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Development of a method for the selection of the stock management technique in the case of Make to Order company

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Introduction

The stock management is a topic that, year after year, assumes an increasingly important role inside a company: in one hand, there is the necessity to maintain a sufficient level of stock to be competitive and to have short response time to market, in the other hand, there is the target to reduce this level in order to contain the costs of the warehouse, that can be important in the company management.
Furthermore, there are different stock management approach to choose from: the traditional Reorder Point and the MRP (Material Requirements Planning) based on the free collateral technique, or the leaner kanban and JIS (Just In Sequence) approaches, or the VMI (Vendor Managed Inventory), in which the management structure considerably changes.
For these reasons, there is the need to develop a method that helps the company to be guided in the choice of the stock management approach depending on the type of the code.
The following thesis work sets exactly this goal, starting from a literature search on the different and more used stock management approaches, to move on the development of a tool that can be useful in the stock management.
The first two parts of this work (literature research and method developing) are made in collaboration with professor A. Ishizaka of the University of Portsmouth (United Kingdom), who, using the great knowledges on the topic, helped in the writing of these pages.
After these two parts, the method will be validated on a scientific level, collaborating with the logistic managers of different companies in the territory.
At the end, the work will be focused on the application of the developed method to understand if it is a real helping and useful tool to use in this environment: this part will be closed with a valuation of the warehouse costs to verify the real effectiveness of the applied method
The following work, then, will consist in four main parts: the first is a literature research on the stock management techniques, the second is the development of the method, the third is the scientific validation of this method, and the last is represented by the application of the work on a case study, a Make to Order company that needs to have a more efficient stock management in order to reduce the costs and to be more competitive in the market.
The Make to Order (MTO) companies, with the Engineering to Order (ETO) and Purchase to Order (PTO) ones, have the higher response time to the market, for this reason

they need to reduce it as much as possible, having a correct level of stock, that allows to not excessively increase the warehouse costs: so, it is chosen a MTO company, that is the more appropriate environment in which is possible to test the method.

Chapter 1

Stocks of materials

Stocks are formed whenever an organization acquires materials that it does not use immediately: a common practice has a delivery of material arriving from a supplier and this is kept in stock until needed.[1]

A customer is anyone or anything whose demand is met by removing units from stock, the customers can be internal, when they are some entities within the same organization, or external, when they come from outside the organization; similarly, a supplier is anyone or anything that replenishes or adds to stock, and again it can be either internal or external (D. Waters, 2003).

The stock cycle can be represented by the following framework:

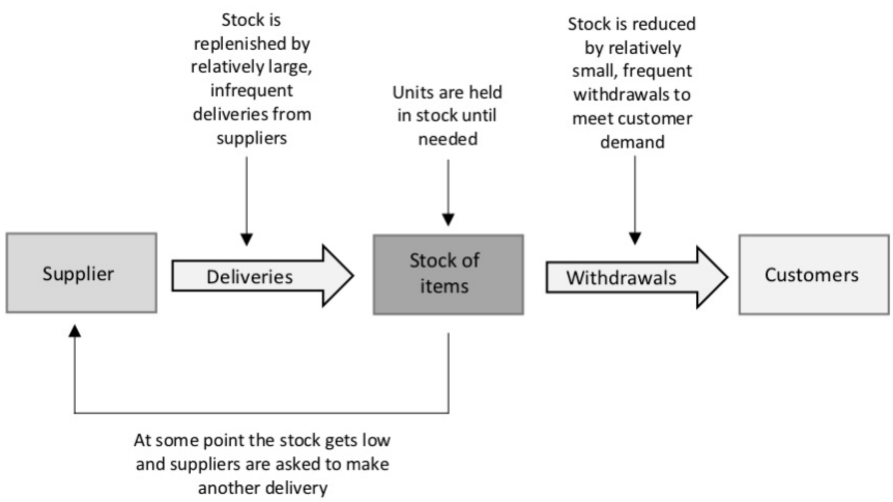


Figure 1.1 *The stock cycle*

[1] To avoid misunderstanding in the following thesis they will be used the ensuing definitions:

- Stock consists off all the goods and materials that are stored by an organization. It is a store of items that is kept for future use
- An inventory is a list of the items held in stock

Organizations hold different types of stock (D. Waters, 2003):

- *Cycle stock*: it is the normal stock used during operations. Stocks in this case are used for different reasons: to operate in batch or to minimized some costs (tooling cost, shipping cost). Cycle stocks are strictly related to job cycle of the organization.
- *Safety stock*: stocks are used to face the uncertainty on the demand of customers or the uncertainty on the supplier. It is a reserve of materials that is held for emergencies.
- *Seasonal stock*: it is used to maintain stable operations through seasonal variation in demand.
- *Pipeline stock*: it is used when the materials from the supplier needs long time to get to the customer.
- *Decoupling stock*: it is used in specific manufacturing processes, in which it is necessary to work materials with different production time or production modality.
- *Speculative stock*: it is used by companies to face the variation of material price (for example in the gold business). In this way, it is possible to minimize purchasing cost.

Another important aspect to consider is the cost of the stock: there are four types of cost linked to stock (D. Waters, 2003).

All stocks incur costs. These vary widely, but are typically around 20 per cent of the value held a year. It is not surprising that organizations want to minimize their inventory costs but they cannot do this by simply reducing stock. Sometimes low stocks give a minimum cost, but this is not inevitable and low stocks can lead to shortages that disrupt operations and have very high costs. To look at this balance more closely, it is needed to describe some details of the costs involved.

The first type of cost linked to stocks is the unit cost: this is the price charged by suppliers for one unit of the item, or the cost to the organization of acquiring on unit. It can be difficult to find an accurate unit cost, and this is particularly true when there are several suppliers offering alternative products or giving different purchase conditions. If the company makes the items itself, it can be difficult to set a reliable production cost or to calculate a valid transfer price. At last is possible to use as unit cost the whole industrial cost or direct cost.

Secondly there is the reorder cost: this is the cost of placing a repeat order for the item and might include allowances for drawing-up an order (with checking, getting authorization, clearance and distribution), correspondence and telephone costs, receiving (with unloading, checking and testing), supervision, use of equipment and follow-up.

Sometimes costs such as quality control, transport, delivery, sorting and movement of received goods are included in the reorder cost.
The third kind of cost linked to stocks is the holding cost: this is the cost of holding one unit of an item in stock for one period of time. The different costs belonging to this group are explained in the following chart

Type of cost	% of unit cost
Cost of money	10 ÷ 15
Storage space	2 ÷ 5
Loss	4 ÷ 6
Hangling	1 ÷ 2
Administration	1 ÷ 2
Insurance	1 ÷ 5
TOTAL	**19 ÷ 35**

Table 1.1 *Different types of holding costs of the stock*

Another type of cost belonging to this group is the foregone earning of alternative investments: the company decides to use one part of the capital to buying materials, instead of using it to invest in something else.
The last cost to consider is the shortage cost: if an organization runs out of stock for an item and there is demand from a customer, then there is a shortage that has an associated cost. In the simplest case a retailer might lose the profit from a lost sale. Usually, though, the effects of shortages are wider than this and include loss of goodwill, loss of future sales and loss of reputation: many of these shortage costs are difficult to measure.
In conclusion, there is a huge variation in the stockholdings of different industries and organizations. Building materials, such as sand and gravel, need large storage areas, but virtually no special attention; expensive items, such as gold and diamonds, need small storage areas, but with high security; perishable good, such as frozen foods, need special types of storage. Despite these differences it is possible to see that stocks play an important role in every organization. At the very least, stocks allow operations to become more efficient and productive. Stocks affect lead times and availability of materials, thereby affecting customer service, satisfaction, and the perceived value of products. They affect operating cost, and hence profit, return on assets, return on investment and just about every other measure of financial performance. They affect broader operations, by determining the best size, location and type of facilities; they can be risky, because of storage requirements, safety, health and environmental concerns. Then, the most important problem that has to be solved is how to manage the stocks of a company keeping in mind the different costs.

1.1 Indicators

To understand the quality of the stock management, exist two groups of indicator.
The first one is the group of service indicators, that help the supplier to understand the satisfaction level of the customer and then it is linked to the service level of the company (SL).
Some of the service indicators examine the quantity requested from the customer, other examine the delivery time to the customer

- quantity indicators:

$$SL_{quantity} = \frac{Delivered\ quantities}{Requested\ quantities}\ (\%) \tag{1.1}$$

$$SL_{order} = \frac{Number\ of\ delivered\ orders}{Total\ number\ of\ the\ orders}\ (\%) \tag{1.2}$$

$$FILL\ RATE = SL_{MIX} = \frac{Number\ of\ delivered\ lines\ of\ the\ order}{Total\ number\ of\ the\ order\ lines}\ (\%) \tag{1.3}$$

- time indicators:

$$SL_{timeliness} = \frac{Real\ delivery\ time}{Offered\ delivery\ time}\ (\%) \tag{1.4}$$

$$SL_{speed} = \frac{Delivery\ time}{Best\ competitor's\ delivery\ time}\ (\%) \tag{1.5}$$

The second group of indicators is called efficiency indicators, and it considers also the amount of material that is present in the warehouse, this is the case of the index of rotation (IR).

$$IR_{quantity} = \frac{Consuption}{Average\ warehousing} \tag{1.6}$$

$$IR_{value} = \frac{Consuption \times Unit\ value}{Average\ warehousing\ value} = \frac{Value\ of\ use}{Average\ warehousing\ value} \tag{1.7}$$

The stocks management, then represent one of the most significant problem that a company has to face. In the following pages, they will be explained the different stock management methods.
There are basically two different type of demand that can be made from the customer to the supplier:

- independent demand, assume that the demand for an item is independent from the demand for any other item. Then the aggregate demand for an item is made up of many independent demands from separate customers.
- dependent demand, in which the demand for different items are related.

The first type of demand is often used for the forecasting of finished goods, the second, instead is used for the forecasting of the work in progress, that is linked to the finished goods demand.

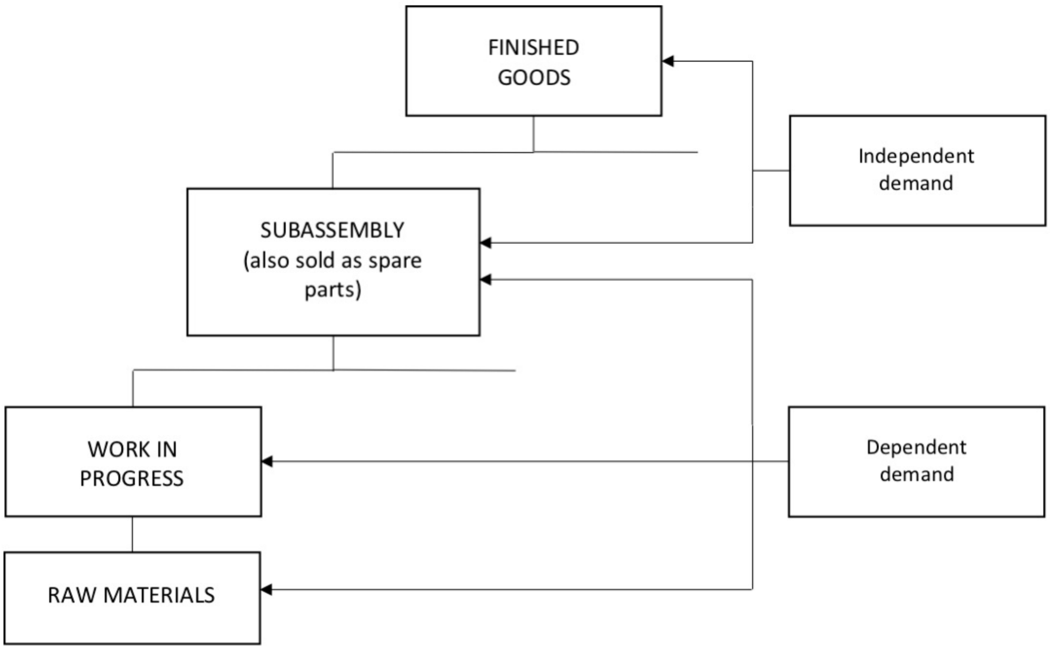


Figure 1.2 *Different types of demand: independent and dependent*

1.2 Economic Order Quantity

The first model takes an idealized stock and finds the fixed order size that minimized costs: this is the economic order quantity, which is the basis of most independent demand methods.

The approach is to build a model of an idealized inventory system and calculate the fixed order quantity that minimized total costs. This optimal order size is called the economic order quantity (EOQ) (D. Waters, 2003).

There are some assumptions to do for using the following method:

- the demand is known exactly, is continuous and is constant over time;
- all costs are known exactly and do not vary;
- no shortages are allowed;
- lead time is zero, so a delivery is made as soon as the order is placed;
- a single delivery is made for each order;
- replenishment is instantaneous, so all the orders arrive in stock at the same time and they can be used immediately

The assumptions give an idealized pattern for a stock level that is showed in the Figure 1.3.

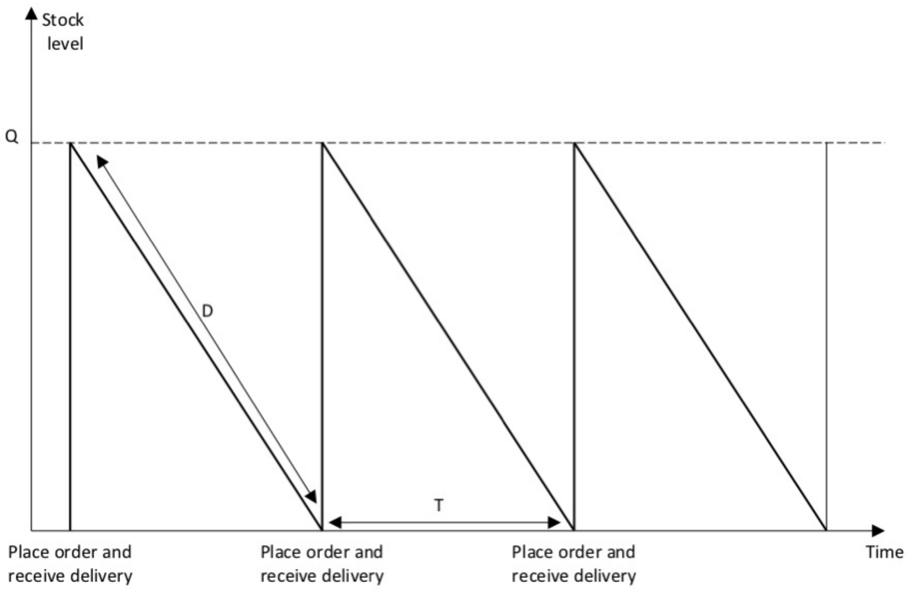


Figure 1.3 *Idealized pattern for a stock level*

There are three different variables in the pattern: order quantity (Q), which is the fixed order size that it is used, the cycle time (T) which is the time between two consecutive replenishment and the demand (D) which sets the number of units to be supplied from stock in a given time period.

The other variables to consider are the unit cost (U_C), the reorder cost (R_C), the holding cost (H_C) and the shortage cost (S_C).

The purpose of this analysis is to find an optimal value for order quantity (Q).

The first step of the analysis finds the total costs for a cycle:

$$total\ cost\ per\ cycle = unit\ cost\ component + reorder\ cost\ component + \ holding\ cost\ component \quad (1.8)$$

Analysing each component:

$$unit\ cost\ component = U_C \times Q \tag{1.9}$$

$$reorder\ cost\ component = R_C \times number\ of\ order\ placed \tag{1.10}$$

$$holding\ cost\ component = H_C \times \frac{Q}{2} \times T \tag{1.11}$$

Using (1.9), (1.10) and (1.11) in (1.8)

$$total\ cost\ per\ cycle = U_C \times Q + R_C + \frac{H_C \times Q \times T}{2} \tag{1.12}$$

Calculating the total cost per unit time and minimizing by Q, it is obtained the following formula for the EOQ:

$$EOQ = \sqrt{\frac{2 \times R_C \times D}{H_C}} \tag{1.13}$$

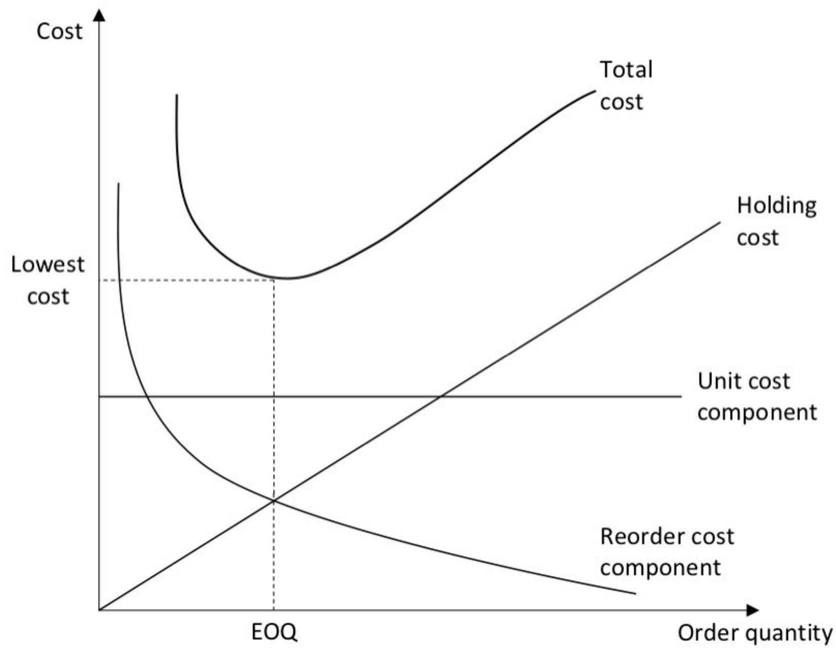


Figure 1.4 *Stock quantity that minimizes different costs: Economic Order Quantity (EOQ)*

Despite the EOQ quantity represent an important datum, it is not sufficient to manage the stocks of a company. Exist three large family of stocks management methods: the Traditional, the Just In Time (JIT) and the Vendor Managed Inventory (VMI) methods.

Chapter 2

Traditional Methods

The first group to consider is the Traditional Methods group. Belong to this group the Reorder Point Method, the Time Phased Order Point (TPOP) and the Material Requirements Planning (MRP).

2.1 Reorder Point Method

In the real situations, there are two types of uncertainty that has to be considered: the first is the lead time uncertainty and the second is the quantity uncertainty (De Toni, Panizzolo & Villa, 2013).
To face these two types of uncertainty it is necessary to implement a safety stock (SS) that is the total of the safety stock for lead time and the safety stock for the quantity.[2]

$$SS = SS_{LT} + SS_Q \tag{2.1}$$

After statistical analysis, it is possible to definite the sequent expression for the safety stock:

$$SS = z\sigma = z\sqrt{\overline{LT}\,{\sigma_D}^2 + \overline{D}^2\,{\sigma_{LT}}^2} \tag{2.2}$$

In which:

- z : safety factor, linked to the stock out risk
- $\overline{LT}$: average lead time
- $\overline{D}$: average customer demand
- σ_{LT} : lead time standard deviation
- σ_D : customer demand standard deviation

[2] It is necessary to explain the different parts that form the lead time; lead time is the sum of manufacturing, tooling, queue and handling times.

After safety stock definition, it is possible to classify the reorder point systems on the basis of two variable: reorder batch (that it can be fixed or variable) and the reorder frequency (fixed or variable).
Following this classification there are five different situations:

		FIXED REORDER QUANTITY	VARIABLE REORDER QUANTITY
VARIABLE REORDER FREQUENCY	with ROP	Q, R Sistem	S, R Sistem
FIXED REORDER FREQUENCY	with ROP	Q, R, T Sistem	S, R, T Sistem
	without ROP	–	S, T sistem

Figure 2.1 *Classification of different ROP systems*

2.1.1 Q, R System – Reorder point system

Considering the average consumption (A_c), the expression for the reorder level (R) is the following:

$$R = LT \times A_c + SS \tag{2.3}$$

In this case the reorder batch is the same quantity of the economic batch.

$$Q = EOQ \tag{2.4}$$

The pattern below shows the situation of Q, R system

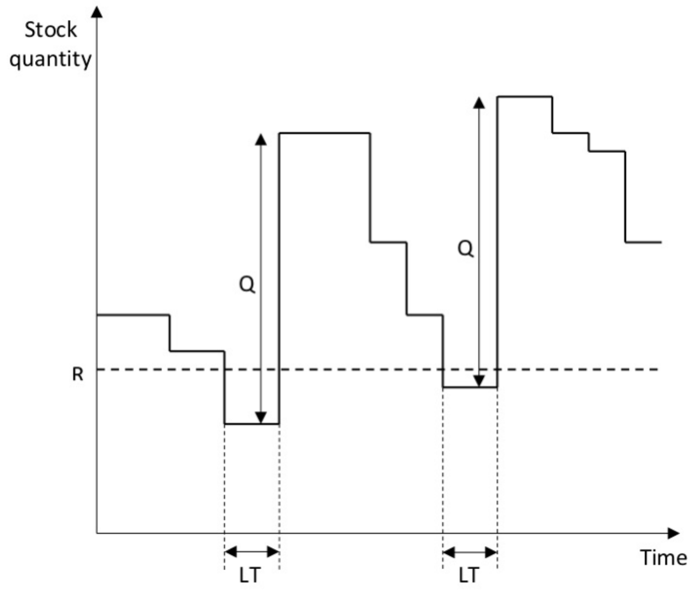


Figure 2.2 *Reorder point system (Q, R system)*

2.1.2 S, R System – Min Max System

The maximum level of the stock quantity is fixed (S). This could happen when there are some spatial or cost restrictions (for example, the space of the warehouse is limited).
In this case, there is the possibility to calculate the economic maximum level of the stock using the following expression:

$$S_{economic} = R + EOQ \tag{2.5}$$

In this case the situation is explained in Figure 2.3.

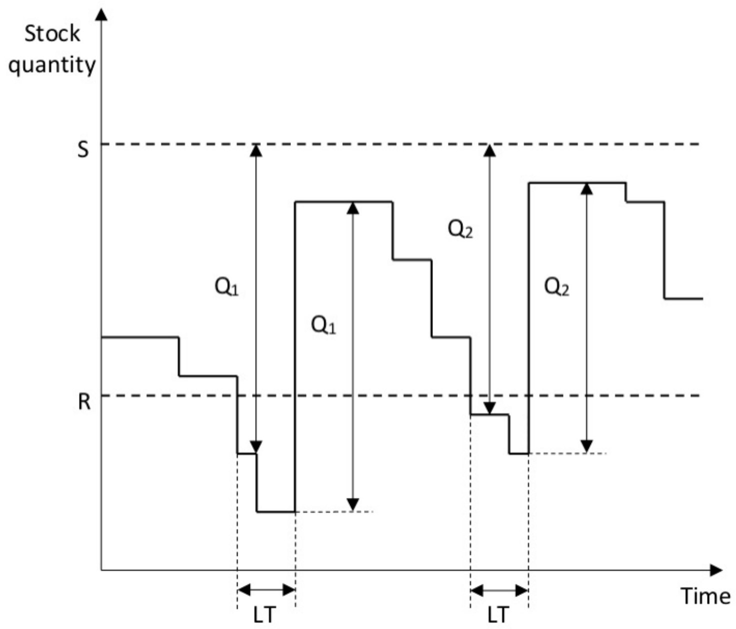


Figure 2.3 *Min max system (S, R system)*

2.1.3 Q, R, T System – Fixed periodicity reorder point system

In this and following situations it is necessary to define the reorder cycle quantity (T):

$$\frac{1}{reorder\ frequency} = T \tag{2.6}$$

In the Q, R, T system the reorder batch and the reorder frequency are fixed, there is also the reorder point: in this case the order is sent not only when the stock quantity is lesser than the reorder pointy quantity, but also when the time T is past.
In this case, it is possible to use the following expression for R point:

$$R = (LT + T) \times A_c + SS \tag{2.7}$$

This situation is shown in the following pattern

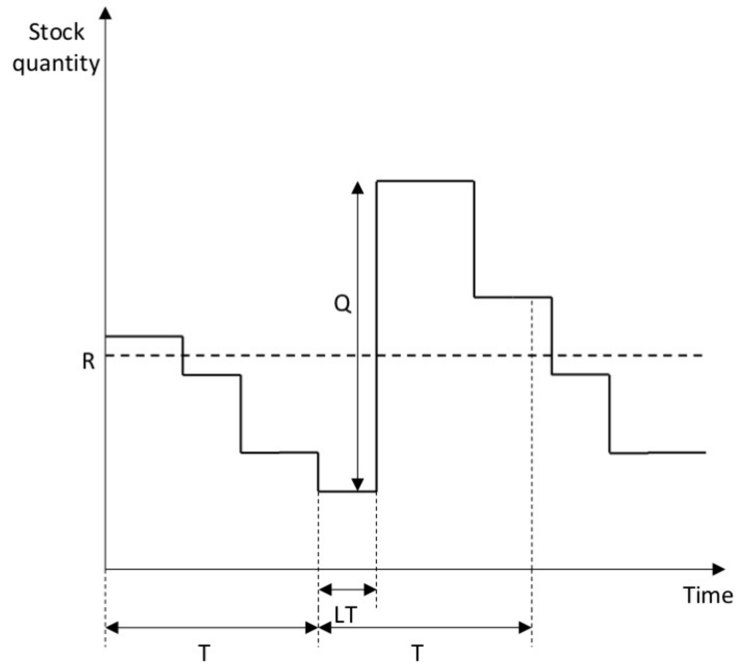


Figure 2.4 *Fixed periodicity reorder point system (Q, R, T system)*

Thanks to the fixed operation time this type of system is frequently used to manage in the best way the handling operations or the economic resources.

