THE EFFECTS OF SPARE PARTS INVENTORY CONTROL ON THE PRODUCTIVITY OF A MANUFACTURING COMPANY

BY

UZOH UGOCHUKWU CELESTINE (B.ENG)
REG. NO.: 20104770858

A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL,
FEDERAL UNIVERSITY OF TECHNOLOGY,
OWERRI.

IN PARTIAL FULLFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER'S OF ENGINEERING (M. Eng) IN MECHANICAL ENGINEERING (INDUSTRIAL AND PRODUCTION ENGINEERING)

JANUARY, 2015

CERTIFICATION

This is to certify that Uzoh, Ugochukwu Celestine with Reg. No 20104770858 of the Department of Mechanical Engineering, Federal University of Technology, Owerri carried out this work ‘The effects of spare parts inventory control on the productivity of a manufacturing company’ as an original research work and that this work satisfies in part, the requirement for the award of the Degree of Master’s of Engineering (M.Eng) in Mechanical Engineering (Industrial and Production Engineering) Federal University of Technology, Owerri.

………………………… ………………………
Engr. Dr.Uche Remy Date
Supervisor

………………………… ……………………
Engr. Dr.Uche Remy Date
H.O.D. MEE

…………………………. ……………………
Engr. Prof E. E. Anyanwu Date
Dean SEET

………………………….
………………………
Engr. Prof. K. B Oyoh Date
Dean PGS

…………………………. ………………………
External Examiner Date

DEDICATION

This thesis is dedicated to God Almighty who has bequeathed in me the wisdom, strength and the zeal to pursue higher education and also to the very loving memory of my unforgettable father who is with God Almighty now.

ACKNOWLEDGEMENTS

Sincerely, my immense gratitude goes to my supervisor and the HOD Mechanical Engineering department, Engr. Dr. Uche Remy for his assistance and encouragement. He is my teacher and a father whose motivation and professional counsels were very valuable. To all my lecturers in this very important programme, Engr. Prof. O.N Oguoma, Engr. Prof. E. E Anyanwu, Engr. Dr. Uzorh A. C, Engr. Dr. Sam Iwuoha, Engr. Dr. G.O. Osueke, Dr. Umanna of Mathematics Department, Dr. A.B.C Akujiobi of Financial Management Department and all the staff of Department of Mechanical Engineering of Federal University of Technology, Owerri for directing me to this path of what I call 'knowledge enlargement', that led to an expansion and improvement of my research skills.

I will not forget my course mates and my friends for their own forms of support and encouragement. May God Almighty bless you all Amen. My appreciation also goes to the Factory Engineer, Engr. Daniel Morales of Nestle Nig. Plc for their unalloyed support and assistance. I wish to appreciate the support of my family particularly for giving me the necessary support that helped me to undertake this project. I salute you all.

Finally, I am highly indebted to God who makes all things to work out in his time.

ABSTRACT

This work aims at reducing spare parts inventory and freeing up tied capital to boost the productivity of a manufacturing company. The work developed a six step inventory reduction process which challenges the condition that creates room for overstocking of spare parts. The Bathtub principle, Single and Double loop learning model and Systems thinking which ensure the process is mutually exclusive and collectively exhaustive (MECE), were used in developing the six steps of inventory reduction. Data collected from Nestle Nig. Ltd were used to validate the developed process. The result shows a 29.4% reduction in inventory and a corresponding increase in productivity of 6.35% which represent a significant amount of money freed from spare part inventory.

Keywords: Productivity; Overstock; Inventory reduction; The Bathtub principle; Single and Double loop learning model; System thinking

TABLE OF CONTENTS

Title Page-- i

Certification .-- ii

Dedication -- iii

Acknowledgement --- iv

Abstract --- v

Table of Content -- vi

List of Tables -- ix

List of Figures -- x

Nomenclature --- xi

CHAPTER ONE

INTRODUCTION

1.1 General Background--- 1

1.2 Statement of Problem -- 7

1.3 Objectives of the Work. -- 8

1.4 Justification--- 8

1.6 Scope of Study--- 9

CHAPTER TWO

LITERATURE REVIEW

2.1.1 Large revenue and investment on spare parts inventory ---------- 10

2.1.2 Decision to stock or not to stock --------------------------------------- 11

2.1.3 Maintenance spare parts versus semi-finished inventories ------ 12

2.1.4 Spare parts management and equipment reliability----------------- 14

2.1.5 Spare parts inventory management and abc analysis. ------------ 17

2.1.6 Productivity measurement -- 18

2.1.7 Single-Loop and Double-Loop Learning Model. -------------------- 22

2.1.8 Just In Time (JIT) Philosophy -- 23

2.1.9 Bath tub principle-- 24

2.2.1 Measures and key performance indicators (KPI) ------------------ 26

2.2.2 Nestle Nig.Plc Agbara– The case study ----------------------------- 26
2.2.3 Risk analysis of factors that affect spare parts inventory
level --- 26
2.2.4 Key stocking input parameters--- 29
2.2.5 Factors influencing the EOQ -- 38
2.2.6 Systems thinking --- 41

CHAPTER THREE

RESEARCH METHODOLOGY

3.1.1 Methods --- 41
3.1.2 Deduction of the relationship between spare parts
partial productivity and spare parts inventory level --------------- 44
3.1.3 Calculation of the actual value of inventory reduction (c_s) ------- 49
3.1.4 Formulation of a step by step process for efficient spare part
Reduction -- 51
3.1.5 Explanation of formulated steps ------------------------------------- 52
3.1.6 Substitution of the actual value of the cost
savings -- 58
3.1.7 Computation of total output and productivity ------------------------ 58
3.1.8 Taking action -- 60
3.1.9 Inventory cost reduction process flow chart ------------------------ 61

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Inventory Review --- 63
4.2 Case Study-- 66

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion -- 74

5.2 Contributions to Knowledge--- 75

5.3 Recommendations --- 76

REFERENCES-- 77

APPENDIX-- 82

LIST OF TABLES.

Table 3.1 Summary of Nestle's total inventory
versus purchased spare parts ------------------------------------- 46

Table 4.1 A spreadsheet containing the top 30 items in
the spare parts inventory list of Nestle Nig. Plc----------------- 64

Table 4.2 Generated list for inventory cash release process ---------- 66

Table 4.3 Classification of Pareto items ------------------------------------- 68

Table 4.4 Results of Poisson's probability distribution ------------------- 70

Table 4.5 Completed form -- 72

LIST OF FIGURES

Figure 2.1 Double loop Vs single loop learning ---------------------------- 23
Figure 2.2 Bath tub principle -- 25
Fig.2.3: Nestle's Spares Inventory Organizational Chart ---------------- 27
Fig. 2.4 The cost of improving availability ---------------------------------- 30
Fig 2.5 ROP Sensitivity to lead time --- 33
Fig 2.6 The effect of different usage rates----------------------------------- 38
Figure 3.1 Work break down structure --------------------------------------- 43
Figure 3.2 A graph of total inventory against purchased
spare parts -- 47
Figure 3.3 The Six Steps of inventory reduction ---------------------------- 52
Figure 3.4 Spare parts decision checklist ----------------------------------- 57
Figure 3.5 Inventory cost reduction process flow chart ------------------ 62
Figure 4.1 Pareto graph --- 67
Figure 4.2 Histogram showing Poisson probabilities --------------------- 70

NOMENCLATURE

MRO	Maintenance, repair and operating stores
EBIT	Earnings Before Interest and Tax
METRIC	Multi-echelon technique for recoverable item control
MADM	Multi-attribute decision making
AHP	Analytic hierarchy process
VED	Vital, Essential and Desirable
KPI	Key performance indicator
JIT	Just in time
ERP	Enterprise resource planning
FMECA	Failure mode effects and criticality analysis
IT	Information Technology
WBS	Work break down structure
WACC	Weighted average cost of capital
ISI	Inventory Solutions Inc.
SKUs	Stock keeping units
ROI	Return on Investment
MECE	Mutually exclusive and collectively exhaustive

CHAPTER ONE

INTRODUCTION

1.1 General background

Spare parts refers to the parts requirement for keeping both owned equipment/machine or service needs of customers in healthy operating condition by meeting repair and replacement needs imposed by breakdown and preventive maintenance. Similarly, Inventory management can provide the capability to fulfil a customer need, repair a broken machine, assemble products for sale, or just keep production going.

