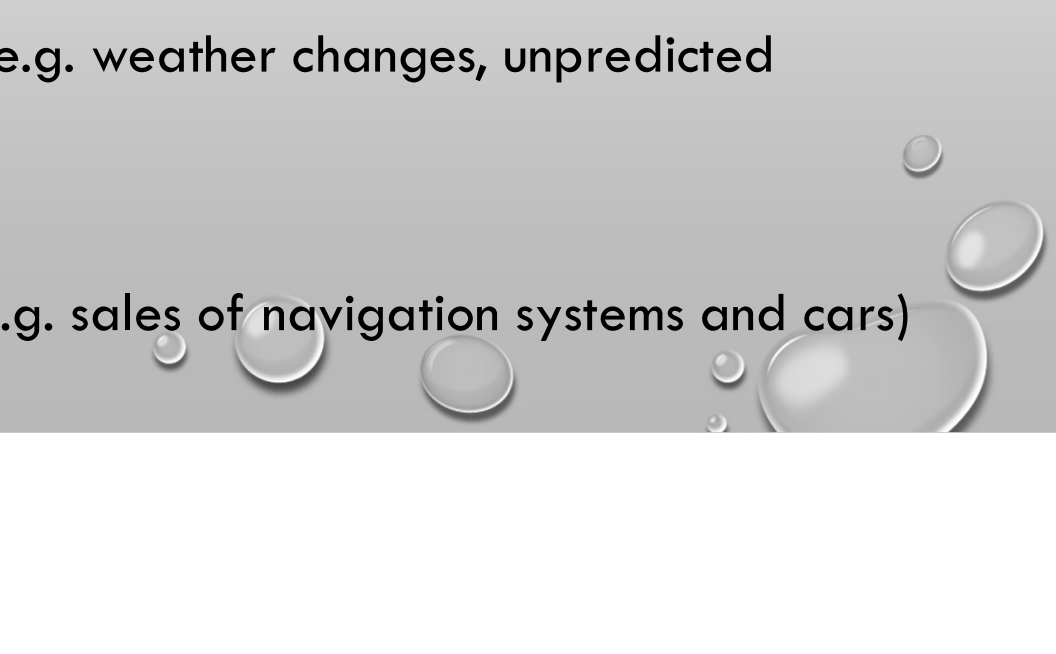
Source: Russell and Taylor, 2011. Operations Management, 7th edition, John Wiley & Sons - Chapter 12.

# EFFECT OF INACCURATE DEMAND FORECASTING IN SCM

- United Airlines
  - ✓ April, 2017
  - ✓ Overbooked flight
  - ✓ Airlines usually oversell, betting on the number of passengers who will miss their flights.
  - ✓ Result: a passenger being blooded was dragged from his seat.
  - ✓ Social media -> customers call for a boycott of United Airlines
  - ✓ Market capitalization dropped by more than \$250 million.
- Nike, 2001
  - ✓ new demand planning system
  - ✓ Inadequate system testing
  - ✓ excess stock of low selling shoes & not enough shoes of fast moving shoes
  - ✓ Sales loss: \$100 million.

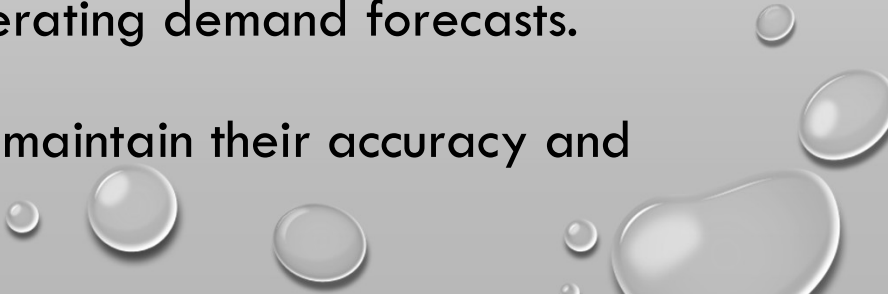


## Forecasting: Facts

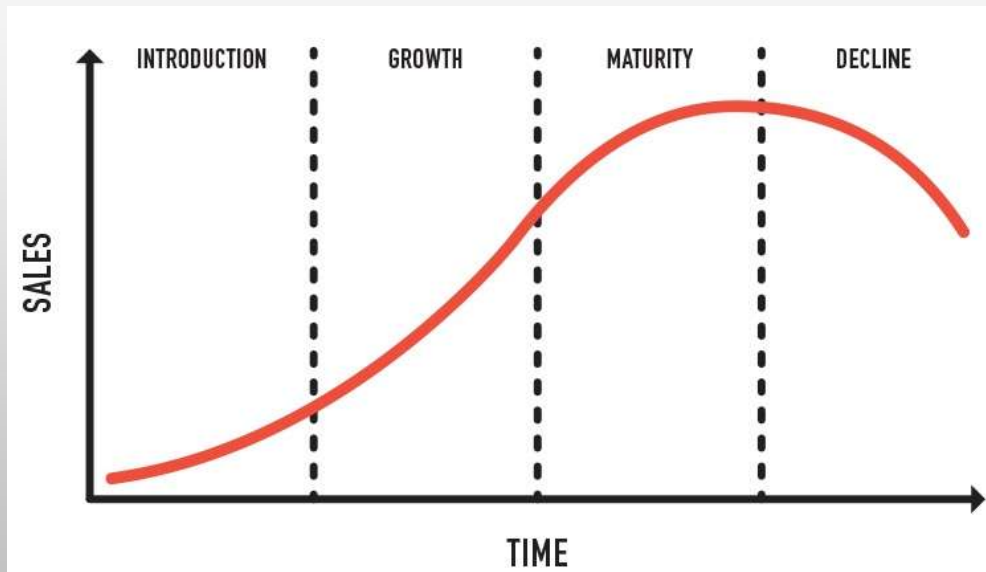
- Forecasts are always inaccurate.
  - Forecasts should always include measures of forecast errors.
  - Long-term forecasts are usually less accurate than short-term forecasts.
  - There is seldom one superior forecasting method.
  - Forecasts may be influenced by:
    - ✓ unpredictable outside factors (e.g. weather changes, unpredicted political events)
    - ✓ product life cycle
    - ✓ demand of related products (e.g. sales of navigation systems and cars)
- 



## Forecasting: Facts

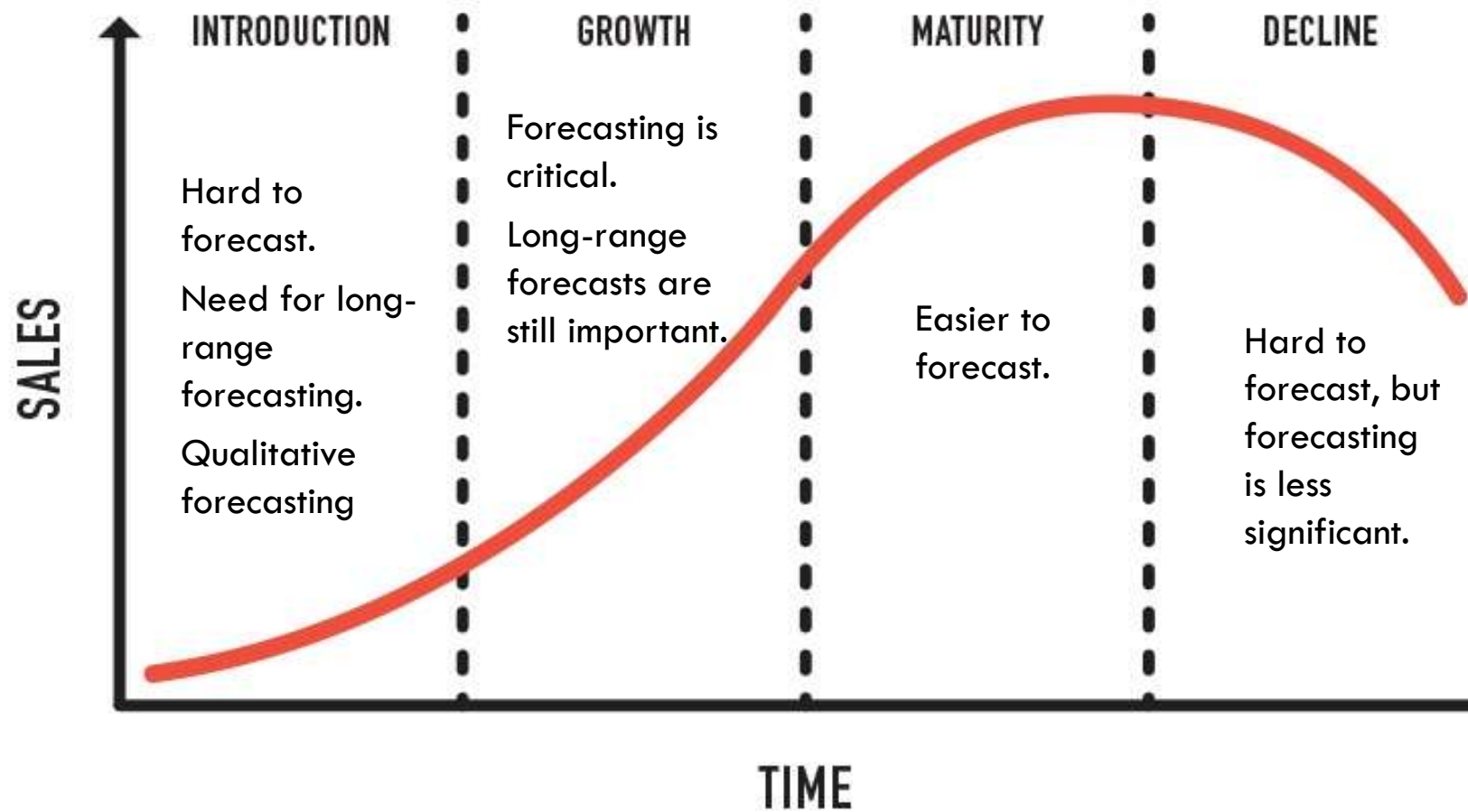
- Aggregated and product family forecasts are more accurate.
  - The farther a supply chain partner is from the consumers, the less accurate the demand forecasts.
  - Balanced mix of quantitative forecasts + human intuition (managers take the final decision).
  - Competitors' actions, state of the economy, pricing strategy, marketing activities should be considered when generating demand forecasts.
  - Forecasts must be updated regularly to maintain their accuracy and integrity.
- 

# PRODUCT LIFE CYCLE EFFECT ON FORECASTING



*Product life cycle:* the stages a product goes through from when it was first thought of until it finally is removed from the market.

- Product introduction and growth require longer forecasts than maturity and decline.
- Forecasting is critical for introduction and maturity stages.
- As products go through their life cycle and reach maturity and decline, forecasts are useful for production capacity and inventory planning.



