SCM
Inventory Management and Control
Independent and Dependent Demand

Andrea Chiarini – andrea.chiarini@univr.it

Why Inventory Management ?

Inventories usually represent the largest part of **current assets** (*assets that are reasonably expected to be converted into cash within one year*) in most manufacturing industries

The turnover of **working capital** which is calculated as **current assets – current liabilities** (*money that is due within one year*) is largely governed by the turnover of inventory

Why Inventory Management ?

Current asset = cash and cash equivalent + **inventory** + accounts receivable

If you have a lot of current asset stuck into inventories you will not have enough cash for paying your staff, taxes, machines, etc.

INVENTORY DRAINS CASH AND UNFORTUNATELY IS NOT SUCH A CURRENT ASSET AS YOU BELIEVE!!

Inventory Management vs Inventory Control, is there any difference?

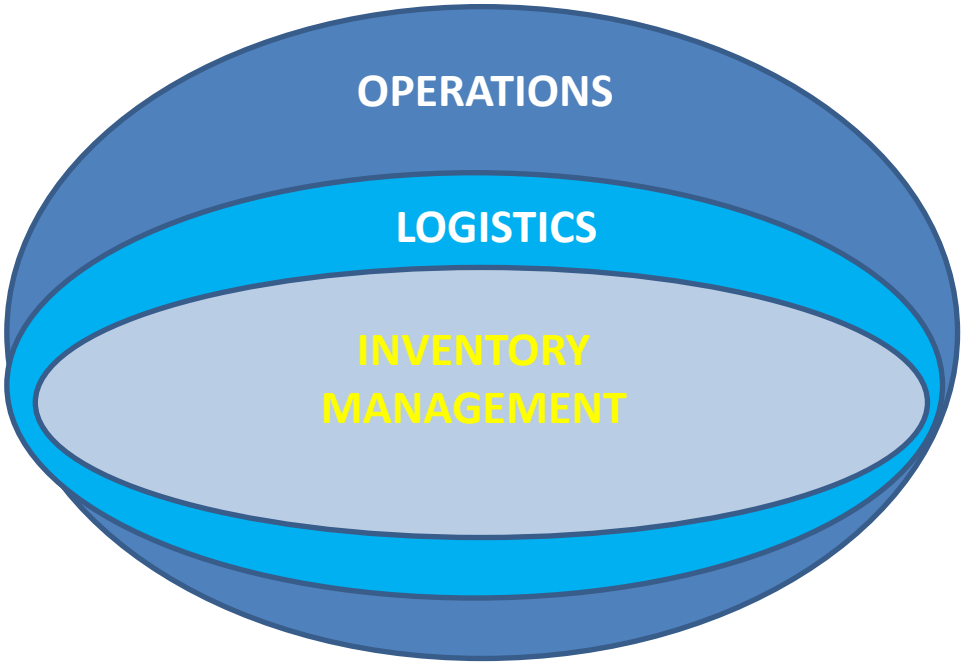
If we like to waste some time, we can say that:
Inventory management is the management system concerning all the processes related to handling (receiving/storage and transporting), managing and controlling inventories

Inventory control is the combination of processes and activities concerning checks, inspections and supervisions of storage locations in terms of quantity, quality and cycle counting

Thence, Inventory management contains Inventory control in some way

In this course we will use both the definitions indistinctly

SCM

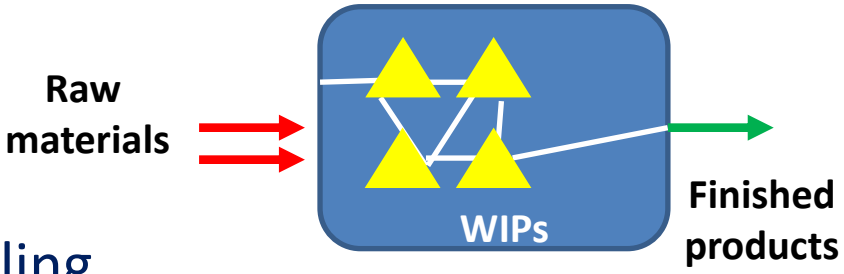


What is an Inventory? Keep it simple with definitions…

Inventories are commodities or goods which occupy a determinate space for a certain period of time…not just finished products !

Basically inventories are stored items such as:

- ✓ raw materials
- ✓ semi-finished supplied parts
- ✓ Work-In-Process (WIP)
- ✓ maintenance spare parts and tooling
- ✓ scrap and rework (non conformance products)
- ✓ office supplies
- ✓ Etc.



How much does inventory cost?

Inventory cost is not just a matter of drained capital, other costs related to carrying inventories can be:

- ✓ Housing cost (e.g. space)
- ✓ Direct handling cost
- ✓ Indirect labour cost (e.g. administrative, inspection, ICT staff)
- ✓ Inventory investment cost (e.g. forklifts, AS/RS, etc.)
- ✓ Obsolescence cost
- ✓ Theft and damage cost (including insurance)
- ✓ Etc.

However, it is physically impossible to have zero inventory level !

Our customers (end-users or other factories) needs a certain **level of service**

Inventory objectives

The main objectives of inventory management are:

- ✓ To minimise the possibility of disruption in the supply chain or in the production schedule of a company
- ✓ To minimise capital investment in inventories

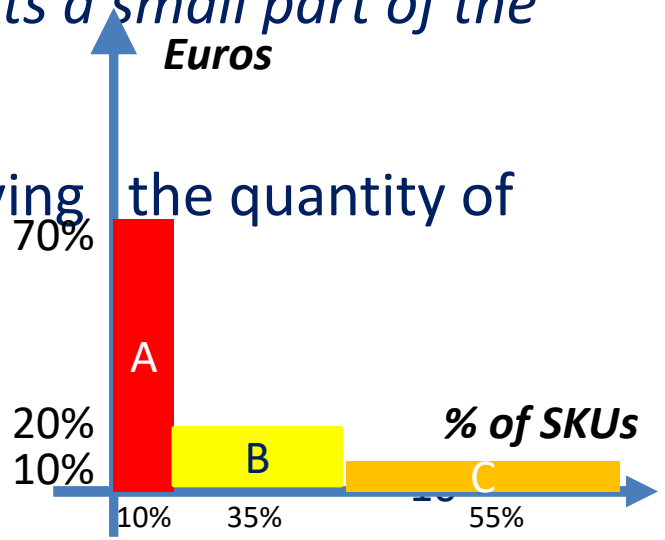
An efficient inventory management, therefore, requires the company to maintain inventories at an optimum level where inventory costs are minimum and at the same time to prevent a **stock-out** which may result in loss of sale or stoppage of production

Even in the most advanced and well implemented Kanban system we will find some inventories !