The unique problems faced by the organisation in controlling/managing the spare parts are as follows. Firstly, there is an element of uncertainty as to when a part is required and also the quantity of its requirement. This is due to the fact that the failure of a component, either due to wearing out or due to other reasons, cannot be predicted accurately. Secondly, spare parts are not that easily available in the market as they are not fast moving items. The original equipment manufacturer has to supply the spares in most of the cases. New models are introduced to incorporate the design improvements and old models are phased out. Hence the spares for old models are not readily available. Particularly, this is more so in case of imported equipment as the design changes are taking place faster in the developed countries. Thirdly, the number and variety of spare parts are too large making the close control more and more tedious. For instance, the number of items of spares in a medium scale engineering industry may be around 15,000 and that in a large scale chemical industry may be around 100,000 [Rajeswari, 1996]. Fourthly, there is a tendency from the stage of purchase of the equipment to the stage of the use of the spare parts, to requisition spare parts more number than that which are actually required, and consequently accumulation of spares take place. Finally, the rate of consumption of spare parts for some are very high and for some are very low. These problems are to be faced by systematic spare parts management.

Observations in many industries show that the non-availability of spare parts, as and when required for repairs, contributes to as much as 50% of the total down time. Also, the cost of spare parts is more than 50% of the total maintenance cost in the industry [Rajeswari, 1996]. It is a paradox to note that the maintenance department is complaining of the non-availability of the spare parts to meet their requirement and finance department is facing the problem of increasing locked up capital in spare parts inventory. This amply signifies the vital importance of spare parts management in any organisation.

For most manufacturing organizations, inventory can account for up to 50% (or more) of the current assets of the business. This means that for most manufacturers, up to 50% of their assets that could be converted to cash in the next 12 months are tied up in inventory. For retail and wholesaler businesses, the figure is even higher. However, unlike cash, the money tied up in inventory is not available for any other use. It cannot be used to fund the business or for further investment in other productive assets. With MRO inventory this is doubly so as the inventory is not purchased with resale in mind. Nor does inventory represent a defined future stream of income like receivables.

Inventory ties up cash and little can be done with that cash until the inventory is sold or moved.

For many people though, inventory isn't a serious business topic. Many business people concern themselves only with strategy or sales or process management or IT solutions. Alternatively, some people consider inventory only as a means to an end. The attitude is stock more and you will sell more or stock more ‘just in case’ of a problem. The cash impact is not always fully appreciated; inventory, it seems, is considered by many to be too low level to be able to create genuine financial advantage. By definition, working capital is an expense that does not appear on the ‘Profit and Loss’ statement and, therefore, gets little attention.

The Inventory reduction process in this work aims to cast inventory in a different light. Taking a proactive approach to inventory reduction can provide significant financial advantage and enable companies to potentially free up millions of dollars in cash. This is money that has been invested in inventory, but which either wasn’t needed in the first place or is no longer needed due to a change in the operating environment. These changes could include a change in the level of demand, a change in the ability to supply, or both. In either case, there is an opportunity to free up cash and make alternative investments.

The difference between inventory management and inventory reduction is that former involves the activity that ensures the availability of inventory items in order to be able to service customers. In an MRO environment, the customer will be the maintenance and production department; in a finished goods environment, the customer is the external customer. Inventory management involves the coordination of purchasing, manufacturing, and demand to ensure the required availability.

Inventory reduction is the activity that minimizes the cash investment in inventory while maintaining the availability promise of inventory management. Inventory reduction focuses on identifying those items where the inventory holding is in excess of the real need, given the current actual demand and supply characteristics, and then works to reduce the cash investment in these items. As a result a significant cash release can be achieved with no change in the inventory risk profile.

Because inventory management aims to ensure availability, the focus is primarily on eliminating stock outs, that is, not having the stock to meet the availability promise. The result of this approach is overstocked inventory. The logic that drives this outcome is as follows: Running out of inventory invariably has consequences and there always seems to be a need for blame. Being blamed for something is an unpleasant experience for most people and in extreme cases can be seen as 'career limiting'. Therefore, any stock out triggers an action, not only to restock but also to typically overstock, in order to avoid a future stock out and the negative consequences that result. With this systematic process driving overstocked inventory, opportunities exist for inventory reduction that will not increase risk.

Conversely, where the inventory is already overstocked, for whatever reason, there is no stock out and no trigger to take action. Hence, a specific program of activity is required to identify these items so that their stocking can be adjusted to more appropriate levels.

Inventory reduction, on the other hand, focuses on identifying the opportunities for reducing the cash investment by eliminating any unnecessary investment in inventory with no change in the inventory risk profile.

Eventually, inventory management must lead to an over-investment of cash in inventory as people seek to eliminate stock outs, whereas, inventory reduction results in a minimized investment of cash while maintaining the availability promise.

The other term that is often used is inventory optimization. So what is the difference between inventory optimization and inventory reduction?

Inventory optimization uses existing data to calculate the required level of inventory for a desired level of availability.

Inventory reduction challenges the constraints to ensure that the result is an improvement to 'what could be,' not just a recalculation of 'what is.'

While this difference may seem subtle, the impact is significant.

Of course, many companies will gain a benefit from using an inventory optimization program. However, the real issues are: is the benefit truly optimized, and is it sustainable?

On its own, an inventory optimization program simply cannot achieve the same level of benefit as an inventory reduction program. Because optimization programs just calculate the 'what is' they can only optimize a single element of the total equation and hence cannot truly optimize the result. Inventory reduction works on 'what could be' by challenging the constraints that drive the result, not just recalculating the result. The inventory reduction approach shown in this work truly optimizes the inventory investment.

With respect to sustainability, the ongoing achievement of an optimized inventory comes from a change in the policies, procedures, measures, and reporting that drive the inventory outcome. Optimization programs are calculation tools that don't address these issues. An inventory reduction program ensures that all the relevant members of your team understand the impact of their decisions on inventory outcomes and it sets up the policies, procedures, measures, and reporting to ensure a lasting result.

In the 1970s, a Harvard professor named Chris Argyris recognized a phenomenon that is used in many fields of management that could be used to identify real opportunities. He called this Single Loop Learning. The problem with Single Loop Learning is that you can never improve beyond yourself imposed constraints.

To achieve breakthrough improvements in any field, Professor Argyris argues that you need what he calls Double Loop Learning. This also includes the field of inventory reduction.

Double Loop Learning requires that you challenge the constraints and assumptions inherent in your original thinking.

So, in any inventory reduction program, rather than just use mathematical techniques to optimize within our constraints, we need to challenge those constraints. This means challenging the assumptions about both supply and demand. Basing our solution on a review that only includes historical data does not do enough to challenge our constraints.

The problem, of course, with MRO inventory is that each and every SKU may have different supply and demand characteristics and, therefore, different constraints to challenge. Challenging these constraints for each and every SKU under our management is a daunting task. What is needed is a process that helps us to focus on the key inventory items that will truly make a difference to our overall investment without the burden of reviewing thousands of items individually. Such a process is part of what this work intend to establish.

Once the key items are identified, we need to then systematically challenge the constraints that are part of the Single Loop Learning mind-set that applies to these items. Only by applying the Double Loop Learning approach can we truly identify the opportunities that are available to us both today and tomorrow.

In order to ensure complete sustainability, however, there is one more problem to solve. There is another shortcoming with the so-called optimization approach that even Double Loop Learning doesn't resolve. Consider for a moment the following statement: "The outcome that is achieved from any process is a direct result of the policies, procedures, measures and reporting that manage that process" This is what is known as Systems Thinking.

Senge, [1992], describes how any outcome results from the inputs and processes that drive the outcome. In the case of MRO inventory, the existence of excess inventory is the direct result of the policies, procedures, measures and reporting applied to managing that inventory.

Because traditional optimization is driven only by data and does not include a systems approach, it does not address Systems Thinking. The traditional approach really is just a tool that can be used to recalculate inventory holding based on assumed constraints. It cannot help to address the systematic issues that led to an over investment in inventory.