# FORECASTING TIME HORIZON

|              | <b>Short-range</b>                                                                                     | <b>Medium<br/>(Intermediate)-<br/>range</b>                          | <b>Long-range</b>                                                                     |
|--------------|--------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| Time horizon | Usually <3 months and,<br>< 1 year                                                                     | > 3 months<br>and < 3 years                                          | ≥ 3 years                                                                             |
| Suitable for | Planning purchasing, job<br>scheduling, workforce<br>levels, job assignments<br>and production levels. | Sales and Production<br>planning, budgeting,<br>operations planning. | Planning new<br>products and<br>facilities locations,<br>research and<br>development. |

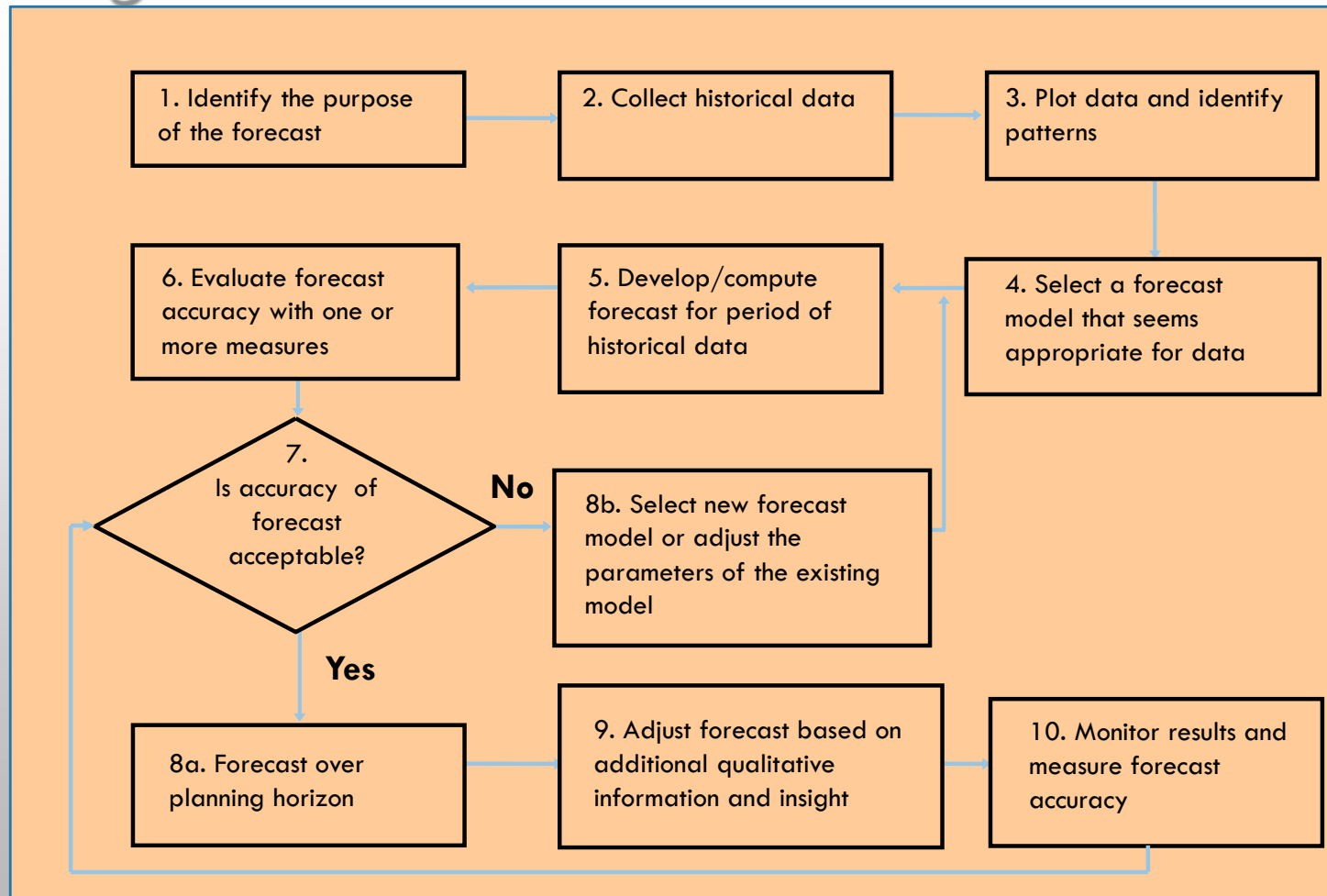
# FORECASTING TIME HORIZON

| Short-range                                                                                                                             | Medium-range                                                                                                                                                                                                                                                                                                                                                                                                                            | Long-range |
|-----------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
| <ul style="list-style-type: none"><li>• Utilizing quantitative approaches.</li><li>• More accurate than long-range forecasts.</li></ul> | <ul style="list-style-type: none"><li>• Utilizing combinations of qualitative and quantitative approaches e.g. launching a new product may require a market survey, a focus group etc.</li><li>• Necessary to decide on more comprehensive issues e.g. a firm's decision to buy a small, national production facility to expand to a new market. Such decisions may take years of study and they are multi-criteria problems.</li></ul> |            |



## Forecasting: FACTORS INFLUENCING THE CUSTOMER DEMAND LIFE CYCLE

- Seasonality
  - Competition
  - Type of product / service
  - Geography
- 



Source: Russell and Taylor, 2011. Operations Management, 7th edition, John Wiley & Sons - Chapter 12.



## DEMAND FORECASTING PROCEDURE

2 Collect historical data + 3 Plot data and identify patterns

Recognize the customer segments and their needs and differences-  
> different segments may need different forecasting approaches.

Recognize factors that have major influence on demand  
(seasonality, different sales channels e.g. e-shops, competitive products, substitute products etc.)



# TYPES OF FORECASTING METHODS

|                    | Qualitative Methods                                                         | Quantitative Methods                                                                         |
|--------------------|-----------------------------------------------------------------------------|----------------------------------------------------------------------------------------------|
| 1. Characteristics | Based on human judgment, opinions; subjective and nonmathematical.          | Based on mathematics; quantitative in nature.                                                |
| 2. Strengths       | Can incorporate latest changes in the environment and "inside information." | Consistent and objective; able to consider much information and data at one time.            |
| 3. Weaknesses      | Can bias the forecast and reduce forecast accuracy.                         | Often quantifiable data are not available. Only as good as the data on which they are based. |



# QUALITATIVE FORECASTING

- Suitable when little prior information/ knowledge is available e.g. launching new products or new technologies, entering new markets etc.
  - Involves intuition, experience of experts.
- 

# QUALITATIVE FORECASTING APPROACHES

- *Jury of executive opinion*

Group of high-level experts gives its opinion, sometimes complemented by statistical forecasting models.

- *Delphi method*

Group of experts queried iteratively.

- *Sales force composite*

Sales staff provide their intuitive forecasts -> review and aggregation.

- *Market Survey*

Consumers are queried.

# JURY OF EXECUTIVE OPINION

- High-level experts and managers form a small group.
- They estimate demand by working together.
- Managerial experience and knowledge + statistical models.
- **Advantage:** Relatively quick, Good for launching new products and technologies.
- **Disadvantage:** one members' opinion may dominate the discussion and the results.



# DELPHI METHOD

Iterative process until consensus is reached.

Collective intelligence

3 types of participants:

- ✓ Decision makers (5-10 experts) make the forecast.
- ✓ Survey respondents (people in different places whose opinion matters)
- ✓ Administrative staff (supporting the whole procedure – managing the survey and producing the results).

**Advantage:** Excellent for launching new products and technologies.

**Disadvantage:** time consuming

# DELPHI METHOD

Start - send a questionnaire to a group of demand forecasting experts

Create a summary of the responses from the first round

Share the summary with your panel.

**Repeat - successive rounds**

The answers from each round, shared anonymously, influence the next set of responses.

The Delphi method is complete when the group comes to a consensus.

Draw on the knowledge of people with different areas of expertise.

Anonymity -> frank answers.

# SALES FORCE COMPOSITE

- Each sales employee is asked to forecast sales in his region and for the products he handles.
- Review each sales person's projection.
- Combination and Aggregation at district & national levels and per product/ service line.
- **Advantage:** sales staff know consumers first hand.
- **Disadvantage:** over optimistic projections

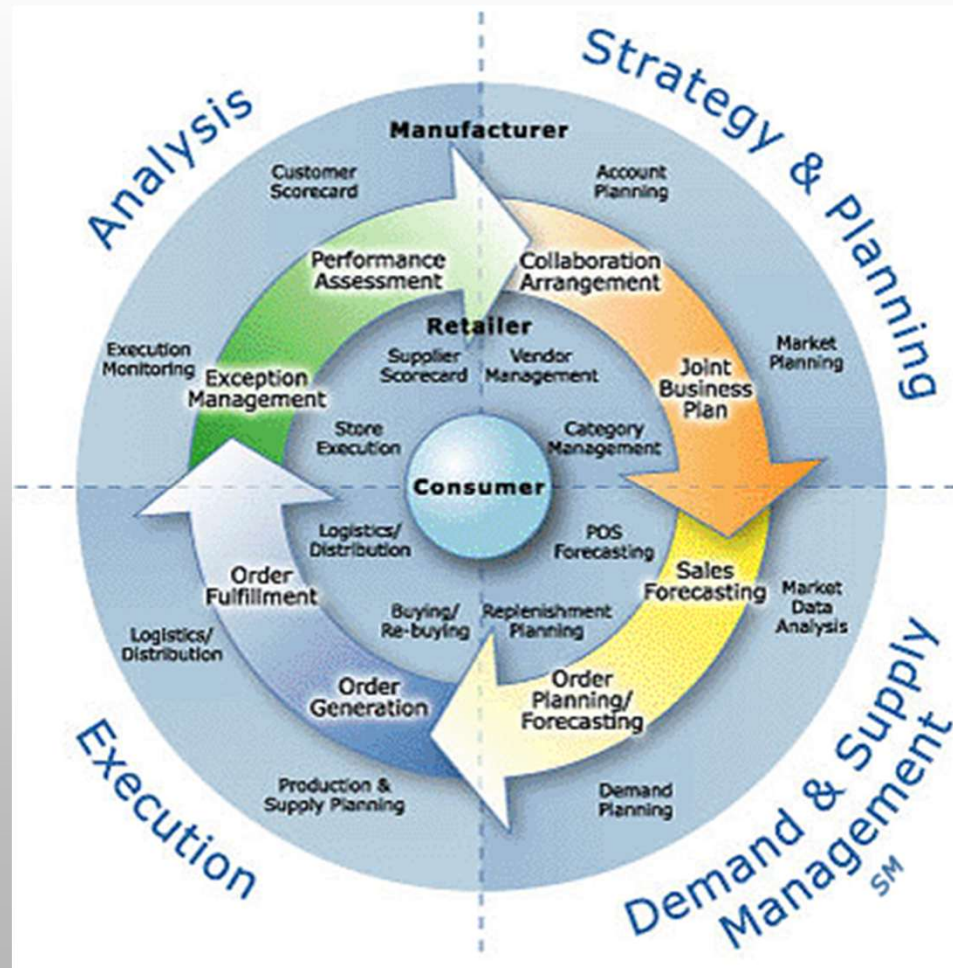


# MARKET SURVEY

- Representative sample of consumers participate to a survey (and on-line).
- Consumers' interviews
- Useful and for product/ service design.
- **Advantage:** simple and direct
- **Disadvantage:**
  - ✓collects optimistic perceptions, not actions.
  - ✓difficult to build a good questionnaire



