



School of Social Sciences

Postgraduate Dissertation

**'INVENTORY MANAGEMENT FOR AGRICULTURAL SPARE PARTS  
UNDER UNCERTAINTY'**

Georgios Exintavelonis

M.Sc. Supply Chain Management

Supervisor of Dissertation

Dr. Stefanos Giakoumatos

Patras, Greece, February 2024

Theses / Dissertations remain the intellectual property of students ("authors/creators"), but in the context of open access policy they grant to the HOU a non-exclusive license to use the right of reproduction, customisation, public lending, presentation to an audience and digital dissemination thereof internationally, in electronic form and by any means for teaching and research purposes, for no fee and throughout the duration of intellectual property rights. Free access to the full text for studying and reading does not in any way mean that the author/creator shall allocate his/her intellectual property rights, nor shall he/she allow the reproduction, republication, copy, storage, sale, commercial use, transmission, distribution, publication, execution, downloading, uploading, translating, modifying in any way, of any part or summary of the dissertation, without the explicit prior written consent of the author/creator. Creators retain all their moral and property rights.



School of Social Sciences

**‘Inventory Management for Agricultural Spare Parts under  
uncertainty’**

**Georgios Exintavelonis**

**M.Sc. Supply Chain Management**

**Supervising Committee**

**Supervisor**

**Stefanos Giakoumatos**

**Professor**

**University of Peloponnese**

**Department of Accounting and  
Finance**

**Co-Supervisor**

**Vasiliki Kazantzi**

**Professor**

**University of Thessaly**

**Department of Business  
Administration**

**Patras, Greece, February 2024**

*Acknowledgements*

*I would like to thank my supervisor Mr. Stefanos Giakoumatos for his support, much-appreciated advice and guidance through this dissertation.*

## **Abstract**

---

The purpose of this dissertation is the management of an inventory, where industrial spare parts are stored before they are sold. More specifically the type of industrial spare parts are spare parts for agricultural tractors. Inventory and inventory management is very important for organizations, simply because it may demand almost 50% of the total invested capital. If we think the inventory of a business as a bank where half of the capital is invested, then we will also very reasonably think that this capital will need a cautious management to return a good amount of money back to the business.

Various academic sources have been used for the theoretical part. In addition, brief information about tractors and their use is given, as well as the main categories of the spare parts that they are using and must be kept in an inventory. For the implementation of the theory, appropriate software which integrates all the relevant theory has been used. For the selection of the proper forecasting method Simulacion5.0 has been used. Simulacion5.0 (<https://sites.google.com/view/simulacion5/main>), is a software which is working as an add-in integrated in Excel. For the Inventory Control Models we run a series of Monte Carlo simulations, again by using Excel and the Crystal Ball software package ([https://docs.oracle.com/cd/E57185\\_01/CBREG/ch07s01s10.html](https://docs.oracle.com/cd/E57185_01/CBREG/ch07s01s10.html)) integrated in it.

The objective of the dissertation is to show that theory is linked to real (professional) life. The application of appropriate methods can lead professionals in viable and realistic business plans. We should highlight that professionals besides causal models may also use qualitative ones. Thus, various tools can help companies understand the markets and products and make the proper calculations for the best possible management of their inventories. Simple indices (Inventory Turnover Ratio & Days in Inventory index) have been calculated to give us a first idea of the impact of the inventory on the financial health of the company and then forecasting and forecasting methods have been assessed for the application of the most suitable forecasting method for the next financial year. The main criterion for the selection of the forecasting method is the minimum value of the Mean Absolute deviation (MAD) and the Mean absolute percent error (MAPE). For the forecasting of the next year, data from the last three previous years have been used. Finally, after using the ABC Analysis tool we define the three most sold types of spare parts and by running Monte Carlo simulations we define the Economic Order Quantity (EOQ).

**Keywords:** tractor spare parts inventory; inventory; reorder point; order quantity; safety stock; lost sales; lead time; optimization

**Περίληψη στα Ελληνικά (Abstract in Greek)**

---

**Τίτλος Διπλωματικής : «Διαχείριση Αποθήκης Ανταλλακτικών Γεωργικών Ελκυστήρων με χρήση ανάλυσης Monte Carlo»****Γεώργιος Εξινταβελώνης**

Σκοπός αυτής της διπλωματικής εργασίας είναι η διαχείριση μιας αποθήκης ανταλλακτικών γεωργικών ελκυστήρων (τρακτέρ). Η σωστή διαχείριση της αποθήκης μιας εταιρίας είναι πολύ σημαντική, αφού μπορεί η αποθήκη αυτή να αποτελεί σε αξία έως και το 50% του συνολικού κεφαλαίου που απαιτείται για μια επένδυση. Θα μπορούσαμε να σκεφτούμε την αποθήκη της εταιρίας μας ως μία τράπεζα, όπου έχουμε φυλασσόμενο έως και το 50% του επενδυτικού μας κεφαλαίου. Είναι εξαιρετικά σημαντικό λοιπόν να διαχειριστούμε αυτό το κεφάλαιο σωστά, ώστε να μας επιστρέψει πίσω ένα καλό χρηματικό όφελος για την επιχείρησή μας.

Για τη διπλωματική έχει χρησιμοποιηθεί αρκετές βιβλιογραφικές πηγές. Επιπλέον, δίνονται σύντομες πληροφορίες για τους γεωργικούς ελκυστήρες και τις βασικές κατηγορίες ανταλλακτικών που χρησιμοποιούν και πρέπει να υπάρχουν σε μια αποθήκη. Για την εφαρμογή της θεωρίας χρησιμοποιείται το Simulacion 5.0 (<https://sites.google.com/view/simulacion5/main>), ένα add in λογισμικό που ενσωματώνεται στο Excel.

Στόχος της διπλωματικής είναι η πρακτική εφαρμογή της θεωρίας στην καθημερινή επαγγελματική ζωή. Η εφαρμογή των κατάλληλων μεθόδων μπορούν να μας οδηγήσουν σε εφικτά και ρεαλιστικά επαγγελματικά πλάνα (business plans). Επιπλέον, οι επαγγελματίες εκτός από ποσοτικές μεθόδους και αριθμητικά μοντέλα μπορούν να χρησιμοποιήσουν και ποιοτικά κριτήρια για τα προϊόντα και τις αγορές που διαχειρίζονται. Κατά συνέπεια, οι επιχειρήσεις έχουν στη διάθεσή τους διάφορα εργαλεία ώστε να κατανοήσουν τα προϊόντα και τις αγορές που αυτά απευθύνονται και να μπορέσουν τελικά να διαχειριστούν σωστά τις αποθήκες τους. Για την αποθήκη που εμείς εξετάζουμε προσδιορίστηκαν κατ' αρχάς απλοί δείκτες, αλλά ενδεικτικοί της οικονομικής υγείας της αποθήκης μας. Αυτοί οι δείκτες είναι οι: (α) Inventory Turnover Ratio και (β) Days in Inventory Index. Έπειτα, αξιολογούνται μέθοδοι πρόβλεψης για την εφαρμογή της πιο κατάλληλης για το επόμενο οικονομικό έτος. Οι προβλέψεις αφορούν τόσο αξίες αποθήκες όσο και ποσότητες κωδικών ανταλλακτικών. Το βασικό κριτήριο για την επιλογή του καταλληλότερου μοντέλου πρόβλεψης είναι η μικρότερη τιμή των Mean Absolute deviation (MAD) και Mean absolute percent error (MAPE). Για την πρόβλεψη του επόμενου οικονομικού έτους χρησιμοποιούνται δεδομένα των τριών προηγούμενων ετών. Στη συνέχεια, εφαρμόζεται η ανάλυση ABC, για την κατάταξη της οικονομικής σημαντικότητας των ανταλλακτικών και τον προσδιορισμό των τριών κωδικών με τις υψηλότερες πωλήσεις της αποθήκης. Τέλος, τρέχουμε προσομοιώσεις Monte Carlo και προσδιορίζουμε την Economic Order Quantity (EOQ) καθώς και το ελάχιστο κόστος της αποθήκης για τον κωδικό με τη μεγαλύτερη αξία.

**Λέξεις κλειδιά:** αποθήκη ανταλλακτικών γεωργικών ελκυστήρων, διαχείριση αποθήκης; reorder point; order quantity; safety stock; costs; lead time; ελαχιστοποίηση κόστους

**Table of Contents**

|  |      |
|--|------|
| Abstract.....  | v    |
| Abstract in Greek.....   | vi   |
| Table of Contents.....   | vii  |
| List of Figures.....   | viii |
| List of Tables.....  | ix   |
| List of Abbreviations & Acronyms.....  | x    |
| I. Introduction.....   | 1    |
| 1. Chapter 1 Forecasting.....  | 2    |
| 1.1. Types of Forecasting Models.....  | 3    |
| 1.2. Components of a Time-Series.....  | 5    |
| 1.3. Methods of Forecast Accuracy.....   | 7    |
| 1.4. Forecasting Models – Trend and Random Variations.....                       | 8    |
| 1.5. Adjusting for Seasonal Variations.....                                      | 10   |
| 1.6. Forecasting Models – Trend, Seasonal and Random Variations.....             | 12   |
| 1.7. Monitoring and Controlling Forecasts.....                                   | 15   |
| 2. Chapter 2 Inventory Control Models.....                                       | 18   |
| 2.1. An Inventory Metric is Supply Chains.....                                   | 20   |
| 2.2. Importance of Inventory Control.....  | 20   |
| 2.3. Inventory Decisions.....  | 22   |
| 2.4. Economic Order Quantity: Determining How Much to Order.....                 | 23   |
| 2.5. Reorder Point: Determining When to Order.....                               | 26   |
| 2.6. EOQ Without the Instantaneous Receipt Assumption.....                       | 27   |
| 2.7. Quantity Discount Models.....   | 29   |
| 2.8. Use of Safety Stock.....  | 30   |
| 2.9. ABC Analysis.....   | 32   |
| 2.10 Valuation of Project Considering Uncertainty   Monte Carlo simulation.....  | 32   |
| 3. Chapter 3 Tractor Spare Parts Inventory.....                                  | 34   |
| 3.1. Introduction .....  | 35   |
| 3.2. Tractor Manufacturing Companies & Range of Products.....                    | 35   |
| 3.3. Number of operating agricultural machinery in Greece.....                   | 37   |
| 3.4. Categories of Spare Parts.....  | 41   |
| 4. Chapter 4 Linking Theory to Practice.....                                     | 43   |
| 4.1. Introduction.....   | 44   |
| 4.2. Inventory Turnover Ratio & Days in Inventory index.....                     | 44   |
| 4.3. Inventory Forecasting in Value and Units.....                               | 44   |
| 4.4. Inventory ABC Analysis.....   | 48   |
| 4.5. Inventory Modeling.....   | 49   |
| 4.6 Defining the EOQ – Considering Uncertainty with Monte Carlo simulations..... | 51   |
| 5. Chapter 5 Conclusions.....  | 53   |
| 5.1 Conclusions.....   | 54   |
| References.....  | 57   |

**List of Figures**

|   |    |
|---|----|
| Figure 1.1 Forecasting models.....  | 3  |
| Figure 1.2 Scatter Diagram for Four Time Series of Quarterly Data.....  | 5  |
| Figure 1.3 Scatter Diagram of a Time Series with Cyclical and Random Components.....  | 7  |
| Figure 1.5 Scatterplot of Turner Industries Original Sales Data and Deseasonalized Data.....  | 13 |
| Figure 1.6 Scatterplot of Turner Industries Original Sales Data and Deseasonalized Data with Unadjusted and Adjusted Forecasts..... | 14 |
| Figure 1.7 Plot of Tracking Signals.....  | 16 |
| Figure 2.1 Inventory Planning and Control.....  | 19 |
| Figure 2.2 Inventory Usage Over Time.....   | 23 |
| Figure 2.3 Total Cost as a Function of Order Quantity.....  | 24 |
| Figure 2.4 Reorder Point Graphs.....  | 27 |
| Figure 2.5 Inventory Control and the Production Process.....  | 28 |
| Figure 2.7 Use of Safety Stock.....   | 31 |
| Figure 4.12 End of Monte Carlo.....   | 52 |



**List of Tables**

|   |    |
|---|----|
| Table 1.1 Computing the Mean Absolute Deviation (MAD).....                                    | 7  |
| Table 1.9 Quarterly Sales (\$1.000.000s) for Turner Industries.....                           | 11 |
| Table 1.10 Centered Moving Averages and Seasonal Ratios for Turner Industries.....            | 12 |
| Table 1.11 Deseasonalized Data for Turner Industries.....                                     | 13 |
| Table 1.12 Turner Industry Forecasts for Four Quarters of Year 4.....                         | 14 |
| Table 2.1 Inventory Cost Factors.....   | 22 |
| Table 2.2 Computing Average Inventory.....  | 24 |
| Table 3.1 Number of Operating agricultural machinery, by Region and Regional Unity, 2021...38 |    |
| Table 4.1 Sales of Spare Parts during years 2020 – 2022.....                                  | 44 |
| Table 4.2 Comparison between naive – moving averages – weighted moving averages.....          | 45 |
| Table 4.3 Comparison between smoothing and exponential smoothing with trend.....              | 46 |
| Table 4.4 Comparison between regression with trend / regression with seasonality.....         | 46 |
| Table 4.5 Forecast for 2023.....  | 47 |
| Table 4.6 Forecast for 2023 vs Actual 2023.....   | 47 |
| Table 4.7 ABC Analysis for 2022.....  | 48 |
| Table 4.8 Highest Valued Parts according to ABC Analysis.....                                 | 49 |
| Table 4.9 Top 3 highest Valued Parts according to ABC Analysis for 2020 – 2022.....           | 50 |
| Table 4.10 SKU Demand per month in 3 years.....   | 50 |
| Table 4.11 Forecast for 2023.....   | 51 |

**List of abbreviations and acronyms**

MAD\_Mean Absolute Deviation

MSE\_Mean Squared Error

MAPE\_Mean Absolute Percent Error

CMA\_Centered Moving Average

RSFE\_Running Sum of the Forecast Errors

EOQ\_Economic Order Quantity

ROP\_Reorder Point

## I. Introduction

---

Academic resources provide us with various tools and methods to help us assess inventories. Initially, simple indices give us an idea of where our inventory is, related to the financial health of the company. We assess forecasting methods for our inventory both in value (in €) and units. We apply forecasting methods for the year 2023, by using actual data of the three previous years (2020-2022). Accurate forecasting is impossible, but by using appropriate methods and techniques we may simulate a year's demand and set up an initial business plan, based on the actual demand of previous years. After setting up this initial forecast, we should always keep monitoring our numbers and see how close to our forecast we are. Of course, necessary adjustments will be made, taking into account also circumstances that they may occur. A very good example of (unexpected) circumstances is the COVID-19 era. Who could forecast that? And reasonably every business should go back to the initial forecast and adjust it accordingly, in order to bring forecasting adjusted to the current circumstances. Finally, an appropriate inventory control model is necessary to provide us with adequate inventory quantities to cover demand.

As already mentioned, our inventory consists of spare parts of agricultural machinery. The structure of the thesis is such that we present relevant theory from academical resources for our calculations as well as a brief presentation of the agricultural spare parts business.

In *Chapter 1*, we present from bibliography different methods of forecasting and the way we choose the appropriate one for our needs.

In *Chapter 2*, we present from academic resources inventory indices and control models, which we will use for our calculations.

In *Chapter 3*, we give brief information about agricultural tractors and their use, we present data by the Hellenic Statistical Authority of the number of tractors in Greece as registered in 2021 to realize the size of the business in our country and finally we show the main categories of spare parts that this machinery needs.

In *Chapter 4*, we apply the theory in practice. By using the literature sources of the first two chapters, we calculate specific indices, assess forecasting methods and run ABC analysis as well as a series of Monte Carlo simulations for top three SKUs of our inventory. Besides the indices and ABC analysis, all the other calculations have been done with appropriate software integrated in Excel. Simulacion5.0 has been used for the assessment of the forecasting methods and the Crystal Ball software package has been used for the estimation of the Economic Order Quantity (EOQ) and the cost minimization of the most valued SKUs of our inventory.

Finally, in *Chapter 5*, we present the conclusions of our dissertation and we make suggestions on future work based on them.

# CHAPTER 1

## Forecasting



Forecasts and forecasting have to do with predictions of what the future will bring. In fact, all of us depend on such predictions; For instance, we need to know the weather prediction in order to prepare ourselves for the next day. Other than that, we use numerous other predictions in our everyday life, for instance in medicine, sports, social science, finance, etc. Beyond any doubt, managers of business firms are the ones also that need to use forecasting methods for decision making. Although forecasting will never give totally accurate results (who can predict the future exactly?), forecasting reduces the uncertainty and is a tool towards better estimations that eventually lead to advanced decision making (Barry Render, Ralph M. Stair Jr., Michael E. Hanna, Trevor S. Hale, 2017).

Forecasting the future can be approached with numerous ways. It can be said that in small firms the approach is subjective, based probably on intuition and experience.

However, there are also more formal forecasting techniques, not only quantitative but also qualitative. The main focus of *Chapter 1*, will be to understand time-series models and conclude to the appropriate model for each set of data.

## 1.1 Types of Forecasting Models

As Figure 1.1 shows, for forecasting a number of qualitative models are available as well as quantitative ones. The latter use mathematical models to give us better forecasts.

Figure 1.1

Forecasting Models

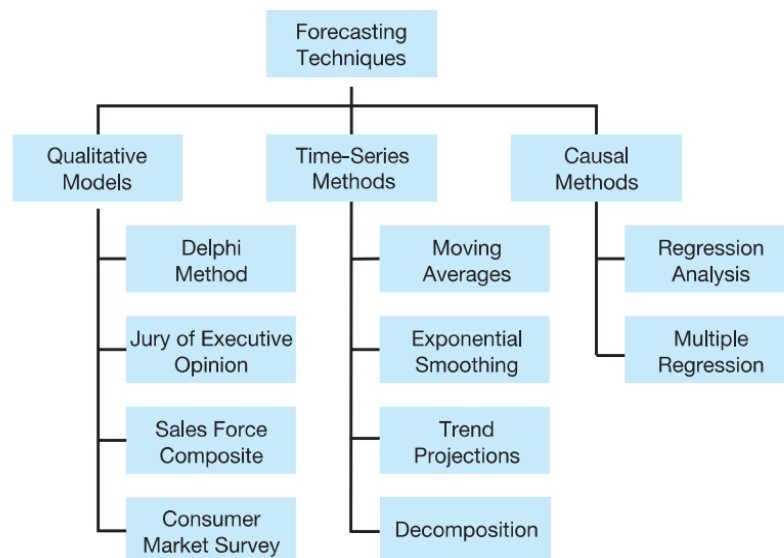


Figure Source: (Barry Render, et al, 2017)

### Qualitative Models

Qualitative models include forecasting techniques dependent on subjective factors or personal judgement. For instance, when a completely new car is introduced in the market, forecasting demand is rather difficult, because no historical data exists for this new product. Thus, the automotive manufacturer has to depend on professionals' opinion, personal experience and judgement and other non-objective factors (Barry Render, et al, 2017).

Below four different qualitative techniques are briefly described:

1. *Delphi method*. It is an iterative group process, where experts – possibly located in different places – are making forecasts. Three types of participants are involved in the **Delphi** process: decision makers, staff personnel and respondents. The decision makers are usually a group of 5 to 10 experts who will be making the actual forecast. The role of the staff personnel is to help decision makers with the preparation, distribution, collection and summary reports of questionnaires and survey outcome. The role of the respondents is highly rated. Their judgment is taken into serious consideration and most importantly their input is provided to the decision makers before they make the forecast.  
Once the results of the first questionnaire are known, a summary of those results is made and then amends are made to the questionnaire. The same respondents get these results as well as the new questionnaire and they give their new responses. The expectation from this process is that the respondents may change their initial approach or view and modify their answers accordingly. As also mentioned at the beginning, it is a repeated process, which hopefully comes to an end when a consensus is reached.
2. *Jury of executive opinion*. A small group of high level managers is involved here. Their opinion is often combined with the use of statistical models and final outcome is a group estimate of demand.
3. *Sales force composite*. The forecast of each salesperson for his or her region is taken into account here. All estimations are reviewed for their realistic (or not) approach and then summarized at the district and national level for the final forecast.
4. *Consumer market survey*. This method takes into consideration future purchasing plans of the consumers by requesting their input. This input can also be used – apart from forecasting – for the improvement of product design and/or release of future products (Barry Render, et al, 2017).