1.2 STATEMENT OF PROBLEM

The complexities and the growing criticality of spare parts inventory control in manufacturing and service operations is on the increase. Factors like tied capital in spare parts inventory, demand unpredictability, high service levels, accurate spare parts forecast, etc, are growing concern. These have led to a stunted growth in industry's productivity as a result of millions of naira investment sitting unproductive in spare parts inventory.

Observations show that some of our local companies like Nestle Nig. Plc have installed new computer software with complex mathematical algorithms to manage their spare part inventory. Despite all of these, the result is inevitably the same-continued increases in inventory and shortage in the availability of items for operations and maintenance. This is so because this approach to problem solving uses "data only" approach, which does not challenge the constraints inherent in the establishment of the data. And also, it does not take advantage of changes in the system in which it interacts.

Therefore, there is a need for an efficient process which does not only uses existing data to calculate the required level of inventory but also challenges the constraints to ensure that the result is effective and sustainable.

1.3 OBJECTIVES

To check the effect of spare parts inventory control on the productivity of a manufacturing company by:

- The development of an efficient process for spare parts inventory reduction.
- The establishment of a measurement for spare parts partial productivity

1.4 JUSTIFICATION

There is a global quest for minimum financial investment in inventories. This is as a result of heavy investments in spare parts inventory.

Strategic growth and competitiveness of organization are dependent on the effective utilization of the critical productive resources of the organization.

The prosperity of any company or society is directly dependent upon the productivity of every activity of economic development. The higher the productivity, greater will be the prosperity and vice-versa. Every company has limited input resources. So, in a world of competition, the only golden rule to survive is higher production and higher productivity with the given input resources. Hence, this research work has the multiplying effects of promoting productivity.

1.5 SCOPE OF STUDY

This work focused on Maintenance spare parts (Parts that support the maintenance activities and are bought from external suppliers) management and does not consider after sales parts (parts that are in-house manufactured and sold to the clients) management or Raw materials of any form.

The productivity measure applied in this work laid an emphasis on only one input factor ignoring other factors and as such does not represent the overall productivity of the firm used as case study.

CHAPTER TWO

LITERATURE REVIEW

In this Chapter a review of the related literature on the spare parts inventory is carried out. Also, the special area of focus of this study within this reviewed domain is highlighted and distinguished in form of subheading.

The related literature to this study has been reviewed under the following subheadings:

1. Large Revenue and Investment on Spare Parts Inventory
2. Decision to stock or not to stock
3. Maintenance spare parts versus semi-finished inventories
4. Spare parts management and equipment reliability
5. Spare parts inventory management and ABC analysis
6. Productivity Measurement
7. Single-Loop and Double-Loop Learning Model
8. Just In Time (JIT) Philosophy
9. Bath tub Principle
10. Measures and key performance indicators (KPI)
11. Nestle Nig.Plc Agbara– The case study
12. Risk analysis of factors that affect spare parts inventory level
13. Key stocking input parameters
14. Factors influencing the EOQ
15. Systems thinking

2.1.1 Large revenue and investment on spare parts inventory

In today's technological environment, huge amount of money are left unproductive in both manufacturing and service industry's spare part inventory. Flint, [1995] stated that the world's spare parts inventory in the aviation industry amounted to $45 billion at that time. Any means to downsize this stock, without decreasing customer service, would be more than welcomed by the aviation industry. Also in other industries, large amounts of money are invested in spare parts inventory and this has increased over the years. Heather, et al [2004], reported that the spare parts market represents $700 billion and 8 percent of the U.S. gross domestic product and many manufacturers find that margins for services can top 40 percent, whereas margins for finished goods top out at around 13 percent. Profitability in service is much higher than profitability for initial products [Cohen, et al. 1997, Aberdeen Group, 2005]. Because of these large amounts of money involved, savings of a few percents only constitute large cost savings in absolute terms.

2.1.2 Decision to stock or not to stock

Silver, et al [1998], approached the specific problem of whether or not to stock, citing [Johnson, 1962], [Popp, 1965], [Croston, 1974], [Shorrock, 1978], and [Tavares, and Almeida, 1983]. Johnson, [1962], proposes two criteria: one to start storing an item currently purchased upon demand, and another to stop stocking an item purchased to stock. Popp, [1965], compared the costs of the alternatives to currently purchased upon demand (zero inventories), purchased to stock, and hybrid strategies. The model disregards the costs to add the item to management system; treats demand as continuous; and considers storage and order costs constant for the three strategies. Shorrock, [1978], proposed an operational decision model based on the formulation proposed by [Popp, 1965]. Croston, [1974] elaborated a similar criterion in periodic review systems with maximum inventory, negligible lead-time, maximum of one demand occurrence for each revision interval, and normal distribution of the amount demanded by occurrence. Tavares, et al. [1983] considered the case of demand following Poisson distribution and inventory options of zero or one. The model evaluates these options through the comparison of their costs: for inventory of “one”, it considers regular costs of holding and ordering; for “zero” inventory, it eliminates the holding costs and increases the ordering cost because it comprises emergency purchases (they will occur only when there is already one order on hold). The option for “zero” inventory will take place when the average demand of the item is greater than a lower bound demand calculated by the specific formulation. Olthof, et al. [1994], Apud, et al. [2004] presented a storage decision rule for spare parts where at least one unit should be kept in inventory if its unit annual holding cost is greater than the expected annual shortage cost (emergency purchase and penalties for downtime). Silver, et al. [1998] modified the original model by Popp, [1965] to consider the existence of the cost to include the item in the inventory control system. Alternative formulations for decision in two conditions are obtained: i) keeping other Popp’s premises; and ii) changing the premises of similar costs for regular and emergency orders. Botter and Fortuin, [2000] applied the AHP method in a case study performed in the electronic industry.

The study uses the VED classification of criticality of items together with a demand classification (high, medium or low) to take or not the decision to store the item.

2.1.3 Maintenance spare parts versus semi-finished inventories

Specific literature addressing maintenance spare part management as spare part inventories differ from semi-finished inventories through several aspects. First difference pointed out by Kennedy, et al. [2002] between spare parts inventories and semi-finished inventories concerns the function of the inventory: semi-finished inventories exist in order to smooth production flow whereas the function of spare parts is to assist maintenance staff in keeping equipment in operating condition. Spare parts are used in the maintenance environment. The British Standards Institutions defines maintenance as the combination of all the technical and associated administrative actions intended to retain an item in, or to restore it to, a state in which it can perform its required function. Secondly, maintenance spare parts inventories are different from other semi-finished inventories because they have the following unique characteristics: their need for a spare part is defined by the maintenance policies. Corrective and preventive maintenance policies affect the stocks levels and inventory policy.

Two review papers have been written on spare parts management. The first one by Guide et al. [1997] discusses the existing literature, examines the various models proposed and the major assumptions made in those models, and classifies them according to their solution and methodology (single versus multi echelon and exact versus approximate solution). One of such model focused on inventory control processes. The other model discusses management issues, age-based replacement, multi-echelon problem, problems involving obsolescence, repairable spare parts. [Kennedy, et al., 2002]

However, none of those reviews give a conceptual framework. A framework is useful because it provides rules of thumbs facilitating management decision-making process. It also gives a general comprehension by showing the connection between the decisions taken in different sub-processes within spare parts management overall processes. A general framework is needed to increase the efficiency, consistency and sustainability of decisions on how to plan and control the spare parts supply chain. In this respect, Cavalieri, et al. [2008] provides a first framework for spare parts control. He presents A five steps decision-making process (part coding, part classification, part demand forecast, stock management policy, policy test and validation) to allow managers to control their maintenance spare parts. Phillip, [2007] provided a broader perspective by incorporating what he called ‘The 7

Actions for Inventory Reduction'. He identified seven key MRO processes : Have someone else hold it for you, Sell excess and obsolete stock, Eliminate duplication, Change the factors that drive safety stock, Reduce reorder stock, More closely match delivery with usage, Reduce the value of item held.