2.1.4 S, R, T System – Fixed periodicity Min Max System

Also in this case, the order is placed only when time T is past.
In this situation, the order quantity Q is not fixed.
The situation is shown in Figure 2.5.

2.1.5 S, T System – Fixed periodicity Min Max System without reorder point

Using this method, the order is placed when the time T is past.
Also in this case the quantity Q is not fixed but it is linked to the quantity S.
This last system is represented in Figure 2.6.

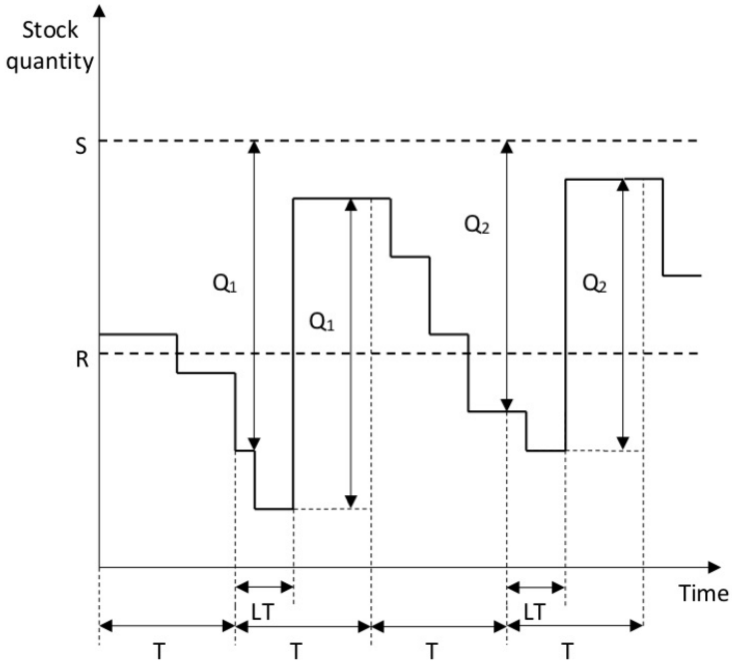


Figure 2.5 *Fixed periodicity min max system (S, R, T system)*

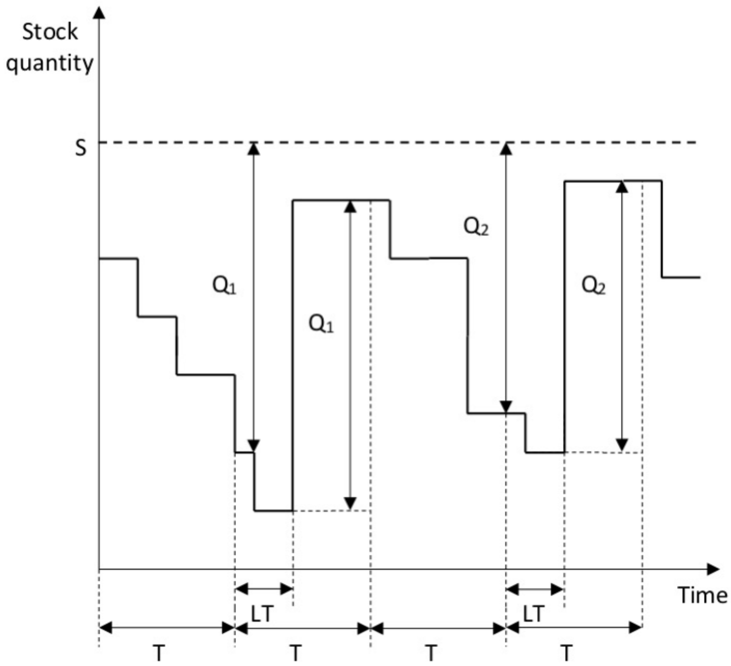


Figure 2.6 *Fixed periodicity min max system without reorder point (S, T system)*

2.2 Reorder point method evolutions

In 1961 Corke studied the reorder point model and its limitations: when EOQ < A_c * LT the model does not work.
In this case, it is necessary to consider not only the order just physically arrived, but also the orders sent to the supplier and still not received: this approach is called virtual stock. According to this model, so, the virtual stock is the sum of the physical stock and the pending orders.
All the methods described in these pages use a look back approach, in fact they need only historical data of the company and they do not look at the future situation.
At the beginning of sixties there was an important change in the habits of consumers: in these years, the market demand became more complex and the requests of the customers became more differentiated. Furthermore, in same years a new type of shop appeared: the supermarket, that changed forever the relationship between the customer and the producer, making the distribution net increasingly important.
Discounts and promotions, not used until this moment, became important for the supply chain management: producer started to use a new type of approach, the look ahead approach, to front the overshot demand during the promotions of supermarkets made by the suppliers.
It started to use a new method considering both historical data of the company and the future previsions, in this perspective it was necessary to change the relationship between producer and supplier, making it more linked: the suppliers started to share information with the producer.
The first development of the new approach it was called free collateral.
The stock level, called free collateral, it is calculated by the following expression:

$$Free\ collateral = virtual\ stock - forecast\ requirements \quad (2.8)$$

Therefore, the stock level calculated with this approach is compared with the reorder point level: in this case the reorder point quantity is equal to the safety stock, because all the requirements are just considered in the free collateral calculation, then it is sufficient to evaluate the possible variations (in lead time or in quantity).
With this approach two variables become important: the planning frequency and the planning period.
The comparison between traditional level stock calculation and free collateral is shown in the pattern bellow

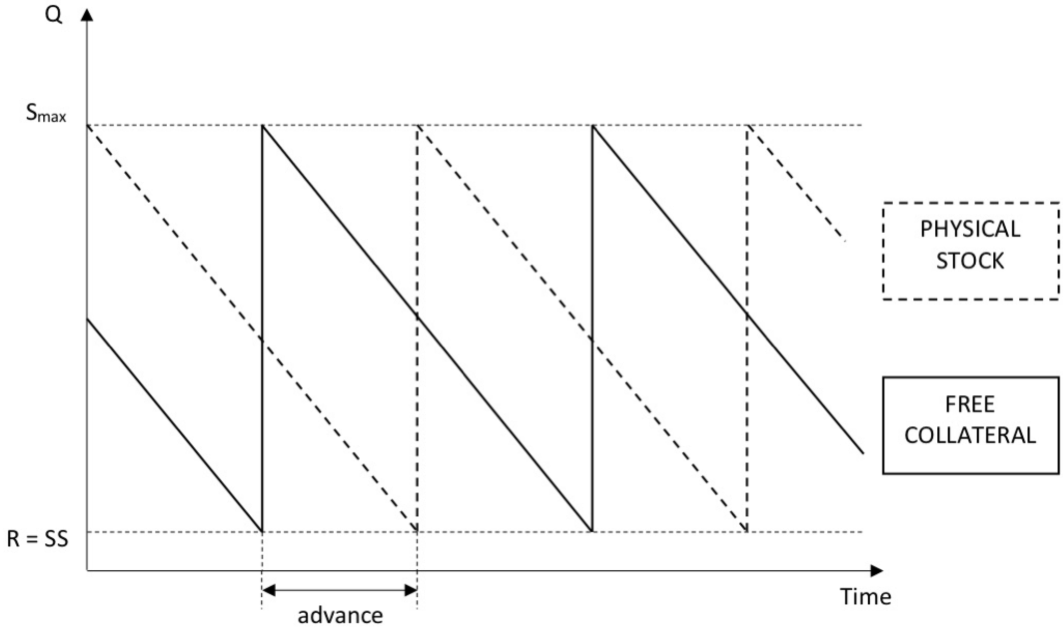


Figure 2.7 *Comparison between free collateral and physical stock trends*

As it can be seen, free collateral and physical stock have the same trend, but the first one is in advice compared to the second: this advance becomes fundamental to manage the different situation previously described (overshoot demand, promotions).
This type of reorder point method is used to manage the independent demand material (De Toni, Panizzolo & Villa, 2013).

2.3 Time Phased Order Point

Time phased order point (TPOP) represent a significant change in the supply chain management: in the free collateral, the future requirements are calculated in an aggregate way, with TPOP started to be used the buckets, single temporal periods that allow to calculate different requirements for different future periods of time: by this method the system can work without the calculation of the reorder point.
In this case, however, another input has to be definite, the initial storage.

2.3.1 Record TPOP

The use of this method is permitted by the record TPOP, a schedule in which are present all the elements of the free collateral method.

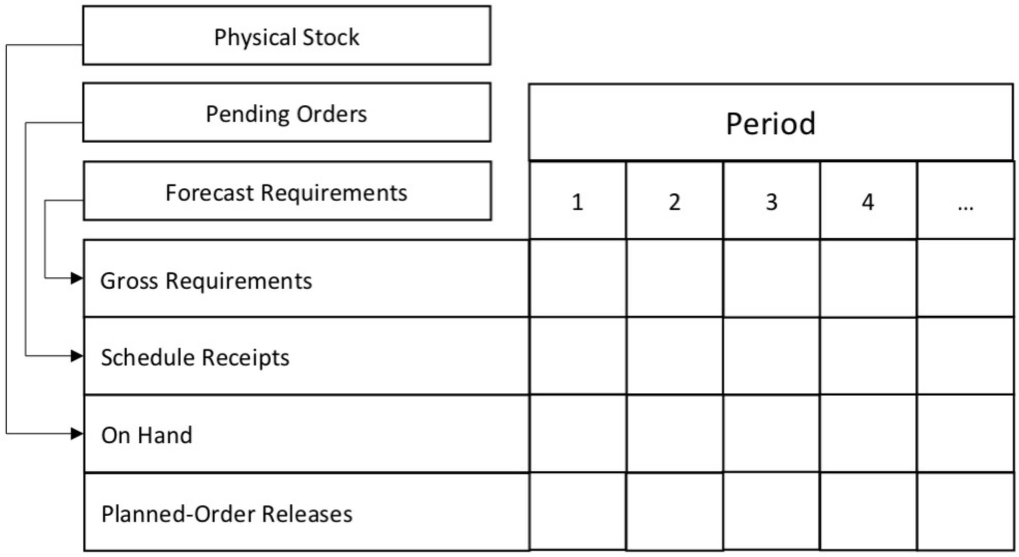


Figure 2.8 *Record TPOP*

At the end of sixties, when the TPOP system was invented, it was used both for dependent and independent demand materials, due to the limited calculating capacity, that was not enough to manage the parent - son relationship between the different codes.

2.4 Material requirements planning - MRP

Material requirements planning is a modern technique and controlling inventory items subject to dependent demand. The system processing logic is identical to TPOP except for the manner in which item demand is calculated. Requirements for independent demand are forecast (using any forecasting technique the user selects), the requirements for dependent demand, instead, is calculated from the requirements of the parent codes as shown in the figure bellow.[3]

[3] It's important to remember that ''parent code'' means a code with independent demand, and ''son code'' means a code managed with dependent demand

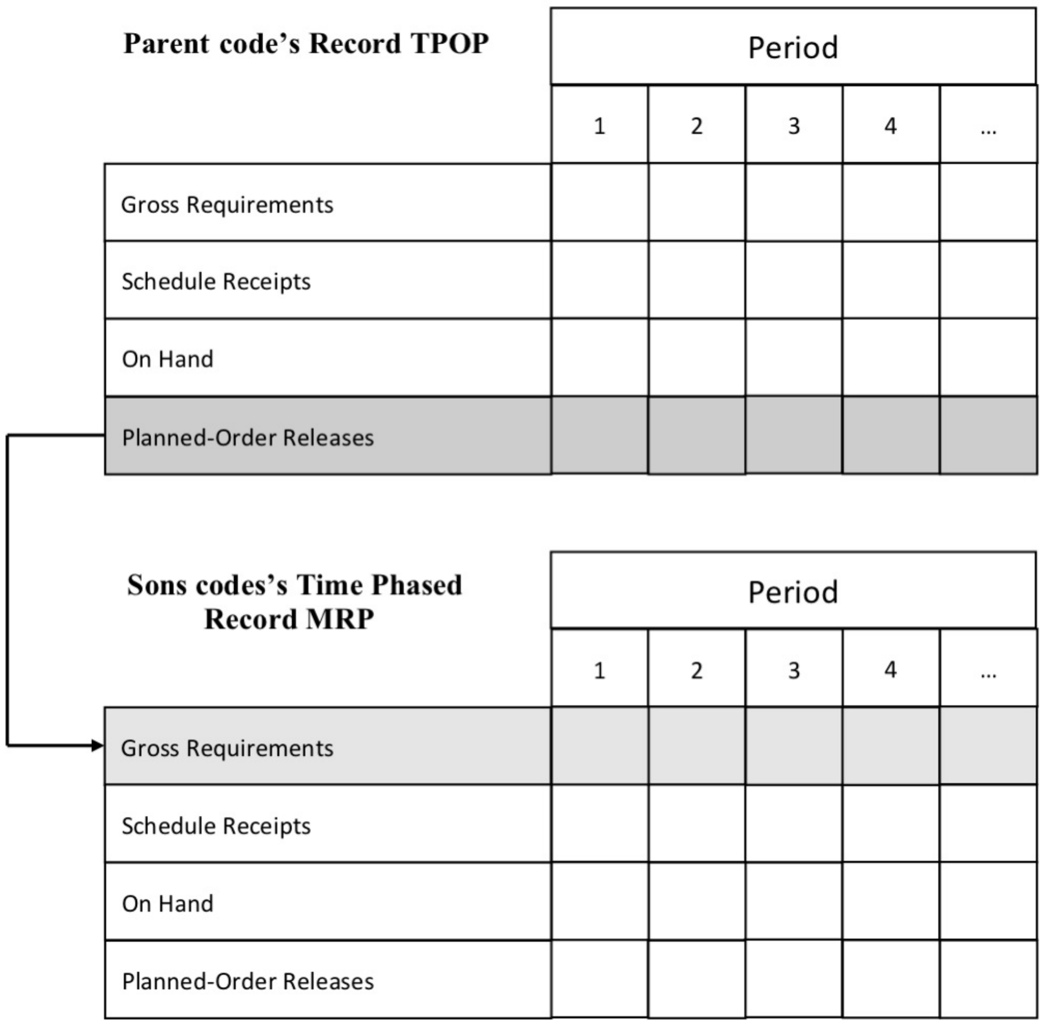


Figure 2.9 *Relationship between the record TPOP of the parent code and the time phased record MRP of the sons codes*

2.4.1 Time Phasing

Time phasing means adding the dimension of time to inventory-status data by recording and storing the information on either specific dates or planning periods with which the respective quantities are associated. In the older era of inventory control, status of a given item normally was shown in the system's records as consisting of only the quantity on hand and the quantity on order. When physical disbursements of the item reduced the sum of these two quantities to some predetermined minimum or reorder point, it was time to place a replenishment order.

This approach was refined around 1950 with the introduction of the perpetual inventory control concept. The principal idea behind this concept was to maintain somewhat expanded status information "perpetually" up to date by posting inventory transactions as they took place; this innovation largely was made feasible by the availability of better office equipment.

Inventory-status information was expanded by adding data on requirements (demand) and availability (the difference between the quantity required and the sum of the on-hand and on-order quantities). The classic inventory status equation was formulated and publicized as follows:

$$A + B - C = X \tag{2.9}$$

in which:

- A = quantity on hand
- B = quantity on order
- C = quantity required
- X = quantity available for future requirements

The quantity required would be derived from customer orders, a forecast, or a calculation of dependent demand. The quantity available had to be calculated. Negative availability signified lack of coverage and a need to place a new order. Using time phased approach, instead it is possible to manage in the proper way the temporal organization of the orders.

The price of time phasing is the added cost of processing and storage of the time-phased data. The value of the additional information thus made available, however, normally more than offsets the price paid for it (Ptark & Smith, 2011).

2.4.2 Input – output of the system and functioning of the MRP system

All MRP system outputs are produced by processing inputs (relating data) from the following sources:

- The MPS
- Orders for component originating from sources external to the plant using the system
- Forecasts for items subject to independent demand
- The inventory record (item master) file
- The bill of material (product-structure) file

The MPS expresses the overall plan of production. It is stated in terms of end items, which may be either (shippable) products or highest-level assemblies from which these products are eventually built in various configurations according to a final assembly schedule. The span of time the MPS covers, termed the planning horizon, is related to the cumulative procurement and manufacturing lead time for components of the products in question. The planning horizon normally equals or exceeds this cumulative lead time.

The MPS serves as the main input to an MRP system in the sense that the essential purpose of this system is to translate the schedule into individual component requirements, and other inputs merely supply reference data that are required to achieve this end. In concept, the MPS defines the entire manufacturing program of a plant and therefore contains not only the products the plant will produce but also orders for components that originate from sources external to the plant, as well as forecasts for items subject to independent demand. In practice, however, such orders and forecasts are normally not incorporated into the MPS document but are fed directly to the MRP system as separate inputs.
Forecasts of independent demand for component items subject to this type of demand can be made outside or inside the MRP system, using some statistical forecasting technique.
The inventory record file, also called the item master file, consists of the individual item inventory records containing the status data necessary for determining net requirements. This file is kept up-to-date by the posting of inventory transactions that reflect the various inventory events taking place. Each transaction changes the status of the respective inventory item. The reporting of transactions therefore constitutes an indirect input to the MRP system. Transactions update item status, which then is consulted and modified during computing requirements.
In addition to status data, the inventory records also contain so-called planning factors used principally for determining the size and timing of planned orders. Planning factors include item lead time, safety stock (if any), scrap allowances, lot-sizing algorithms, and so on. Planning-factor values are subject to change at the system user's discretion. A change in one or more planning factors normally changes inventory status.
The bill of material (BOM) file, also known as the product-structure file, contains information on the relationships of components and assemblies that are essential to the correct development of gross and net requirements (Ptark & Smith, 2011).
Regarding the outputs, using the MRP system there are two levels of output that it is possible to obtain: the first group includes order release notices calling for the placement of planned orders, rescheduling notices calling for the changes in open-order, cancellation notices, item status data and planned order scheduled for release in the future. The second group is called by-product outputs and it includes a group of notices for errors, incongruities and out-of-bound situation and others notices that can help to control the flow of future orders (like inventory forecast, performance report and trace to demand sources).
Regarding the functioning of the system, this is formed by two parts: the time analysis part includes the time phased operation in which the MRP system computes the possible release date for the order, and the second in which it considers the release quantities.
In the first part the software considers the lead time of the product to calculate the date of release of the row materials or work in progress necessary for the completion of the

finished good order. In this case, it can be used two different approach: the original MRP approach and the cutting approach.
To understand the difference between the two approaches it is useful to resort to the situation described in Figure 2.10.

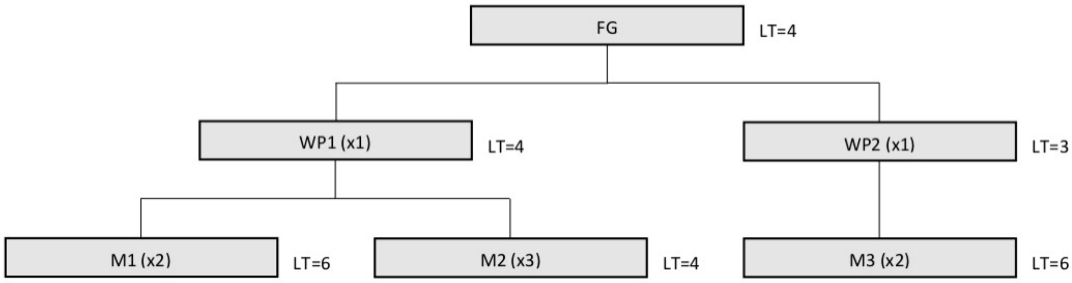


Figure 2.10 *Example of bill of material (BOM)*

Figure 2.10 represents the BOM of a product made from two works in progress, which are made from three different raw materials.
In this case the lead time of every single item is expresses in period of time and the cumulative lead time (CLT) of the finished good is 14 period.
The order for every single item can be placed in two different ways corresponding to the two different approaches:

- Original MRP approach

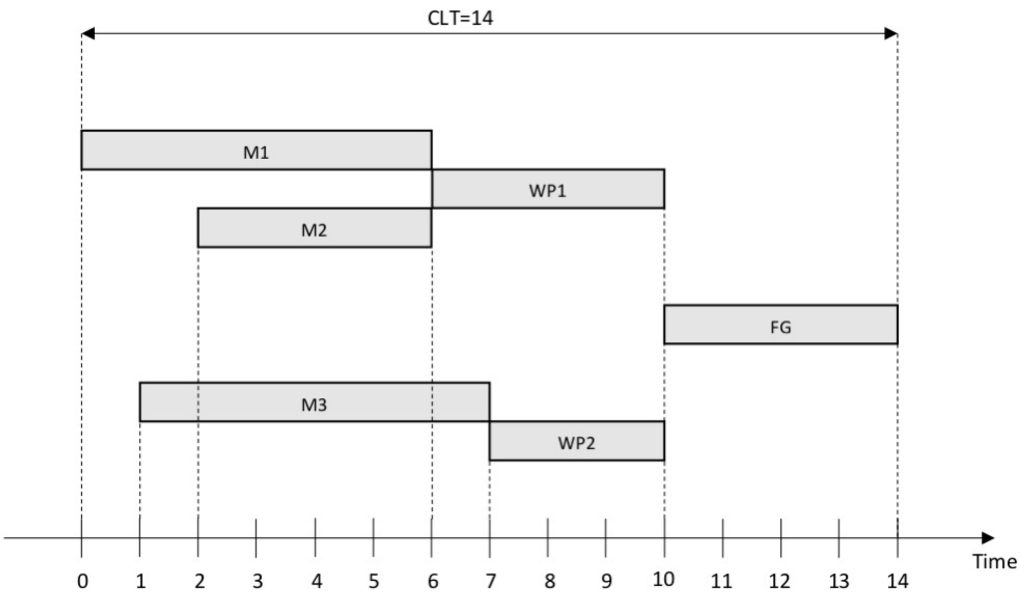


Figure 2.11 *Original approach used in MRP system*

- Cutting approach

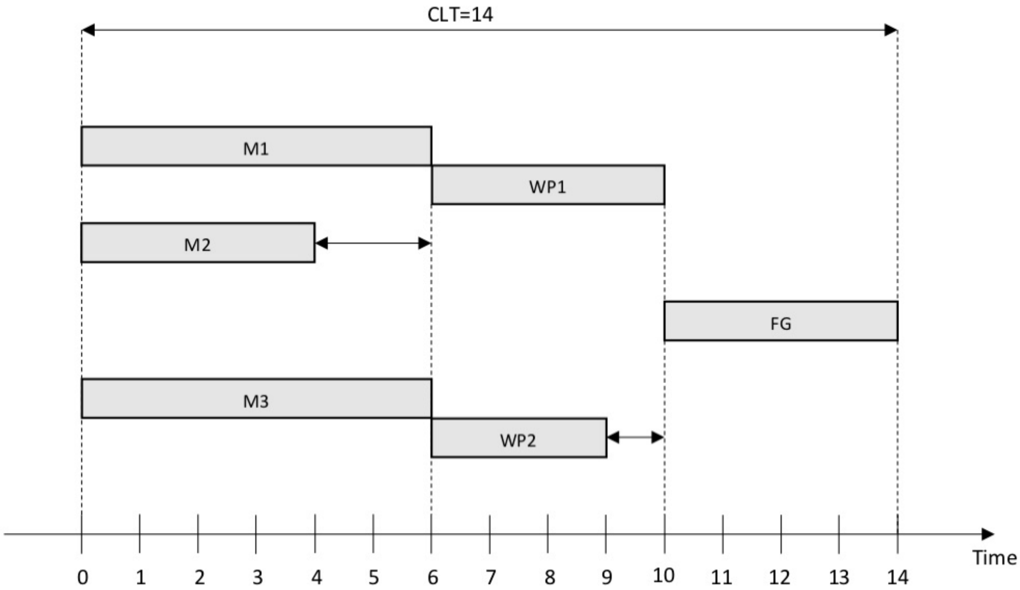


Figure 2.12 *Cutting approach*

Every approach has positive and negative sides: the original MRP permits the times optimization and the goods minimization in the warehouses, but it is less able to front the possible problems (orders delays or cancellations), on the contrary the cutting approach permits to manage in an easier way the problems, but increasing the volume of materials in the warehouses.
The second function of the MRP system is to transform gross requirements into net requirements, in this case the software uses the following formula:

$$NET\ REQUIREMENTS = GROSS\ REQUIREMENTS - INVENTORY\ ON\ HAND - INVENTORY\ ON\ ORDE \quad (2.10)$$

Thanks to these two levels of analysis, the MRP system is capable to manage the orders both as regard time and quantity.

