CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE
FACULTY OF ENGINEERING
QUALITY AND RELIABILITY OF MACHINES DEPARTMENT

Optimization of industrial spare parts inventories' management system improving machine availability within production processes in a selected organization

Master of Science Thesis in Operations Management

Degree Programme in Technology and Environmental Engineering

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CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Department for Quality and Dependability of Machines

Faculty of Engineering

DIPLOMA THESIS ASSIGNMENT

Awad Mohamed Abdelhadi Tamer

Thesis title

Optimisation of spare parts inventories in a selected organisation.

Objectives of thesis

Optimisation of selected spare parts management processes and spare parts inventory in a chosen organization based on analysis of current state.

Methodology

1) Analysis of the current state of spare parts management processes

2) Analysis of the current spare parts inventory (with application of standard spare parts inventory analysis methods like ABC analyses using various criteria)

3) Identification of existing problems and inefficiencies (from the process point of view and inventory point of view)

4) Proposal of solution or optimization of selected problems supported with application of suitable methods of process optimization and inventory management.

6) Economic evaluation of proposed solutions (savings, return on ivestment etc.)

7) Conclusion – summary of achieved results and economic evaluation (savings)

Outline of the structure

1) Introduction
2) Literature review
3) Objectives
4) Methodology
5) Analysis of current state
6) Proposed solutions
7) Conclusion

The proposed extent of the thesis

40-60 pages including figures, charts and tables

Keywords

spare parts, inventory management, optimization

Recommended information sources

RUSSELL, R.S. – TAYLOR, B.W.: Operations management. Prentice Hall, Upper Saddle River, 2000, ISBN: 0-13-013092-3
GOULD, F.J. – EPPEN, G.D. – SCHMIDT, C.P.: Introductory management science. Prentice Hall, Singapore, 1997, ISBN: 981-3076-99-2

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DECLARATION

"I hereby declare that this thesis focuses on optimizing an inventory management system of spare parts used for operating plastic injection moulding machines within a manufacturing plant, where this study area has been chosen independently and implemented in a selected organization under the expert guidance of Ing. Tomáš Hladík, Ph.D., using literature and resources listed in the references".

Prague, April 4th 2014 ....

Handwritten signature

ACKNOWLEDGMENTS

I would like to thank VALEO Automotive, located at Rakovník, Czech Republic, where this thesis was conducted for providing the opportunity to practice my skills and at the same time contribute to the organization's success throughout one and half year of research targeting for development of a spare parts inventories' management system to avoid stock outs of spare parts and downtimes of machinery at minimum costs of average inventory value.

Extra thanks go to my supervisor Ing.Tomáš Hladík, Ph.D. for his support and guidance to solve both major and minor issues along the way.

I would also like to thank all persons who had shared their thoughts regarding the subject, especially Monika Lovecká (VALEO Specialist), and Josef Váňa (VALEO Injection Moulding Manager).

ABSTRACT

An inventory of service spare parts needs to exist when it is needed to ensure proper coverage of both scheduled and unscheduled requirement of maintenance for a set of operating machinery. Replenishment of these parts is a complex task as they have different functions and sources. Optimization of Spare parts' inventories is a strategic analysis to support management decision making process to avoid extended downtime as a consequence of fulfilling intermittent consumption of service parts and minimize inventory holding cost.

This research is conducted in VALEO Rakovník located at Czech Republic. The company manufactures heating & air conditioning units and control panels for automotive industry. Consumption demand of spare parts for upcoming year 2013 is predicted by selecting a special forecasting method, with least forecast error, based on spares' consumption demand from 2010 to 2012 of 900 parts associated with 21 plastic injection moulding machines.

A solution is provided in form of MS Excel® spreadsheet calculations, which determines the right safety stock quantity of each spare part. The calculations are based on three influencing parameters, which are service level, standard deviation of consumption, and lead time factor, to support ordering system, throughout calculation of optimum level of inventory on-hand.

As a result, value of spares average inventory for 2013 is reduced by 833,080 CZK at 98% service level, at minimum possibility of stock-outs, which is used as an input data source for existing SAP®'s enterprise resource planning (ERP) system. Spares inventory is classified into three categories based on Pareto analysis to identify high, medium, and low value items.

KEYWORDS: Spare Parts, forecasting intermittent demand, inventory management

ABSTRAKT (ČESKÝ)

Správná zásoba náhradních dílů je nezbytná pro zajištění plánované preventivní i korektivní (poruchové) údržby výrobního zařízení. Řízení zásoby náhradních dílů je zpravidla náročný proces, který musí zohledňovat rozdílné funkce, použití a způsoby dodání jednotlivých položek náhradních dílů. Podstatou optimalizace zásob náhradních dílů je strategická analýza s cílem minimalizovat prostoje způsobené nedostatkem náhradních dílů, a zároveň minimalizovat náklady na držení zásob. Významnou komplikací této analýzy je sporadický charakter spotřeby, který je typický pro náhradní díly.

V rámce této práce byla zpracována analýza a optimalizace zásob náhradních dílů ve firmě VALEO Autoklimatizace Rakovník v České Republice. Tato firma dodává klimatizační jednotky a ovládací panely pro automobilový průmysl. V zásobě náhradních dílů je vedeno 900 položek pro 21 vstřikovacích lisů. Spotřeba náhradních dílů pro rok 2013 byla predikována metodou vybranou podle minimální chyby předpovědi na základě údajů o spotřebách náhradních dílů z let 2010 až 2012.

Navržené řešení (nástroj pro řízení zásob náhradních dílů) využívá tabulkový kalkulátor MS Excel®. Kalkulace navrhuje správnou hladinu pojistné zásoby pro jednotlivé položky náhradních dílů. Pro stanovení správné hladiny jsou uvažovány 3 faktory: požadovaná dostupnost náhradního dílu na skladě, směrodatná odchylka spotřeby a dodací lhůta dodavatele.

Výsledkem aplikace navrženého nástroje bylo dosaženo snížení úrovně zásoby o 833 080 Kč při zachování 98% úrovně dostupnosti. Navržené hladiny zásob jsou vstupem pro firemní ERP systém SAP®. Zásoby náhradních dílů byly zároveň rozděleny do tří kategorií podle hodnoty (Pareto analýza).

KLÍČOVÁ SLOVA: náhradní díly, předpovídání sporadické spotřeby, řízení zásob

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1 INTRODUCTION

Every organization, involved with equipment and plant facilities applies a maintenance system, such as corrective, preventive or predictive system. Protracted manufacturing cycle time is responsible for high work in progress and spare parts should be readily available to reduce the frequency of machinery breakdown. Obsolete spares might exist, in form of potential major components of machinery, which are not likely to be consumed, due to non-existence of a series failure during an asset's life time and is accumulated due to either overbuying at initial stages, or project surplus to avoid non availability. These items are categorized as insurance emergency spare parts. Excess inventory leads to high holding costs and stock-out might occur, which is avoided to improve reliability, where an equipment is capable not to breakdown during operation. Managing an inventory of spare parts is one of operations management activities, which ensures efficient physical transformation, as in converting inputs into outputs within manufacturing operations. Stocking of spare parts is controlled and managed depending on lead time available for obtaining a spare part. The time period that elapses between the recognition of the need of a spare part and its fulfillment is defined as lead time, which varies considerably where parts are available from diverse sources such as factory main stores, shop floor sub stores, suppliers' factory, local dealers, and foreign sources, like OEM "Original Equipment Manufacturer", while some special parts, such as jigs, that are not available with suppliers are manufactured in-house at company's own workshop.

An inventory management of service spare parts for plastic injection moulding machines is essential within a manufacturing company to determine the level of replenishment and when parts need to be ordered. The production process is stabilized within final product's assembly line at least for a while, due to existence of a buffer stock following plastic injection moulding process, where a breakdown might occur in one of the machines. The more inventories management is carried out to control inventory in a manner that best achieves the business objectives; the less coordination is needed to achieve an optimum balance between inventory level and coordination in the operating system. Identification of slow moving, non-moving, high value spare parts is required by maintenance department, which rarely declare the non- moving items as obsolete item, as a precautionary measure against repercussions of stock outs. Few organizations appoint technical committee to shortlist the recommended list of spares based on past experience or getting machine history from other users and segregate proprietary spares separately.

Condition monitoring provides information in advance, whether any particular part is likely to fracture and cause a breakdown. Therefore, identifying the requirements of spare parts and consumables, this is planned and obtained well in time, thus reducing downtime. Forecasting is used to predict exact requirement of spares utilizing consumption records of spares, as an approach for materials requirement planning (MRP). Time series forecasting methods are commonly used to determine long-term (2 to 5 years) capacity needed, in order to design facilities, and to determine midterm (3 to 18 months) fluctuations in demand.

The area of planning and provisioning has been considered to be critical by many companies due to unpredictable failures and uncertain lead times. A maintenance plan commences with criticality determination. The factors affecting the planning process include operating conditions, maintenance policy, lead time, availability of spare parts, failure data, price of spare parts, carrying cost, obsolescence rate, type of industry, and organization structure. It is difficult to correlate the effects of these factors, many firms set apart at least one standby set per machine for insurance items. The characteristic of demand for spare parts inventories is difficult to predict because of not only random demand but also a large proportion of zero values. Croston's forecasting method is widely used to predict this kind of demand.

The inventory system and the operations system within an organization are strongly interrelated. The plans concerning the acquisition and storage of materials or "inventories" are vital to the production system. The use of ABC analysis develops criteria for requirement planning of high number of spares, in which it has proved to be applied with advantage.

This thesis includes a challenging case study, which describes a solution for optimizing and controlling an inventory of service parts for the repair of plastic injection moulding machines in a manufacturing plant of air conditioning units feeding other companies, such as Škoda, Audi, Volkswagen, Mercedes-Benz, SAAB, Nissan, Opel, Renault, Toyota, Peugeot, and Citroën. The company is called VALEO, located at Rakovník in Czech Republic, while it has other branches, located at Žebrák, Humpolec, and Prague with different scope of work in automotive industry.

The following sections include analysis of current state, calculation of safety stock and re-order quantities, implementing various forecasting methods, selection of best forecasting method by comparison of forecast accuracy, generation of an ordering system with a feature of changing influencing variables capable of calculating value of spares average inventory, categorization of spare parts inventory based on ABC classification system, economic evaluation, interpretation & discussion of results.

2 SCOPE OF RESEARCH OBJECTIVES

A company needs to decide the quantity of spare parts to be kept in stock, which is an important decision because it can result in high holding costs or high penalty cost when the wrong decision is made, either the quantity is more or less than that actually required.

2.1 ANALYSIS OF AN INVENTORY OF SPARE PARTS

Analysis of a spare parts inventory include all incurred costs that vary as the level of inventory changes, these costs are:

- Acquisition costs: calculated as the unit price multiplied by the number of spares bought.
- Ordering costs: associated with the processing of a purchase, from creation to receipt, are related to costs of managing the inventory. They include capital costs of the investment tied up in inventory, operational costs of warehousing, and deterioration or monetary depreciation of the items.
- Stock-out or shortage costs: are incurred whenever demand cannot be satisfied from inventory, due to lack of spares.

2.2 MINIMIZE INVENTORY TO OPTIMUM LEVEL

An important feature in inventory control is the determination of the minimum number of items that should be on stock, which can be tolerated, before replenishment order is placed. Reduction in quantities of spare parts kept as a safety stock is quite essential, and considered as a basic goal.

A procurement order of a spare part component is placed when inventory level drops below certain level of stock, which is called "Re-order level" that is determined by summing re-order quantities for all spares.

2.3 DEVELOPING AN INVENTORY MANAGEMENT POLICY

Determining an inventory policy involves determining inventory control parameters, such as re-order points and safety stocks, which supports decision-making process of the company by computing the minimum level of inventory considering the consumption during the lead time, in which it is necessary to place a new order when the stock falls below this level.

The minimum stock of an item depends on the estimated consumption during the lead time, and on the probability of a higher or lower consumption.

2.4 REDUCE CONSUMPTION OF KEY SPARE PARTS

Establish an expedited spare parts ordering process and understand the costs involved. This is carried out by measuring, evaluating and further stream line spare parts inventory control processes throughout understanding existing consumption of Spare parts based on actual historic consumption.

3 REVIEW OF LITERATURE

3.1 INTRODUCTION TO INVENTORY MANAGEMENT

A database of information is kept by a manufacturing company, known as an inventory master file, which contains an extensive amount of information on every item that is ordered in the system. It includes such data as detailed description of an item, on-hand quantities, on-order quantities, lot sizes, safety stock, lead time, and past usage figures. It updates the physical inventory count, summarizes the item year to date usage. Accuracy of inventory transactions is essential to keep inventory levels at minimum (Russel & Taylor et al., 2000).

A conservative policy is adopted to avoid stock-outs of spare parts at any cost, considering difficulty in predicting rate of failure, long lead time for imported items, and lack of professional scientific conscious approach to spare parts management, which could lead to increased stock level. Inventories are held for many reasons. They smooth out the time gap between supply and demand, and are categorized into consumable, insurance, overhauling, and project surplus (Eppen et al., 1998).

Spare parts components with varying lead time and availability characteristics have to be planned to balance the inventory levels of different categories, where the distribution chains at different channels such as warehouses, depots, stocklists, and dealer network are controlled by different organizations. The average lead time of spare part fluctuates from time to time, whereas the total lead time could be broken into four components, internal administration lead time of converting intent to a purchase order, manufacturing time, transportation period, inspection lead time (Gopalakrishnan & Banerji et al., 2008).

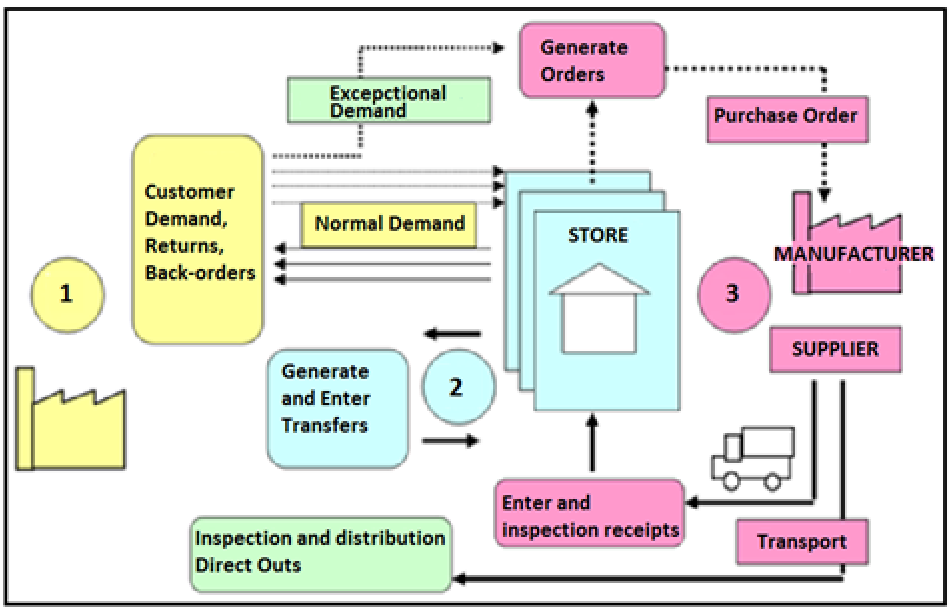


Figure 3-1: A flow diagram distinguishing areas of consumption, transfer, distribution network, & ordering [Source: MultiView LOGIC Manual, SCADA Software, Operations Support V7.0]

An enterprise resource planning (ERP) systems manages the resources of an entire enterprise. SAP®'s premier product R/3 is an example, which is a software consisting of a series of application modules that connects processes that belong together, giving every employee convenient access to the information required for their jobs. These modules form an integrated information technology strategy for effectively managing the entire enterprise, use a common database, and support processes that extend across functional areas. Transactions in one module are immediately available to all other modules at all relevant sites, whether they are corporate headquarters, manufacturing plants, suppliers, or subsidiaries. In most cases sites are connected via the Internet or intranets. Materials management module manages all tasks related to supply chain, including purchasing, inventory functions, supplier evaluation, just in time deliveries, and invoice verification (Russel & Taylor et al., 2000).

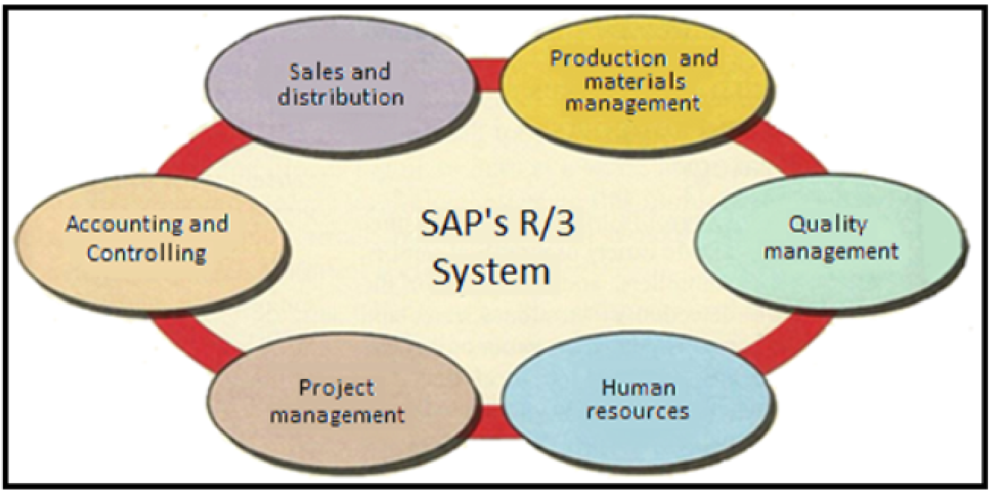


Figure 3-2: SAP's enterprise Resource Planning Modules [Source: Russel & Taylor, "Operations Management" (2000)]

Inventory management not only involves physical management of inventory, but also management of systems used to process the data used to describe an inventory. It consists of a series of decisions. At the top levels, these decisions relate to choosing inventory strategies, designing distribution networks, and setting inventory policies. In the middle, are decisions related to system setup, forecasting methods, replenishment methods, and safety stock, also known as buffer stock is carried to compensate for variable demand of spare parts. At the most detailed level, these decisions are related to whether or not on a given day an order for a given item needs to be given, if so, how much should be ordered (Piasecki et al., 2009).

The entire spare parts management revolves round the quantity of spares available in the warehouse. Parts cannot be ordered beyond the warehousing capacity, nor can afford to have nil stocks in the store, particularly for critical parts (Gopalakrishnan & Banerji et al., 2008).

3.2 FEATURES OF SPARE PART INVENTORIES

Inventories are defined as "idle goods in storage, waiting to be used". Maintenance, repair, and operating (MRO) supplies are "items used to support and maintain the operation, including repair parts, maintenance supplies, and repair other consumables" (Meredith & Shafer et al., 1999). When evaluating MRO inventory, total investment in the inventory, the time it takes to manage it and the tool available to manage it need to be considered (Piasecki et al., 2009). There are many types of inventories, for example, inventories of raw materials, inventories of in-process materials, or inventories of finished goods (Eppen et al., 1998).

Spare parts might look small and appear cheaper than the machine or raw material, but they play a vital role in maintaining, ensuring, and reinforcing the reliability of any equipment. They include material such as, pipes, tubes, springs, electrical cables, knobs, wires, hoses, belting, and sub-assemblies for essential parts of the machine, like engines, compressors, alternators, in addition to complete units, which are fitted with a machine. Spare parts are kept in categorized inventories, whose target is to develop procedures to optimize the working capital and satisfy the user, in which best inventory control, allows for maximum availability of service with minimum cost. (Gopalakrishnan & Banerji et al., 2008).

There are generally there types of costs associated with the inventory activity. First are ordering costs, which incurred each time an order is placed to replenish an inventory. These costs are independent. Second are carrying costs, referred to sometimes as opportunity cost, the magnitude of this cost is closely tied to the interest rate. The larger the inventories, the larger the holding costs. Third are stock-out costs, which represents loss in production due to non- existence of a spare part causing machinery breakdown (Eppen et al., 1998).

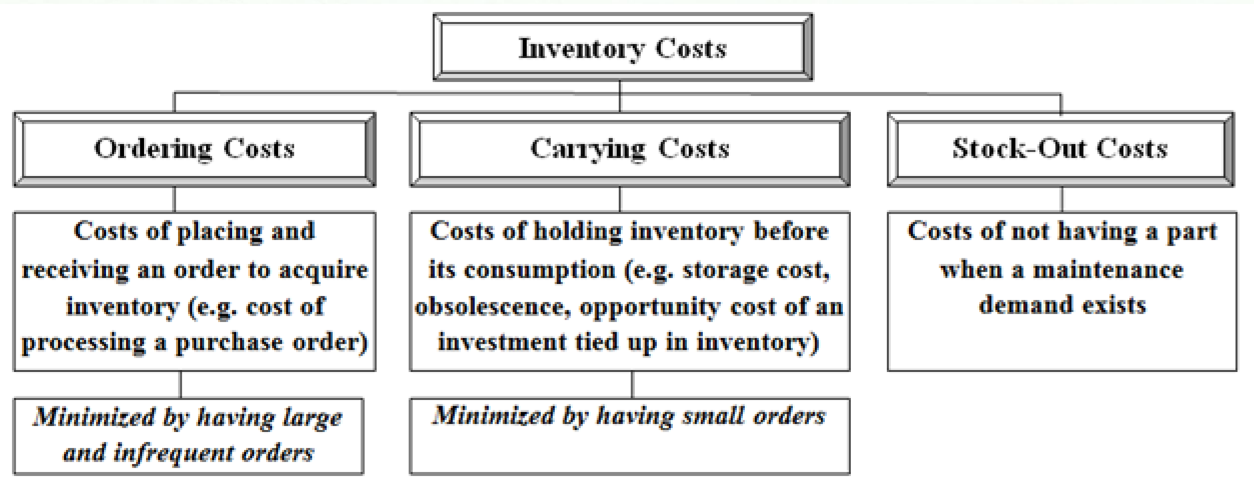


Figure 3-3: Costs associated with inventory activity [Source: Eric Y.W.Leung, "Inventory Management"]

Spare parts have excessive stock, in all positions of the distribution channels, they are uneconomical to manufacture as their demand is uncertain and low, having large variety, and difficulty in standardization, with small number of suppliers. They have long lead time; their cost of stock out is greater than their own price, with difficulty in forecasting future requirement. Usage is increased with the age of the machine. An inventory of spare parts is held as a precaution or contingency for increase in the lead time or consumption rate, also for transaction purposes, as in any organization there is invariably a time lag between recognition of the need of spare part to the satisfaction of the need and during this lead time, the spare part in the warehouse becomes handy. Stock out or under stocking cost arises due to non-stocking of the spare part. This is usually measured in terms of opportunity lost due to loss of production by idling cost of a production line. This cost is particularly useful in grading the spares into vital, essential and desirable categories depending on the degree of damage (Gopalakrishnan & Banerji et al., 2008).

Data analysis is a critical part of managing inventory. A spreadsheet program is a tool used to build an optimization model out of a series of smaller simple calculations, that would be made up of a value targeted to be optimized, in other words maximized or minimized, having a mathematical relationship with one or more changeable values (Piasecki et al., 2009).

3.3 TYPES OF SPARE PARTS

Spare Parts are defined as "items held in inventories that are used to replace a failed parts or components. This could be anything from a drive belt or bearing through to entire components such as a pump set" (Slater et al., 2012).

A spare part is defined as "a part of a machine ready to replace an identical part of it, if it becomes faulty due to wear and tear or breakage during operating life of the equipment".

In many organizations spare parts are defined as "parts of machinery, which are kept standby to be substituted when a part of machinery breaks down or is worn out" (Gopalakrishnan & Banerji et al., 2008).

In automotive plants, the production line operates in a flow shop transformation system consisting of a fixed set of inputs, constant throughput times, and a fixed set of discrete products, equipped with special purpose machines, and continuous types of materials-handling equipment built into the system itself. The equipment needs to be serviced to overcome possibility of a production line going to an immediate halt if the line should stop, due to a breakdown of a machine or a conveyor (Meredith & Shafer et al., 1999).

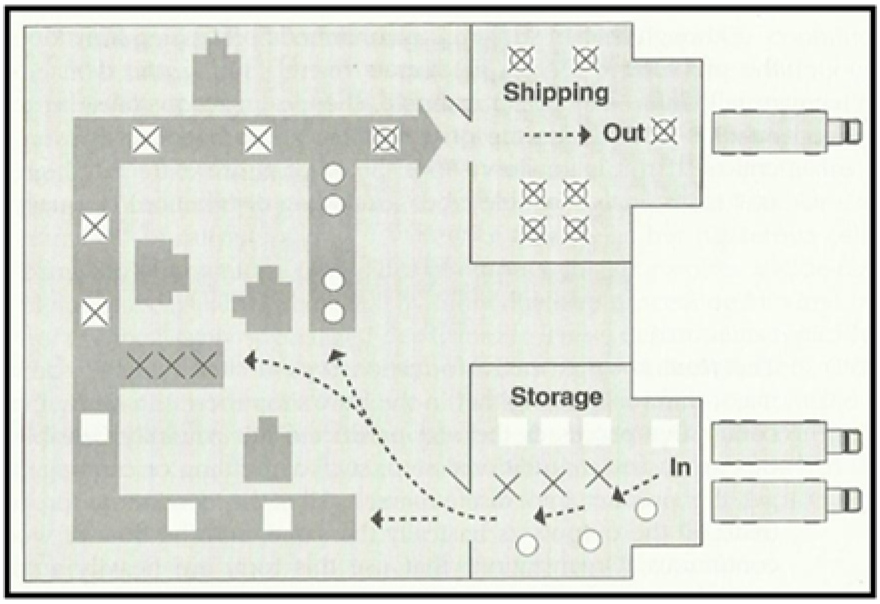


Figure 3-4: A generalized flow shop operation [Source: Meredith & Shafer, "Operations Management for MBAs" (1999)]

Maintenance spares are those which are fast moving like bearings, belts, and hardware items; these are available in plenty and can be stocked after building a database on the consumption pattern. Overhauling spares are those which are specially needed during regular overhauls in order to give a new lease of life to the equipment. Hence, these need not to be ordered and stocked just in time before overhauling.

Commissioning spares are needed to start a project or commission a newly installed machine, and these parts are declared as project surplus after the machine starts its operation. Insurance spares are those vital parts of a machine, which have life nearly equal to that of a machine itself and are held as a standby against any breakdowns. These standby units have a high reliability of performance and can be capitalized. Cycle inventories result from ordering in batches or lots rather than as needed (Gopalakrishnan & Banerji et al., 2008).

Too much or too early inventory results in added expenses related to handling costs, and risk of obsolescence, while too little or too late inventory can result in added costs related to expediting and order processing. Service level is a term used to describe a key input to statistical-based safety stock calculations (Piasecki et al., 2009).
It is usually set on the basis of two opposing costs, namely over-stocking cost and under-stocking cost, depending on a number of factors including, maintenance policy, cost of spare parts, criticality of the item, reliability, lead time, warranty, and availability of working capital (Gopalakrishnan & Banerji et al., 2008).

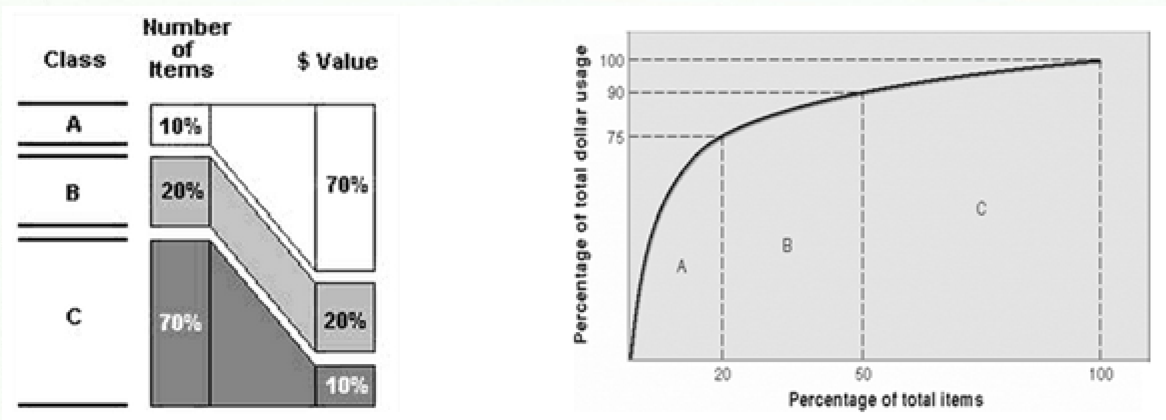
3.4 ABC CONCEPT

ABC stratification is an activity of applying a ranking system to a characteristic, based on Pareto principle, which states that a small number of causes are responsible for a greater number of effects (Piasecki et al., 2009).

ABC classification system is a management's guide to the priorities of inventory items. It is based on a universal principle "vital flow, trivial many". The spare parts are rated as three classes known as A, B, and C, respectively based on the annual usage value or sales or consumption value. For this purpose, the quantity issued from a warehouse in a year is multiplied by the average or standard price. The items are arranged in a descending order of the consumption value (Meredith & Shafer et al., 1999).