Inventory Control methodologies

Inventory Control and ABC Analysis

- ✓ Speaking of ABC analysis, different kinds of analysis can be performed. For instance we saw ABC popularity analysis in warehouse management
- ✓ ABC inventory control analysis is firstly based on the value of stock
  - *a small part of the items (A family) typically represents the greater part of money value of the total inventory stored, while a relatively large number of items (C family) represents a small part of the money value of the inventory stored*
- ✓ The money value is calculated by multiplying the quantity of material of each item by its unit price



Andrea Chiarini – andrea.chiarini@univr.it

Should we control these two inventories in the same way?

A – Engines
(Independent Items)
100 SKUs x 1700 Euros each = 170 K Euros

C – Screws and Bolts
(Dependent items)
10000 SKUs x 0.1 Euros each = 1K Euros

Inventory Control methodologies

ABC Analysis

- ✓ According to this inventory control methodology, high value items are more carefully controlled than low value items

Process/activity	A family	B family	C family
General Control	Tight	Moderate	Loose
Inventory accuracy	Exact	Within a range	Estimated
Check and inspection	Very frequent	Periodical	Little
Storage location (Bin)	Individual	Group	Group/none
Safety stock	Low	Medium	Large
Replenishment	JIT/Kanban (MTO-PTO)	JIT/Kanban/ Forecast	Forecast/ Two bins

Inventory Control methodologies

Replenishment/Reordering

- ✓ One of the most common problems facing inventory control is **replenishment**
- ✓ **Replenishment** is a process that consists in making the stock full again in order to avoid **stock-out** **(no service)**
- ✓ Replenishment typically starts with a **backorder** passed to a supplier or to a manufacturer

- ✓ Storage locations may contain items/SKUs that have either **dependent or independent demand**

Inventory Control methodologies

Independent and dependent demand

- ✓ **Independent demand items** are finished products or other items for end-users. Their demand is independent of the demand of any other item carried in storage. Examples: drugs in a pharmacy, clothes in a shop, finished products within a factory

- ✓ **Dependent demand items** are products whose demand depends on the demand of other items also stored. Example: components (semi-finished or raw-materials) which have to be assembled in order to make a finished product

Inventory Control methodologies

Replenishment/Reordering – Independent demand

- ✓ Example of organisations based on independent demand items:
  - Pharmacy department within hospitals
  - Retail shops
  - Wholesale distributors, Distributions centres
  - Etc.

In these cases they MUST keep independent demand items!

Would you enter a completely empty shop for buying some clothes? And what about a hospital without a minimum stock of life-saving drugs?

Andrea Chiarini – andrea.chiarini@univr.it

Inventory Control methodologies

Replenishment/Reordering – Independent demand

- ✓ We saw that in an efficient inventory management we have to keep inventories at an optimum level balancing inventory costs and service level to customers (external or internal)

- ✓ This implies the determination of:
  - **re-order level**
  - **safety stock**
  - **order quantity**

- ✓ Basically it is all about to evaluate:
  - When to order
  - How much to order

Inventory Control methodologies

Reordering – Re-Order level or Point (ROP) – When?

- ✓ **Re-Order level or Point (ROP)** is the inventory level that 'triggers' a new order. It answers the question, when do we have to order?
- ✓ Re-ordering is basically bound to the **lead time** of the supplier or manufacturer or internal process that have to consign the new stock for the replenishment
- ✓ **Lead Time** is defined as the interval between the placing of an order and the time at which SKUs are available for being stored
- ✓ ROP is usually calculated as follows:

(Average daily (or weekly) demand x Lead time) + safety stock

Only when lead time and demand are very certain
we can drop safety stock from the formula !

Inventory Control methodologies

Reordering – Re-order level or point (ROP) - EXERCISE

Assuming we are in a wholesale distributor and we sell some particular mechanical joints. Analysing data, last year we sold 10,000 items over 250 working days. The supplier lead time is certain and equal to 5 days. We want to calculate the ROP
The average daily demand of these joints is 40 (10000/250), thence:

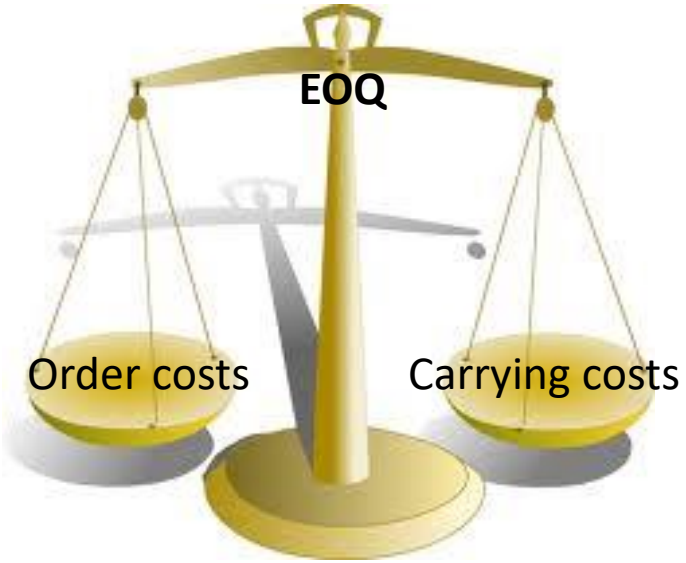
(Average daily (or weekly) demand x Lead time) = 40x5 = 200

When the inventory level drops to 200, an order to the supplier should be placed

Inventory Control methodologies

Reordering – EOQ (Economic Order Quantity) – How much?