2.4.3 LOT-SIZING TECHNIQUES

Another important aspect regarding the MRP system is the lot-sizing techniques, in fact it is necessary to focalize the different techniques that the MRP can use to order the material quantities requested.
The first procedure, called lot for lot (LFL), permits to order a quantity of material in the amount of the net requirement: in this way, the material quantity in warehouse is minimize, but it is not the same for the emission cost of the order (due to the high number of orders).

Another technique is the fixed order quantity (FOQ) in which the quantity of the order is not variable. This may be due to technological or transport limitations, or to limitation given by the supplier.
In some cases, the economic order quantity (EOQ) is used as fixed order quantity, in this way is it possible to minimize the total cost.
In other situations, it is useful to fix the reorder period of time: this method is called fixed period requirements (FPR), the MRP system releases an order quantity to cover the requirements of a fixed number of buckets. Using this procedure, it is possible to minimize the transport and handling costs.
The last method that can be used by MRP system is the minimum unitary cost. The system, in this case, considers also the reorder and maintenance costs, instead to consider only the total cost like the EOQ.
The MRP allows to use a different method for every material in order to manage different situations more effectively.

2.5 SELECTION OF THE STOCK MANAGEMENT METHOD

To choose the correct provisions technique is necessary to consider the following variables (De Toni, Panizzolo & Villa, 2013):

- Comparison between the cumulative lead time of the product and the delivering time to the customer
- Value of use
- Continuity of the demand
- Type of demand
- Width of BOM
- Length of BOM

The first variable to consider is the value of use. Employing an ABC analysis, it is possible to identify the materials with a high value of use (it means that this types of material can have a remarkable exiting quantity and/or a high unit value), for the material with a high value of use it is preferable to use the MRP analysis, more onerous for the computational calculation, but more exact. In reverse for the materials with a lower value of cost it is possible to use a ROP method (materials like bolts and screw).
To analyse the demand it is useful to use the following matrix

		Variability	
		LOW	HIGH
Frequency	HIGH	HL	HH
	LOW	LL	LH

Figure 2.13 *Matrix for the analysis of the demand considering variability and frequency*

For HL products, it possible to use the ROP method, in fact they have a low variability and a high frequency, and then it is possible to use a lowered safety stock.
For LH products, instead, it is preferable to use a MRP system, trying to front the usage discontinuity.
Regarding the type of demand, it uses the MRP for the dependent demand materials, for the independent demand it is used the TPOP.
It is useful to analyse the dimensions of the BOM to understand the stock management method to use.
A large BOM means a bill of material in which a parent code has a high number of sons code (at least four or five), this type of BOM is typical of the assembly product. In this case it necessary to use a MRP, the using of the ROP would imply a low service level. This idea is expresses by the following example.

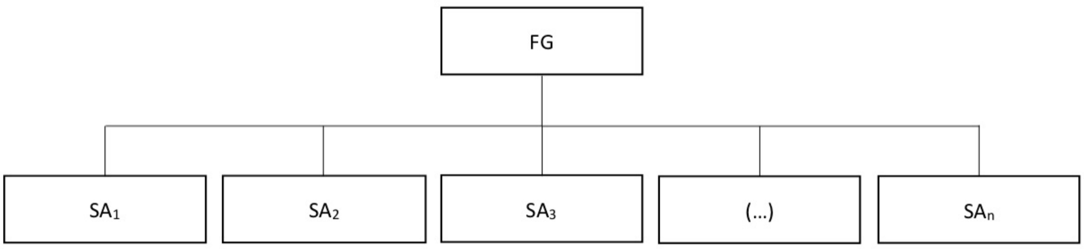


Figure 2.14 *Generic large BOM*

In this situation, the service level of the parent code is the product of the service level of all the subassembly.
Suppose every subassembly with the same service level, the service level of FG is

$$SL_{FG} = (SL_{SA})^n \quad (2.11)$$

Using a LS_{SA}=0.98 and n=8, the level service of the parent code will be LS_{FG}=0.85, that it could be not sufficient.
The other dimension that influences the choice of the stock management method is the length, intended as the number of levels of the BOM.
A BOM with a number of levels greater than three can cause a lumpy phenomenon, that causes the increase of the standard deviation used to obtain the safety stock: for this reason, is preferable to use a MRP system for the codes that stays on the bottom of the BOM.
For the stand alone code the situation is different and it is explained in the following summary chart:

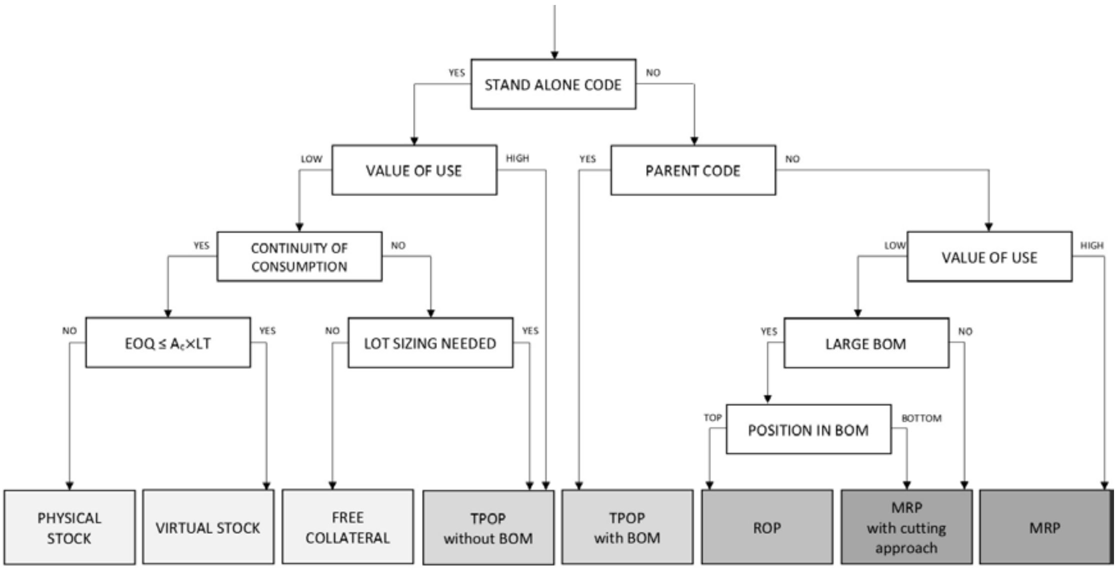


Figure 2.15 *Final chart for selection of the stock management method*

Chapter 3

Just in Time

The Just In time systems (JIT) represent a significant change in the stock management methods compared to the traditional methods. These systems originate to a simple idea: they organize all operations so they occur at exactly the time they are needed; they are not done too early (which would leave product not needed in warehouses) and they are not done too late (to avoid a poor customer service).

To pursue this objective is necessary a change of the entire way of thinking of the production system, placing at the centre of the work a rigorous relationship with the customer; for this reason, the JIT system is based on five principles (Azavedo, Govain, Matias, Pimentel & Pinto, 2018):

1. Focus on the problem of the customer and solve it, working together.
2. Not wasting time, especially client's time.
3. Delivery exactly what the client requests make use of this relationship
4. Delivering exactly where and when is required
5. Continuous improvement to reduce the customer's time and problems in production and delivery.

Besides these five principles that regulate the rapport with the client there are five assumptions on which the JIT system is based (Azavedo, Govain, Matias, Pimentel & Pinto, 2018):

I. Emphasis on creating added value in production and information flow.
   In the JIT system, it is necessary to create an attentive analysis that are based on a data collection from the order emission to the delivery to the client. The principal objective of this accurate analysis is to do more with less, identifying the waste of materials and time and reducing them.

II. Systematic leadership with an entrepreneurial vision.
   Whit this leadership is it possible to understand the necessities of the customer, thanks to a great experience in managing crisis situations. Leadership should be adaptable, competent and enabling it to act appropriately.

III. Continuous and cadenced pulled flow.
   The information flow should be available to all the employees at the exact time, in the exact place and in the required quantity. This assumption represents a great change in the production organization. Comparing this way of thinking with the

traditional one, it is possible to notice that in traditional organization there are no-communicating separate workstations whit lack of information. In JIT system, there is a flow that maintain a continuous rhythm in order to make capable the employees to pull this information and acquire knowledge in an in-depth level.

IV. During the development of a product, the information flow has to involve all the entity that are involved in every part of the design. The specialists have the responsibility to overcome technological barriers and to find the best way to act.

V. Concurrent engineering, that means collaboration between production and design of a product.
In the traditional production, the collaboration between these two parts is not necessary, and this causes problems in every part of the development of a product: from the design to the production, whit waste of material and time.

The JIT systems completely change the view of the stock: in the traditional approaches the stocks are used to front the uncertainty or the problems that can arise in the supply chain management, on the contrary in the JIT the stocks are considered as a waste of resources, and so they are removed. To remove the stock, then, it is necessary to find ways of reducing the variation removing the uncertainty.
Matching supply to the demand it is possible to reduce stocks that are needed to cover any differences and so solving the problem of materials in warehouse.
JIT are also called ''pull systems'', because every operation is driven from the following supply chain part, on the contrary the traditional methods are called ''push'' system, because every operation is pushed from the previous part of the supply chain.
There are two different methods in the JIT group: Kanban system and Just In Sequence (JIS) system.

3.1 KANBAN

The term *Kanban* (看板) is a Japanese word that literally means signboard or billboard. It is precisely the signboard in the centre of this model: when a requirement is born, the necessary amount of the material is ready to replace this empty, and at the same time the kanban is placed to explain the needed of new materials.
The kanban technique is used in many parts of the supplying chain, such as the production, the handling operation or the material provision: in this thesis, it will consider the material provision kanban.
Through a robust relationship between the customer and the supplier, the supplier commits to make available a predetermined amount of material. When the customer has a requirement, picks up the material and, using signboard, the material is replaced by the supplier.

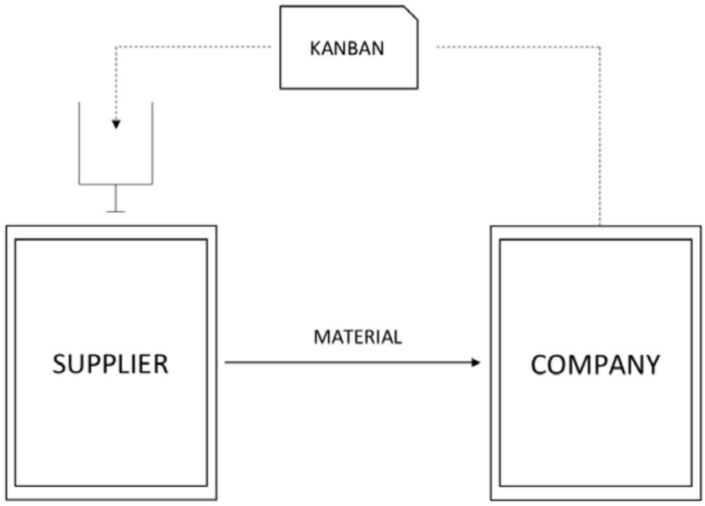


Figure 3.1 *Schematisation of a kanban system*

There are several ways of using kanban, but they are based on the same principles:

- A message is passed backwards, asking preceding operations to send materials.
- The containers in which the material is moved are standard and the hold a specific amount.
- Containers can only be moved if the container has a kanban attached.
- With this method, it is simple to verify that stocks cannot accumulate.

Starting from these principles, different types of kanban were developed (Sintesia, 2018).

Figure 3.2 *Example of a container used in kanban system (source: LeanProducts)*

3.1.1 Double bin kanban

Is the simplest way to apply the kanban system: every code has two different containers, one is full of material and used for the final product, the other is filled up by the supplier with the material needed.
In this case, often, the empty container represents the kanban, that show the necessity of new material.
This type of kanban is more used in the production instead of the material provision.

3.1.2 Signal kanban

Signal kanban is used when the production batch of the supplier is lower than the customer consumption. In this case the supply system is similar to the ROP: the kanban is not linked to the container, but it is sent to the supplier when the material level is lower than predetermine limit.

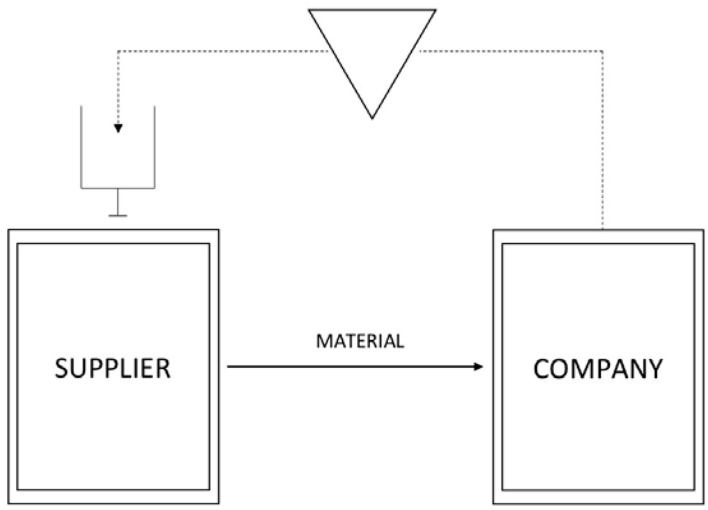


Figure 3.3 *Signal kanban*

3.1.3 Batch kanban

Signal kanban is used when the production batch of the supplier is bigger than the customer consumption.

The functioning of the batch kanban is similar to the functioning of the traditional one, the only difference is that the supplier waits a certain number of kanban (intended as tags) of the same code before dispatching the material to the customer.
This type of kanban provides a particular billboard to divide and to collect the kanban for every code. This billboard is normally formed by three parts to indicate the demand of a particular code.

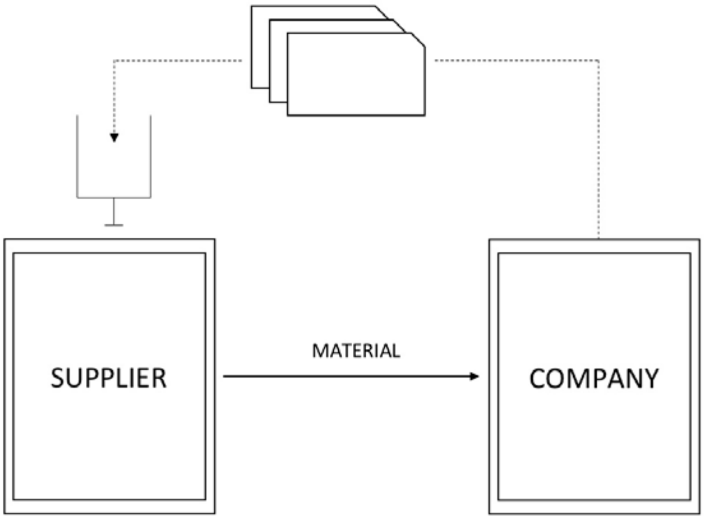


Figure 3.4 *Batch kanban*

3.1.4 Sizing of kanban number

Another important task is the determination of the number of kanban (KB). For every type of kanban there is a particular expression (Sintesia, 2018).
In the case of traditional kanban the expression is the following:

$$KB = \left(\frac{C \times LT}{Q}\right) + 1 \quad (3.1)$$

in which:

- C = maximum daily consumption during the refurbishment lead time of the material
- LT = refurbishment lead time
- Q = number of pieces for kanban or container (independent variable)

For the Batch kanban the situation is different:

$$KB = \left(\frac{C \times LT}{Q}\right) + N \quad (3.2)$$

in which N is the number of tags necessary to cover the minimum supply lot.
In the Double Bin kanban the number of tags is fixed, therefore it is necessary to calculate the quantity of pieces to associate with the kanban:

$$Q = C \times LT \tag{3.3}$$

In the calculation of the kanban number it is possible to use the average consumption (A_C) instead of the maximum consumption (C). In this case, it is necessary to consider a safety stock in order to avoid the uncertainty during the lead time. The expression that can be used is the Toyota formula for the determination of the number of kanban (Monden, 2011):

$$KB = \frac{A_C \times LT \times (1+SS)}{Q} \tag{3.4}$$

In this case the safety stock (SS) is considered in percentage form, and, also in this expression, the lead time contemplated is not a production lead time, but the response time of the supplier (refurbishment lead time).
Beside the Toyota formula, a different variant has been developed.
Smalley introduces the concept of total inventory (TI) in order to manage in an easier way the variation of the demand.

$$TI = A_C \times LT + Buffer\ Stock + Safety\ Stock \tag{3.5}$$

In one hand the buffer stock is used to manage the variability of the demand and the prevision error, in the other hand the safety stock is used to consider the problems in production (Smalley, 2004).
Then:

$$KB = \frac{\mathrm{TI}}{Q} \tag{3.6}$$

To make the kanban system work it is fundamental to focus in two aspect. The first one is the levelling of the production (Heijunka), to make the consumption of material uniform in time and then, to avoid the oscillation of the request.
The second fundamental aspect is the respect of supply lead time: through a strong relationship with the supplier it is necessary to respect this lead time in order to reduce the uncertainty and then the amount of stocks.

3.2 JIS – Just In Sequence

The second group of stock management method, that belongs to the pull systems, is called Just in Sequence (JIS).
In JIS system the modality of supplies is stricter than the kanban situation, in fact in this case the supplier and the customer share a great number of data to make the operations more efficient and rapid.
In particular, the customer company shares with the supplier the production plan (even weeks in advance) in order to make it possible to align the supplier production to the client demand (Harrison, van Hoek & Skipworth, 2014).
The supply plan, that is sent to the vendor, is frozen: in this way, the supplier is able to provide the customer with the exactly amount of material needed.
There are two different possibilities that can be used to respond to the customer demand (De Toni, Panizzolo & Villa, 2013).
In the first case the supplier completely adjusts the production to the client request, without the necessity of an intermediate buffer; in this way, the supply chain is more lean, but also more rigid to the change of demand. For this reason, in this case the demand of the customer is totally frozen.
The situation is shown in the figure below.

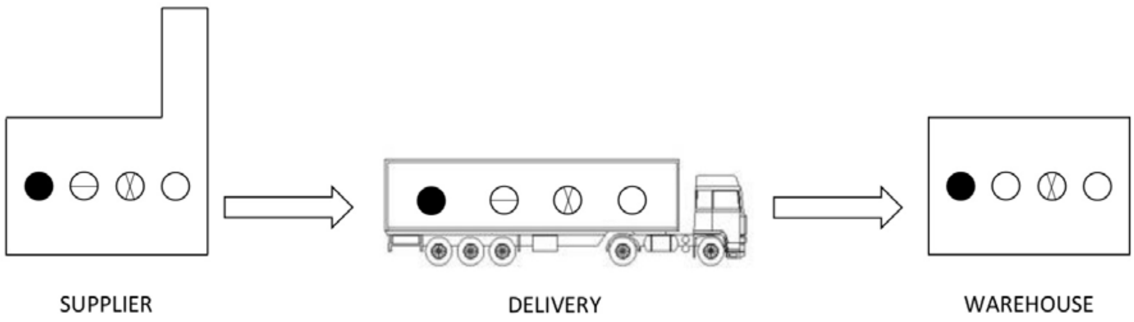


Figure 3.5 *Case of just in sequence (JIS) system in which the supplier completely adjusts the production to the client request*

The second case allows to use an intermediate buffer between the supplier production and the delivery to the customer: in this way the supplier can manage the manufacturing in a more levelly way, to the detriment of the efficiency. Thanks to the greater availability of material, it is possible to face the variation of the customer.

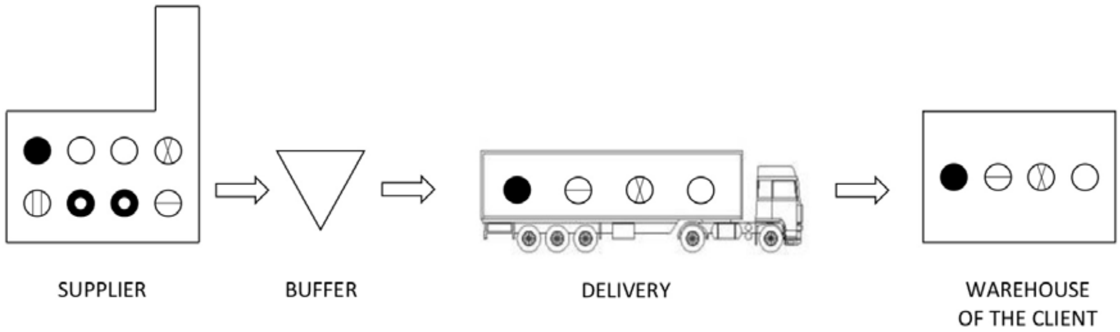


Figure 3.6 *Just in sequence (JIS) with intermediate buffer*

3.3 Differences between kanban and JIS system

It is important to focus on the main differences between the two methods that belong to the JIT group.
The first difference concerns the delivering. In the kanban the delivering system is based on the kanban (meant as tag), none material is moved without the regulation of these cards.
In the JIS system instead, the delivering system is strictly linked to the assembly plan of the customer: the supplier bases the production plan on the client plan, it means that the supply chain management will be more efficient but also less flexible; in the first case the assembly plans of the customer are only shared, in the second case they are shared and binding.
Regarding the production plans of the supplier in the case of the kanban they are defined by the levelling of the production (Heijunka), in the case of JIS they are defined by the same levelling or they are imposed by the assembly plan of the client.
Another aspect to consider is the buffer. The kanban system allows to reduce stocks of material at a low level (this stocked of material is used only as safety stock).
The JIS method permit an additional step forward, allowing the elimination of the buffer in the case of sequenced production, to reach levels of efficiency not possible in other methods.
This high efficiency, as already mentioned, is reached to the detriment of the sensitivity to the changes of the client plan, that is high in kanban system and very high in JIS.

Both of these systems, while needing of changes in the structure of supply change (five assumptions), allow to reach cost and production efficiency, not achieve by the traditional methods.