# COLLABORATIVE PLANNING FORECASTING & REPLENISHMENT (CPFR)





# COLLABORATIVE PLANNING FORECASTING & REPLENISHMENT (CPFR)

- Establish collaborative relationships between buyers and sellers (they share data)
  - Create a joint business plan
  - Create a collaborative sales forecast
  - Identify exceptions for sales forecast
  - Resolve/collaborate on exception items
  - Create collaborative order forecast
  - Identify exceptions for order forecast
  - Resolve/collaborate on exception items
  - Generate orders
- 

## CPFR WHEN:

- Demand is hard to Predict
- New product introductions are frequent
- Lead-times for production and/or replenishment are long
- Product life cycles are short
- Forecast accuracy is low
- High levels of inventory exist in the supply chains
- Consumer expectations are frequently not met
- Seasonal demand variances are significant.

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### 3 But:

1. Internal Change
2. Cost
3. Trust

# CPFR IN WALMART:

CPFR plays an important role in SCM of WALMART:

- By Avoiding Stock outs
- By Avoiding Lost Sales
- Lost Customers
- By Better controlling inventory
- By Eliminating bullwhip effect
- By Reducing manual orders
- By Reducing excess inventory
- By Improving service levels.

WHAT Role does CPFR Plays:

- By Improving Responsiveness to Consumer Demand
- By Greater Forecast accuracy with single shared forecast
- By Increasing Sales
- By Reducing Inventory
- By Reducing Costs
- By Improving production capacity Utilization and
- By Improving relationship b/w all the trading partners.

# CPFR IN WALMART:

- 693 Million Items
- 20 Million Customers / Day
- 5000 Stores
- 3500 Vendors
- 7.5 TB Data of Inventory

CPFR

Collaborative Planning, Forecasting and Replenishment

Enriching Collaboration

**Wal-Mart**  
Save Money. Live Better.

| Measuring Metrics (Performance) | % age Improvements     |
|---------------------------------|------------------------|
| Cycle Time                      | From 25 Days to 3 Days |
| Increased Sales                 | 11%                    |
| On-Time Deliveries              | 74% to 94%             |
| Inventory Turnover              | 7 Times / Day          |
| Sales Forecast Accuracy         | 20% to 60%             |
| Sales Lost due to Stock outs    | 23% to 15%             |
| Out of Stock Orders             | Cut Down by 30%        |
| Cancelled Orders                | Reduced 60%            |
| On-time Deliveries              | Increased by 95%       |

## Facts & Figures

source

<https://www.slideshare.net/DanishAliSyed1/collaborative-planning-forecasting-replenishment-at-walmart>

# TOP DEMAND PLANNING SOFTWARE

- ◆ SAP Integrated Business Planning (Cloud deployment - Real-time scenarios and simulation)
- ◆ Oracle Demantra (incremental forecasting, excel-like worksheets, web-based personalized UI)
- ◆ Demand Planning (ingests demand-driving variables, uses machine learning)
- ◆ Logility Solutions (Logility Digital Supply Chain Platform - blend of artificial intelligence (AI) and advanced analytics)
- ◆ NETSTOCK (cloud-based inventory management solution, easy to use dashboard)
- ◆ Forecast Pro (off-the-shelf forecasting software trusted by 12,000+ organizations globally to create statistically-based forecasts, integrates into broader planning systems)

Predictive  
analysis,  
Machine  
learning



# QUANTITATIVE FORECASTING

- Utilized when there are available historical data and the context is relatively 'stable'.
  - Past is a good indicator of the future.
  - Involves mathematical, objective approaches.
- 

# QUANTITATIVE FORECASTING

Forecast = Systematic component (S) + Random component (R)

- ✓ S : expected value of demand
- ✓ Forecasting techniques focus on identifying the systematic component.
- ✓ R part of demand (noise) is not explicitly determined.
- ✓ The size and variability of R reflect the forecast error.

Forecasting aspires to filter out the random component and calculate the systematic component.

# QUANTITATIVE FORECASTING APPROACHES

## Time Series models

- ✓ Historical data are formed as a time series of data
- ✓ Assume that future resembles the past.
- ✓ Demand is only related to time.
- ✓ The simplest demand forecasting approach.

## Causal/ Associative models

- ✓ Explores cause-and-effect relationships between demand and context factors.
- ✓ Uses leading context indicators to predict the future e.g. how price is related with demand.

# TIME SERIES DEMAND FORECASTING

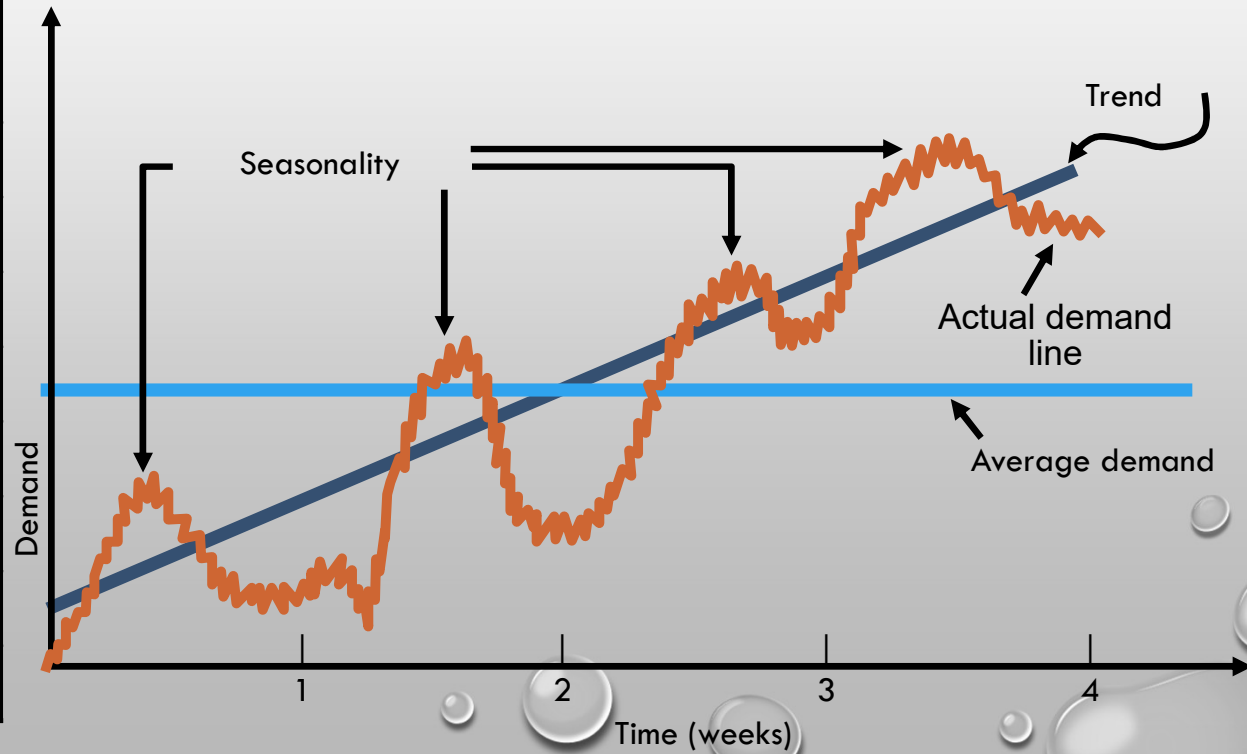
Forecast = Systematic component (S) + Random component (R)

- Systematic component (S) = (level + trend)  $\times$  seasonal factor
  - ✓ Level : deseasonalized demand
  - ✓ Trend: rate of growth or decline in demand (increasing or decreasing pattern)
  - ✓ Seasonal factor – predictable seasonal fluctuations in demand (demand pattern of constant length that regularly repeats itself)

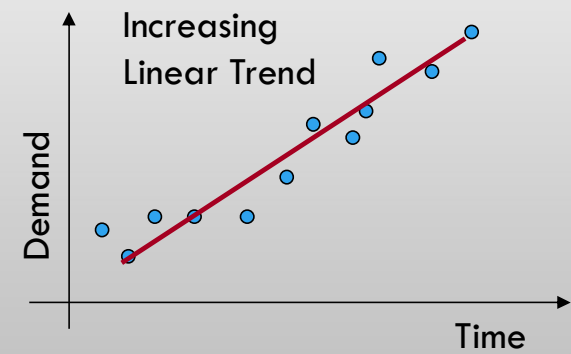
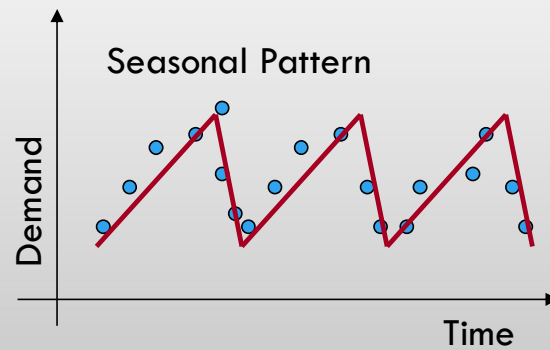
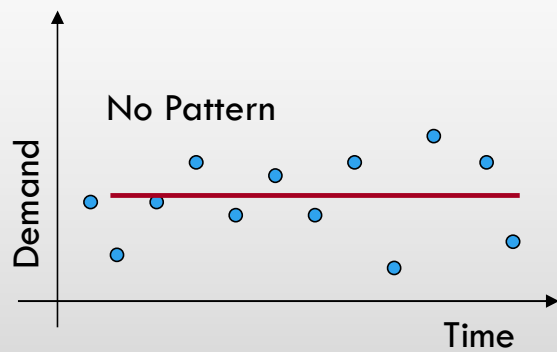
# TIME SERIES

**Time series:** a sequence of evenly spaced (weekly, monthly, quarterly, and so on) data points.

| Period<br>(Week) | Orders (in cases) |
|------------------|-------------------|
| 1                | 275               |
| 2                | 315               |
| 3                | 200               |
| 4                | 285               |
| 5                | 245               |
| 6                | 215               |
| 7                | 240               |
| 8                | 210               |