2.1.4 Spare parts management and equipment reliability

Spare Parts Management dispensing in an organized maintenance storeroom is one of the key processes which support effective maintenance planning and scheduling and equipment reliability improvement. Improved materials and spare parts management will free up time for maintenance planners, maintenance supervisors, and hourly maintenance personnel. Spare parts availability and its prompt accessibility is among the major factors leading to a reduction of the protraction of downtime when a breakdown occurs. Thus, a logical approach to solving the issue of spare parts availability lies in preserving requisite sizes of inventories of spare parts for immediate disposition whenever needed. On the other hand, stocking is limited by space and cost; for these reasons, designing the reserve of spare parts in an optimal way represents a critical and important task for every parts inventory manager. There are many aspects that must be considered when reviewing any MRO materials and asset management program. In those organizations where Purchasing and Materials management are not directly involved or empowered to impact the management and direction of these programs, significant opportunities exist for cost reductions and process improvements. Many times the responsibility for selecting items to be stocked, replenished, maintained and disposed of is the responsibility of departments other than Material Planning or Management. The question that is commonly raised regarding the management of assets and MRO by Maintenance and Operations is, "why shouldn't those departments that use and require these materials also order, stock, repair, and maintain these materials?" The fact is that many companies effectively "carve out" several of the fiscal duties and responsibilities from the Materials and Purchasing Management function, and make it the direct responsibility of Maintenance and Operations; the issue is not whether the required repairs and services are performed, but rather how can this process be managed and performed at the same or higher service level at a lower cost. The other major problem is increasing the awareness of why the change is necessary and implementing the change inside the organization is critical, once opportunities have been identified [Timme, and Christine, 2003].

Two main approaches that have been followed to develop a possible spares provisioning decision model are: Mathematical models; and Classification approaches. The first approach concerns the development of mathematical models based on linear programming, dynamic programming, goal programming, and simulation [Kennedy, et al. 2002]. Similar approaches have been examined extensively in the past and a vast number of inventory models have been developed during the last decades. Starting from the multi-echelon technique for recoverable item control (METRIC) model of Sherbrooke, [1968], several researches have been conducted that deal with a variety of different aspects of the spare parts inventory management. These works are generally concentrated on the mathematical optimisation of the inventory costs and service levels associated with a potential spares inventory policy in terms of economic order quantity, reorder point, safety stocks, and so on [Kennedy, et al. 2002]. Application of multi-attribute decision making (MADM) techniques and analytic hierarchy process (AHP) methodology for spares classification have also been considered in the literature [Sharaf,and Helmy, 2001, de Almeida, 2001]. Attributes such as, usage rate, standard characteristics of spare, lead time of supply, spare cost are considered in their models [de Almeida, 2001].

However, most of these methodologies are too complex, abstract or oversimplified, because they are too rigorous and time consuming thus reducing their usefulness for maintenance managers working in low-tech low-risk industries such as palm oil mills.

Apart from new generation turbines and decanters whose maintenance is usually outsourced, most of the critical equipment in palm oil mills is low-tech [Sivasothy, et al. 2006]; it does not warrant a finer spare parts management system that might be essential for, say, an automotive plant; as most of the mills still operate equipment that was designed in 1950's and 1960's [Sivasothy, et al. 2006]. Given this level of sophistication, the classical ABC model is adequate to manage spare parts inventory in palm oil mills. The use of classification schemes as a spare parts management tool represents a popular approach in industrial world. ABC-classification according to the Pareto's principle is the most well known and used classification scheme to manage the spare parts inventory management problems. A criticality classification of spare parts is generally based on administrative efficiency considerations (such as inventory costs, usage rates, etc.) derived from historical data of the company. The modern production planning software packages, such as ERP, are able to obtain similar analyses easily and with a reduced time consuming operation. Based on these analyses, oversized inventories, obsolescence aspects or stock-out problems for the different items are recognised [Braglia, et al. 2004].

2.1.5 Spare parts inventory management and abc analysis

The ABC analysis provides an apparatus for identifying items that have a significant impact on overall inventory cost, while providing a mechanism for identifying different categories of stock that will require

different management and controls. The ABC analysis suggests that inventories of an organization are not of equal value.
Thus, the inventory is grouped into three categories (A, B, and C) in order of their estimated importance [Cheng, 2010].

Primarily, a spare part inventory is generally analysed through a failure mode effects and criticality analysis or FMECA to obtain a first reduction of the problem dimensions; that is only the most critical spares are analysed.

Thereafter, an ABC analysis according to Pareto's principle of the most critical spares is carried out to classify the different items. In this way a second reduction of the items is obtained (i.e. only the spare parts classified into the most critical class will be considered in the next step). The conventional ABC analysis adopted by many firms, classifies the plant components into three classes of criticality: very important (A-class), important (B-class), and less important (C-class); only the components belonging to class A require management attention. An accurate re-definition of the stock levels for the different spare parts is executed; thousands of items may be potentially held in inventory by a typical company, but only a small portion of them deserve management's close attention and accurate control [Sharaf, and Helmy, 2001].

The classification of spare parts is frequently based on a single criterion; the most frequently adopted is the annual cost usage. Spares with low utilisation and low inventories are considered to be of low importance. Only obsolescence/deterioration problems must be carefully taken into account for this type of item. A careful revision of the safety stocks, reorder points and order quantities is generally required so as to attempt to reduce the stocks. In particular, for the items that are already characterised by low safety stocks, improvements can be obtained adopting the just-in-time paradigms. Besides quantifiable factors that are taken into account during these standard types of analysis, such as: item costs, usage rate, and historical inventory levels; other attributes concerning more intangible aspects such as safety objectives, provisioning characteristics, type of maintenance adopted, and loss of production, should also be considered.

2.1.6 Productivity measurement

The term ‘productivity’ means different things to different persons. As a phenomenon, it ranges from efficiency to effectiveness, to rates of turnover and absenteeism, to output measures, to measure of client or consumer satisfaction, to intangibles such as disruption in workflow and to further intangibles such as morale, loyalty and job satisfaction. To put it bluntly, the definition of productivity is complex and this is because it is both a technical and managerial concept. Krugman [1990] intended to assert that defining or measuring productivity is a Herculean task when he asserted that “productivity isn’t everything, but in the long run it is almost everything”. In the OECD (Organisation for economic co-operation and development) manual productivity is commonly defined as a ratio of a volume measure of output to a volume measure of input use [www.sourceOECD.org]. While there is no disagreement on this general notion, a look at the productivity literature and its various applications reveals very quickly that there is neither a unique purpose for, nor a single measure of, productivity.

However, within the similar definitions, there are three broad categorizations: i) the technological concept: the relationship between ratios of output to the inputs used in its production; ii) the engineering concept: the relationship between the actual and the potential output of a process; and iii) the economist concept: the efficiency of resource allocation [Wazed et al. 2008]. According to Sink [1983], the overall performance of a company is comprised of at least seven criteria: effectiveness, efficiency, quality, productivity, quality of work life, innovations, and profitability. Productivity is thus a key success factor for all companies. Hannula [2002] has stated that organizations must be able to continuously increase their productivity in order to stay profitable. Therefore, productivity should also be managed. Productivity measurement is one traditional and practical tool for managing productivity. Ideally, total productivity would be measured. Total productivity is the total output divided by the sum of all inputs. As a concept, total productivity is fairly simple. However, the measurement of total productivity is very difficult in practice. The main problem is that different outputs (products and services) and inputs (e.g. labour, material, energy) cannot be summed up. An obvious solution would be to use monetary values but then it would be about profitability measurement. There are several more practical methods available for productivity measurement. Perhaps the most common of them is to use partial productivity measures. Partial productivity ratios can be calculated by dividing total output by some input factor. For example, labour productivity is the ratio between total output and labour input. If partial productivity ratios cannot be calculated because the total output cannot be determined, even more simple method is to use physical productivity measures. They are obtained by dividing some typical output (e.g. number of serviced customers or production amount of main product) by an essential input (e.g. machine hours or labour hours). Productivity combines the concepts of effectiveness and efficiency, where effectiveness is the degree to which end results are achieved to the required standard [Slack, 1997]. Growth is a function of total factor productivity (TFP), which is the aggregation of partial productivities [Heap, 2007]. When focusing on the industries, national, and international levels, many approaches have been designed by economists such as the total factor productivity (TFP), or Bureau of Labor Statistics (BLS) multifactor productivity techniques [Duke et al. and Mayer et al. 2005]. Craig and Harris [1973] provided a total productivity model at the firm level comprising output and four inputs. Mike Hannula [2002] devised a method of expressing total factor productivity as a function of partial productivity. Sumanth [1985] considers the impact of all input factors on the output in a tangible sense. Total productivity [Schroeder, 1985], total productivity in firm [Slack et al. 2001] and total productivity of products [Anderson, 1996] are defined as mentioned below,

Total productivity = (Total tangible output) ÷ (Total tangible input)

Total productivity in a firm = (Total output of the firm) ÷ (Total input of the firm)

Total productivity of product I = (Total output of product i) ÷ (Total input for product i)

Various productivity models

Productivity models are used to measure the Total factor productivity and partial productivities. Various models have been suggested by different authors so as to fit to different productivity measurement scenario such as business level, national accounts or industry level. However all of them should satisfy the basic productivity equation which is defined as productivity = Output ÷ Input. There are some well-known approaches / methods adopted for analysis of productivity. These are stated below.

a) Kendrick-creamer model

Kendrick and Creamer (1955) introduced productivity indices at the company level in their book “Measuring company productivity”. Their indices are basically two types; total productivity and partial productivity. It can be calculated as below.