Chapter 4

VMI – Vendor Managed Inventory

Vendor Managed Inventory (VMI) is an approach to inventory that includes an important difference compare to the other stocks management methods: the supplier, not the customer is responsible for the managing and replenishing inventory.
At first sign this way of working contrast the principle of pull systems, in which every operation is pulled by the successive supply chain parts, in practice, the basis on which decisions will be made is agreed with the client, and it is based on the customer's sales information.
Under VMI, the supplier assumes responsibility for monitoring sales and stocks, and uses this information to trigger replenishment orders.
The supplier tracks the inventory level and the sales of the customer product, sending goods only when stocks run low: the decision to supply is taken not by the customer (as in the traditional or JIT systems), but by the supplier, thanks to a great level of collaboration between the two parts.
To make this innovative system works is in the interests of the both parts to maximise product availability, avoiding lost sales. By emphasising the supplier's responsibility for maximising product availability, VMI aims to achieve this with minimum inventors (Harrison, van Hoek & Skipworth, 2014).
In order to combine the necessity to avoid lost sales and the objective to minimize the stock level, the supplier has the necessity to have access to real-time demand of the final customer.
The most widely used technology for broadcasting demand data is *electronic data interchange* (EDI). This provides the means for exchanging data from customer to supplier in a standard format. Internet-based applications using EDI protocols providing the same facilities at lower cost: customer demand and stocks data are processed by the software to automate the application of decision rules and to identify stock lines that need replenishment.
The benefits for the customer are evident: the client can have a leaner flow of stock, without incurring in management stock problem.
On the other side, also the supplier has benefits, being able to reduce the amount of the material and consequently the costs. With this integrated approach and the sharing of the

data, in the longer term, supplier should integrate demand information into their organization and develop the capability to drive production with it.

4.1 EDI – Electronic Data Interchange

Electronic data interchange (EDI) is a form of inter-organizational electronic commerce where one trading partner (a buyer or a seller) establishes individual links with one or more trading partners through a computer-to-computer electronic communication method. EDI is a system that involves suppliers, distributors and retailers in order to respond to the consumer demand in a more quick and efficient way.

Using EDI it is possible to reduce stocks (then costs) and also to increase sales.

The development of EDI system has enabled the companies to improve traditional relationship and at the same time to reduce the total lead time of the entire realisation circle of the product.

Basically, it is the electronical transmission and reception of commerce documentation (purchase orders and invoices). Using this technological approach, it is possible to delated the additional controls of the data and the delays caused by the preparation of documentation.

The primary elements of the EDI system are:

- The use of an electronic transmission medium, rather than a physical storage media. The messages are structured, formatted and standardised (in this way they can be translated, interpreted and checked to make the process quicker).
- The reception of the information is generally fast (hours or even minutes).
- Direct communication between applications (rather than between computers).
- EDI system needs a moderately sophisticated information technology infrastructure in order to enable the efficient capture of data into electronic form, the processing and retention of data, controlled access to it, and efficient and reliable data transmission between remote sites.

EDI is a system that saves unnecessary recapture of data. This leads to faster transfer of data, far fewer errors, less time wasted on exception-handling, and hence a more streamlined business process (Buiten, Erikson, Erikson, Saraiva & Snijkers, 2018).

4.2 CPFR – Collaborative planning, forecasting and replenishment

In the VMI system the sales forecasts are made by the customer in collaboration with the supplier through CPFR, collaborate planning, forecasting and replenishment.
CPFR is aimed at improving collaboration between buyer and supplier so that customer service is improved whilst inventory stocks management is made more efficient.
Historically the CPFR movement originated in 1995, by the collaboration between two software companies, SAP and Manugistics, and five companies, Warner-Lambert, Wal-Mart and Benchmarking Partners. The objective of this collaboration was to generate a business model to forecast and replenish inventory collaboratively, in order to reduce the response time to the market and reduce the costs.
An initial pilot was made between Wal-Mart and Warner-Lambert using the Listerine mouthwash product and focusing on stocks kept in the retail outlets: it was demonstrated that the internet could be used as a channel for this data exchange.
Having shown the success of the CPFR test, companies are looking to expand the programmes from the items involved in the pilots to many of the products covered in most trading relationship. This has been a challenge for all organizations, including the software providers. One of the most important aspect of the CPFR organization is that there are no limits to the number of organizations and products involved in the CPFR network (Harrison, van Hoek & Skipworth, 2014).
The benefits of an electronic collaboration are manifold:

- There is improved availability of product to the customer, and hence more sales.
- Total service is improved.
- Total costs are reduced.
- The integration of the operations between two or more companies became more integrated and hence simple.
- The information becomes more transparent across the supply chain.
- The data that are in the system can be used for monitoring and evaluation purposes.

Summarise, the difference between the traditional structure of the cycle of orders and the structure in the VMI approach is represented in Figure 4.1 and Figure 4.2.

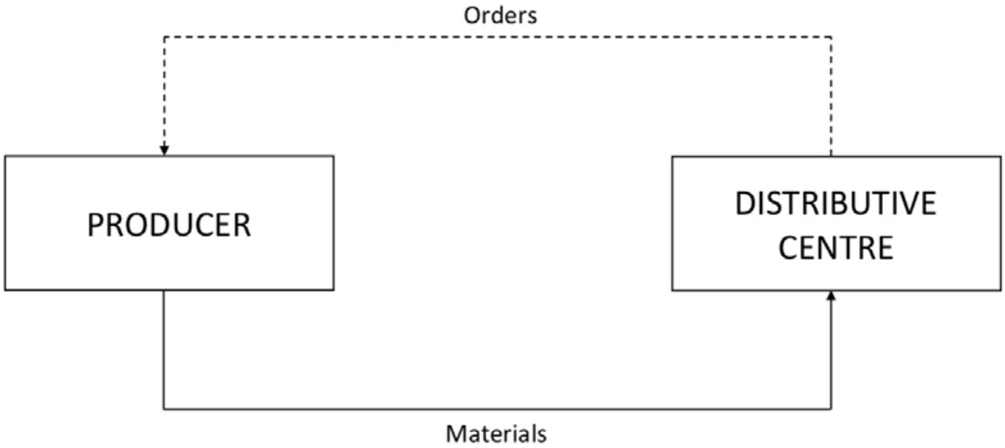


Figure 4.1 *Traditional structure of the order cycle*

Meanwhile in the traditional structure the customer sends the orders to the supplier, and then the supplier sends the materials to the customer, in the VMI the client shares the needed information with the supplier, who sends the materials without the receiving of the order.

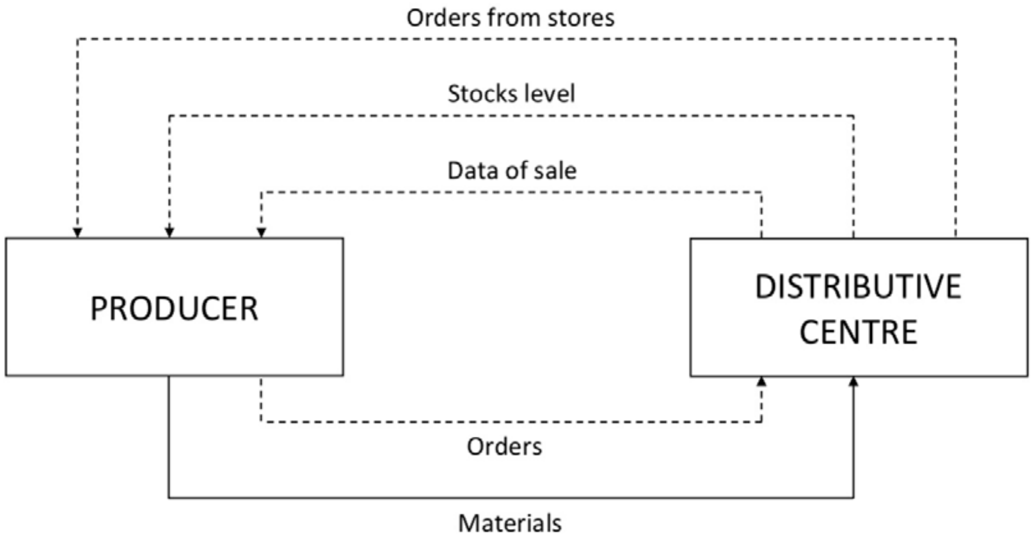


Figure 4.2 *Cycle of the orders in the case of VMI system*

4.3 Various application of VMI system

During the development of VMI system, three different declinations were generated: Continuous Replenishment (CR), Consignment Stock (CS) and Reverse Consignment Stock (RCS).

4.3.1 Continuous Replenishment (CR)

In the Continuous Replenishment the collaborative approach allows to give the stock management responsibility to the supplier (as in all VMI methods) in which the location of the materials is in the structures (warehouse, storage) owned by the client.
Regarding the ownership of the goods, the materials are owned by the customer, whereas the delivering are made by the decision of the supplier.
In the CR the planning of the supplies are organized using a planned stock level, the target stocks (TAS), this level is not completely fixed, but it follows the variation of the market. In this way, the customer can maintain a part of control in stock management.
This innovative organizational approach, in which the supplier manages the warehouse, presents some variant: Consignment Stock and Reverse Consignment Stock.

4.3.2 Consignment Stock (CS)

The CS is another collaborative approach in which the responsibility of the stock management is given to the supplier.
In this case the characteristics are the following: the goods are located in the customer's buildings, the delivering of the materials is made by the decision of the supplier, but, conversely to the CR, the materials are owned by the supplier.
The supplier decides to use this approach for two reasons: there may be an imposition from the customer, or the supplier can decide to do it to better manage the stocks.

4.3.3 Reverse Consignment Stock (RCS)

In this case the situation presents some differences.
First of all, the buildings used for the goods stock are owned by the supplier, moreover the propriety of the materials in these structures is of the customer.
Regarding the delivering of the materials, it is done at the request of the client.

Chapter 5

Comparison between methods

It is necessary to compare the methods, analysing the different aspects of the stock management. In this way, it will be possible to underline the them differences in order to outline a model that finds the most suitable method in a certain situation.

5.1 Management logic

	Traditional Methods			JIT		VMI		
	ROP	TPOP	MRP	KANBAN	JIS	CR	CS	RCS
Management Logic	PUSH	PUSH	PUSH	PULL	PULL	PULL	PULL	PULL
Vision	LOOK BACK	LOOK AHEAD previsions	LOOK AHEAD previsions	-	-	-	-	-
Used for demand	Dependent/ Independent	Independent	Depeendent	Dependent/ Independent	Dependent/ Independent	Dependent/ Independent	Dependent/ Independent	Dependent/ Independent

Table 5.1 *Comparison between different approaches considering management logic, vision and type of demand*

In the pull logic, it makes no sense to define a look back or look ahead vision, because everything is drag by the following supply chain part. The required materials are not planned in advance, but there are pulled by the following operations, when and where they are needed.

According to this logic the JIT methods and the VMI methods belong to the same group. Anyhow, it is necessary to separate the two groups due to the fact that in the VMI approach the supplier has the responsibility for the stock management, while in JIT the responsibility remains to the customer: this represents an important difference that it has to be considered.

All the methods can be used to manage both dependent and independent demand codes, except for MPR and TPOP, that can be used respectively for dependent demand and independent demand, as mentioned in *Chapter 2.4*.

5.2 Relationship with the supplier

	Traditional Methods			JIT		VMI		
	ROP	TPOP	MRP	KANBAN	JIS	CR	CS	RCS
Approach	Not collaborative			Collaborative		Collaborative		
Buffer	Necessary			Low	Low or absent	Present		
Sensitivity to variation of client demand	Low			High	Very high	-	-	High
Deliveries	On costumer's order			On client's kanban	On client's FAS	On supplier's decision		On client's request
Shared data	Purchase orders			MPS/ FAS	FAS	Sales forecast and stock level of the costumer		
Management responsability	Costumer			Costumer		Supplier		
Site of stocks	Care of costumer			Care of costumer		Care of costumer		Care of supplier
Propriety of stocks	Costumer			Costumer		Costumer	Supplier	Costumer

Table 5.2 *Comparison between different approaches considering the relationship whit the supplier*

From the comparison of all the methods the JIT and the VMI groups result to be collaborative approaches, instead the traditional group is a not collaborative method, due to the lack of exchange of data and information between the customer and the supplier.

Using the traditional method, in fact, the client sends only the purchase order to the supplier, without any other information. In the case of the JIT methods, the customer shares with the supplier the short and middle term plans (MPS and FAS) in order to make the system work. In the case of the VMI methods, the customer has to share also the sales forecast and the level of the stock, in fact the relationship results to be even more collaborative.

More precisely, the MPS (Master Production Schedule) is a plan for individual commodities to be produced in each time period such as production, staffing and inventory, it indicates when and how much of each product will be demanded. This plan quantifies significant processes, parts, and other resources in order to optimize production, to identify bottlenecks, and to anticipate needs and completed goods (J.E. Beasley, 2009).

FAS (Final Assembly Schedule) involves assembly, final mixing, cutting and all the final operations. The FAS is prepared after receipt of customer order and schedules the operations required to complete the product from the level where it is stocked (or master-scheduled) to the end-item level (K. Sheikh, 2003).

Both of this plans are fundamental for the managing of the production, then their sharing results to be at the base of a collaborative relationship between the customer and the supplier.
Analyzing the buffer situation, it is important to underline the presence of this in the traditional methods: according to the pull logic, in fact, it is necessary to stock the material to cover the requirements of a period of time. In this situation the buffer is used to stock also the quantity of material defined in the safety stock. The presence of the buffer, then, is inherently necessary in the pull logic, the only possible operation is the reduction of this buffer in order to reduce the costs.
On the contrary, the Just in Time logic theoretically allows to have absence of the buffer, indeed the material arrives only when requirements arise. In the practical situation, it is necessary to have a buffer in order to front problems or unexpected situation, anyway the level of this buffer is low.
In the VMI approach the situation is different, in fact the supplier is responsible for the stock management and he has always to guarantee a predetermined stocks level. The buffer, then, is present, to make the system works.
Analyzing the sensitivity to variation of client demand, in the traditional situation this is low, in fact there is always a safety stock defined precisely to front this possible problem.
In the JIT methods the variations of client demand should be absent and the agreements between customer and supplier should be frozen, only in this way the Just in Time logic can work efficiently. If there is a variation in the client demand, the close connection between the production plan of the supplier and the customer request cause problems and inefficiency at the management level (delays, loss of materials): this is true particularly in the Just in Sequence approach, in which the production plan of the supplier follows exactly the customer requests (for this reason the sensitivity to variation of client demand is very high).
In the Continuous Replenishment and in the Consignment Stock logics it has no sense to consider this aspect, in fact the stock management and the delivers are made on the supplier's decisions after the stipulation of agreements, that are at the base of the relationship between customer and supplier.
The situation changes considering the Reverse Consignment Stock logic. In this case in fact, the customer is the responsible for the delivering of the orders, and then he can modify them. In any case, the RCS operates in pull logic, then the sensitivity to variation of client demand results to be high.
Regarding the deliveries, then, only in the CR and CS approaches they are made on supplier's decision, while in the other methods there is always the involving of the customer side.
Considering the site of stock the situation in the traditional and in the Just in Time approaches the materials are stored in structures or buildings owned by the customer.

The situation in the VMI is different: in the CR and in CS the structures are owned by the costumer, in the RCS, instead, they are owned by the supplier.
The care of the site of stocks is not a secondary aspect, in fact it involves costs and commitments to a management level
The last element to consider in the relationship between customer and supplier is the propriety of the stocks. This is an important aspect because it entails costs and responsibilities that must be faced by one side or the other, as previously mentioned.
In all the methods considered this propriety is of the client, only in the Vendor Managed Inventory, and more precisely in the Consignment Stock, the close link between customer and supplier entails that this propriety results to be of the supplier.

Chapter 6

Method development for the identification of the appropriate stock management approach

This section of the thesis will be dedicated to the development of a method to define the more appropriate stock management approach for every code belonging to the bill of material (BOM).
In order to reach this aim, it is necessary to start considering and analysing the information included in the Plan For Every Part (PFEP).

6.1 Plan For Every Part (PFEP)

A PFEP is a material flow plan that includes specific data on every part number coming from suppliers and every finished good going to customers.
It contains all the information necessary to manage the code inside the company.
The information is the following:

- Item code
- Description
- Average daily use
- Point of using inside the company
- Frequency of the order to the supplier
- Supplier
- City of the supplier
- Type of used container
- Weight of empty container
- Weight of one piece
- Weight of the packed product
- Length of the container
- Width of the container
- Height of the container

- Utilization for work in progress
- Hourly use
- Standard number of pieces for container
- Number of containers used hourly
- Time needed for the delivery (usually expressed in working days)
- Number of billboard used in the system (in the case of kanban approach)
- Supplier performance

6.2 Main variables to consider for the method development

The first variable to consider for the development of the method is the value of use.
The expression of the value of use, as mentioned, is the following:

$$Value\ of\ use = Consuption \times Unit\ value \tag{6.1}$$

The value of use not only expresses the value of a code, but it gives also importance to the consumption of a certain code in order to better describe the outgoing flow of resources.
At the same time, it is necessary to focus on the ''consumption'' parameter to deeply understand the meaning: the consumption used in the value of use expression (6.1) is an average value in a period of time. Other two parameters have to be considered to better understand the flow of output material: frequency and variability of consumption.
The consumption frequency measures, in a period, how many times the consumption has occurred, regardless of the amount of this consumption.
The indicator used to measure the consumption frequency is the Average inter-Demand Interval (ADI). This indicator has the following expression:

$$ADI = \frac{\sum_i^N \tau_i}{N} \tag{6.2}$$

in which τ_i is the number of periods of time between two consumptions and N the total number of periods of time (Heinecke, Syntetos & Wang, 2011).
The consumption variability, instead, is the amount of the single consumption compared to the average one.
The analysis of the variability consists of the following passages.
Firstly, it is necessary to calculate the Average Demand (D), using the sum of all the consumptions (D_i) and the number of periods considered (N):

$$D = \frac{\sum_i^N D_i}{N} \tag{6.3}$$

Then the standard deviation (σ_{A_D}):

$$\sigma_D = \frac{\sqrt{\sum_i^N (D-D_i)^2}}{N-1} \tag{6.4}$$

And at the end it is possible to obtain the coefficient of variation (ν_D):

$$\nu_D = \frac{\sigma_D}{D} \tag{6.5}$$

These two parameters, (6.2) and (6.5), can be crossed to obtained four different classes of codes (Heinecke, Syntetos & Wang, 2011).

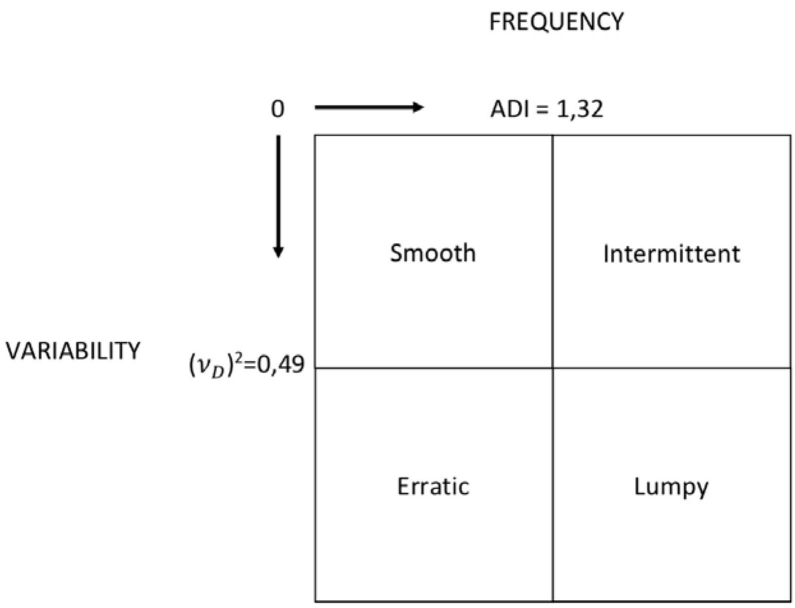


Figure 6.1 *Classification of the codes considering frequency and variability of consumption (Heinecke, Syntetos & Wang, 2011)*

If ADI < 1,32, the code has a middle-high frequency, on the contrary if the ADI > 1,32, the frequency of the consumption is to consider low.
Regarding the coefficient of variation, if $(\nu_D)^2$ > 0,49 the variability is high, on the contrary it is low.
According to this classification, the codes belonging to the lumpy group result to have a high variability and a low frequency of consumption, then they could result to be the most difficult to manage.
Exists another classification that uses a different parameter to measure the frequency of the consumption, the Density of Zeros (DZ).
DZ indicates the number of periods of time without consumption.

Using this parameter, it is possible to define three different categories of codes regarding the frequency (Bystron, Conze & Günthner, 2010):

- Runners codes: $0 \leq DZ < 15 \div 20\ \%$
- Repeaters codes: $15 \div 20\ \% \leq DZ < 50 \div 60\ \%$
- Strangers codes: $DZ \geq 50 \div 60\ \%$

The runners codes have the highest frequency, on the contrary the strangers the lowest. Crossing this classification with the coefficient of variation, it is possible to obtained the following matrix.

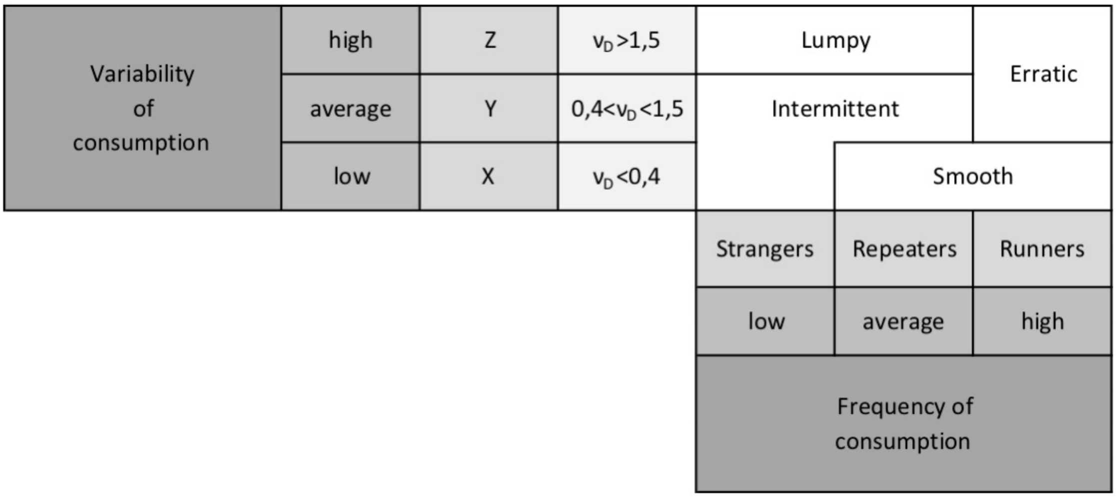


Figure 6.2 *Classification of the codes considering frequency and variability of consumption (Bystron, Conze & Günthner, 2010)*

The third variable to consider is the lead time (LT), meant as the time of response of the supplier in relation to the customer.

It is important to consider the LT in order to manage in the most efficient way the stock and to have the fastest response time to market: companies, in fact, need to reduce this response time to market to become more competitive in the global landscape, trying to front the increasing number of competitors.

Nowadays, in fact, the time with whom the company responds to the market is becoming increasingly important, and then there is the necessity to consider the supplier lead time to choose the most efficient stock management method. For example, if the supplier LT of a code is considerably bigger than the response time to market it is necessary to adopt a ROP method to manage the stock, in order to avoid problems or delay (this situation trivialise the problem, more complex situations will be faced in the next pages).

The supplier lead time, then, results to be decisive for the choice of the stock management method, and for this reason it will be used as first in the development of the method for the identification of the stock management approach.
The other necessary information about the profile of the supplier to define the method are focused on the supplier distance from the company: it will be explained in the next pages how this parameter influences the stock management decision.
At the end, it is necessary to consider also the most important characteristic of a code: the size. This characteristic, in fact, results to be discerning for one method compared to another.
The parameters that will be considered for the developing of the method are the following:

- Value of use
- Consumption of the code (frequency and variability)
- Lead time
- Distance between the company and the supplier
- Dimensions of the codes

6.3 The A.B.C. analysis

One of the most used tool to manage the inventory is the A.B.C. analysis.
This approach stems from the well-proved position that many articles represent only a very small fraction and a few article the bulk of the total monetary value (Monhemius & Van Hees, 1972).
In the A.B.C. system of inventory control articles are classified as A.B.C, namely:

- A-articles: the small group of articles representing much of the total turnover.
- B-articles: the middle group.
- C-articles: the wide range of articles whose share of the total turnover is small.