# TIME SERIES





# TIME SERIES FORECASTING

## Time Series models

- ✓ Naive approach
  - ✓ Mean
  - ✓ Moving Average
  - ✓ Weighted Average
- 

# NAIVE APPROACH

Demand in next period = actual demand in the last period

- ✓  $F_{t+1} = L_t, L_t = A_t$
- ✓  $F_{t+1} = A_t$
- ✓  $F_{t+1}$ : Forecast of demand for period  $t+1$
- ✓  $L_t$ : Level of demand in period  $t$
- ✓  $A_t$ : Actual demand in period  $t$

- Sometimes cost effective and efficient
- Can be good starting point

| Period<br>(Week) | Orders (in cases)     |
|------------------|-----------------------|
| 1                | 275                   |
| 2                | 315                   |
| 3                | 200                   |
| 4                | 285                   |
| 5                | 245                   |
| 6                | $F_{5+1} = A_5 = 245$ |

## SIMPLE MEAN

Demand in next period = average of all available demand data in n periods

$$\checkmark F_{t+1} = L_t, L_t = \sum A_t / n$$

$$\checkmark F_{t+1} = \sum A_t / n$$

| Period (Week) | Orders (in cases)                                                                       |
|---------------|-----------------------------------------------------------------------------------------|
| 1             | 275                                                                                     |
| 2             | 315                                                                                     |
| 3             | 200                                                                                     |
| 4             | 285                                                                                     |
| 5             | 245                                                                                     |
| 6             | $F_{5+1} = (A_5 + A_4 + A_3 + A_2 + A_1) / 5 \Leftrightarrow$<br>$F_6 = 1320 / 5 = 264$ |

# MOVING AVERAGE

Demand in next period = average of demand in the most recent N periods

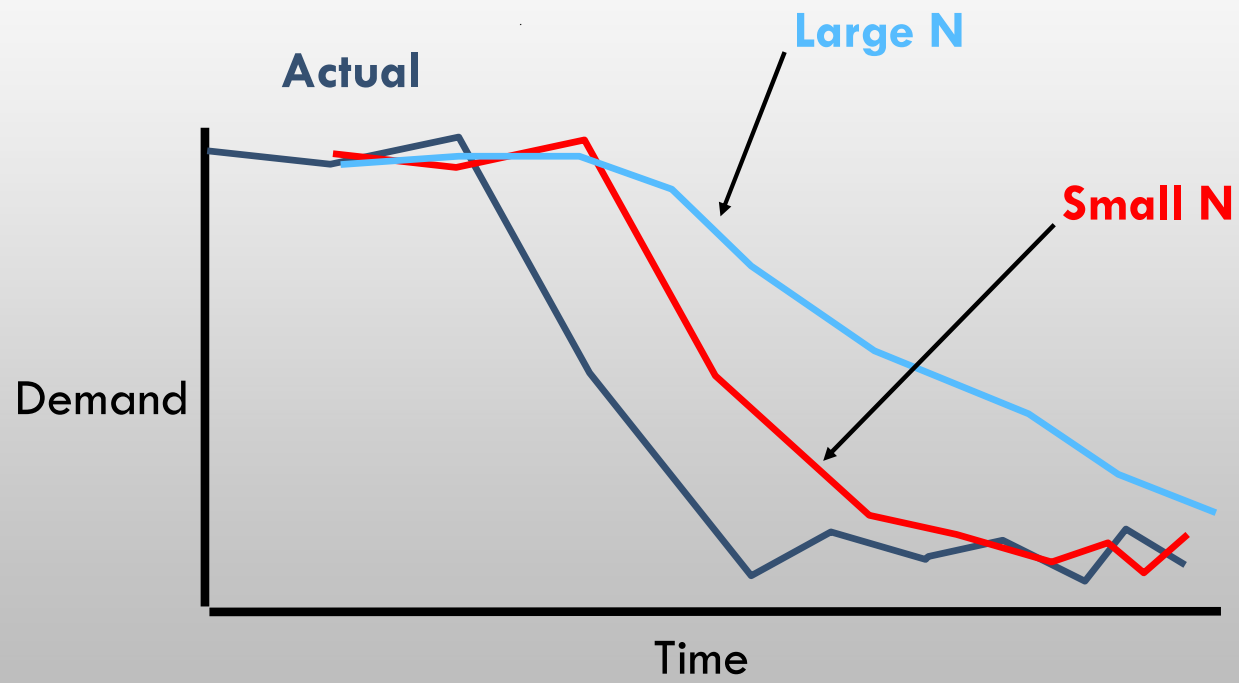
- N-period moving average

- ✓  $F_{t+1} = L_t, L_t = D_t + D_{t-1} + D_{t-2} + \dots + D_{t-N+1} / N$

- ✓  $F_{t+1} = D_t + D_{t-1} + D_{t-2} + \dots + D_{t-N+1} / N$

- For each new forecast, you add the most recent demand observation and you drop the earliest.
- Useful if there is little or no trend.
- Useful for smoothing out short-term irregularities in the data series.

# Moving Average



# Moving Average Example

| t | Month     | Actual Demand (A) | 3-month Moving Average                    |
|---|-----------|-------------------|-------------------------------------------|
| 1 | May       | 10                |                                           |
| 2 | June      | 12                |                                           |
| 3 | July      | 13                |                                           |
| 4 | August    | 16                | $F_4 = (10 + 12 + 13)/3 = 11 \frac{2}{3}$ |
| 5 | September | 19                | $F_5 = (12 + 13 + 16)/3 = 13 \frac{2}{3}$ |
| 6 | October   | 23                | $F_6 = (13 + 16 + 19)/3 = 16$             |
|   |           |                   |                                           |

← Drop  $A_1$ , Get  $A_4$   
 ← Drop  $A_2$ , Get  $A_5$

# WEIGHTED MOVING AVERAGE

- Useful when a demand trend or pattern is present -> focus on recent values with **weights**.
- Weights are selected based on intuition and experience.
- All weights add to 100% or 1.
- N-period weighted moving average
  - ✓  $F_{t+1} = L_t, L_t = w_t D_t + w_{t-1} D_{t-1} + w_{t-2} D_{t-2} + \dots + w_{t-N+1} D_{t-N+1}$
  - ✓  $F_{t+1} = w_t D_t + w_{t-1} D_{t-1} + w_{t-2} D_{t-2} + \dots + w_{t-N+1} D_{t-N+1}$
  - ✓  $\sum w_t = 1$
- Simple moving average weights equally all demand periods.
- **The higher the weight, the more emphasis on the specific demand period over the others.**

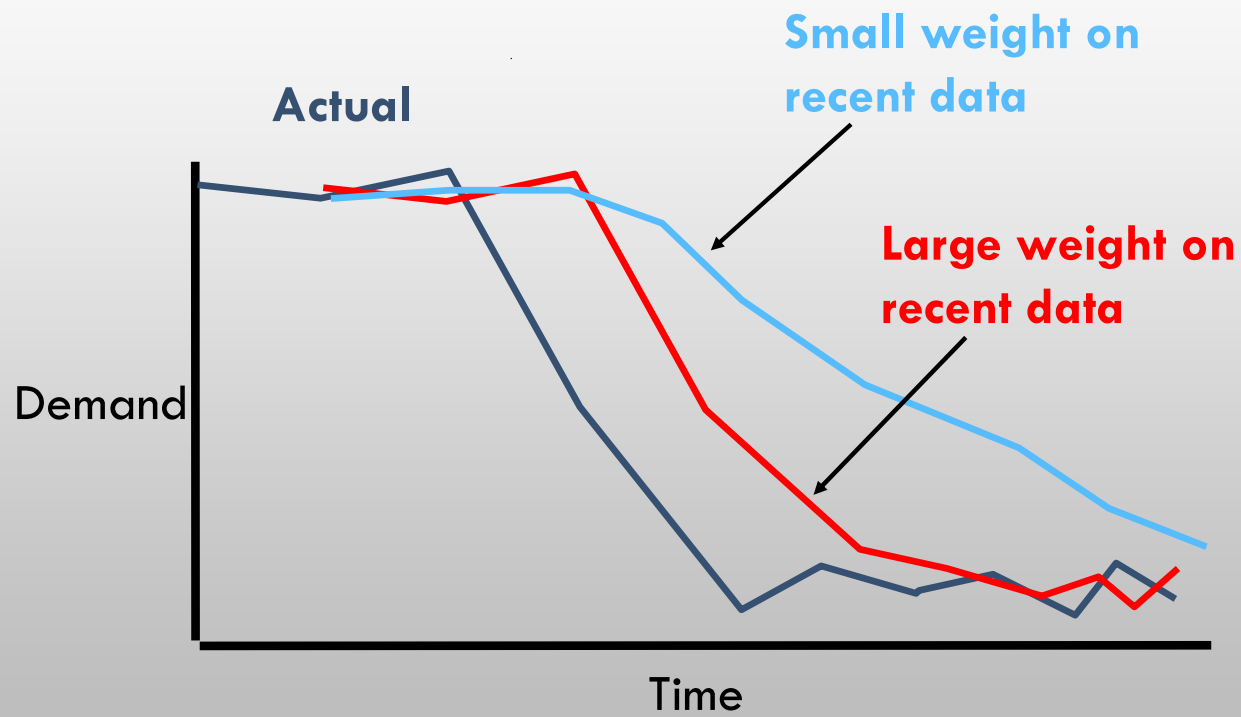
## Weighted Moving Average Example

| t | Weight (w) | Month     | Actual Demand (A) |
|---|------------|-----------|-------------------|
| 1 | 20%        | May       | 10                |
| 2 | 30%        | June      | 12                |
| 3 | 50%        | July      | 13                |
| 4 |            | August    | 16                |
| 5 |            | September | 19                |
| 6 |            | October   | 23                |

# Weighted Moving Average Example

| t | Weight (w) | Month     | Actual Demand (A) | 3-month Moving Average                                                       |
|---|------------|-----------|-------------------|------------------------------------------------------------------------------|
| 1 | 20%        | May       | 10                |                                                                              |
| 2 | 30%        | June      | 12                |                                                                              |
| 3 | 50%        | July      | 13                |                                                                              |
| 4 |            | August    | 16                | $F_4 = 0.2 \times 10 + 0.3 \times 12 + 0.5 \times 13 = 2 + 3.6 + 6.5 = 12.1$ |
| 2 | 20%        | June      | 12                |                                                                              |
| 3 | 30%        | July      | 13                | ← Drop $A_1$ , Get $A_4$                                                     |
| 4 | 50%        | August    | 16                |                                                                              |
| 5 |            | September | 19                | $F_5 = 0.2 \times 12 + 0.3 \times 13 + 0.5 \times 16 = 2 + 3.9 + 8 = 13.9$   |