Total productivity index for given period = (Measured period output in base period price) / (Measured period input in base period price) and partial productivity such as labour, capital or material productivity index can be calculated as; partial productivity = (Output in base period price) / (Any one input in base period price).

b) Craig-Harris model The next most impartment study using the index approach at the company level is of Craig and Harris (1972-75). They define total productivity measure.

Pt =Qt / (L+C+R+Q)

Where Pt = total productivity, L = labour input, C = capital input, R = raw material input and Q = miscellaneous input and Qt = total output.

c) American productivity center model

American Productivity center has measured that productivity relates profitability and price factor.

The measure is given by Profitability =Sales / cost

= [(output quantity) (price)] ÷ [(Input quantity) (unit cost)]

= [(output quantity) ÷ (Input quantity)] × [(price) ÷ (unit cost)]

= (Productivity) (Price recovery factor)

Where productivity = Output / Input

Price recovery factor = A factor which captures the effect of inflation.

d) Productivity accounting model

H. S. Davis introduced this model. It fulfils almost all the requirements of accounting for productivity.

This model takes into account all possible outputs and inputs used, keep out external factors such as price rise etc. Here productivity means total productivity and partial productivity. This can be calculated as below.

$$Total\ Productivity = \frac{Monetary\ Value\ of\ Production}{Monetary\ Value\ of\ all\ Input\ required\ for\ Production}$$

$$Partial\ Productivity = \frac{Monetary\ Value\ of\ Production}{Monetary\ Value\ of\ any\ Input\ required\ for\ Production}$$

2.1.7 Single-loop and double-loop learning model

Some researchers recognized that in almost any type of problem solving people work within constraints that may or may not be real. Such approaches have been described as Single Loop Learning [Argyris,1970]. There are two problems with Single Loop Learning. First, you can never improve beyond your self-imposed constraints (Argyris calls these governing variables).

Second, you may not realize that you are imposing these constraints on your thinking (Otherwise they are unlikely to be constraints). Achieving breakthrough improvements in any field requires a challenge to the constraints inherent in the original thinking. Professor Argyris called this Double Loop Learning. Figure 2.1 shows how Double Loop Learning extends the thinking of Single Loop Learning.

The model supports group development processes, global teamwork, and intercultural learning. Single-loop learning involves connecting a strategy for action with a result. For example, if an action we take yields results that are different to what we expected, through single-loop learning, we will observe the results, automatically take in feedback, and try a different approach.

This cyclical process of applying a new strategy to achieve an expected or desired outcome may occur several times and we may never succeed. Running out of strategies may push us to re-evaluate the deeper governing variables that make us behave the ways we do. Re-evaluating and reframing our goals, values and beliefs is a more complex way of processing information and involves a more sophisticated way of engaging with an experience. This work is a product of this theory and also presents an opportunity for company managers to acknowledge their self- imposed constraints and work hard to surpass these governing variables and as such achieve desired result.

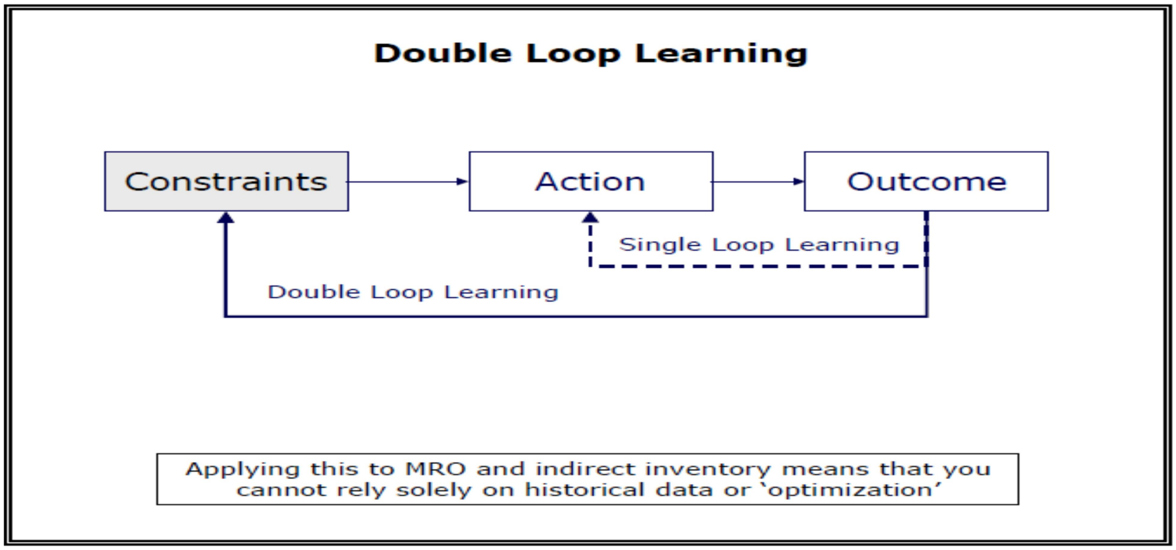


Figure 2.1: Double Loop Vs Single Loop Leaning

2.1.8 Just in time (JIT) philosophy

JIT is viewed as a production methodology which aims to improve overall productivity through elimination of waste and which leads to improved quality. JIT provides for cost efficient production in an organisation and delivery of only the necessary parts in the right quantity at the right time and place while using minimum of facilities.

The root of the JIT systems can probably be traced to the Japanese environment. Japan has inherent limitation of lack of space and lack of natural resources. Japanese has developed an aversion towards all kinds of wastes. They view scrap and rework as waste and hence strive for perfect quality. They strongly believe that inventory storage waste space and result in locking up of valuable materials and capital.

JIT is dependent on the balances between the ability of the user's schedule requirements and the supplier's manufacturing flexibility. It is accomplished through the application of specific techniques which require total employee involvement and teamwork.

Although JIT enables significant carrying cost savings, there are risks involved. The best replenishment formulas cannot predict an emergency breakdown, a vendor going out of business, a carrier going on strike, or a sudden shortage of raw materials.

However, this study borrowed JIT idea of space reduction and unlocking of tied capital in inventory as a means to provide cost efficient production. This research work went further to develop a step by step approach for achieving this.

2.1.9 Bath tub principle

Phillip Slater, [2007], cited in his work -the bathtub principle which is: to effect a change in the water level in a bathtub, you need to change either the input or the output. That is, either adjust the faucet or the drain.