### Causal models

If past arithmetical data are available, a number of quantitative models can be used, the **causal models**. **Causal models** are those forecasting models that their variable may be influenced by the presence of other variables in the model. For instance, it is reasonable that the daily sales of bottled water are dependent on variables such as the average temperature or the average humidity. Thus, such factors are included in the mathematical model of causal models. Regression analysis and other more complex models are sorted as causal models (Barry Render, et al, 2017).

### Time-series models

In addition to causal models, time series are also quantitative models. A number of different time-series methods exist. A **time-series model** is a method used to forecast the value of a variable by using historical data only of this variable. These models are extrapolations of the older values of the series used. Possible factors that influenced the older values are included in the values being forecasted (Barry Render, et al, 2017).

Thus, if we are forecasting monthly sales of cars, we use old monthly data for cars, without taking into account factors such as the economy, competition, technological changes or the selling price of the cars.

## 1.2 Components of a Time-Series

Time-series is what reasonably sounds; a sequence of values known at continuous intervals of time. These intervals may include daily, weekly, monthly, yearly records or different specific time units. For instance we may examine weekly sales of laptops, quarterly earnings reports for businesses, daily shipments of beverages and annual consumer price indices. Four are the possible components that may be observed at time series; trend, seasonal, cyclical and random.

When the data moves upward or downward throughout a relatively period of time, then that is **trend (T) component**. For instance, the sales of a business may be continuously growing over time. An index that is continuously growing over time is the consumer price index, which is also a measure of inflation. We need to mention here that although consistent upward (or downward) movements over time indicate the presence of a positive (or negative) trend, that does not mean that the values will be only increasing (or decreasing) among the time periods. The presence of random or other fluctuations may cause occasional movements to the values, that are not consistent with the trend (*Barry Render, et al, 2017*).

In Figure 1.2 scatter diagrams for different time series are shown. The time interval is four months and the total period of the data is four years. In Series 3 the presence of trend and random components can be noticed (*Barry Render, et al, 2017*).

The characteristic of a **seasonal (S) component** is a pattern with values varying above or below an average value. This pattern is repeated at specific time intervals. For instance, consumers spend more money during Christmas period, or flights are more expensive during summer due to tourism period and vacations. In both cases this pattern is expected to remain the same the next years. Sales in a retail store are expected to be higher on Saturdays than every other day of the week. Moreover, obviously heating demands are increasing during winter or agricultural sales are increased during harvest time. In Figure 1.2, Series 2 are indicative of seasonal fluctuations within time periods of quarters (*Barry Render, et al, 2017*).

**Figure 1.2**

Scatter Diagram for  
Four Time Series of  
Quarterly Data

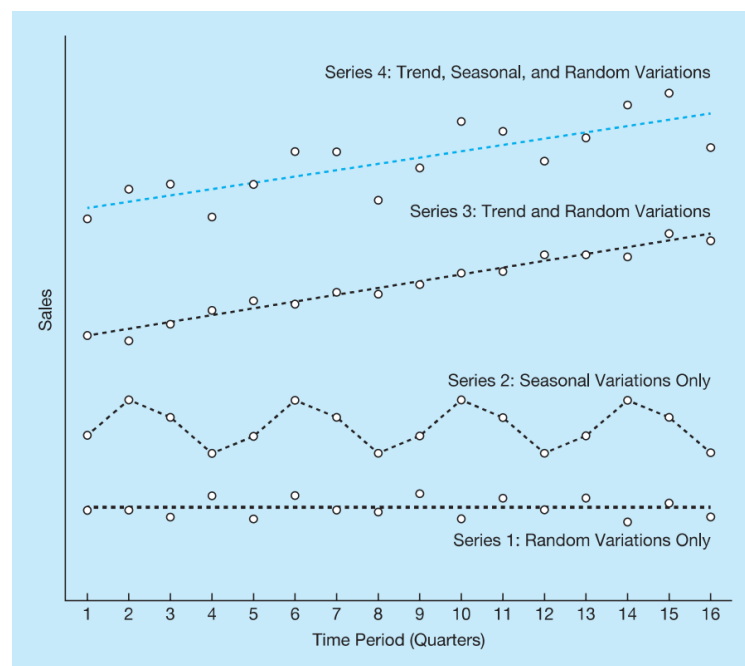


Table Source: (*Barry Render, et al, 2017*)



In the case of a seasonal component, the number of seasons varies according to the type of data. If we examine data in quarters, we are discussing about 4 seasons. When we examine data month by month, then we have 12 seasons, because 12 are the months of each year. Following this way of thinking, a retail store which remains open seven days a week, examines seven seasons. Finally, any business that remains open 24 hours a day, should consider examining 24 seasons.

In time series when a pattern in yearly data has the tendency to be repeated every several years, then it is characterized as a **cyclical (C) component**. It is useful for very long-range forecasts and normally is related to business cycles. In business, financial activity or sales of any kind of products might reach a top, then decline to a minimum and begin increasing again followed by a new decline. This cycle keeps on repeating for several years. That is presented in Figure 1.3, where a cyclical as well as random component is shown in a time series of a sixteen years period.

The significant difference between cyclical and seasonal components in time series is the irregular length of cyclical components (they vary in periods from some years, to ten or more). Moreover, the magnitude is also irregular and it is too difficult to make predictions for these components. On the other, seasonal components have a very consistent length and magnitude; are examined in much smaller periods (annually or even less than a year); and probably most importantly predictions are much easier for these components.

Finally, there is the **random (R) component**. As it is expected, this type of components is characterized by not regular and not predictable variations in a time series. When we cannot categorize a time series component to any of the first three categories (trend, seasonal or cyclical component) then it is consequently ranked as a random component. When the variations in a time series do not show a clearly visible trend, then the explanation is the random change of these variations among the periods of the data. In Figure 1.2, Series 1 is representative of a time series with random variations only.

In statistics two are the general forms of time series models. The first one assumes that demand is the product of the four components and it is a multiplicative model. It is shown below:

$$\text{Demand} = T \times S \times C \times R$$

On the other hand, the use of an additive model gives the estimation by adding the components. The method used for the development of additive models is multiple regression. Below is shown the relationship of an additive model:

$$\text{Demand} = T + S + C + R$$

However, there may be models, that combine these two. For instance, one component (i.e trend) can be an additive model, whereas another component (i.e seasonality) can be a multiplicative model. The appropriate forecasting technique will be chosen once the analyst has comprehended the components of a time series (Barry Render, et al, 2017).



**Figure 1.3**

Scatter Diagram of a Time Series with Cyclical and Random Components

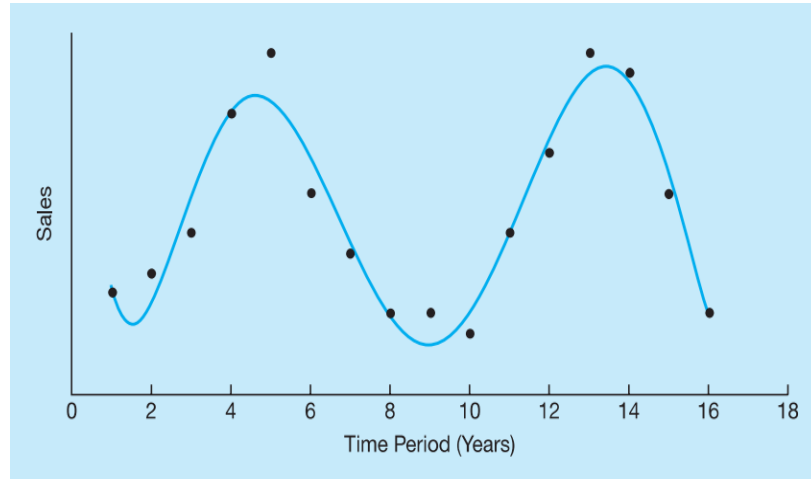


Table Source: (Barry Render, et al, 2017)

### 1.3 Methods of Forecast Accuracy

Several forecasting models will be discussed in chapter. The main idea in checking how well a model works or how the models compare to each other is to compare the forecast values with the actual or compared values. Below, the **forecast error** (or **deviation**) is shown:

$$\text{Forecast error} = \text{Actual value} - \text{Forecast value}$$

**Mean absolute deviation (MAD)** is a measure of accuracy. **MAD** is equal to the sum of the absolute values of the individual forecast errors divided by the number of errors (n):

$$MAD = \frac{\sum |\text{Forecast error}|}{n}$$

In order to show how we calculate the measures of the accuracy, we will use the **naive model**, which is a quick and easy model. In the naive model we just assume that the forecast of the next period is the actual value that is written down at the present period. A naive assumption for instance is when we are asked to forecast the high temperature in our city for the next day. We just make the quick assumption that the high temperature tomorrow will be the high temperature of today. It is very clear that this is a naive forecast and it is used when we need a quick forecast, without caring significantly about the accuracy (Taylor, Bernard W. *Introduction to Management Science*. Harlow, Pearson, 2016).

In Table 1.1 we see the sales of wireless speakers of Walker Distributors. We make the assumption that for a forecast in the past, Walker assumed that the forecast sales of each month would be the sales of the previous month. Table 1.1 shows us those forecasts and the absolute value of the errors. We may notice that for month 1 forecast is not applicable, as long as we do not know the previous month and that in month 11 we still do not know the sales of that month. Therefore the total number of errors (n) is 9.

That, gives us the following:

$$MAD = \frac{\sum |\text{Forecast error}|}{n} = \frac{160}{9} = 17.8$$

That concludes us that the average missing forecast is 17,8 units.

**Table 1.1**

Computing the Mean Absolute Deviation (MAD)

| MONTH | ACTUAL SALES OF WIRELESS SPEAKERS | FORECAST SALES | ABSOLUTE VALUE OF ERRORS (DEVIATION).  ACTUAL-FORECAST |
|-------|-----------------------------------|----------------|--|
| 1     | 110                               | —              | —  |
| 2     | 100                               | 110            | 100 – 110  = 10  |
| 3     | 120                               | 100            | 120 – 100  = 20  |
| 4     | 140                               | 120            | 140 – 120  = 20  |
| 5     | 170                               | 140            | 170 – 140  = 30  |
| 6     | 150                               | 170            | 150 – 170  = 20  |
| 7     | 160                               | 150            | 160 – 150  = 10  |
| 8     | 190                               | 160            | 190 – 160  = 30  |
| 9     | 200                               | 190            | 200 – 190  = 10  |
| 10    | 190                               | 200            | 190 – 200  = 10  |
| 11    | —                                 | 190            | —  |
|       |                                   |                | Sum of  errors  = 160                                  |
|       |                                   |                | MAD = 160/9 = 17.8                                     |

*Table Source: (Barry Render, et al, 2017)*

Besides the MAD, the most usual measure for the accuracy of historical errors in forecasting is the **mean squared error (MSE)**. MSE is the average of the squared errors:

$$MSE = \frac{\Sigma(Error)^2}{n}$$

Apart from the MAD and the MSE the **mean absolute percent error (MAPE)** can be used. The MAPE is the average of the absolute values of the errors expressed as percentages of the actual values. Below is shown how is calculated:

$$MAPE = \frac{\Sigma \left| \frac{Error}{Actual} \right|}{n} 100\%$$

Finally, **bias** is another usual term related to error in forecasting. Bias can be negative or positive. It is the average error and shows how much high or low the forecast will be. It is a method that does not give a good measure of the actual size of the errors, because the negative errors counterbalance the positive errors (*Barry Render, et al, 2017*).

## 1.4 Forecasting Models – Trend and Random Variations

When trend is present in a time series, then it should be taken into consideration. Two techniques are very common and will be presented below; (a) exponential smoothing with trend and (b) trend projection or simpler trend line.

### (A) Exponential smoothing with trend

As it sounds reasonable exponential smoothing with trend is an extension of the exponential smoothing, where trend is integrated into this model. For this reason, two smoothing constants  $\alpha$  and  $\beta$  are included, with the range of their values being between 0 and 1. The level of the forecast is adjusted by multiplying the first smoothing constant,  $\alpha$ , by the most recent forecast error and adding it to the previous forecast. The trend is adjusted by multiplying the second smoothing constant,  $\beta$ , by the most recent error or excess amount in the trend. The

higher the value of the constants is, the more weight is falling to the recent observations, which makes it quickly responsive to changes in the patterns.

Once the initial forecast is developing, we need to know or estimate a previous forecast  $F_t$ . When that is not feasible, we make the assumption that the initial forecast is perfect. Accordingly, we need to know or estimate a previous trend ( $T_t$ ). Past data is frequently used for that if they exist or by doing a subjective estimation or by calculating the increase (or decrease) observed during the first few time periods of the data available. If such an estimate is not available, we assume that the initial value of the trend is zero (0), however this may result in bad forecasts, when the trend is high and  $\beta$  is small. When we establish these initial conditions, the exponential smoothing forecast including trend ( $FIT_t$ ), is developed using three steps:

STEP1. Compute the smoothed forecast ( $F_{t+1}$ ) for time period  $t + 1$  using the equation

Smoothed forecast = Previous forecast including trend +  $\alpha$ (Last error)

$$F_{t+1} = FIT_t + \alpha(Y_t - FIT_t) \quad \boxed{1-10}$$

STEP 2. Update the trend ( $T_{t+1}$ ) using the equation

Smoothed trend = Previous trend +  $\beta$ (Error or excess in trend)

$$T_{t+1} = T_t + \beta(F_{t+1} - FIT_t) \quad \boxed{1-11}$$

STEP 3. Calculate the trend-adjusted exponential smoothing forecast ( $FIT_{t+1}$ ) using the equation

Forecast including trend ( $FIT_{t+1}$ ) = Smoothed forecast ( $F_{t+1}$ ) + Smoothed trend ( $T_{t+1}$ )

$$FIT_{t+1} = F_{t+1} + T_{t+1} \quad \boxed{1-12}$$

Where

$T_t$  = smoothed trend for time period  $t$

$F_t$  = smoothed forecast for time period  $f$

$FIT_t$  = forecast including trend for time period  $t$

$\alpha$  = smoothing constant for forecasts

$\beta$  = smoothing constant for trend

### (B) Trend Projections

As mentioned before **trend projections** is another method for forecasting time series with trend. This technique fits a trend line to a series of historical data points and then projects the line into the future for medium- to long-range forecasts. We need to highlight that we only examine linear (straight line) trends. We need to think a trend line as just a linear regression equation with the independent variable ( $X$ ) being the time period. Period 1 will be the first time period, period 2 the second and so on. The last one will be period  $n$ . Below is shown the form that describes it:

$$\hat{Y} = b_0 + b_1X$$

where,  $\hat{Y}$  = predicted value

$b_0$  = intercept

$b_1$  = slope of the line

$X$  = time period (i.e.  $X = 1, 2, 3, \dots, n$ )

The method that will be used to find the coefficients that minimize the sum of the squared errors and thus minimize the mean squared error (MSE) is the least squares regression. We can run and solve different scenarios to either Excel QM or by using QM for Windows (*Barry Render, et al, 2017*).

### 1.5 Adjusting for Seasonal Variations

---

It is occasionally observed during a set of annual data, variations at certain seasons, that make a seasonal adjustment in the trend line forecast essential. It is known for instance that during cold winter months demand for coal and fuel oil is topping. Demand for golf clubs or suntan lotion is probably highest during summer. If we want to spot easier seasonal patterns, then analysis of the data monthly or quarterly, gives us this possibility. The reason behind the use of a seasonal index in multiplicative time series forecasting models is for adjusting the forecast when we notice a seasonal component. Alternatively, an additive model such as a regression one may be used (*Taylor, Bernard W. Introduction to Management Science. Harlow, Pearson, 2016*).

#### Seasonal Indices

A **seasonal index** is indicative of how a specific season (i.e. month or quarter) contrasts to an average season. An index with value 1 for a season refers to an average season. An index greater than 1 is indicative of a season higher than the average, while an index less than 1 is indicative of a season lower than the average.

Seasonal indices are used with multiplicative forecasting models in two ways. First, each observation in a time series is divided by the appropriate seasonal index to remove the impact of seasonality. The values that we get by these calculations are called **deseasonalized data**. With a variety of forecasting techniques we can develop forecasts for future values by using these deseasonalized data. When the forecasts of future deseasonalized data have been set up, they are multiplied by the seasonal indices to develop the final forecasts, including finally fluctuations due to seasonality.

Seasonal indices are estimated with two methods. The first one is easy data has no trend and is based on an overall average. The other one is not that easy our data has trend and the base of this method is a centered-moving-average approach (*Barry Render, et al, 2017*).

#### Calculating Seasonal Indices with No Trend

In the case of no trend the index can be easily estimated by dividing the average value for a particular season by the average of all the data. So, we have an average season when the index is equal to 1. For instance, in a case where in May we have average sales of 150 while the average monthly sales are 200, then the seasonal index for May is  $150/200 = 0.75$ . That means that May is below average (*Barry Render, et al, 2017*).

### Calculating Seasonal Indices with Trend

When we spot trend as well as seasonal components in a time series, variations from one month to another can be because of the seasonal effect, of a trend or just of random variations. The solution to this issue, is the estimation of the seasonal indices with the assist of a **centered moving average (CMA)**, as long as trend is present. In that way, we can avoid misinterpretation among variations because of trend and because of seasonality. Let's examine the following example.

In Table 1.9 we see the quarterly sales for Turner Industries. There is an obvious trend, with an annual increase each year. At the same time there is an increase for each quarter from year to year. As long as we notice a clear decrease from the fourth quarter of year 1 to the first quarter of year 2 and again a drop from the fourth quarter of year 2 to the first quarter of year 3, then we have an obvious seasonal component. This pattern is also noticed in the third and fourth quarter of each year, where we see again a drop of the sales.

The obvious drop in quarter 1 means that these quarters have less trend than any of the others. So, if we estimate a seasonal index for quarter 1 using the overall average, this index would be misleading and low. Assuming that the first quarter of year 1 were not taken into consideration and were replaced by the first quarter of year 4 (if data were known), the average for quarter 1 (and as consequence the seasonal index for quarter 1) would be extensively increased. A precise seasonal index must be 'produced' by using a CMA (Barry Render, et al, 2017).

Let's examine quarter 3 of the first year for the case of Turner Industries. Actual sales are 150. In order to define the magnitude of the seasonal variation, we need to compare this with an average quarter centered at that time period. So, what we need to have is four quarters in total (1 year of data) and then equal number of quarters before and after quarter 3. In that way we may determine the average trend. Thus, necessary are 1.5 quarters before quarter 3 and equally 1.5 quarters after that. To compute the CMA, we use quarters 2,3 and 4 of the 1<sup>st</sup> year, adding half of the quarter 1 of year 1 and half of the quarter 1 of year 2. This gives us the average:

$$\text{CMA (quarter 3 of year 1)} = \frac{0.5(108) + 125 + 150 + 141 + 0.5(116)}{4} = 132.00$$

The seasonal ratio is given by dividing the actual sales to the CMA:

$$\text{Seasonal ratio} = \frac{\text{Sales in quarter 3}}{\text{CMA}} = \frac{150}{132.00} = 1.136$$

**Table 1.9**

Quarterly Sales  
(\$1,000,000s) for Turner  
Industries

| QUARTER | YEAR 1 | YEAR 2 | YEAR 3 | AVERAGE |
|---------|--------|--------|--------|---------|
| 1       | 108    | 116    | 123    | 115.67  |
| 2       | 125    | 134    | 142    | 133.67  |
| 3       | 150    | 159    | 168    | 159.00  |
| 4       | 141    | 152    | 165    | 152.67  |
| Average | 131.00 | 140.25 | 149.50 | 140.25  |

Table Source: (Barry Render, et al, 2017)

This means that sales in quarter 3 of year 1 are approximately 13.6% higher than an average quarter at this time. In Table 1.10 we may see the CMAs and the seasonal ratios.