# Weighted Moving Average



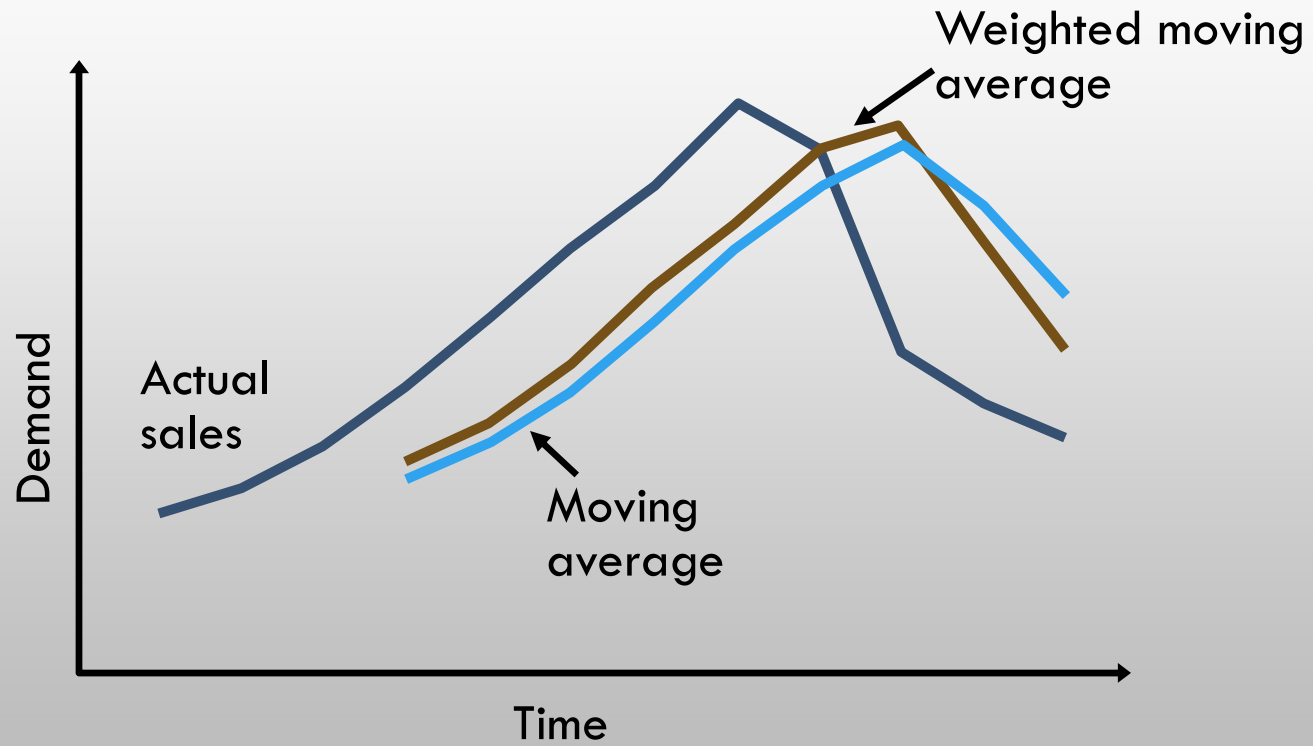
Higher weight on recent demand data -> more accurate forecast

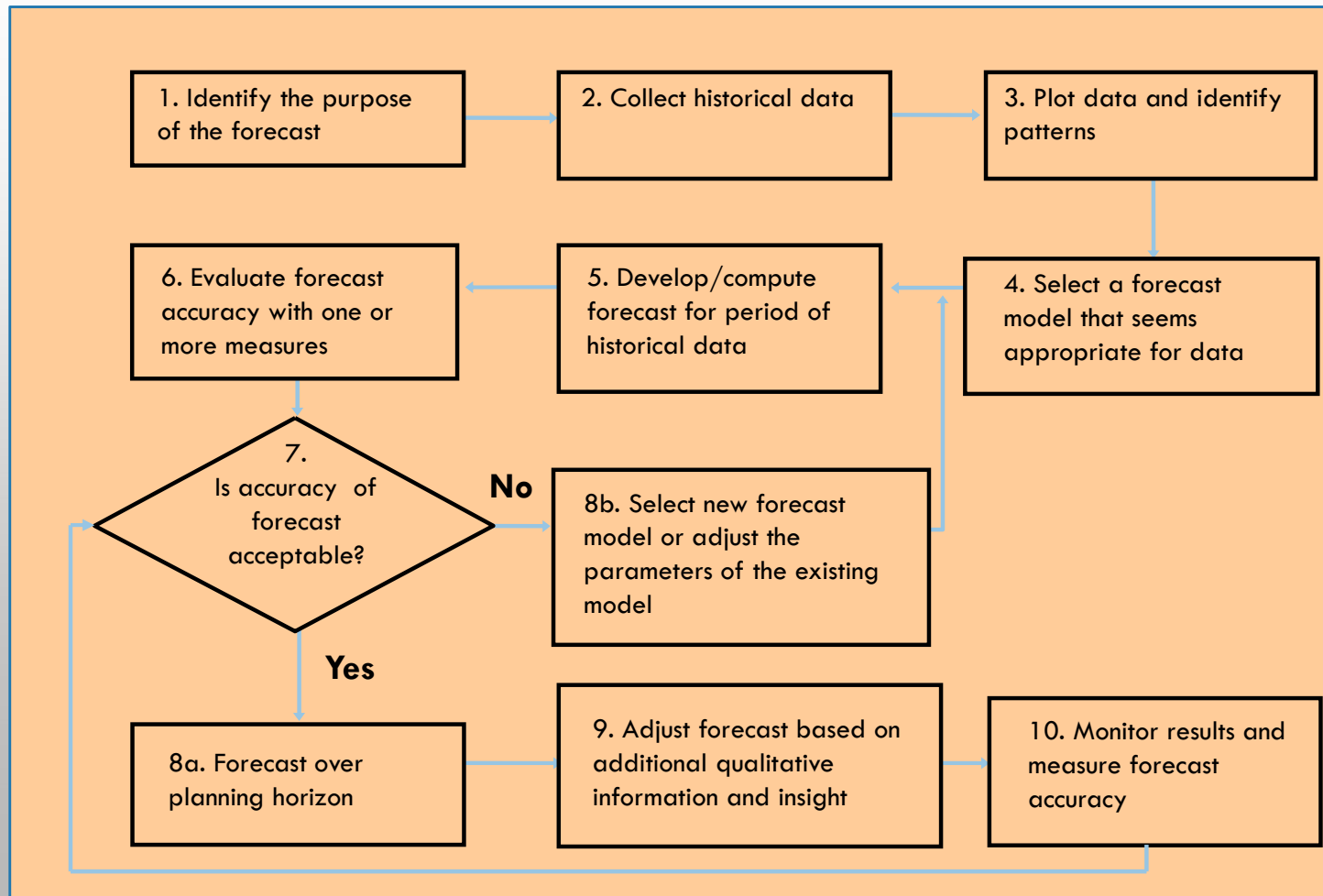


## MOVING AVERAGE APPROACHES - PROBLEMS

1. Increasing  $N$  smooths the forecast, but it is less sensitive to changes in demand.
  2. Trends are not recognized very well; they cannot predict higher or lower levels of demand.
  3. We need extensive historical demand data.
- 

# Moving Average Approaches - Problems





Source: Russell and Taylor, 2011. Operations Management, 7th edition, John Wiley & Sons - Chapter 12.

# TIME SERIES FORECASTING MODELS

$F_{t+1}$ : Forecast of demand for period  $t+1$

$A_t$ : Actual demand in period  $t$

| Time Series Model         | Formula                                                                               | More                                                                                 |
|---------------------------|---------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| Naive                     | $F_{t+1} = A_t$                                                                       |                                                                                      |
| Mean                      | $F_{t+1} = \sum A_t / n$                                                              | Avg. of all available demand data in $n$ periods                                     |
| N-period Moving Average   | $F_{t+1} = D_t + D_{t-1} + D_{t-2} + \dots + D_{t-N+1} / N$                           | For each new forecast, add the most recent demand observation and drop the earliest. |
| N-period Weighted Average | $F_{t+1} = w_t D_t + w_{t-1} D_{t-1} + w_{t-2} D_{t-2} + \dots + w_{t-N+1} D_{t-N+1}$ | All weights add to 100% or 1.<br>$\sum w_t = 1$                                      |

# TIME SERIES DEMAND FORECASTING

Forecast = Systematic component (S) + Random component (R)

- Systematic component (S) = (level + trend)  $\times$  seasonal factor
  - ✓ Level : deseasonalized demand
  - ✓ Trend: rate of growth or decline in demand (increasing or decreasing pattern)
  - ✓ Seasonal factor – predictable seasonal fluctuations in demand (demand pattern of constant length that regularly repeats itself)

## TIME SERIES FORECASTING MODELS (MORE)

- Exponential smoothing (Εκθετική Εξομάλυνση)
- Exponential smoothing with Trend adjustment (Holt's model)
- Exponential smoothing with Trend and Seasonality adjustment (Winter's model)

# EXPONENTIAL SMOOTHING

- Demand Forecast = Last Forecast +  $\alpha$  (Last Actual Demand – Last Forecast Demand)
- Last Actual Demand – Last Forecast Demand: random component
- $F_{t+1} = L_t$ ,  $L_t = F_t + \alpha (A_t - F_t)$
- $F_{t+1} = F_t + \alpha (A_t - F_t)$ 
  - ✓  $F_{t+1}$ : Forecast of demand for period  $t+1$ ,  $F_t$ : Forecast of demand for period  $t$
  - ✓  $L_t$ : Level of demand in period  $t$
  - ✓  $A_t$ : Actual demand in period  $t$
  - ✓ Smoothing (weighting) coefficient  $0 \leq \alpha \leq 1$  (subjective value)
- Easy to implement, minimal amount of data -> **most frequently used** time series forecasting approach

# EXPONENTIAL SMOOTHING

$$F_{t+1} = L_t, L_t = F_t + \alpha (A_t - F_t)$$

$$F_{t+1} = F_t + \alpha (A_t - F_t)$$

- $L_o$  : Average of all historical demand data
- $L_o = \sum A_t / n$
- New demand observation  $A_{t+1}$   $\rightarrow$  revision of  $L$ 
  - ✓  $L_{t+1} = F_{t+1} + \alpha (A_{t+1} - F_{t+1}) = \alpha A_{t+1} + (1-\alpha)F_{t+1} \Leftrightarrow$
  - ✓  $L_{t+1} = \alpha A_{t+1} + (1-\alpha)L_t$
  - ✓ Weighted average of current demand and old level  $L$