- ✓ **EOQ** is the oldest and most famous methodology to calculate how much to order **for independent items**
- ✓ The EOQ gives the order size that will result in the lowest total of order and carrying (holding) costs for inventories
- ✓ The EOQ is the result of a trade-off between two different typologies of cost



ECONOMIC ORDER QUANTITY (EOQ)

EOQ assumptions:

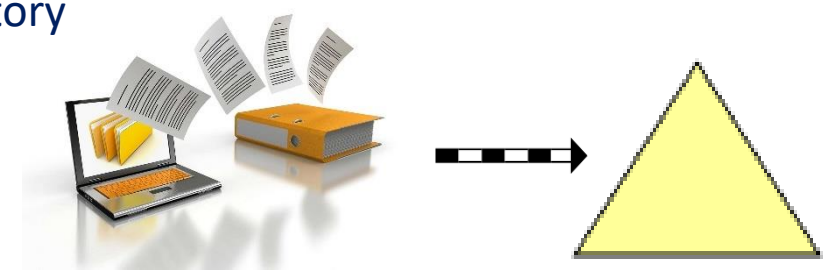
- Demand is stable and known over the year(s)
- Sales occur at a constant rate (Customers buy the product nearly with the same rate of demand and with the same lot size)
- Costs associated with lost sales are not considered. These costs are considered in the determination of safety stock in the re-order point formula
- There is no delay in delivering the ordered quantity
- There is no discount depending on the order size

In this case we can use the **EOQ** formula

Andrea Chiarini – andrea.chiarini@univr.it

ECONOMIC ORDER QUANTITY (EOQ)

In such a stable situation you have to find the optimised quantity Q which reduces to the minimum the cost of placing and order (cost to fulfil an order) and cost of carrying (or holding) the inventory



Cost of the order + Cost of holding the inventory

✓ The cost to fulfil an order is mainly related to the supplier's or manufacturer's organisation. We will see that for a manufacturer is largely due to the so-called **set-up cost**

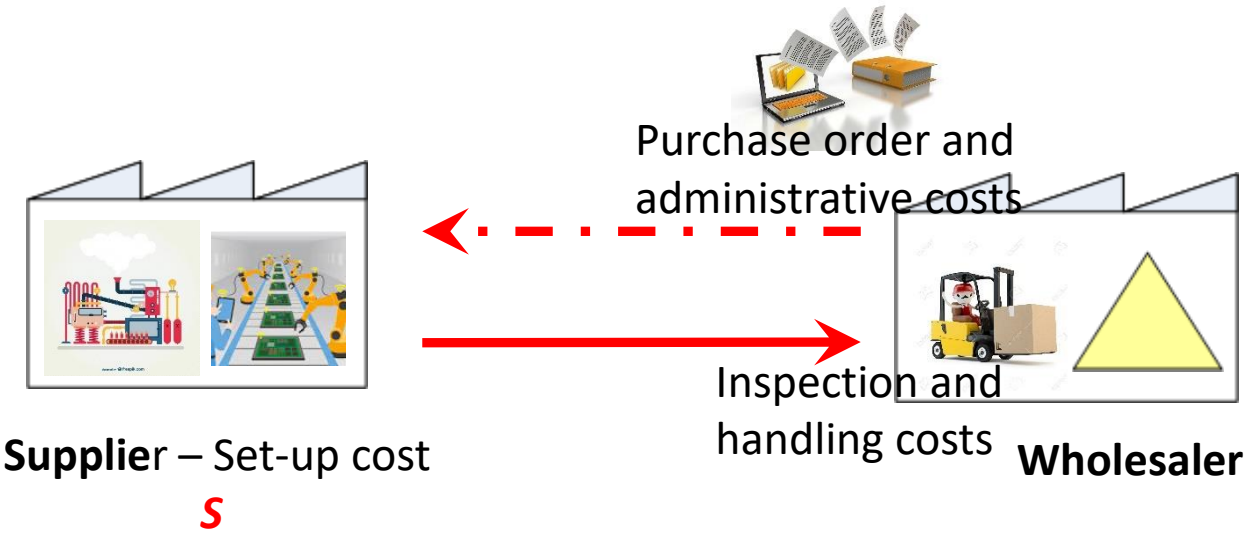
✓ The cost of the warehouse is related to the costs for holding the products

ORDER QUANTITY (EOQ)

Ordering costs *O* are costs such as:

- ✓ Cost of placing (receiving) a purchase order
- ✓ Cost of inspection of received (shipped) products
- ✓ Documentation and administrative costs
- ✓ Handling costs
- ✓ **Machine set-up costs (for manufacturers) = *S***
- ✓ Etc.

O



ORDER QUANTITY (EOQ)

Ordering costs ***O*** are costs such as:

- ✓ Cost of placing (receiving) a purchase order
- ✓ Cost of inspection of received (shipped) products
- ✓ Documentation and administrative costs
- ✓ Handling costs
- ✓ **Machine set-up costs (for manufactures) = *S***
- ✓ Etc.

} ***O***

In the traditional approach these costs are considered fixed, therefore they tend to decrease with the lot size (quantity Q, independent variable).

Therefore, assumed D the steady Demand over the year, it is better to divide D into lots which are as big as you can. If *Q* is the variable quantity (independent variable) inside the lot (lot size), the **Cost of the Order** over the year is =

$$O*(D/Q)$$

where *O* is the ordering cost and D/Q the number of orders per year

ORDER QUANTITY (EOQ)

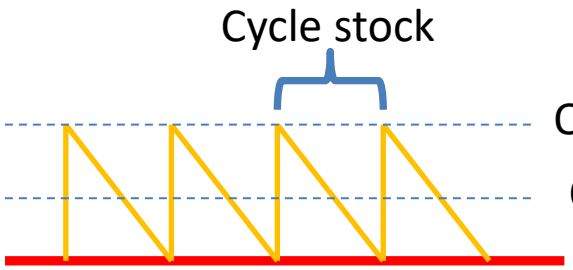
On the other hand, if you increase the lot size (Q), when the lot comes to the warehouse you will increase the costs of holding the lot. As already discussed, costs related to holding inventories can be:

- ✓ Housing cost
- ✓ Handling cost
- ✓ Labour cost
- ✓ Storage system cost
- ✓ Obsolescence cost
- ✓ Theft and damage cost (including insurance)
- ✓ Etc.