**Table 1.10**

Centered Moving Averages and Seasonal Ratios for Turner Industries

| YEAR | QUARTER | SALES<br>(\$1,000,000s) | CMA     | SEASONAL<br>RATIO |
|------|---------|-------------------------|---------|-------------------|
| 1    | 1       | 108                     |         |                   |
|      | 2       | 125                     |         |                   |
|      | 3       | 150                     | 132.000 | 1.136             |
|      | 4       | 141                     | 134.125 | 1.051             |
| 2    | 1       | 116                     | 136.375 | 0.851             |
|      | 2       | 134                     | 138.875 | 0.965             |
|      | 3       | 159                     | 141.125 | 1.127             |
|      | 4       | 152                     | 143.000 | 1.063             |
| 3    | 1       | 123                     | 145.125 | 0.848             |
|      | 2       | 142                     | 147.875 | 0.960             |
|      | 3       | 168                     |         |                   |
|      | 4       | 165                     |         |                   |

*Table Source: (Barry Render, et al, 2017)*

As long as we have two seasonal ratios for each quarter, we compute the average between the two values to get the final one. Below we may see the calculations:

Index for quarter 1 =  $I_1 = (0.851 + 0.848)/2 = 0.85$ . Indices for quarters 2-4 are calculated accordingly. Thus,  $I_2 = 0.96$ ,  $I_3 = 1.13$  and  $I_4 = 1.06$ .

It is not by accident that the sum of theses ( $I_1 + I_2 + I_3 + I_4 = 4$ ) indices equals the number of seasons (4), because an average season should have an index of 1. If the sum were not 4, an adjustment would be necessary. Each index would be multiplied by 4 and then divided by the sum of the indices.

Below, we give a brief description of the necessary steps for the calculation of seasonal indices:

#### **Steps Used to Compute Seasonal Indices Based on CMAs**

1. Compute a CMA for each observation (where possible).
2. Compute Seasonal ratio = Observation/CMA for that observation.
3. Average seasonal ratios to get seasonal indices.
4. If seasonal indices do not add to the number of seasons, multiply each index by (Number of seasons)/(Sum of the indices).

*Photo Source: (Barry Render, et al, 2017)*

The seasonal indices help us to remove the impact of seasons and identify more easily the impact of trend. Later the seasonal indices will be used again to adjust the trend forecast based on the seasonal variations (Barry Render, et al, 2017).

### **1.6 Forecasting Models – Trend, Seasonal and Random Variations**

Once trend and seasonal components are present in parallel in a time series, then these must be addressed by the forecasting model that we will use. A very common approach is the decomposition method, where seasonal indices are used. Additionally, multiple regression models are used, with dummy variables adjusting seasonal variations in an additive time-series model.

## The Decomposition Method

**Decomposition** is called the process of isolating linear trend and seasonal factors in order to approach more accurate forecasts. The initial step is to calculate seasonal indices for each season, as we did previously in the example with the Turner Industries. After that, we deseasonalize the data, by dividing each value by its seasonal index. That is shown in table 1.11. In Figure 1.5, we may see a graph of the original data in parallel with a graph of the deseasonalized data, where it is also worth noticing the smoothness of the deseasonalized data.

Table 1.11  
Deseasonalized Data  
for Turner Industries

| SALES (\$1,000,000s) | SEASONAL INDEX | DESEASONALIZED SALES (\$1,000,000s) |
|----------------------|----------------|-------------------------------------|
| 108                  | 0.85           | 127.059                             |
| 125                  | 0.96           | 130.208                             |
| 150                  | 1.13           | 132.743                             |
| 141                  | 1.06           | 133.019                             |
| 116                  | 0.85           | 136.471                             |
| 134                  | 0.96           | 139.583                             |
| 159                  | 1.13           | 140.708                             |
| 152                  | 1.06           | 143.396                             |
| 123                  | 0.85           | 144.706                             |
| 142                  | 0.96           | 147.917                             |
| 168                  | 1.13           | 148.673                             |
| 165                  | 1.06           | 155.660                             |

Table Source: (Barry Render, et al, 2017)

After deseasonalizing the data, a trend line is defined. With the help of computer software at these data, we get:

$$b_1 = 2.34, b_0 = 124.78$$

The trend equation is:

$$\hat{Y} = 124.78 + 2.34X, \text{ where } X = \text{time}$$

Using this equation enables us to develop the forecast based on trend and then multiplying the result by the suitable seasonal index to adjust the values to seasonality.

Figure 1.5

Scatterplot of Turner Industries Original Sales Data and Deseasonalized Data

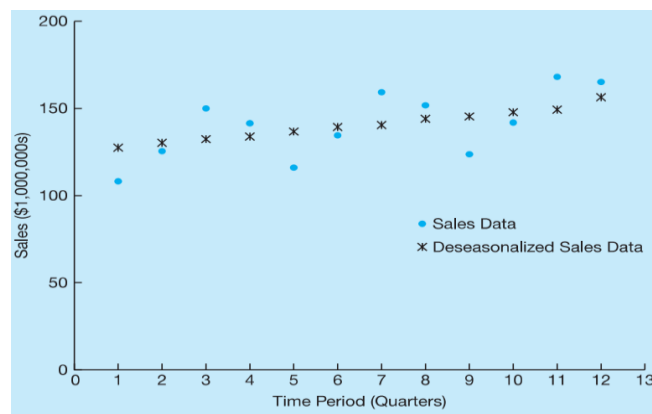


Figure Source: (Barry Render, et al, 2017)

**Table 1.12** | Turner Industry Forecasts for Four Quarters of Year 4

| YEAR | QUARTER | TIME PERIOD (X) | TREND FORECAST<br>$\hat{Y} = 124.78 + 2.34X$ | SEASONAL INDEX | FINAL (ADJUSTED) FORECAST |
|------|---------|-----------------|--|----------------|---------------------------|
| 4    | 1       | 13              | 155.20                                       | 0.85           | 131.92                    |
|      | 2       | 14              | 157.54                                       | 0.96           | 151.24                    |
|      | 3       | 15              | 159.88                                       | 1.13           | 180.66                    |
|      | 4       | 16              | 162.22                                       | 1.06           | 171.95                    |

Table Source: (Barry Render, et al, 2017)

Now, if we want to forecast for the Turner Industries the first quarter of year 4 (time period  $X=13$ , and seasonality index  $I_1=0.85$ ) that would be as follows:

$$\hat{Y} = 124.78 + 2.34X = 155.2 \text{ (forecast before seasonality adjusts it)}$$

And after multiplying by the relevant seasonal index for Q1, we have:

$$\hat{Y} \times I_1 = 155.2 \times 0.85 = 131.92$$

By following the same procedure, we get the forecasts for Q2, Q3 and Q4 of the fourth year. In Table 1.12 we see the unadjusted forecast based on the trend line for every quarter of year 4. In the last column of this table, we get the final forecasts, which are the multiplication of each trend forecast by the relevant seasonal index. In Figure 1.6, we may see in a scatter diagram the original and the deseasonalized data, as well as the unadjusted forecast and the final forecast for the next four quarters of year 4 (Barry Render, et al, 2017).

#### Steps to Develop a Forecast Using the Decomposition Method

1. Compute seasonal indices using CMAs.
2. Deseasonalize the data by dividing each number by its seasonal index.
3. Find the equation of a trend line using the deseasonalized data.
4. Forecast for future periods using the trend line.
5. Multiply the trend line forecast by the appropriate seasonal index.

Photo Source: (Barry Render, et al, 2017)

**Figure 1.6**

Scatterplot of Turner Industries' Original Sales Data and Deseasonalized Data with Unadjusted and Adjusted Forecasts

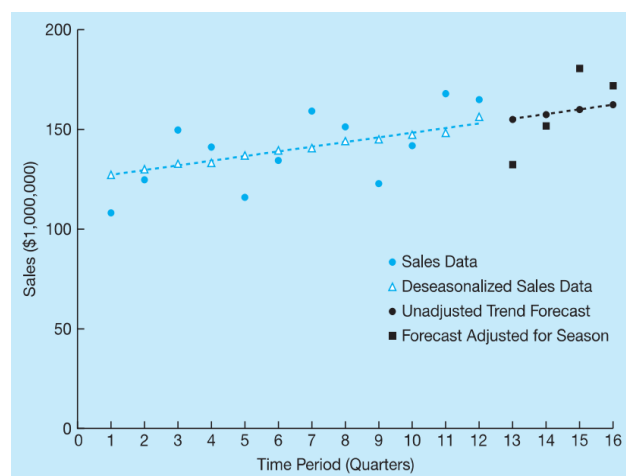


Figure Source: (Barry Render, et al, 2017)



We should say here that most forecasting software, including Excel QM and QM for Windows, have intergrated the decomposition method as one of the available techniques. Thus, CMAs are automatically calculated. Following the steps that were earlier described, the data is deseasonalized, the trend line is developed, the forecast is made using the trend equation and the final forecast is adjusted according to seasonality.

### Using Regression with Trend and Seasonal Components

As mentioned earlier multiple regression is another technique that may be used to forecast in a time series when trend and seasonal components are present. One independent variable is time. At the same time other independent variables are dummy variables, indicating season. Forecasting quarterly data, means that we have four categories (quarters), thus three dummies should be used. The basic model is an additive decomposition model, being expressed as below:

$$\hat{Y} = \alpha + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4$$

Where,

$X_1$  = time period,  $X_2 = 1$  if quarter 1 | =0 otherwise,  $X_3 = 1$  if quarter 3 | =0 otherwise,  $X_4 = 1$  if quarter 4 | =0 otherwise

If  $X_2 = X_3 = X_4 = 0$  then quarter 1 would be the quarter. There is no rule to which of the quarters will not have a specific dummy variable associated with it. Regardless of which quarter will not have the dummy variable, forecasts will not change, they will remain the same (*Barry Render, et al, 2017*).

### 1.7 Monitoring and Controlling Forecasts

Once we complete our forecasts, have we finished the job? Of course not. Forecasts should remain under our attention. No manager wants to be reminded due to forecasts lacking terribly in accuracy. At the same time a business needs to understand why the actual variable examined (demand, sales, etc) had a significant deviation from its projections.

Employing a **tracking signal** is one way to monitor forecasts to ensure their good performance. A tracking signal is measuring how well the forecast is predicting actual values. As forecasts are updated every period we examine (week, month, or quarter), the newly available examined data are compared to the values of our forecasts (*Barry Render, et al, 2017*).

The tracking signal is calculated as the **running sum of the forecast errors (RSFE)** divided by the mean absolute deviation:

$$\text{Tracking signal} = \frac{\text{RSFE}}{\text{MAD}} = \frac{\Sigma(\text{Forecast Error})}{\text{MAD}}$$

1-13

Where,

$$\text{MAD} = \frac{\Sigma(\text{Forecast Error})}{n}$$

When the tracking signal is positive, that is a sign that demand is higher that the forecast. On the other hand, negative tracking signals indicate that demand is less than the forecast. A good tracking signal is the one with a low RSFE, in which positive error equals negative error. Thus,

small deviations are the key, whereas positive and negative deviations balance, giving the tracking signal centers at around zero (Barry Render, et al, 2017).

For the calculation of tracking signals, predetermined control limits have been set up. A signal is tripped when a tracking signal exceeds an acceptable range between a lower and upper limit. That shows a problem in the forecasting method and probably the management may need to reassess their forecasts. In Figure 1.7 we may see the graph of a tracking signal that surpasses the acceptable range. For instance if exponential smoothing was the method that was used for forecasting, probably readjusting the smoothing constant would be the solve the issue (Barry Render, et al, 2017).

The reasonable question is how firms decide about the range of the upper and lower tracking limits. There is no specific answer. The key is to define reasonable values, with not so low range as to be triggered with every small forecast error and not so high as to allow inadequate forecasts to be often being passed by. George Plossl and Oliver Wight, two experts in inventory control, suggested using maximums of  $\pm 4$  MADs for high volume stock items and  $\pm 8$  MADs for lower volume items (Barry Render, et al, 2017).

A bit lower ranges are suggested by other forecasters. One MAD is equivalent to approximately 0.8 standard deviation, so that  $\pm 2$  MADs = 1.6 standard deviations,  $\pm 3$  MADs = 2.4 standard deviations, and  $\pm 4$  MADs = 3.2 standard deviations. This suggests that for a forecast to be “in control,” 89% of the errors are expected to fall within  $\pm 2$  MADs, 98% within  $\pm 3$  MADs, or 99.9% within  $\pm 4$  MADs whenever the errors are approximately normally distributed.

An example for the calculation of the tracking signal and RSFE is the Kimball’s Bakery’s quarterly sales of croissants (in thousands) in the following table. Forecast demand and error calculations are also shown. The objective is to calculate the tracking signal and determine whether forecasts have an adequate performance (Barry Render, et al, 2017).

**Figure 1.7**

Plot of Tracking Signals

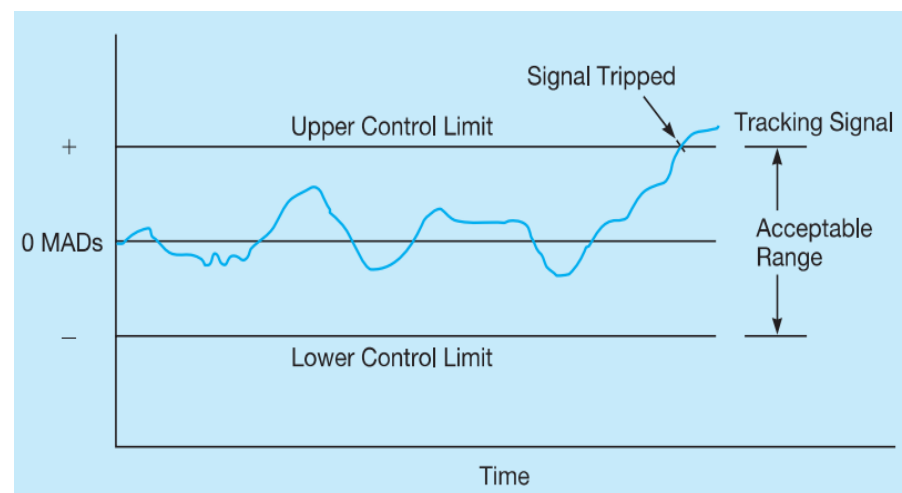


Figure Source: (Barry Render, et al, 2017)

| TIME PERIOD | FORECAST DEMAND | ACTUAL DEMAND | ERROR | RSFE | FORECAST ERROR | CUMULATIVE ERROR | MAD  | TRACKING SIGNAL |
|-------------|-----------------|---------------|-------|------|----------------|------------------|------|-----------------|
| 1           | 100             | 90            | -10   | -10  | 10             | 10               | 10.0 | -1              |
| 2           | 100             | 95            | -5    | -15  | 5              | 15               | 7.5  | -2              |
| 3           | 100             | 115           | +15   | 0    | 15             | 30               | 10.0 | 0               |
| 4           | 110             | 100           | -10   | -10  | 10             | 40               | 10.0 | -1              |
| 5           | 110             | 125           | +15   | +5   | 15             | 55               | 11.0 | +0.5            |
| 6           | 110             | 140           | +30   | +35  | 30             | 85               | 14.2 | +2.5            |

Period 6 gives us the calculations below:

$$MAD = \frac{\sum |Forecast Error|}{n} = \frac{85}{6} = 14.2$$

$$Tracking\ signal = \frac{RSFE}{MAD} = \frac{35}{14.2} = 2.5\ MADs$$

This tracking signal is within acceptable limits. Its range is between -2.0 MADs to +2.5 MADs.

### **Adaptive Smoothing**

A lot of research has been published on the subject of adaptive forecasting. This refers to computer monitoring of tracking signals and self-adjustment if a signal passes its preset limit. In exponential smoothing, the  $\alpha$  and  $\beta$  coefficients are first selected based on values that minimize error forecasts and are then adjusted accordingly whenever the computer notes an errant tracking signal. This is called **adaptive smoothing** (Barry Render, et al, 2017).

CHAPTER  
**2**

## Inventory Control Models



Inventory is one of the most expensive and crucial assets of many companies, standing for more or less 50% of the total invested capital. Thus, good inventory levels can earn firms money. On the one hand by saving them with reducing inventory costs and on the other by maintaining an adequate level of stock, which will be as close as possible to the demand and will also result in satisfied customers. So, the objective for companies is the balance between high and low inventory levels, which finally is a matter of cost minimization for the companies to get the most out of proper inventory management.

Inventory is an area where resources are stored and are used to cover current or future demands. An inventory may have raw materials, work in progress or finished goods. Finished goods in an inventory are related directly to the demand. For instance, when the demand for completed cloth dryers is forecasted, then probably this information will be useful for the estimation of the amounts of sheet metal, paint, electric motors, switches and any other raw materials and work in process that are necessary for the production of the final product (Taylor, Bernard W. *Introduction to Management Science*. Harlow, Pearson, 2016).

Every organization has a type of inventory planning and control system. A bank has methods of controlling its inventory of cash. A hospital has methods to control blood and other important supplies. Inventory planning and control is of top priority for state and federal governments, schools and manufacturing and production organizations. The way organizations achieve their objectives by supplying goods and services to their customers is directly related to the way they control their inventory. All the functions and departments of the organization are tied with the common thread of inventory.

**Figure 2.1**  
Inventory Planning and Control

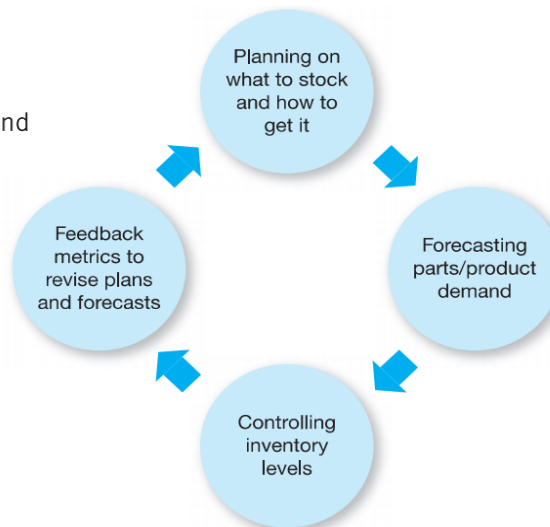


Figure Source: (Barry Render, et al, 2017)

Figure 2.1 is indicative of the basic components of an inventory planning and control system. The *planning* phase focuses on what the stock will be and how this stock will be acquired (it can be a final product inventory or an inventory with purchased goods). This information is then given to *forecasting* demand for the inventory and *controlling* of the inventory levels. Finally, the feedback loop in Figure 2.1 is the way to revise the plan and forecast based on observations and experience.

Inventory planning enables an organization to decide which goods and/or services will be produced. When physical products should be produced, the organization must define which of them will be produced and which of them will be purchased from another manufacturer.

Once all these have been defined, the important next step is to properly forecast the demand (Barry Render, et al, 2017).

## 2.1 An Inventory Metric in Supply Chains

---

In business, simple ratios and formulas are used in order to evaluate the influence of inventories on the financial health of the company. The **turnover ratio** is a common metric:

$$\text{Turnover ratio} = \frac{\text{Cost of goods sold in a period}}{\text{Cost of average inventory in the same period}}$$

Turnover ratio calculates the number of times a business has sold its inventory during a specified period (most of the times that is a year) to realize given sales. We need to highlight here that the numerator is the *cost* of the goods sold, *not the revenue*.

A general rule is that a ratio less than 1 means that a business carries too much inventory, for its realized sales volume. However, high turnover ratio is desirable, because it is an indicator of a lower inventory and high sales volume. On the other hand, extremely high inventory turnover may indicate that the business maintains low inventory, which has the consequence of lost sales, due to low stock levels.

The data for the calculation of the turnover ratio are usually taken from the company's balance sheet. Having said that, the turnover ratio is computed over the period of one year and the average inventory is the simple average of the opening and the closing inventory costs for the year. The assumption of this simple average is that the inventory is depleted uniformly over the duration of the year, which may not be true. For instance, distortion will occur in the extreme case of a constant inventory for ten months, which will then be depleted sharply in November and December, due to Christmas shopping period. This can be solved by checking the actual inventory over the period of a month or during the quarters of the year. Nevertheless, this process of data collection may prove costly, instead of just taking the data from the balance sheet (Taha, Hamdy A. *Operations Research: An Introduction*. Harlow, Essex, Pearson Education Limited, 2017).