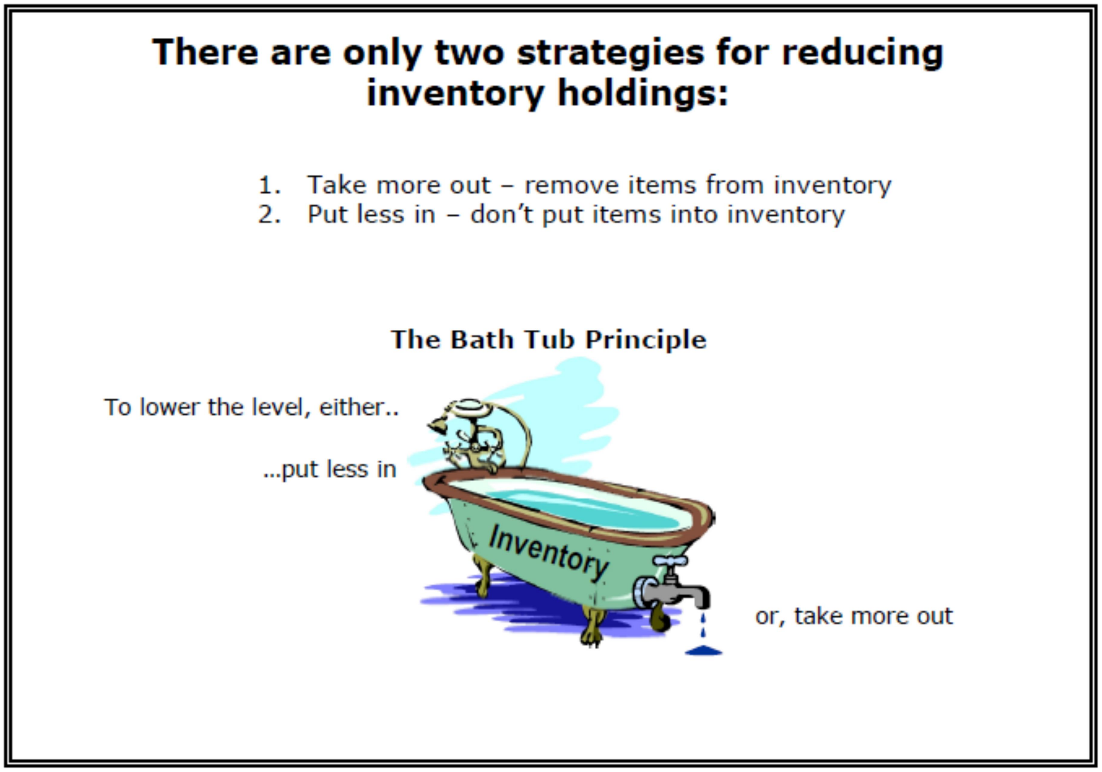


Figure 2.2: the Bath tub Principle

With inventory, the issue is very similar. To effect a reduction in your inventory level you need to either increase the output or reduce the input. Therefore, the actions will fall into one of two categories:

1. Take more out,
2. Put less in

Understanding the Bath tub Principle cuts through all of the jargon and over-complication that gets presented with respect to inventory management. There are only two strategies for inventory reduction and all actions are variations of those strategies. The application of the Bath Tub Principle is demonstrated in Figure 2.2.

The Bath Tub Principle is a key concept because many people find inventory reduction to be a complex exercise involving supply chain review and initiatives, IT installation, and major operational change. At the heart of that though, you are only trying to find ways to take more out, or put less in.

This approach in fact, is the basis of this research work.

2.2.1 Measures and key performance indicators (KPI)

There are several measures and KPIs to gauge performance of storeroom operation, the major indicators are: Inventory accuracy (cycle count adjustment / total cycle counts); Percentage of stock-outs (number of stock-outs /total parts issues); Percentage of inactive inventory (parts inactive in the past year / total parts); Parts to labour ratio (parts inventory value / maintenance labour cost). When measures and indicators are recorded over time, these become a benchmark for the organization. Continuous improvement efforts can then be launched to improve upon these standards, with the desired result of cost reduction and higher productivity. Without tracking performance, it is not possible for the storeroom to know whether improvements have indeed been worth the effort. JIT inventory management have only a limited ability to assist the efficiency of the maintenance process. Issues such as just-in-case inventory management are far more important. This has implications not only within the area of operations, but throughout the entire supply chain. Often the improvement of a supply chain is based on "how we buy," the probabilistic nature of asset maintenance means also that we need to be thinking about "why we buy" [Mather, 2008].

2.2.2 Nestle Nig. Plc Agbara– The case study

Nestlé Nigeria Plc is a Nigeria – based company engaged in the manufacture, marketing, and distribution of food products including Purified water throughout the country and West Africa. The company offers infant cereals under the Nestlé Nutrend and Nestlé Cerelac brand names; family cereals under the Nestlé Golden Morn brand name; beverage drinks under the Nestlé Milo brand name; confectionery under the Nestlé Chocomilo brand name; and bouillon under the Maggi cube, Maggi chicken, Maggi crayfish, and Maggi mix'py brand names. It also provides table water under the Nestlé Pure life brand name; coffee under the Nescafé classic, Nescafé crem 3-in-1, and Nescafé Breakfast brands; and full cream milk products under the Nestlé Nido brand name.

Nestle Nigeria has a central Technical Store located at the main engineering building where engineering spares are stored. There is also another smaller spare parts store located off the engineering building, close to maggi production section. The spare parts inventory is managed by an intelligent software called SAP- (System Application Procedures).

Through the Technical store supervisor, I was able to get hold of the most current spare parts inventory and its worth in Naira value from the store close to maggi section. The summary of production volume (output) data for the year 2011 and 2012 for the maggi section of the company was also collected through the Production manager. The collections of these data were possible through SAP.

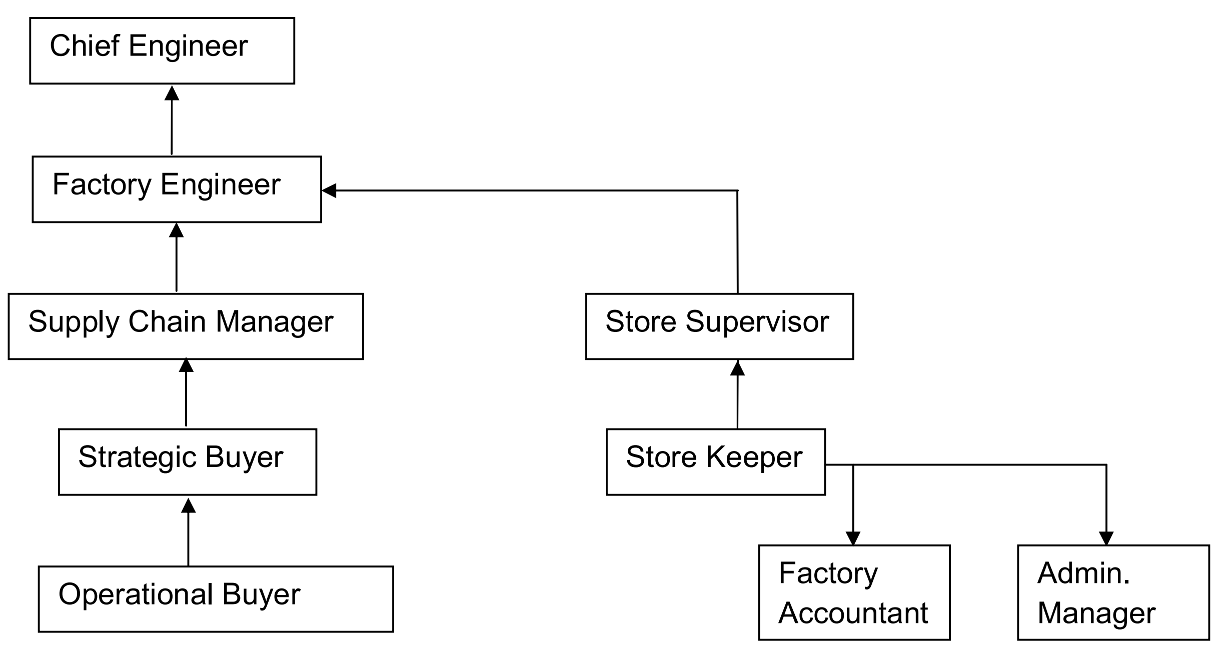


Fig.2.3: Nestle's Spares Inventory Organizational Chart

2.2.3 Risk analysis of factors that affect spare parts inventory level

In 1984, ISI first introduced the concept of risk-based techniques to set stocking levels for non-forecastable rarely-used production spare parts. The benefits of using this technique have been dramatic, as it measures both availability improvement and net stock reductions. Now, for the first time, tools were available to calculate stocking levels for slow-moving items and replace the seat-of-the-pants techniques previously used. These older techniques led to the cost bias in stocking spares that has been observed worldwide in every storeroom, in every industry.