# Exponential Smoothing Example

| t | Month     | Actual Demand (A) | Forecast (F)<br>$F_{t+1} = L_t$<br>$\alpha = 0.3$ | Level (L)<br>$L_t = \alpha A_t + (1 - \alpha)F_t$<br>$L_o = \sum A_t / n$       |
|---|-----------|-------------------|---------------------------------------------------|---------------------------------------------------------------------------------|
| 1 | May       | 37                | $F_1 = L_o = 41.67$                               | $L_o = (37+40+41+37+45+50)/6 = 41.67$                                           |
| 2 | June      | 40                | $F_2 = L_1 = 40.27$                               | $L_1 = \alpha A_1 + (1 - \alpha)F_1 =$<br>$= 0.30*37 + 0.70*41.67$<br>$= 40.27$ |
| 3 | July      | 41                | $F_3 = L_2 = 40.19$                               | $L_2 = \alpha A_2 + (1 - \alpha)F_2 =$<br>$= 0.30*40 + 0.70*40.27$<br>$= 40.19$ |
| 4 | August    | 37                | $F_4 = L_3 = 40.43$                               | $L_3 = \alpha A_3 + (1 - \alpha)F_3 =$<br>$= 0.30*41 + 0.70*40.19$<br>$= 40.43$ |
| 5 | September | 45                |                                                   |                                                                                 |
| 6 | October   | 50                |                                                   |                                                                                 |

# Exponential Smoothing Example

| t | Month     | Actual Demand (A) | Forecast (F)<br>$F_{t+1} = L_t$<br>$\alpha = 0.5$ | Level (L)<br>$L_t = \alpha A_t + (1 - \alpha)F_t$<br>$L_o = \sum A_t / n$                     |
|---|-----------|-------------------|---------------------------------------------------|-----------------------------------------------------------------------------------------------|
| 1 | May       | 37                | $F_1 = L_0 = 41.67$                               | $L_o = (37+40+41+37+45+50)/6 = 41.67$                                                         |
| 2 | June      | 40                | $F_2 = L_1 = 39.33$                               | $L_1 = \alpha A_1 + (1 - \alpha)F_1 =$<br>$= 0.50*37 + 0.50*41.67$<br>$= 39.33$               |
| 3 | July      | 41                | $F_3 = L_2 =$                                     | $L_2 = \alpha A_2 + (1 - \alpha)F_2 =$ <span style="color: purple;">← Please, practice</span> |
| 4 | August    | 37                | $F_4 = L_3 =$                                     | $L_3 = \alpha A_3 + (1 - \alpha)F_3 =$                                                        |
| 5 | September | 45                |                                                   |                                                                                               |
| 6 | October   | 50                |                                                   |                                                                                               |

# SMOOTHING COEFFICIENT $\alpha$

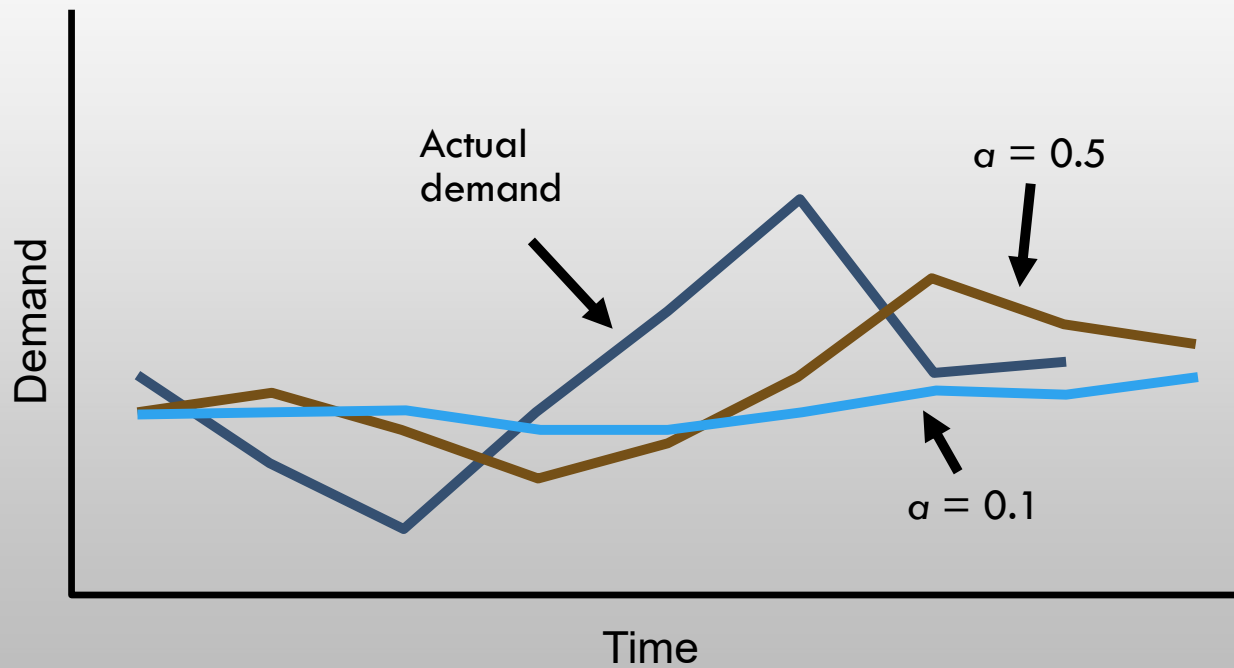
$$F_{t+1} = F_t + \alpha (A_t - F_t)$$

- $\alpha$  is selected by the forecaster
- $\alpha = 0$ ,  $F_{t+1} = F_t$  (the forecast does not focus on the recent data)
- $\alpha = 1$ ,  $F_{t+1} = A_t$  (the forecast focuses on the most recent data – naïve approach)

The higher the  $\alpha$  becomes, the less we consider the older demand values.

- $\alpha = 0.2$ ,  $F_{t+1} = 0.2A_t + 0.8F_t$
- $\alpha = 0.35$ ,  $F_{t+1} = 0.35A_t + 0.75F_t$
- $\alpha = 0.5$ ,  $F_{t+1} = 0.5A_t + 0.5F_t$

# SMOOTHING COEFFICIENT $\alpha$



- $0.05 \leq \alpha \leq 0.5$  for business applications
- Higher  $\alpha$   $\rightarrow$  more responsive to recent observations

## TREND-ADJUSTED EXPONENTIAL SMOOTHING

- Suitable for data that exhibit a trend, but no seasonality.
- Exponentially smoothed/ weighted average of demand data + adjustment for positive or negative lag in trend.
- $F_{t+1} = L_t + T_t$
- $L_t = F_t + \alpha (A_t - F_t) \Leftrightarrow L_t = (L_{t-1} + T_{t-1}) + \alpha [A_t - (L_{t-1} - T_{t-1})] \Leftrightarrow$
- $L_t = \alpha A_t + (1-\alpha)(L_{t-1} + T_{t-1})$
- $T_t = (1-\beta)T_{t-1} + \beta (L_t - L_{t-1})$ 
  - ✓  $L_t$ : exponentially smoothed average of demand in period  $t$
  - ✓  $T_t$ : exponentially smoothed trend in period  $t$
  - ✓  $\beta$ : smoothing (weighting) coefficient of trend  $0 \leq \beta \leq 1$  (subjective value)

## TREND-ADJUSTED EXPONENTIAL SMOOTHING

$$F_{t+1} = L_t + T_t$$

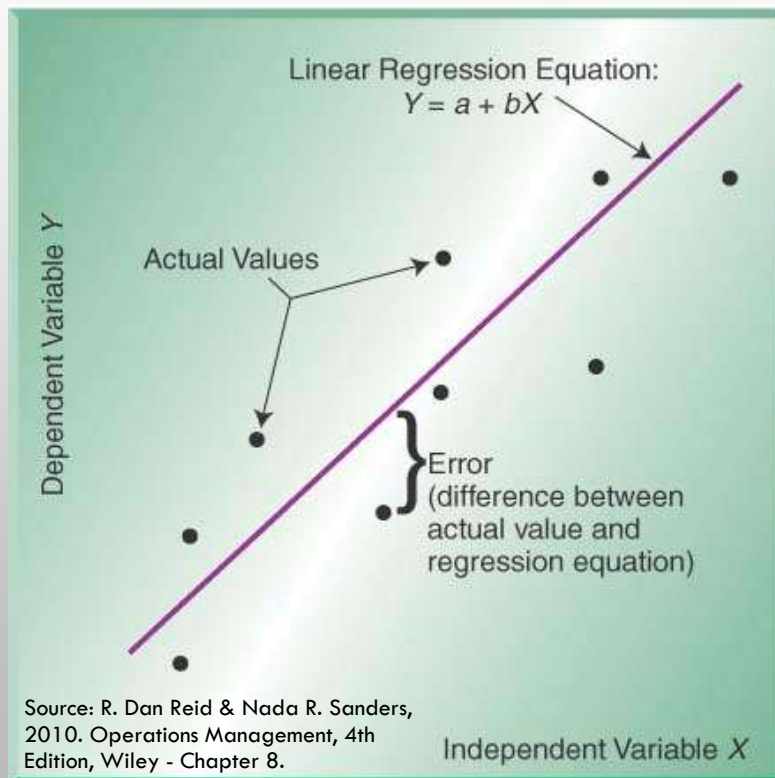
- $L_t = \alpha A_t + (1-\alpha)(L_{t-1} + T_{t-1})$
- $T_t = (1-\beta)T_{t-1} + \beta (L_t - L_{t-1})$
- **Linear regression** between demand (A) and time (t)  $\rightarrow T_0, L_0$

✓  $A_t = at + b$

✓  $T_0 = a$

✓  $L_0 = b$

# Linear Regression



Models the relationship between two variables as a straight line.