A metric that accompanies the turnover ratio is the number of days inventory is held in the system before it is turned over, which is calculated as follows:

$$\text{Days in inventory} = \frac{360}{\text{Turnover ratio}}$$

## 2.2 Importance of Inventory Control

---

Inventory control is related to and serves many important functions within an organization and with proper management adds a great deal of flexibility to the operation of the organization. Consider the following five uses of inventory (Barry Render, et al, 2017):

1. The decoupling function
2. Storing resources
3. Irregular supply and demand
4. Quantity discounts
5. Avoiding stockouts and shortages

### Decoupling Function

A major function of the inventory is to decouple manufacturing processes within an organization. Not storing inventory may result in many delays and inefficiencies. For instance, if one stage of a manufacturing process has to be complete so that the next one can start, then the entire process may stop. However, a proper stored inventory between the processes may be the regulator that will not allow the standstill of the manufacturing process (*Barry Render, et al, 2017*).

### Storing Resources

There are cases such as the agricultural and seafood products that are gathered during specific periods, however they appear to have a constant demand throughout the year. The solution for the storage of these products is inventory.

Let us examine a manufacturing process where raw materials can be stored either in work in progress or at the final product. Thus, if your company produces cars, you may have tires from an external supplier. Supposing that you have 100 finished cars and 60 tires in inventory, your actual amount of tires stored in inventory is 460. Sixty tires are stored by themselves and 400 (100 cars X 4 tires = 400) tires are stored on the finished cars. Respectively, *labor* is stored in inventory. Supposing that you have 100 subassemblies and 20 hours of labor are needed to produce each assembly, your actual labor hours stored in inventory in the subassemblies is 2.000. Out of these two simple examples we may understand that that any kind of resource – physical or any other – may be stored in inventory (*Barry Render, et al, 2017*).

### Irregular Supply and Demand

For cases of irregular supply of or demand for an item, having an area to store certain quantities in inventory can be crucial. If during the summer diet soft drinks appear to have the greatest demand, we will need to assure that there is adequate supply to cover this irregular demand. An option would be to produce more of the soft drink during the winter than it is actually needed to cope with the winter demand. Thus, high inventory levels of the diet soft drink will be the result during the winter, however that is necessary in order to meet the high demand during the summer. The same concept applies for irregular *supplies* (*Barry Render, et al, 2017*).

### Quantity Discounts

Another advantageous use of inventory is the aspect to cope with **quantity discounts**. It is reasonable that suppliers may offer discounts for large orders. For instance, a spare part for a truck may cost 500€, but the supplier is willing to offer a 3% discount for an order of at least 10 units. It is common practice for buyers to negotiate larger orders for reducing the cost of products. However, buying larger quantities has also disadvantages. It results in higher storage costs, and higher costs because of spoilage, damaged stock, theft, insurance and other risks. Moreover, spending more in inventory, leaves less cash to invest on other operations (*Barry Render, et al, 2017*).

### Avoiding Stockouts and Shortages

Avoiding stockouts and shortages is a very important contribution of inventory. It is not good for firms to lose customers because they regularly run out of stock. Consistently failing to



provide the market with the appropriate item at the appropriate time may prove very costly for firms (Barry Render, et al, 2017).

## 2.3 Inventory Decisions

Among the countless small or big items that our society produces, there are just two primary decisions that the producer has to make for the proper control of its inventory:

1. How much to order
2. When to order

The rational objective of every inventory model and technique is how much to order and when to order. Inventory is involved in many functions within organizations. However, as inventory levels increase to support these functions, storing and inventory holding costs also increase. Thus, minimizing total inventory costs is the main aim for the inventory levels that are necessary for each organization. Below, some of the most important inventory costs are defined:

1. Cost of the items (purchase cost or material cost)
2. Cost of ordering
3. Cost of carrying, or holding, inventory
4. Cost of stockouts

Table 2.1 indicates the most frequent factors related to ordering and holding cost. We should take into account the ordering cost in general not dependent on the size of the order and often personnel time is involved. Each time an order is placed, an order cost incurs, independent of the size (1, 500 or 1500 units) of the order. The number of the units does not change the procedure (paperwork administration, bill payment and so on) that is necessary for the completion of each order.

**Table 2.1 | Inventory Cost Factors**

| ORDERING COST FACTORS   | CARRYING COST FACTORS                              |
|---|--|
| Developing and sending purchase orders                          | Cost of capital                                    |
| Processing and inspecting incoming inventory                    | Taxes  |
| Bill paying   | Insurance  |
| Inventory inquiries   | Spoilage   |
| Utilities, phone bills, and so on for the purchasing department | Theft  |
| Salaries and wages for purchasing department employees          | Obsolescence                                       |
| Supplies such as forms and paper for the purchasing department  | Salaries and wages for warehouse employees         |
|   | Utilities and building costs for the warehouse     |
|   | Supplies such as forms and paper for the warehouse |

*Table Source: Barry Render, et al, 2017*

On the contrary, the holding cost depends on the size of the inventory. The taxes, insurance, cost of capital and other factors in the holding cost will be higher if – for instance - 500 units will be placed into inventory rather than 50. Likewise, the lower the inventory level is, the lower the chances of spoilage and obsolescence are.

The cost of the items or the purchase cost, is obviously what is paid to obtain the inventory. The stockout cost is indicative of the lost sales and goodwill (future sales) that result from not



being able to have the goods available to the customer. Later in the chapter that will be discussed (Taylor, Bernard W. *Introduction to Management Science*. Harlow, Pearson, 2016).

## 2.4 Economic Order Quantity: Determining How Much to Order

The **economic order quantity (EOQ)** is one of the oldest and generally most popular inventory control techniques, dating its initial use since 1915, with a publication by Ford W. Harris. Many organizations still use this technique, which is relatively easy to use, however a number of assumptions are necessary. Below are listed the most important of them:

1. Known and constant demand.
2. Lead time is also known and constant.
3. Each order is received in one batch, at a specific time. In other words, the receipt is instantaneous.
4. Quantity discounts are not applicable, in other words the purchase cost per unit is constant during the year.
5. Only ordering cost and holding or carrying cost are variable, however the holding cost per unit per year and the ordering cost per order are constant throughout the year.
6. The objective of placing orders is to avoid completely stockouts or shortages.

When these assumptions are *not* met, the EOQ model needs to be adjusted. We will discuss them later in the chapter.

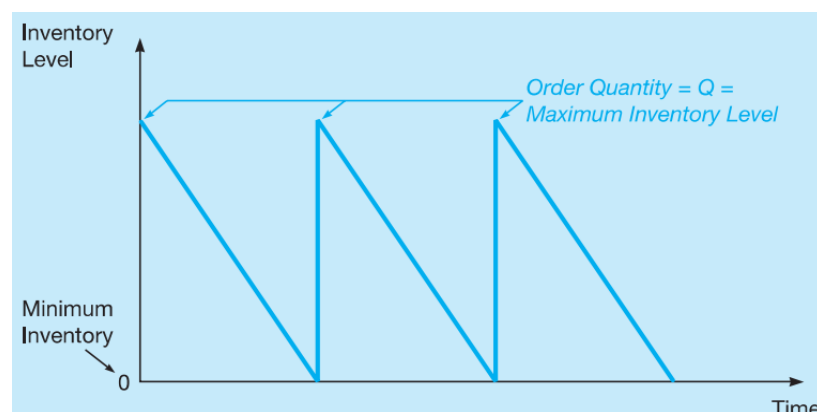
Given these assumptions the shape of the inventory usage is a sawtooth shape as shown in Figure 2.2. In Figure 2.2,  $Q$  is the amount of an order. If the amount is 100 laptops, all of them arrive at one time with order is received. Thus, the inventory level increases from 0 to 100 laptops. The concept is that, with the arrival of an order, the inventory level raises from 0 to  $Q$ .

According to the first assumption of the constant demand over time, respectively the inventory decreases with a constant rate over time. (Please see the sloped lines in Figure 2.2). When the inventory level decreases to 0, another order of  $Q$  units is placed, which is showed by the vertical lines. This process is repeated continuously over time (Barry Render, et al, 2017).

**Figure 2.2**

**Inventory Usage Over Time**

**Figure Source:** (Barry Render, et al, 2017)



### Inventory Costs in the EOQ Situation

Most inventory models have the objective of minimizing the total costs. With above given assumptions, the ordering cost and the carrying or holding cost are the relevant costs. All other costs, such as the cost of the inventory itself (the purchase cost) are constant. Thus, minimizing the total costs is a matter of minimizing the sum of the ordering and carrying costs.

**Table 2.2**

Computing

Average

Inventory

| DAY                      | INVENTORY LEVEL |        |         |
|--------------------------|-----------------|--------|---------|
|                          | BEGINNING       | ENDING | AVERAGE |
| April 1 (order received) | 10              | 8      | 9       |
| April 2                  | 8               | 6      | 7       |
| April 3                  | 6               | 4      | 5       |
| April 4                  | 4               | 2      | 3       |
| April 5                  | 2               | 0      | 1       |

Maximum level April 1 = 10 units  
Total of daily averages = 9 + 7 + 5 + 3 + 1 = 25  
Number of days = 5  
Average inventory level = 25/5 = 5 units

*Table Source: (Barry Render, et al, 2017)*

The **annual ordering cost** is the number of orders per year times the cost of placing each order. As long as the inventory level changes daily, it is suitable to use the average inventory level to estimate annual holding or carrying cost. The annual carrying cost will equal the average inventory times the inventory carrying cost per unit per year. Looking at Figure 2.2, we can easily notice that the maximum inventory is the order quantity ( $Q$ ) and the **average inventory** will be one-half of that. Table 2.2 gives an indicative numerical example. For that case if the order quantity is 10, the average inventory will be 5, or one-half of  $Q$ . Thus:

$$\text{Average inventory level} = \frac{Q}{2} \quad \boxed{2-1}$$

Using the following variables, mathematical expressions can be developed for the annual ordering and carrying costs:

$Q$  = number of units in an order

$EOQ = Q^*$  = optimal number of units to order

$D$  = annual demand in units for the inventory item

$C_o$  = ordering cost of each order

$C_h$  = holding or carrying cost per unit per year

Annual ordering cost = (Number of orders placed per year) x (Ordering cost per order)

$$= \frac{\text{Annual Demand}}{\text{Number of units in each order}} \times (\text{Ordering cost per order})$$

$$= \frac{D}{Q} C_o$$

Annual holding or carrying cost = (Average inventory) x (Carrying cost per unit per year)

$$= \frac{\text{Order Quantity}}{2} \times (\text{Carrying cost per unit per year})$$

$$= \frac{Q}{2} C_h$$

Figure 2.3 is indicative of a graph of the holding cost, the ordering cost and the total of these two. Once the ordering cost is the same as the carrying cost, we get the lowest point on the

total cost. Thus, at the point where these two costs are equal, we manage the minimization of the total costs in this case (Barry Render, et al, 2017).

### Finding the EOQ

Once the EOQ assumptions are met, total cost is minimized when:

Annual holding cost = Annual ordering cost

$\frac{Q}{2} C_h = \frac{D}{Q} C_o$ , solving this for Q we calculate the optimal order quantity:

$$Q = \sqrt{\frac{2DC_o}{C_h}}$$

**Figure 2.3**

Total Cost as a Function of Order Quantity

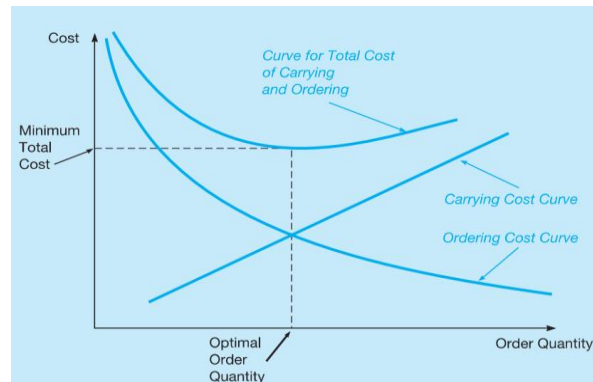


Figure Source: (Barry Render, et al, 2017)

This optimal order quantity is often denoted by  $Q^*$ . Therefore, the economic order quantity is given by the following formula:

$$EOQ = Q^* = \sqrt{\frac{2DC_o}{C_h}}$$

This EOQ formula is the basis even more advanced models. Some of them are discussed later in the chapter.

---

### Economic Order Quantity (EOQ) Model

$$\text{Annual ordering cost} = \frac{D}{Q} C_o \quad \boxed{2-2}$$

$$\text{Annual holding cost} = \frac{Q}{2} C_h \quad \boxed{2-3}$$

$$EOQ = Q^* = \sqrt{\frac{2DC_o}{C_h}} \quad \boxed{2-4}$$


---

Figure Source: (Barry Render, et al, 2017)

### Purchase Cost of Inventory Items

There are times which the total inventory cost expression is written to include the actual cost of the material purchased. With the EOQ assumptions, the purchase cost does not depend on

the particular order policy found to be optimal because, regardless of how many orders are placed each year, we still incur the same annual purchase cost of  $D \times C$ , where  $C$  is the purchase cost per unit and  $D$  is the annual demand in units (*Barry Render, et al, 2017*).

If the price per unit is known, it is good to know how to calculate the average inventory level in dollar terms. If  $Q$  is used to represent the quantity of units ordered and  $C$  is used to represent the cost of units, then the average dollar value of inventory can be estimated as follows:

$$\text{Average dollar level} = \frac{(CQ)}{2} \quad \boxed{2-6}$$

This formula is analogous to Equation 2-1.

Very often businesses or industries express the inventory carrying cost as an annual percentage of the unit cost or price. If that is the case, then variable  $I$  is introduced, which is the annual inventory holding charge as a percent of unit price or cost. Then the cost of storing one unit of inventory for the year,  $C_h$ , is given by  $C_h = IC$ , where  $C$  is the unit or cost price of an inventory item. In this case  $Q^*$  can be expressed as:

$$Q^* = \sqrt{\frac{2DCo}{IC}} \quad \boxed{2-7}$$

### Sensitivity Analysis with the EOQ model

The assumptions of the EOQ model are that all input values are fixed and known with certainty. Despite that, these values may be re-estimated or change over time. Thus, it is significant to understand how the order quantity will change if input values change as well. **Sensitivity analysis** will determine that.

The EOQ formula is given as follows:

$$EOQ = \sqrt{\frac{2DCo}{C_h}}$$

Due to the square root in the formula, minor changes will occur in the optimal order quantity if the values in the inputs ( $D$ ,  $C_o$ ,  $C_h$ ) also change. For instance, if  $D$  increases by 9, then the EOQ will increase only by 3 (*Barry Render, et al, 2017*).

### 2.5 Reorder Point: Determining When to Order

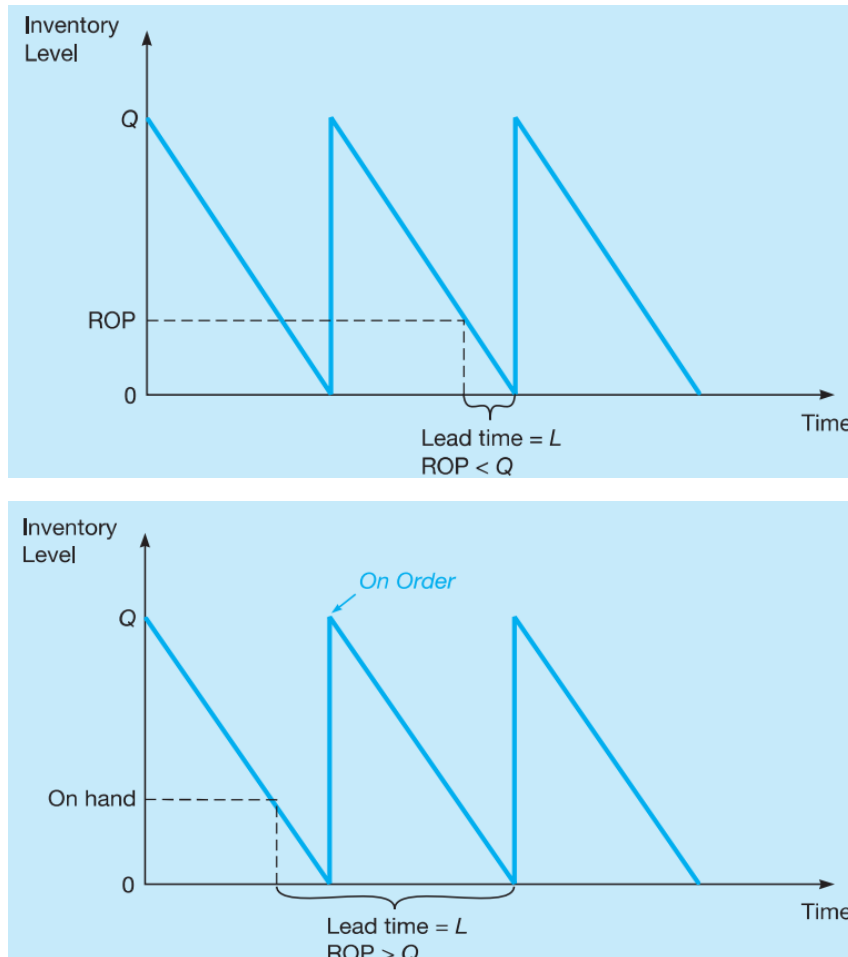
Now that the first question of how much to order has been answered, we are looking at the second question: when to order. Between placing and receiving an order there is always a time gap – of a few days or up to a few weeks – which called the **lead time** or delivery time. During this time inventory must have the availability to meet the demand. This inventory can either be on hand now or on order, but not yet received. The total of these is called the **inventory position**. Thus, the *when to order* decision is usually expressed in terms of a **reorder point (ROP)**, the inventory position when an order should be placed (*Barry Render, et al, 2017*).

The ROP is given as:

$$ROP = (\text{Demand per day}) \times (\text{Lead time for a new order in days}) = d \times L$$

In Figure 2.4 we may see two graphs presenting the ROP. The first one has a relatively large lead time comparing to the relatively small of the second one. Once the inventory position reaches the ROP, it is time for a new order to be placed. In the meantime, before the order is received, the demand must be met; and this will happen either with inventory currently on hand or with inventory that already has been ordered but will arrive once the on-hand inventory decreases to zero (Barry Render, et al, 2017).

**Figure 2.4** | Reorder Point Graphs | Source: Barry Render, et al, 2017



## 2.6 EOQ Without the Instantaneous Receipt Assumption

When inventory continuously flows or builds up over a period of time, then it is very reasonable that the assumption of instantaneous inventory receipt is not applicable. Therefore, a new model is necessary, which should include the daily demand rate. Due to the fact that this model fits very well to the production environment, it is commonly called the **production run model**.

The ordering cost is replaced by the **setup cost** in this model. This setup cost includes all the cost of setting up the production facility to manufacture the final product. The salaries and wages of the employees who are responsible for the setup of the equipment are included, as well as engineering and design costs of the setup, paperwork, supplies, utilities and so on. and so on. The carrying cost per unit is composed of the same factors as in the traditional EOQ model, although the annual carrying cost equation changes due to a change in average inventory (Taylor, Bernard W. *Introduction to Management Science*. Harlow, Pearson, 2016).

Setting the setup cost equal to the holding or carrying cost will give us the optimal production quantity. Let's start building up the carrying cost. Nevertheless, equaling the setup cost to carrying cost is not always a guarantee of optimal solutions for models more complex than the production run model (Barry Render, et al, 2017).