The items accounting for the bulk of annual spares sales value, which are usually very few, should be closely controlled and watched strictly with regard to management information, planning, control, follow-up, monitoring deliveries, records, auditing, stock levels, replenishment, forecasts, and application of cost –reduction techniques.

Experience indicates that the top 10% of items accounts for a vital portion of about 70% of annual consumption value and are therefore classified as "A" category items. The middle 20% account for about 20% of annual consumption value, and are categorized as "B" category items. The remaining 70% of items account for a trivial annual consumption value of about 20% and classified as "C" category items.



(a) (b)

Figure 3-5: ABC classification system [Source: (a) Abey Francis, "ABC system of inventory control", http://www.mbaknol.com/, (2012). (b) Meredith & Shafer, "Operations management for MBAs", (1999)]

The records for the management information system should be accurate, and updated for the "A" category items, since they are fast moving, with high annual average inventory value, fast rotation stocks, the percentage of profit margin could be lower as compared to other categories of spares. They must be reviewed and ordered frequently to reduce the working capital commitment for inventories. The "C" category items, on the other hand are slow moving in nature and account for only a small percentage of annual average inventory value, usage. For these items, there can be high safety stocks. Care should be taken to avoid obsolescence in such cases (Gopalakrishnan & Banerji et al., 2008).

3.5 FACILITY LAYOUT

Process layouts group similar activities together in work centers according to their performed function, and are characterized by intermittent operations, or batch production. Material storage and movement are directly affected by the type of layout. Storage space in a process layout is large to accommodate the large amount of in-process inventory in form of batches waiting to be processed, because material moves from work center to another by means of a forklift with wide aisles to accommodate heavy loads and two-way movement.

Product layout, known as assembly lines, arranges activities in a line according to the sequence of operations that need to be performed to assemble a particular product. Each product has its own "line" specifically designed to meet its requirements. A product layout needs material moved in one direction along the assembly line and always in the same pattern. Conveyors are the most common material handling equipment. Aisles are narrow because material is moved only one way, and the conveyor is an integral part of the assembly process. Storage space along an assembly line is quite small because in-process inventory is consumed in the assembly of the product (Russel & Taylor et al., 2000).

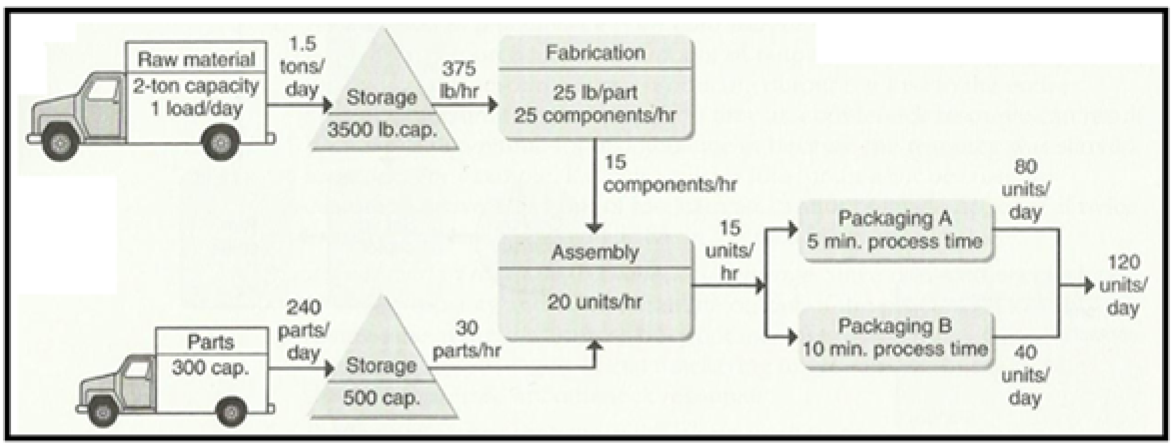


Figure 3-6: Process flow for manufactured unit [Meredith & Shafer, "Operations management for MBAs", (1999)]

Either two types of assembly lines can be used. A paced line, commonly used in automobile assembly line, where some sort of conveyor is used to move the output along at a continuous rate, and operators do their work as the output passes to them, whereas unpaced lines, workers build up queues between workstations and can then vary their pace to meet the needs of the job or their personal desires, while maintaining same average daily output (Meredith & Shafer et al., 1999). As long as a spare part is lying idle in the warehouse, the working capital is locked up till the part is consumed by the workshop, and maintenance department. On the other hand, if an item is not kept in store, there will be a stock-out if demand arises.

The warehouse activities include, receipt, storage, liaising with quality control inspectors, handling, issues and disposal of spares, which is influenced by type of spare parts, number of spares, quantity stored, reorder quantity levels, service level or meeting customer demand.

The efficiency of a warehouse is measured on a negative scale, i.e. in terms of stock-outs. Depending on the cost and criticality, a service level can be fixed. For a vital spare part, the service level can be fixed at 99.5%, which implies that if there are 100 demand requisitions, they will be met at least on 99 occasions. As the criticality of the spare part decreases, the service level can be decreased (Gopalakrishnan & Banerji et al., 2008).

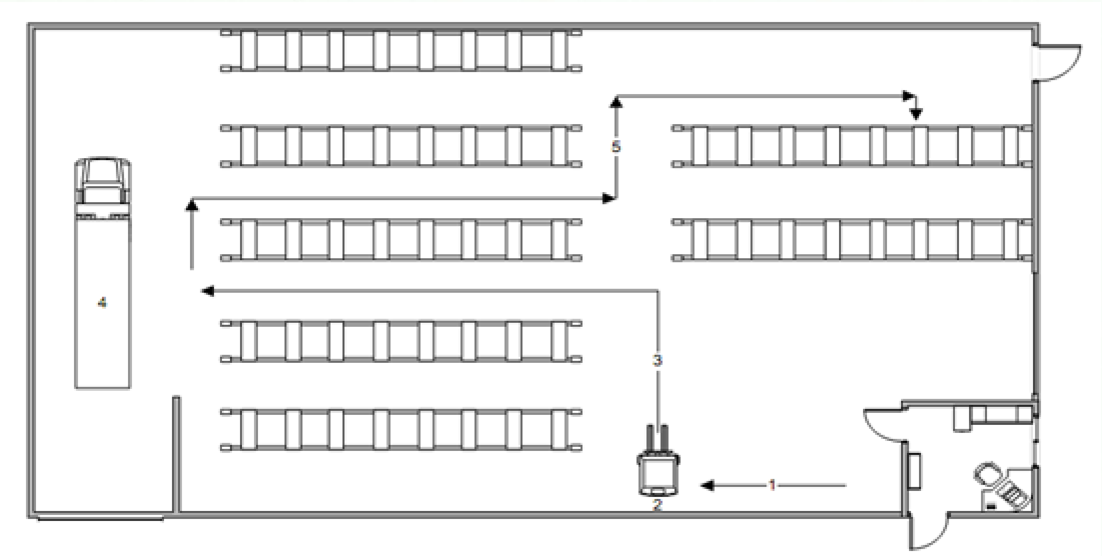


Figure 3-7: Receipt and retrieval of spare parts within a warehouse [Source: Rastislav Beňo & Petra Marková, "Carpathian Logistics Congress CLC, Jeseník, Czech Republic", (2012)]

3.6 INVENTORY CONTROL SYSTEMS

The ultimate goal of an inventory system is to make decision regarding the level of inventory that will result in a good balance between the purposes for holding inventories and the costs associated with them. In reorder point systems, an inventory level is specified at which a replenishment order for a fixed quantity of the inventory items is to be placed (Meredith & Shafer et al., 1999).

There are two basic types of inventory systems, a continuous and a periodic system. In a continuous inventory system, also referred to as a perpetual system, and a fixed order quantity system, a continual record of the inventory level for every item is maintained, whenever the inventory on hand decreases to a predetermined level, referred to as the reorder point, a new order is placed to replenish the stock of inventory. In a periodic inventory system, also referred to as a fixed time period system, the inventory on hand is counted at a specific time intervals, for example, at the end of the month. After the inventory in stock is determined, an order is placed for an amount that will bring inventory back up to a desired level (Russel & Taylor et al., 2000).

A perpetual inventory system is a computer system designed to track inventory balances, maintain basic ordering information, including reorder point & lot size by item, and process individual inventory transactions whenever inventory is received or consumed at any given point of time (Piasecki et al., 2009).

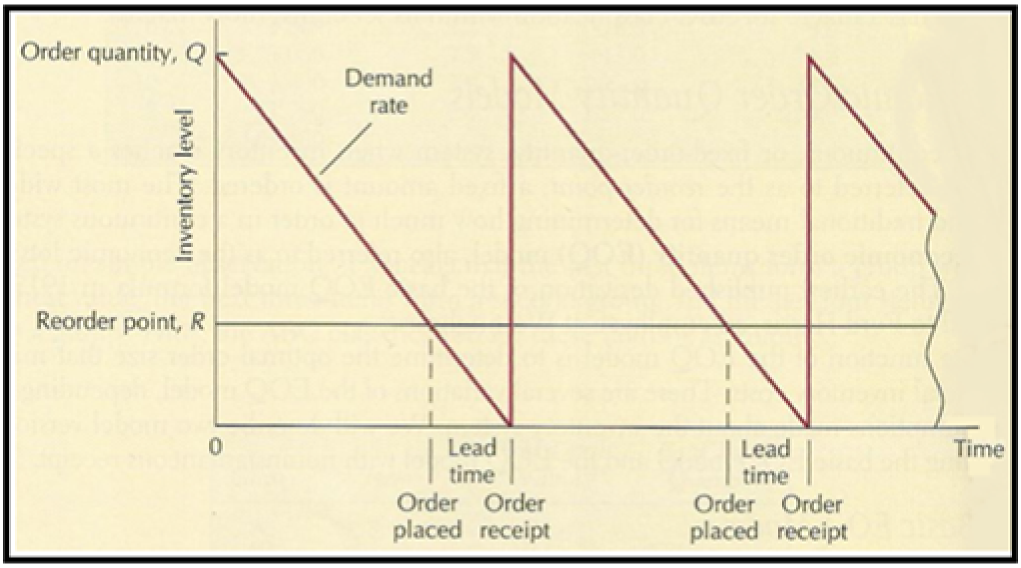


Figure 3-8: The inventory order cycle [Source: Russel & Taylor, "Operations Management" (2000)]

The amount of safety stock carried depends upon the accuracy of forecasts, consistency of supply and processes and desired service level. Lead time is defined as the amount of time it takes for a purchased item to be delivered after it is ordered, or the amount of time it takes for a manufactured item to be completed after it is ordered (Piasecki et al., 2009).

An accurate estimate of demand for the output by means of forecasting is crucial to the efficient operation of a production system and hence, to managing the organization's resources. To ascertain short term (1 week to 3 month) fluctuations in demand for the purpose of production planning, materials planning. These forecasts support a number of operational activities and can have significant effect on organizational productivity.

Quantitative forecasting methods are generally divided between methods that simply project the past history or behavior of the variable into the future, known as time series analysis, which ranges from just using an average of the past data to using regression analysis connected to seasonality in the data (Meredith & Shafer et al., 1999).

4 METHODOLOGY AND THEORETICAL APPROACH

4.1 INTERPRETATION OF PROVIDED DATA AND RESEARCH FRAMEWORK

The historical raw data provided by VALEO Rakovník, could be classified into two major groups, first is an MS Excel® spreadsheet named "Categories of spare parts" for plastic moulding machines located at the workshop manufacturing automotive air conditioning units, where spare parts are divided into different categories according to their function, each item has a unique category number, and with the aid of SAP® software, safety stock, present value of item, and value of items necessary to be ordered is calculated, considering that the ordering quantity does not fall below pre-set maximum quantity of each item.

Second are "material movement records" MS Excel® spreadsheets, which include daily records of "Goods issued" and "Good received" on monthly basis, from 2010 until 2012, forming 36 files in total, each provides detailed information about date and quantity, that each item was released or received in stock, in connection with the value of inventory.

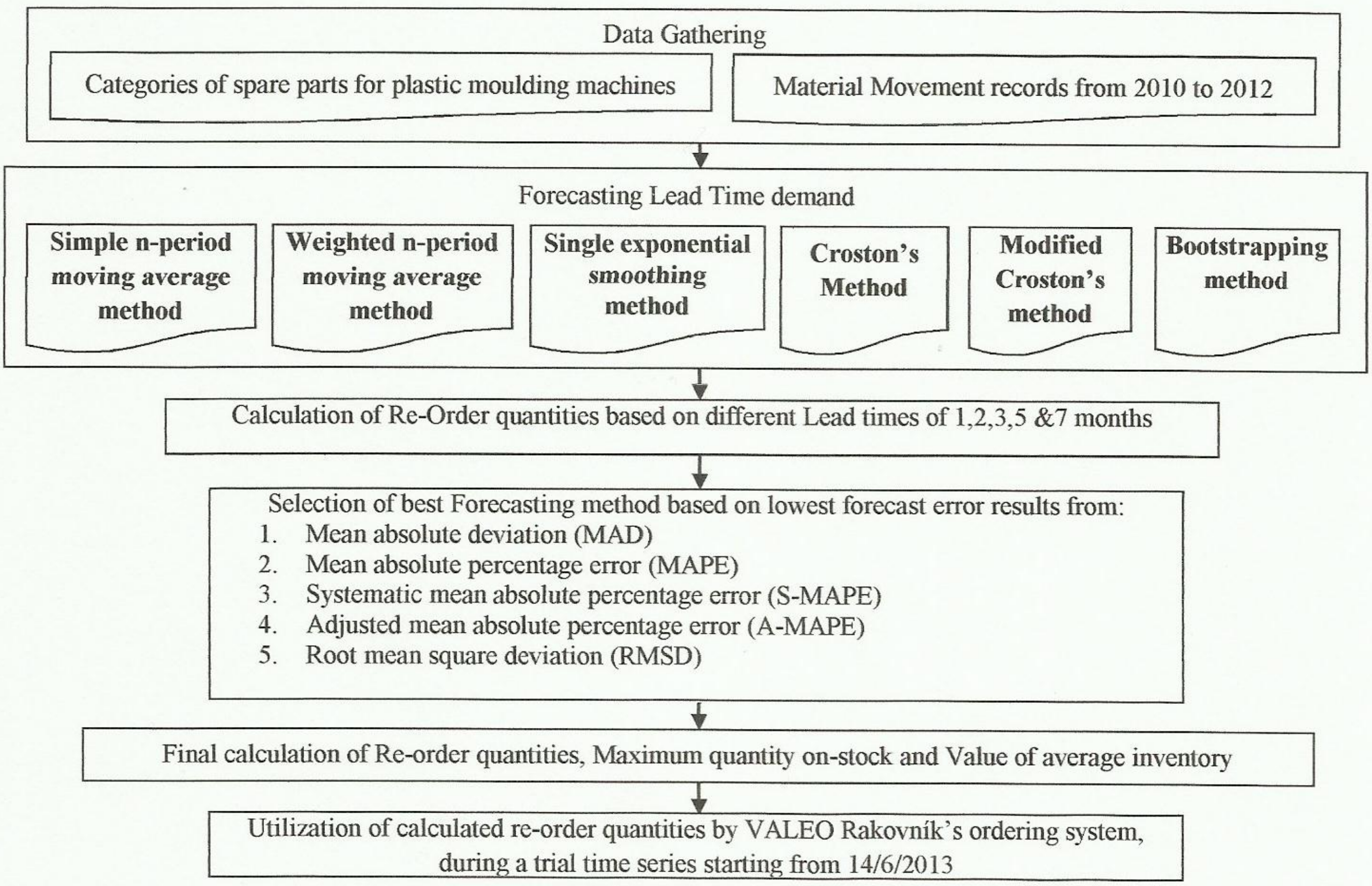


Figure 4-1: Research Framework [Source: Author]

The data is transferred into a newly created MS Excel® spreadsheet gathering all information from the previously mentioned provided data sources, to form a full list of in total 920 spare part items, including item category number, description, current quantity, safety stock, unit price, quantity received and quantity issued, which enables carrying out complete analysis by generating a detailed historical movement of each item. The Research Framework is presented in **Figure 4-1 in the previous page.**

4.2 PROBABILITY DISTRIBUTION OF HISTORICAL CONSUMPTION DEMAND

Probability distribution is used to describe the probability that a certain value, or set of values will occur within a set of data. It is sometimes called frequency distribution, because the frequency of a value or set of values occurring is directly related to these values occurring. Historical data is analyzed by aggregating the data into time periods, months typically.

An uncertainty exists in the consumption demand of spare parts, which represents a bias that indicates a systematic error assumed to be normally distributed throughout the years 2010 and 2011.

A normal distribution is defined by two parameters: its mean "μ" and variance "σ^2". The variance within the historical data is used as a good heuristic to estimate the forecast error variance.

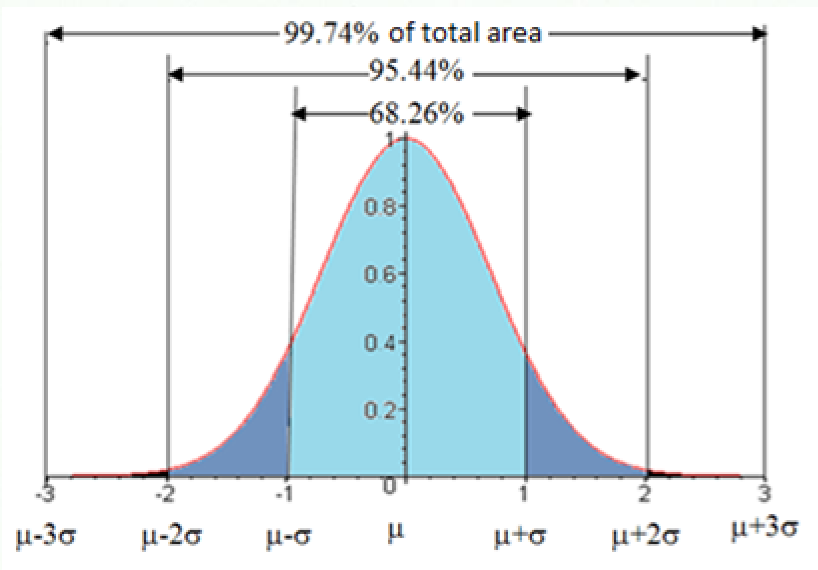


Figure 4-2: Normal distribution of consumption demand of spare parts [Source: Gopalakrishnan & Banerji, "Maintenance & Spare Parts Management", (2008)]

Normally distributed data describes a set of data where fewer values exist at extreme distances from the mean value, and the total number of values occurring above the mean value is close to the total number of values occurring below the mean value.

The consumption demand is examined during the year 2012, by taking into consideration that lead time demand forecasts are unbiased. Therefore an error is very often correlated to the amount of expected variation, the greater the upcoming variations, the greater the error in the forecasts. The next step is to calculate the acceptable error level within the normal distribution by introducing a "service level" in form of a percentage assuming static lead time. A "cumulative distribution function" is a range of values is the functionality of the probability distribution to assign cumulative probability of the demand variability, and accordingly view the frequency of certain levels of demand occurring based on history.

"Service factor" is a term defied as the multiplier that represents number of standard deviations that will be used to calculate Safety stock. The safety stock is calculated by multiplying standard deviation of error by the service factor.

Equation 4-1: Theoretical calculation of safety stock

$$S.S = \sigma * \text{icdf}(P) \qquad \textbf{(1)}$$

Where: S.S : Safety stock

σ : Standard deviation (the square root of σ^2 is the variance)

icdf : Inverse cumulative normal distribution (zero mean & variance equal to 1).

P : Service level.

The service level of the basic safety stock calculation represents the percentage of periods in which all demand is expected to be met, if at the beginning of each period a quantity on hand exists equal to exactly the mean demand plus the result of the service factor multiplied by the standard deviation (Piasecki et al., 2009).

4.3 LEAD TIME CONNECTION WITH PERIOD OF FORECAST

Lead time demand is the expected demand during the lead time period. It can be computed as the sum of the forecasted values for the future periods that intersect the lead time segment. Let T be the period and L the lead time. Then $L = k * T + \alpha * T$

Where: k is integer and $0 \leq \alpha < 1$. Let D be the lead time demand. Then, the final expression for the lead time demand is:

Equation 4-2: Theoretical calculation of lead time demand

$$D = (\Sigma_{t=1\ldots K} y'_t) + \alpha y'_{k+1} \qquad \textbf{(2)}$$

Where: y'_n : Forecasted demand for n^{th} period in the future.

The forecast error variance is computed as:

Equation 4-3: Average forecast per period

$$\sigma^2 = E\,[(y_t - y')^2] \text{ and } y' = D / (k+\alpha) \qquad \textbf{(3)}$$

Where: y' : Average forecast per period.

Yet, σ^2 is computed as per-period variance. Let σ_L^2 be the adjusted per lead time variance needed to match the lead time as described by (Piasecki et al. 2009). Therefore:

Equation 4-4: Adjusted per lead time variance

$$\sigma_L^2 = (k+\alpha)\,\sigma^2 \qquad \textbf{(4)}$$

4.4 METHODS OF FORECASTING CONSUMPTION DEMAND

Technological forecasting has become increasingly crucial to compete in the modern international business environment. Forecasting is not simply identifying and using a method to compute a numerical estimate of what demand will be in the future. It is a continuing process that requires constant monitoring and adjustment.

4.4.1 CONVENTIONAL STATISTICAL FORECASTING METHODS

Time series methods are statistical techniques popular for short-range forecasting among service and manufacturing companies; include moving average and exponential smoothing methods that make use of historical data accumulated over a period of time, assuming that identifiable historical patterns for demand over time will repeat themselves.

4.4.1.1 SIMPLE N-PERIOD MOVING AVERAGE METHOD

The simple moving average method uses several demand values during the recent past to develop a forecast. This tends to smooth out, the random increases and decreases of a forecast that uses only one period. Moving average is computed for specific periods, taken as five months in this research's analysis, depending on how much it is required to smooth the demand data. The longer the moving average period, the smoother it will be. The formula for computing the moving average according to (Eppen et al.,1998) is:

Equation 4-5: Forecasting demand using simple moving average method

$$y'_{t+1}=\frac{1}{n} * (y_t + y_{t-1} + \ldots . + y_{t-n+1}) \qquad (5)$$

Where: y'_{t+1} : Forecast of the next period.

n : number of periods in the moving average

y_t : Actual consumption demand in the present period.

4.4.1.2 WEIGHTED N-PERIOD MOVING AVERAGE METHOD

The moving average method can be adjusted to more closely reflect fluctuations in the data, with the notation that recent data are more important than old data, which is implemented with a weighted five months period moving average in this research's analysis, where smaller weights are assigned to old data, and all weights sum to one, according to (Eppen et al.,1998):

Equation 4-6: Forecasting demand using weighted moving average method

$$y'_{t+1}=\frac{n}{t} * y_t + \frac{n-1}{t} * y_{t-1} + \frac{n-2}{t} * y_{t-n+1} \qquad (6)$$

Where: y'_{t+1} : Forecast of the next period.

n : number of periods in the moving average

y_t : Actual consumption demand in the present period.

n/t, $(n-1)/t$, & $(n-2)/t$:Initial weights

4.4.1.3 SINGLE EXPONENTIAL SMOOTHING METHOD

The single Exponential Smoothing is a simple method that can approximate the results of weighted moving averages with minimal data requirements, (Brown et al., 1959), where most recent data are weighted more strongly. As such, the forecast will react more to recent changes in demand. This is useful if the recent changes in the data result from a change such as seasonal pattern instead of just random fluctuations. Data required includes forecast & actual demand for the current period, and a weighting factor called smoothing constant, with weights summing to one, according to (Eppen et al.,1998), calculated as follows:

Equation 4-7: Forecasting demand using single exponential smoothing method

$$y'_{t+1} = \alpha * y_t + (1-\alpha) * y'_t \qquad (7)$$

Where: y'_{t+1} : Forecast of the next period.

y_t : Actual demand in the present period.

y'_t : Previously determined forecast for the present period.

α : A weighting factor referred to as smoothing constant, with value ranges between 0.1 and 0.4, on the basis of demand features.

4.4.2 SPECIAL DEMAND FORECASTING METHODS

Classical forecasting approach gives unsatisfactory results, when an inventory with irregular demands exists, which is found in an inventory of spare parts. Data for such items is composed of time series of non-negative integer values where some values are zero.

Different approaches that estimate the lead time demand are applied to the demand data, including Croston and Bootstrapping forecasting methods that were developed to provide a more accurate estimate for items with irregular demand.

4.4.2.1 CROSTON'S METHOD

The Croston method was developed by the statistician (J.D. Croston et al., 1972), which consists of a routine stock control system in which updating occurs at fixed unit time intervals, which are typically much shorter than the times between successive demands for the product. Thus there will be frequent occasions for which the demand will be zero, although the average demand can be greater than one since it is calculated over multiple periods from demands of varying size.

This method consists of two main steps. First, calculating mean demand per period by separately applying exponential smoothing. Second, the mean interval or variant of exponential smoothing between demands is calculated. It is assumed that lead time demand follows normal distribution. A certain form of a model is used as follows to predict future demand (Kalchschmidt et. al., 2003):

If $X(t) = 0$, then: $Y(t) = Y(t-1)$,

$P(t) = P(t-1)$, and

$Q = Q+1$

Else $Y(t) = \alpha * X(t) + (1-\alpha) * Y(t-1)$,

$P(t) = \alpha Q + (1-\alpha) * P(t-1)$, and

$Q = 1$

Equation 4-8: Forecasting demand using Croston's method

$$M(t) = {Y(t)}/{P(t)} \quad \textbf{(8)}$$

Where: $M(t)$: Estimate of mean demand per time

$X(t)$: Consumption demand during time period t.

$Y(t)$: Estimate of mean size of non-zero demand.

$P(t)$: Estimate of mean interval between non-zero demands.

Q : Time interval since the last non-zero demand.

α : Smoothing factor

4.4.2.2 MODIFIED CROSTON'S METHOD

A few modifications to Croston's method were introduced by (Johnston & Boylan et al., 1996). One of such modifications is to use logarithmic transformation of the demands and Geometric distribution of inter-arrival times. The modification of Croston's Method estimates the mean demand per period, taking into account the intervals between non-zero demands and their sizes. Under this circumstance, exponentially weighted average method is applied of two last past values, due to two reasons.

Firstly, this kind of method will bring out the results that are better than the original one due to considering the effects of two last periods on next period's the forecasting value. Secondly, two last periods are only considered because irregular demand is not influenced much by past trends. The modification of Croston's method is implemented in the following way, (Kalchschmidt et al., 2003):

If $X(t) = 0$, then: $Y(t) = Y(t-1)$,

$P(t) = P(t-1)$, and

$Q = Q+1$

Else $Y(t) = \alpha * X(t) + \alpha * (1-\alpha) * Y(t-1) + (1-\alpha)^2 * Y(t-2)$

$P(t) = \alpha * Q + \alpha * (1-\alpha) * P(t-1) + (1-\alpha)^2 * P(t-2)$, and

$Q = 1$, with $\alpha + \alpha * (1-\alpha) + (1-\alpha)^2 = 1$

Equation 4-9: Forecasting demand using Modified Croston's method

$$M(t) = {Y(t)}/{P(t)} \qquad (9)$$

Where: M(t) : Estimate of mean demand per period

X(t) : Consumption demand during time period t.

Y(t) : Estimate of mean size of non-zero demand.

P(t) : Estimate of mean interval between non-zero demands.

Q : Time interval since the last non-zero demand.

α : Smoothing factor

4.4.2.3 BOOTSTRAPPING METHOD

(B. Efron et al., 1979) introduced the Bootstrap method. It is a statistical method that accurately forecasts both average demand per period and service level inventory requirements. It does this by using samples of historical demand data to create thousands of realistic scenarios that show the evolution of cumulative demand over a fixed lead time, which includes the real-world possibility that non-zero demand values for a part item that is expected to occur in the future might differ from those that occurred in the past, reflecting all aspects of the new Smart-Willemain methodology (Thomas R. Willemain et al., 2003).

The forecast horizon is the length of time into the future over which the forecast is based. It must be at least as long as the cumulative lead time of the spare part component being forecast. Forecat horizon can also be defined as the period of time into the past over which historical demand was used to produce the forecast (Piasecki et al., 2009).

Implementation of bootstrapping method in estimating consumption demand includes the following steps:

(1) Generating a bootstrap scenario of demand, in which a number of samples are randomly selected from zero/non zero values of actual consumption demand, with replacement, equal to number of months over forecast horizon where lead time demand is considered.
(2) Summation of forecast values over the horizon to get one predicted value of Lead time demand (D).
(3) Steps 1–2 are repeated many times.

Conventional statistical forecasting methods cannot produce accurate estimates of the complete spare parts distribution for all possible lead time demand values in case of intermittent demand, which commonly exists in service parts of industrial machinery.