} ***I*** (percentage of the cost of the product ***C***)

ORDER QUANTITY (EOQ)

To calculate the cost of the warehouse over the year we consider a stable and linear customer demand. In this way we employ the so-called **slump model**



Q/2 (average quantity inside the storage location, supposing a linear demand)

We can call '*H*' the cost for holding one product in the warehouse (*H = IC*).
Q/2 is the average inventory over the year in the warehouse
In this way, the **cost of the warehouse** is:

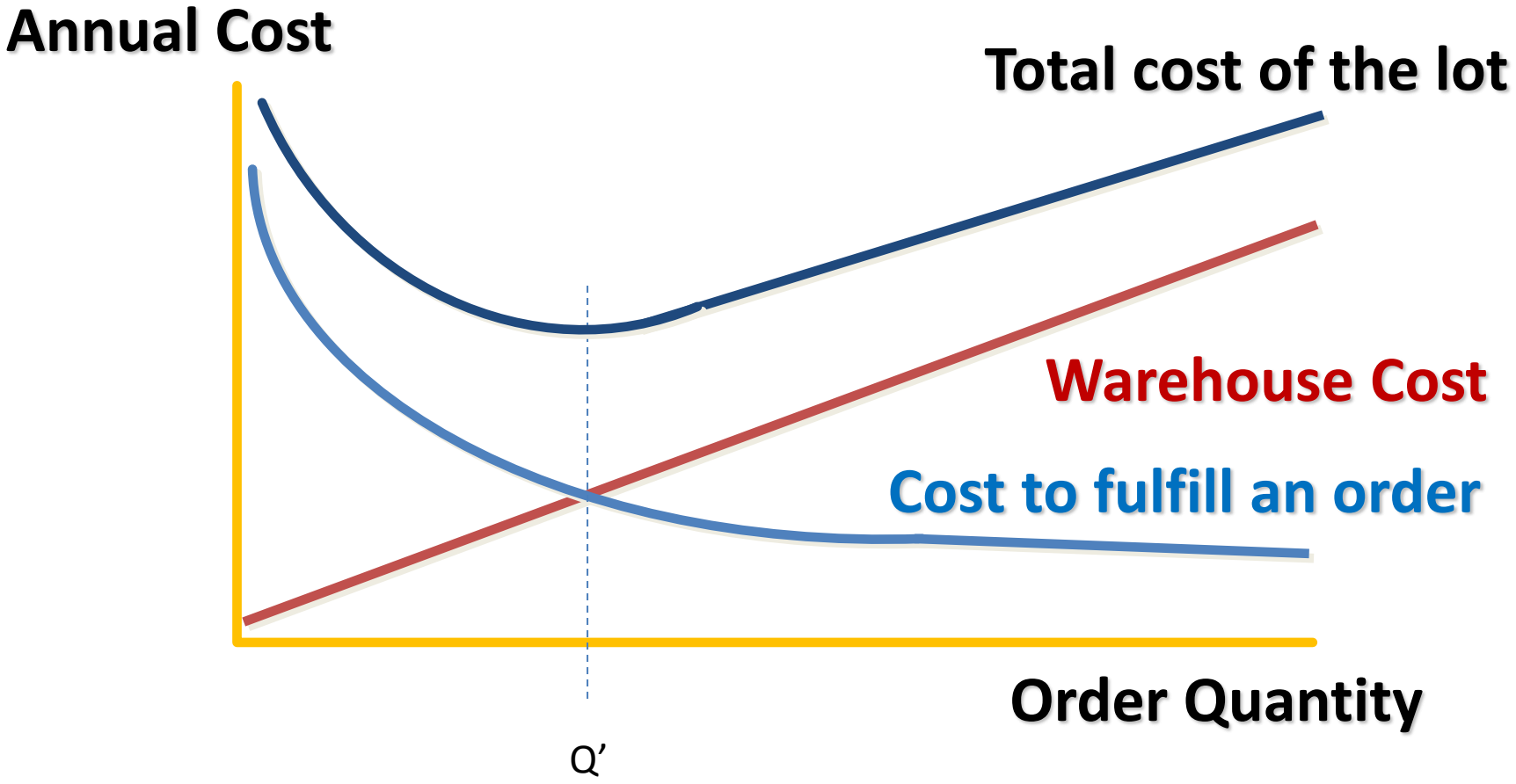
$$(Q/2)*H$$

H usually is calculated as a percentage of the product cost per unit (it can vary from 10 to 40%)

ECONOMIC ORDER QUANTITY (EOQ)

EOQ tries to get the optimised quantity *Q'* which minimizes the two different kind of costs:

- ✓ The cost of holding products within a warehouse in your storage locations
- ✓ The cost of fulfilling an order of a certain lot size



ECONOMIC ORDER QUANTITY (EOQ) – THE FORMULA

D = Annual demand (products)
H = IC = Cost for Holding a product (€)
Q = Order quantity (lot size)
O = Ordering costs (€)

Number of Orders = D / Q
Cost to fulfill an order = $O (D / Q)$

Average inventory products = $Q / 2$

Cost to carry
average inventory = $(Q / 2) H$

Total cost TC = $(Q/2) H + O(D/Q)$
warehouse cost *order cost*

Take the 1st derivative:

$d(TC)/d(Q) = H/2 - (DO) / Q^2$

To optimize: set $d(TC)/d(Q) = 0$

$DO/ Q^2 = H / 2$

$Q^2/DO = 2 / H$

$Q^2= (DO \times 2)/ H$

$Q' = (2DO / H)^{1/2}$

ECONOMIC ORDER QUANTITY (EOQ) – EXERCISE

D = Annual demand (products)
H = Cost for Holding a product (€)
Q = Order quantity (lot size)
O = Ordering cost (€)

$$Q' = (2DO / H)^{1/2}$$

A case study. In the last year, the company had a Demand D of a some metallic joints D = 10,000. Ordering costs cost is 125€ and the cost for holding a product is H = 0.625€

$Q' = (2*10{,}000*125/0.625)^{1/2} = 2{,}000$

ECONOMIC ORDER QUANTITY (EOQ) AND CYCLE STOCK

Once we have calculated the EOQ we can also calculate:

Cycle Stock = EOQ/Average Daily Demand

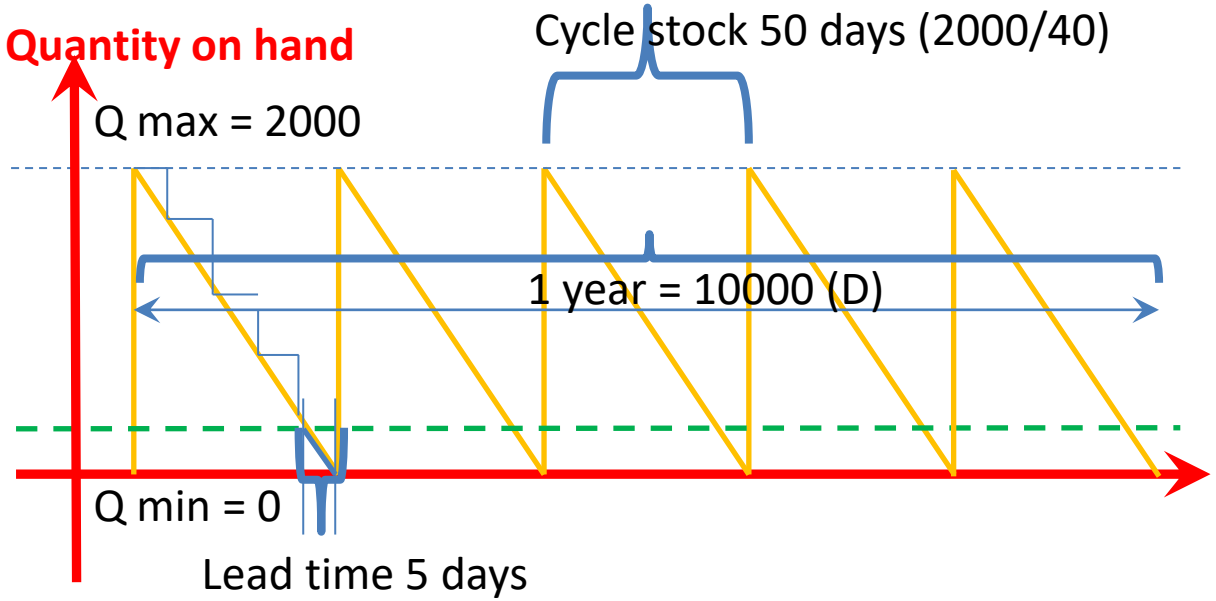
This represents the time for consuming all the EOQ items

Inventory Control methodologies - EOQ and ROP

In our example, the diagram below shows the evolution of the **inventory on hand** over 1 year. This model is named **slump model** and you know exactly:

- **Supplier lead time** (in our example 5 days)
- Customer quantity **Demand** (stable and linear = daily equal to a fraction of the **EOQ**)
- **Cycle stock** (time for consuming all the EOQ items; in this case 50 days)

Bear in mind that this model works well when both supplier lead time and customer demand are constant.... you know perfectly when and how much to reorder....



D = 10,000
250 working days
Daily demand = 40
Supplier LT = 5days
ROP = 200
EOQ = 2,000

Inventory Control methodologies - Safety stock

In our example, let's suppose that we have reached the ROP and we are waiting for the replenishment from the supplier. Unfortunately something unplanned happens: bad planning on supplier's part, a strike, bad weather, an accident, equipment failure, etc. in this case the lead time could increase…and you run out of stock !

Or it can happen a customer suddenly requires less or more items….or worse the customer calls off an order; in these cases the demand varies and consequently the quantity on hand

When lead time and demand are uncertain (stochastically) you need a **safety stock**

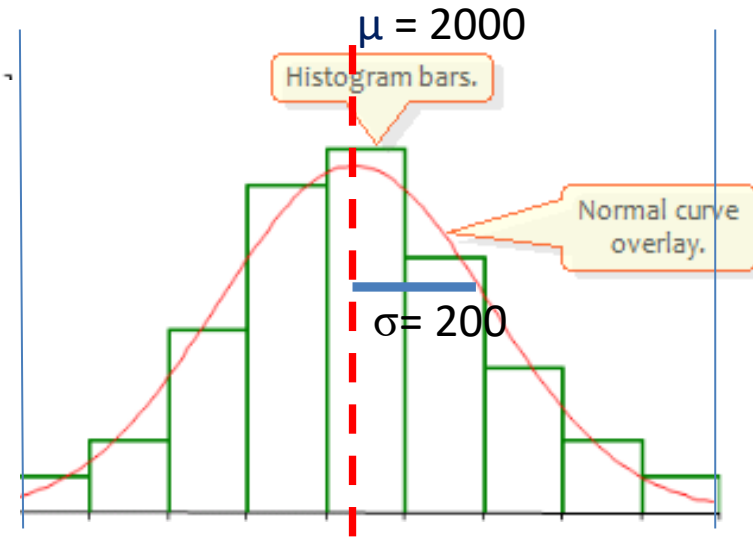
Inventory Control methodologies – Safety stock

- ✓ **Safety stock is inventory that is held to prevent stock-out or shortage due to variability in lead time or demand**
- ✓ Stock-out causes in the supply chain:
  - variability in suppliers lead times
  - customer demand fluctuating
  - forecast inaccuracy
  - quality problems, defects, in the supplied items