### Annual Carrying Cost for Production Run Model

The carrying cost of the production run model has as a base the average inventory, which is one-half the maximum inventory level. However, just because a longer time is necessary for the replenishment of inventory, while demand continues during this time, the maximum inventory will be less than the order quantity  $Q$ . The annual carrying, or holding cost expression can be developed using the variable below:

$Q$  = number of units per order, or production run

$C_s$  = setup cost

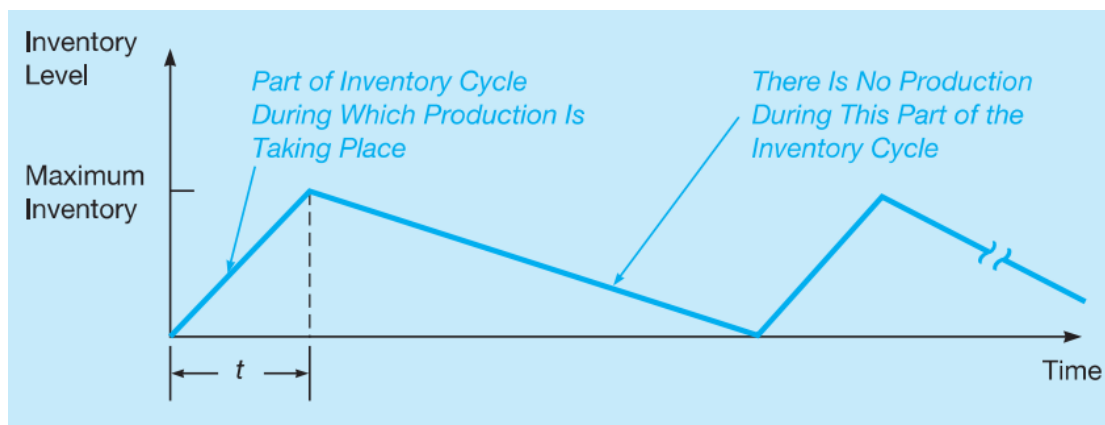
$C_h$  = holding or carrying cost per unit per year

$p$  = daily production rate

$d$  = daily demand rate

$t$  = length of production run in days

**Figure 2.5** | Inventory Control and the Production Process | Source: Barry Render, et al, 2017



The maximum inventory level is shown below:

(Total produced during the production run) — (Total used during production run)

= (Daily production rate) (Number of days of production) - (Daily demand) (Number of days of production) =  $(pt) - (dt)$

As long as, Total produced =  $Q = pt$ ,

we know that  $t = Q/p$

Maximum inventory level =  $pt - dt = p(Q/p) - d(Q/p) = Q[1 - (d/p)]$

As long as the average inventory is one-half of the maximum,

$$\text{Average inventory} = \frac{Q}{2} \left(1 - \frac{d}{p}\right)$$

2-9

and

$$\text{Annual holding cost} = \frac{Q}{2} \left(1 - \frac{d}{p}\right) Ch \quad \boxed{2-10}$$

### Annual Setup Cost or Annual Ordering Cost

If there is production of a product over time, setup cost replaces ordering cost. These two do not depend on the size of the order and the size of the production run. This cost is the number of orders (or production runs) times the ordering cost (setup cost). Therefore,

$$\text{Annual setup cost} = \frac{D}{Q} Cs \quad \boxed{2-11}$$

and

$$\text{Annual ordering cost} = \frac{D}{Q} Co \quad \boxed{2-12}$$

### Determining the Optimal Production Quantity

Once the assumptions of the production run model are met, if the setup cost equals the holding cost, then costs are minimized. Optimal quantity is calculated by equalling these costs and solving for Q. Therefore,

Annual holding cost = annual setup cost

$$\frac{Q}{2} \left(1 - \frac{d}{p}\right) Ch = \frac{D}{Q} Cs$$

Solving this for Q, we get the optimal production quantity (Q\*):

$$Q^* = \sqrt{\frac{2DCs}{Ch \left(1 - \frac{d}{p}\right)}} \quad \boxed{2-13}$$

Please note that if no production is involved during time, but the receipt of inventory over a period of time is involved, that same model is suitable, with  $C_0$  replacing  $C_s$  in the formula.

---

#### Production Run Model

$$\text{Annual holding cost} = \frac{Q}{2} \left(1 - \frac{d}{p}\right) Ch$$

$$\text{Annual setup cost} = \frac{D}{Q} Cs$$

$$\text{Optimal production quantity } Q^* = \sqrt{\frac{2DCs}{Ch \left(1 - \frac{d}{p}\right)}}$$

---

*Photo Source: Barry Render, et al, 2017*

## 2.7 Quantity Discount Models

---

Another assumption that was made for the development of the EOQ model was that quantity discounts were not available. It is still possible to find the quantity that minimizes the total

inventory cost, when such discounts are applicable. It is just necessary all the other EOQ assumptions to be met and then with some adjustments the EOQ model will still give us the solution (Barry Render, et al, 2017).

Total cost = Material cost + Ordering cost + Carrying cost

$$Total\ cost = DC + \frac{D}{Q} Co + \frac{Q}{2} Ch \quad \boxed{2-14}$$

Where,

$D$  = annual demand in units

$Co$  = ordering cost of each order

$C$  = cost per unit

$Ch$  = holding or carrying cost per unit per year

As long as the holding cost per unit per year is based on the cost of the item, it is convenient to express it as

$$Ch = IC$$

Where  $I$  = holding cost as a percentage of the unit cost ( $C$ )

---

#### Quantity Discount Model

1. For each discount price ( $C$ ), compute  $EOQ = \sqrt{\frac{2DC_o}{IC}}$ .
  2. If  $EOQ < \text{Minimum for discount}$ , adjust the quantity to  $Q = \text{Minimum for discount}$ .
  3. For each EOQ or adjusted  $Q$ , compute Total cost =  $DC + \frac{D}{Q} Co + \frac{Q}{2} Ch$ .
  4. Choose the lowest-cost quantity.
- 

Photo Source: Barry Render, et al, 2017

## 2.8 Use of Safety Stock

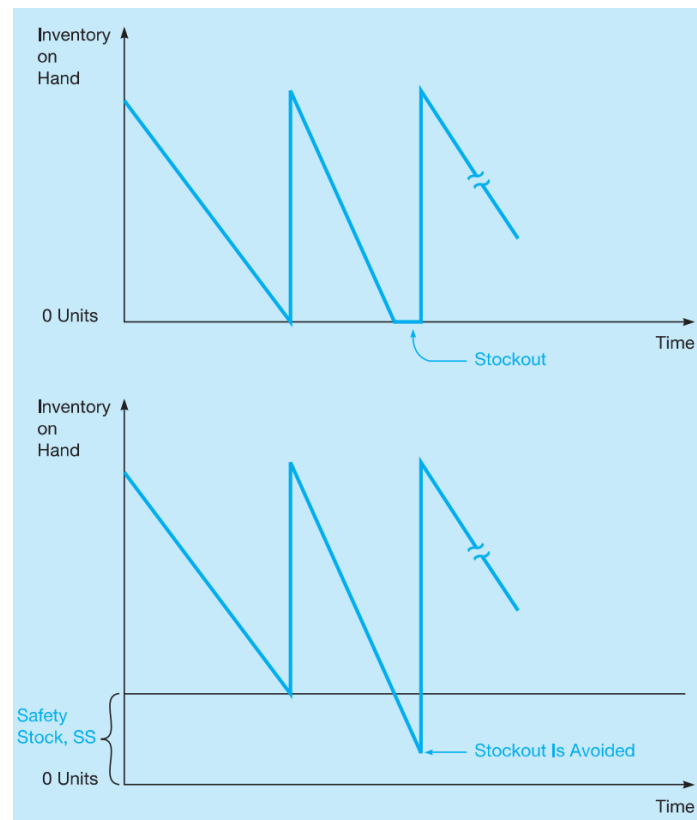
---

As long as the EOQ assumptions are met, orders can be scheduled so that stockouts will not be a problem. Nevertheless, if there is uncertainty in demand or lead time, the precise demand during lead time (which is the ROP in the EOQ situation) will not be known with certainty. Thus, to avoid stockouts the presence of additional inventory called **safety stock** is a necessity.

The main objective of safety stock is to avoid stockouts in periods when demand is higher than expected. Figure 2.7 is indicative of its use. Of course, safety stock will not always avoid stockouts. There are cases of extremely high demand, that although all the stock is used, stockouts may still appear.



Figure 2.7 | Use of Safety Stock



A proper and wise use of a safety stock policy may be to adjust the reorder point. In the EOQ situation where lead time and demand remain constant, the reorder point is the amount of inventory that would be used during the lead time. That is assumed to be known with certainty, so there is no need to place an order when the inventory position is more than this. Nevertheless, when the daily demand or the lead time changes and is not certain, the exact amount of inventory that will be used during the lead time is also not certain. The average inventory usage should be calculated and some safety stock should be added to this to avoid stockouts. The reorder point becomes:

$$ROP = (\text{Average demand during lead time}) + (\text{Safety Stock})$$

$$ROP = (\text{Average demand during lead time}) + SS$$

2-15

The only question to be answered is how to calculate the correct amount of safety stock. The holding cost and the stockout cost are two significant factors in this decision. Lost goodwill and lost sales are the result of the stockout insufficiency. Everything depends on how low or high the holding cost and the stockout cost are. Low holding cost but high stockout cost means a large amount of safety stock should be carried to avoid stockouts. The opposite applies for high holding cost and low stockout cost (Barry Render, et al, 2017).

How is the optimum stock level determined? If demand fluctuates, the lead time is constant, and both the stockout cost per unit and the holding cost per unit are known, the use of a payoff/cost table might be considered. With only a small number of possible demand values during the lead time, a cost table could be constructed in which the different possible demand

levels would be the states of nature and the different amounts of safety stock would be the alternatives.

However, a more general approach is to determine what service level is desired and then find the safety stock level that would accomplish this. A prudent manager will look at the holding cost and the stockout cost to help determine an appropriate service level. A service level indicates what percentage of the time customer demand is met. In other words, the service level is the percentage of time that stockouts are avoided. Thus,

Service level =  $1 - \text{Probability of a stockout}$

Or

Probability of a stockout =  $1 - \text{Service level}$

Once the desired service level is established, the amount of safety stock to carry can be found using the probability distribution of demand during the lead time (*Barry Render, et al, 2017*).

## **2.9 ABC Analysis**

---

**ABC analysis** is a very practical consideration that may be incorporated into the implementation of inventory decisions and policies. ABC analysis divides the company's items into three groups (group A, B and C) with focus on the overall value of the items. It is wise to concentrate on greatest value of the inventory, because this is where the greatest potential savings are. But let's see what is the idea behind this categorization.

Group A is the group that should be monitored carefully, because it accounts for a very large portion of the inventory costs. The worth of these items is more than 70% of the total value of the inventory but these items may be up to 10% of all inventory items. Thus, it is very wise for the company to pay extra attention on forecasting the demand and develop good inventory management policies for this group of items.

Group B needs considerably lower attention than Group A, due to the also much lower cost of these items. Typically, the Group B items represent about 20% of the total value of the inventory, while they do not exceed 20% of all inventory items.

Finally, as it is very reasonable, Group C consists of very low-cost items and spending much time on them compared to Group A and Group B is not worth it. Group C items represent 10% of the total value of the inventory and about 70% of all inventory items.

Group A items need attention due to their high cost. Thus, a very good analysis of the demand is necessary for the proper calculation of the safety stock. Unnecessary safety stock may result in high holding cost. On the other hand the policy for Group C items may be a large safety stock due to their very low cost (*Taylor, Bernard W. Introduction to Management Science. Harlow, Pearson, 2016*).

## **2.10 Valuation of Project Considering Uncertainty | Monte Carlo simulation**

---

Monte Carlo simulation is a simple piece of technology when it comes to the valuation of a project taking into account uncertainty. Monte Carlo is a computer procedure considering fairly the effects of the possible uncertainties. Practically, this simulation

- ✓ *Samples a large number of scenarios*

- ✓ *Calculates* and stores the corresponding realized system performance for every scenario, i.e the NPV of the project, and
- ✓ *Presents* these stored performance data in a range of convenient forms

Most importantly Monte Carlo procedures are mathematically solid and reliable. This type of simulation transforms distributions of uncertain inputs into a distribution of uncertain performance. The corresponding performance of repeatedly sampling the uncertain inputs is recorded. Monte Carlo simulation is efficient, simply because a laptop computer can examine in just a few seconds a financial spreadsheet for thousands of possible outcomes (*Richard De Neufville, and Stefan Scholtes. Flexibility in Engineering Design. Cambridge, Mass., MIT Press, 2011*).

In mathematical terms, Monte Carlo simulation calculates separately the performance of every solution taking into account the joint distribution of uncertainties. This happens in two phases. Initially, it samples the distributions of possible circumstances (i.e future demand, prices, etc.). This gives one possible outcome. Secondly, the sampling process is repeated many times (i.e. 1.000), giving every possible future circumstance its appropriate chance of being sampled. In that way, the distribution of the performance of the design is created, which is consistent with the joint distribution of possible circumstances (*Richard De Neufville, and Stefan Scholtes. Flexibility in Engineering Design. Cambridge, Mass., MIT Press, 2011*).

Below we give the brief - in steps – description of how a static valuation model becomes a Monte Carlo model, which enables us to take advantage of the value of flexibility:

- ✓ *Step 1:* A standard valuation model is produced
- ✓ *Step 2:* Apply a standard sensitivity analysis: One variable at a time is changed
- ✓ *Step 3:* Apply a probabilistic sensitivity analysis: Change all variables at the same time
- ✓ *Step 4:* Introduction of distributional shapes for uncertain numbers
- ✓ *Step 5:* Introduce dependence between uncertain numbers
- ✓ *Step 6:* Introduce dynamically changing uncertain numbers
- ✓ *Step 7:* Model flexibility via rules for exercising flexibility

The processing of a Monte Carlo model nowadays can be executed in Microsoft Excel®. The use of additional commercial software packages integrated in Excel can accelerate the calculations. Example of commercial packages are @Risk®, Crystal Ball®, XLSim®, and RiskSolver®. These Monte Carlo software packages have three main components:

- ✓ A collection of built-in random number generators, which are special spreadsheet formulas that allow sampling from prespecified distributions.
- ✓ A convenient and fast way of executing thousands of scenarios and storing the results.
- ✓ An interface that facilitates the calculation of summary statistics and the generation of charts to analyze, visualize, and communicate the results of simulations.

Users who work on Monte Carlo simulations frequently should invest in a commercial package, because they will gain a respectable amount of time (*Richard De Neufville, and Stefan Scholtes. Flexibility in Engineering Design. Cambridge, Mass., MIT Press, 2011*).

In this dissertation we worked with the Crystal Ball® software package.

CHAPTER  
**3**

## Tractor Spare Parts Inventory



### **3.1 Introduction**

---

There are many different types of inventories for machinery that are used in our everyday life. For these types of machinery, it is a necessity to hold inventories of spare parts to ensure their proper and as continuous as possible operation. Examples of machinery are trucks, buses, agricultural tractors, ships, power generators and so on. What makes significant the presence of a well equipped inventory is that these machinery should be well maintained and provide the users with the highest possible uptime. The truck driver should deliver the goods within strict schedules. There are many cases that trucks carry sensitive cargo such as fresh food or medicine, so a possible breakdown during a delivery should be fixed as quickly as possible. A bus going to a tour full of passengers must not face any breakdown and if that happens, then this must be fixed immediately. Farmers – especially in seeding and harvesting periods - must also have their equipment well maintained and when mechanical problems occur, these must be solved rapidly. The same applies for a ship that probably is traveling around the world or a power generator that probably powers a hospital. The common element to all these examples is a well equipped inventory with spare parts that will allow dealerships provide their customers with high level after sales services. And high level of after sales services is translated into high level of customer satisfaction and hopefully into a good amount of money for the dealerships. This is the reason why managing well a spare parts inventory is so important. The type of machinery and their spare parts that we will examine is agricultural tractors.

### **3.2 Tractor Manufacturing Companies & Range of Products**

---

Globally there are a few tractors manufacturers that target to provide farmers with the best possible machinery to achieve maximum performance for the goods that farmers produce. According to [tractorjunction.com](http://tractorjunction.com), the top 10 tractor companies for 2024 are: Mahindra, John Deere, Massey Ferguson, Case IH, Sonalika International, Escorts Group, Kubota, Fendt, Deutz Fahr and Claas.

Each company provides their customers with a wide range of products that will assist them with their everyday work on the field. Looking into the websites of the companies we share the range of products of two randomly chosen companies: Kubota ([www.kubota.com/products/tractor/index.html](http://www.kubota.com/products/tractor/index.html)) and Deutz Fahr ([www.deutz-fahr.com/en-nd/tractors](http://www.deutz-fahr.com/en-nd/tractors)). The range of each company is indicative and probably products differ from country to country according to the country's needs. The websites of the companies offer thorough information for anyone that is interested in their products.



## Kubota Tractors and their Indicative Application



Paddy Field



Upland Field



Orchard



Farmstead



Garden



## Deutz Fahr Indicative Range of Products



**Series 9 TTV**  
295-336 HP



**Series 8 TTV**  
287 HP



**Series 7 TTV**  
247 HP



**Series 6 TTV**  
192-230 HP



**NEW**  
**Series 6**  
161-217 HP



**NEW**  
**Series 6.4**  
129-171 HP



**NEW**  
**Series 6C**  
116-143 HP



**NEW**  
**Series 5D Keyline**  
66-102 HP



**Series 5**  
95-126 HP



**Series 5D TTV**  
95-116 HP



**Series 5D**  
95-106 HP



**Series 4E**  
66-102 HP



**NEW**  
**The Next Generation**

353 HP



**SERIES C9300**



327-353 HP



**SERIES C7000**



250 HP



**SERIES C6000**



Offering a wide range of products for different applications means that respectively a wide range of spare parts is necessary for the maintenance and good operation of this machinery.

Below, by using data from the Hellenic Statistical Authority, we will present the number of agricultural machinery in our country, in order to realize the size of the market across our country.