4.5 SELECTION OF APPROPRIATE FORECASTING METHOD

Forecasts value deviates from actual demand. This difference between the forecast and the actual demand is the forecast error. The forecasting methods are compared with each other, as an approach for method evaluation, utilizing several measures of forecast error, which are mean absolute deviation, mean absolute percentage error, symmetric mean absolute percentage err, adjusted mean absolute percentage error, and root mean square deviation.

The formulas used in each of the said measures are presented in the next section, considering the following parameters:

A_i : Actual consumption demand

F_i : Lead time demand forecast

N : Total number of items

1. MAD: Mean absolute deviation, which is an average of the difference between the forecast and actual demand, as computed by the following formula:

Equation 4-10: Formula of mean absolute deviation

$$MAD = \frac{|A_i - F_i|}{N}$$

(10)

2. MAPE: Mean Absolute Percentage Error, measures the absolute error as a percentage of demand rather than per item. As a result, it eliminates the problem of interpreting the measure accuracy relative to magnitude of demand and forecast value, which MAD does. The Mean absolute percentage error is calculated according to the following formula:

Equation 4-11: Formula of mean absolute percentage error

$$MAPE = \frac{1}{N} * \sum_{i=1}^{N} \frac{|A_i - F_i|}{A_i} * 100$$

(11)

There are two drawbacks in practical application.

Firstly, in case zero values exist, which sometimes happens in spare parts demand series; there will be a division by zero. Secondly, there might be few number of items series that have a very high MAPE and might distort a comparison between the average MAPE fitted with one method compared to the average MAPE when using another method. In order to avoid this problem other measures have been defined, for example symmetrical MAPE.

3. S-MAPE: Symmetric Mean Absolute Percentage Error is an accuracy measure based on percentage (or relative) errors. It is usually defined as follows:

Equation 4-12: Formula of symmetric-mean absolute percentage error

$$S - MAPE = \frac{1}{N} * \sum_{i=1}^{N} \frac{|A_i - F_i|}{(A_i + F_i)/2} * 100 \qquad (12)$$

The absolute difference between A_i and F_i is divided by half the sum of the actual value A_i and the forecast value F_i. The value of this calculation is summed for every fitted point i and divided again by the number of fitted points N.

S-MAPE has a lower bound and an upper bound. A percentage error between 0% and 100% is much easier to interpret. However, one problem with S-MAPE is that it is not as symmetric as it sounds since over- and under-forecasts are not treated equally.

4. A-MAPE: Adjusted Mean Absolute Percentage Error

An important work has been done by (Hover et al., 2006), among which adjusted mean absolute percentage error (A-MAPE) is one of the most used in comparing spare parts demand forecasting methods. The formula is used as follows:

Equation 4-13: Formula of adjusted-mean absolute percentage error

$$A - MAPE = \frac{\sum_{i=1}^{N} \frac{|A_i - F_i|}{N}}{\sum_{i=1}^{N} \frac{A_i}{N}} \qquad (13)$$

5. RMSD: Root Mean Square Deviation

The root mean square deviation (RMSD) is a frequently used measure of the differences between values predicted and values actually observed, defined as per the following formula:

Equation 4-14: Formula of root mean square deviation

$$RMSD = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (A_i - F_i)^2} \qquad (14)$$

A study conducted by (Armstrong and Collopy et al., 1992), evaluated measures for making comparisons of errors across 90 annual and 101 quarterly time-series data, and it concluded that MAPE should not be the choice if large errors are expected because MAPE is biased in favour of low forecasts, also the root mean square error (RMSE) is not reliable, even though most practitioners prefer RMSE since it describes magnitude of errors in terms useful to decision makers, (Carbone and Armstrong et al., 1982), The study recommended the adjusted mean absolute percentage error (A-MAPE) for selecting the most accurate methods when many time-series data are available.

4.6 ABC CLASSIFICATION SYSTEM

Typically hundreds of independent demand items are held in inventory by a company, especially in manufacturing, but small percentage is of such high value to warrant close inventory control. In ABC analysis each class of inventory requires different levels of inventory control, the higher the value of inventory, the tighter the control. Class "A" items should experience tight inventory control, "B" and "C "require minimal attention. About 10 % of all inventory items account for 70% of total value of inventory. These are classified as class "A" items. "B" items represent approximately 20% of total inventory units, but only about 20% of total inventory value. "C" items account for 70% of all inventory units, but represent only 10% of total inventory value.

The first step in ABC analysis is to classify all inventory items as either A, B, or C. Each item is assigned a value, which is computed by multiplying the cost of one unit by the annual demand for that item. All items are then ranked according to their said computed value, with for example the top 70% of total inventory value classified as class "A" items, the next 20%, as class "B" items, and the last 10%, as class "C" items. These classifications have been found to be close to actual occurrence in firms with remarkable frequency.

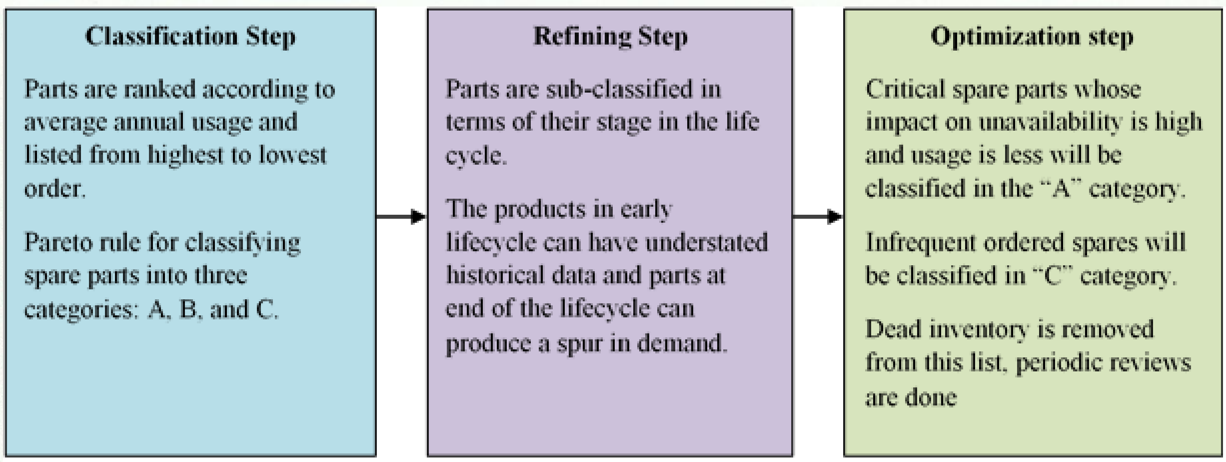


Figure 4-3: Steps of carrying out ABC classification of spare parts [Source: Natarajan & Tarannumm, "Spare Parts Pricing Optimization, Cognizant 20-20 insights", (www.cognizant.com)]

Class "A" items requires appropriate inventory management system to determine order quantity accurately, implementing a system of continuous monitoring of inventory level. In addition, close attention should be given to purchasing policies and procedures. Class "B", and "C" items require less stringent inventory control, since carrying costs are usually lower for "C" items, higher inventory levels can sometimes be maintained with larger safety stocks. It may not be necessary to control class "C" items beyond simple observation. That's to say a periodic review system with less monitoring will suffice for class "C" items.

4.7 CALCULATION OF REORDER QUANTITIES, AND AVERAGE INVENTORY LEVEL

The reorder point is the amount of stock set to trigger an order of a specific item. In practice, because of the uncertainties, it is generally calculated as the expected usage during the lead time plus safety stock. If there was no uncertainty (i.e. future demand being perfectly known and supply being perfectly reliable), the reorder point would simply be equal to the total forecasted demand during the lead time. Assuming that for a given lead time, future demand forecast is produced, the lead time demand can be calculated as the sum of the forecasted values for the future periods that intersects the lead time segment (Piasecki et al., 2009).

Equation 4-15: Initial formula of re-order point calculation

$$R = y' + \sigma * icdf(P) \qquad \textbf{(15)}$$

Where: R : Re-order point.

y' :Average forecast per period.

icdf : Inverse cumulative normal distribution (zero mean &variance equal to one).

σ : Standard deviation.

P : Service level

Finally, reorder point is re-expressed, (Piasecki et al., 2009) as:

Equation 4-16: Final formula of re-order point calculation

$$R = D + \sigma_L * cdf(P) \qquad \textbf{(16)}$$

Where: D : Lead time demand

σ_L : Adjusted per lead time standard deviation.

cdf : cumulative normal distribution function

The reorder point is calculated with Microsoft Excel®, which intends to implement a replenishment feature for automated inventory management, using the following functions:

- STDEV function estimates standard deviation "σ" in equation 4-15 for actual consumption demand during the years 2010 & 2011. Standard deviation is used to measure spread of event frequencies for a sample as a unit of measure in the normal distribution model.

- An "inverse cumulative normal distribution" is applied as NORMSINV function, which transforms the percentage into an area under the curve, the X-axis threshold corresponds to the service factor value, and estimates cumulative normal distribution, "cdf" as in equation 4-16. Accordingly, computing Service factor, associated with a desired service level.

- SQRT function, computes the lead time factor, which is a multiplier used to adjust a standard deviation based on forecast periods, to an estimated standard deviation based on lead time periods.

1. Safety stock quantity is computed by multiplying the result of the above mentioned three functions, whereas value of safety stock is computed by multiplying the calculated safety stock quantity by the cost of one unit of a specific item.
2. Reorder quantity is calculated by summing the forecasted demand during the lead time, which is the lead time demand (D) and the calculated of safety stock quantity.
   Fixed lot size is defined as per the company's usual practice of ordering of items.
3. On stock inventory value as on 2012 is considered as an average inventory value in 2012.
4. Maximum inventory value is computed by subtracting one from each of re-order quantity and adding the quantity of fixed lot size to it, multiplied by item unit price.
5. The average aggregate inventory value in 2013 is calculated by computing the average of difference between the maximum inventory value and safety stock and adding the value of safety stock to it, then multiply it by the unit cost of each item, which is compared to the said average inventory value in 2012.

4.8 COMPARISON BETWEEN CALCULATED AND ACTUAL INVENTORY

Individual Microsoft Excel ® spreadsheets are created for each of the six forecasting methods described in section 4.4, each includes five separate sheets of different lead times initially considered for all of inventory items, which are one, two, three, five, and seven months, where lead time demand is computed according to assigned forecasting method, considering a high service level of 99.9% unchanged in all spreadsheets calculation.

The value of safety stock and average inventory varies between each forecasting method implemented and the other. Several measures of forecast error are applied, which leads to selection of the best method to be implemented based on the minimum error in forecast. One model is generated, targets to identify amount of saving in average inventory value for the year 2012 for known spare parts consumption demand, so as to verify the calculations.

A second model is generated targeting to identify amount saving in average inventory value during upcoming year 2013, validating the calculations to allow examining predicted consumption demand of spare parts. ABC classification system is implemented consequently according to value of items, and class "A","B", "C items are determined, where "A" items have service level of 99%, "B" items have a service level of 95%, and "C" items have a service level of 90%. Amount saving in inventory value in each category items in observed.

5 ANALYSIS OF CURRENT STATE

5.1 COMPANY DESCRIPTION

In this research a study is implemented in an industrial plant of VALEO Rakovník, located at Rakovník in the Czech Republic, consisting of manufacturing, conveyor system and administrative areas. Manufacturing area forms 27,000 m^2 for production and storage facilities, aims to streamline the flow of materials and finished products, throughout 24 pre-assembly and final assembly lines with buffer stocks, before it is finally inspected by operators and loaded into trucks for shipment either internally or externally. The plant is equipped with 21 plastic injection moulding machines with 80 replaceable moulds, including one machine newly installed in December 2012, and put into operation in 5th of January 2013. The study is focused on spare parts management of plastic injection moulding machines, concerned with production of air conditioning units compiled from more than 120 components, while there is a second production line for control panels made up of 60 components, used in automotive industry.

VALEO group of companies includes two more plants feeding automotive industry in Czech Republic, first is located at Žebrák, which produces heat exchangers, evaporators, and air heaters, and second is located at Humpolec, which manufactures compressors used in automobile air conditioning systems. In addition to a company located in Prague, providing development and technical support for manufacturing plants of VALEO all over the world.

5.2 REVIEW OF OVERALL INVENTORY LEVELS

The spare parts inventory is segregated into twenty categories of items, where each category is identified by a certain code, including items with various functions.

S.N.	Items Category Description	Items Identification Code	Quantity
1	Connectors	LIS101 to LIS106	43
2	Repair Sensors for moulds and machines	LIS301 to LIS3012	87
3	Hydraulic Components (STAUBLI)	LIS401 to LIS405	32
4	Spare parts for injection mould (DME)	LIS501 and LIS502	40
5	Spare parts for ejectors	LIS601 to LIS606	121
6	Bearings	LIS701 and LIS702	24
7	Lubricants	LIS801 and LIS802	11
8	Valve accessories & filters for presses	LIS901 to LIS910	103
9	Automation Plastic components (MORETTO)	LIS1101 to LIS1103	24
10	Machine Coupling	LIS1201	1
11	Electronic Components & Cards	LIS1301 to LIS1307	42
12	Greenbox cooling & Pump accessories	LIS1401 to LIS1405	26
13	Fuses, relays, contactors, terminals	LIS1501 to LIS1504	65
14	Cables	LIS1601	12
15	Heating mould & Machines	LIS1701 to LIS1709	121
16	Process automation, robot (FESTO)	LIS1801 to LIS1808	64
17	Water hoses & hydraulic fittings	LIS1901 to LIS1903	33
18	Parts for gas filling system (MUCELL)	LIS2001 to LIS2002	24
19	Conveyor system (ATYKO)	LIS2101 to LIS2103	33
20	Pressed part labeling (Special printing staff)	LIS2111	14
	Number of spare part components		**920**

Table 5-1: Spare Parts Components

The net on-stock quantities in each category is compared with each other, where categories for hydraulic components (11%) and spare parts for ejectors (35%) have the highest on-stock quantities, while lubricants, machine coupling, parts for gas filling system, conveyor system, and special printing staff holds for the lowest on-stock quantities, **as shown in Figure 5-1.**

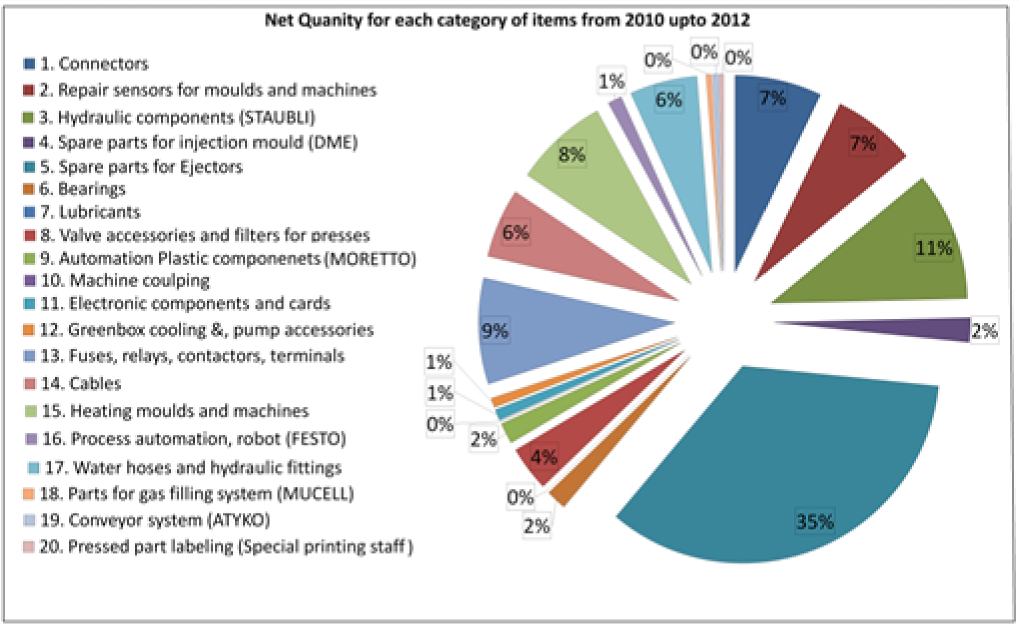


Figure 5-1: Net quantity of each spare parts items category [Source: Author]

The highest on-stock values of items were found at categories for spare parts for ejectors (10%), valve accessories & filters for presses (25%), and heating moulds & machines (20%), while lubricants, machine coupling, cables, conveyor system, and special printing staff accounts for the lowest on-stock value, **which can be seen in Figure 5-2.**

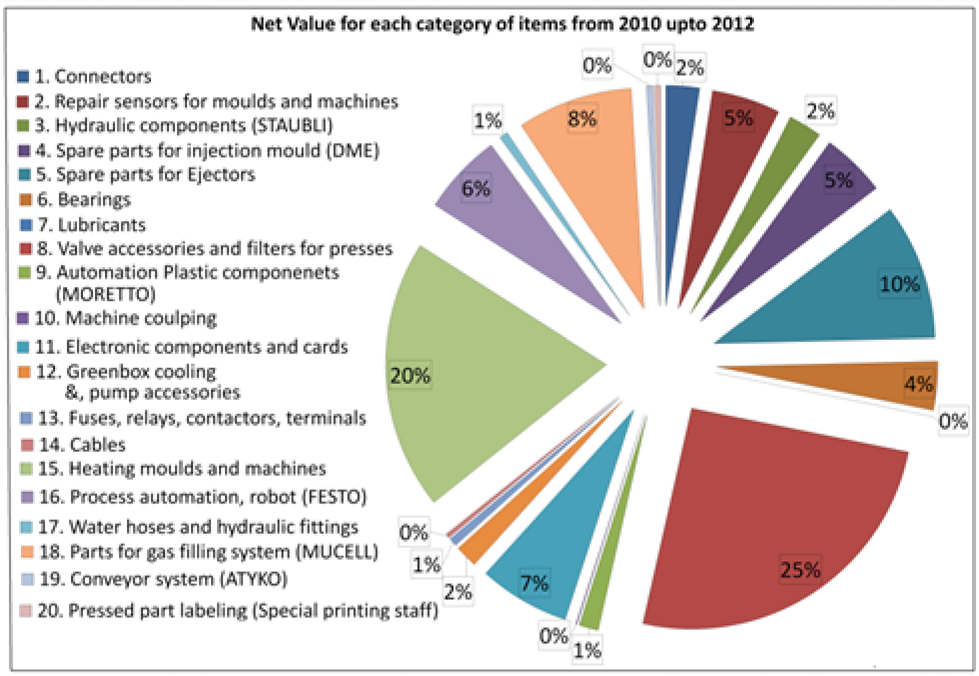


Figure 5-2: Net value of each spare parts items category [Source: Author]

Data was gathered to form a full view of material movement throughout a time series starting from the year 2010 until 2012. Consumed quantity from each item for its use in a maintenance purpose could be defined as the goods issued from the warehouse.

The relation between accumulated consumed quantity and items category, shows that categories number 3,5,14, &17 include hydraulic components, spare parts for ejectors, cables, water hoses and hydraulic fittings forms the highest consumed items. Categories number 1,2,13, &15 include Connectors, repair sensors for mould and machines, fuses, relays, contactors, terminals, heating moulds and machines stands in the second place for high consumed items, from January 2010 to December 2012, In addition to December 2012.

An increase in consumption of items lie in category number 5,14, &17 include spare parts for ejectors, cables, water hoses and hydraulic fittings is observed, due to installation of a new plastic injection moulding machine, **which can be viewed in Figure 5-3**.

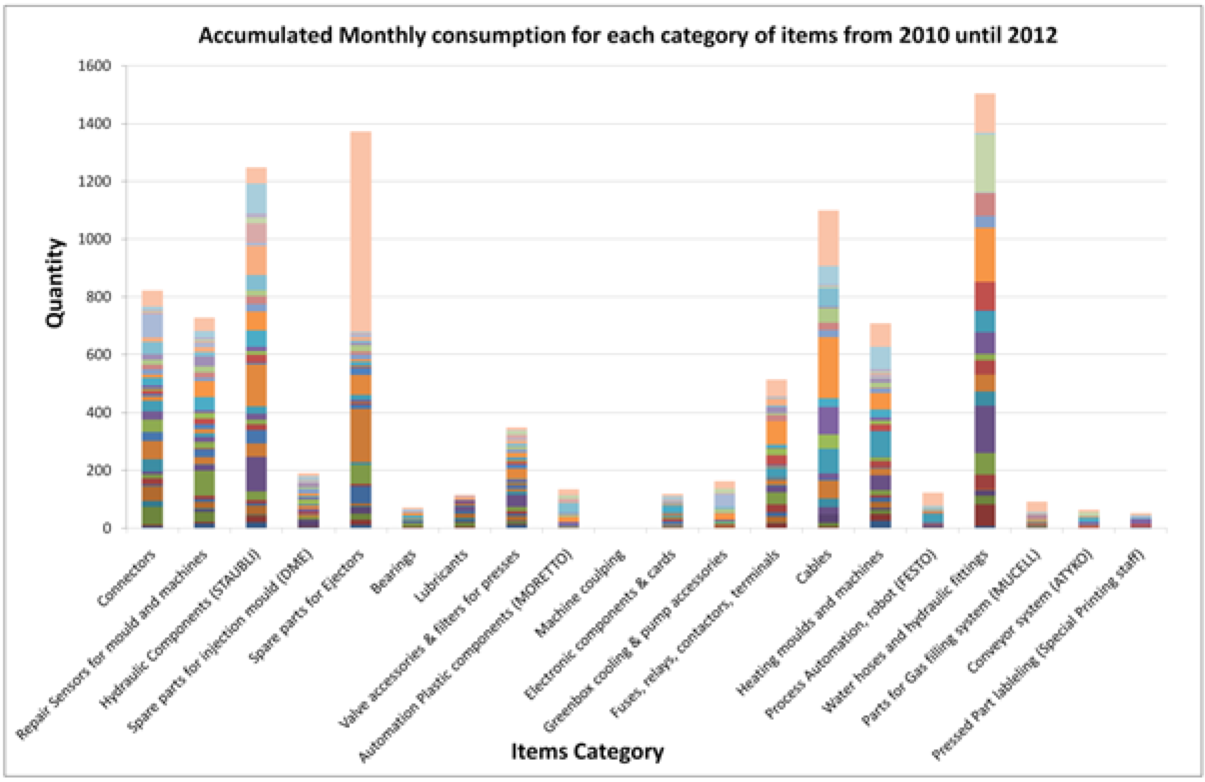


Figure 5-3: Accumulated monthly spare parts consumption [Source: Author]

The value of existing monthly stock of spare parts is calculated by SAP® software, which varies, as per maintenance requirement. The relation between the inventory value and time interval from January 2010 to December 2012 shows fluctuations in inventory value, where sudden drops existed in October, & December 2010, March, September, & December 2011, February, May, & June 2012. Peak values of inventory at lowest spare parts consumption were found at November 2011, & January 2012, **as shown in Figure 5-4 in the next page**.

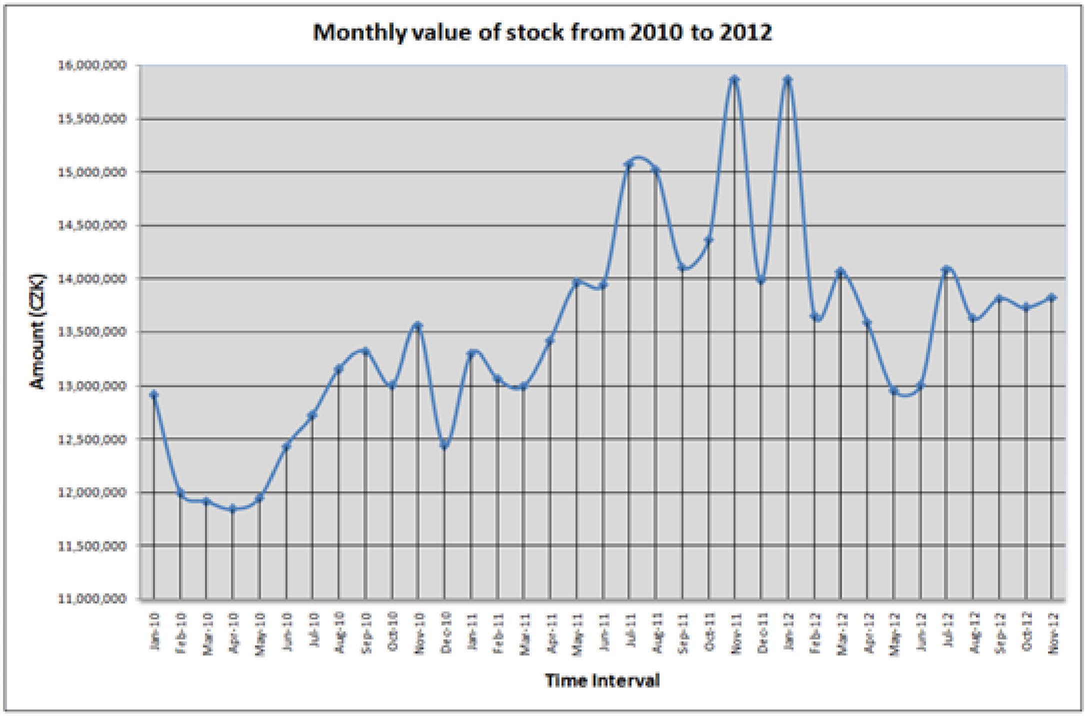


Figure 5-4: Monthly value of SAP® calculated inventory [Source: Author]

The difference between "Goods issued" and "Goods received" is calculated for each item category by creating a Microsoft Excel® spreadsheet, includes a categorized list of items, with material movement in form of consumed and received quantities. A bar chart is plotted as a percentage from 0 to 100, representing the relation between consumed minus received quantities, and time interval, where negative values indicates that the quantity of "Goods received" is higher than that of "Goods issued", interpreted as overstocking of spare parts, that appears in January, February, March, April, September, October & December 2010, February, March, November, & December 2011, and January, May, September, November, and December 2012, **which can be viewed in Figure 5-5.**

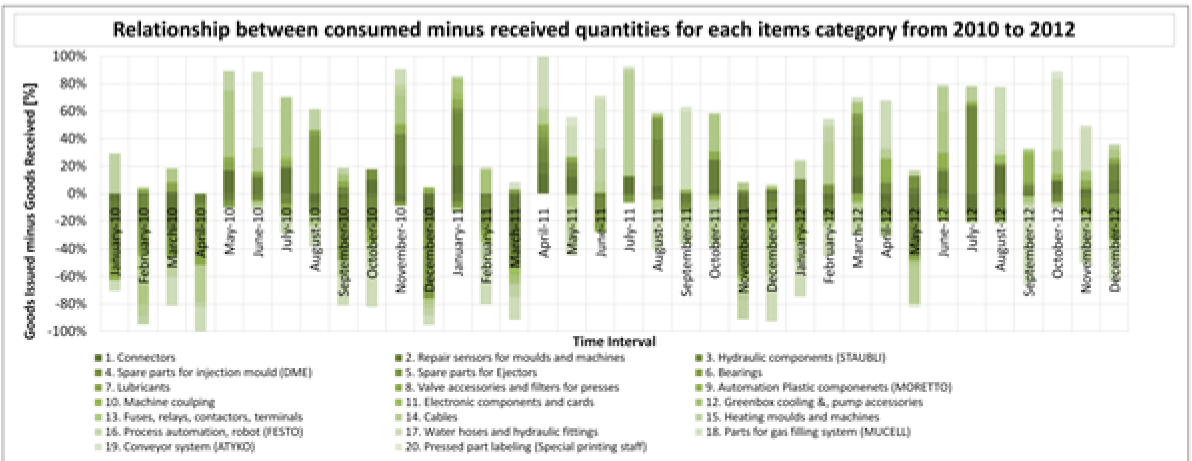


Figure 5-5: Relationship between consumed minus received quantities of items and time interval [Source: Author]

5.3 PROBLEM DESCRIPTION

The plastic injection moulding machines existing at VALEO Rakovník's production and assembly lines have clamping force ranges from 150 to 1300 tons (Make: Engel, Austria), (Demag, Germany) and (Sandretto, UK). A downtime for each type of machine might occurs in case a spare part required for repair could not be provided due to its stock-out leading to prohibitive losses in mass production, which goes for capital intensive.

Figure 5-6: An example of a Plastic injection moulding machine. Make: DEMAG, Germany [Source: http://www.plastika.cz/en/photo/002-demag.htm]

An initial over buying decision, could take years to remedy the situation due to rarely occurring demands. Also, the cost of spare parts is more than 50% of the total maintenance cost in the industry, at the same time the company financial department might face a problem of increasing locked up capital in spare parts inventory.

5.3.1 SPARE PARTS DEMAND PATTERN

The historical data gathered was monthly consumption of spare parts from January 2010 to December 2012 having an extremely stochastic and random demand pattern, with a large proportion of zero values that is defined as an intermittent or irregular demand. Those spare part items are referred to as slow moving items, having low lead time demand, for example once in six months, which is quite common for spare parts.

Intermittent demand is characterized by frequent zero values intermixed with non-zero values, in other words lumpy demand, having great variability among the non-zero values, **which can be seen in Figure 5-7 in the next page**. Reducing the occurrence of spare parts' shortages necessitates predicting the probability that various demands will occur. These probabilities can then be used in calculations designed to facilitate important logistics decisions such as procurement and stockage.