- ✓ Safety stock has to balance the conflicting goals of maximising customer service and minimising inventory cost
- ✓ Safety stock can be calculated as a percentage of the inventory (not recommended) or better using the normal distribution

Inventory Control methodologies – Safety stock

- ✓ We start supposing there is a variability in the demand and demand is normally distributed. In this case we can calculate the average demand or **mean** (μ) and the **standard deviation** (σ)
- ✓ For example, analysing some historical (good) data we have calculated that during a cycle stock of 50 days customers demand 2000 items on average but with a standard deviation of 200 items (that does not mean that demand can vary from 1800 up to 2200 items!).
- ✓ When we reach our ROP, If we just order 2000 (μ), without having any safety stock…. statistically we have 50% of probability of stock-out. Indeed, 50 percent of the time we expect demand to be less than 2000 and 50 percent of the time we expect demand to be greater than 2000



Andrea Chiarini – andrea.chiarini@univr.it

Inventory Control methodologies – Safety stock

- ✓ From the previous example, 50% of stock-out probability is a very low **cycle service level.** We could lose many customers!
- ✓ From statistics you should remember the **Z-score** or **Z value**
- ✓ Supposing there is a certain variability (normal distributed) in both Demand and Lead Time we have:

$$\text{Safety Stock} = Z\sqrt{\mu_{LT}\,\sigma_D^2 + \mu_D^2\,\sigma_{LT}^2}$$

Where μ is the average and σ the standard deviation

- ✓ If you have just variability in Demand :

$$\text{Safety Stock} = Z\,\sigma_D\,\sqrt{\mu_{LT}}$$

- ✓ And if you have only variability in Lead Time:

$$\text{Safety Stock} = Z\,\sigma_{LT}\,\mu_D$$

Inventory Control methodologies – Safety stock

- ✓ Using **Z-score** or **Z value** you can standardise your normal distribution setting the mean equal to zero: $z = (X-\mu)/\sigma$

- ✓ Z-score is a very useful statistic because it allows us to calculate the probability of a score or event, (example customer demand) occurring within our normal distribution and enables us to compare two scores which are from different normal distributions. This happens because the two different normal distributions have the same mean equal to zero

Inventory Control methodologies – Safety stock

- ✓ Z is basically linked to the desired service level. For our calculation we can use the **cumulative standard normal distribution table** (you can easily find it on the internet) and fill out the following useful table

Cycle Service Level	Z-score
84	1
85	1.04
90	1.28
95	1.65
98	2.05
99	2.33
99.9	3.09

The quickest way to calculate Z-score is to use the Excel function NORM.S.INV

- ✓ Statistically speaking, 100 % of service level is impossible to achieve; it would need a disproportionate amount of stock (and costs !!)

Inventory Control methodologies – Safety stock, Exercise

- ✓ Referring to the previous example, we want to be 90 percent sure of not stocking out, so we need to carry a few more items or a safety stock
- ✓ From the 'cumulative standard normal distribution' table we see that we need approximately 1.28 standard deviation of extra items to be 90 percent sure of not stocking out. Let's suppose there is no variability in the supplier's lead time and this is equal to 5

- ✓ Therefore:

$$\text{Safety Stock} = 200 \times 1.28 \times (5)^{1/2} \approx 572$$

- ✓ From the previous case study, that means the real ROP is 200 + 572 !!

Inventory Control methodologies – EOQ, ROP, SS Exercise

A wholesale distributor sells SSD memories. They have to buy these memories in the Far-East and each time they launch an order to the supplier they spend around 250 €. SSD memory demand is stable over the year and the average order is 5 memories. Last year they sold 6000 SSDs, with a unit price of 100 Euros. SSD memories can become obsolete quickly and are also at risk of theft. Therefore, holding one SSD item costs around 40% of its price. When they launch an order to the supplier, they should receive the lot in 7 days. The supplier manager has extrapolated a sample of the last 28 delivery times (reliable data). According to the table below, there is a certain variation in the supplier lead time; from 4 days up to 11. Anyhow, customers want at least 95% of service level

LT1 = 7	LT11 = 5	LT21 = 8
LT2 = 7	LT12 = 6	LT22 = 8
LT3 = 7	LT13 = 7	LT23 = 4
LT4 = 9	LT14 = 7	LT24 = 7
LT5 = 8	LT15 = 10	LT25 = 7
LT6 = 7	LT16 = 11	LT26 = 8
LT7 = 7	LT17 = 9	LT27 = 6
LT8 = 5	LT18 = 9	LT28 = 7
LT9 = 5	LT19 = 5	
LT10 = 6	LT20 = 7	

Inventory Control methodologies – EOQ, ROP, SS Exercise

First of all we calculate the EOQ quantity:

EOQ = $[(2*6000*250)/(0.4*100)]^{1/2} \approx 273.86 \approx 274$

Then the ROP:

ROP = Average daily demand x Lead time = $(6000/365)*7 \approx 115$

And finally the SS = Z $\sigma_{LT}\, \mu_D$

We can use the Excel formula STDDEV.P (or STDDEV.S) to calculate $\sigma_{LT} \approx 1.56$ and the formula NORM.S.INV for Z = 1.65. In the end