### **3.3 Number of operating agricultural machinery in Greece**

As mentioned above, by using data from Hellenic Statistical Authority ([www.statistics.gr/en/statistics/-/publication/SPG43/-](http://www.statistics.gr/en/statistics/-/publication/SPG43/-)) we present the number of operating agricultural machinery in Greece. Table 3.1 shows the number of the machinery from the latest registration in 2021.

| Agricultural machinery  |                       |                      |                       |  |  |                        |                              |                         |                                   |               |   |              |                     |               |                          |                 |                   |  |
|---|-----------------------|----------------------|-----------------------|--|--|------------------------|------------------------------|-------------------------|-----------------------------------|---------------|---|--------------|---------------------|---------------|--------------------------|-----------------|-------------------|--|
| Table 3-1. Number of operating agricultural machinery, by Region and Regional Unity, 2021 |                       |                      |                       |  |  |                        |                              |                         |                                   |               |   |              |                     |               |                          |                 |                   |  |
| Regions and Regional Unities<br>(NUTS 2)  | Agricultural Tractors |                      | Sowing Machines       |  |  |                        | Sprayers                     |                         |                                   |               | Combine Harvesters - Mowers - Threshers |              |                     |               |                          |                 |                   |  |
|   | Single-axis tractors  | Double-axis tractors | Wheat sowing machines | Sowing machines for cotton, maize, beans etc | High technology linear sowing machines | Potato sowing machines | High pressure power sprayers | Portable power sprayers | Linear cultivation power sprayers | Power dusters | Threshers-harvesters                    | Harvesters   | Threshers all types | Simple mowers | Cotton pick-up threshers | Beet harvesters | Potato harvesters | Other harvesting machines (for industrial tomato, onions, carrots, etc.) |
| <b>Greece Total</b>   | <b>113.035</b>        | <b>248.446</b>       | <b>39.841</b>         | <b>12.632</b>                                | <b>2.241</b>                           | <b>3.226</b>           | <b>117.899</b>               | <b>80.531</b>           | <b>41.793</b>                     | <b>8.304</b>  | <b>6.236</b>                            | <b>8.640</b> | <b>2.605</b>        | <b>12.305</b> | <b>3.984</b>             | <b>252</b>      | <b>4.469</b>      | <b>1.225</b>   |
| <b>Region of Eastern Macedonia and Thrace</b>   | <b>1.538</b>          | <b>37.338</b>        | <b>6.168</b>          | <b>2.573</b>                                 | <b>227</b>                             | <b>584</b>             | <b>10.713</b>                | <b>2.985</b>            | <b>4.969</b>                      | <b>754</b>    | <b>1.031</b>                            | <b>507</b>   | <b>245</b>          | <b>919</b>    | <b>496</b>               | <b>20</b>       | <b>814</b>        | <b>61</b>  |
| Rodopi  | 105                   | 12.814               | 2.486                 | 405  | 89                                     | 2                      | 2.443                        | 152                     | 1.772                             | 5             | 183                                     | 150          | 64                  | 280           | 183                      | 5               | 14                | 3  |
| Drama   | 456                   | 5.584                | 744                   | 756  | 67                                     | 543                    | 667                          | 1.268                   | 1.136                             | 13            | 172                                     | 223          | 35                  | 314           | 74                       | 8               | 704               | 10   |
| Evros   | 345                   | 8.210                | 2.393                 | 847  | 45                                     | —                      | 4.856                        | 40                      | 19                                | 4             | 474                                     | 13           | 40                  | 58            | 192                      | 3               | 62                | 29   |
| Thasos  | 78                    | 82                   | —                     | —  | —                                      | —                      | 27                           | 21                      | —                                 | —             | —                                       | —            | —                   | —             | —                        | —               | 1                 | 1  |
| Kavala  | 460                   | 6.793                | 144                   | 307  | 3                                      | 12                     | 2.452                        | 592                     | 1.465                             | 715           | 133                                     | 56           | 34                  | 131           | 4                        | —               | 10                | 11   |
| Xanthi  | 94                    | 3.855                | 401                   | 258  | 23                                     | 27                     | 268                          | 912                     | 577                               | 17            | 69                                      | 65           | 72                  | 136           | 43                       | 4               | 23                | 7  |
| <b>Region of Central Macedonia</b>  | <b>8.053</b>          | <b>77.816</b>        | <b>13.428</b>         | <b>3.189</b>                                 | <b>566</b>                             | <b>287</b>             | <b>29.360</b>                | <b>8.965</b>            | <b>14.859</b>                     | <b>699</b>    | <b>2.440</b>                            | <b>1.715</b> | <b>503</b>          | <b>3.917</b>  | <b>929</b>               | <b>119</b>      | <b>413</b>        | <b>349</b>   |
| Thessaloniki  | 1.919                 | 12.799               | 4.384                 | 497  | 204                                    | 4                      | 2.088                        | 876                     | 3.864                             | 376           | 1.253                                   | 195          | 69                  | 354           | 154                      | 5               | 44                | 60   |
| Imathia   | 480                   | 10.219               | 199                   | 272  | 81                                     | 24                     | 3.954                        | 1.089                   | 920                               | 66            | 86                                      | 184          | 84                  | 242           | 240                      | 29              | 32                | 69   |
| Kilkis  | 672                   | 5.874                | 3.409                 | 137  | 40                                     | 73                     | 583                          | 166                     | 800                               | 46            | 204                                     | 56           | 33                  | 182           | 44                       | 9               | 50                | 13   |
| Pella   | 924                   | 21.819               | 749                   | 574  | 39                                     | 118                    | 11.353                       | 889                     | 2.128                             | 30            | 122                                     | 729          | 27                  | 677           | 121                      | 43              | 133               | 5  |
| Pieria  | 539                   | 7.851                | 533                   | 187  | 13                                     | 2                      | 5.580                        | 2.133                   | 575                               | —             | 145                                     | 8            | 6                   | 66            | 45                       | 13              | 6                 | 11   |
| Serres  | 2.288                 | 13.089               | 2.026                 | 1.398  | 156                                    | 65                     | 2.719                        | 2.790                   | 4.678                             | 30            | 471                                     | 528          | 267                 | 2.310         | 299                      | 20              | 117               | 153  |
| Chalkidiki  | 1.231                 | 6.165                | 2.128                 | 124  | 33                                     | 1                      | 3.083                        | 1.022                   | 1.894                             | 151           | 159                                     | 15           | 17                  | 86            | 26                       | —               | 31                | 38   |
| <b>Region of Western Macedonia</b>  | <b>4.344</b>          | <b>12.496</b>        | <b>6.303</b>          | <b>540</b>                                   | <b>151</b>                             | <b>370</b>             | <b>3.412</b>                 | <b>1.761</b>            | <b>3.911</b>                      | <b>77</b>     | <b>493</b>                              | <b>1.051</b> | <b>41</b>           | <b>1.063</b>  | <b>4</b>                 | <b>43</b>       | <b>311</b>        | <b>71</b>  |
| Kozani  | 1.739                 | 5.506                | 3.442                 | 247  | 48                                     | 241                    | 1.209                        | 843                     | 2.879                             | 2             | 195                                     | 307          | —                   | 112           | —                        | 40              | 162               | 33   |
| Grevena   | 407                   | 1.857                | 1.422                 | 39   | 33                                     | 3                      | 1.173                        | 460                     | 7                                 | 31            | 131                                     | 21           | 3                   | 301           | —                        | —               | 12                | 7  |
| Kastoria  | 643                   | 1.863                | 478                   | 57   | 16                                     | 46                     | 545                          | 115                     | 462                               | 10            | 76                                      | 17           | 21                  | 133           | 4                        | 3               | 50                | 23   |
| Florina   | 1.555                 | 3.270                | 961                   | 197  | 54                                     | 80                     | 485                          | 343                     | 563                               | 34            | 91                                      | 706          | 17                  | 517           | —                        | —               | 87                | 8  |
| <b>Region of Epirus</b>   | <b>3.275</b>          | <b>4.586</b>         | <b>283</b>            | <b>424</b>                                   | <b>202</b>                             | <b>162</b>             | <b>2.503</b>                 | <b>7.248</b>            | <b>598</b>                        | <b>17</b>     | <b>190</b>                              | <b>525</b>   | <b>244</b>          | <b>1.025</b>  | <b>4</b>                 | <b>0</b>        | <b>154</b>        | <b>7</b>   |
| Ionnina   | 803                   | 879                  | 170                   | 108  | 18                                     | 102                    | 81                           | 64                      | 115                               | 10            | 36                                      | 41           | 13                  | 295           | —                        | —               | 110               | 4  |
| Arta  | 1.043                 | 1.642                | 8                     | 85   | 4                                      | 1                      | 741                          | 6.842                   | 63                                | —             | 38                                      | 249          | 17                  | 120           | 4                        | —               | 2                 | —  |
| Thesprotia  | 897                   | 977                  | 25                    | 81   | 172                                    | 53                     | 613                          | 91                      | 278                               | 6             | 42                                      | 139          | 158                 | 411           | —                        | —               | 36                | 3  |
| Preveza   | 532                   | 1.088                | 80                    | 150  | 8                                      | 6                      | 1.068                        | 251                     | 142                               | 1             | 74                                      | 96           | 56                  | 199           | —                        | —               | 6                 | —  |
| <b>Region of Thessally</b>  | <b>14.912</b>         | <b>34.337</b>        | <b>7.129</b>          | <b>3.479</b>                                 | <b>631</b>                             | <b>89</b>              | <b>5.981</b>                 | <b>11.481</b>           | <b>5.515</b>                      | <b>269</b>    | <b>811</b>                              | <b>551</b>   | <b>239</b>          | <b>1.666</b>  | <b>1.740</b>             | <b>44</b>       | <b>185</b>        | <b>362</b>   |
| Larissa   | 8.736                 | 15.092               | 4.864                 | 1.070  | 209                                    | 87                     | 4.228                        | 4.073                   | 1.088                             | 80            | 370                                     | 97           | 134                 | 449           | 539                      | 21              | 152               | 322  |
| Karditsa  | 2.697                 | 10.378               | 731                   | 1.863  | 286                                    | —                      | 335                          | 4.876                   | 1.359                             | 80            | 172                                     | 126          | 27                  | 549           | 861                      | 12              | 24                | 21   |
| Magnesia  | 895                   | 3.447                | 1.130                 | 47   | 123                                    | 1                      | 620                          | 1.799                   | 1.033                             | 87            | 181                                     | 228          | 12                  | 135           | 143                      | 11              | 2                 | 14   |
| Sporades Islands  | 14                    | 34                   | 3                     | —  | —                                      | —                      | 41                           | 54                      | —                                 | —             | —                                       | —            | —                   | —             | —                        | —               | —                 | —  |
| Trikala   | 2.570                 | 5.386                | 401                   | 499  | 13                                     | 1                      | 757                          | 679                     | 2.035                             | 22            | 88                                      | 100          | 66                  | 533           | 197                      | —               | 7                 | 5  |



|                                  |               |               |              |              |            |            |               |               |              |              |            |              |            |              |            |           |            |            |
|----------------------------------|---------------|---------------|--------------|--------------|------------|------------|---------------|---------------|--------------|--------------|------------|--------------|------------|--------------|------------|-----------|------------|------------|
| <b>Region of Central Greece</b>  | <b>7.869</b>  | <b>18.753</b> | <b>3.432</b> | <b>1.728</b> | <b>187</b> | <b>106</b> | <b>6.691</b>  | <b>3.532</b>  | <b>1.495</b> | <b>253</b>   | <b>597</b> | <b>379</b>   | <b>172</b> | <b>884</b>   | <b>727</b> | <b>22</b> | <b>205</b> | <b>131</b> |
| Pthiotida                        | 2.163         | 11.642        | 2.187        | 1.203        | 60         | 33         | 4.040         | 1.388         | 821          | 135          | 346        | 151          | 77         | 574          | 398        | 17        | 64         | 78         |
| Viotia                           | 2.067         | 4.067         | 878          | 497          | 103        | 52         | 982           | 1.134         | 534          | 27           | 124        | 186          | 59         | 171          | 317        | 5         | 93         | 45         |
| Evia                             | 2.624         | 2.330         | 268          | 16           | 17         | 21         | 1.474         | 1.006         | 124          | 91           | 108        | 38           | 35         | 118          | 6          | —         | 43         | 6          |
| Evritania                        | 487           | 111           | 3            | —            | —          | —          | 11            | —             | —            | —            | 1          | 1            | —          | 2            | —          | —         | —          | —          |
| Fokida                           | 528           | 603           | 96           | 12           | 7          | —          | 184           | 4             | 16           | —            | 18         | 3            | 1          | 19           | 6          | —         | 5          | 2          |
| <b>Region of Ionian Islands</b>  | <b>3.874</b>  | <b>2.513</b>  | <b>43</b>    | <b>0</b>     | <b>6</b>   | <b>12</b>  | <b>463</b>    | <b>869</b>    | <b>1.373</b> | <b>70</b>    | <b>16</b>  | <b>12</b>    | <b>9</b>   | <b>81</b>    | <b>0</b>   | <b>0</b>  | <b>25</b>  | <b>0</b>   |
| Corfu                            | 403           | 213           | 7            | —            | —          | 7          | 195           | 10            | —            | —            | —          | —            | —          | 4            | —          | —         | 18         | —          |
| Zakynthos                        | 1.135         | 1.457         | —            | —            | —          | —          | 113           | 36            | 1.370        | 44           | —          | 4            | 1          | 6            | —          | —         | —          | —          |
| Ithaka                           | 5             | —             | —            | —            | —          | —          | —             | —             | —            | —            | —          | —            | —          | —            | —          | —         | —          | —          |
| Kefallonia                       | 1.726         | 377           | 33           | —            | 6          | 5          | 63            | 823           | 3            | 15           | 16         | 7            | 7          | 53           | —          | —         | 6          | —          |
| Lefkada                          | 605           | 466           | 3            | —            | —          | —          | 92            | —             | —            | 11           | —          | 1            | 1          | 18           | —          | —         | 1          | —          |
| <b>Region of Western Greece</b>  | <b>10.799</b> | <b>21.442</b> | <b>631</b>   | <b>541</b>   | <b>148</b> | <b>296</b> | <b>10.685</b> | <b>13.310</b> | <b>3.279</b> | <b>1.756</b> | <b>293</b> | <b>1.131</b> | <b>174</b> | <b>1.186</b> | <b>78</b>  | <b>0</b>  | <b>456</b> | <b>94</b>  |
| Achaia                           | 4.723         | 4.528         | 165          | 22           | 27         | 87         | 2.993         | 5.553         | 879          | 1.569        | 96         | 73           | 61         | 456          | —          | —         | 116        | 51         |
| Etolia and Akarnania             | 1.596         | 9.385         | 146          | 360          | 70         | 15         | 4.245         | 1.090         | 1.973        | 56           | 115        | 96           | 43         | 360          | 57         | —         | 89         | 15         |
| Ilia                             | 4.480         | 7.529         | 320          | 159          | 51         | 194        | 3.447         | 6.667         | 427          | 131          | 82         | 962          | 70         | 370          | 21         | —         | 251        | 28         |
| <b>Region of Peloponnese</b>     | <b>14.076</b> | <b>24.121</b> | <b>813</b>   | <b>129</b>   | <b>37</b>  | <b>423</b> | <b>21.851</b> | <b>11.333</b> | <b>3.275</b> | <b>2.178</b> | <b>159</b> | <b>405</b>   | <b>555</b> | <b>660</b>   | <b>0</b>   | <b>0</b>  | <b>897</b> | <b>69</b>  |
| Arkadia                          | 1.565         | 2.389         | 242          | 14           | 14         | 342        | 1.204         | 56            | 337          | 132          | 40         | 72           | 492        | 224          | —          | —         | 496        | —          |
| Argolida                         | 1.745         | 4.487         | 52           | —            | 1          | 1          | 3.961         | 2.175         | 104          | 22           | 26         | 20           | 16         | 40           | —          | —         | 42         | 7          |
| Korinthia                        | 5.330         | 4.706         | 381          | 26           | 7          | 2          | 4.915         | 1.704         | 2.576        | 1.774        | 32         | 37           | 16         | 100          | —          | —         | 190        | 9          |
| Lakonia                          | 1.965         | 5.856         | 87           | 62           | 8          | 7          | 2.315         | 1.853         | 118          | 70           | 34         | 85           | 4          | 79           | —          | —         | 46         | 26         |
| Mesinia                          | 3.471         | 6.683         | 51           | 27           | 7          | 71         | 9.456         | 5.545         | 140          | 180          | 27         | 191          | 27         | 217          | —          | —         | 123        | 27         |
| <b>Region of Attica</b>          | <b>1.634</b>  | <b>2.561</b>  | <b>53</b>    | <b>4</b>     | <b>18</b>  | <b>22</b>  | <b>1.278</b>  | <b>1.071</b>  | <b>209</b>   | <b>24</b>    | <b>26</b>  | <b>26</b>    | <b>31</b>  | <b>15</b>    | <b>4</b>   | <b>1</b>  | <b>32</b>  | <b>24</b>  |
| Athens Central Section           | —             | —             | —            | —            | —          | —          | —             | —             | —            | —            | —          | —            | —          | —            | —          | —         | —          | —          |
| Athens North Section             | 1             | 70            | —            | —            | —          | —          | 2             | —             | —            | —            | —          | —            | —          | —            | —          | —         | —          | —          |
| Athens West Section              | —             | 4             | —            | —            | —          | —          | 2             | 1             | —            | —            | —          | —            | —          | —            | —          | —         | —          | —          |
| Athens South Section             | —             | —             | —            | —            | —          | —          | —             | —             | —            | —            | —          | —            | —          | —            | —          | —         | —          | —          |
| Athens East Section              | 228           | 1.576         | 31           | —            | —          | —          | 414           | 348           | 167          | 18           | 13         | 9            | 1          | 4            | —          | —         | 9          | 18         |
| West Attica                      | 1.253         | 825           | 19           | 4            | 18         | 22         | 825           | 375           | 42           | 6            | 13         | 17           | 30         | 11           | 4          | 1         | 23         | 6          |
| Pireaus                          | —             | —             | —            | —            | —          | —          | —             | —             | —            | —            | —          | —            | —          | —            | —          | —         | —          | —          |
| Attica Islands                   | 152           | 86            | 3            | —            | —          | —          | 35            | 347           | —            | —            | —          | —            | —          | —            | —          | —         | —          | —          |
| <b>Region of Northern Aegean</b> | <b>8.523</b>  | <b>2.104</b>  | <b>126</b>   | <b>3</b>     | <b>1</b>   | <b>83</b>  | <b>941</b>    | <b>1.895</b>  | <b>32</b>    | <b>264</b>   | <b>70</b>  | <b>331</b>   | <b>96</b>  | <b>470</b>   | <b>0</b>   | <b>0</b>  | <b>133</b> | <b>30</b>  |
| Lesbos                           | 2.702         | 1.055         | 34           | 2            | 1          | 7          | 114           | 305           | 22           | 18           | 18         | 124          | 55         | 147          | —          | —         | 19         | 22         |
| Ikaria                           | 1.210         | 2             | —            | —            | —          | 4          | —             | —             | —            | 9            | —          | —            | 1          | 1            | —          | —         | 5          | —          |
| Limnos                           | 441           | 150           | 49           | 1            | —          | —          | 141           | 3             | —            | 5            | 40         | 13           | 1          | 16           | —          | —         | 1          | 1          |
| Samos                            | 1.458         | 284           | 26           | —            | —          | 39         | 182           | 705           | —            | 220          | 5          | 15           | 16         | 53           | —          | —         | 60         | —          |
| Chios                            | 2.712         | 613           | 17           | —            | —          | 33         | 504           | 882           | 10           | 12           | 7          | 179          | 23         | 253          | —          | —         | 48         | 7          |
| <b>Region of Southern Aegean</b> | <b>5.788</b>  | <b>2.055</b>  | <b>293</b>   | <b>7</b>     | <b>53</b>  | <b>357</b> | <b>468</b>    | <b>425</b>    | <b>155</b>   | <b>319</b>   | <b>48</b>  | <b>681</b>   | <b>73</b>  | <b>93</b>    | <b>0</b>   | <b>3</b>  | <b>469</b> | <b>11</b>  |
| Syros                            | 558           | 35            | —            | —            | —          | —          | 78            | 21            | —            | —            | —          | 172          | —          | 1            | —          | —         | 30         | —          |
| Andros                           | 912           | 87            | 2            | —            | —          | 50         | 23            | 13            | —            | 3            | 2          | 99           | 13         | 13           | —          | —         | 50         | —          |
| Thira                            | 489           | 99            | —            | 6            | 4          | —          | —             | 1             | 1            | —            | 3          | 1            | 14         | 2            | —          | —         | 6          | —          |
| Kalimnos                         | 230           | 76            | 4            | —            | —          | 1          | 103           | 10            | —            | 35           | 1          | 5            | 1          | 6            | —          | —         | 3          | —          |

|                        |               |              |              |           |           |            |               |               |              |              |           |              |            |            |          |          |            |           |
|------------------------|---------------|--------------|--------------|-----------|-----------|------------|---------------|---------------|--------------|--------------|-----------|--------------|------------|------------|----------|----------|------------|-----------|
| Karpathos              | 10            | 5            | —            | —         | —         | —          | —             | —             | —            | 5            | —         | —            | —          | —          | —        | —        | —          | —         |
| Kythnos                | 109           | 209          | 22           | —         | —         | 8          | —             | 17            | —            | —            | —         | 157          | —          | —          | —        | —        | 2          | 1         |
| Kos                    | 711           | 168          | 39           | —         | 3         | 11         | 57            | 54            | 12           | 7            | 17        | 13           | 23         | 28         | —        | —        | 20         | 1         |
| Milos                  | 865           | 296          | 1            | —         | —         | 2          | 13            | —             | —            | —            | 1         | 23           | 1          | 5          | —        | —        | 1          | —         |
| Mykonos                | 40            | 9            | 8            | —         | —         | —          | —             | —             | —            | —            | —         | —            | —          | —          | —        | —        | —          | —         |
| Naxos                  | 858           | 615          | 207          | 1         | —         | 271        | 132           | 309           | 132          | —            | 2         | 183          | 11         | 29         | —        | 3        | 347        | —         |
| Paros                  | 286           | 139          | —            | —         | —         | —          | 14            | —             | 10           | —            | 22        | 7            | —          | 9          | —        | —        | —          | 6         |
| Rhodes                 | 489           | 243          | 10           | —         | 46        | 13         | 48            | —             | —            | 269          | —         | —            | —          | —          | —        | —        | 8          | 3         |
| Tinos                  | 231           | 74           | —            | —         | —         | 1          | —             | —             | —            | —            | —         | 21           | 10         | —          | —        | —        | 2          | —         |
| <b>Region of Crete</b> | <b>28.350</b> | <b>8.324</b> | <b>1.139</b> | <b>15</b> | <b>14</b> | <b>435</b> | <b>23.553</b> | <b>15.656</b> | <b>2.123</b> | <b>1.624</b> | <b>62</b> | <b>1.326</b> | <b>223</b> | <b>326</b> | <b>2</b> | <b>0</b> | <b>375</b> | <b>16</b> |
| Heraklion              | 18.211        | 5.489        | 524          | 9         | 14        | 333        | 8.328         | 8.449         | 1.731        | 728          | 37        | 393          | 159        | 90         | —        | —        | 280        | 12        |
| Lasithi                | 3.442         | 533          | 6            | —         | —         | 1          | 12.248        | 1.039         | 253          | 15           | 2         | 2            | 9          | —          | —        | —        | 10         | 4         |
| Rethymno               | 3.065         | 979          | 609          | 6         | —         | 85         | 973           | 1.822         | 7            | 805          | 16        | 877          | 19         | 66         | 2        | —        | 74         | —         |
| Chania                 | 3.632         | 1.323        | —            | —         | —         | 16         | 2.004         | 4.346         | 132          | 76           | 7         | 54           | 36         | 170        | —        | —        | 11         | —         |

From Table 3.1 we may realize the size of the business, which is spread across the whole country. This means that a dealership must have an organized inventory of spare parts, that will help them offer high level after sales services to their customers. We should also take into account that especially large tractors are not maintained or serviced in workshops, but on the field, due to the size of the machinery. That is another reason that a well equipped inventory should exist. In the next paragraph we will see the most common types of spare parts and why these spare parts are necessary for the operation of the tractors.