This approach it can be used in many application, in this case it will be used to classify the codes on the base of the value of use.
In literature, there are different classification, in these pages it will be used the following one (De Toni, Panizzolo & Villa, 2013):

Value of use	Class	Description
80%	A	Group of element with numerosity approximately equal of 20% of the total
15%	B	Group of element with numerosity approximately equal of 30% of the total
5%	C	Group of element with numerosity approximately equal of 50% of the total

Table 6.1 *Different classes of A.B.C. analysis (De Toni, Panizzolo & Villa, 2013)*

The situation is shown in the following chart:

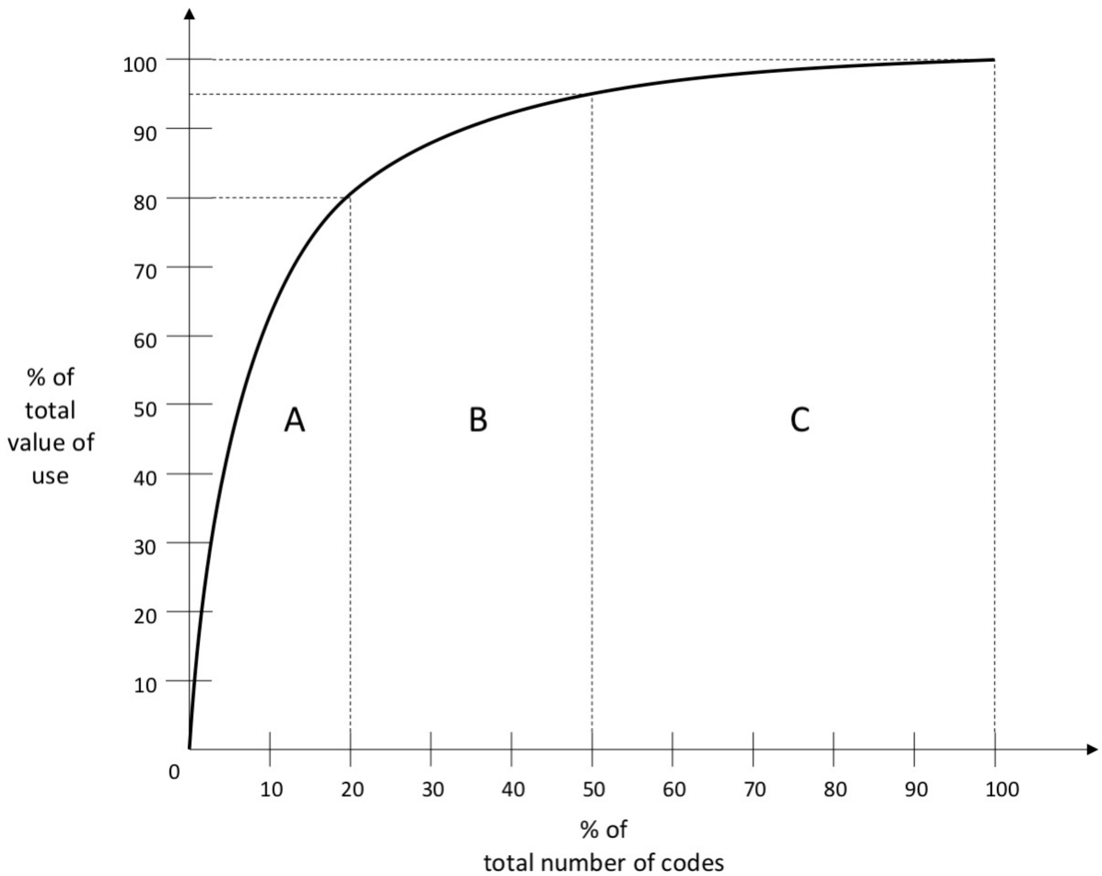


Figure 6.3 *A.B.C. analysis considering value of use*

6.4 Method for the identification of the stock management approach

The first step of the developing of the method is the identification of the most important codes, in order to understand which are the material responsible of the biggest part of the entire value of use.
For this purpose, it is possible to use the tool mentioned in the Chapter 6.3, the A.B.C. analysis.
After a simple mathematical analysis, it is possible to identify the three categories of codes, considering the value of use.
According to this method there are a few codes that own the majority of the total value of use, these ones will be protagonist of a deeply studying.
Simultaneously to the A.B.C. analysis it is important to consider one of the other parameters: the consumption of the code, meant as variability and frequency of the consumption.
To make the method more comprehensible, the classification of Heinecke, Syntetos & Wang is considered (Figure 6.1). Across the studying of the ADI and ν_D parameters it is possible to define the four groups of codes: intermittent, lumpy, smooth and erratic.
The model is also displayed below:

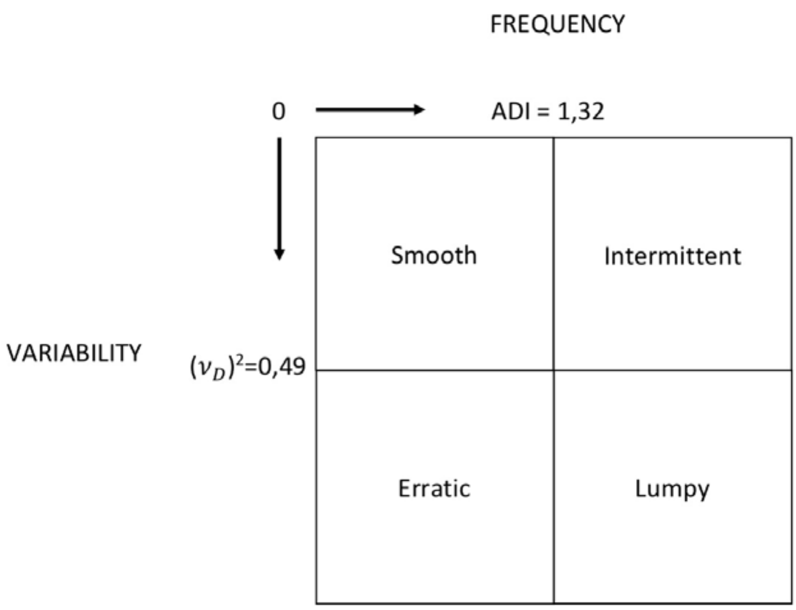


Figure 6.4 *Classification of the codes considering frequency and variability of consumption (Heinecke, Syntetos & Wang, 2011)*

After the definition of the “value of use” and “consumption” classes, it is possible to proceed with a cross analysis between them, as shown in the following figure.

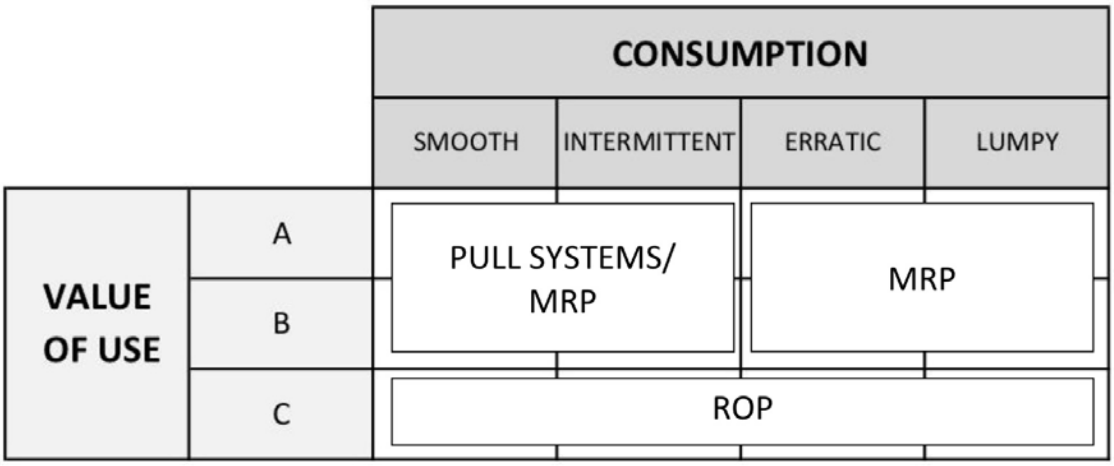


Figure 6.5 *Cross analysis between value of use and consumption*

The classification shown in Figure 6.5 is obtained by means of the following observations:

- All the codes belonging to the C-class of value of use can be managed with ROP method.
  Thanks to this low value of use, in fact, it is possible to manage these codes using the simplest method, the ROP.
  Considering the low value, then, it is possible to stock these materials without increasing in a critical way the costs. These materials will be always ready to be used, avoiding delays or problem.
- The pull approaches need a variability of consumption low (and preferably a frequency of consumption high), for this reason the pull methods can be considered only for the smooth and intermittent classes.
- If the variability of the consumption is high, the best way to manage the stock is to calculate the requirements, considering also the historical data. This means that it is necessary to use a MRP method.
- If the value of use is high (A and B classes) and the variability of consumption is low (smooth and intermittent classes) it is necessary to analise in a more depth way the situation, considering other factors, in order to use a pull method in the situations that allow it, so as to reduce costs, inefficiencies and stock problem. This topic will be considered in the next pages.

After the examination of the first two parameters, value of use and consumption, it is necessary to consider the third parameter: the lead time meant as the time of response of the supplier in relation to the customer.
For the codes belonging to the "Pull systems/MRP" group, it will be considered the lead time in order to classify the ones that can be managed with an easier MRP method, and the others that needs a more efficient pull method (like kanban, JIS or VMI). The pull methods, in fact, in one hand allow to have a reduced level of stock and a more efficient stock management (less issues, less delays), in the other require agreements between costumer and supplier not always simple to stipulate, and they require service costs that have to be beard by the company.
For this reason, it is appropriate to consider the possibility to adopt a pull method only when the supply lead time is great as compared to the response time to market.
At this purpose the parameter "Critical Lead Time" (CLT) is defined.
All lead time of the codes belonging to the "Pull systems/MRP" group are compared to the CLT:

- If the code has LT > CLT, it needs a more efficient way to be managed, and then, it will be included in the "Pull method" category
- If the code has LT < CLT, it does not need a pull approach, then it can be managed with an MRP system (that, in any case, allows to have a lower level of stock compared to ROP). The problems, that can be shown during the supply process, can be solved thanks to the more time availability, without incurring in a too nervous system or delays.

The Critical Lead Time is a parameter that can be defined considering the response time to market that the company wants or has to have.
To define the CLT parameter, it is necessary to involve the opinion of experts. This topic, then, will be fronted in the next pages.
For the moment, it is important to underline the dependence of this parameter to the response time to market.
According to this definition of CLT, it is not a fixed parameter: if the company wants to try to decrease the response time to market, it can reduce the CLT in order to manage more codes with a pull method, so as to have a more efficient and lean stock system, avoiding delay and problem.
Once the "Pull method" group has been defined (the group of all the codes with LT > CLT), to arrive to the final matrix is necessary to consider the last two parameters: the distance of the supplier and the size of the code.
The considerations to reach the final classification are the following:

- If the company of supplier is at a considerable distance from the client company, the more indicated approach to use is the Vendor Managed Inventory (VMI).

Thanks to the fact that the management responsibility of the stock is owned by the supplier, this distance can be organised in the most proper way.

- If the size of the code is contained, it is possible to use the kanban method: the containers used in this approach, in fact, allow to manage in the best way little materials.
- For bigger materials, instead, it is necessary to use the JIS approach, in which the dimensions of the codes do not represent a problem.

Obviously, the concepts of ''big'' and ''little'' are subjective, it is necessary to define case by case the limit.
According to these considerations it is possible to define the final classification using the one developed by De Toni, Panizzolo and Villa (De Toni, Panizzolo & Villa, 2013):

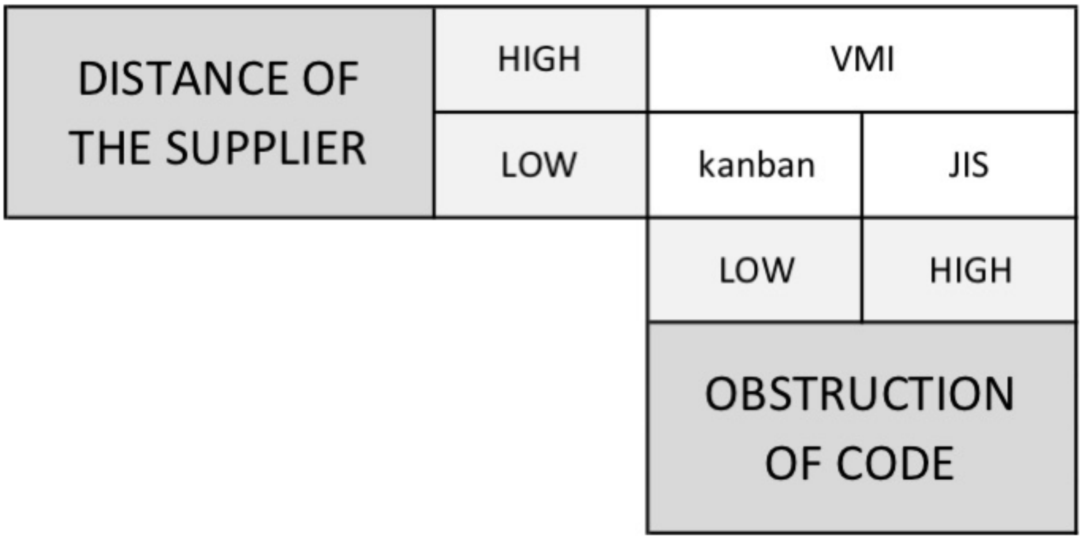


Figure 6.6 *Stock management approach selected considering distance of the supplier and size of codes*

6.5 Summary of the method

The developed method consists in the following passages:

I. A.B.C. Analysis of value of use and consumptions classification

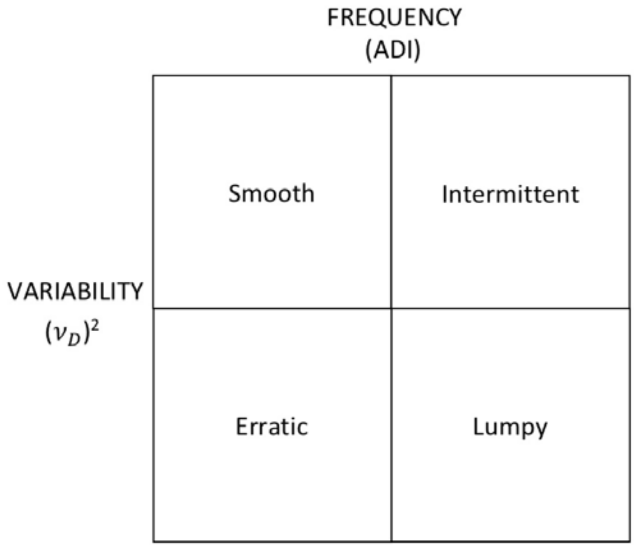


Figure 6.7 *Consumptions classification*

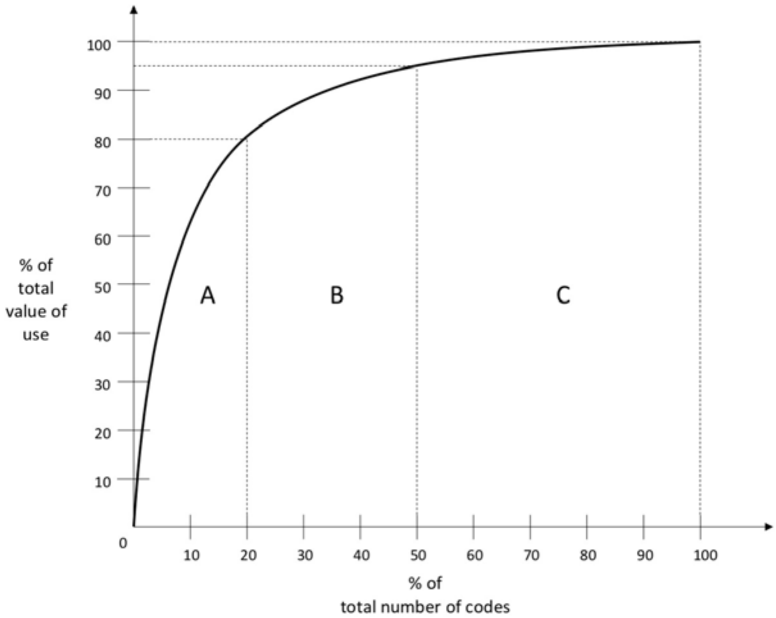


Figure 6.8 *A.B.C. Analysis of value of use*

II. Cross analysis between consumption and value of use classes

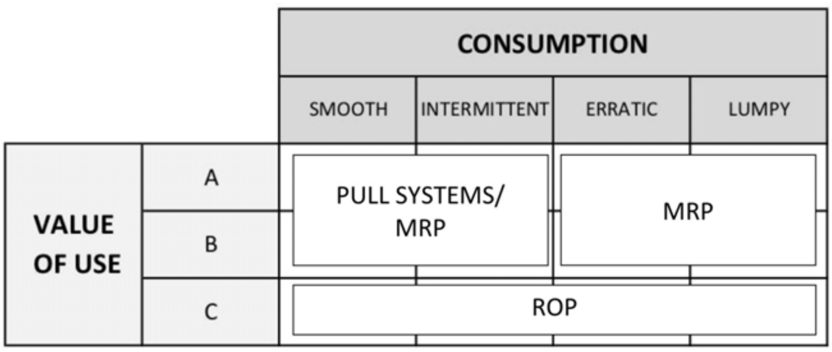


Figure 6.8 *Second step of the method: cross analysis between consumption and value of use classes*

III. Comparison between the lead time of the codes belonging to the “Pull systems/MRP” group and the Critical Lead Time (that it will be defined in the next pages).

IV. For the codes with LT > LTC: consider distance of supplier and size of code to define the approach to use.

		SIZE OF CODE	
		LOW	HIGH
DISTANCE	HIGH	VMI	
	LOW	kanban	JIS

Figure 6.9 *Fourth step of the method: final classification of codes that can be managed with pull approach considering size of code and distance of the supplier (De Toni, Panizzolo & Villa, 2013)*

6.6 Opinion of the companies and validation of the method

After the definition of the method it is necessary to validate it in order to have a tool that can be used in practical application: at this purpose, it is necessary to collaborate with the logistic manager of some companies.
The topics that have to be exanimated during the collaboration are two:

- It is necessary to justify, using the opinion of the expert, the order used to consider the different parameters during the method. This sequence has an explanation at the qualitative level, but it needs a justification in practical field.
- The second element that has to be examined is the definition of Critical Lead Time: using the opinion and the experience of the logistic manager of the different companies, it is necessary to obtain a mathematical expression for the CLT, that shows the relationship between this parameter and the time to response to market.

For this reason, a collaboration with the managers of the logistic of 21 different companies is instituted.
The companies are chosen in Veneto area, and they are selected to consider all the different types of companies: Engineering To Order (ETO), Purchase To Order (PTO), Make To Order (MTO), Assemble To Order (ATO), Make To Stock (MTS) and Delivery To Stock (DTS).

NAME	TYPE	SECTOR
COMPANY 1	MTO	Production of technical articles in rubber and polyurethane
COMPANY 2	MTS	Trade in cosmetic products
COMPANY 3	ATO	Production of burners
COMPANY 4	MTO	Production of heat transfers
COMPANY 5	MTO	Trade in fire-fighting components
COMPANY 6	PTO/MTS	Paper production
COMPANY 7	MTS	Production of electrical connection technologies
COMPANY 8	ETO	Production of metal shelving for warehouses
COMPANY 9	MTO/MTS	Spring production
COMPANY 10	ATO	Flooring production
COMPANY 11	ETO	Building material production
COMPANY 12	MTO	Production of vehicles for gas transport
COMPANY 13	ATO	Graphic design services
COMPANY 14	MTS	Production of sanitary products
COMPANY 15	MTO/ATO	Electric pumps production
COMPANY 16	MTO/MTS	Saddle production
COMPANY 17	MTS	Production of gardening articles
COMPANY 18	PTO/MTO	Production of catering equipment
COMPANY 19	MTO	Production of rubber tubes
COMPANY 20	PTO	Production of water management equipment
COMPANY 21	MTO	Electromechanical constructions

Figure 6.10 *List of the 21 companies that collaborated in the research*

The used tool is a questionnaire composed of two part, in relation with the two main topics that has to be analysed:

1. The first part allows to understand, which of the six parameters considered in the method are the main, in order to be used as first in the method
2. The second part permit to obtained a mathematical expression of the Critical Lead Time, using the opinion of the experts.

6.6.1 Results of part 1

Firstly, it is necessary to recall the six different parameters considered in the method, the same six parameters used in the collaboration with the companies:

1. Frequency of the consumption
2. Variability of the consumption
3. Value of use of the code
4. Lead time
5. Size of the code
6. Distance of the supplier

To make the computational part easier, the 1 and 2 parameters are summarised in one generic "consumption" parameter.

To manage the different opinions of the different logistic managers it is used an open source software: *Weka – Waikato Environment for Knowledge Analysis.*

This software, in addition to being a suite of machine learning software written in Java, contains tools and algorithms for data analysis useful to manage the different points of view of the managers.

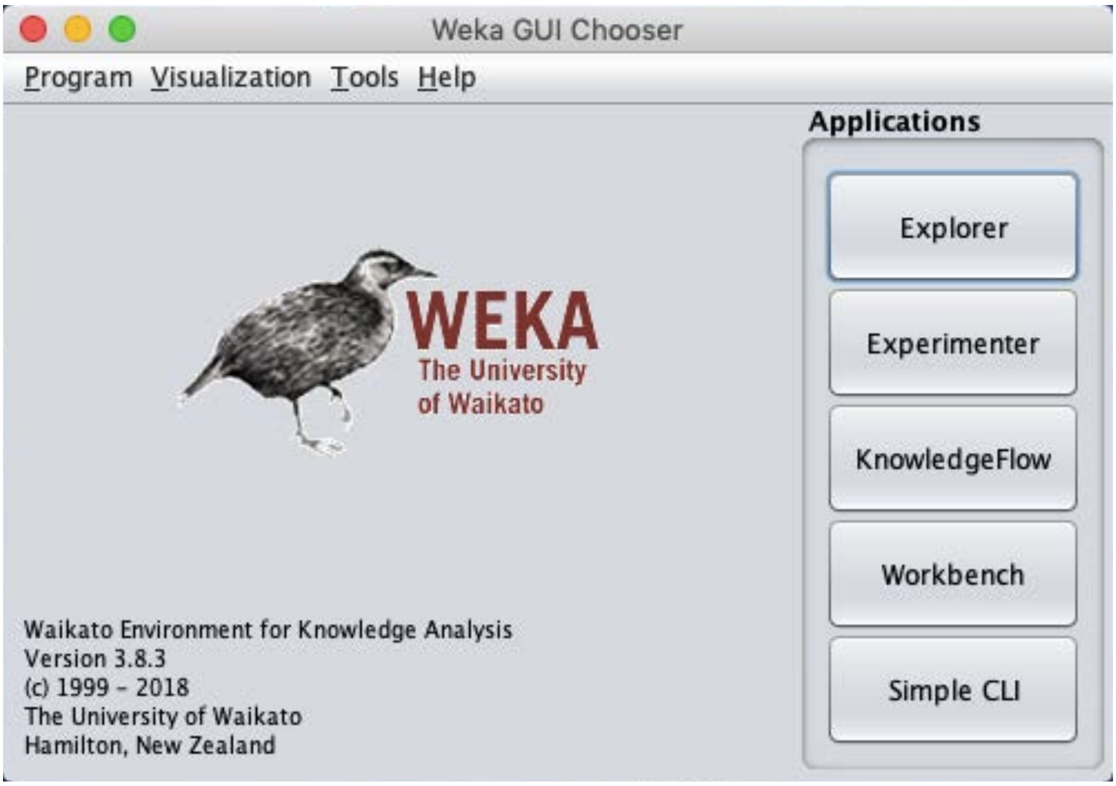


Figure 6.11 *User interface of WEKA software*

Firstly, it's necessary to modify the data to make them usable by the softwere.