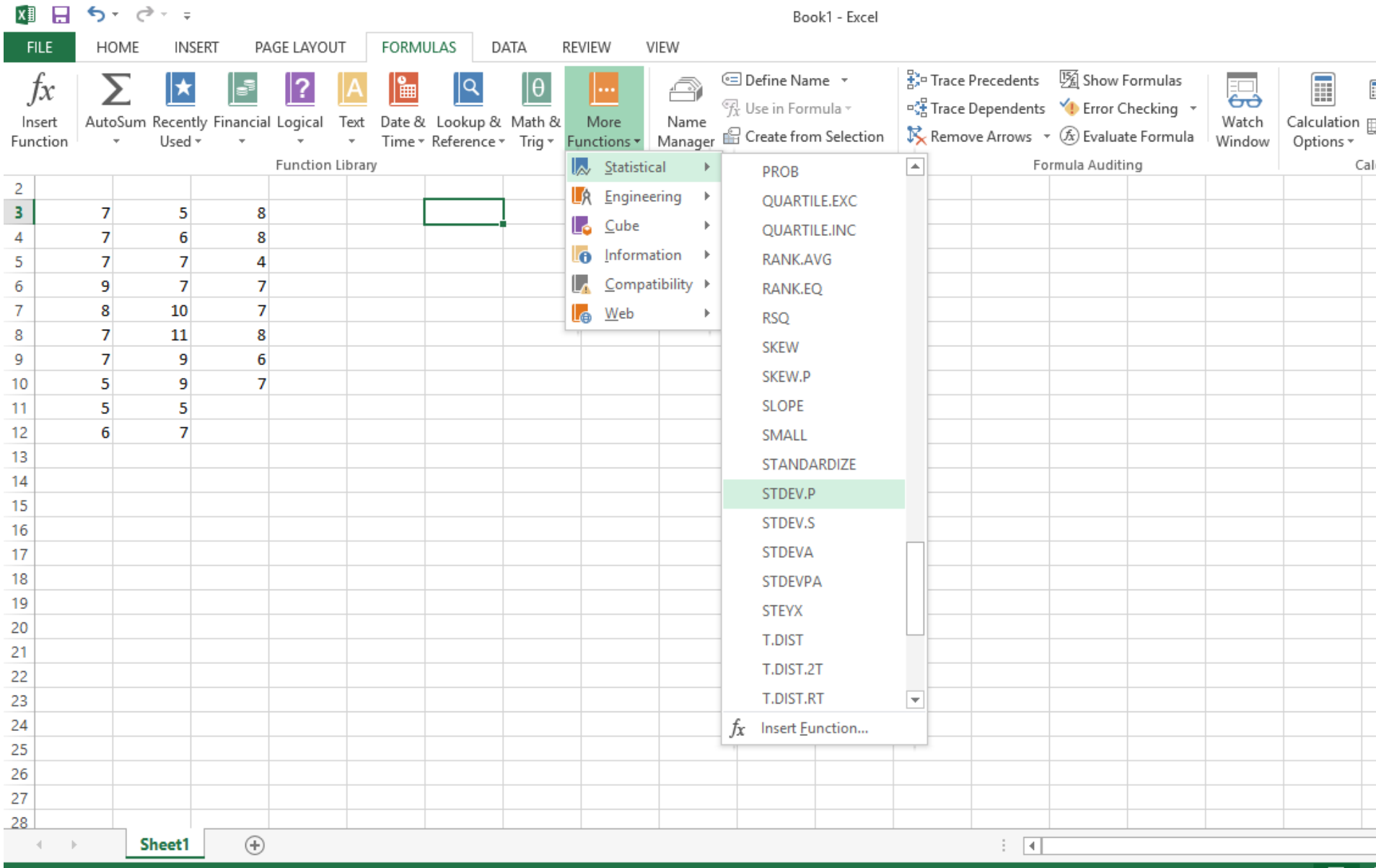
SS = $1.56*1.65*5 \approx 12.9$

The company has rounded off the results:

each time they order 275 and ROP has been set at 125

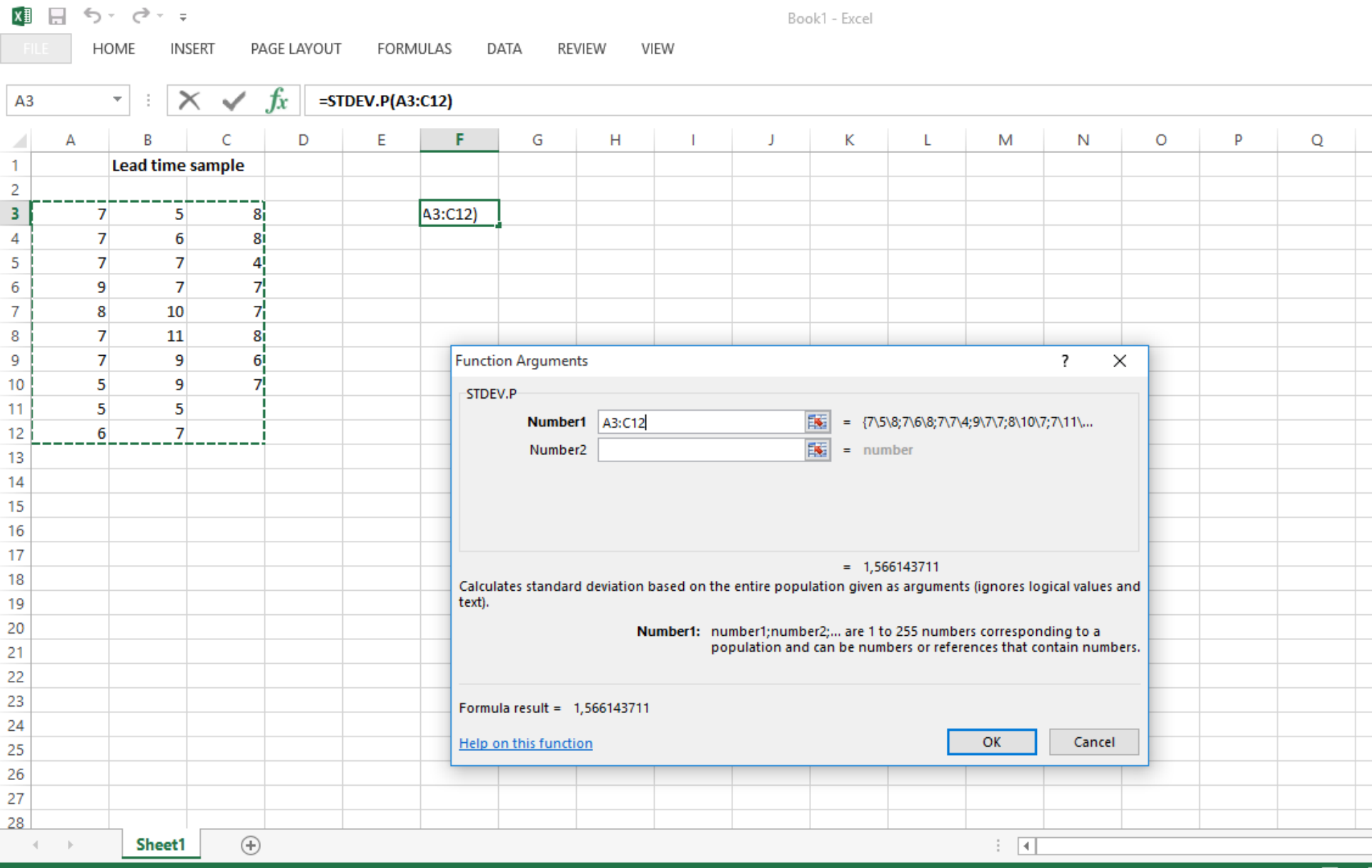
PRODUCTION MANAGEMENT

Using Excel: enter your data – Formulas – Statistical – STDEV.P



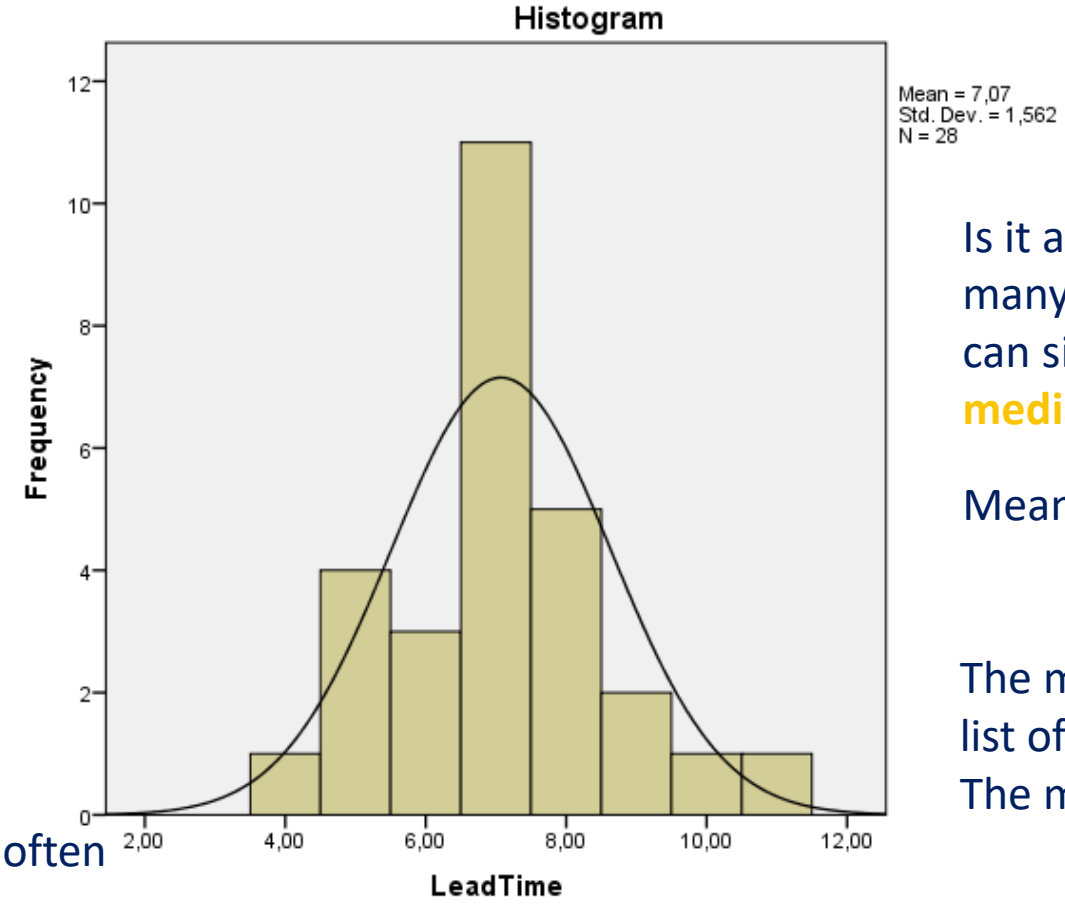
PRODUCTION MANAGEMENT

Then select all your cells (in this case the range is A3:C12, C11 and C12 are empty)



Inventory Control methodologies – EOQ, ROP, SS Exercise

Using Excel or IBM-SPSS ® we can also plot the frequency hystogram and the bell-shaped curve that approaches the hystogram



Is it a real normal distribution? There are many statistical tests for evaluating it. We can simply compare **mean, mode and median .** From SPSS (or Excel) we find:

Mean=7.0714; Median=7.0000;Mode=7.00

The median is the middle value in the list of numbers
The mode is the value that occurs most often

Inventory Management – some relevant KPIs

We have already seen some KPIs related to Warehouse Management and Material Handling. Senior Managers and Managers are usually interested in a particular KPI named **Inventory Turnover** as well as the **Average Stock** in a certain period (one week, one month, one year)

If the company has implemented an effective **WMS** software the average stock can be automatically calculated over a certain period T as:

Average Stock (AS) = $\sum_{i=1}^{n} S_i / T$

If T = 1 year we have n = T = 365

Inventory Management – some relevant KPIs

If we do not have an effective software we can less accurately calculate the AS as the average of the Stocks at the end of each month. Obviously in 1 year we have 12 months (12 Stocks) and an initial Stock S_0 on the first day of the year

AS = $(S_0 + \sum_{i=1}^{12} S_i)/13$

Inventory Management – some relevant KPIs

Once we have calculated AS we can calculate the **Inventory Turnover**

Inventory Turnover (TURN) = Consumption/Average Stock

(of the determined period, for example one year)

Inventory Turnover – Exercise

Last year ACME company sold 12,000 items of a certain family of products. The average stock was 1,000

TURN = Consumption/Average Stock = 12000/1000 = 12

What does it mean this value?

In this case we can say that the inventory has been renewed 12 times over the year (once a month)

It is a measure of how much fast moving (popular) are your products

The higher the better !