### 3.4 Categories of Spare Parts

In general, spare parts are categorized according to their application on the mechanical components of a machinery. Below main categories of tractor spare parts are shown:

#### Filters

Filters are very significant for every machinery. They keep away particles that may be harmful for mechanical components of the tractor. Fluid and air filters exist. Their presence maximizes engine performance, reduces fuel consumption and improves quality of life in the cab. Changing them according to the maintenance schedule ensures maximum performance as well as highest uptime ([www.deutz-fahr.com/en-nd/spare-parts-lubricants](http://www.deutz-fahr.com/en-nd/spare-parts-lubricants)).



#### Lubricants

Lubricants reduce friction within the mechanical components and ensure proper temperatures of operation, which is very important specifically for tractors because they operate in heavy duty conditions and peak seasonal periods. They maximize uptime and they have a variety of different formats: engine oil, transmission oil, hydraulic fluid, brake fluid, bearing grease and both concentrated and ready-to-use coolant ([www.deutz-fahr.com/en-nd/spare-parts-lubricants](http://www.deutz-fahr.com/en-nd/spare-parts-lubricants)).



#### Belts

Belts are necessary equipment to ensure the sustainable and economical operation of the tractor. They should offer slip and quiet resistance among the mechanical components, while they transmit high power loads. Failure of this component while operating a tractor may result in standstill of the machinery ([www.deutz-fahr.com/en-nd/spare-parts-lubricants](http://www.deutz-fahr.com/en-nd/spare-parts-lubricants)).



### Clutches

Clutches are fundamental components in the efficiency and proper operation of a tractor, because they transfer power. If that is not happening properly then the whole operation of the machinery is affected and problems may occur between the mechanical components that clutches are involved ([www.deutz-fahr.com/en-nd/spare-parts-lubricants](http://www.deutz-fahr.com/en-nd/spare-parts-lubricants)).



### Batteries

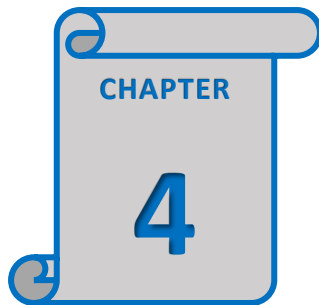
The batteries of a machinery are the spare parts that are responsible for delivering electricity to the utilities of the tractor. They should operate in any condition (especially at the demanding conditions of low temperatures) and in any terrain. The latter means that they have to withstand the vibrations of the terrains that tractors are working at ([www.deutz-fahr.com/en-nd/spare-parts-lubricants](http://www.deutz-fahr.com/en-nd/spare-parts-lubricants)).



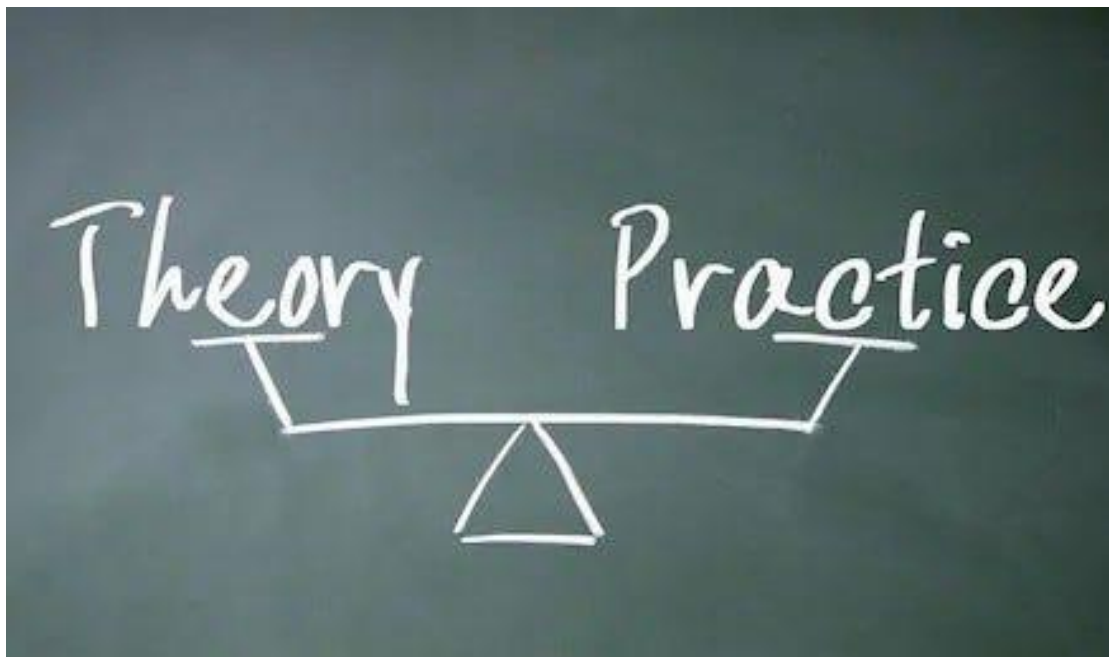
### Engines

The engine is the heart of every machinery. An engine should be efficient, reliable and environmentally friendly. It must ensure maximum uptime for the customer accompanied by high level after sales services ([www.deutz-fahr.com/en-nd/spare-parts-lubricants](http://www.deutz-fahr.com/en-nd/spare-parts-lubricants)).





## Linking Theory to Practice



## 4.1 Introduction

---

As written before we will examine an inventory of agricultural spare parts of a very popular tractor manufacturer, represented in Greece by also a very known Greek company. We have data of sales from previous years of this inventory and initially we will forecast the sales in 2023 as well as the demand of basic stock keeping units (SKUs), using Simulacion 5.0 (<https://sites.google.com/view/simulacion5/main>), a software which is working as an add-in integrated in Excel. Then, as indicated by the theory of Chapter 2, we will use inventory control models for basic SKUs.

We need to mention that this brand of tractors has more than 19.000 SKUs for the whole range of models, varying in size from small bolts, belts, lubricants, clutches, engines, up to cabins when these are necessary for the tractor. Before forecasting it is worth calculating two indices for our inventory as they are described in §2.1; turnover ratio and days in inventory.

## 4.2 Inventory Turnover Ratio & Days in Inventory index

---

According to literature turnover ratio is:

$$\text{Turnover ratio} = \frac{\text{Cost of goods sold in a period}}{\text{Cost of average inventory in the same period}}$$

By extracting the appropriate values from the balance sheet, we get:

Cost of goods sold (for 2022) = 742.860, and

Cost of average inventory during 2022 = 1.861.394

Thus, **Turnover ratio for 2022 = 0,399**

Then,

$$\text{Days in inventory} = \frac{360}{\text{Turnover ratio}} = \frac{360}{0,399} = 902,057$$

First of all, the interesting conclusion we get out of the Turnover ratio is that with a value less than 1 this business carries too much inventory. The days in inventory value is also very high. It is a strong indication that this inventory carries a lot of stock, in which is probably included a respective amount of stock from previous years, otherwise the days in inventory index would not be 902 days or 2,5 years. After realizing these two very significant conclusions, we move on with forecasting and forecasting methods assessment.

## 4.3 Inventory Forecasting in Value and Units

---

For the forecast of sales of 2023, we used the data of the last 3 years (2020, 2021, 2022). Below they are shown in Table 4.1:

**Table 4.1 | Sales of Spare Parts during years 2020 - 2022**

|          | 2020   | 2021    | 2022    |
|----------|--------|---------|---------|
| January  | 71.010 | 78.522  | 50.148  |
| February | 81.795 | 60.066  | 87.708  |
| March    | 92.432 | 121.907 | 95.567  |
| April    | 53.641 | 116.784 | 95.197  |
| May      | 86.001 | 123.290 | 107.731 |

|                  |                  |                  |                  |
|------------------|------------------|------------------|------------------|
| <b>June</b>      | 114.521          | 116.344          | 109.159          |
| <b>July</b>      | 78.623           | 103.711          | 74.635           |
| <b>August</b>    | 47.049           | 48.061           | 52.342           |
| <b>September</b> | 106.414          | 101.786          | 101.637          |
| <b>October</b>   | 89.844           | 81.298           | 100.235          |
| <b>November</b>  | 86.010           | 110.662          | 147.552          |
| <b>December</b>  | 123.435          | 98.857           | 83.835           |
| <b>TOTAL</b>     | <b>1.030.775</b> | <b>1.161.288</b> | <b>1.105.746</b> |

With the help of Windows QM, we started working the forecasting methods, as described in Chapter 1. Main criterion is the **minimum MAD** and **MAPE**. Initially we will present the results we got by using the naive, moving averages and the weighted moving averages methods. Table 4.2 below shows these results. Of course, we don't expect that these methods will give the minimum values for MAD and MAPE. What we expect is to show how well our model will run as we evolve our calculations. We see that with our initial approach we get values for MAD over 24.500 and for MAPE over 32,2%. If we had to choose one out of these three methods that would be the weighted moving averages. However, the fact that nor this method, or the moving averages do not minimize the values significantly compared to the naive, should make us suspicious that none of the three will give us good forecasts for 2023, which is our objective.

**Table 4.2 | Comparison between naive – moving averages – weighted moving averages**

|                                    | Methods |                 |                          |
|------------------------------------|---------|-----------------|--------------------------|
|                                    | NAIVE   | Moving Averages | Weighted Moving Averages |
|                                    |         |                 |                          |
| Measure                            | Value   | Value           | Value                    |
| MAD (Mean Absolute Deviation)      | 27.435  | 26.695          | 24.819                   |
| MAPE (Mean Absolute Percent Error) | 33,95%  | 34,45%          | 32,26%                   |

### **Exponential smoothing and exponential smoothing with trend**

Next comparison will be the exponential smoothing and exponential smoothing with trend, with three values for alpha ( $\alpha$ ) parameter: 0.1, 0.25, 0.5. We must remind here that a value for alpha towards 1 means that the latest values are more weighted. Table 4.3 below shows us the results for these two methods:

**Table 4.3 | Comparison between smoothing and exponential smoothing with trend**

|                                    | Methods               |        |        |                                  |         |        |
|------------------------------------|-----------------------|--------|--------|----------------------------------|---------|--------|
|                                    | Exponential Smoothing |        |        | Exponential Smoothing with trend |         |        |
|                                    | a=.5                  | a=.25  | a=.1   | a,b=.5                           | a,b=.25 | a,b=.1 |
| Measure                            | Value                 | Value  | Value  | Value                            | Value   | Value  |
| MAD (Mean Absolute Deviation)      | 23.747                | 21.595 | 21.212 | 26.169                           | 22.194  | 21.099 |
| MAPE (Mean Absolute Percent Error) | 30,38%                | 27,43% | 25,75% | 33,21%                           | 28,35%  | 25,79% |

We notice that our values for MAD and MAPE are further minimized for alpha equal to 0.1. MAD decreased to about 21.000 whereas MAPE decreased to about 25,7%. Our results improved, however it seems that still there is room for further decrease of MAD and MAPE. At this point we need to highlight that every professional / manager needs to know the market that his or her products address to and must have a sense of how demand varies. Thus, speaking about agricultural machinery and their spare parts, we expect a trend in demand as well as a seasonality. Specifically for seasonality, that should occur because agricultural tractors are not operating all the year.

#### **Regression with trend and seasonality**

Nevertheless, we expect from our methods to prove it as well and more specifically that regression with trend and seasonal components will provide us with constructive results. Those two will be our final set of methods. Table 4.4 shows these results:

**Table 4.4 | Comparison between regression with trend / regression with seasonality**

|                                    | Methods               |                             |
|------------------------------------|-----------------------|-----------------------------|
|                                    | Regression with Trend | Regression with Seasonality |
|                                    |                       |                             |
| Measure                            | Value                 | Value                       |
| MAD (Mean Absolute Deviation)      | 18.268                | 12.849                      |
| MAPE (Mean Absolute Percent Error) | 19,94%                | 13,68%                      |

As expected, these two methods would further decrease MAD and MAPE. More specifically regression with seasonality gives us very good results, decreasing MAD to the value of 12.849 and MAPE to the value of 13,68%. Regression with seasonality gave us another important element, which is that seasonality appears on January, February and August. That is reasonable, because farmers do not harvest or sow during these months. Thus, tractors are used less and less spare parts are needed for service or maintenance. The positive outcome



we took from regression with seasonality will be used for forecasting demand in 2023. In table 4.5 the forecast for 2023 is presented:

**Table 4.5 | Forecast for 2023**

|                  | <b>Forecast 2023</b> |
|------------------|----------------------|
| <b>January</b>   | 73.178               |
| <b>February</b>  | 83.141               |
| <b>March</b>     | 106.174              |
| <b>April</b>     | 106.450              |
| <b>May</b>       | 106.726              |
| <b>June</b>      | 107.002              |
| <b>July</b>      | 107.277              |
| <b>August</b>    | 55.769               |
| <b>September</b> | 107.829              |
| <b>October</b>   | 108.105              |
| <b>November</b>  | 108.381              |
| <b>December</b>  | 108.656              |
| <b>TOTAL</b>     | <b>1.178.689</b>     |

#### **Linking theory to practice | Check for proper application**

This dissertation started during 2023, so by using data of older years we attempted to forecast the sales of the inventory in 2023. As long as this dissertation will finally be presented at the beginning of 2024, we have the opportunity to compare our forecast with the **actual** results of the company and see whether our approach was efficient or not. In table 4.6 we can see this comparison:

**Table 4.6 | Forecast for 2023 vs Actual 2023**

|                  | <b>Forecast 2023</b> | <b>Actual 2023</b> |
|------------------|----------------------|--------------------|
| <b>January</b>   | 73.178               | 75.314             |
| <b>February</b>  | 83.141               | 95.784             |
| <b>March</b>     | 106.174              | 167.514            |
| <b>April</b>     | 106.450              | 96.719             |
| <b>May</b>       | 106.726              | 96.108             |
| <b>June</b>      | 107.002              | 129.851            |
| <b>July</b>      | 107.277              | 69.630             |
| <b>August</b>    | 55.769               | 59.924             |
| <b>September</b> | 107.829              | 103.186            |
| <b>October</b>   | 108.105              | 111.957            |
| <b>November</b>  | 108.381              | 96.701             |
| <b>December</b>  | 108.656              | 103.797            |
| <b>TOTAL</b>     | <b>1.178.689</b>     | <b>1.206.484</b>   |

We can see that our annual total forecast was just 2,3% far off the actual results of the company, and as this chapter shows the bond between theory and practice, the actual results are proof of proper application of the theory. As mentioned many times before, forecasts will never be accurate, but our case shows that proper application of the theory in real life can lead us in laying foundations for establishing viable and reasonable business plans in the professional life. Significant factors are that managers should know their market and products. In addition, suitable assumptions concerning changes in the product range or the market should be made. In any case forecasting methods give us the tools to approach forecasts for many possible scenarios in real life.

#### 4.4 Inventory ABC Analysis

---

As mentioned at the theory, ABC analysis can be very useful, because it helps us define our SKUs in three categories related to the value of the units. In real life that is very practical, because in inventories such as ours we have over 19.000 SKUs. First of all we need to define which of them are movable, an information that ABC analysis can also give to us. Thus, running an ABC analysis in our inventory for the last year (2022) out of about 19.080 SKUs, 3.144 were used for that year. In Category A of the ABC analysis there are 283 SKUs, making up 70% of the total sales, while in Category B 615 SKUs are making up 20% of the total sales. Finally in Category C 2.246 SKUs are making up 10% of the total sales. Table 4.7 shows us the results of the ABC analysis.

Table 4.7 | ABC Analysis for 2022

| ABC Analysis |       |         |         |
|--------------|-------|---------|---------|
|              | Value | % Value | % Units |
| Category A   | 283   | 70%     | 9,0%    |
| Category B   | 615   | 20%     | 19,6%   |
| Category C   | 2246  | 10%     | 71,4%   |
| Movable      | 3144  |         |         |
| Total SKUs   | 19080 |         |         |

At this point we will sum up the advantages of the ABC Analysis in real life applications, especially for inventories such as ours with more than 19.000 SKUs:

- ✓ ABC analysis helps us separate the moving SKUs from the immobile ones
- ✓ Out of this procedure we may also define the dead stock. For inventories with industrial spare parts, items must not stay in the inventory for long because they have a specific timeframe that they may be used. That is the case for instance for spare parts such as lubricants, belts or rubbery spare parts, which they lose their physical or chemical properties over a relatively short time.
- ✓ After we categorize our inventory, we understand better our property. We realize the number of spare parts that are transferred and most importantly their size. In this way we may also organize our inventory better. For instance, bigger and more movable spare parts must be approached easily in order to load them quicker. For such type of spare parts calculating proper stock levels is also very important because such spare parts have higher ordering and carrying costs. Below we will further refer to that.

#### 4.5 Inventory Modeling

As written above we need to manage an inventory with more than 19.000 SKUs. Our ABC analysis helped us define the movable SKUs to 3.144 and categorize our products in the three categories of the analysis according to their value. After running the analysis for the three years that we are examining (2020 – 2021 – 2022), we conclude to the highest valued spare parts. Thus, ABC analysis is a tool that definitely assist us in understanding better our inventory and focus on the most important and most valued items of it. We present them in Table 4.8. Please note that prices and spare parts numbers have been avoided for confidentiality reasons.

**Table 4.8 | Highest Valued Parts according to ABC Analysis**

| <b>PART Description</b>      | <b>Sales Volume</b> | <b>YEAR</b> |
|------------------------------|---------------------|-------------|
| OIL DF 10-30 MULTI 20L       | 687                 | <b>2022</b> |
| OIL SDF 15-40 20L            | 613                 |             |
| OIL SDF 10-30 20L MULTI FCT  | 298                 |             |
| OIL DF 10/40 20L PREMIUM OIL | 113                 |             |
| TOOL D-TECH                  | 3                   |             |
| OIL 15-40W SDF               | 207                 |             |
| OIL DF 15/40 20L SPECIAL ENG | 139                 |             |
| OIL 5W30 20L                 | 81                  |             |
| OIL FILTER                   | 1010                |             |
| DIESEL FILTER                | 175                 |             |
| OIL DF 10-30 MULTI 20L       | 1054                | <b>2021</b> |
| OIL SDF 15-40 20L            | 700                 |             |
| OIL SDF 10-30 20L MULTI FCT  | 579                 |             |
| TOOL D-TECH                  | 6                   |             |
| OIL DF 10/40 20L PREMIUM OIL | 207                 |             |
| OIL DF 15/40 20L SPECIAL ENG | 224                 |             |
| OIL 15-40W SDF               | 232                 |             |
| OIL 5W30 20L                 | 95                  |             |
| OIL DF 10-30 MULTI 20L       | 1077                | <b>2020</b> |
| OIL SDF 15-40 20L            | 990                 |             |
| OIL SDF 10-30 20L MULTI FCT  | 412                 |             |
| OIL DF 10/40 20L PREMIUM OIL | 243                 |             |
| TOOL D-TECH                  | 4                   |             |
| OIL 15-40W SDF               | 212                 |             |
| CLUTCH PLATE                 | 23                  |             |
| ENGINE                       | 1                   |             |
| OIL 20W50 PROFITECH 20 LIT   | 185                 |             |
| VALVOLINE 90 LS              | 90                  |             |
| OIL DF 15/40 20L SPECIAL ENG | 111                 |             |
| HYDRAULICS FILTER            | 467                 |             |

Generally, almost 40% of this inventory consists of oils, fluids and filters (air, oil and fuel). Having concluded on that, reasonably the first three parts with the highest sales in price are oils every year. That is shown below in Table 4.9.