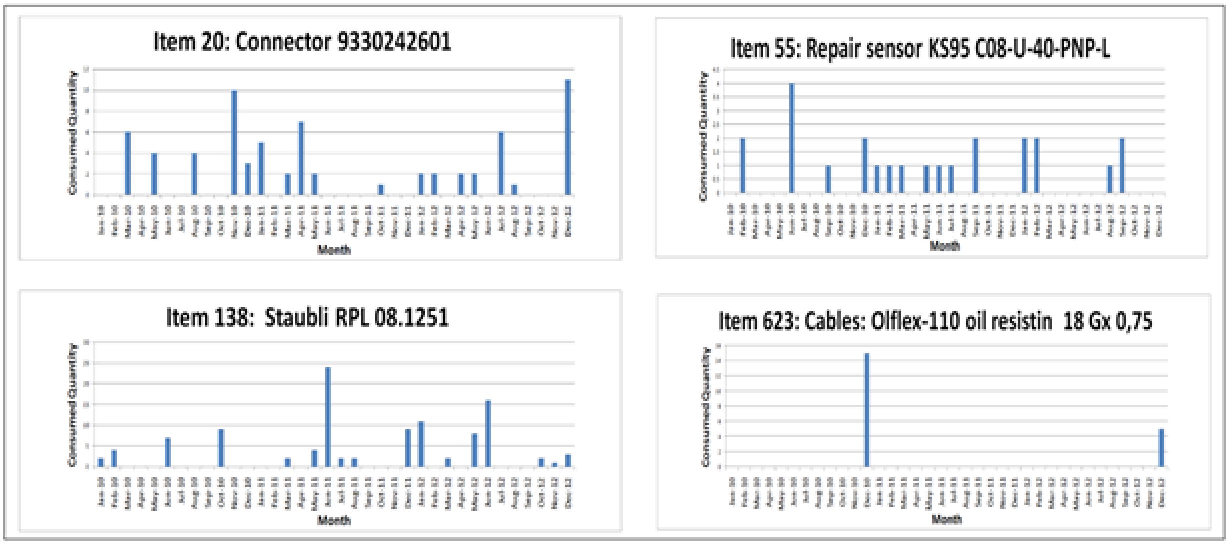


Figure 5-7: Intermittent consumption demand pattern for randomly selected items [Source: Author]

5.3.2 FACTORS INFLUENCING SPARE PARTS MANAGEMENT

Spare parts management targets to ensure availability of spares with the right quantity for maintenance and repairs of machinery and plant as and when required at an optimum cost. There are several systematic actions required to ensure effectiveness of spare parts management, which are: identification of spare parts and maintain stocking policies for capital & insurance spares or sub-assemblies, forecasting of spare parts requirement, formulation of selective control policies for various categories, development of inventory control systems introducing computer applications.

The main concerns faced by VALEO Rakovník in managing of spare parts consist of the following areas:

1. An element of uncertainty exists, as to when a part is required and also the quantity of its requirement. This is due to the fact that failure of a component, either due to wearing out or due to other reasons, cannot be predicted accurately.
2. Both number and variety of spare parts are too large making close control more tedious.
3. Different rate of consumption among spare parts, which is very high for some of the items, and very low for other items.
4. Spare parts are not that easily available in the market as they are not fast moving items and new models of machinery are introduced to incorporate design improvements. The original equipment manufacturer (OEM) has to supply the spares in most of the cases.
5. There is a tendency from the stage of purchasing an equipment to the stage of the use of the spare parts, to requisition spare parts more number than that are actually required and accumulation of spares takes place.

5.4 INVENTORY PRIORITIZATION USING ABC CLASSIFICATION SYSTEM

All of the spare part items were classified using ABC classification system during two different time series from 2010 until 2012 and 2012 separately, based on different characteristics of spare parts, which are net quantity, net value, consumed quantity, consumed value, frequency of consumption, received quantity, received value, and frequency of receipt for total 920 items in stock.

Items have been prioritized using a Pareto analysis, (Vilfredo Pareto et al., (1848-1923)), commonly referred to as 80/20 rule, by stratifying the parts into three categories namely "A", "B", and "C", hence the name ABC analysis, in which high value items account for 70% of value of all items, defined as category "A" items, medium value items account for 20% of value of all items, defined as category "B" items, and low value items account for 20% of value of all items, defined as category "C" items.

5.5 BENEFITS OF IMPLEMENTING ABC CLASSIFICATION SYSTEM

A wide range of benefits are obtained by implementing ABC approach, in which other systems are associated with it, such as quality management "six sigma", maintenance management "Vital, essential, desirable analysis", time management "activities prioritization" and inventory management with advantages, including cycle counting, critical spare parts & inactive parts identification, and investment goals related to turnover ratio.

5.5.1 ASSIGNING AN INTERVAL OF CYCLE COUNTING

A cycle counting is an inventory auditing technique, where a subset of inventory, in a specific location is counted on a specified day and reconciling differences as they occur. By segmenting inventory, based on an ABC analysis and setting up a time schedule for when items should be counted throughout the year so that all SKU's (Stock keeping units) items are counted at least once, with the faster moving SKU's being counted multiple times per year. "A" items are counted once every quarter, "B" items once every 6 months, and "C" items once every 12 months.

Unlike physical inventory counting, the operation does not have to be shut down during a cycle count, in which an ongoing measure of inventory accuracy is provided, little number of people with more experience need to perform a cycle count. Systematic improvement of processes dictating inaccurate records takes place. Significant cost saving is achieved when correct cycle count procedures are applied that specify not only the part number to be counted but also the location where it should be located.

5.5.2 IDENTIFICATION OF CRITICAL SPARE PARTS

Items for potential consignment or vendor stocking are identified as "A" category items, which tend to have greater impact on investment, these are often very expensive with long lead times, because of potential implications of an equipment failure requiring these part. It is the best to investigate the potential for alternative stocking arrangements that would reduce investment liability and associated carrying costs, while it is imperative to keep them in stock or readily available to minimize the impact on production, ensuring that crucial inventory does not fall below minimum levels.

5.5.3 SUPPORT ESTABLISHMENT OF AN INVESTMENT

ABC analysis identifies the items that represent the greatest investment for a company in terms of monetary value and turnover rate. "A" category items will have greater usage than "B" or "C" category items, accordingly, should have higher turnover ratios. When establishing investment and turnover metrics, inventory data can be segregated by ABC classification, with different targets for each category.

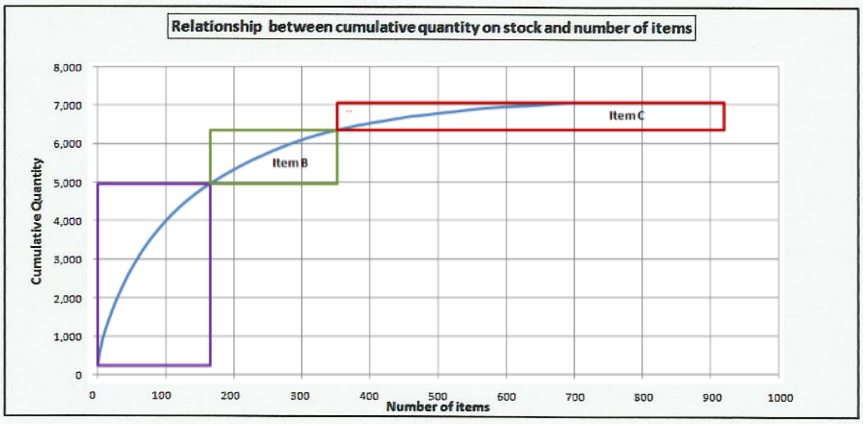
5.5.4 IDENTIFICATION OF INACTIVE ITEMS

Inactive items will fall to the bottom of the prioritized list. Therefore, "C" category items are the best place to start when performing a periodic obsolescence review. An original equipment manufacturer of newly installed equipment provides recommendations for spare parts, which is evaluated by maintenance department of the manufacturing plant, by comparing it to the current bill of spare parts. Replenishment takes place using continuous stocktaking to ensure holding all necessary spare parts in a warehouse.

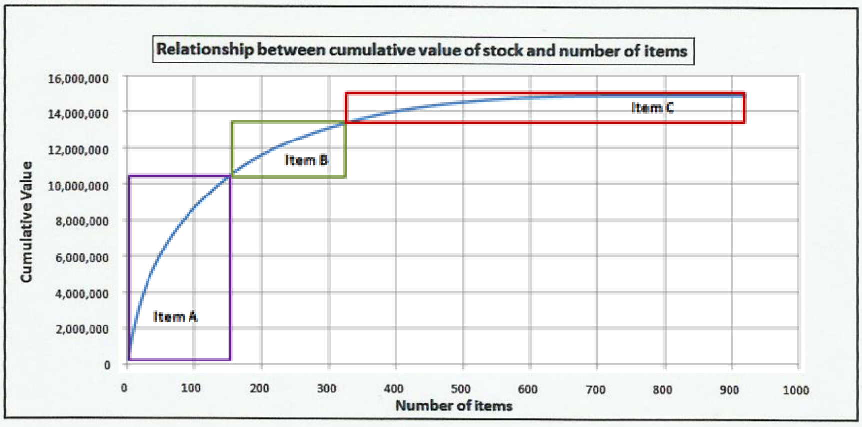
5.6 CLASSIFICATION ACCORDING TO NET CURRENT QUANTITY AND VALUE OF INVENTORY

The first classification is based on sorting of spare parts items in descending order with respect to their net quantity on stock, and calculating the cumulative quantity of items, so as to enable plotting a Pareto diagram. As a result Category "A" items were found to be consisting of 164 items, with a current quantity of 4,931 units, Category "B" items were found to be consisting of 189 items, with a current quantity of 1,418 units, and Category "C" items were found to be consisting of 565 items, with a current quantity of 705 units. The second classification is based on sorting of spare parts items in descending order with respect to their net value on stock, and calculating the cumulative value of items, so as to enable plotting Pareto diagram. As a result Category "A" items were found to be consisting of 149 items, with a current value of 10,373,956 CZK, Category "B" items were found to be consisting of 174 items, with a current value of 2,984,729 CZK, and Category "C" items were found to be consisting of 597 items, with a current value of 1,493,382 CZK.

Figure 5-8 (a) & (b) show Pareto diagram obtained from both classifications.



5-8 (a)



5-8 (b)

Figure 5-8: (a) & (b) Pareto diagram based on net current quantity and value of items [Source: Author]

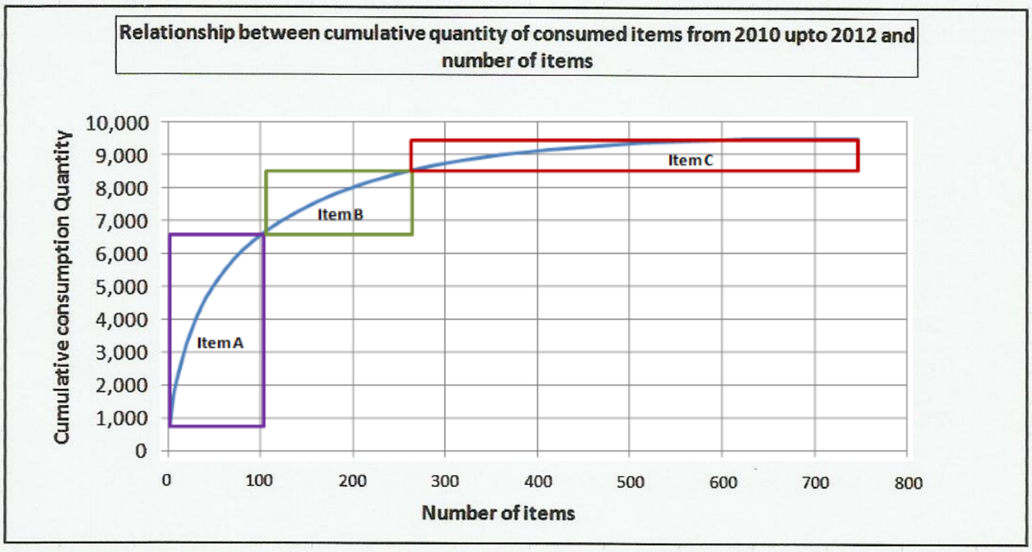
5.7 CLASSIFICATION ACCORDING TO CONSUMED QUANTITY, VALUE & FREQUENCY FROM 2010 TO 2012

The first classification is based on segregation of spare parts items in descending order with respect to their net consumed quantities from 2010 to 2012, and calculating the cumulative consumed quantity of items, so as to enable plotting Pareto diagram. As a result Category "A" items were found to be consisting of 102 items, with a consumed quantity of 6,610 units, Category "B" items were found to be consisting of 160 items, with a consumed quantity of 1,904 units, and Category "C" items were found to be consisting of 658 items, with a consumed quantity of 952 units.

The second classification is based on sorting of spare parts items in descending order with respect to their net consumed values, and calculating the cumulative consumed value of items, so as to enable plotting Pareto diagram. As a result Category "A" items were found to be consisting of 77 items, with a consumed value of 14,721,533 CZK, Category "B" items were found to be consisting of 136 items, with a consumed value of 4,273,249 CZK, and Category "C" items were found to be consisting of 707 items, with a consumed value of 2,112,234 CZK.

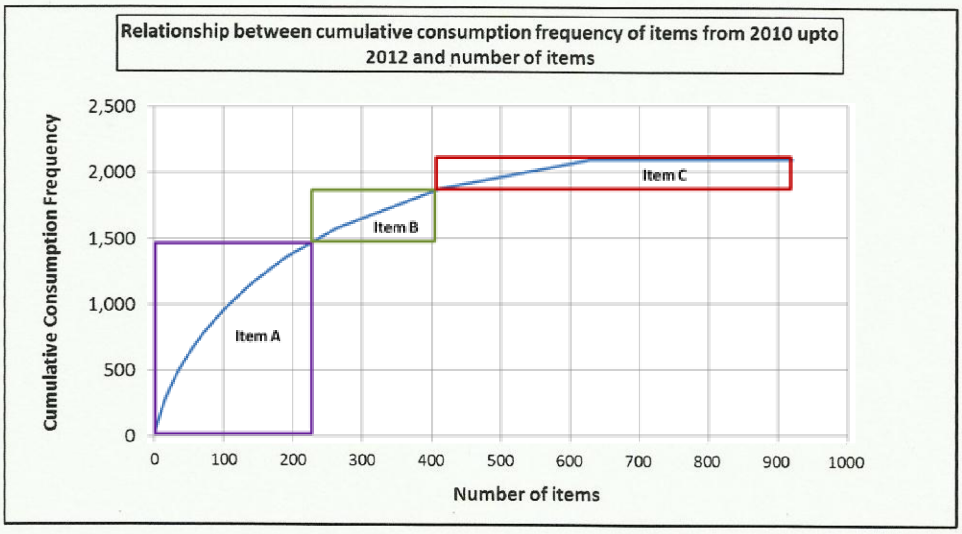
The third classification is based on sorting of spare parts items in descending order with respect to their frequency of consumption, and calculating the cumulative value of items, so as to enable plotting a Pareto curve. As a result Category "A" items were found to be consisting of 226 items, with a consumption frequency of 1,464, Category "B" items were found to be consisting of 180 items, with a consumption frequency of 397, and Category "C" items were found to be consisting of 514 items, with a consumption frequency of 230.

Figure 5-9 (a), (b) & (c) show Pareto diagrams obtained from all three classifications.



5-9 (a)

5-9 (b)



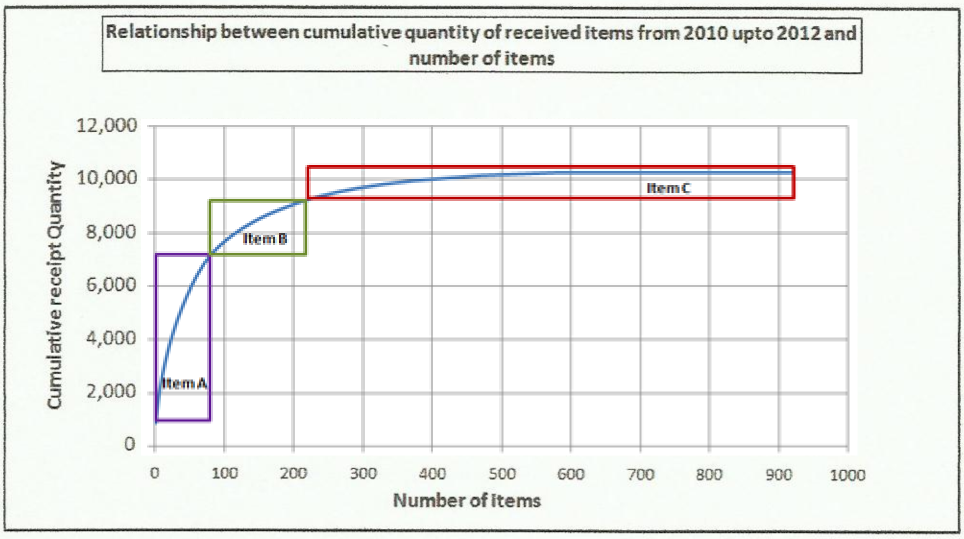
5-9 (c)

Figure 5-9: (a), (b), & (c) Pareto diagram based on consumed quantity, value, and frequency 2010 to 2012 [Source: Author]

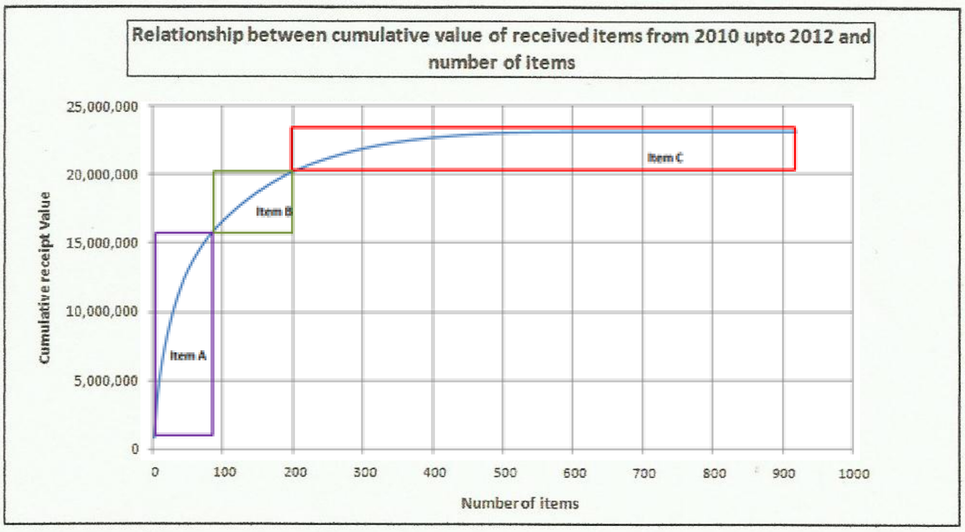
5.8 CLASSIFICATION ACCORDING TO RECEIPT QUANTITY, VALUE & FREQUENCY FROM 2010 TO 2012

The first classification is based on sorting of spare parts items in descending order with respect to their net received quantities from 2010 to 2012, and calculating cumulative received quantity of items, so as to enable plotting Pareto diagram. As a result Category "A" items were found to be consisting of 80 items, with a received quantity of 7,170 units, Category "B" items were found to be consisting of 139 items, with a received quantity of 2,065 units, and Category "C" items were found to be consisting of 701 items, with a consumed quantity of 1,031 units. The second classification is based on sorting of spare parts items in descending order with respect to their net received values, and calculating cumulative receipt value of items, so as to enable plotting Pareto diagram. As a result Category "A" items were found to be consisting of 90 items, with a received value of 16,171,301 CZK, Category "B" items were found to be consisting of 136 items, with a received value of 4,638,894 CZK, and Category "C" items were found to be consisting of 694 units, with a received value of 2,322,093 CZK. The third classification is based on sorting of spare parts items in descending order with respect to their frequency of receipt, and calculating cumulative value of items, so as to enable plotting Pareto diagram.

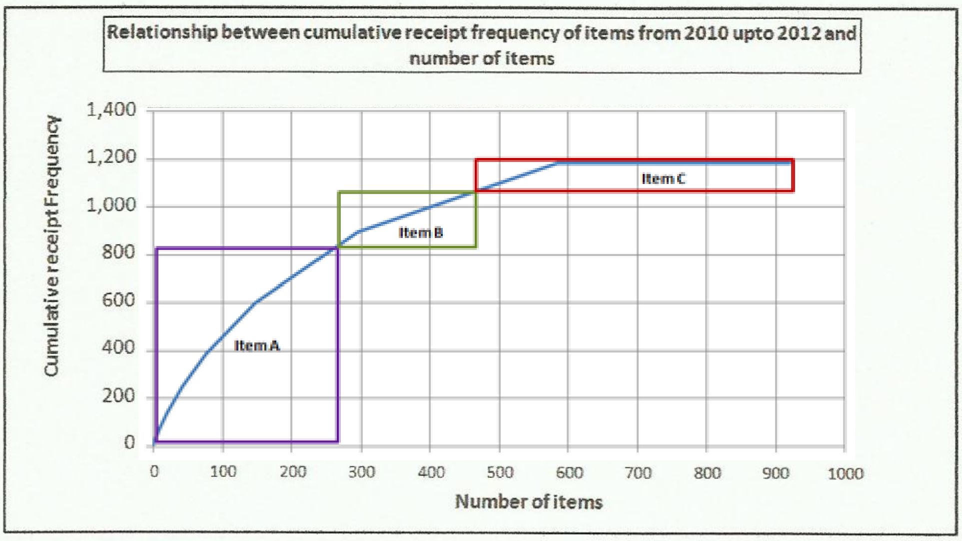
As a result Category "A" items were found to be consisting of 262 items, with a receipt frequency of 829, Category "B" items were found to be consisting of 204 items, with a receipt frequency of 238, and Category "C" items were found to be consisting of 454 units, with a receipt frequency of 119, **which can be seen in Figure 5-10 (a), (b) & (c) in the next page.**



5-10 (a)



5-10 (b)



5-10 (c)

Figure 5-10: (a), (b), & (c) Pareto diagram based on received quantity, value, and frequency 2010 to 2012 [Source: Author]

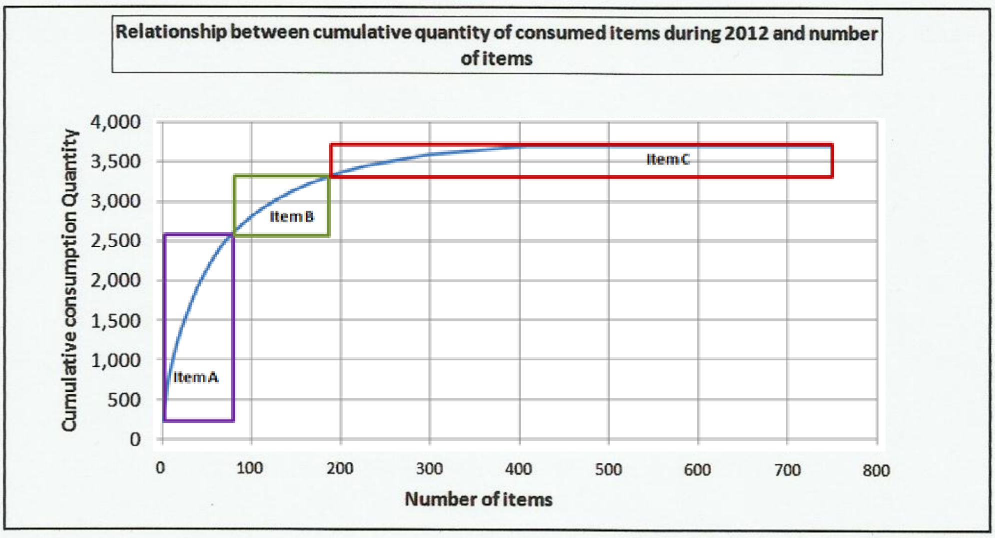
5.9 CLASSIFICATION ACCORDING TO CONSUMED QUANTITY, VALUE AND FREQUENCY DURING 2012

The first classification is based on sorting of spare parts items in descending order with respect to their net consumed quantities, and calculating the cumulative consumed quantity of items, so as to enable plotting Pareto diagram. As a result Category "A" items were found to be consisting of 77 items, with a consumed quantity of 2,590 units, Category "B" items were found to be consisting of 114 items, with a consumed quantity of 753 units, and Category "C" items were found to be consisting of 729 items, with a consumed quantity of 371 units.

The second classification is based on sorting of spare parts items in descending order with respect to their net consumed values, and calculating the cumulative consumed value of items, so as to enable plotting Pareto diagram. As a result Category "A" items were found to be consisting of 55 items, with a consumed value of 5,266,953 CZK, Category "B" items were found to be consisting of 89 items, with a consumed value of 1,543,227 CZK, and Category "C" items were found to be consisting of 776 units, with a consumed value of 757,326 CZK.

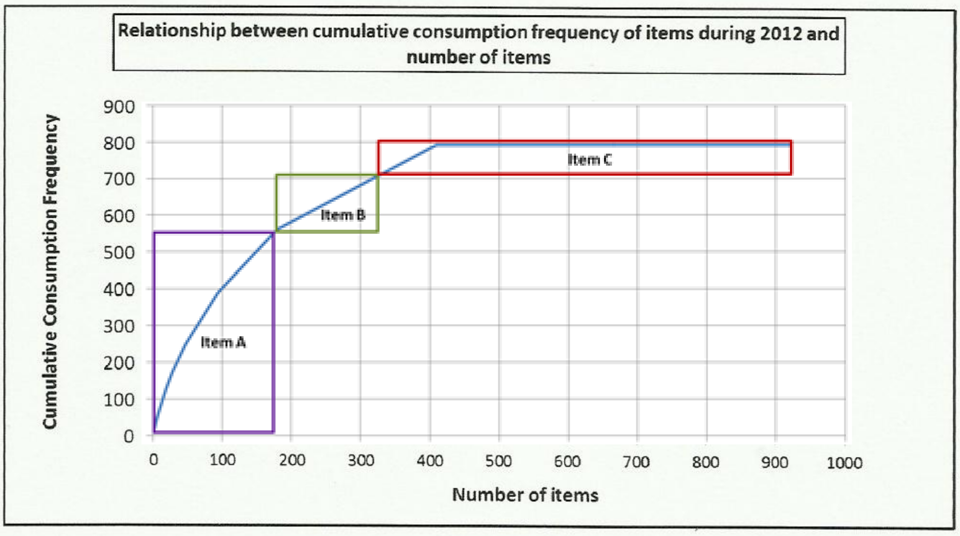
The third classification is based on sorting of spare parts items in descending order with respect to their frequency of consumption, and calculating the cumulative value of items, so as to enable plotting Pareto diagram. As a result Category "A" items were found to be consisting of 176 items, with a consumption frequency of 554, Category "B" items were found to be consisting of 155 items, with a consumption frequency of 159, and Category "C" items were found to be consisting of 589 items, with a consumption frequency of 79.

Figure 5-11 (a), (b) & (c) show Pareto diagrams obtained from all three classifications.



5-11 (a)

5-11 (b)



5-11 (c)

Figure 5-11: (a), (b), & (c) Pareto diagram based on consumed quantity, value, and frequency during 2012 [Source: Author]

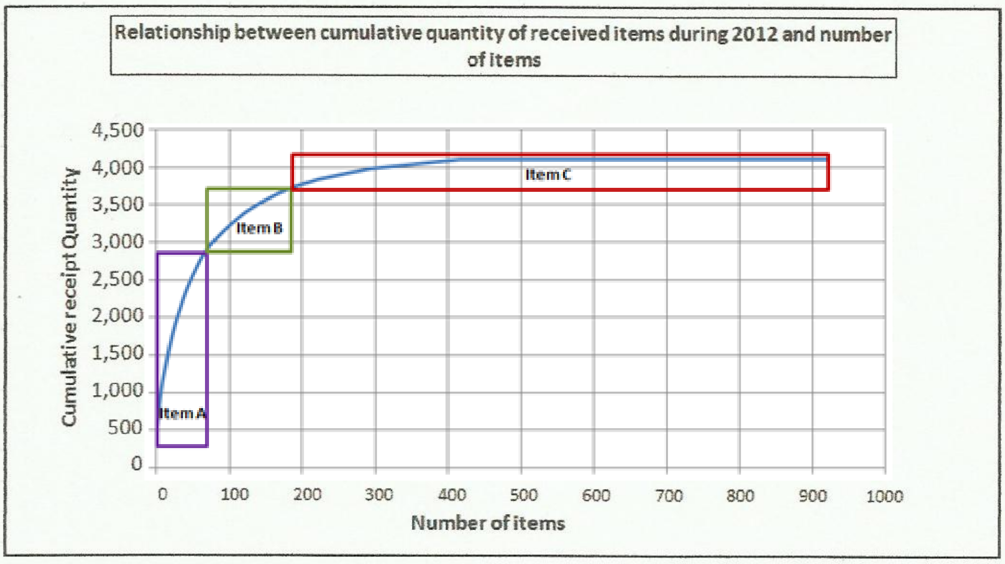
5.10 CLASSIFICATION ACCORDING TO RECEIPT QUANTITY, VALUE AND FREQUENCY DURING 2012

The first classification is based on sorting of spare parts items in descending order with respect to their net received quantities in 2012, and calculating the cumulative received quantity of items, so as to enable plotting Pareto diagram. As a result Category "A" items were found to be consisting of 68 items, with a received quantity of 2,870 units, Category "B" items were found to be consisting of 111 items, with a received quantity of 825 units, and Category "C" items were found to be consisting of 741 items, with a consumed quantity of 410 units. The second classification is based on sorting of spare parts items in descending order with respect to their net received values in 2012, and calculating the cumulative receipt value of items, so as to enable plotting Pareto diagram.