Fits a straight line to a time series data.

$$y = a + bx$$

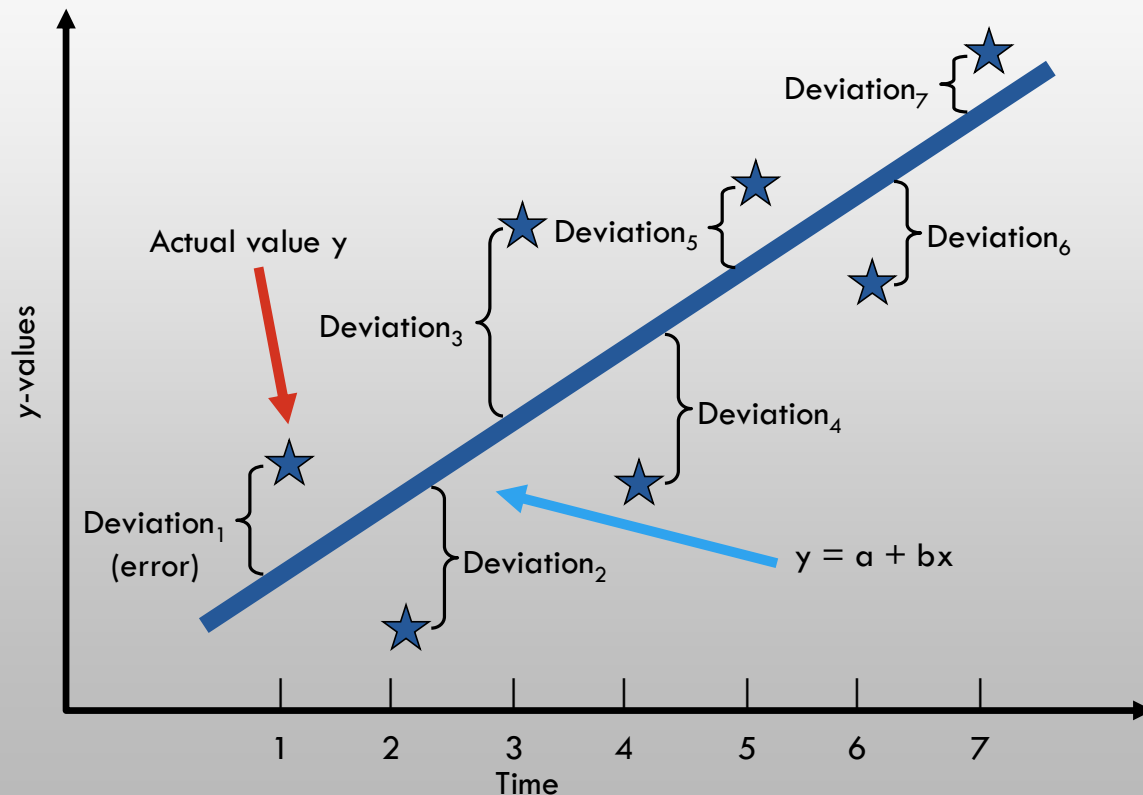
x: time period (independent variable)

y: value for time period x (dependent variable)

a: y-intercepts of the line - height at which the line intercepts the y-axis (y value at  $x=0$ )

b: slope of the line (expected change)

# Linear Regression



We select to build a straight line that minimizes the deviations of the actual values from the line, namely

- $a$  and  $b$  define a straight line that minimizes the sum of the squared errors.
- error = difference between actual value and  $y$
- Least-squares straight line

# Linear Regression

- $y = a + bx$
- $b = (\sum xy - n \text{avg}(x) \text{avg}(y)) / (\sum x^2 - n \text{avg}(x)^2)$
- $a = \text{avg}(y) - b \text{avg}(x)$
- $n$ : number of data points
- $\text{avg}(x)$ : average of the  $x$ -values
- $\text{avg}(y)$ : average of the  $y$ -values

# PERFORM TREND-ADJUSTED EXPONENTIAL SMOOTHING

1. Smoothing the demand series

$$L_t = \alpha A_t + (1-\alpha)(L_{t-1} + T_{t-1})$$

2. Smoothing the trend

$$T_t = (1-\beta)T_{t-1} + \beta (L_t - L_{t-1})$$

3. Forecasting including Trend

$$F_{t+1} = L_t + T_t$$

# Trend-adjusted Exponential Smoothing Example

| t  | Actual Demand (A) |
|----|-------------------|
| 1  | 8,000             |
| 2  | 13,000            |
| 3  | 23,000            |
| 4  | 34,000            |
| 5  | 10,000            |
| 6  | 18,000            |
| 7  | 23,000            |
| 8  | 38,000            |
| 9  | 12,000            |
| 10 | 13,000            |
| 11 | 32,000            |
| 12 | 41,000            |

1. Calculate  $L_0, T_0$
2. Smoothing the demand series

$$L_t = \alpha A_t + (1-\alpha)(L_{t-1} + T_{t-1})$$

3. Smoothing the trend

$$T_t = (1-\beta)T_{t-1} + \beta (L_t - L_{t-1})$$

4. Forecasting including Trend

$$F_{t+1} = L_t + T_t$$

# Perform Trend-adjusted Exponential Smoothing – Using Excel

| <div> <div>FILE</div> <div>HOME</div> <div>INSERT</div> <div>PAGE LAYOUT</div> <div>FORMULAS</div> <div>DATA</div> <div>REVIEW</div> <div>VIEW</div> </div>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |      |        |                                                          |                                                       |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|--------|----------------------------------------------------------|-------------------------------------------------------|
| <div> <div> <div>fx</div> <div>Insert Function</div> </div> <div> <div>Σ</div> <div>AutoSum</div> </div> <div> <div>★</div> <div>Recently Used</div> </div> <div> <div>📊</div> <div>Financial</div> </div> <div> <div>?</div> <div>Logical</div> </div> <div> <div>A</div> <div>Text</div> </div> <div> <div>📅</div> <div>Date &amp; Time</div> </div> <div> <div>🔍</div> <div>Lookup &amp; Reference</div> </div> <div> <div>θ</div> <div>Math &amp; Trig</div> </div> <div> <div>⋮</div> <div>More Functions</div> </div> <div> <div>📁</div> <div>Name Manager</div> </div> <div> <div>🔗</div> <div>Define Name</div> </div> <div> <div>🔗</div> <div>Use in Formula</div> </div> <div> <div>🔗</div> <div>Create from Selection</div> </div> <div> <div>🔗</div> <div>Defined Names</div> </div> </div> |      |        |                                                          |                                                       |
| <div> <div>C6</div> <div> <div>✕</div> <div>✓</div> <div>fx</div> </div> <div>=INTERCEPT(B7:B18,A7:A18)</div> </div>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |      |        |                                                          |                                                       |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | A    | B      | C                                                        | D                                                     |
| 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |      |        |                                                          |                                                       |
| 2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | α    | 0.1    |                                                          |                                                       |
| 3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | β    | 0.2    |                                                          |                                                       |
| 4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |      |        |                                                          |                                                       |
| 5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Week | Sales  | Level $L_{t+1} = \alpha A_{t+1} + (1-\alpha)(L_t + T_t)$ | Trend $T_{t+1} = \beta(L_{t+1} - L_t) + (1-\beta)T_t$ |
| 6                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | 0    |        | 12,015.15                                                | 1,548.95                                              |
| 7                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | 1    | 8,000  |                                                          |                                                       |
| 8                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | 2    | 13,000 |                                                          |                                                       |
| 9                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | 3    | 23,000 |                                                          |                                                       |
| 10                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 4    | 34,000 |                                                          |                                                       |
| 11                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 5    | 10,000 |                                                          |                                                       |
| 12                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 6    | 18,000 |                                                          |                                                       |
| 13                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 7    | 23,000 |                                                          |                                                       |
| 14                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 8    | 38,000 |                                                          |                                                       |
| 15                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 9    | 12,000 |                                                          |                                                       |
| 16                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 10   | 13,000 |                                                          |                                                       |
| 17                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 11   | 32,000 |                                                          |                                                       |
| 18                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 12   | 41,000 |                                                          |                                                       |

1. Calculate  $L_o$ ,  $T_o$

$$T_o = \text{SLOPE}(y, x)$$

$$L_o = \text{INTERCEPT}(y, x)$$

# Perform Trend-adjusted Exponential Smoothing – Using Excel

| <div> <div>FILE</div> <div>HOME</div> <div>INSERT</div> <div>PAGE LAYOUT</div> <div>FORMULAS</div> <div>DATA</div> <div>REVIEW</div> <div>VIEW</div> </div>                                                                                                                  |          |        |                                                          |                                                       |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|--------|----------------------------------------------------------|-------------------------------------------------------|
| <div> <div> <div>Cut</div> <div>Copy</div> <div>Paste</div> <div>Format Painter</div> </div> <div>Clipboard</div> </div>                                                                                                                                                     |          |        |                                                          |                                                       |
| <div> <div> <div>Arial</div> <div>12</div> <div>A<sup>+</sup></div> <div>A<sup>-</sup></div> </div> <div> <div>B</div> <div>I</div> <div>U</div> <div></div> </div> <div> <div></div> <div></div> <div></div> </div> <div> <div></div> <div></div> <div></div> </div> </div> |          |        |                                                          |                                                       |
| <div> <div> <div>Wrap Text</div> <div>Merge &amp; Center</div> </div> <div> <div>Number</div> <div>\$</div> <div>%</div> <div></div> </div> <div> <div>0.00</div> <div>0.00</div> </div> </div>                                                                              |          |        |                                                          |                                                       |
| <div> <div>C7</div> <div> <div>✕</div> <div>✓</div> <div>fx</div> </div> <div>=B\$2*B7+(1-B\$2)*(C6+D6)</div> </div>                                                                                                                                                         |          |        |                                                          |                                                       |
|                                                                                                                                                                                                                                                                              | A        | B      | C                                                        |                                                       |
| 1                                                                                                                                                                                                                                                                            |          |        |                                                          |                                                       |
| 2                                                                                                                                                                                                                                                                            | $\alpha$ | 0.10   |                                                          |                                                       |
| 3                                                                                                                                                                                                                                                                            | $\beta$  | 0.20   |                                                          |                                                       |
| 4                                                                                                                                                                                                                                                                            |          |        |                                                          |                                                       |
| 5                                                                                                                                                                                                                                                                            | Week     | Sales  | Level $L_{t+1} = \alpha A_{t+1} + (1-\alpha)(L_t + T_t)$ | Trend $T_{t+1} = \beta(L_{t+1} - L_t) + (1-\beta)T_t$ |
| 6                                                                                                                                                                                                                                                                            | 0        |        | 12,015.15                                                | 1,548.95                                              |
| 7                                                                                                                                                                                                                                                                            | 1        | 8,000  | 13,007.69                                                | 1,437.67                                              |
| 8                                                                                                                                                                                                                                                                            | 2        | 13,000 | 14,300.83                                                | 1,408.76                                              |
| 9                                                                                                                                                                                                                                                                            | 3        | 23,000 | 16,438.63                                                | 1,554.57                                              |
| 10                                                                                                                                                                                                                                                                           | 4        | 34,000 | 19,593.88                                                | 1,874.71                                              |
| 11                                                                                                                                                                                                                                                                           | 5        | 10,000 | 20,321.73                                                | 1,645.33                                              |
| 12                                                                                                                                                                                                                                                                           | 6        | 18,000 | 21,570.35                                                | 1,565.99                                              |
| 13                                                                                                                                                                                                                                                                           | 7        | 23,000 | 23,122.71                                                | 1,563.27                                              |
| 14                                                                                                                                                                                                                                                                           | 8        | 38,000 | 26,017.38                                                | 1,829.55                                              |
| 15                                                                                                                                                                                                                                                                           | 9        | 12,000 | 26,262.23                                                | 1,512.61                                              |
| 16                                                                                                                                                                                                                                                                           | 10       | 13,000 | 26,297.36                                                | 1,217.11                                              |
| 17                                                                                                                                                                                                                                                                           | 11       | 32,000 | 27,963.02                                                | 1,306.82                                              |
| 18                                                                                                                                                                                                                                                                           | 12       | 41,000 | 30,442.86                                                | 1,541.42                                              |
| 19                                                                                                                                                                                                                                                                           |          |        |                                                          |                                                       |