All the attributes of Weka, in fact, have to be nominal: it is necessary to modify the collected data in Excel, with the tool *Find and Replace,* in this way, all the numbers are replaced with a letter and the same number (for example, the number "1" become "c1", so that the software can use it).

The values that can be assumed by every parameter are the following: c1, c2, c3, c4 and c5, depending on the importance that is given to them, in ascending order (then, the most important parameter has the "c1", while the less important has the "c5").

Moreover, it necessary to rename every parameter without using space: for example, *lead time* becomes *LT*, or *Value of use* become *Valueofuse.*

The only format that the software can use is the `.arff` one. This format is formed from:

- A header (@relation), that contain the tile of the file and the names of the attributes (@attribute), whit all the value can be assumed
- A body of the data (@data), comma separated and one line each

The `.arff` file is open as follows:

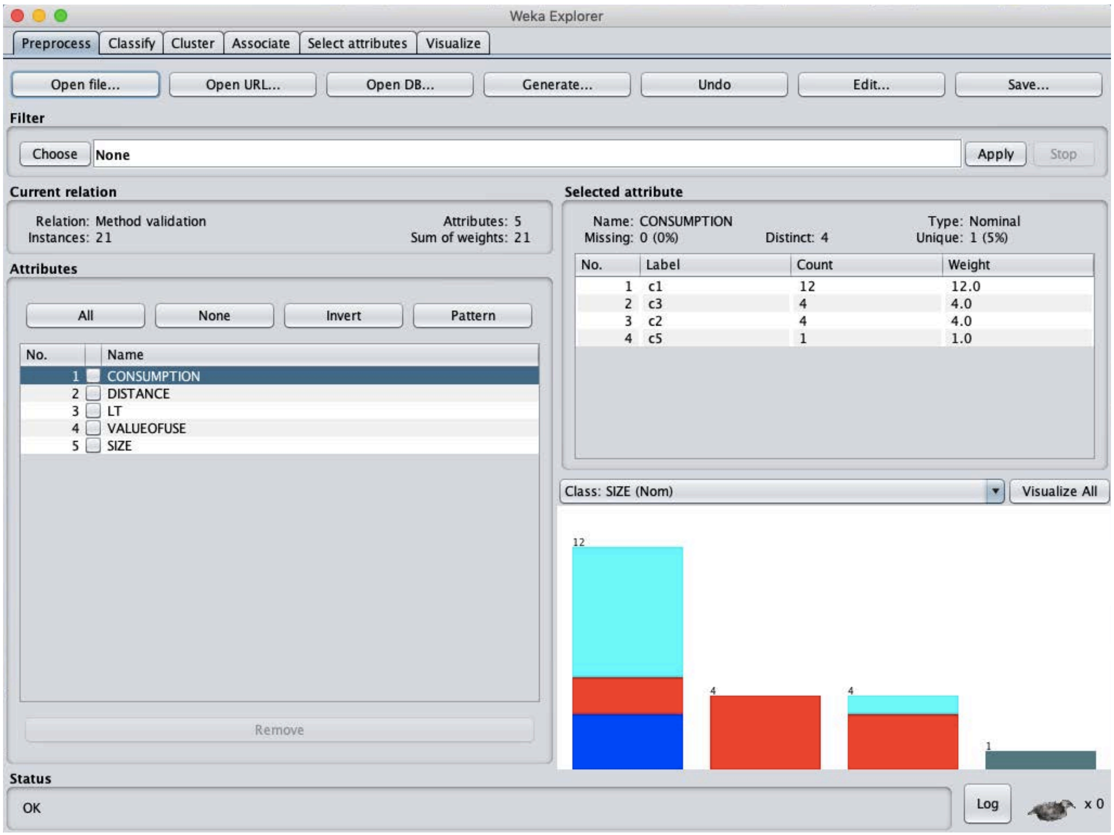


Figure 6.12 *"Consumption" section of the data in Weka software*

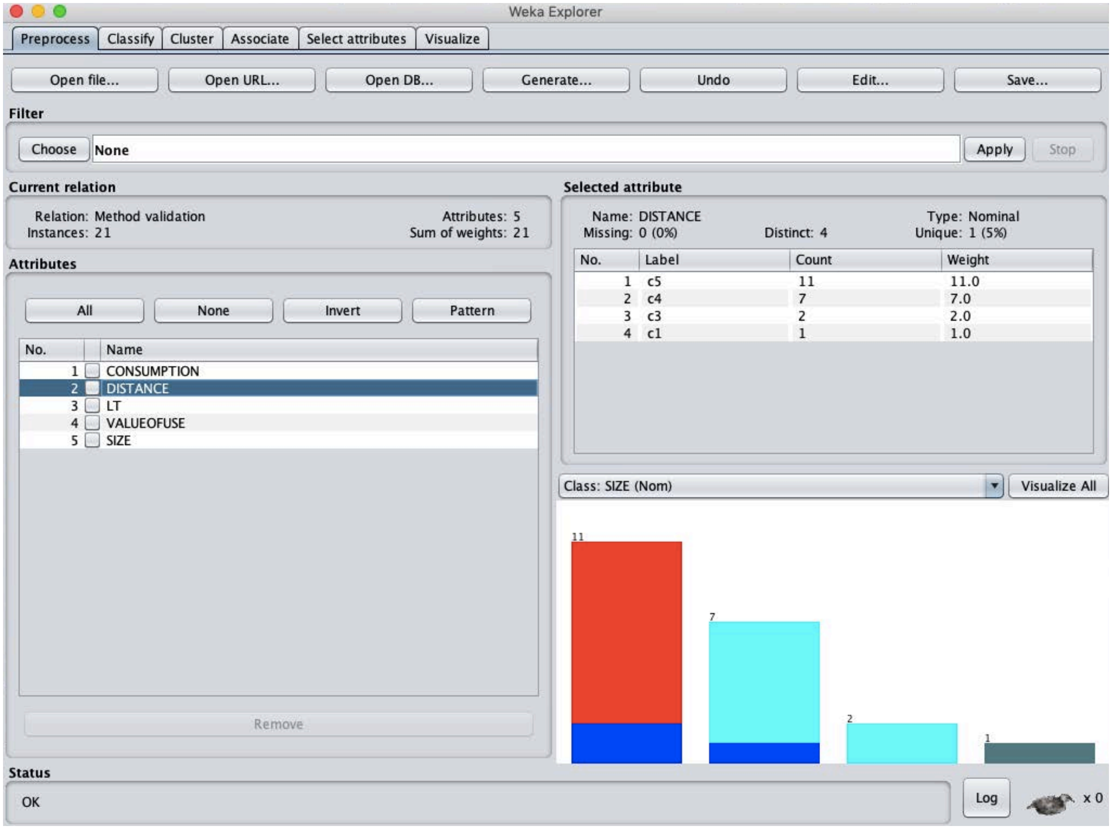


Figure 6.13 *"Distance of the supplier" section of the data in Weka software*

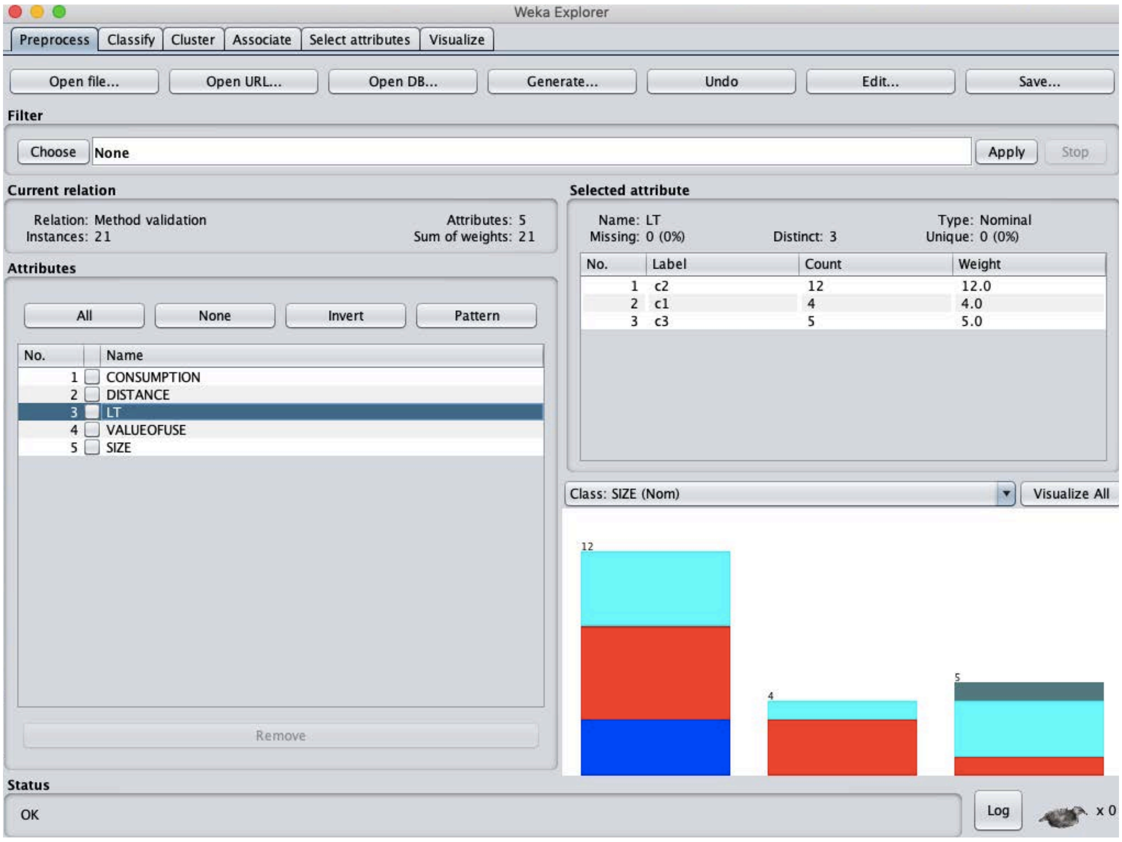


Figure 6.14 *"Lead Time" section of the data in Weka software*

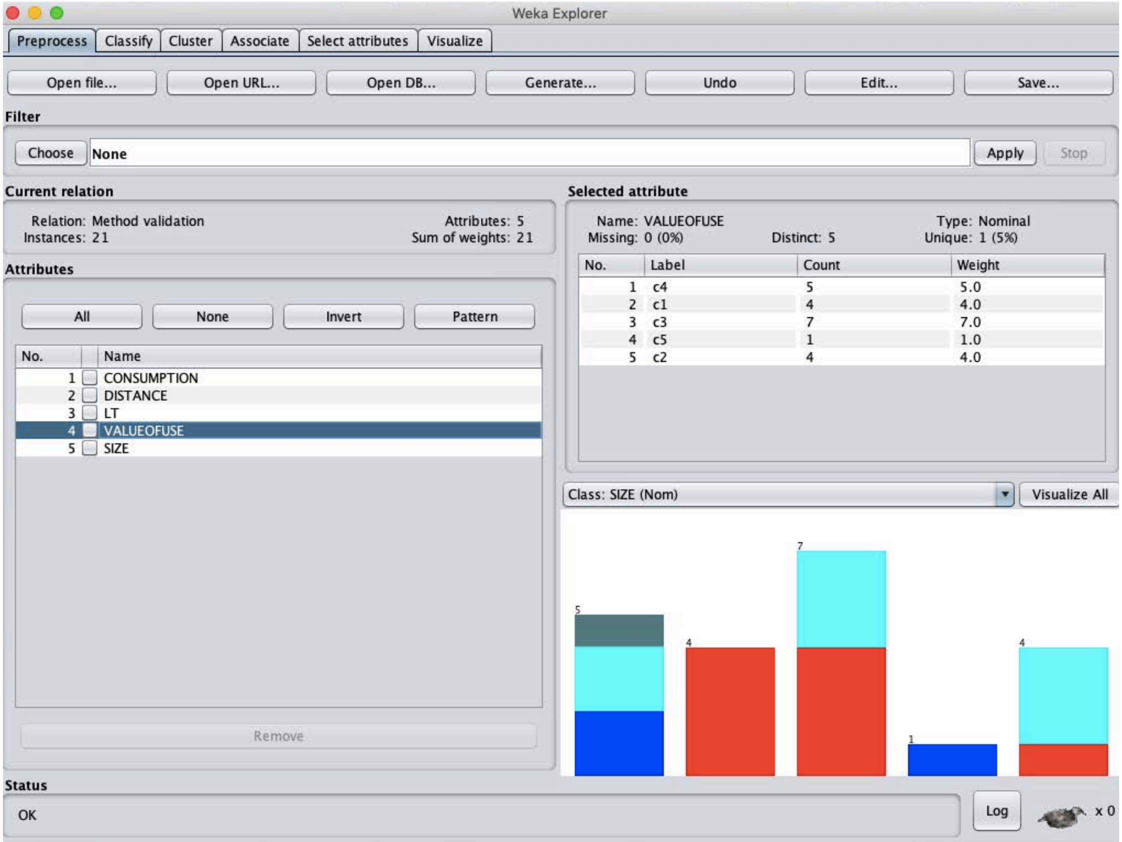


Figure 6.15 *"Value of use" section of the data in Weka software*

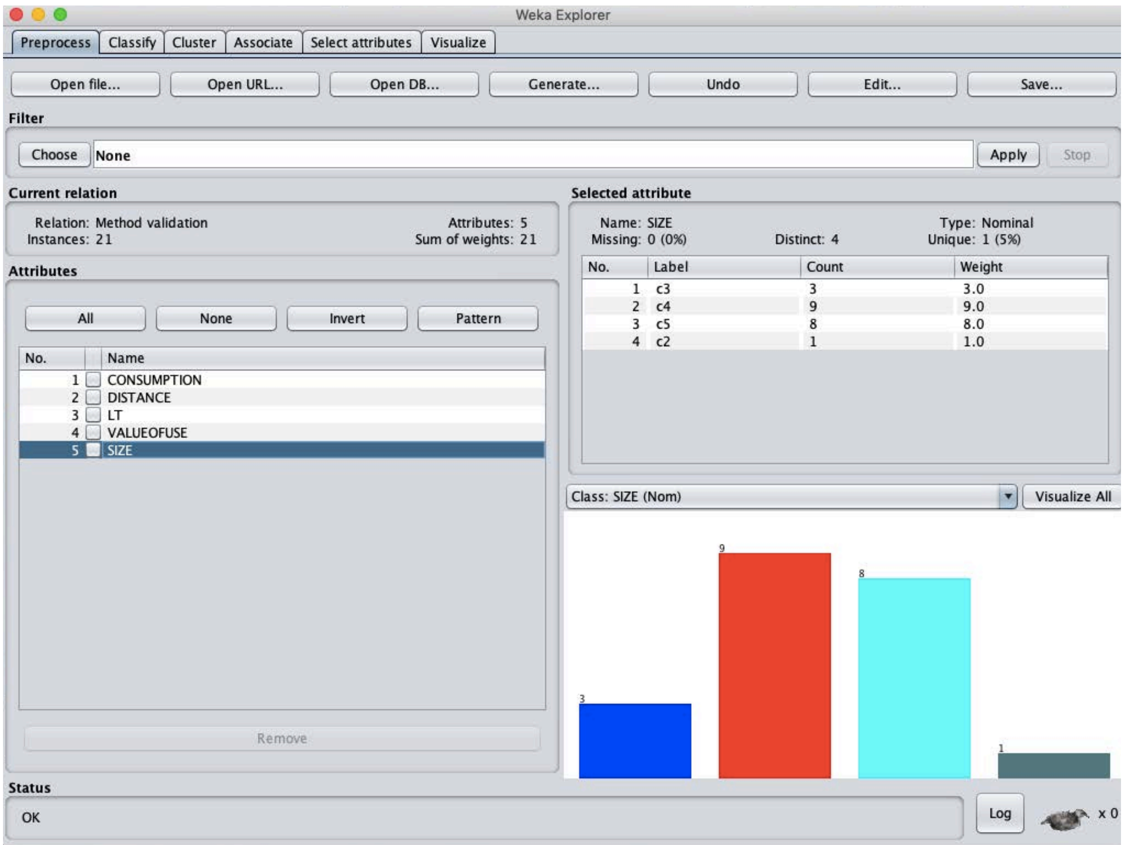


Figure 6.16 *"Size of the code" section of the data in Weka software*

After the correct data uploading is used the *Classify* section of the software: Weka, using algorithms that can be set, is able to give as output the precedence chart of the parameters based on the opinion of the 21 logistic manager of the different companies. In this way, it is possible to compare the precedence chart used in the developed method to the one obtained from the software data elaboration.

For the data elaboration, Weka uses *ZeroR* as classifier algorithm.

Using this algorithm is given to every parameter the class value between c1, c2, c3, c4 and c5: the parameter with the c1 class value is the most important one according to the software based on the manager opinion, and then, it has to be used as first in the method, so on to the parameter with c5 class of value that is considered the less important and has to be used as last in the method.

The results are shown in the following imagines:

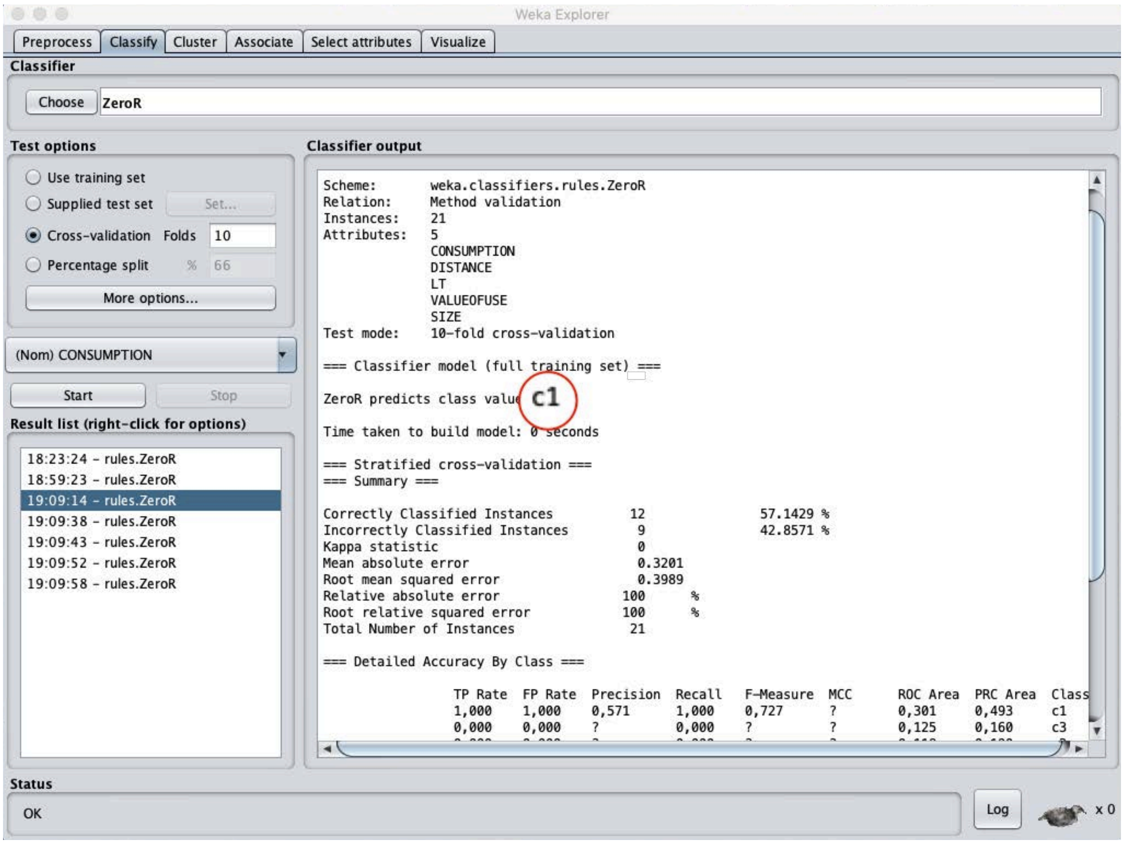


Figure 6.17 *"Consumption" parameter final classification*

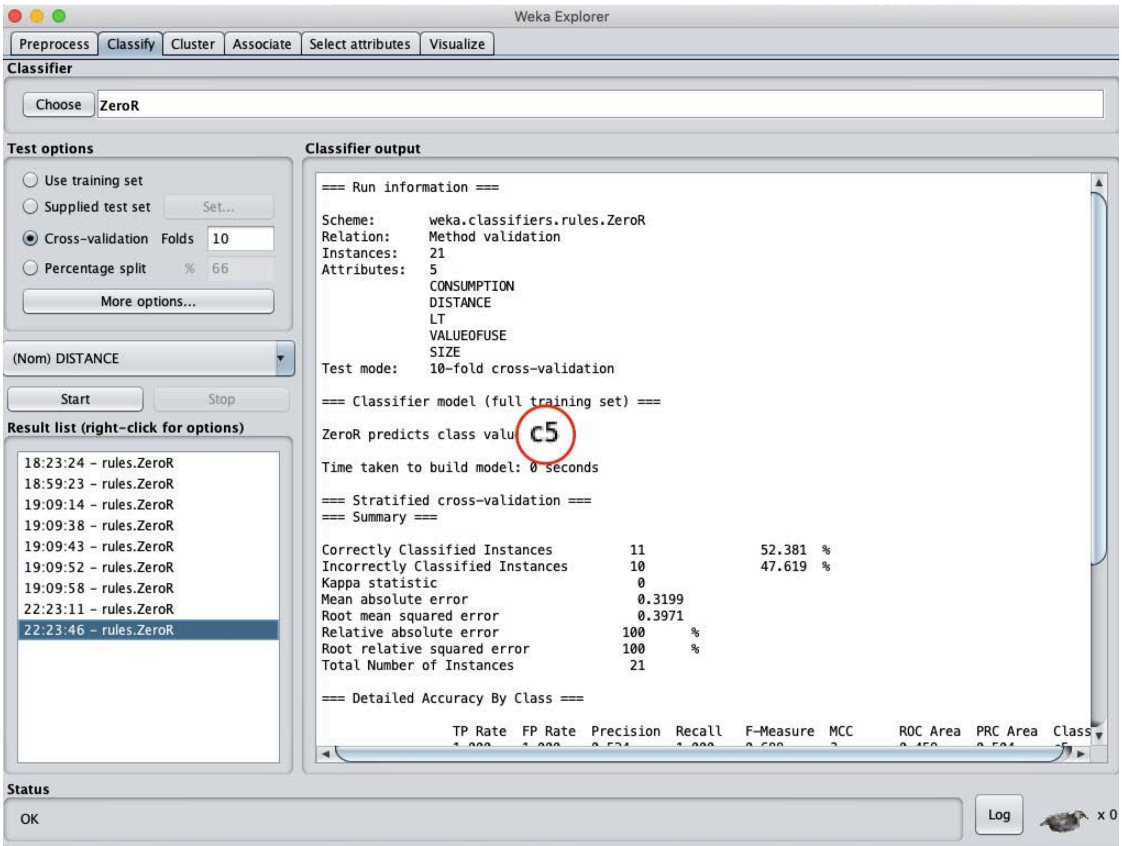


Figure 6.18 *"Distance of the supplier" parameter final classification*

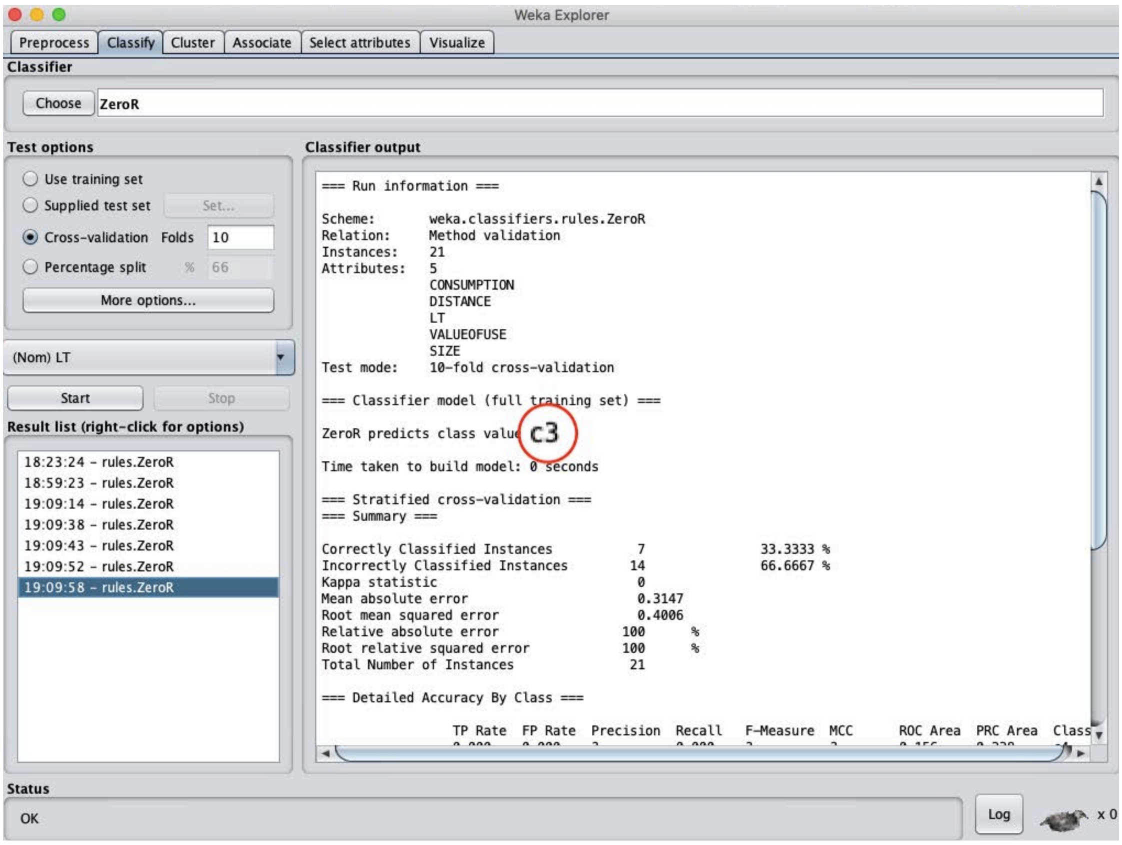


Figure 6.19 *"Lead Time" parameter final classification*

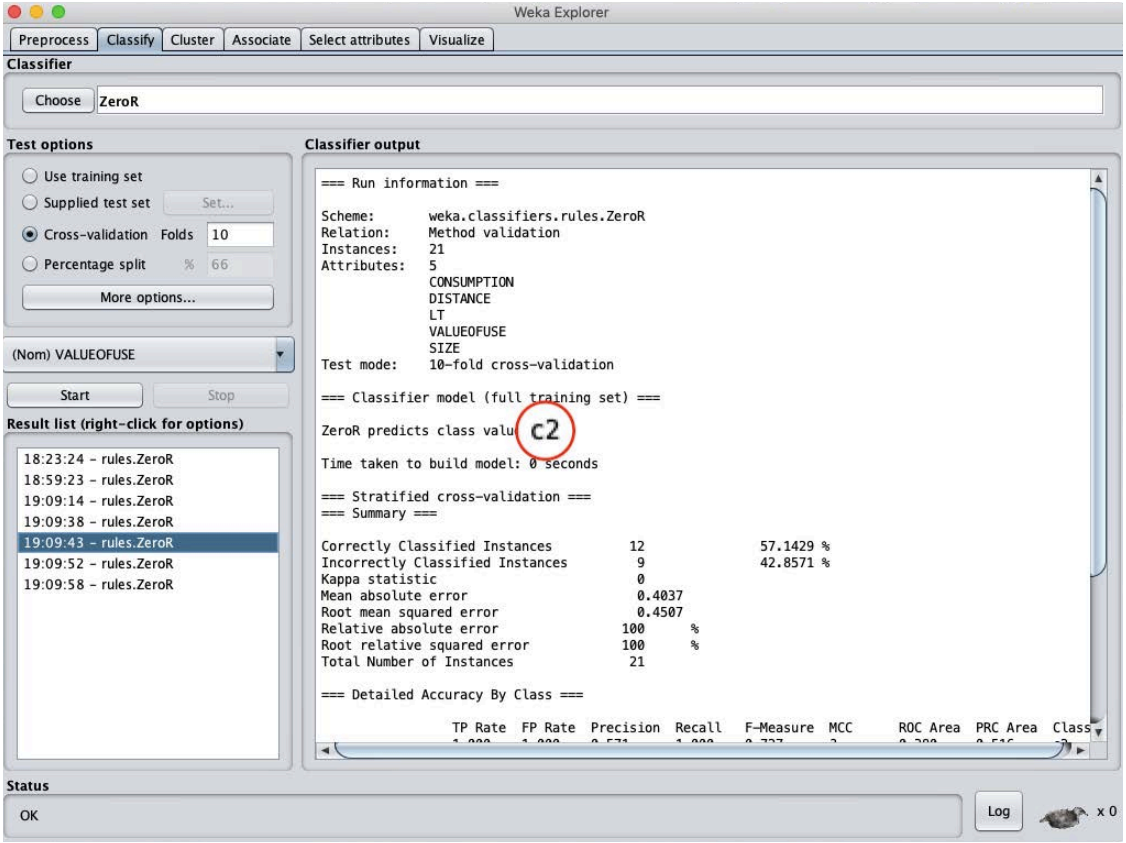


Figure 6.20 *"Value of use" parameter final classification*

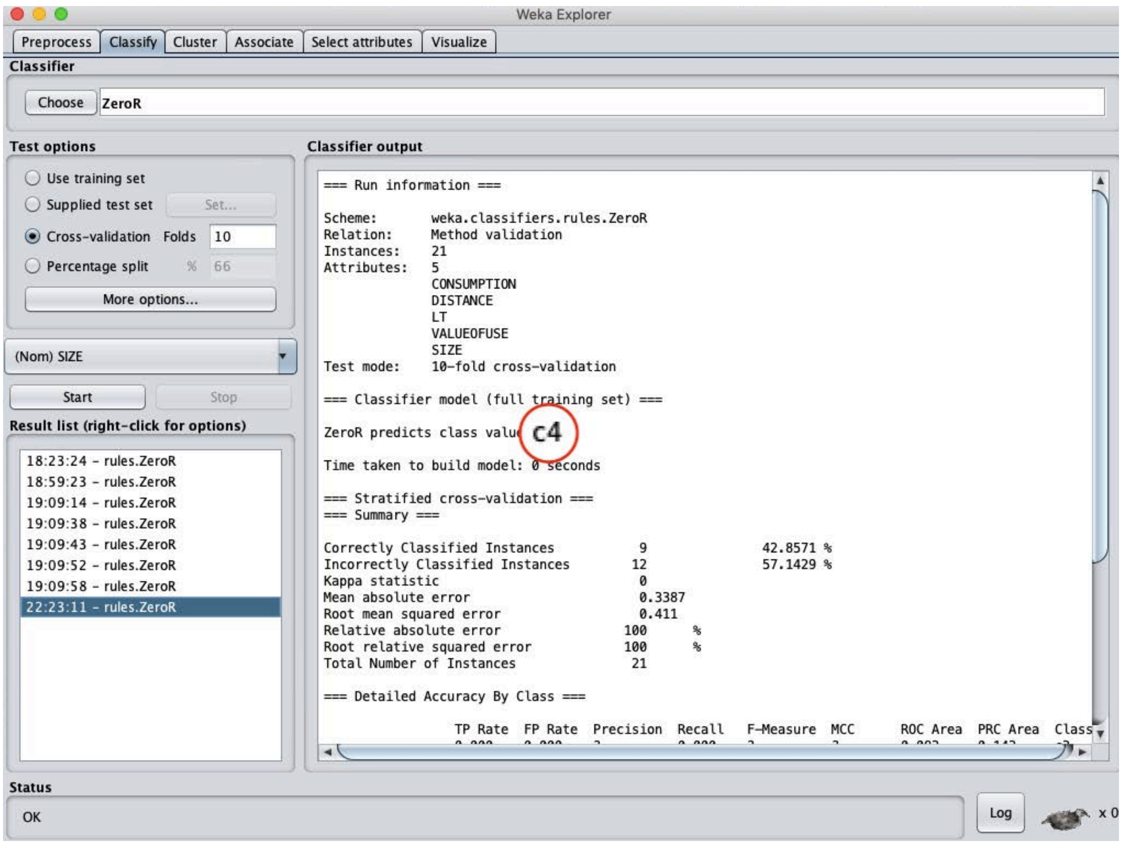


Figure 6.21 *"Size of the code" parameter final classification*

Thanks to the data collection and the use of the software is possible to obtain the following precedence chart:

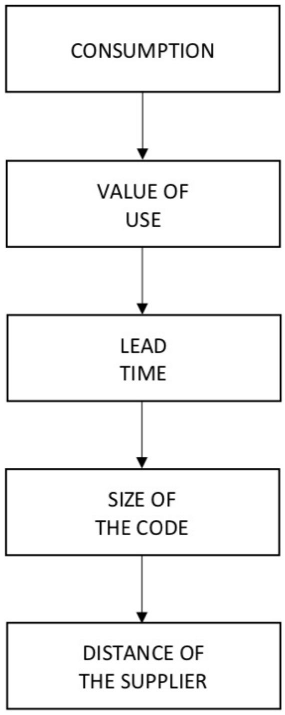


Figure 6.21 *Precedence charts obtained using the software*

Analysing the Figure 6.21, it is possible to notice that this order of the parameters corresponds to the one considered in the developed method.
For this reason, it is possible to consider justified the order used.
After the definition of the order to use to consider the parameters, it is possible to confirm the precedence chart of the method, that is an advancement of the basilar order obtained with the software.

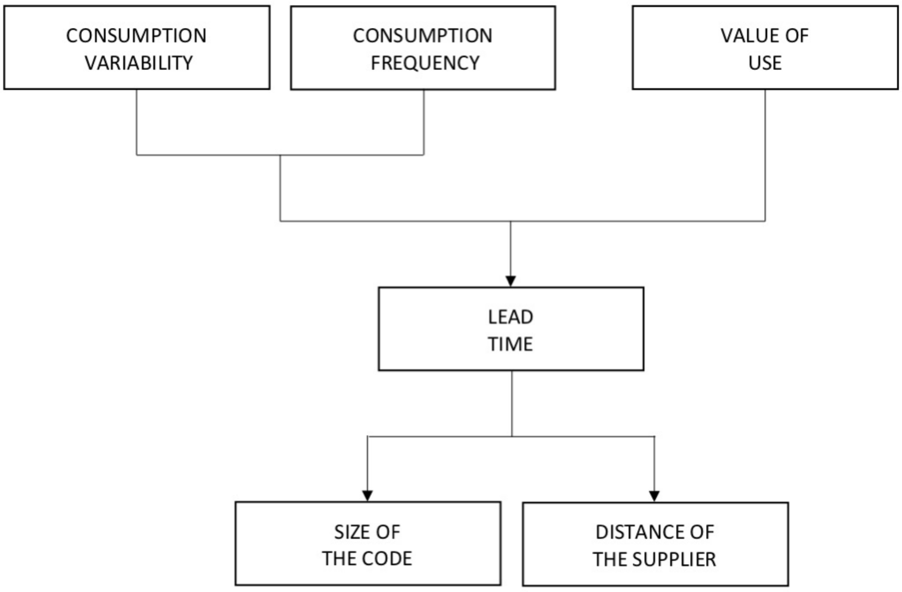


Figure 6.22 *Final precedence charts used in the method*

6.6.2 Results of part 2

The second part of the research is focused on the identification of the Critical Lead Time, using the experience and the opinion of the logistic managers of the different companies.
It is requested to indicate an estimate expression of a supply lead time that can be considered high as compared to the response time to market: the codes whit this “high” supply lead time, then, need to be managed with a more efficient and a no traditional stock management approach.
Clearly, this LT changes depending on the type of the considered company: for example, the logistic manager of a MTO company consider a “high” lead time, a LT bigger than the manager of a MTS.
For this reason, it is requested to express this time as a function of the response time to market.
The expression, then, assumes the following form:

$$CLT = \ldots \times T \tag{6.6}$$

In which “CLT” is the Critical Lead Time to define, and “T” is the response time to the market.
The results for the different companies are shown in the following chart:

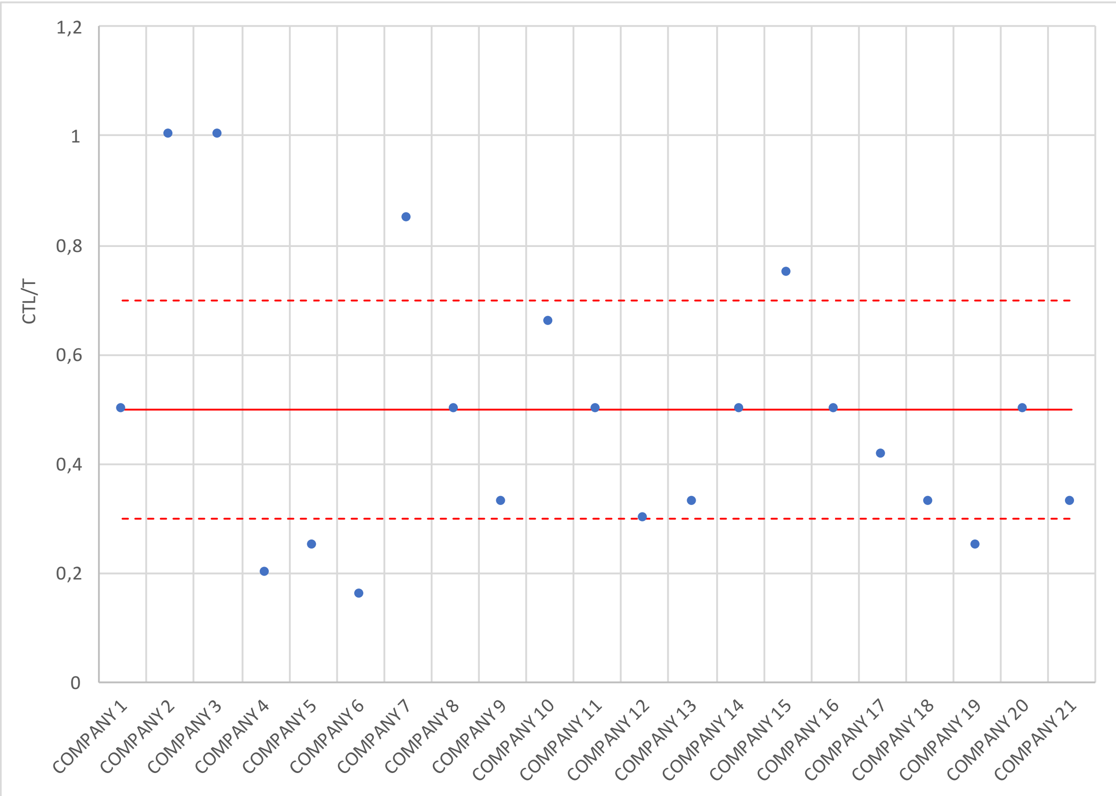


Figure 6.23 *Data collected from the different companies. CLT is the Critical Lead Time and T is the response time to market*

The statistical analysis of the 21 different opinions gives the following result:

$$CLT = 0{,}5 \pm 0{,}2\, T \tag{6.7}$$

Using this expression, it is possible to identify the codes with a LT > CLT in order to manage them with a more lean and efficient stock management approach.
The used questionnaire is displayed in Appendix A.

Chapter 7

Application of the method

The method for the selection of the stock management approach developed in Chapter 6 will be apply in a case study of a real company, in order to understand if it is possible to reduce the costs linked to the materials and if it is possible to enhance the stock management.
The selected company is a Make To Order company (MTO), inasmuch its principal operations are the production and the assembly in order to get to the finished products.
This company is focused in the production of filling machines, for the manufacturing of container of foodstuffs. These filling machines need a great variety of customization and, then, they are not always manageable in an efficient productive way.

7.1 Tools used and method application

In the following part of the thesis the method developed in Chapter 6 will be applied, starting from the data contained in the Plan For Every Part (PFEP).
As mentioned, the selected company is a MTO, then it is necessary to reduce the response time to market choosing a pull approach in order to make the stock management lean and more efficient.
To manage the huge amount of data, it is used an Excel spreadsheet, using different types of function, as:

- `=IF (logical_test, [value_if_true], [value_if_false])`
- `=IF (OR (logical1, [logical2], ...), [value_if_true], [value_if_false])`
- `=IF (AND (logical1, [logical2], ...), [value_if_true], [value_if_false])`
- `=SUM (number1, [number2], [number3], ...)`
- `=COUNTIF (range, criteria)`
- `=LARGE (array, n)`
- `=AVERAGE (number1, [number2], ...)`
- `=STDEV (number1, [number2], ...)`

- `=MAX (number1, [number2], ...)`
- `=MIN (number1, [number2], ...)`
- `=INT (number)`

7.1.1 A.B.C. analysis of value of use

The first step for the application of the method is the A.B.C. analysis of the value of use, considering two of the data contained in PFEP: standard cost and quantity of use.
The relationship between the two data is the following:

$$Value\ of\ use = Consuption \times Unit\ value \tag{7.1}$$

CODE	STANDARD COST [€]	QUANTITY	VALUE OF USE [€]	CLASS	COMULATIVE VALUE OF USE [%]
CODE 1	18000	10	180000	A	5,1
CODE 2	59500	3	178500	A	10,1
CODE 3	6000	18	108000	A	13,2
CODE 4	7100	10	71000	A	15,2
CODE 5	21150	3	63450	A	17
CODE 6	2500	23	57500	A	18,6
CODE 7	4495	11	49445	A	20
CODE 8	263	177	46551	A	21,4
CODE 9	15000	3	45000	A	22,6
CODE 10	15000	3	45000	A	23,9
CODE 11	43500	1	43500	A	25,1
CODE 12	4250	9	38250	A	26,2
CODE 13	2220	17	37740	A	27,3
CODE 14	705	44	31020	A	28,2
CODE 15	4385	7	30695	A	29
CODE 16	1635	18	29430	A	29,9
CODE 17	2431,14	11	26742,62	A	30,6
CODE 18	130	198	25740	A	31,4
CODE 19	6315	4	25260	A	32,1
CODE 20	63,26	376	23787,75	A	32,8
CODE 21	21200	1	21200	A	33,4
CODE 22	940	21	19740	A	33,9
CODE 23	1622	12	19464	A	34,5
CODE 24	1077	18	19386	A	35
CODE 25	19332,65	1	19332,65	A	35,6
CODE 26	872	22	19184	A	36,1
CODE 27	1870	10	18700	A	36,6
CODE 28	1499,85	12	17998,2	A	37,2
CODE 29	803	22	17666	A	37,7
CODE 30	17130	1	17130	A	38,1
CODE 31	1900	9	17100	A	38,6
CODE 32	742	22	16324	A	39,1
CODE 33	1800	9	16200	A	39,6
CODE 34	163	99	16137	A	40

Table 7.1 *Codes classified according to the value of use*

For summary reason, in Table 7.1 are shown only the codes until the 40% of cumulative percentage value of use.
In Figure 7.1 it is possible to see the typical curve of the A.B.C. analysis with all the 2263 codes.

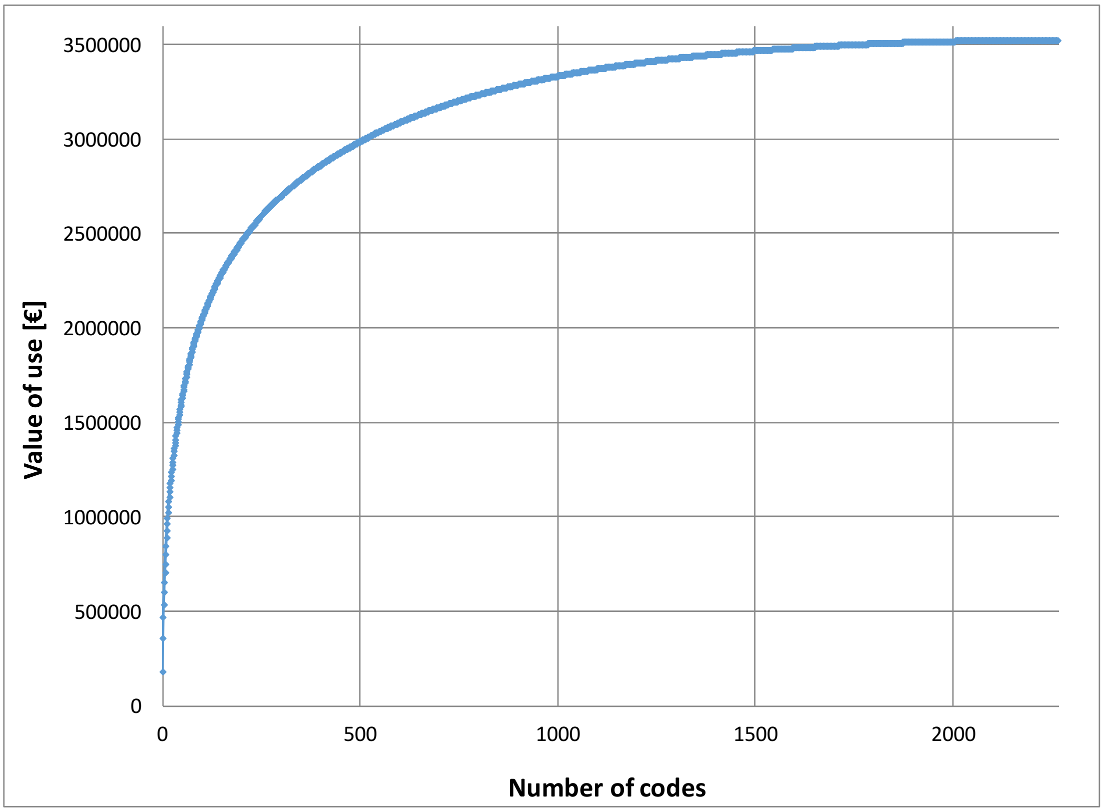


Figure 7.1 *A.B.C. curve of the value of use for the 2263 codes*

After the analysis, it is possible to obtain the following data:

- 382 codes belong to the A class (80% of the total value of use)
- 608 codes belong to the B class (15% of the total value of use)

- 1273 codes belong to the C class (5% of the total value of use)

7.1.2 Analysis of the consumptions

In parallel with the A.B.C. Analysis of the Value of use, following the method developed in Chapter 6, it is necessary to classify the different codes according to the consumption, and following the classification of Heinecke, Syntetos and Wang.
The classification shown in Figure 7.2 is obtained.