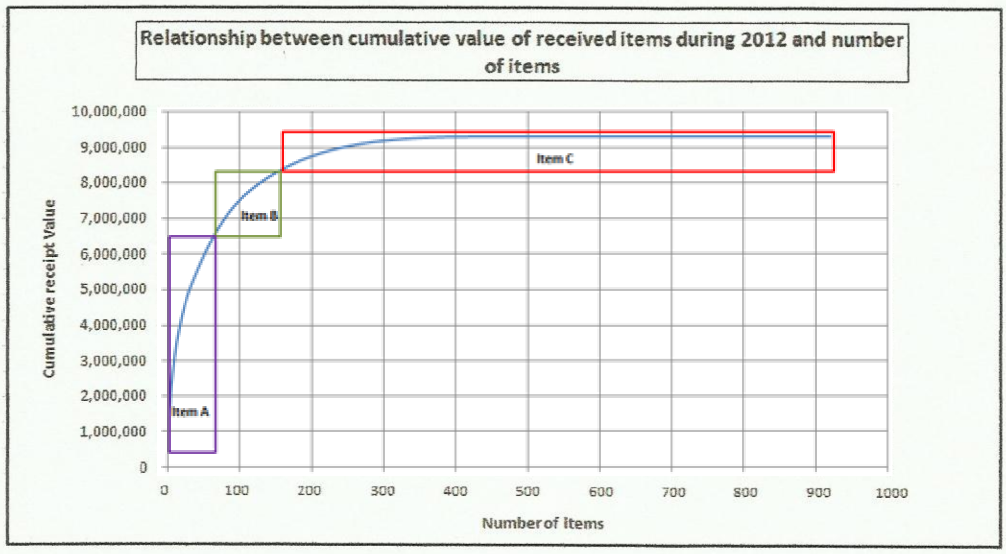
As a result Category "A" items were found to be consisting of 64 items, with a received value of 6,490,972 CZK, Category "B" items were found to be consisting of 93 items, with a received value of 1,860,154 CZK, and Category "C" items were found to be consisting of 763 items, with a received value of 938,434 CZK.

The third classification is based on sorting of spare parts items in descending order with respect to their frequency of receipt in 2012, and calculating the cumulative value of items, so as to enable plotting Pareto diagram. As a result Category "A" items were found to be consisting of 252 items, with a receipt frequency of 389, Category "B" items were found to be consisting of 111 items, with a receipt frequency of 111, and Category "C" items were found to be consisting of 557 units, with a receipt frequency of 55.

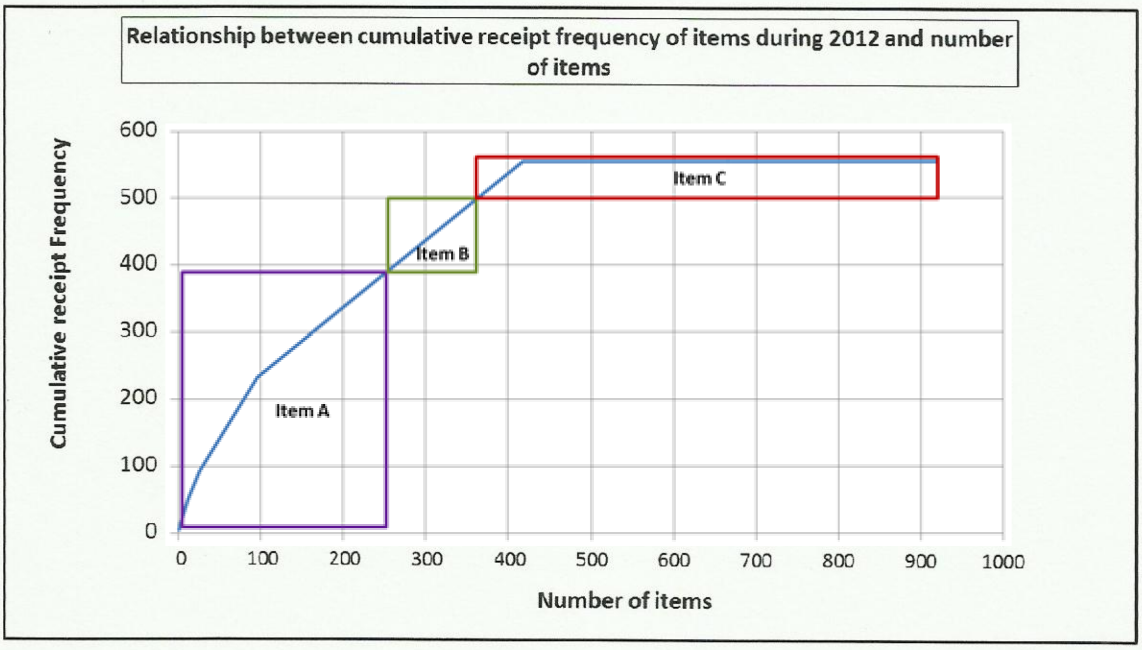
Figure 5-12 (a), (b) & (c) show Pareto diagrams obtained from all three classifications.



5-12 (a)



5-12 (b)



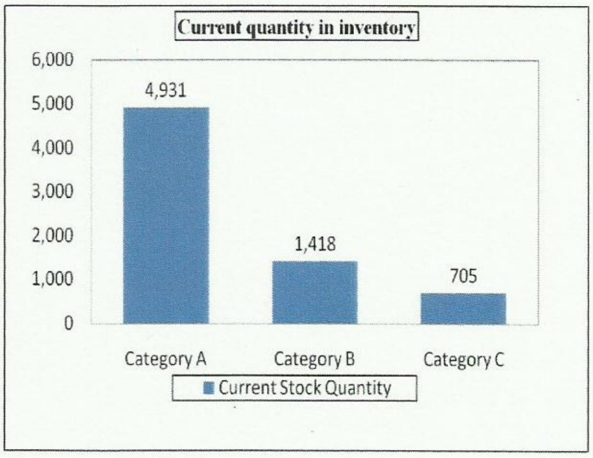
5-12 (c)

Figure 5-12 (a), (b), & (c): Pareto diagram based on received quantity, value, and frequency during 2012 [Source: Author]

5.11 COMPARISON BETWEEN DIFFERENT ABC CLASSIFICATION SYSTEMS

The current quantity of inventory could be divided three categories, according to items category "A", "B", and "C", throughout the years 2010 to 2012, with number of units equal to 4,931, 1,418 and 705 respectively, and inventory value of 10,373,956, 2,984,729, and 1,493,382 CZK respectively **as presented in Figure 5-13.**

The consumed quantity of inventory could be divided three categories, according to items category "A", "B", and "C", throughout the years 2010 to 2012, with number of units equal to 6,610, 1,904 and 952 respectively, and during the year 2012, number of units was found to be 2,590, 753, and 371 respectively.



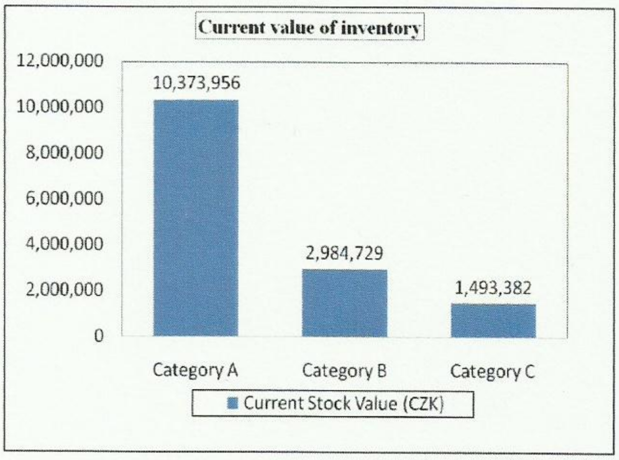
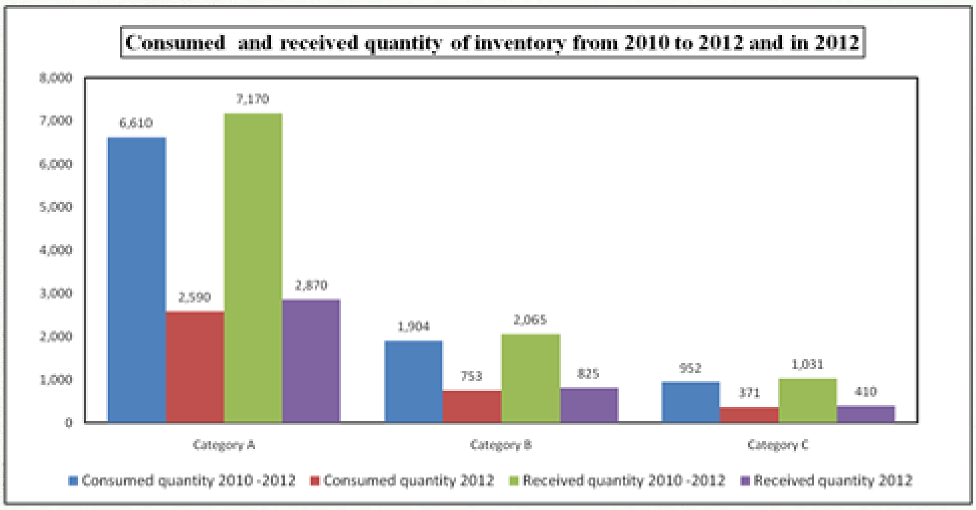


Figure 5-13: ABC classification comparison according to net current quantity and value [Source: Author]

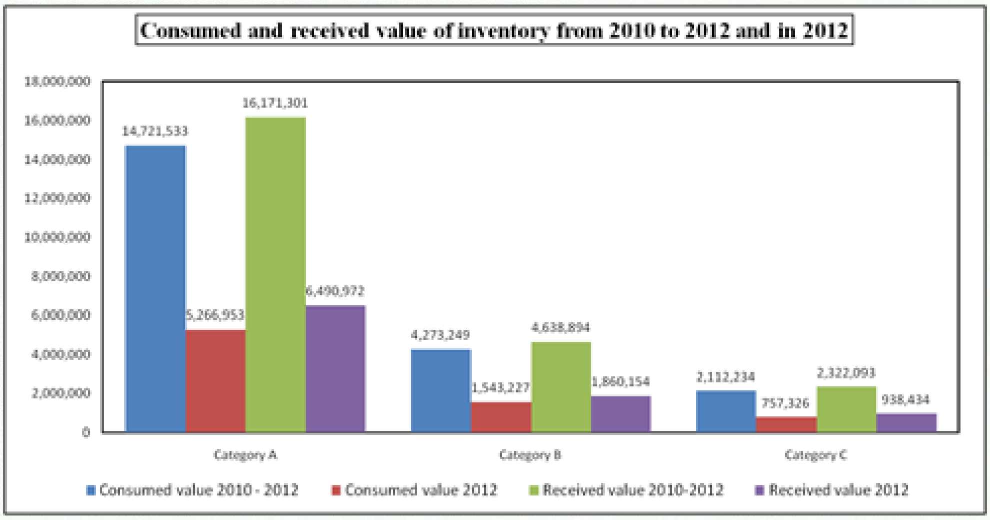
The receipt quantity of inventory could be divided three categories, according to items category "A","B", and "C", throughout the years 2010 to 2012, with number of units equal to 7,170, 2,065 and 1,031 respectively, and during the year 2012, number of units was found to be 2,870, 825, and 410 respectively **as shown in Figure 5-14 (a) in the next page.**

The consumed value of inventory could be divided into three categories, according to items category "A","B", and "C", throughout the years 2010 to 2012, with total consumed value equal to 14,721,533, 4,273,249, and 2,112,234 CZK respectively, and during the year 2012, total consumed value was found to be 5,266,953, 1,543,227, and 757,326 CZK respectively.
The receipt value of inventory could be divided three categories, according to items category "A","B", and "C", throughout the years 2010 to 2012, with total received value equal to 16,171,301, 4,638,894, and 2,322,093 CZK respectively, and during the year 2012, total received value was found to be 6,490, 972, 1,860,154, and 938,434 CZK respectively, **as shown in Figure 5-14 (b) in the next page.**

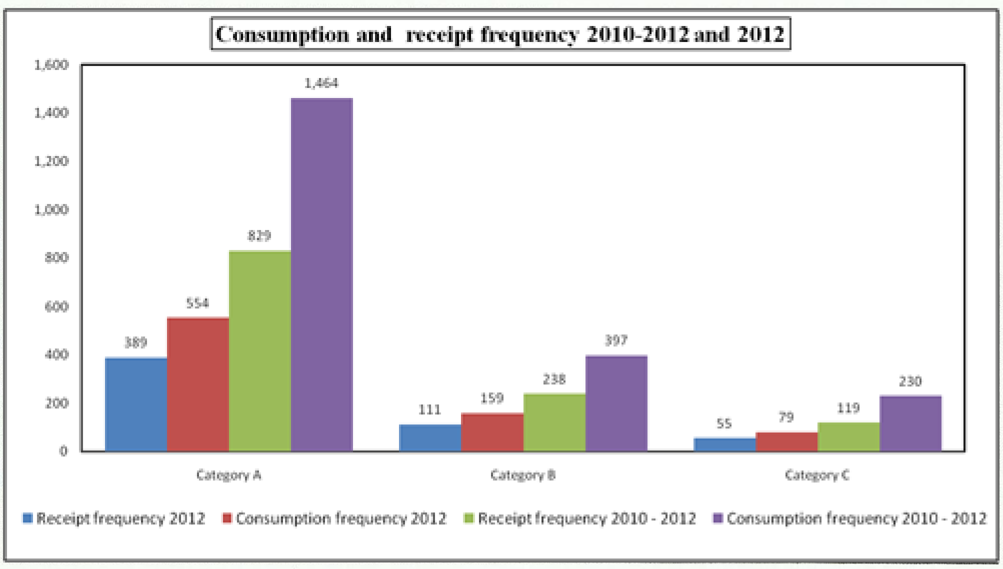
The frequency of inventory consumption could be divided into three categories, according to items category "A", "B", and "C", throughout the years 2010 to 2012, with consumption frequency equal to 1,464, 397 and 230 respectively, and during the year 2012, consumption frequency was found to be 554, 159, and 79 respectively.
The frequency of inventory receipt could be divided into three categories, according to items category "A","B", and "C", throughout the years 2010 to 2012, with receipt frequency equal to 829, 238 and 119 respectively, and during the year 2012, receipt frequency was found to be 389, 111, and 55 respectively, **as shown in Figure 5-14 (c) in the next page.**



5-14 (a)



5-14 (b)



5-14 (c)

Figure 5-14: (a), (b) & (c) ABC classification comparison between consumed and received quantities, values, and frequencies from 2010 to 2012 and during the year 2012 [Source: Author]

5.12 CALCULATION OF SAFETY STOCK

The data provided by VALEO Rakovník contains calculated quantities for each item considered as a safety stock, which is generated by their used Software "SAP®", which assigns automatically a quantity of safety stock, when the inventory falls below a predetermined maximum stock level.

New calculations are introduced in this study, aiming to recalculate the safety stock quantities for each item implementing Microsoft Excel® functions, according to the following formula (Piasecki et al., 2009).

Equation 5-1: Computation of safety stock using MS Excel

$$S.S_{Calculated} = STDEV(C1{:}C24) * NORMSINV(P) * SQRT(LT) \qquad \textbf{(17)}$$

Where: $S.S_{Calculated}$: Calculated safety stock.

STDEV(C1:C24) : Standard deviation of consumption demand of spare parts during 24 months from 2010 to 2011.

NORMSINV(P) : Inverse of standard normal cumulative distribution with probability of service level "P".

SQRT(LT) : Square root of lead time "LT".

Lead time demand is calculated by summation of forecasted consumption demand in 2012, which is calculated according to both weekly and monthly consumption demand history from 2010 to 2012, which was done in steps **as shown in Figure 5-15.**

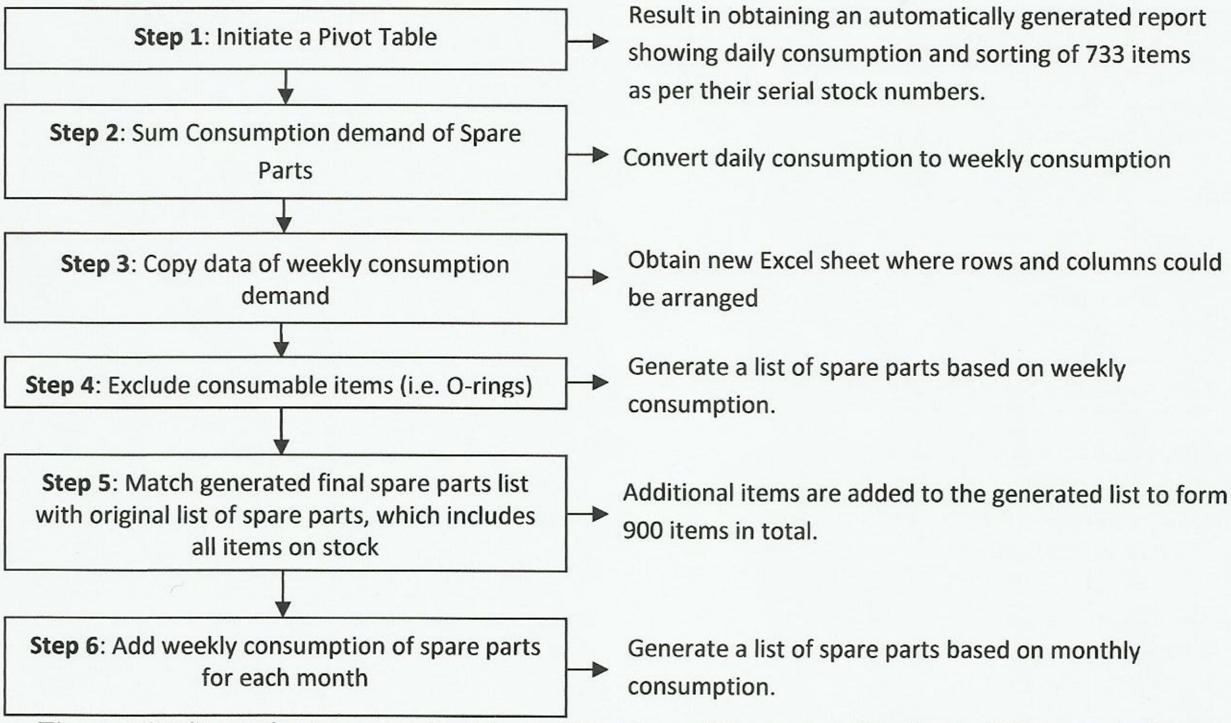


Figure 5-15: Steps of data conversion into weekly and monthly consumption demand [Source: Author]

The value of calculated safety stock could then be calculated by multiplying safety stock quantities by the unit price of each item, and then comparing it with the safety stock value obtained from existing safety stock quantities. An amount of reduction in safety stock values was produced, which indicates a good initial step forward.

5.13 CALCULATION OF REORDER QUANTITY

Lead time demand for examining a time series during the year 2012, is calculated by summing consumption demand forecast obtained from previous year 2011, based on selected lead time, when spare part requirement is determined, and being available in stock. Total numbers of 900 spare parts items were considered excluding 20 items, having neither consumption demand movement nor quantities in stock, as listed in **Table 5-2.**

List of excluded items from calculation of ROP & Safety Stock of items		
Those items do not have neither movement nor quantity in stock		
Original item Category Number	Category /Serial number	Item Description
Item Category: 6. Bearings		
342	LIS702015	THK SHS20 FN7L141
Items Category: 11. Electronic components & Cards		
521	LIS1304010	Li baterie 14250CNA, GME 542-016
532	LIS1401006	EBARA CNEB0027 (čerpadlo 3ME 40-160/4)
533	LIS1401007	Vodárna ISH CNIS0065 (ISH 50NHD16014LC2001)
Item Category: 12. Greenbox cooling, & pump accessories		
551	LIS1404008	Zpětná klapka 3/4" DN20 PN25
Item Category: 15. Heating moulds and machines		
701	LIS1705030	HTFR36251430 YUDO
702	LIS1705031	HTFR36250530 YUDO
704	LIS1705033	25x100mm 240V 820W YUDO HTFR36250830
Item Category: 16. Process automation, robot (FESTO)		
788	LIS1804023	Kyvny pohon DSR-25
Items Category 17: Water Hoses and Hydraulic fittings		
827	LIS1901010	T-kus M18x1,5 bm
828	LIS1901011	T-kus M18x1,5 sm
829	LIS1901012	Koleno 3/8" zm
830	LIS1901013	Koleno 3/8" zz
831	LIS1901014	Koleno M18x1,5 zz
832	LIS1901015	Záslepka 12/M18x1,5
833	LIS1901016	Matice M18x1,5
834	LIS1901017	Záslepka kužel 12/M18x1,5
835	LIS1901018	Záslepka 3/8"
836	LIS1901019	Spojka 3/8" - 1/2"
Items Category: 19. Conveyor system (ATYKO)		
875	LIS2101000	Frekv.měnič Optidrive ODE-2-12075-1KB12. Invertek CZ

Table 5-2: List of excluded spare part items

Forecasting methods in section 4.4 were implemented to calculate intermittent consumption demand forecast, in which a period of five months was used in computing simple and weighted moving average, while a smoothing factor of 0.1 was used in computing exponential smoothing, Croston and modified Croston's methods, in addition to Bootstrapping method, in which 20 samples were used with replacement equal to the number of months corresponding to lead time, creating a bootstrap scenario of demand over the lead time, that build a statistically robust picture of the lead time demand distribution, where most of values are zero, from the 36 values from 2010 to 2012. The Reorder quantity is calculated based on the following formula:

Equation 5-2: Computation of re-order quantity using MS Excel®

$$R = S.S_{Calculated} + L.T.D \quad \textbf{(18)}$$

Where: R : Reorder quantity.

$S.S_{Calculated}$: Calculated safety stock.

L.T.D : Lead time demand obtained from forecasting spare part consumption during lead time.

As per VALEO Rakovník practice, spare parts are ordered in lots from their suppliers. Accordingly, it was necessary to insert a new column, determining the quantity of so called "Fixed lot size", defined with regard to calculated re-order quantities, in the sense that if the re-order quantities fall below five pieces, the fixed lot size would be equal to one, and if not, fixed lot size would be equal to 5.

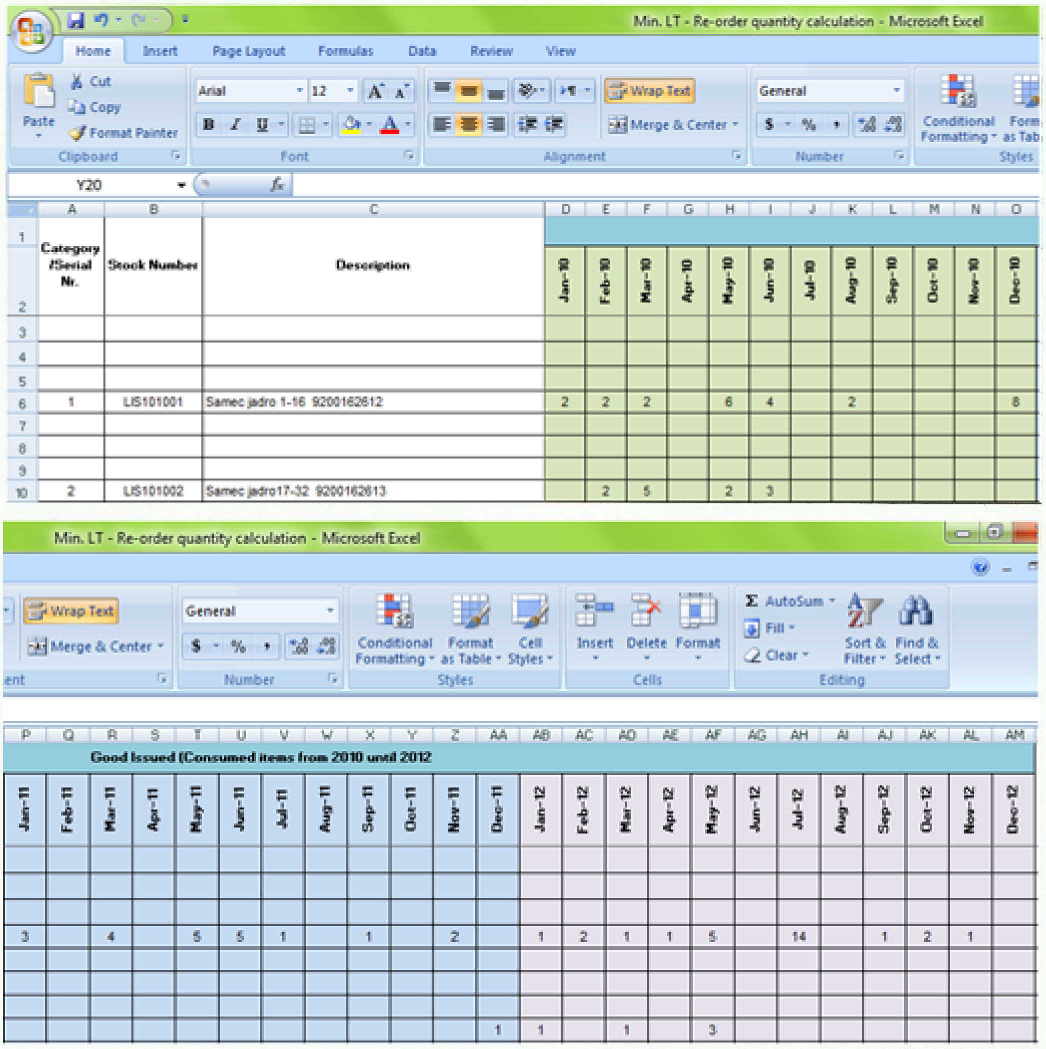


Figure 5-16: Sample of demand consumption applying Croston's forecasting method [Source: Author]

The maximum quantities on stock were calculated from the following formula:

Equation 5-3: Computation of maximum quantity in stock using MS Excel®

$$Q_{Max} = (R - 1) + Q_{Fixed} \qquad \textbf{(19)}$$

Where: Q_{Max} : Maximum quantity on stock

R : Re-order quantity

Q_{Fixed} : Fixed lot size

The average aggregate quantity on stock is calculated from the following formula:

Equation 5-4: Calculation of average aggregate quantity using MS Excel®

$$Q_{Avg} = (Q_{Max} - S.S_{Calculated})/2 + S.S_{Calculated} \qquad \textbf{(20)}$$

Where: Q_{Avg} : Average quantity on stock

The values of calculated safety stock quantities, and average inventory quantities could be calculated within the Excel® sheet calculations, by multiplying calculated quantities by the unit price for each item, and summing all values together. By subtracting the calculated safety stock value from the current value of safety stock, an amount reduction in safety stock could be examined. Similarly, by subtracting the sum of calculated average inventory value on 2012 from the sum of on-stock inventory value as on 2012, the amount reduction in average inventory value could be examined.

5.13.1 MINIMUM CONSUMPTION LEAD TIME DEMAND CONSIDERATION

Initial calculations considering the least possible lead time of one month for all of the items, with fixed service level of 99.9% to avoid stock-outs of items has been carried out.

Figure 5-17 shows calculation of consumption demand using one of applied forecasting methods, which is Croston's method, considering one month lead time.