A cost bias is the tendency to overstock less-expensive spares and understock expensive spares. As the tendency to overstock decreases, the likelihood of understocking increases until it is common to see spares priced at $10,000 or more at least 50 percent understocked. As a result, two risks are inherent in any stocking decision; (1) the risk of getting caught short (the probable amount of time each year a part will be needed, but not in stock, times the cost implication of its unavailability) and (2) the risk of getting caught long (The average inventory value waiting for demand that does not occur). The sum of these two risk costs is the total annual risk cost for any given stock level decision.

The end objective is to get a balanced inventory, one without too much overstocking nor too much understocking. Because the input data used to feed stocking algorithms are not always accurate, and other biases come into play when stocking spares, it is unreasonable to expect 100 percent acceptance of any result based on a mathematical computation.

2.2.4 Key stocking input parameters

Most computer codes for setting stocking levels use algorithms that depend on specific input parameters to establish the recommended order point for items, whether active or rarely-used. The key input parameters needed to set the reorder point are: Criticality, lead time to replenish, Issued in set of, and Usage (demand).

a. Criticality

Any discussion of criticality must first start with an understanding of the meaning of Availability, which in this context is defined as the combination of first needing a spare part (because a part has failed) and second the likelihood of having one in the storeroom to meet the demand. For example, a 99% availability level means that, 99 days out of 100, either a spare part is not needed because the equipment is functioning properly or, if the spare part is required, one is available in the storeroom. Conversely, 1 day out of 100 there will be a need for the part and it will not be available. Clearly, availability is synonymous with risk.

Not all spares are highly critical to the production process. Yes, some are so important that they must be available at all times or production will be lost. Others may be only a minor nuisance if not in stock, and replacement deliveries of several weeks can be tolerated.

Maintenance is usually responsible for setting the criticality of a spare part. Although other plant personnel may have an opinion, only maintenance personnel really know the consequences of not having the part when needed. They also are more likely to know if some other part can be substituted for the failed item, possibly lowering the criticality from high to medium, or even low.

It is not practical to assign 100% availability to a spare part because, in theory, an infinite amount of inventory would be required to protect against creating a backorder. What is clear is that as availability increases, more inventory is required to support the lower risk of running out of stock.

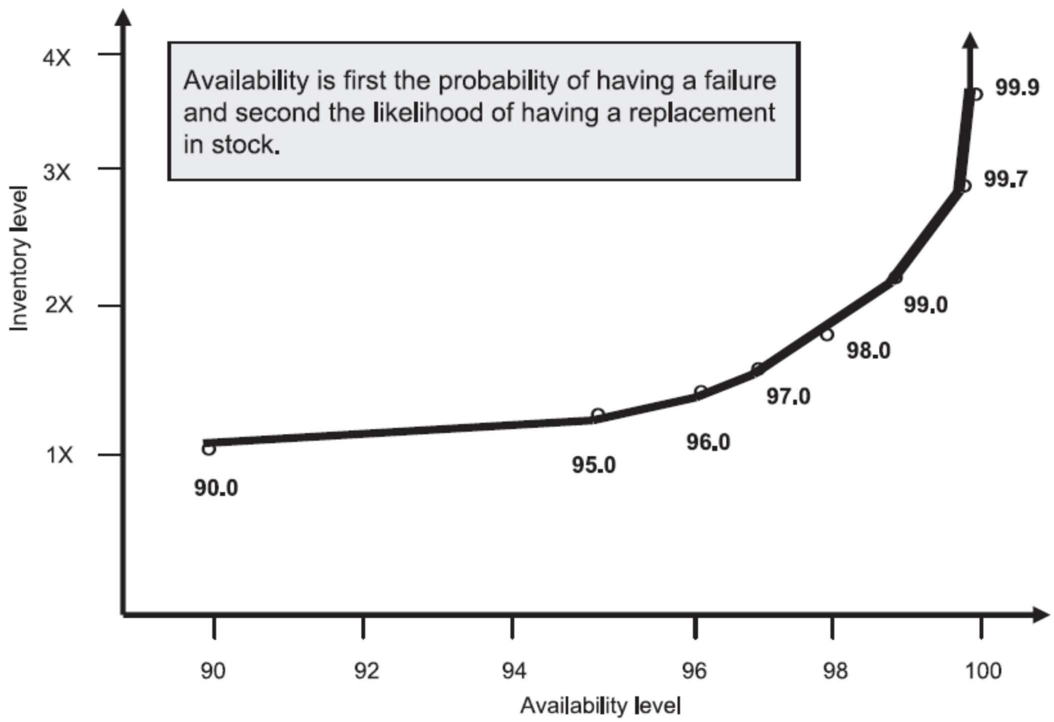


Figure 2.4: The Cost of Improving Availability

Figure 2.4 graphically displays the diminishing return on investment found on the availability-inventory curve. For example, raising availability from 90.0% to 98.0% can nearly double the amount of inventory required, all other stocking parameters remaining the same. To go to 99.9% can double the required stocking again. Because the vast majority of the spare part criticalities assigned in Nestle are either 99.0 or 99.9.

b. Lead Time

Normally, the lead-time chain starts with a requisition to replenish a spare part that has hit the reorder point in the storeroom. Once the paper reaches purchasing, the requisition turns into a purchase order (or blanket order). This step may take several days, or even weeks, waiting in queue to have delivery date, price, or other information verified before issuing the purchase order. Once the spare part is received back at the plant, there may be other delays getting the part into the storeroom bin; some of these delays may be caused by receipt administration and quality inspection. Consequently, these front-end and back-end administrative/ inspection delays can often equal or exceed the actual supplier's lead time to manufacture or supply many parts. Other factors, including shipping, can take up a large amount of the overall lead time.

To understand better the influence of lead time on the stocking of inventory, it is useful to look at how inventory is impacted by changes in lead time. Table 2.1 highlights two significant points. First, as replenishment lead time increases, the Minimum and Maximum stocking levels also increase. Second, as the lead time gets longer, the spread in weeks over which the same MIN/Max applies widens.

Table 2.1: How Replenishment Lead Time Affects the Stocking Level

Replenishment Lead Time (Weeks)	Stocking Level Minimum	Stocking Level Maximum
0	-1	0
1	0	1
2 – 4	1	2
5 – 9	2	3
10 – 16	3	4
17 – 25	4	5
26 – 34	5	6
35 – 44	6	7

For example, any lead time between 10 and 16 weeks (a 6-week spread) requires the same stocking level (MIN 3 and Max 4). A stocking MIN of -1 means the spare does not have to be stocked, but only ordered when there is a demand at the storeroom counter. At a 20-week lead time, the recommended stocking is a MIN/MAX of 4/5. The analysis also reveals that the lead time would have to increase to 26 weeks before more stock was required, whereas a decrease to 16 weeks could reduce required stock by one unit. A decrease of four units (MAX goes from 5 to 1) is possible if the supplier could routinely deliver the replacement spare within one week.

Table 3.3 shows the sensitivity of the reorder point to changes in the lead time for spare parts. The impact of increasing lead time on the MIN/ROP, MAX and average inventory are all shown. Notice that the economic order quantity (EOQ) is not impacted by the lead time changes because the EOQ formula does not contain lead time as a variable. Figure 3.1.4 displays the results in graphical form. Notice the stair step shape of the chart as lead time increases. As indicated, a lead time of 16 weeks requires a MIN of 5 units, a MAX of 7 units (because the EOQ is 2), and $4,503 of average inventory.