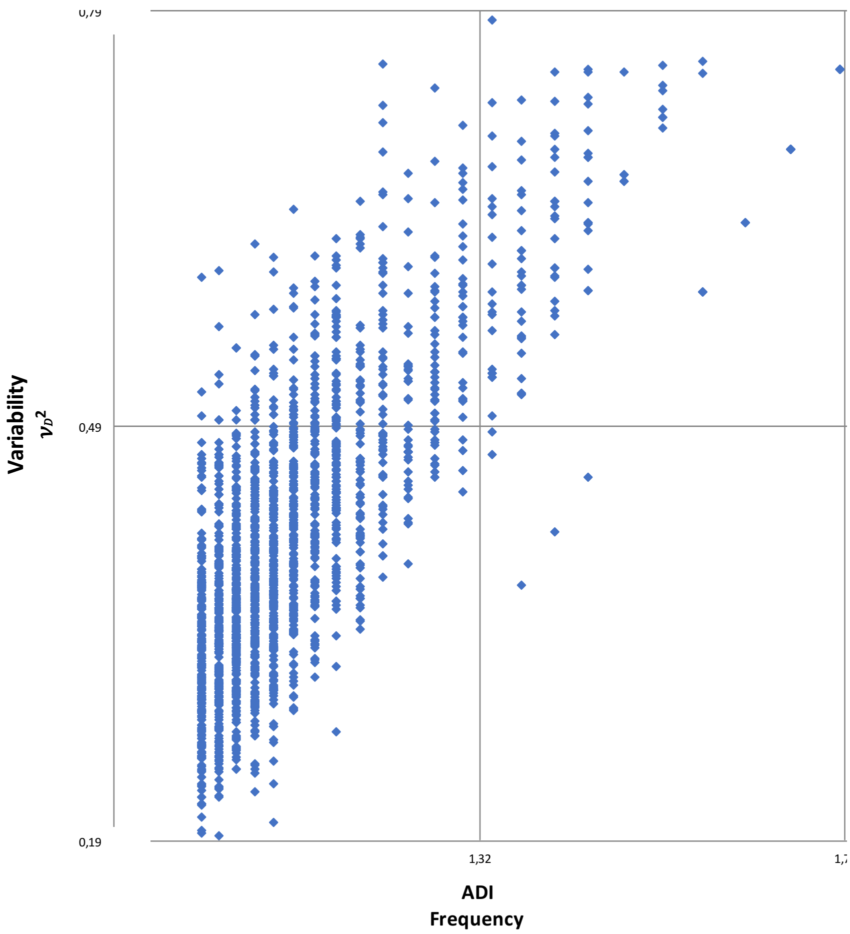


Figure 7.2 *Consumption analysis*

After the consumption analysis, as shown in Figure 7.6, it is possible to obtain the following results:

- 1490 codes belong to the “SMOOTH” group
- 5 codes belong to the “INTERMITTENT” group
- 483 codes belong to the “LUMPY” group
- 285 codes belonging to the “ERRATIC” group

7.1.3 Cross analysis between consumption and value of use classes

Now it is possible to proceed with the cross analysis between the different classes of consumption just defined and the classes of the value of use obtained in the Chapter 7.1.1.
In this way, it is possible to follow the structure of the method described in the Chapter 6, in order to identify the codes that can be considered for the more deepened analysis. Crossing the different classes, the following chart is obtained.

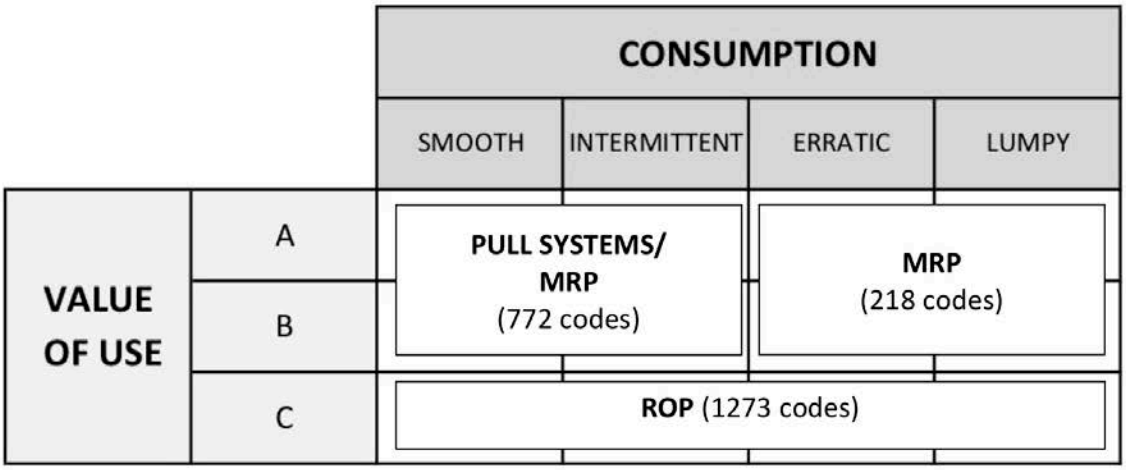


Figure 7.3 *Cross analysis between consumption and value of use*

7.1.4 Lead Time analysis

Following the structure of the method, after the cross analysis it is essential to identify an expression for the Critical Lead Time.
As mentioned in Chapter 6.6.2, the obtained expression for the CLT is the following:

$$CLT = 0{,}5 \pm 0{,}2\,T \tag{7.2}$$

Considering that, for the considered company, the response time to the market is

$$T = 6 \div 10\,weeks \tag{7.3}$$

For easier analysis, it is possible to consider the following expression for the Critical Lead Time:

$$CLT = 0{,}5 \pm 0{,}2\,T = 0{,}3 \times 7\,weeks \cong 2\,weeks \tag{7.4}$$

The LT of the 772 codes belonging to the "PULL SYSTEMS/MPR" is compared to the CLT just defined.
More in detail:

- 734 codes have

$$LT > CLT = 2\,weeks \tag{7.5}$$

- 38 codes have

$$LT < CLT = 2\,weeks \tag{7.6}$$

Using this tool, it is possible to find the codes that need a more lean and efficient managing, and then, they can be managed whit a pull method.

7.1.5 Supplier analysis

After the detection of the codes that can be managed with a pull method, it is necessary, for the same codes, to proceed with the supplier analysis.
Analyzing the data of the company, names and sites of the suppliers are available: it is possible, then, to select the suppliers that are relatively far from the company in order to manage them code whit an VMI approach.
It is considered the following assumption, taking into account the observations made in Chapter 6:

- a supplier can be considered "close to the company" if his site is in the same region of the considered company (Veneto). In this case a Kanban or a JIS approach can be used for the codes delivered from this supplier.

- a supplier can be considered "far from the company", if his site is in another region or country. In this case a VMI approach can be used for the codes delivered from this supplier.

So, for the 734 codes manageable with a pull method, the following results are obtained:

- 607 codes can be managed with a Kanban or a JIS approach.
- 127 codes can be managed with a VMI approach.

7.1.6 Dimensional analysis

The dimensional analysis represents the last step of the method application: for the 607 codes coming from a supplier "close to the company" it is necessary to identify the most appropriate stock management method between the JIS and the Kanban approaches.
First of all, it is necessary to find a Kanban container from the catalog, in order to understand which are the codes that can be managed using this approach.
A R-KLT 600x400 mm VDA 4500 with reinforced bottom was chosen.
At this point it is necessary to make two comparisons:

1. it is necessary to compare the total volume of every codes with the capacity of this container
2. it is also necessary to confront the largest size of the codes with the largest size of the container, in order to avoid error with the codes having a low volume, but one or two considerably large dimensions (like sheet metal or panels). In this case, in fact, the total volume of the code results minor than the capacity of container, but the large planar dimensions do not allow its use. The dimensional comparison is repeated also for the other two dimensions of the codes with the other two of the container.

CODE	EXTERNAL DIM. [mm]	INTERNAL DIM. [mm]	VOLUME [mm^3]	WEIGHT [kg]
LP-R64147	600 x 147 x 400	544 x 109 x 364	21583744	2,2

Table 7.2 *Features of the kanban container chosen*

Figure 7.4 *Kanban container R-KLT 600x400 mm VDA 4500 with reinforced bottom (source: LeanProducts)*

After the dimensional analysis, for the 607 codes manageable with kanban or just in sequence approaches the following results are obtained:

- 447 of them can be managed with kanban system
- 160 of them can be managed with just in sequence system

7.2 Achieved results

The application of the method allows to obtain the following results:

- 1273 codes can be managed with ROP method
- 256 codes can be managed with MRP method
- 447 codes can be managed with kanban approach
- 160 codes can be managed with JIS approach
- 127 codes can be managed with VMI approach

From these results, it is possible to make the following observation:

- the high number of codes whit a low value of use allows to use the ROP approach in the 56,25% of the cases. It is necessary an economic analysis to verify if the method permits a more efficient stock management.

- due to the proximity of most of the suppliers, the VMI approach can be used in the 5,61% of the cases.
- the presence of numerous codes with restrained dimensions but A-class value of use, allows to use the kanban approach in the 19,75% of the cases.
- it is possible to use a not-traditional approach in the 32,43% of the cases.

As mentioned, it is necessary to carry out a costs analysis of the stock and to confront it with the cost of the stock of the current management in order to understand if actually the application of the method involve an economic saving.

Chapter 8

Comparison with the current stock management and warehouse costs analysis

The aim of this chapter is the comparison between the current stock management used in the selected company and the one derived from the application of the method developed in this work.
Successively, the costs of the warehouse in the two cases will be considered, in order to underline the advantages of the application of the method.

8.1 Comparison between the current stock management and the one derived from the application of the method

The only approaches for the stock management used in the company are the ROP and the MRP methods, that belong to the traditional group.
For this reason, it is important to apply the just developed method in order to make the stock management more lean and more efficient, to set the sights on the reduction of the response time to market and to become more competitive.

ROP	997
MRP	1266
TOT	2263

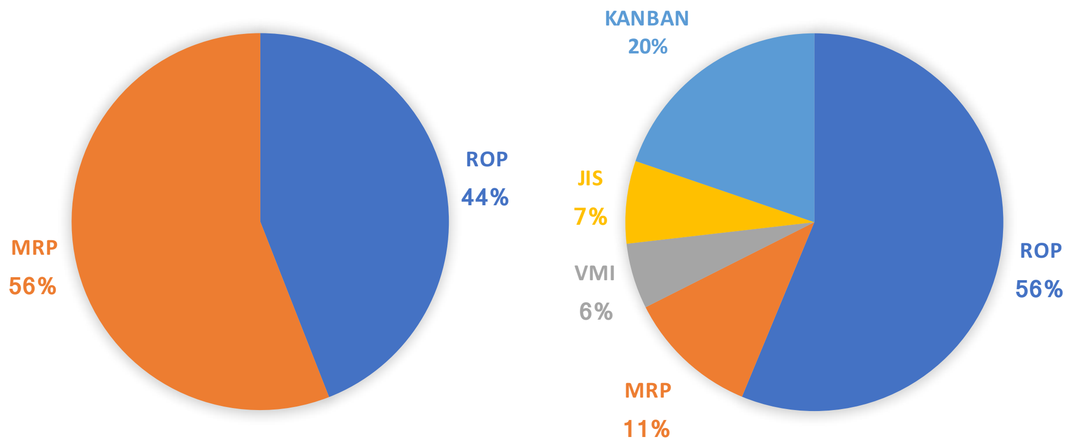
(a)

ROP	1273
MRP	256
VMI	127
JIS	160
KANBAN	447
TOT	2263

(b)

Figure 8.1 *Stock management: (a) in the current case (b) derived from the method application*

As it is possible to notice with the comparison in Figure 8.1 and from the data of the company, the codes managed with the ROP method do not necessarily belonging to the C group of the value of use A.B.C. analysis, making the immobilised resources in the warehouse considerably high.
Indeed, 146 codes that belong to the A class of the value of use, are currently managed with the ROP method, whit a considerable loss of resources.



(a) (b)

Figure 8.2 *Stock management: (a) in the current case (b) derived from the method application*

8.2 Definition of the safety stocks

The first step for the analysis of the warehouse costs is the definition of the safety stocks (SS) for the different codes.
This quantity is defined only for the codes that currently are managed with ROP, but, after the application of the method, some codes that are currently managed with MRP method, need a ROP approach, then the SS quantity for these codes is not currently defined. For this reason, it is decided to calculate the SS for all the codes, not considering the data of the company.
This is the moment to more thoroughly analyse the information mentioned in Chapter 2.1. The dimensioning of the safety stock is based on statistical considerations applied to the historical data, collected from the company.

The variability of the consumption and the supplier lead time implicates the necessity to use the SS in order to obtained an adequate service level F(z), that allows in one and to not fall into the lack of stock (and then the risk of the order loss), in the other hand to not have a too high quantity of material in the warehouse.
F(z), then, is a value, expressed in percentage, that indicates the probability to satisfy the requested order of the client, in time and in the quantities defined.
For example, imposing F(z) = 90%, it means that one in ten times the stock will be not enough to satisfy the order of the client.
To define the quantity of the SS, corresponding to a precise service level, it is necessary to analise the consumption and supplier LT variability, that is the frequency distribution. It is possible to consider this distribution as a normal distribution (or Gauss distribution): considering a normal distribution for a x_i variable it is possible to calculate the average value μ (8.1) and the standard deviation σ (8.2).

$$\mu = \frac{\sum_{i=1}^{n} x_i}{N} \tag{8.1}$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \mu)^2}{N}} \tag{8.2}$$

Every normal distribution can be stardandise whit a variable change, using the standardised variable z.
It is possible to approximate the distribution with a bell-shaped Gauss curve, shown in Figure 8.3.

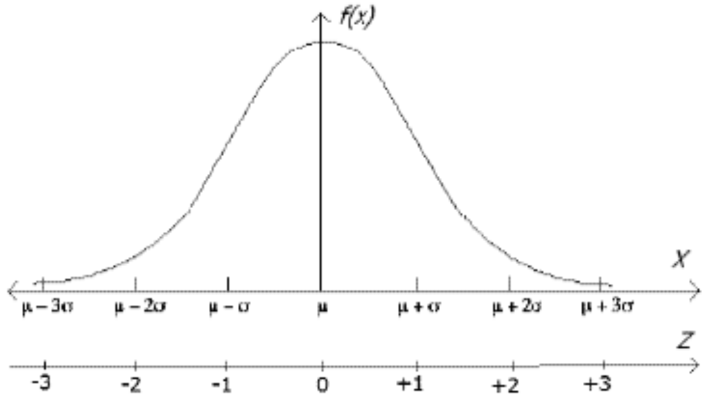


Figure 8.3 *Gauss curve*

The service level is defined as following:

$$F(z) = \mu + k\sigma \tag{8.3}$$

And the safety stock (SS) is:

$$SS = k \cdot \sigma \tag{8.4}$$

Or

$$SS = z \cdot \sigma \tag{8.5}$$

In which “k” is the security factor.
It is possible to calculate k, standardising the distribution, obtaining the standard normal distribution, using the z coordinate:

$$z = \frac{x - \mu}{\sigma} \tag{8.6}$$

In this way, it is possible to obtain a standardized distribution, with the x-variable, standard deviation σ=1 and average value μ=0.
The relationship between the two distribution is

$$f(x) = \frac{f(z)}{\sigma} \tag{8.7}$$

The cumulative function of the two variables, using (8.7), is the same

$$F(x) = F(z) \tag{8.8}$$

It is possible, then, to calculate the service level F(z), from which it is obtained z, otherwise the security factor that correspond with the probability needed.
The service level is calculated with the following formula:

$$F(z) = \int_{-\infty}^{z} f(z)\, dz \tag{8.9}$$

The values of this integral are decided by the chart collected in the Appendix B.
Summarising, the steps are the following:

- the service level desired is defined
- it is possible, then, to calculate the k coefficient
- the k coefficient corresponds to the z standardised variable deduced from the charts

Some main values are summerised in the Table 8.1.

x	z	F(z)
μ	0	0,5
μ+σ	1	0,8431
μ+2σ	2	0,9772
μ+3σ	3	0,9987

Table 8.1 *Some main values of the integral*

In this way, it is possible to express the SS quantity, considering the service level throughout the z variable.
As mentioned in Chapter 2.1, the SS has two part: one, that considers the variability of the quantity of the consumption (SS_Q), and the other that considers the variability of lead time (SS_{LT}).

8.2.1 Consumptions Safety Stock (SS_Q)

The part of the SS connected to the consumptions is necessary to front the variability of the consumption compared to the average demand calculated with a forecast or statistical approach: the consumption, in fact, can result different, involving possible out-of-stock or over-stock.
To calculate this part of the SS the weekly consumptions of one year is consider: the average quantity and the standard deviation are calculated (σ_c).
In this way, it is possible to use the following formula:

$$SS_Q = z \cdot \sigma_c \cdot \sqrt{LT} \tag{8.10}$$

in which "z" is the standardised variable that is referred to the service level.
It is important to notice that both the standard deviation and the lead time have to be expressed whit the same temporal unity (in this case week).

8.2.2 Lead Time Safety Stock (SS_{LT})

The second part that form the total safety stock, is the SS connected to the Lead Time.

It is possible, in fact, that the supplier LT is not respected, causing issues in the stock management.
To front this problem, it is used the SS_{LT}.
The procedure to calculate it is similar to the SS_Q: the average LT and the standard deviation (σ_{LT}) are calculated for every code. The formula, then, is:

$$SS_{LT} = z \cdot \sigma_{LT} \cdot D \quad (8.11)$$

in which "z" is the standardised variable that is referred to the service level and "D" is the average demand (and then the average consumption).

8.2.3 Total Safety Stock (SS_{TOT})

Using (8.10) and (8.11) it is possible to obtain the final expression for the Safety Stock:

$$SS_{TOT} = SS_Q + SS_{LT} = z \cdot \sqrt{\sigma_Q{}^2 \cdot \mathrm{LT} + \sigma_{LT}{}^2 \cdot D^2} \quad (8.12)$$

Due to the lack of information in the company, it is not considered only the SS_{LT}.
The final formula used it is:[4]

$$SS_{TOT} = SS_Q = z \cdot \sqrt{\sigma_Q{}^2 \cdot \mathrm{LT}} \quad (8.13)$$

8.3 Warehouse cost

Considering all the information debated in the previous chapters, it is possible to define the expression for the Reorder Point:

$$ROP = D \cdot LT + SS_{TOT} = D \cdot \mathrm{LT} + z \cdot \sqrt{\sigma_Q{}^2 \cdot \mathrm{LT}} \quad (8.14)$$

in this way, it is possible to calculate the level for stock in the case of the codes managed with ROP.
For the other codes, managed with MRP, JIS method or VMI, it is considered only the SS level.
Multiplying the level of the stock for the standard cost, it is possible to obtain the cost of the warehouse.

---

[4] It is chosen z=1,2

The operation has to be repeated for all the codes, for this reason it is used an *Excel* spreadsheet.

WAREHOUSE COST	
Current Management	€ 282.841,85
After the application of the method	€ 145.973,32
REDUCTION	≅48%

Figure 8.4 *Cost of the warehouse before and after the application of the method*

It is interesting to notice, considering Figures 8.1, 8.2 and 8.4 that, despite the number of the codes managed with a ROP method is increased, the total cost of the warehouse is decreased: it means that the current management is not attentive to the value of the codes. The ROP method, in fact, is a useful and not risky approach, that has to be used only for the codes belonging to the C class of the value of use classification, in this way it is possible to reduce the warehouse cost, without to risk to go out-of-stock.
Despite of the reduction of the cost of the warehouse is considerable, it is necessary to make an observation: the implementation of the nontraditional methods implies costs that are not considered in this analysis.
These costs are necessary for the stipulation of agreements, for the sharing of information and for the changing of the management involved in the nontraditional methods (service costs).
In any case, this method turned out to be an efficient tool to reduce the warehouse cost and for a better managing of the stock.

Conclusions

After a literature search, the main stock management approaches were presented: Reorder Point, Material Requirements Planning based on the free collateral technique, kanban, Just In Sequence and Vendor Managed Inventory methods were compared to underline common characteristics and different aspects.
Successively, the main aim of this work was fronted: the development of a method that allows to choose which of the stock management approaches is the best, considering the main characteristic of the codes.
Thanks to the method, it is possible to choose the stock management approach, code by code, considering first the consumption of the code (meant as variability and frequency), moving to the analysis of value of use, the supply lead time, the size of the codes and last, the distance of the supplier.
The next part of the thesis was focused on the validation of the developed method: thanks to the collaboration with 21 logistic managers from different companies, it was possible to justify the method to have a useful tool from a practical point of view.
After the collection of the different data, it was used the *Weka* software to manage them, and to reach the conclusion that the method is valid.
Having a suitable and practical tool, it has switched to the using of this method on a case study.
The analised company is a Make To Order one, specialised in the production of filling machines. The chosen company needed a more efficient stock management, in one hand to reduce the level of stock in the warehouse, in the other hand to be more competitive reducing the response time to market.
The necessary data were shared by the company and the method was applied: the conclusion is a considerable decrease of the warehouse cost (-48%), and a leaner and more efficient stock management for the codes that had a more difficult one.
It is important to underlain that, for all the application of the method, the program *Microsoft Excel* was used.
Thanks to the collaboration of more than twenty experts, then, the method can be considered as a useful tool to use in the stock management
A possible development of this work can be the improvement of the number of the consulted experts: increasing the number of the opinions, the validation can become more reliable. It has to be considered that it is not always easy to institute a collaboration with the logistic managers, indeed, this, represented the most difficult part of the work.

Another possible development can be the application of the method on the case of different types of companies (ATO, DTS, etc.) to understand if it is equally efficient or if it is more efficient in some cases instead of others.

APPENDIX A

QUESTIONARIO

L'ambito della seguente ricerca è lo *stock management*, inteso come gestione dello scambio di materiali tra azienda e fornitori.

Più in particolare questa analisi si pone l'obbiettivo di definire un metodo per la selezione della tecnica di gestione delle scorte da adottare per ogni codice presente nella Plan For Every Part (PFEP), partendo da determinati parametri.

Le tecniche di gestione delle scorte, infatti, sono numerose e spesso non è semplice definire quella più appropriata: è utile, quindi, sviluppare una metodologia che aiuti a selezionare quale è la migliore partendo da dati raccolti e contenuti nella PFEP (come distanza del fornitore, variabilità e frequenza di consumo del codice, dimensioni del codice).

Le tecniche di gestione considerate nella ricerca sono le seguenti: Reorder Point (ROP), Material Requirements Planning (MRP), Kanban, Just in Sequence (JIS) e Vendor Managed Inventory (VMI).

Si invita a procedere con la compilazione del seguente breve questionario.

NOME AZIENDA:

SETTORE:

TIPOLOGIA AZIENDA:

- ❑ ETO (Engineer to order)
- ❑ PTO (Purchase to order)
- ❑ MTO (Make to order)
- ❑ ATO (Assemble to order)
- ❑ MTS (Make to stock)
- ❑ DTS (Delivery to stock)

QUESITO 1

Tenendo conto della Sua esperienza professionale, ordini i seguenti parametri considerando l'influenza che questi hanno sulla scelta della tecnica di gestione delle scorte da adottare per un determinato codice.

Indichi con (1) il parametro che secondo Lei influenza maggiormente tale scelta, e proceda in ordine crescente fino ad indicare con (5) il parametro meno influente.

- … CONSUMO DEL CODICE (inteso come variabilità e frequenza del consumo)
- … DISTANZA DEL FORNITORE
- … LEAD TIME DI FORNITURA
- … VALORE D'IMPIEGO (consumo medio x costo standard del codice)
- … DIMENSIONI DEL CODICE

QUESITO 2

Si ipotizzi di avere un prodotto finito PF a cui si può arrivare tramite l'acquisto, da fornitori, di diversi codici.

Indicati con:

- T = tempo di risposta al mercato per quanto riguarda PF
- LT = lead time di fornitura di un codice generico che fa parte della distinta base di PF

Secondo la sua esperienza professionale, indichi, in funzione di T, quale potrebbe essere considerato il LT critico (ossia il lead time di fornitura su cui bisogna lavorare per rendere il processo di approvvigionamento più veloce e per poter migliorare il tempo di risposta al mercato di PF) di un generico codice facente parte della distinta base di PF.

Per esempio: si consideri un PF per cui il tempo di risposta al mercato è T = 1 mese.

Si potrebbe considerare critico il lead time di un generico codice, utilizzato per arrivare a PF,

LT = 1 settimana. Ciò significa che un codice con LT = 1 settimana è da considerarsi più delicato nella gestione delle scorte rispetto ad un codice con LT minore e su cui bisogna lavorare adottando tecniche di approvvigionamento più innovative.

In questo caso si indicherà:

LT CRITICO = ¼ T *oppure* LT CRITICO = 0,25 T *oppure* LT CRITICO = 25% T

Si indichi ora la propria espressione di Lead Time Critico:

LT CRITICO = … T

APPENDIX B

Values of standardised normal distribution

$$\Phi(\mathrm{z}) = \int_{-\infty}^{z} \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}t^2} dt$$

Z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389
1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
2.0	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
2.4	0.9918	0.9920	0.9922	0.9924	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936
2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
2.6	0.9953	0.9955	0.9956	0.9957	0.9958	0.9960	0.9961	0.9962	0.9963	0.9964
2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
2.9	0.9981	0.9982	0.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986

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