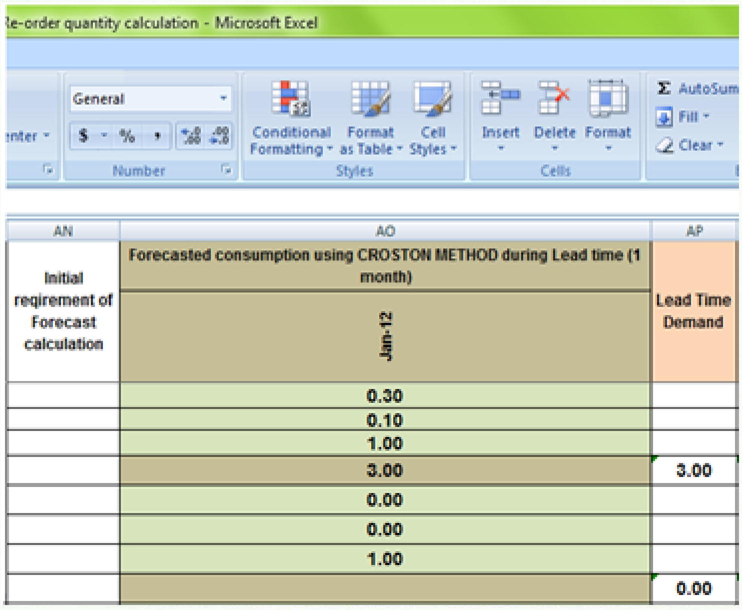
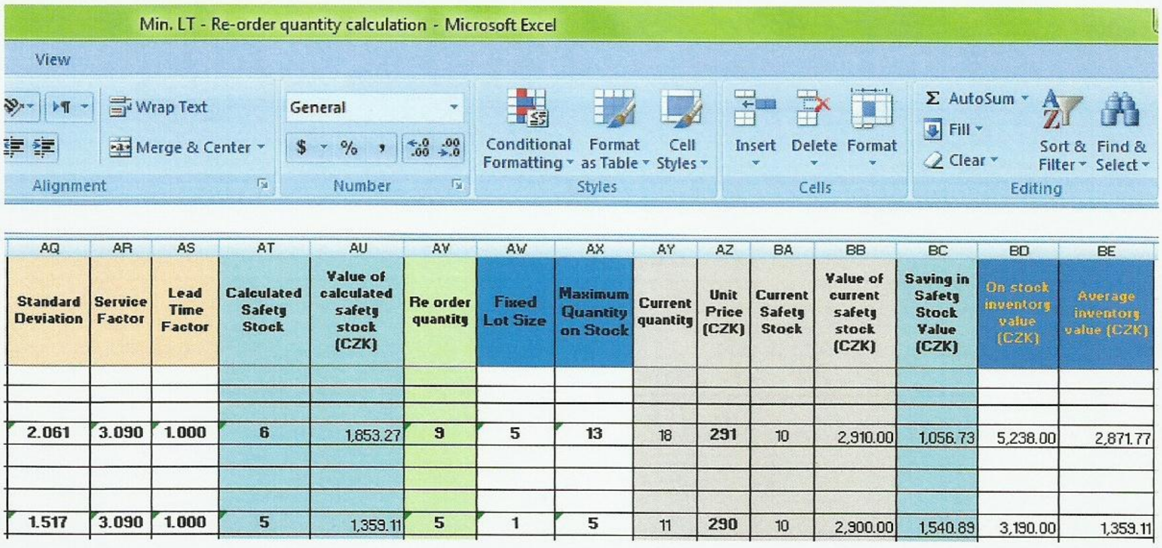


Figure 5-17: Croston's forecasting method of consumption demand [Source: Author]

The rest of formulas were used in calculating safety stock, re-order quantities, maximum quantity and average inventory value, **which is presented in Figure 5-18.**



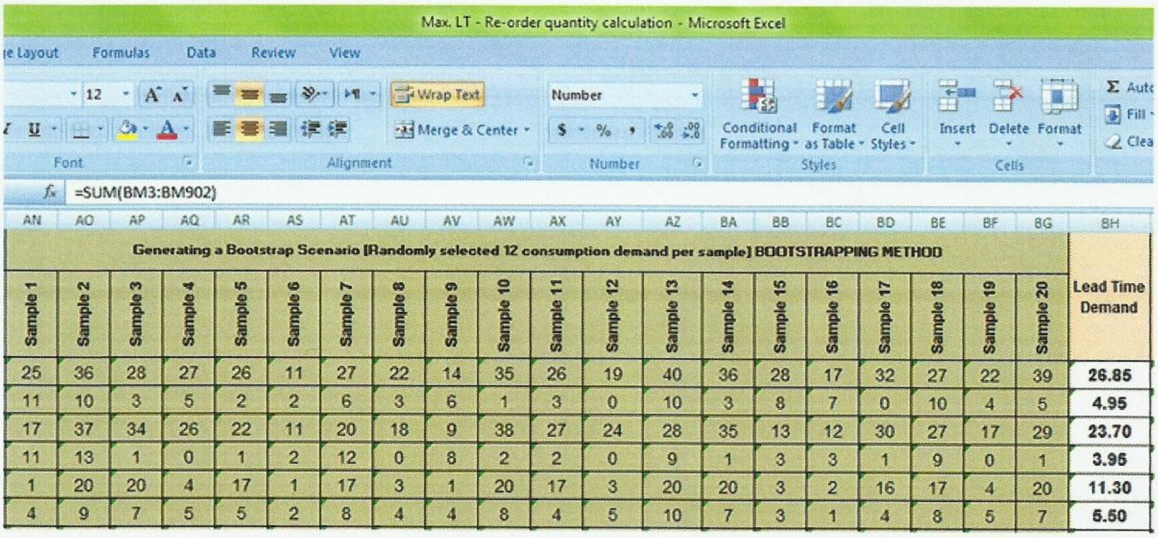
AQ Standard Deviation	AR Service Factor	AS Lead Time Factor	AT Calculated Safety Stock	AU Value of calculated safety stock (CZK)	AV Re order quantity	AW Fixed Lot Size	AX Maximum Quantity on Stock	AY Current quantity	AZ Unit Price (CZK)	BA Current Safety Stock	BB Value of current safety stock (CZK)	BC Saving in Safety Stock Value (CZK)	BD On stock inventory value (CZK)	BE Average inventory value (CZK)
2.061	3.090	1.000	6	1,853.27	9	5	13	18	291	10	2,910.00	1,056.73	5,238.00	2,871.77
1.517	3.090	1.000	5	1,359.11	5	1	5	11	290	10	2,900.00	1,540.89	3,190.00	1,359.11

Figure 5-18: Calculation of inventory value based on minimum lead time of one month [Source: Author]

As a result, relatively low sum of safety stock values, computed as 2,917,941 CZK, while sum of average inventory values has considerably decreased. It is noted that forecasting of consumption demand utilizing Bootstrapping method has resulted in achieving minimum value of average inventory of 3,390,804 CZK.

5.13.2 MAXIMUM CONSUMPTION LEAD TIME DEMAND CONSIDERATION

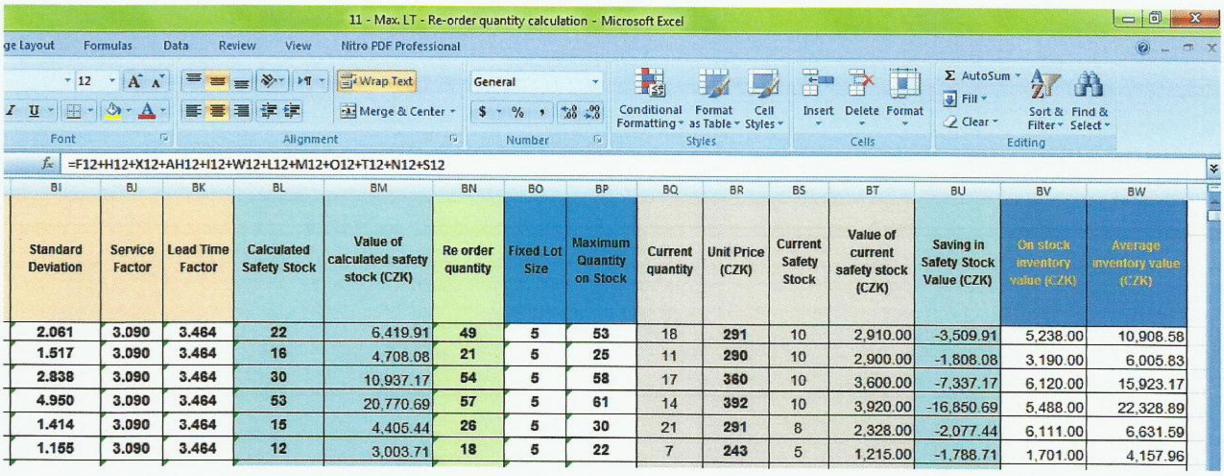
Maximum lead time of 12 months is considered as a second trial involving change of one of influencing parameter which is the lead time in Excel® sheet calculations for all of the items, where a fixed service level of 99.9% to avoid stock-outs of quantities in stock remained the same. **Figure 5-19 shows** calculation of consumption demand using one of applied forecasting methods, which is Bootstrapping method, considering twelve months lead time.



Generating a Bootstrap Scenario [Randomly selected 12 consumption demand per sample] BOOTSTRAPPING METHOD																				
Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	Sample 9	Sample 10	Sample 11	Sample 12	Sample 13	Sample 14	Sample 15	Sample 16	Sample 17	Sample 18	Sample 19	Sample 20	Lead Time Demand
25	36	28	27	26	11	27	22	14	35	26	19	40	36	28	17	32	27	22	39	26.85
11	10	3	5	2	2	6	3	6	1	3	0	10	3	8	7	0	10	4	5	4.95
17	37	34	26	22	11	20	18	9	38	27	24	28	35	13	12	30	27	17	29	23.70
11	13	1	0	1	2	12	0	8	2	2	0	9	1	3	3	1	9	0	1	3.95
1	20	20	4	17	1	17	3	1	20	17	3	20	20	3	2	16	17	4	20	11.30
4	9	7	5	5	2	8	4	4	8	4	5	10	7	3	1	4	8	5	7	5.50

Figure 5-19: Bootstrapping forecasting method of consumption demand [Source: Author]

The rest of formulas were used in calculating safety stock, re-order quantities, maximum quantity and average inventory value, **which is presented in Figure 5-20.**



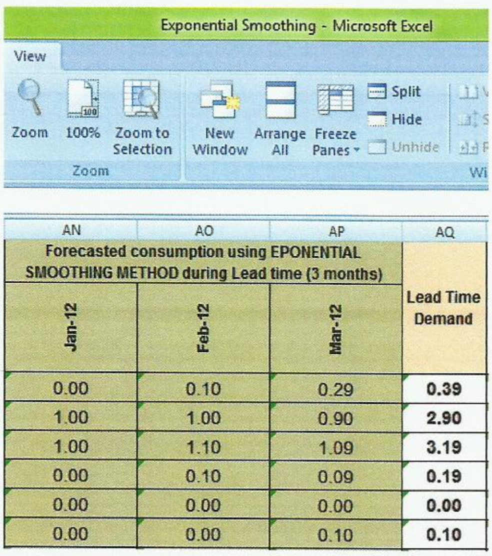
Standard Deviation	Service Factor	Lead Time Factor	Calculated Safety Stock	Value of calculated safety stock (CZK)	Re order quantity	Fixed Lot Size	Maximum Quantity on Stock	Current quantity	Unit Price (CZK)	Current Safety Stock	Value of current safety stock (CZK)	Saving in Safety Stock Value (CZK)	On stock inventory value (CZK)	Average inventory value (CZK)
2.061	3.090	3.464	22	6,419.91	49	5	53	18	291	10	2,910.00	-3,509.91	5,238.00	10,908.58
1.517	3.090	3.464	16	4,708.08	21	5	25	11	290	10	2,900.00	-1,808.08	3,190.00	6,005.83
2.838	3.090	3.464	30	10,937.17	54	5	58	17	360	10	3,600.00	-7,337.17	6,120.00	15,923.17
4.950	3.090	3.464	53	20,770.69	57	5	61	14	392	10	3,920.00	-16,850.69	5,488.00	22,328.89
1.414	3.090	3.464	15	4,405.44	26	5	30	21	291	8	2,328.00	-2,077.44	6,111.00	6,631.59
1.155	3.090	3.464	12	3,003.71	18	5	22	7	243	5	1,215.00	-1,788.71	1,701.00	4,157.96

Figure 5-20: Calculation of inventory value based on maximum lead time of 12 months [Source: Author]

It was observed that high safety stock value of 9,546,520 CZK was obtained, while a remarkable increase in re-order quantities occurred, leading to reaching higher values of inventories. It is noted that forecasting of consumption demand utilizing weighted n-period moving average method has resulted in achieving minimum value of average inventory of 14,883,854 CZK.

5.14 SELECTION OF BEST FORECASTING METHOD

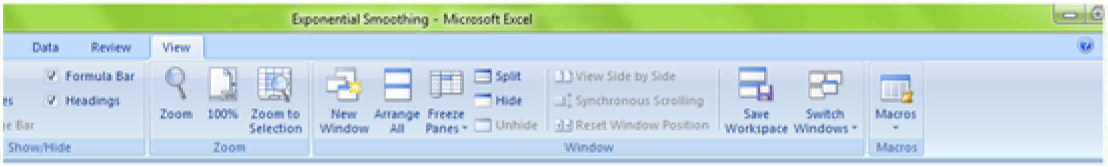
Different lead times are considered, while repeat calculations of safety stock and re-order quantities, at a service level of 99.9%. This is done by creating an individual Microsoft Excel® spreadsheet for each of the six forecasting methods implemented, each includes five spreadsheets for one, two, three, five, and seven months lead time. A sample calculation considering three months lead time is presented in **Figure 5-21.**



Forecasted consumption using EPONENTIAL SMOOTHING METHOD during Lead time (3 months)			
Jan-12	Feb-12	Mar-12	Lead Time Demand
0.00	0.10	0.29	0.39
1.00	1.00	0.90	2.90
1.00	1.10	1.09	3.19
0.00	0.10	0.09	0.19
0.00	0.00	0.00	0.00
0.00	0.00	0.10	0.10

Figure 5-21: Exponential Smoothing forecasting method of consumption demand [Source: Author]

Figure 5-22 shows a sample MS Excel® spreadsheet, which calculates safety stock quantities; re-order quantities, maximum quantity on stock, based on implementing exponential smoothing demand forecasting method, considering three months lead time.



AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD
Standard Deviation	Service Factor	Lead Time Factor	Calculated Safety Stock	Value of calculated safety stock (CZK)	Re order quantity	Fixed Lot Size	Maximum Quantity on Stock	Current quantity	Unit Price (CZK)	Current Safety Stock	Value of current safety stock (CZK)	Saving in Safety Stock Value (CZK)
2.061	3.090	1.732	11	3,209.95	11	5	15	18	291	10	2,910.00	-299.95
1.517	3.090	1.732	8	2,354.04	11	5	15	11	290	10	2,900.00	545.96
2.838	3.090	1.732	15	5,468.58	18	5	22	17	360	10	3,600.00	-1,868.58
4.950	3.090	1.732	26	10,385.34	27	5	31	14	392	10	3,920.00	-6,465.34
1.414	3.090	1.732	8	2,202.72	8	5	12	21	291	8	2,328.00	125.28
1.155	3.090	1.732	6	1,501.85	6	5	10	7	243	5	1,215.00	-286.85

5-22: Calculations based on exponential smoothing forecasting method [Source: Author]

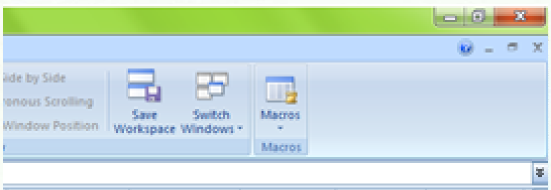
The summation of average inventory values is compared from obtained values using six different demand forecasting methods, which are simple moving average, weighted moving average, exponential smoothing, Croston's, modified Croston's, and Bootstrapping forecasting methods, as a result of using different lead times.

The error in forecast in each of the Microsoft Excel® spreadsheets is calculated using five measures, presented in section 4.5, which is done by inserting three columns in all spreadsheets, **as shown in Figure 5-23**. which represents:

$(A_t - F_t)$: Difference between actual and forecasted consumption demand.

$(A_t+F_t)/2$: Half the sum of actual and forecasted consumption demand.

$(A_t - F_t)^2$: Difference between actual, and forecasted consumption demand squared.



BE	BF	BG	BH	BI
Difference between Actual and forecasted consumption demand $(A_t - F_t)$	Half the sum of Actual and forecasted consumption demand $(A_t+F_t)/2$	$(A_t - F_t)$^2	On stock Inventory value (CZK)	Average Inventory value (CZK)
3.61	2.195	13.0321	5,238.00	3,848.70
0.9	2.45	0.81	3,190.00	3,354.54
0.19	3.095	0.0361	6,120.00	6,762.78
0.81	0.595	0.6561	5,488.00	11,206.58
1	0.5	1	6,111.00	2,784.72
1.9	1.05	3.61	1,701.00	2,000.00

Figure 5-23: Forecast error calculation and calculation of average inventory value based on 3 months lead time [Source: Author]

Measures of forecast error are calculated in each of 30 Microsoft Excel® spreadsheets, include Mean absolute deviation (MAD), Mean absolute Percentage error (MAPE), Symmetric mean absolute percentage error (S-MAPE), Adjusted Mean Percentage Error (A-MAPE), and Root Mean square deviation (RMSD), **which can be viewed in Figure 5-24.**

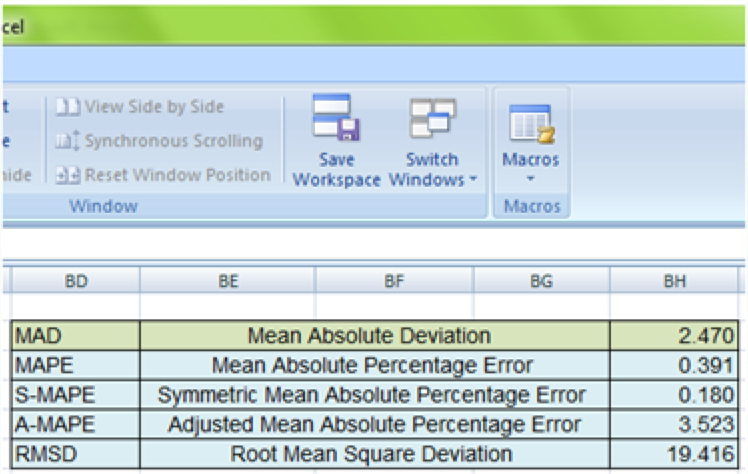


Figure 5-24: Calculation of forecast error [Source: Author]

The least values of forecast error could be identified using Croston's and modified Croston's, consumption demand forecasting methods, where they resulted in same amount of calculated safety stock value, and for the average inventory value, it was the same considering lead time of one and two months, and started to change considering three, five, and seven months, which was observed to be less in Croston's Method, at a value of 6,271,692 CZK and 10,589,327 CZK, for three and seven months lead time respectively.

However, selection of most appropriate demand forecasting method was based on comparing forecast error measures obtained using one, two, three, five, and seven months lead time of MAD, which were respectively 0.319, 0.501, 0.840, 1.399, and 1.827 for Croston's method, while 0.319, 0.501, 0.854, 1.400, and 1.859 for modified Croston's method, measures for MAPE were respectively 0.001, 0.124, 0.133, 0.139, and 0.130 for Croston's method, while 0.169, 0.124, 0.135, 0.139, and 0.132 for modified Croston's method, measures for S-MAPE were respectively 0.183, 0.144, 0.158, 0.135, and 0.124 for Croston's method, while 0.183, 0.144, 0.158, 0.134, and 0.125 for modified Croston's method, measures for A-MAPE were respectively 0.007, 1.120, 1.198, 1.247, and 1.171 for Croston's method, while 1.519, 1.120, 1.219, 1.247, and 1.919 for modified Croston's method, measures for RMSD were respectively 1.628, 2.593, 3.386, 5.162, and 5.667 for Croston's method, while 1.628, 2.593, 3.428, 5.184, and 5.763 for modified Croston's method.

Accordingly, Croston's demand forecasting method is considered as the best method with least error in forecast, **which can be observed in Table 5-3, 5-4, and 5-5.**

	Table shows comparison between quantitative performance measures for different implemented forecasting methods at service level of 99.9 %									
Consumption Demand Forecasting Method	Simple Moving Average					Weighted Moving Average				
Leadtime (Months)	1	2	3	5	7	1	2	3	5	7
Calculated safety stock value (CZK)	2,930,978	4,145,029	5,076,602	6,553,866	7,754,638	2,957,825	4,182,996	5,123,103	6,613,897	7,825,669
Average Inventory value (CZK)	3,715,387	5,308,201	6,566,286	9,214,755	11,735,903	4,749,952	7,383,623	9,584,435	13,676,006	17,251,269
Mean Absolute Deviation [MAD]	0.458	0.846	1.070	1.507	1.537	0.898	1.802	2.700	4.706	5.522
Mean Absolute Percentage Error [MAPE]	0.242	0.210	0.085	0.149	0.109	0.475	0.447	0.428	0.466	0.393
Symmetric Mean Absolute Percentage Error [S-MAPE]	0.177	0.162	0.134	0.115	0.090	0.188	0.181	0.169	0.161	0.148
Adjusted Mean Absolute Percentage Error [A-MAPE]	2.179	1.889	0.765	1.343	0.985	4.274	4.025	3.851	4.193	3.539
Root Mean Square Deviation [RMSD]	2.317	4.747	5.569	9.051	9.313	5.280	10.352	15.596	30.662	33.167

Table 5-3: Forecast accuracy comparison for simple and weighted moving average methods

	Table shows comparison between quantitative performance measures for different implemented forecasting methods at service level of 99.9 %									
Consumption Demand Forecasting Method	Expeonential Smoothing					Croston's				
Leadtime (Months)	1	2	3	5	7	1	2	3	5	7
Calculated safety stock value (CZK)	2,917,941	4,126,592	5,054,023	6,524,715	7,720,147	2,957,825	4,182,996	5,123,103	6,613,897	7,825,669
Average Inventory value (CZK)	3,740,454	5,620,974	7,161,242	9,545,940	12,347,180	3,474,079	5,160,989	6,271,692	8,506,516	10,589,372
Mean Absolute Deviation [MAD]	0.919	1.794	2.470	3.799	4.887	0.319	0.501	0.840	1.399	1.827
Mean Absolute Percentage Error [MAPE]	0.486	0.445	0.391	0.376	0.348	0.001	0.124	0.133	0.139	0.130
Symmetric Mean Absolute Percentage Error [S-MAPE]	0.194	0.192	0.180	0.177	0.171	0.183	0.144	0.158	0.135	0.124
Adjusted Mean Absolute Percentage Error [A-MAPE]	4.376	4.006	3.523	3.385	3.133	0.007	1.120	1.198	1.247	1.171
Root Mean Square Deviation [RMSD]	7.142	14.082	19.416	30.105	38.670	1.628	2.593	3.386	5.162	5.667

Table 5-4: Forecast accuracy comparison for Exponential Smoothing and Croston's methods

	Table shows comparison between quantitative performance measures for different implemented forecasting methods at service level of 99.9 %									
Consumption Demand Forecasting Method	Modified Croston's					Bootstrapping				
Leadtime (Months)	1	2	3	5	7	1	2	3	5	7
Calculated safety stock value (CZK)	2,957,825	4,182,996	5,123,103	6,613,897	7,825,669	2,755,843	3,897,350	4,773,260	6,162,252	7,291,275
Average Inventory value (CZK)	3,474,079	5,160,989	6,273,321	8,501,550	10,594,033	3,390,804	5,032,442	6,728,804	9,315,344	11,887,602
Mean Absolute Deviation [MAD]	0.319	0.501	0.854	1.400	1.859	0.268	0.557	0.931	1.332	1.568
Mean Absolute Percentage Error [MAPE]	0.169	0.124	0.135	0.139	0.132	0.142	0.138	0.148	0.132	0.112
Symmetric Mean Absolute Percentage Error [S-MAPE]	0.183	0.144	0.158	0.134	0.125	0.141	0.137	0.131	0.114	0.101
Adjusted Mean Absolute Percentage Error [A-MAPE]	1.519	1.120	1.219	1.247	1.191	1.274	1.244	1.328	1.187	1.005
Root Mean Square Deviation [RMSD]	1.628	2.593	3.428	5.184	5.763	1.022	2.342	3.350	5.026	6.498

Table 5-5: Forecast accuracy comparison for Modified Croston's and Bootstrapping methods

6 REPORT OF FINDINGS AND PROPOSED SOLUTION

The outcome of categorizing the spare parts inventory using ABC classification system, based on prioritizing of items according to different criteria, as described previously in section 5.6, 5.7, 5.8, 5.9, and 5.10 **is presented in Table 6-1.**

Net current quantity and value		
	Current Stock Quantity	Current Stock Value (CZK)
Category A	4,931	10,373,956
Category B	1,418	2,984,729
Category C	705	1,493,382

(a)

Consumed and received quantity, value, & frequency from 2010 to 2012						
	Consumed Quantity	Received Quantity	Consumed Value (CZK)	Received Value (CZK)	Consumption Frequency	Receipt Frequency
Category A	6,610	7,170	14,721,533	16,171,301	1,464	829
Category B	1,904	2,065	4,273,249	4,638,894	397	238
Category C	952	1,031	2,112,234	2,322,093	230	119

(b)

Consumed and received quantity, value, & frequency during 2012						
	Consumed Quantity	Received Quantity	Consumed Value (CZK)	Received Value (CZK)	Consumption Frequency	Receipt Frequency
Category A	2,590	2,870	5,266,953	6,490,972	554	389
Category B	753	825	1,543,227	1,860,154	159	111
Category C	371	410	757,326	938,434	79	55

(c)

Table 6-1: ABC Classification system according to (a) Net current quantity and value , (b) Consumed and received quantities, values, and frequencies from 2010 to 2012 (c) Consumed and received quantities, values, and frequencies during 2012

Calculation of lead time demand of spare parts, utilizing different forecasting methods has resulted in obtaining different sums of average inventory values. At minimum lead times of one month described in section 5.13.1, sums of inventory values were below 5,000,000 CZK, whereas at maximum lead time of 12 months described in section 5.13.2, sums of average inventory values were higher than 14,000,000 CZK, while current value of inventory is 14,891,227 CZK, **which can be observed in Figure 6-1, and Table 6-2 in the next page.**

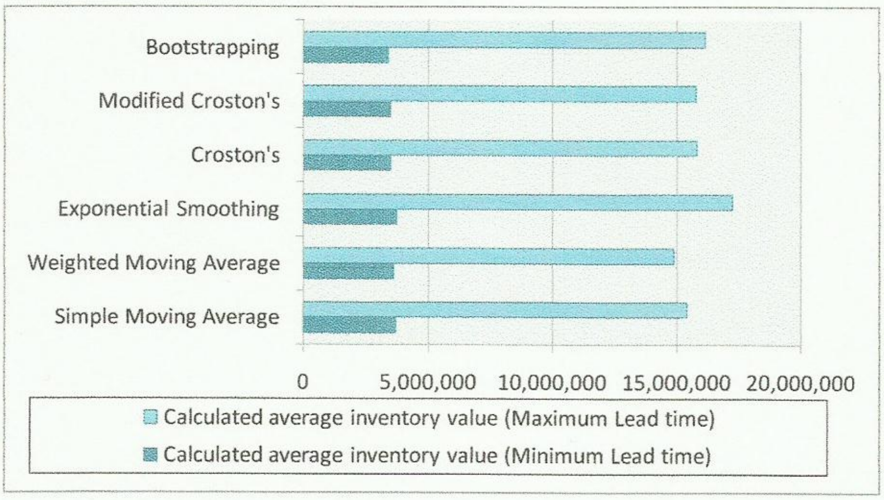


Figure 6-1: Calculated sum of average inventory value [Source: Author]

Lead time demand Forecasting method	Sum of Average value of inventory (CZK)	
	Minimum Lead time (one month)	Maimum Lead time (12 months)
Simple Moving Average	3,715,387	15,425,878
Weighted Moving Average	3,599,461	14,883,854
Exponential Smoothing	3,740,454	17,251,315
Croston's	3,474,079	15,809,825
Modified Croston's	3,474,079	15,777,565
Bootstrapping	3,390,804	16,155,638

Table 6-2: Obtained sums of average inventory value

The same calculations were repeated considering different lead times starting from one, two, three, five, and seven months, so as to select the most appropriate spare parts consumption demand forecasting method, based on lowest forecasting error obtained.