**Table 4.9 | Top 3 highest Valued Parts according to ABC Analysis for 2020 - 2022**

| PART                        | 2022 | 2021 | 2020 |
|-----------------------------|------|------|------|
| OIL DF 10-30 MULTI 20L      | 687  | 1054 | 1077 |
| OIL SDF 15-40 20L           | 613  | 700  | 990  |
| OIL SDF 10-30 20L MULTI FCT | 298  | 579  | 412  |

Before running a model for these parts we need also to forecast their demand per month in units for 2023. Unfortunately, we only have the demand per month only for the total amount of sales in price. As for parts we have the total sales in units of each part per year. We could divide the total annual demand by 12 to find the equal monthly demand. Instead, we will **assume** that the sales in units of each part follow the percentage of the total annual sales in price. Although we don't have the real numbers, we approached their demand in a reasonable way. Table 4.10 below shows us these results:

| Table 4.10 SKU   Demand per month in 3 years |    |                          |                   |                               |
|--|----|--------------------------|-------------------|-------------------------------|
|  |    | DF 10-30<br>MULTI<br>20L | SDF 15-<br>40 20L | SDF 10-30<br>20L MULTI<br>FCT |
| 2020   | 1  | 74                       | 68                | 28                            |
|  | 2  | 85                       | 79                | 33                            |
|  | 3  | 97                       | 89                | 37                            |
|  | 4  | 56                       | 52                | 21                            |
|  | 5  | 90                       | 83                | 34                            |
|  | 6  | 120                      | 110               | 46                            |
|  | 7  | 82                       | 76                | 31                            |
|  | 8  | 49                       | 45                | 19                            |
|  | 9  | 111                      | 102               | 43                            |
|  | 10 | 94                       | 86                | 36                            |
|  | 11 | 90                       | 83                | 34                            |
|  | 12 | 129                      | 119               | 49                            |
| 2021   | 13 | 71                       | 47                | 39                            |
|  | 14 | 55                       | 36                | 30                            |
|  | 15 | 111                      | 73                | 61                            |
|  | 16 | 106                      | 70                | 58                            |
|  | 17 | 112                      | 74                | 61                            |
|  | 18 | 106                      | 70                | 58                            |
|  | 19 | 94                       | 63                | 52                            |
|  | 20 | 44                       | 29                | 24                            |
|  | 21 | 92                       | 61                | 51                            |
|  | 22 | 74                       | 49                | 41                            |
|  | 23 | 100                      | 67                | 55                            |
|  | 24 | 90                       | 60                | 49                            |
|  | 25 | 31                       | 28                | 14                            |

|             |    |    |    |    |
|-------------|----|----|----|----|
| <b>2022</b> | 26 | 54 | 49 | 24 |
|             | 27 | 59 | 53 | 26 |
|             | 28 | 59 | 53 | 26 |
|             | 29 | 67 | 60 | 29 |
|             | 30 | 68 | 61 | 29 |
|             | 31 | 46 | 41 | 20 |
|             | 32 | 33 | 29 | 14 |
|             | 33 | 63 | 56 | 27 |
|             | 34 | 62 | 56 | 27 |
|             | 35 | 92 | 82 | 40 |
|             | 36 | 52 | 46 | 23 |

After defining the demand per month in units for the top three highest valued parts for the years 2020-2022, we will now forecast the demand for these three parts for 2023. Again, we will use Simulacion 5.0. The results are shown below in Table 4.11.

**Table 4.11 | Forecast for 2023**

| <b>SKU   Forecast for 2023</b> |           |                                   |                              |  |
|--------------------------------|-----------|-----------------------------------|------------------------------|--|
|                                |           | <b>DF 10-30<br/>MULTI<br/>20L</b> | <b>SDF<br/>15-40<br/>20L</b> | <b>SDF 10-30<br/>20L MULTI<br/>FCT</b> |
| <b>2023</b>                    | January   | 28,01                             | 18,02                        | 18,21                                  |
|                                | February  | 33,96                             | 24,71                        | 19,95                                  |
|                                | March     | 62,93                             | 49,73                        | 32,26                                  |
|                                | April     | 42,87                             | 28,47                        | 31,89                                  |
|                                | May       | 60,35                             | 47,25                        | 31,53                                  |
|                                | June      | 59,07                             | 46,01                        | 31,16                                  |
|                                | July      | 57,78                             | 30,04                        | 30,79                                  |
|                                | August    | 10,91                             | 4,63                         | 10,15                                  |
|                                | September | 55,21                             | 42,29                        | 30,06                                  |
|                                | October   | 53,92                             | 41,05                        | 29,69                                  |
|                                | November  | 52,64                             | 39,81                        | 29,32                                  |
|                                | December  | 51,35                             | 38,57                        | 28,96                                  |
| <b>TOTAL</b>                   |           | 569,00                            | 410,58                       | 323,96                                 |

#### **4.6 Defining the EOQ – Considering Uncertainty with Monte Carlo simulations**

The most significant objective of all this analysis is the calculation of optimal levels of inventory for each item. ABC analysis gives managers the opportunity to focus on the most crucial items of their inventory and run different strategies for each one in order to avoid shortages or stockouts and at the same time minimize the cost of their inventory.

In our case study we will define the EOQ and run Monte Carlo simulation for the first most valued item of our inventory: the 'DF 10-30 MULTI 20L'. We will run the simulation for the forecasted demand of 2023 weekly, by dividing the monthly forecasted demand of 2023 to 4 in order to define demand for every week of 2023.

First of all let's define certain necessary values for this item:

Lead time (default by the manufacturer) = 2 weeks

Initial Inventory = 20 units

Order Cost = 95€

Holding Cost = 2,75€

Lost Sales Cost = 114€

We also need to add that Monte Carlo simulation uses the Poisson distribution and we used the crystal ball software package to produce the simulations. After running multiple simulations we get the optimal EOQ values:

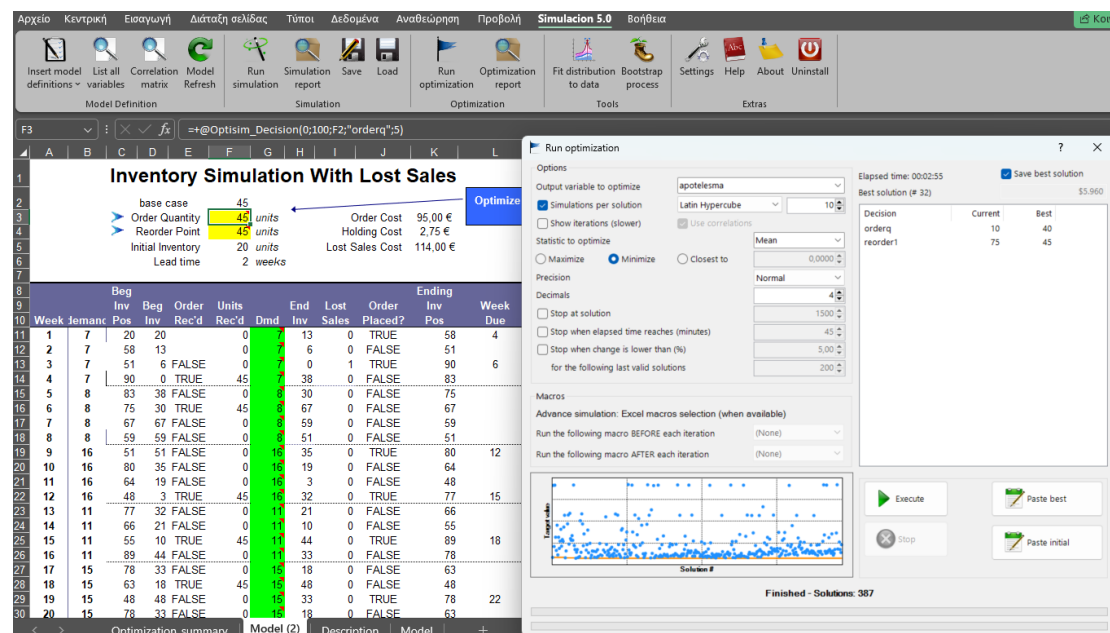
Order Quantity = 40 units

Reorder Point = 45 units, minimizing the costs (Holding – Ordering – Lost Sales) to: 5.568€

| Total Annual Costs |         |       |         |
|--------------------|---------|-------|---------|
| € 3.839            | € 1.615 | € 114 | € 5.568 |

Figure 4.12 below shows the end of the optimization process of the Monte Carlo simulation. We may notice that the Crystal Ball checked 387 solutions in less than 3 minutes.

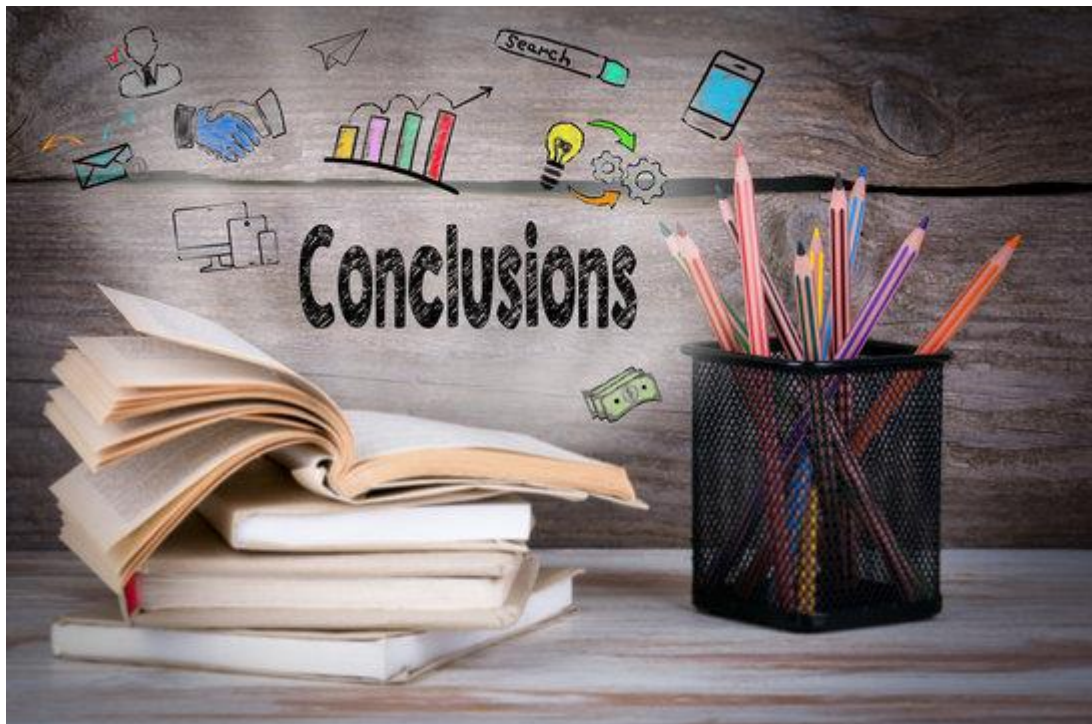
Figure 4.12 | End of Monte Carlo simulation



Thus, by using a very simple tool we may define the EOQ as well as the minimization of our inventory per item. As long as the necessary data (lead time, initial inventory, holding cost, ordering cost, lost sales) are correctly defined the tools are present to assist us define optimal levels for each item of our inventory. For our inventory we will not run any other simulations at this dissertation. We applied the Monte Carlo simulation for the highest valued item and following the same approach we can easily apply it to any item of our inventory in order to define the EOQ and minimize the cost.

CHAPTER  
**5**

## Conclusions





## 5.1 Conclusions

---

Proper inventory management is a key factor for every business, because it is one of the most expensive assets of a company. As already mentioned, it may require up to 50% of the total invested capital. Thus, it goes without saying that managing almost 50% of our business in a proper way, will lay the foundation for a successful business management.

In our case we examined an inventory with spare parts for agricultural machinery. For confidentiality reasons only the necessary numbers are showed and used. The manufacturer of the machinery is well known globally and in our country is represented by also a well known Greek company-importer. Before analysing any sector, managers need to know the market and its needs very well. In the case of agricultural machinery we need to take into consideration two key factors:

- ✓ For this type of machinery it is not easy to drive them many kilometres away from their base to maintain or service them.
- ✓ Most importantly if a problem occurs, it must be solved as soon as possible, so that the tractor will be as soon as possible back on the field to perform the job for the farmer. There is little time to waste in this business.

Thus, it is very important to forecast a well equipped inventory with the necessary spare parts for the tractors. It is of vital importance to be able to provide these customers with immediate assistance. At once you gain **high customer satisfaction** and **customer loyalty**.

These spare parts are in many cases very large in volume and weight. Manufacturers have a specific lead time to deliver the spare part from their inventories. The basic option of delivery is by road, which is the cheapest one. Of course, if an immediate necessity occurs there is the option of the airplane. However, this is a very expensive option due to the large volume and weight as mentioned above. Thus, another advantage of proper forecasting in our case is the **cost minimization of our inventory**.

Our primary focus was to forecast our inventory for 2023 both in value (in €) and in units. We used data from the last three years (2020-2022) to perform time-series forecasting. Before we began doing the assessment, we calculated two basic indices to see how good financially this inventory is. The values of the ratio are taken from the **balance sheet** of the firm.

### 1. The **turnover ratio**,

$$\text{Turnover ratio} = \frac{\text{Cost of goods sold in a period}}{\text{Cost of average inventory in the same period}} = \frac{742.860}{1.861.394} = 0,399$$

By literature reviews, a ratio less than 1 means that a company carries too much inventory.

### 2. The **Days In Inventory Index**,

$$\text{Days in inventory} = \frac{360}{\text{Turnover ratio}} = \frac{360}{0,399} = 902,057$$

That index shows us a 'days in inventory' of about 2,5 years.

Thus, by defining two simple indices we get two significant conclusions for the inventory that we examine:

1. This inventory carries too much stock from the past. Probably most of it is dead stock and it should be removed from the inventory.



2. Not only it ruins the financial health of the company – among others the holding cost is increased - but it also occupies space in the inventory which may be used better after reorganizing the inventory.

Then, we forecasted our inventory in value (in €), using the criterion, as referred in bibliography, of the lowest **MAD (Mean Absolute Deviation)** and **MAPE (Mean Absolute Percent Error)**. Again here, every manager needs to know well its market and what to expect. We don't expect for this type of business the demand to be such of a cyclical or random component. We should expect a trend component with seasonality pattern in it, because there are months when farmers are not using their machinery so much. Nowadays, appropriate software leads us to these conclusions. QM for windows - after assessing various methods (naive, moving averages, weighted moving averages, exponential smoothing, exponential smoothing with trend, regression with trend and regression with seasonality) - gave us as the best forecasting method the regression with seasonality, showing that the latter occurs in months January, February and August with lowest demand. Then, we forecasted demand for year 2023 and because this dissertation is presented in 2024 we had the opportunity to check the validity of our forecasting. Our forecast was just 2,3% far off the actual results of the company in 2023. Thus, we conclude that:

- ✓ Forecasting can be a useful tool in establishing viable and reasonable business plans at the end of each year for the next one based on previous years data. Of course, forecasting must be monitored and updated according to each product needs and according to how the market is developing, because as already mentioned many times forecasts will never be accurate. However, they can be the base for market realization and business development as it was proved in our case study.

Following the same route we forecasted the demand for certain SKUs (Stock Keeping Units). However, in order to achieve this we took advantage of another analysis tool: the ABC analysis. The case with industrial spare parts is that they may include a large number of SKUs. In our case the manufacturer has more than 19.000 SKUs. However, the ABC analysis help us focus on the ones that contribute most financially and defines which of them are not movable. It is very important to realize that out of these 19.000 SKUs, only about 1/3 of them are really used. Thus, we briefly present the advantages of an ABC analysis in Inventory Management:

- ✓ Items are categorized according to their value and financial contribution on the business. Managers can focus on the important items and manage them efficiently.
- ✓ Different strategies can be implemented for each category in order to hold optimal levels for each unit, which will also lead to cost minimization of the inventory.

After implementing the ABC analysis we concluded on the three most valued items of the inventory and we presented a forecast for 2023. As suggested above after applying the ABC analysis, we propose the optimal levels for the first valued item resulting in the cost minimization of the inventory for this item. It is very important for such types of inventories to suggest optimal levels for important items because in cases of large volume and weights per item, high holding costs occur. In industrial spare parts manufacturers deliver the spare parts with a specific lead time. Thus, by using appropriate software, we can calculate the EOQ, which is the reorder point and the reorder quantity. We used for these calculations the Crystall Ball software package to produce Monte Carlo simulation.

Summarizing all the above, we may conclude that although we didn't have full access in the actual numbers of an inventory of agricultural spare parts, by using appropriate literature sources we approached the most basic aspects of it and we had a very good understanding of inventory management.

Finally, **future work** which may be done is related to:

- A. The financial consolidation of the inventory due to the high values of the Turnover Ratio and the Days in Inventory Index. Clearing the old and probably dead stock will not only improve the financial health of the inventory, but will also create space for the better SKUs management. After this process we expect a value of turnover ratio around 1.
- B. Inventory best practices, with focus on optimal levels that will result in cost (ordering and holding) minimization of the inventory.

Finally, we will remind once more, that through this dissertation, only the necessary data and calculations have been shown and used due to confidentiality reasons. No appendices will be used and the names of the companies have also been avoided.

## References

---

Barry Render, Ralph M. Stair Jr., Michael E. Hanna, Trevor S. Hale *Quantitative Analysis for Management, Global Edition*. Pearson Education UK, 2017

Taylor, Bernard W. *Introduction to Management Science*. Harlow, Pearson, 2016

Taha, Hamdy A. *Operations Research: An Introduction*. Harlow, Essex, Pearson Education Limited, 2017

Chatfield, Chris. *Time-Series Forecasting*. Chapman And Hall/Crc, 2000

Vandeput, Nicolas, and Walter De. *Inventory Optimization Models and Simulations*. Berlin De Gruyter, 2020.

Richard De Neufville, and Stefan Scholtes. *Flexibility in Engineering Design*. Cambridge, Mass., MIT Press, 2011.

Top 10 Tractor Companies in the World - Tractor List 2021. *Tractorjunction*, 27 June 2020, [www.tractorjunction.com/blog/top-10-tractor-companies-in-the-world-tractor-list/](http://www.tractorjunction.com/blog/top-10-tractor-companies-in-the-world-tractor-list/)

Tractor | Products & Solutions | Kubota Global Site. *Www.kubota.com*, [www.kubota.com/products/tractor/index.html](http://www.kubota.com/products/tractor/index.html)

All Tractors - DEUTZ-FAHR. *Www.deutz-fahr.com*, [www.deutz-fahr.com/en-nd/tractors](http://www.deutz-fahr.com/en-nd/tractors)

Original Spare Parts and Lubricants - DEUTZ-FAHR. *Www.deutz-fahr.com*, [www.deutz-fahr.com/en-nd/spare-parts-lubricants](http://www.deutz-fahr.com/en-nd/spare-parts-lubricants)

Statistics - ELSTAT. *Www.statistics.gr*, [www.statistics.gr/en/statistics/-/publication/SPG43/-](http://www.statistics.gr/en/statistics/-/publication/SPG43/-)

Author's Statement: I hereby expressly declare that, according to the article 8 of Law 1559/1986, this dissertation is solely the product of my personal work, does not infringe any intellectual property, personality and personal data rights of third parties, does not contain works/contributions from third parties for which the permission of the authors/beneficiaries is required, is not the product of partial or total plagiarism, and that the sources used are limited to the literature references alone and meet the rules of scientific citations.