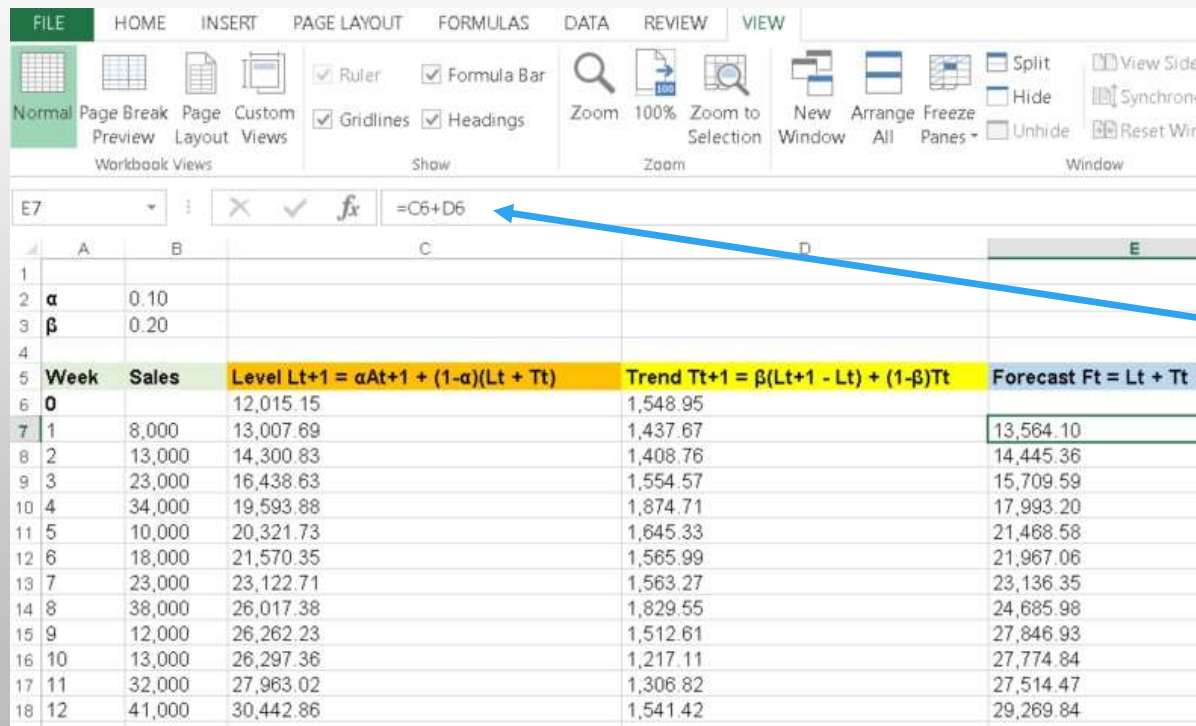
2. Smoothing the demand series

# Perform Trend-adjusted Exponential Smoothing – Using Excel

| <div> <div>FILE</div> <div>HOME</div> <div>INSERT</div> <div>PAGE LAYOUT</div> <div>FORMULAS</div> <div>DATA</div> <div>REVIEW</div> <div>VIEW</div> </div>                                                                          |          |        |                                                          |                                                       |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|--------|----------------------------------------------------------|-------------------------------------------------------|
| <div> <div> <div>Cut</div> <div>Copy</div> <div>Paste</div> <div>Format Painter</div> </div> <div>Clipboard</div> </div>                                                                                                             |          |        |                                                          |                                                       |
| <div> <div> <div>Arial</div> <div>12</div> <div>A<sup>+</sup></div> <div>A<sup>-</sup></div> </div> <div> <div>B</div> <div>I</div> <div>U</div> </div> <div> <div>Font Color</div> </div> <div> <div>Font Style</div> </div> </div> |          |        |                                                          |                                                       |
| <div> <div> <div>Wrap Text</div> </div> <div> <div>Alignment</div> </div> </div>                                                                                                                                                     |          |        |                                                          |                                                       |
| <div> <div> <div>Number</div> </div> <div> <div>\$</div> <div>%</div> <div>,</div> <div>0.00</div> <div>0.0</div> </div> <div> <div>Number</div> </div> </div>                                                                       |          |        |                                                          |                                                       |
| <div> <div> <div>D7</div> </div> <div> <div>fx</div> <div>=B\$3*(C7-C6)+(1-B\$3)*D6</div> </div> </div>                                                                                                                              |          |        |                                                          |                                                       |
|                                                                                                                                                                                                                                      | A        | B      | C                                                        | D                                                     |
| 1                                                                                                                                                                                                                                    |          |        |                                                          |                                                       |
| 2                                                                                                                                                                                                                                    | $\alpha$ | 0.10   |                                                          |                                                       |
| 3                                                                                                                                                                                                                                    | $\beta$  | 0.20   |                                                          |                                                       |
| 4                                                                                                                                                                                                                                    |          |        |                                                          |                                                       |
| 5                                                                                                                                                                                                                                    | Week     | Sales  | Level $L_{t+1} = \alpha A_{t+1} + (1-\alpha)(L_t + T_t)$ | Trend $T_{t+1} = \beta(L_{t+1} - L_t) + (1-\beta)T_t$ |
| 6                                                                                                                                                                                                                                    | 0        |        | 12,015.15                                                | 1,548.95                                              |
| 7                                                                                                                                                                                                                                    | 1        | 8,000  | 13,007.69                                                | 1,437.67                                              |
| 8                                                                                                                                                                                                                                    | 2        | 13,000 | 14,300.83                                                | 1,408.76                                              |
| 9                                                                                                                                                                                                                                    | 3        | 23,000 | 16,438.63                                                | 1,554.57                                              |
| 10                                                                                                                                                                                                                                   | 4        | 34,000 | 19,593.88                                                | 1,874.71                                              |
| 11                                                                                                                                                                                                                                   | 5        | 10,000 | 20,321.73                                                | 1,645.33                                              |
| 12                                                                                                                                                                                                                                   | 6        | 18,000 | 21,570.35                                                | 1,565.99                                              |
| 13                                                                                                                                                                                                                                   | 7        | 23,000 | 23,122.71                                                | 1,563.27                                              |
| 14                                                                                                                                                                                                                                   | 8        | 38,000 | 26,017.38                                                | 1,829.55                                              |
| 15                                                                                                                                                                                                                                   | 9        | 12,000 | 26,262.23                                                | 1,512.61                                              |
| 16                                                                                                                                                                                                                                   | 10       | 13,000 | 26,297.36                                                | 1,217.11                                              |
| 17                                                                                                                                                                                                                                   | 11       | 32,000 | 27,963.02                                                | 1,306.82                                              |
| 18                                                                                                                                                                                                                                   | 12       | 41,000 | 30,442.86                                                | 1,541.42                                              |

3. Smoothing the trend

# Perform Trend-adjusted Exponential Smoothing – Using Excel



| Week | Sales  | Level $L_{t+1} = \alpha A_{t+1} + (1-\alpha)(L_t + T_t)$ | Trend $T_{t+1} = \beta(L_{t+1} - L_t) + (1-\beta)T_t$ | Forecast $F_t = L_t + T_t$ |
|------|--------|----------------------------------------------------------|-------------------------------------------------------|----------------------------|
| 0    |        | 12,015.15                                                | 1,548.95                                              |                            |
| 1    | 8,000  | 13,007.69                                                | 1,437.67                                              | 13,564.10                  |
| 2    | 13,000 | 14,300.83                                                | 1,408.76                                              | 14,445.36                  |
| 3    | 23,000 | 16,438.63                                                | 1,554.57                                              | 15,709.59                  |
| 4    | 34,000 | 19,593.88                                                | 1,874.71                                              | 17,993.20                  |
| 5    | 10,000 | 20,321.73                                                | 1,645.33                                              | 21,468.58                  |
| 6    | 18,000 | 21,570.35                                                | 1,565.99                                              | 21,967.06                  |
| 7    | 23,000 | 23,122.71                                                | 1,563.27                                              | 23,136.35                  |
| 8    | 38,000 | 26,017.38                                                | 1,829.55                                              | 24,685.98                  |
| 9    | 12,000 | 26,262.23                                                | 1,512.61                                              | 27,846.93                  |
| 10   | 13,000 | 26,297.36                                                | 1,217.11                                              | 27,774.84                  |
| 11   | 32,000 | 27,963.02                                                | 1,306.82                                              | 27,514.47                  |
| 12   | 41,000 | 30,442.86                                                | 1,541.42                                              | 29,269.84                  |

4. Forecasting with trend

## SMOOTHING COEFFICIENT B

- $\beta$  is selected by the forecaster
- High  $\beta$   $\rightarrow$  more responsive to recent changes in trend.
- Low  $\beta$   $\rightarrow$  smooths out the present trend.
- Values of  $\alpha$  and  $\beta$  can be found by the trial-and-error approach  
 $\rightarrow$  test different values and calculate the respective forecast error.

# FORECASTING ACCURACY

Forecasting results are never perfect!!

The accuracy of forecasting models should be assessed over time.

$E_t = F_t - A_t$ , Forecast error in period  $t$

- over-forecast = negative forecast error
- under-forecast = positive forecast errors

# FORECASTING ACCURACY METRICS

Mean Absolute Deviation (**MAD**) : average of the absolute forecast error over all periods n

$$MAD = \sum \text{Absolute}(E_t) / n$$

Mean Squared Error (**MSE**)

$$MSE = \sum (E_t)^2 / n$$

- Mean Absolute Percentage Error (**MAPE**)

$$MAPE = [\sum \text{Absolute}(E_t / A_t) * 100] / n$$

# FORECASTING ACCURACY METRICS

**Bias** : sum of forecast errors over all periods n

- ✓ shows whether the forecast model consistently under- or overestimates demand
- ✓ If bias fluctuate around 0, the error is truly random.

$$\text{Bias} = \sum E_t$$

Tracking signal **TS**: how well a forecasting model performs

- ✓ should be within the range of  $\pm 6$
- ✓  $TS < -6$  under forecasting,  $TS > 6$  over forecasting

$$TS_t = \text{bias}_t / \text{MAD}_t = \sum E_t / \text{MAD}_t$$



# SELECTING THE RIGHT FORECASTING MODEL

1. Amount & Type of available data
  2. Degree of forecast accuracy expected
  3. Length of forecast horizon
  4. Presence of data patterns
- 

Καλή συνέχεια!!