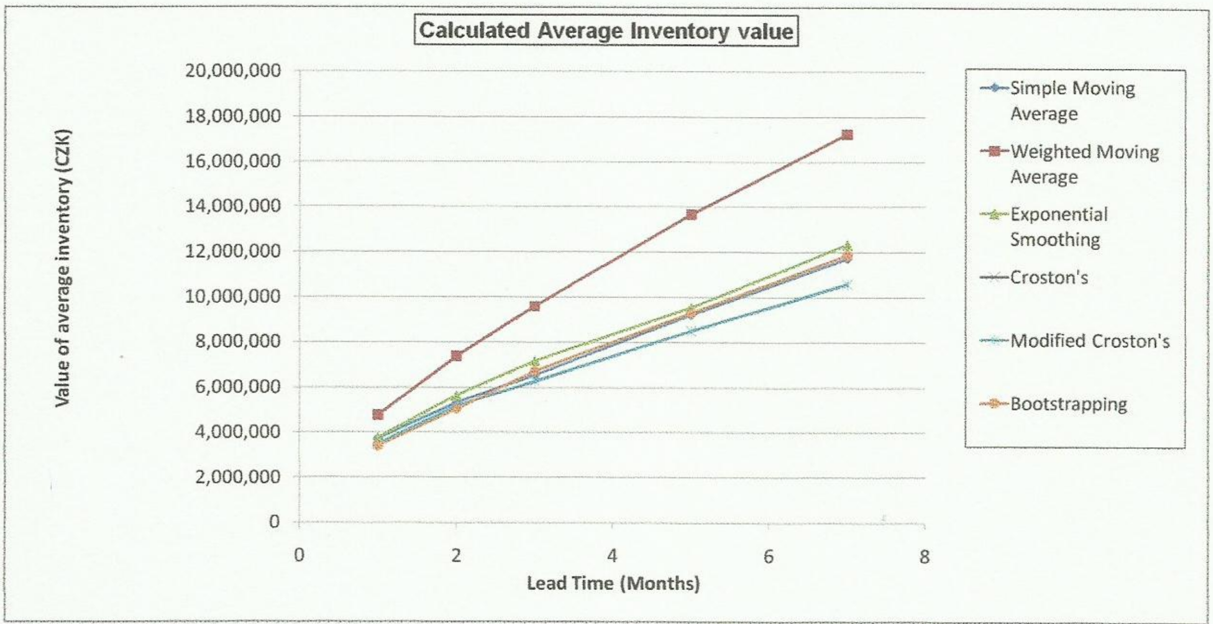


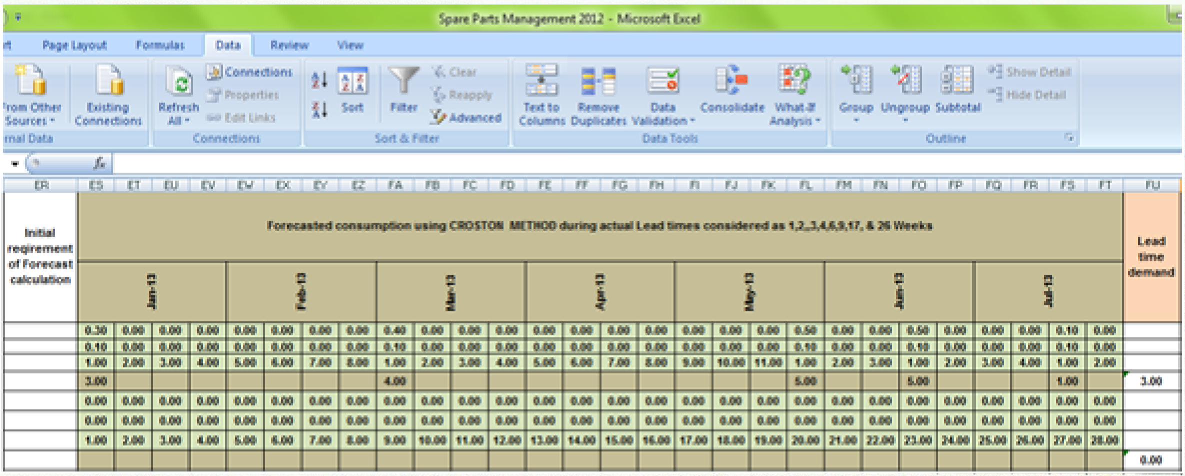
Figure 6-2: Calculated Average inventory value using different forecasting methods [Source: Author]

6.1 IMPLEMENTATION OF CROSTON'S FORECASTING METHOD

The most appropriate method for forecasting consumption demand of spare parts was found to be Croston's method, as presented in section 5.14. A Microsoft Excel® spreadsheet was created aiming to implement the calculations of inventory levels at VALEO Rakovník. This was done by considering the actual lead times for each of the items, that was inserted in SAP® software, which are 5, 7, 10, 14, 15, 20, 25,30, 40, 60, 120, and 180 days.

The first calculation is done aiming to forecast weekly demand of spare parts in the year 2012 based on weekly consumption demand from 2010 to 2012, considering lead times in weeks, which are 1, 2, 3, 4, 6, 9, 17, 26 weeks **as shown in Figure 6-3 in the next page.**

The second calculation is done based on approximated values of lead times aiming to forecast monthly demand of spare parts.

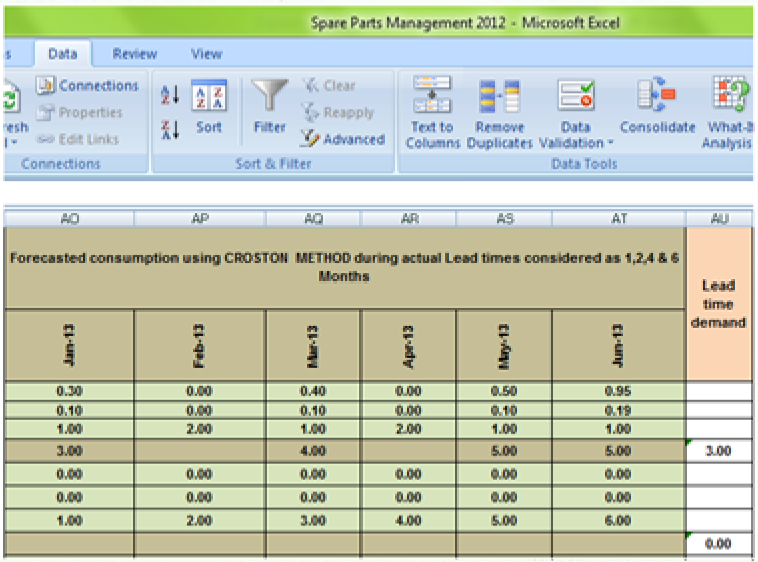


ER	ES	ET	EU	EV	EW	EX	EY	EZ	FA	FB	FC	FD	FE	FF	FG	FH
Initial reqirement of Forecast calculation	Forecasted consumption using CROSTON METHOD during actual Lead times considered as 1,2,,3,4,6,9,17, & 26 Weeks															
	Jan-13				Feb-13				Mar-13				Apr-13			
	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00
	3.00								4.00							
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00

ER	FI	FJ	FK	FL	FM	FN	FO	FP	FQ	FR	FS	FT	FU
Initial reqirement of Forecast calculation													Lead time demand
	May-13				Jun-13				Jul-13				
	0.00	0.00	0.00	0.50	0.00	0.00	0.50	0.00	0.00	0.00	0.10	0.00	
	0.00	0.00	0.00	0.10	0.00	0.00	0.10	0.00	0.00	0.00	0.10	0.00	
	9.00	10.00	11.00	1.00	2.00	3.00	1.00	2.00	3.00	4.00	1.00	2.00	
				5.00			5.00				1.00		3.00
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	17.00	18.00	19.00	20.00	21.00	22.00	23.00	24.00	25.00	26.00	27.00	28.00	
													0.00

Figure 6-3: Forecasting consumption demand of 2012 based on weekly consumption demand from 2010 to 2012 [Source: Author]

Lead times ranging from 5 to 30 days, holds for the majority of items kept on stock, were approximated to one month in the calculations. Similarly lead times ranging from 40 to 60 days, were approximated to two months in the calculations, 120 days lead time was considered as 4 months lead time , and finally 180 days lead time was considered as 6 months lead time **as shown in Figure 6-4.**



AO	AP	AQ	AR	AS	AT	AU
Forecasted consumption using CROSTON METHOD during actual Lead times considered as 1,2,4 & 6 Months						Lead time demand
Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13	
0.30	0.00	0.40	0.00	0.50	0.95	
0.10	0.00	0.10	0.00	0.10	0.19	
1.00	2.00	1.00	2.00	1.00	1.00	
3.00		4.00		5.00	5.00	3.00
0.00	0.00	0.00	0.00	0.00	0.00	
0.00	0.00	0.00	0.00	0.00	0.00	
1.00	2.00	3.00	4.00	5.00	6.00	
						0.00

Figure 6-4: Forecasting consumption demand of 2012 based on monthly consumption demand from 2010 to 2012 [Source: Author]

The majority of items have one month lead time; safety stock was calculated for these items as zero quantities, due to intermittent demand of spare parts. Subsequent to discussions made with VALEO Rakovník, it was recommended to keep at least one item in each type of spare part on stock. Hence a column was inserted into the Microsoft Excel® sheet calculations, named "Calculated safety stock correction"; using IF function, when the calculated safety stock quantity is less than or equal to zero, then safety stock quantity is corrected to one, if not, the calculated quantity remains the same, accordingly re-order quantities were calculated, and values of average inventory, safety stock, and maximum inventory were calculated, **which can be observed in Figure 6-5.**

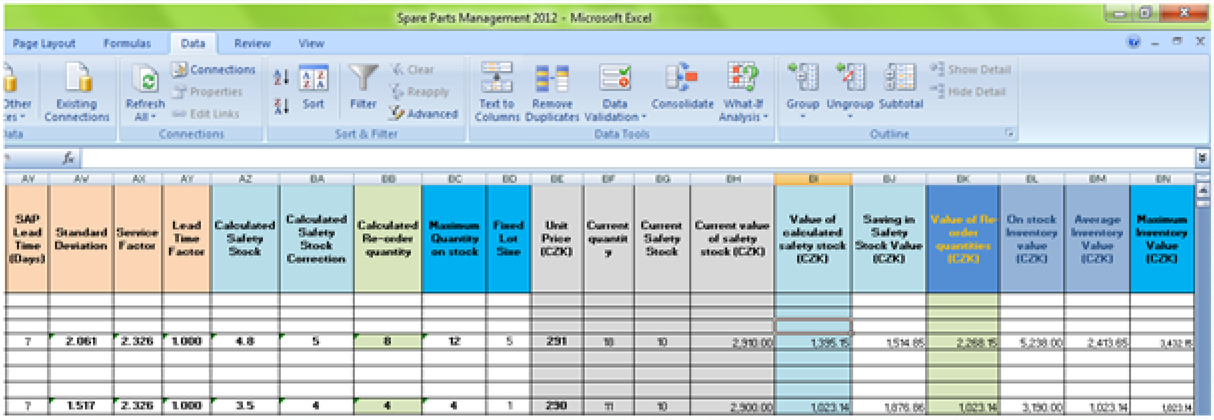


Figure 6-5: Calculating average inventory, safety stock, & maximum inventory values [Source: Author]

6.1.1 CONSUMPTION DEMAND FORECAST VERIFICATION

The Microsoft Excel® spreadsheet is developed to enable changing parameters of calculations and provide an automatically generated inventory management tool, by entering any value for service level, lead time, and fixed lot size.

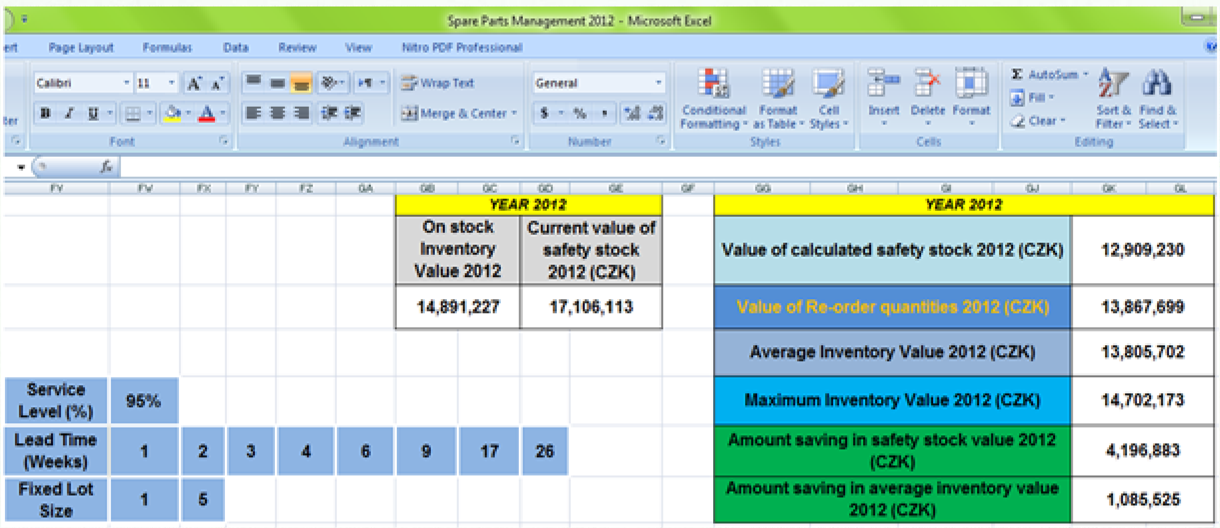


Figure 6-6: Automatically generated inventory management tool during 2012 based on forecasting weekly spare parts consumption [Source: Author]

This is done by assigning individual cells for service level, lead times, and fixed lot size, where values are entered, and are kept as reference cells connected with use of IF Function in a column named "Lead time demand", to enable changing lead times, and calculating lead time demands accordingly, SQRT Function in a column named "Lead time factor", NORMSINV Function in a column named "Service Factor", and IF Function in a column named "Fixed Lot Size", when calculated re-order quantity is less than five, then fixed lot size is equal to one, if not, then fixed lot size is equal to five, **as shown in Figure 6-6.**

Forecasting the demand for both weekly and monthly consumption of spare parts has been carried out during the year 2012, to verify the accuracy of calculations, in which re-order quantities are calculated based on corrected values of safety stock, with an ability to change parameters of service level, lead time, and fixed lot size.

At 95% Service level an amount saving of 1,085,525 CZK in average inventory value and 4,196,883 CZK in safety stock value during 2012 were obtained based on forecasting weekly consumption demand in 2012. At 99% Service level an amount saving of 1,226,695 CZK in average inventory value and 4,267,205 CZK in safety stock value during 2012 were obtained based on forecasting monthly consumption demand in 2012.

6.1.2 CONSUMPTION DEMAND FORECAST VALIDATION

Forecasting the demand for both weekly and monthly consumption of spare parts has been carried out during the year 2013, which is unknown in reality, as an approach to allow implementation of calculations at existing ordering system in VALEO Rakovník, in order to validate the calculations, and use the calculated re-order quantities based on corrected values of safety stock, with the ability to change parameters of service level, lead time, and fixed lot size as described in previous section 6.1.1, which is **presented in Figure 6-7.**

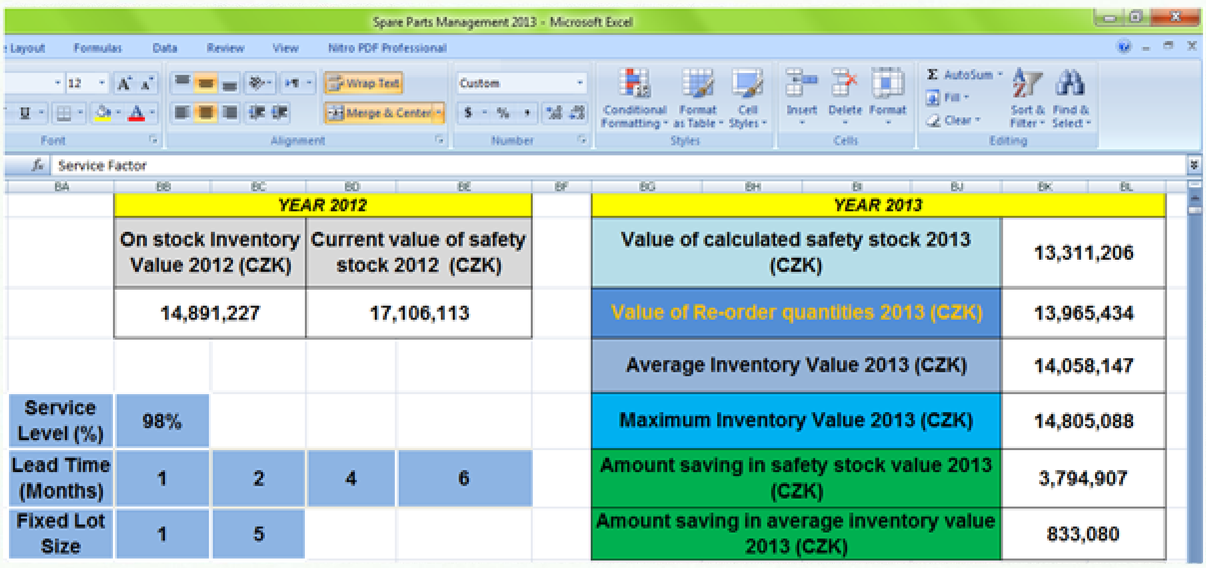


Figure 6-7: Automatically generated inventory management tool during 2013 based on forecasting monthly spare parts consumption [Source: Author]

At 91% Service level an amount saving of 871,694 CZK in average inventory value and 3,746,232 CZK in safety stock value during 2013 were obtained based on forecasting weekly consumption demand in 2013. At 98% Service level an amount saving of 833,080 CZK in average inventory value and 3,794,907 CZK in safety stock value during 2013 were obtained based on forecasting monthly consumption demand in 2013.

6.2 PROPOSED SOLUTION

An optimum level of inventory is achieved by utilization of a reliable inventory management system, which consists of changing different parameters which affect the inventory levels, consist of service level and lead times, consequently changes the value of safety stock and re-order quantities. Critical items which have high cost of replacement with new parts and down time, in case of their non-availability are identified resulting in placing optimum inventory policies. Hence, all spare parts components are categorized according to ABC classification system, where items are sorted in descending order based on the current on-stock value of each item, **as shown in Figure 6-8.**

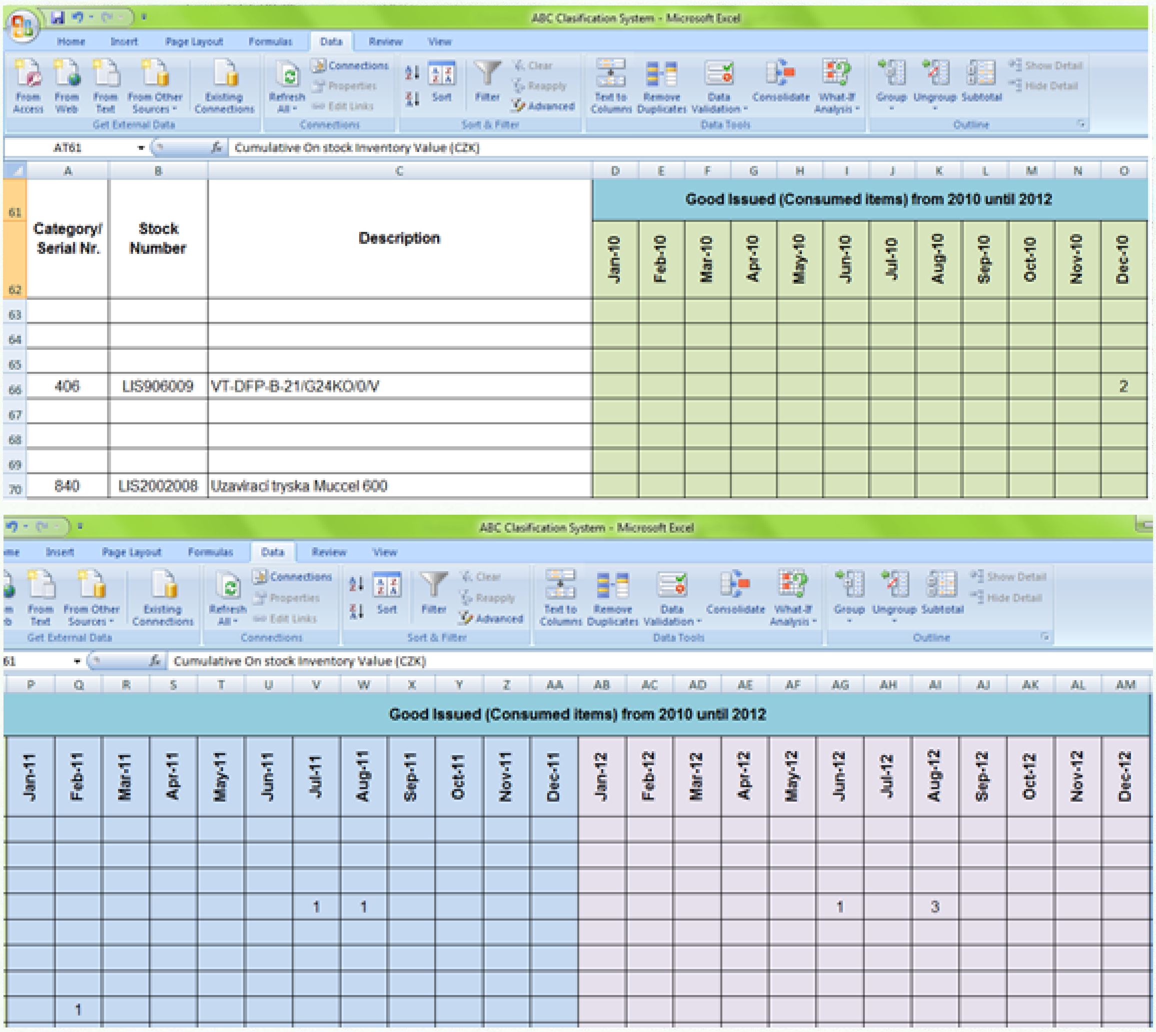


Figure 6-8: Sorting of items as part of ABC Analysis [Source: Author]

Groups of items are identified based on setting boundaries of 70%, 20%, and 10% of total inventory value for category "A", "B", and "C" items respectively, **which can be viewed in Figure 6-9 in the next page**, which shows Pareto diagram on primary axis, representing relation between cumulative On-stock inventory value and number of items. Besides, a relation between on-stock inventory value and number of items, on secondary axis.

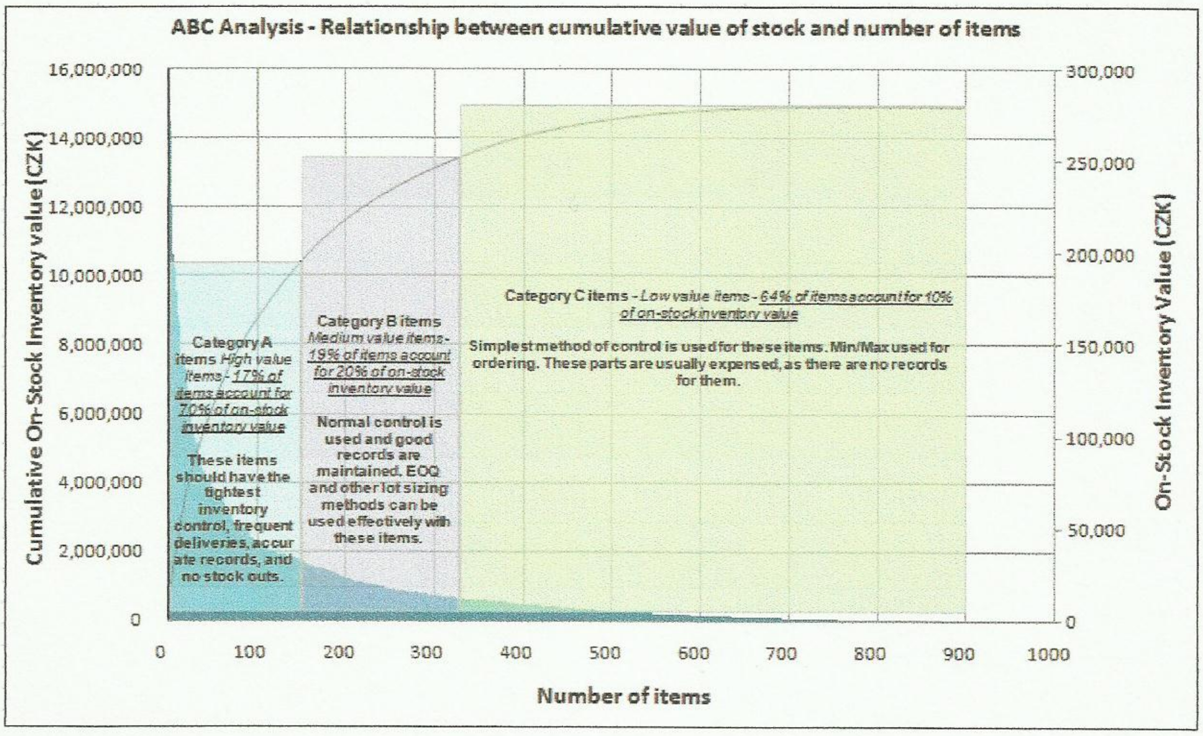


Figure 6-9: Pareto diagram according to value of each item on stock [Source: Author]

There are two calculations made after categorizing spare part items using ABC classification system, which are described as follows:

Firstly, the value of re-order quantity for each item is calculated, based on forecasting of spare parts monthly consumption demand in 2013, **as presented in Figure 6-10.**

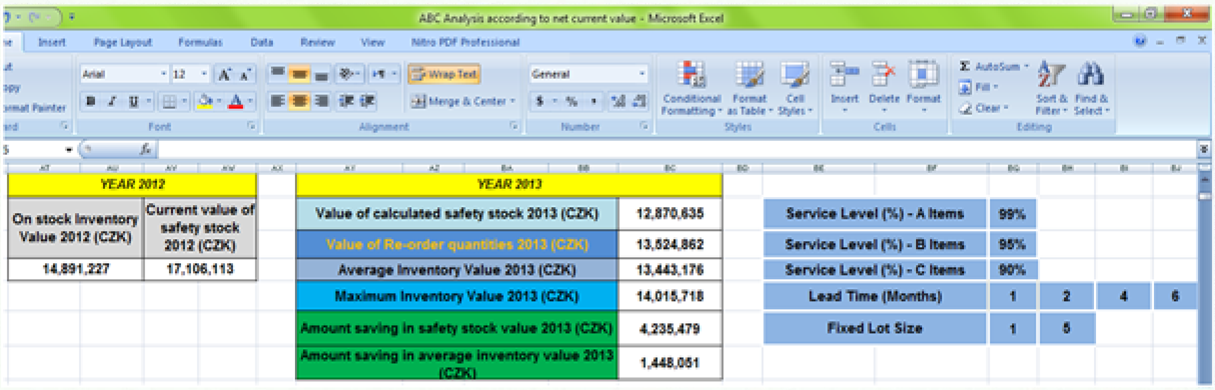


Figure 6-10: Calculated inventory values of 2013, obtained from ABC analysis, based on forecasting monthly consumption demand [Source: Author]

Accordingly, the values of average inventory, maximum inventory, re-order quantities, and safety stock for each of category "A","B", and "C" spare parts items is calculated, where at 99%, 95%, & 90% Service level accounts for items category "A","B", and "C" respectively. An amount saving is reached when comparing with same values during previous year 2012, which are 1,448,051 CZK in average inventory value, and 4,235,479 CZK in safety stock value based on forecasting monthly consumption demand in 2013.

Secondly, The value of re-order quantity for each item is then calculated, based on forecasting of spare parts weekly consumption demand in 2013, **which is presented in Figure 6-11.**

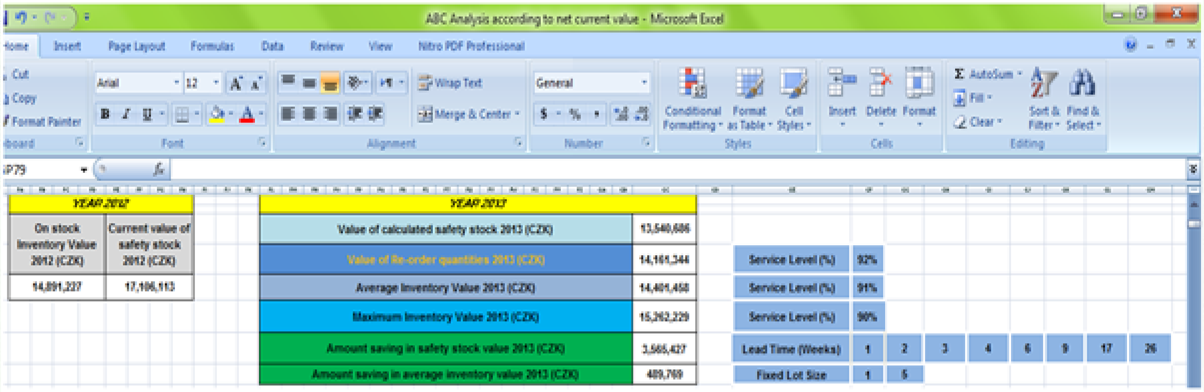


Figure 6-11: Calculated inventory values of 2013, obtained from ABC analysis, based on forecasting weekly consumption demand [Source: Author]

The values of average inventory, maximum inventory, re-order quantities, and safety stock for each of category "A", "B", and "C" spare parts items is calculated, where at 92%, 91%, & 90% Service level accounts for items category "A", "B", and "C" respectively, an amount saving is reached when comparing with same values during previous year 2012, which are of 489,769 CZK in average inventory value, and 3,565,427 CZK in safety stock based on forecasting weekly consumption demand in 2013.

6.3 ECONOMIC EVALUATION

As an outcome of implementing Microsoft Excel® spreadsheet calculations, the amount of saving in safety stock value and average inventory value could be identified, in which an ability to change the parameters of service level, and lead time exists, so as to find the optimum value of savings. **Figure 6-12 in the next page** shows a relationship between different levels of inventories and time.

The re-order level represents sum of forecasted lead time demand and calculated safety stock, both are calculated accurately using Microsoft Excel® spreadsheet calculations, in which at this level, a procurement order is placed, which requires a lead time until its fulfillment and therefore no stock outs occur for any of a spare part components, based on calculated re-order quantities.

The amount of saving in safety stock value is calculated by subtracting the sum of current safety stock value as on 2012, and the sum of calculated safety stock value as on 2013.

The amount of saving in average inventory value is calculated by subtracting the sum of current on stock inventory value as on 2012, and the calculated sum of average inventory value as on 2013.

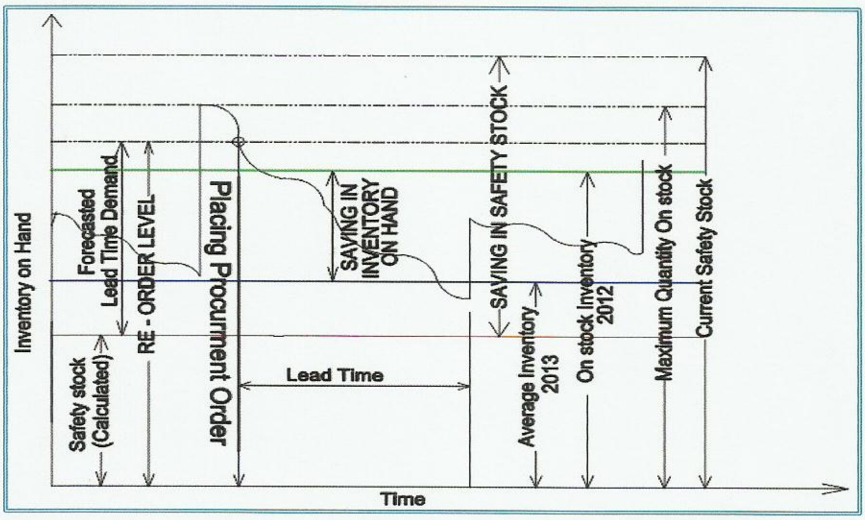


Figure 6-12: Relationship between inventory on hand and time [Source: Author]

6.3.1 RESULTS OBTAINED WHEN CHANGING SERVICE LEVEL AT SAME LEAD TIME

Different percentages of service levels are entered in the Microsoft Excel® calculations considering same lead time for each item, according to consideration of weekly and monthly spare parts consumption demand, resulting in obtaining different values of safety stock, average inventory, and maximum inventory, **which can be observed in Table 6-3 and 6-4.**

Case 1: Changing service level at the same lead times (Monthly Spare Parts Consumption)					
Type of Inventory on hand	Current value of 2012 [CZK]	Calculated Inventory values in 2013 [CZK] at different service levels [%]			
		96%	97%	98%	99%
Average Inventory	14,891,227	13,230,187	13,599,312	14,058,147	14,602,548
Maximum Inventory		13,734,374	14,221,391	14,805,088	15,367,507
Safety Stock	17,106,113	12,725,999	12,977,233	13,311,206	13,837,589

Amount Saving achieved in Case 1 (Monthly Spare parts Consumption)				
Service Level [%]	96%	97%	98%	99%
Amount Saving in Safety Stock [CZK]	4,380,115	4,128,880	3,794,907	3,268,525
Amount Saving in Average Inventory [CZK]	1,661,040	1,291,915	833,080	288,679

Table 6-3:Case 1: Results obtained at different service levels with same lead times (Monthly consumption) [Source: Author]

Case 2: Changing service level at the same lead times (Weekly Spare Parts Consumption)					
Type of Inventory on hand	Current value of 2012 [CZK]	Calculated Inventory values in 2013 [CZK] at different service levels [%]			
		90%	91%	92%	93%
Average Inventory	14,891,227	13,754,342	14,019,533	14,401,458	14,664,135
Maximum Inventory		14,315,233	14,679,184	15,262,229	15,588,780
Safety Stock	17,106,113	13,193,450	13,359,881	13,540,686	13,739,491

Amount Saving achieved in Case 2 (Weekly Spare Parts Consumption)				
Service Level [%]	90%	91%	92%	93%
Amount Saving in Safety Stock [CZK]	3,912,663	3,746,232	3,565,427	3,366,622
Amount Saving in Average Inventory [CZK]	1,136,885	871,694	489,769	227,092

Table 6-4: Case 2: Results obtained at different service levels with same lead times (Weekly consumption) [Source: Author]

6.3.2 RESULTS OBTAINED WHEN CHANGING LEAD TIME, AT DIFFERENT SERVICE LEVELS

The majority of items were found to be having lead time of one month, which is increased to two months, and two weeks according to monthly and weekly consumption demand considerations respectively, resulting in reaching different values of safety stock, average inventory, and maximum inventory, **which can be observed in Table 6-5 and 6-6.**

Case 3: Changing Lead times at different service levels (Monthly Spare Parts Consumption)					
Type of Inventory on hand	Current value of	Calculated value of 2013 [CZK] at different service			
		94%	95%	96%	97%
Average Inventory	14,891,227	13,863,513	14,085,969	14,357,969	14,777,772
Maximum Inventory		14,652,698	14,881,568	15,171,745	15,699,311
Safety Stock	17,106,113	13,074,329	13,290,371	13,544,193	13,856,234

Amount Saving achieved in Case 3 (Monthly Spare Parts Consumption)				
Service Level [%]	94%	95%	96%	97%
Amount Saving in Safety Stock [CZK]	4,031,784	3,815,742	3,561,921	3,249,880
Amount Saving in Average Inventory [CZK]	1,027,713	805,258	533,258	113,455

Table 6-5: Case 3: Results obtained at different service levels & lead times (Monthly Consumption) [Source: Author]

Case 4: Changing Lead times at different service levels (Weekly Spare Parts Consumption)					
Type of Inventory on hand	Current value of	Calculated value of 2013 [CZK] at different service			
		90%	91%	92%	93%
Average Inventory	14,891,227	13,844,195	14,114,184	14,500,419	14,766,853
Maximum Inventory		14,421,821	14,791,990	15,379,984	15,710,012
Safety Stock	17,106,113	13,266,570	13,436,379	13,620,854	13,823,693

Amount Saving achieved in Case 4 (Weekly Spare Parts Consumption)				
Service Level [%]	90%	91%	92%	93%
Amount Saving in Safety Stock [CZK]	3,839,543	3,669,734	3,485,260	3,282,420
Amount Saving in Average Inventory [CZK]	1,047,032	777,042	390,808	124,374

Table 6-6: Case 4: Results obtained at different service levels & lead times (Weekly Consumption) [Source: Author]

6.3.3 RESULTS OBTAINED FROM ABC ANALYSIS

The value of safety stock, average inventory, and maximum inventory is determined form Microsoft Excel® calculations, distributed for each category of spare parts items, were total 150 items at 16.7% of total items forms category "A" items, considered as critical items, while 176 items at 19.6% of total items forms category "B" items, represents less critical items, and 574 items at 63.8% of total items forms category "C" items, which are least critical items.

Calculated value of safety stock, average inventory and maximum inventory is distributed for each category of spare parts items with respect to ABC classification system according to net current value of inventory, based on forecasting monthly consumption demand of spare parts in 2013 **as presented in Table 6-7 in the next page**, which shows the inventory values calculated for each category of items "A", "B", and "C", with high, medium, and low inventory value respectively. For category "A" items, sum of calculated safety stock values is 6,377,294 CZK, sum of average inventory values is 6,651,343 CZK, and sum of maximum inventory values is 6,925,391 CZK.

An amount saving of 1,448,051 CZK in average inventory value, and 4,235,279 CZK in safety stock value were obtained based on forecasting monthly consumption demand in 2013, considering at 99%, 95%, & 90% Service level, for items category "A","B", and "C" respectively.

Summary of ABC classification system				
Category	A	B	C	Total
Criticality	Critical	Less Critical	Least Critical	
Inventory Control	Tight	Reasonably Accurate	Minimum	
Value of calculated safety stock (CZK)	6,377,294	1,370,181	5,123,160	12,870,635
Average Inventory Value(CZK)	6,651,343	1,449,728	5,342,105	13,443,176
Maximum Inventory Value (CZK)	6,925,391	1,529,276	5,561,051	14,015,718
Quanity of items	150	176	574	900
Percentage of items	16.7%	19.6%	63.8%	100%

Table 6-7: ABC Classification system according to net current value of stock based on monthly spare parts consumption demand 2013 [Source Author]

Moreover, calculated value of safety stock, average inventory and maximum inventory is distributed for each category of spare parts items with respect to ABC classification system, according to net current value of inventory, based on forecasting weekly consumption demand of spare parts in 2013 **as presented in Table 6-8,** which shows the inventory values calculated for each category of items "A", "B", and "C", with high, medium, and low inventory value respectively. For category "A" items, sum of calculated safety stock values is 6,320,449 CZK, sum of average inventory values is 6,852,045 CZK, and sum of maximum inventory values is 7,383,641 CZK. An amount saving of 489,769 CZK in average inventory value, and 3,565,427 CZK in safety stock value were obtained based on forecasting monthly consumption demand in 2013, considering at 92%, 91%, & 90% Service level, for items category "A","B", and "C" respectively.

Summary of ABC Analysis classification system				
Category	A	B	C	Total
Criticality	Critical	Less Critical	Least Critical	
Inventory Control	Tight	Reasonably Accurate	Minimum	
Value of calculated safety stock (CZK)	6,320,449	1,546,418	5,673,819	13,540,686
Average Inventory Value(CZK)	6,852,045	1,618,917	5,930,495	14,401,458
Maximum Inventory Value (CZK)	7,383,641	1,691,417	6,187,172	15,262,229
Quanity of items	150	176	574	900
Percentage of items	16.7%	19.6%	63.8%	100%

Table 6-8: ABC Classification system according to net current value of stock based on weekly spare parts consumption demand 2013 [Source: Author]

7 INTERPRETATION AND DISCUSSION

Spare Part components are categorized using ABC classification system according to different criteria. It was found that considering the consumption value of spare parts leads to different amounts of saving in average inventory and safety stock values.

The inventory values calculated for each category of items "A", "B", and "C" with high, medium, and low consumption value respectively based on forecasting monthly consumption demand of spare parts in 2013, **which can be seen in Figure 7-1**. For category "A" items, sum of calculated safety stock values is 6,514,568 CZK, sum of average inventory values is 7,085,086 CZK, and sum of maximum inventory values is 7,655,603 CZK.

An amount saving of 827,961 CZK in average inventory value, and 3,761,305 CZK in safety stock value were obtained, considering at 99%, 95%, & 90% Service level, for items category "A","B", and "C" respectively.

Summary of ABC classification system				
Category	A	B	C	Total
Criticality	Critical	Less Critical	Least Critical	
Inventory Control	Tight	Reasonably Accurate	Minimum	
Value of calculated safety stock (CZK)	6,514,568	1,875,751	4,954,490	13,344,809
Average Inventory Value(CZK)	7,085,086	1,991,150	4,987,031	14,063,266
Maximum Inventory Value (CZK)	7,655,603	2,106,549	5,019,572	14,781,723
Quanity of items	82	137	681	900
Percentage of items	9.1%	15.2%	75.7%	100%

Figure 7-1: ABC Classification system according to consumption value based on monthly spare parts consumption demand 2013 [Source Author]

A second classification based on forecasting weekly consumption demand of spare parts in 2013, **which can be seen in Figure 7-2**. For category "A" items, sum of calculated safety stock values is 6,342,485 CZK, sum of average inventory values is 7,050,119 CZK, and sum of maximum inventory values is 7,757,753 CZK. An amount saving of 570,652 CZK in average inventory value, and 3,641,410 CZK in safety stock value were obtained, considering at 92%, 91%, & 90% Service level, for items category "A","B", and "C" respectively.

Summary of ABC classification system				
Category	A	B	C	Total
Criticality	Critical	Less Critical	Least Critical	
Inventory Control	Tight	Reasonably Accurate	Minimum	
Value of calculated safety stock (CZK)	6,342,485	2,063,028	5,059,190	13,464,704
Average Inventory Value(CZK)	7,050,119	2,177,096	5,093,360	14,320,575
Maximum Inventory Value (CZK)	7,757,753	2,291,164	5,127,530	15,176,447
Quanity of items	82	137	681	900
Percentage of items	9.1%	15.2%	75.7%	100.0%

Figure 7-2: ABC Classification system according to consumption value based on weekly spare parts consumption demand 2013 [Source Author]

Availability of plastic injection moulding machine, relates to maintenance practice applied and maintenance efficiency, which concerns with planning, spare part, control, and economy management. In order to determine if it is beneficial to keep a certain spare part in inventory, the shortage cost must be greater than the cost of purchasing, ordering and carrying the part. The shortage cost is based upon the total cost of the time that the spare part prevents performing its function, in other words, cost of production loss. The time of a shortage will therefore be based upon the lead time of receiving the part. To increase the accuracy of the shortage cost, more parameters can be added, which are service level, forecasting lead time demand, and fixed lot size.

For the spare parts which are very expensive and those which are to be imported, it is essential that the useful life for such spares is extended by appropriate applications of reconditioning and repair techniques. Suppliers providing critical spare parts should be under contract to mitigate unexpected lost production time and delayed deliveries. If parts availability is limited to a single supplier, the risk that these specific parts become obsolete or the manufacturer is no longer producing them, would necessitate the decision to purchase what is available and hold the parts in inventory to mitigate that risk, as a hedge against possible equipment failure. Annual costs of spare parts storage are not considered since the total cost is deprecated as the spare part is bought, regardless of when the cost is deprecated, the spare will always carry a small annual carrying cost.

In connection to daily reviews of material plans, the responsible Engineer evaluates whether new parts needs to be procured. The evaluation is based upon experience and statistics of the turnover. During weekly meetings critical failures is brought to attention. The Engineer reports different types of analysis and counter measures. A possible counter measure might be to reevaluate existing spare parts routines. When equipment is phased out, the bill of spare parts is adjusted and removes spare parts related to the equipment.

Actual numbers of items do not correspond to defined quantities by SAP® software. Also, purchasing costs, ordering costs, material frequency, which exists within SAP®, is more like failure documentation, and is not easy to interpret.Recently, the application of computers for processing of spare parts through a suitable information system operates an effective spare parts control system by establishing so called spare parts banks, has proved to be very helpful for an organization for the exchange of spares, resulting in reducing total inventory holding of expensive spare parts and also reduces the stock holding cost.

A risk analysis that evaluates the lead time from the time a procurement order is placed with the supplier until receipt of the item to the manufacturing plant is a factor that affects the decision to stock a spare part component as part of inventory, considering the reliability of the supplier to meet the expected lead time.

Failure modes effects and criticality analysis (FMECA) is a methodology for reliability analysis. It is used to review part's function, failure modes, failure causes and failure consequences, carried out by analyzing dependencies between failure modes and failure consequences.

The FMECA can also be used as a risk assessment tool, aimed to Identify components with high risk of causing sudden failure in a production line by defining criticality of equipment's components through calculating risk priority number (RPN) of each group of items, by multiplying the Severity “S”: Defines consequences of failure occurrence (example: Hours of downtime), Occurrence “O”: Defines frequency of failure, based on failure rate (example: Number of occurrence over a specific time, (6 months or one year), and Detection ”D”: Defines symptoms of detecting potential failure before having actual failure occurrence “Can be neglected, as in most of studies” (D. Tsakatikas & G. Kaisarlis et al., 2007).

8 CONCLUSIONS AND RECOMMENDATIONS

An inventory management tool was created for VALEO Rakovník in Microsoft Excel® capable of determining inventory levels of spare parts used for maintaining 21 plastic injection moulding machines by calculating safety stock, re-order, and maximum quantities providing an ability to predict consumption demand of spare parts for one year in advance. Review of inventory levels is essential to support decision of placing a replenishment schedule consisting of quantities of spare parts when it falls below an identified re-order level, as a solution to avoid holding excessive or less quantities of parts on stock.

These calculations were necessary to accurately optimize inventories of spare parts having different functions and suppliers' lead times to ensure proper coverage of both scheduled and unscheduled maintenance to maximize availability of machines as the maintenance activities will be carried out without delay which may occur due to unavailability (Stock-outs) of a spare part due to long suppliers' lead times for spare parts with high value or because of not keeping the right quantity of a spare part on stock, which is avoided by sorting spare parts according to their values where high priority was given to spare parts with higher values.

The said created Microsoft Excel® inventory management tool has been implemented into the process of VALEO Rakovník for periodic use which consequently supported management decision making. The tool avoids extended downtime by meeting challenges of intermittent consumption of service spare parts while maintaining adequate stock of spare parts not high or low leading to minimization of average value of inventory.

Considering actual lead time and consumption demand of previous three years from 2010 to 2012, a computer based calculations were created through an inventory management tool providing optimum determination of safety stock, re-order, and maximum quantities on stock of spare part for upcoming year 2013. Croston's forecasting method was implemented to accurately calculate monthly demand of spare parts during supplier's lead time which have an intermittent consumption demand.

The spare parts' inventory management tool in form of Microsoft Excel® spreadsheet provides a feature of changing service level, lead time, and fixed lot size, supporting organizations' ordering existing system SAP® software. As a result the value of average inventory was calculated for the year 2013 and compared with on stock inventory value during 2012. Accordingly an amount saving of 833,080 CZK in average inventory value was reached at a service level of 98% considered as an optimum level of inventory at minimum costs, which avoids extended down time and ensures machine availability within a production process.

One of the objectives of the thesis was to analyze an inventory of spare parts through understanding value, quantity, and frequency of consumption of each spare part as a preliminary approach. This analysis has been carried out and extended successfully to streamline inventory management of spare parts and determine minimum quantity of each spare part that should be kept on stock prior to placing a replenishment order.

The quantities of spare parts kept as a safety stock were reduced at the same time while still avoiding shortage costs which may arise whenever demand cannot be fulfilled due to lack of spare parts. Consumption demand of spare parts was estimated during lead time based on probability of a higher or lower consumption of spare parts to establish an inventory management policy able to expedite ordering process of key spare parts as well as the rest of spare parts and classify spare parts according to ABC classification system based on the value of on stock quantities.

8.1 OUTCOMES OF WORK DONE

The entire objectives specified in Chapter 2 (Scope of Research Objectives) were fulfilled. The key achieved outcomes of the work are listed and explained below:

- A solution was proposed to VALEO Rakovník based on most appropriate demand forecasting method, where re-order quantities for each spare part could be entered in the company's existing ordering system SAP® software, consequently leading to minimization of inventory values, and developing expediting process of key spare parts.

- The safety stock quantities of each spare part kept on stock during lead time were reduced at high service level ranging from 94 to 99% considering monthly consumption demand, and from 90 to 93% considering weekly consumption demand.

- Calculation of re-order quantity and maximum quantity on stock given the individual unit price of each spare part has enabled calculation of average inventory value and comparing it with on stock inventory value based on forecasted consumption demand.

- Taking into account that each spare part has an intermittent demand pattern, the uncertainty in its consumption demand is assumed to be normally distributed. Accordingly the parts consumption was forecasted during supplier's lead time at assigned service level during required time series and entered into a function in Microsoft Excel® spreadsheet.

- At a service level of 98% based on forecasting monthly consumption demand of spare parts, the average inventory value for the year 2013 were calculated as 14,058,147 CZK which is less than on stock inventory value during 2012 of 14,891,227 CZK by 833,080 CZK. Hence, re-order level is considered as optimum level of inventory.

- An optimum level of inventory was obtained where a procurement order is placed in advance prior to the time of scheduled maintenance when stock falls below this specified level at minimum holding costs of inventory.

- An inventory management policy was introduced to VALEO Rakovník to be utilized with respect to determined re-order points of each spare part. This assists the company in establishing appropriate policies for selective control, and also helps in focusing all efforts on real problem areas.

- Applying the proposed inventory management policy has eliminated stock outs of spare parts which cause an interruption in production processes. Down times for one or a group of machinery cause inconvenience in form of loss in gross profit. Allow subordinate managers and maintenance person to make good decisions on what to order and expedite on standard orders.

- By implementing the obtained calculations of re-order quantities, spare parts arrives to the warehouse just in time when it is needed with sufficient time, keeping suppliers' lead times in consideration. Lead times are specific to each spare part depending on its source: either local or abroad supplier.

- The created Microsoft Excel® inventory management tool was designed to permit changing of influencing input parameters. Minimizing lead time decreases sum of safety stock value, and decreases sum of average inventory values at a selected service level.

- Spare parts were categorized into three different groups according to the value of each category of items (high, medium, or low) where ABC classification system was implemented with respect to value of on-stock quantities of spare parts.

- ABC classification system was done for the whole inventory consisting of 900 spare parts forming a tool to control inventory throughout computing turnover ratio, and performing cycle counting.

8.2 RECOMMENDATIONS FOR FUTURE RESEARCH

- This study could be extended to introduce Failure mode effects and criticality analysis "FMECA", which is a prevention tool used to assess, manage, and reduce risk associated with potential failure of manufacturing processes within the injection moulding operations by conducting a risk assessment utilizing data, including current quality, and manufacturing operation control reports. Repairs occur due to system failures rather than as part of a production plan that would be eliminated.

- A list of all possible failures can be generated especially for new equipment. The list should include regularly prevented failures as well as failures that have not happened yet but have the possibility of occurrence. Potential failures caused by human error (not only the ones that are caused by usual wear and tear) can be also included.

- The magnitude of consequences of failures should be determined. This should cover each failure effect either hidden failure consequences having no immediate impact, but often catastrophic outcome safety or environmental consequences if the failure could violate environmental standards or cause an injury to personnel, or operational consequences if failure affects outcome, quality, or operational costs.

- A number of preventive and proactive tasks should then be conducted, that describe how the consequences of a certain failure should be avoided by avoiding that particular failure mode. These tasks are suggested to include two main scopes. First is scheduled restoration where a component is overhauled before it wears out either after a certain age or before a certain point in time. Second is Scheduled on-condition task, which is based on the fact that equipment gives a warning that a failure is about to occur. Equipment is kept in use on the condition that it continues to meet the performance standards.

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APPENDICES

The Microsoft Excel® Spreadsheet includes total quantity of 900 spare part components, and the following tables shows the calculations carried out for the first ten listed spare parts.

Appendix A: Sample of spare parts

Category/ Serial Nr.	Stock Number	Description
1	LIS101001	Samec jadro 1-16 9200162612
2	LIS101002	Samec jadro17-32 9200162613
3	LIS101003	Samice jadro 1-16 9200162812
4	LIS101004	Samice jadro17-32 9200162813
5	LIS101005	Na prodluzovak nahoru 9200160441
6	LIS101006	Na prodluzovak strany 9200160541
7	LIS101007	Nizke formy 9200160301
8	LIS101008	Vysoká formy 9200160252
9	LIS101009	Samec 10 pinHan A 10 Pos. M kodovani materialu
10	LIS101010	Samice 10pin Han A 10 Pos. F kodovani materialu

Table A: Description and stock number of first 10 items out of total 900 items in MS Excel® spreadsheet [Source: Author]

Appendix B: Consumption demand of spare parts components from 2010 to 2012

Goods issued (Consumed items) from 2010 until 2012										
Jan-10	2		2							
Feb-10	2	2								
Mar-10	2	5	4	8		3	2			
Apr-10										
May-10	6	2			1	1				
Jun-10	4	3					1			
Jul-10			5							
Aug-10	2		2					2		
Sep-10										
Oct-10										
Nov-10										
Dec-10	8		11		3	3				
Jan-11	3		2			1	1			
Feb-11										
Mar-11	4		4					3		
Apr-11								1		
May-11	5									
Jun-11	5		3							
Jul-11	1							1		
Aug-11										
Sep-11	1							2		
Oct-11			2							
Nov-11	2		1	1					3	
Dec-11		1	1						6	3
Jan-12	1	1	2	1						
Feb-12	2		1			1		1	1	
Mar-12	1	1			1	1			1	1
Apr-12	1		1		1	1				
May-12	5	3	6	3	1					1
Jun-12			1						4	
Jul-12	14		13	1	16	3		7		1
Aug-12				2						
Sep-12	1									
Oct-12	2									
Nov-12	1									3
Dec-12									5	1

Table B: Consumption demand of first 10 items out of total 900 items in MS Excel® spreadsheet [Source: Author]

Appendix C: Calculation of safety stock quantities and re-order quantities

Initial reqirement of Forecast calculation	Forecasted consumption using CROSTON'S METHOD during actual Lead times considered as 1,2,4 & 6 Months						Lead time demand	SAP Lead Time (Days)	Standard Deviation	Service Factor	Lead Time Factor	Calculated Safety Stock	Calculated Safety Stock Correction	Calculated Re-order quantity
	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13								
	0.10	0.29	0.36	0.42	0.88	0.00								
	0.10	0.19	0.27	0.34	0.41	0.00								
	1.00	1.00	1.00	1.00	1.00	2.00								
	1.00	1.53	1.33	1.24	2.15		1.00	7	3.033	2.054	1.000	6.2	6	7
	0.10	0.00	0.10	0.00	0.30	0.00								
	0.10	0.00	0.10	0.00	0.10	0.00								
	1.00	2.00	1.00	2.00	1.00	2.00								
	1.00		1.00		3.00		1.00	7	1.389	2.054	1.000	2.9	3	4
	0.20	0.28	0.00	0.10	0.69	0.72								
	0.10	0.19	0.00	0.10	0.19	0.27								
	1.00	1.00	2.00	1.00	1.00	1.00								
	2.00	1.47		1.00	3.63	2.66	2.00	7	3.519	2.054	1.000	7.2	7	9
	0.10	0.00	0.00	0.00	0.30	0.00								
	0.10	0.00	0.00	0.00	0.10	0.00								
	1.00	2.00	3.00	4.00	1.00	2.00								
	1.00				3.00		1.00	7	2.733	2.054	1.000	5.6	6	7
	0.00	0.00	0.10	0.19	0.27	0.00								
	0.00	0.00	0.10	0.19	0.27	0.00								
	1.00	2.00	1.00	1.00	1.00	2.00								
			1.00	1.00	1.00		0.00	7	6.014	2.054	1.000	12.4	12	12
	0.00	0.10	0.19	0.27	0.00	0.00								
	0.00	0.10	0.19	0.27	0.00	0.00								
	1.00	1.00	1.00	1.00	2.00	3.00								
		1.00	1.00	1.00			0.00	7	1.035	2.054	1.000	2.1	2	2
	0.00	0.00	0.00	0.00	0.00	0.00								
	0.00	0.00	0.00	0.00	0.00	0.00								
	1.00	2.00	3.00	4.00	5.00	6.00								
							0.00	7	0.577	2.054	1.000	1.2	1	1
	0.00	0.10	0.00	0.00	0.00	0.00								
	0.00	0.10	0.00	0.00	0.00	0.00								
	1.00	1.00	2.00	3.00	4.00	5.00								
		1.00					0.00	7	2.149	2.054	1.000	4.4	4	4
	0.00	0.10	0.19	0.00	0.00	0.40								
	0.00	0.10	0.19	0.00	0.00	0.10								
	1.00	1.00	1.00	2.00	3.00	1.00								
		1.00	1.00			4.00	0.00	7	2.066	2.054	1.000	4.2	4	4
	0.00	0.00	0.10	0.00	0.10	0.00								
	0.00	0.00	0.10	0.00	0.10	0.00								
	1.00	2.00	1.00	2.00	1.00	2.00								
			1.00		1.00		0.00	7	1.033	2.054	1.000	2.1	2	2

Table C: Forecasting consumption demand of first 10 items out of total 900 items in MS Excel® spreadsheet [Source: Author]

Appendix D: Calculation of average inventory values

Maximum Quantity on stock	Fixed Lot Sixe	Unit Price (CZK)	Current quantity	Current Safety Stock	Current value of safety stock (CZK)	Value of calculated safety stock (CZK)	Saving in Safety Stock Value (CZK)	Value of Re-order quantities (CZK)	On stock Inventory value (CZK)	Average Inventory Value (CZK)	Maximum Inventory Value (CZK)
11	5	**291**	18	10	2,910.00	1,812.89	1,097.11	2,103.89	5,238.00	2,540.39	3,267.89
4	1	**290**	11	10	2,900.00	827.11	2,072.89	1,117.11	3,190.00	972.11	1,117.11
13	5	**360**	17	10	3,600.00	2,601.67	998.33	3,321.67	6,120.00	3,681.67	4,761.67
11	5	**392**	14	10	3,920.00	2,199.87	1,720.13	2,591.87	5,488.00	3,179.87	4,159.87
16	5	**291**	21	8	2,328.00	3,594.14	-1,266.14	3,594.14	6,111.00	4,176.14	4,758.14
2	1	**243**	7	5	1,215.00	516.58	698.42	516.58	1,701.00	516.58	516.58
1	1	**290**	14	5	1,450.00	343.86	1,106.14	343.86	4,060.00	343.86	343.86
4	1	**381**	22	5	1,905.00	1,681.70	223.30	1,681.70	8,382.00	1,681.70	1,681.70
4	1	**221**	15	10	2,210.00	937.53	1,272.47	937.53	3,315.00	937.53	937.53
2	1	**263**	11	10	2,530.00	536.64	1,993.36	536.64	2,783.00	536.64	536.64

Table D: Calculation of inventory values for first 10 items out of total 900 items in MS Excel® spreadsheet [Source: Author]