Table 2.2: ROP Sensitivity to Lead Time

Price of part = $1,000 Carrying cost = 20%
Cost of purchase order = $70.00

Lead time (wks)	MIN/ROP	MAX	EOQ	Avg. invy ($)
1	0	2	2	1,375
2	1	3	2	2,250
4	2	4	2	3,001
8	3	5	2	3,501
12	4	6	2	4,202
16	5	7	2	4,503
20	6	8	2	5,003
26	7	9	2	5,254
32	8	10	2	5,505
40	9	11	2	5,806
50	11	13	2	6,258

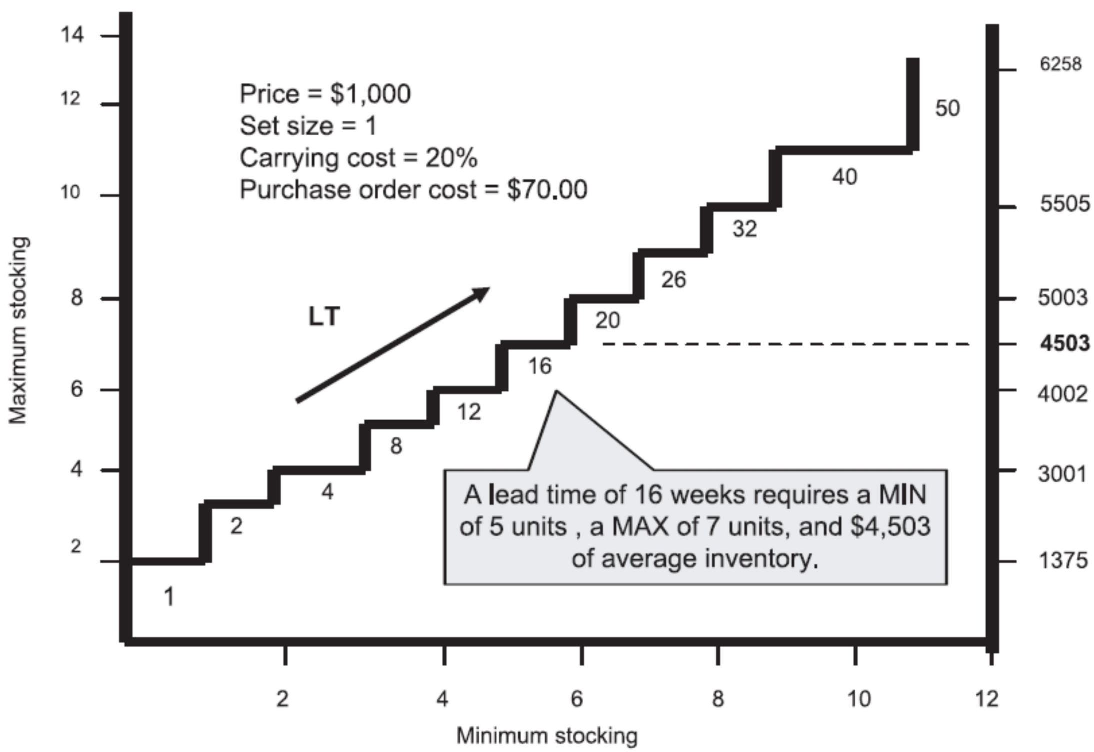


Fig 2.5: ROP Sensitivity to Lead Time

c. Lead time bias

In the preceding pages, we saw that stocking rarely-used inventory in most storerooms results in a cost bias. Likewise, stock levels determined without using a good decision support tool also exhibit a lead time bias. Table 3.4 below shows a typical lead time bias for Nestle Maggi production plant storeroom. For items with a short lead time, 0-2 weeks, actual inventory was overstocked by a factor of 5.6 compared to the recommended level. At a lead time of 16-20 weeks, actual and recommended stock levels were in balance (A/R=1.0). After 21 weeks there was a consistent tendency to understock versus the recommended level. Overall, the actual and recommended inventory for the 2,577 items was in balance as seen by the totals (A/R=1.0).

Table 2.3: Everybody Has a Lead Time Bias

Lead time (Weeks)	Number of items	Actual inventory ($) (A)	Recommended inventory ($) (R)	A/R
0 - 2	2	1,476	260	5.6
3 - 4	61	185,938	58,048	3.2
5 - 6	259	416,749	305,268	1.4
7 - 8	97	256,760	197,507	1.3
9 - 10	93	250,184	202,276	1.2
11 - 15	1,519	4,757,338	4,333,100	1.1
16 - 20	213	697,317	699,178	1.0
21 - 30	210	1,209,580	1,511,970	0.9
31 - 40	65	547,900	602,830	0.8
41 - 50	58	433,745	683,920	0.6
Totals	2,577	8,756,987	8,594,357	1.0

Simply stated, a lead time bias means that readily available parts tend to be heavily overstocked. As a result, parts that can be procured quickly are almost never needed in a hurry. Conversely, long lead-time parts tend to be understocked. Hence, Murphy's Law

– the part that is back ordered is always the most difficult to expedite because it probably has the longest lead time!

Summary

By taking actions to shorten both the replenishment time (Lead time) and the variation in replenishment time, we can hold less stock. These actions could include reviewing our own processes or working with suppliers on improving their response. Increasing the speed and reliability of replenishment has formed the basis of most supply chain improvements in the past ten years. The key difference here is that we know exactly the value of SKU we are seeking to reduce and can easily determine the viability of making any change and at what point it does or does not make sense.

d. **Set Size**

Most spare parts carry a stocking designation of each, meaning they are normally purchased, priced, and stocked as a single unit of each. However, although designated as each, they are frequently bought in cases of 12 or some other number.

Consider the example of two bearings on the shaft of a pump. In the storeroom, the bearings are probably stocked as each, but when maintenance repairs the pump due to a bearing failure, they are likely to draw out two and replace both bearings of the pump, even though only one has failed. The bearing becomes a set of two. Therefore, at least two, or a multiple of two, should be stocked. What happens if maintenance draws out two bearings (a set), but only replaces one in the pump, returning the unused bearing to stores? Now we have a problem, because we are stocking only one-half of a set!

This practice happens frequently, causing delays in getting equipment back into service, as well as costly expedites by purchasing. Special care is needed to determine the most likely set size if a spare part is used in sets. The experience of maintenance now comes into play because they must determine what needs to be stocked as a set, and how many constitute the set size

Table 2.4: ROP Sensitivity to Set Size

Price of part = $1,000 Availability = 99.00 Number in service = 2
Carrying cost = 20% Cost of purchase order = $70.00

Set size	Normal MIN	Adjusted MIN	MAX	EOQ	Avg. Invy ($) for adj. MIN
1	6	6	9	3	6,055
2	8	9	10	2	8,004
4	8	11	12	4	10,503
6	12	17	18	6	15,903
12	24	35	36	12	33,724

Sometimes the MIN is adjusted to be one unit below the MAX to protect against not having a full set available if part of a set is returned to the storeroom and not used during maintenance.

Table 2.4 shows a sensitivity analysis for a spare over a range of set sizes. Given the parameters shown (two in service, availability = 99.00), if the spare is not a set (only one unit required for routine maintenance) the MIN would be 6, the MAX 9, and the EOQ 3, resulting in an average inventory of $6,055. As a set of 2, the values become 8, 10, and 2 respectively for the MIN, MAX and EOQ; at a set size of 12, we get 24, 36 and 12. Notice the column labelled “Adjusted MIN”. By setting the MIN one unit below the MAX, we can compensate for the possibility of stocking a partial set. For example, if the set size was 2, the normal MIN would be 8 and the MAX 10 (EOQ=2). By setting the MIN at 9 units instead of 8, we have programmed the reorder point to trigger a requisition in the event maintenance uses only one unit of a two-unit set when making the repair. Yes, it is true that ordering 2 units at a MIN of 9 would cause the stock to rise to 11 units, exceeding the normal MAX of 10. However, that option is generally considered a lesser evil than not having full sets in the storeroom when needed.

e. **Demand**

The demand for a spare part is a function of how soon it is used in the production process either due to failure, preventive maintenance, or scheduled overhauls. As with criticality, not all demand (usage) is the same. Some spares (active) have high demand and are forecastable, whereas others (rarely-used) have little or no usage and are non-forecastable. The usage rate of a spare part has been found to be the most important factor in determining which inventory management technique should be applied. A frequently chosen cut-off defining a rarely-used item is any item that is issued once per month or less on average. There are two reasons for setting the cut-off at this level:

- Even with the most sophisticated multi-model forecasting systems, some models fail to work properly below this rate of usage.
- Most inventory items are issued either significantly more than once per month, or are hardly used at all.

Also, the rate of usage is not always steady, as shown in Figure 2.5. With steady usage we expect the average stocking level to be equal to one-half the order quantity. Slower or faster usage will have a different impact on the average inventory.

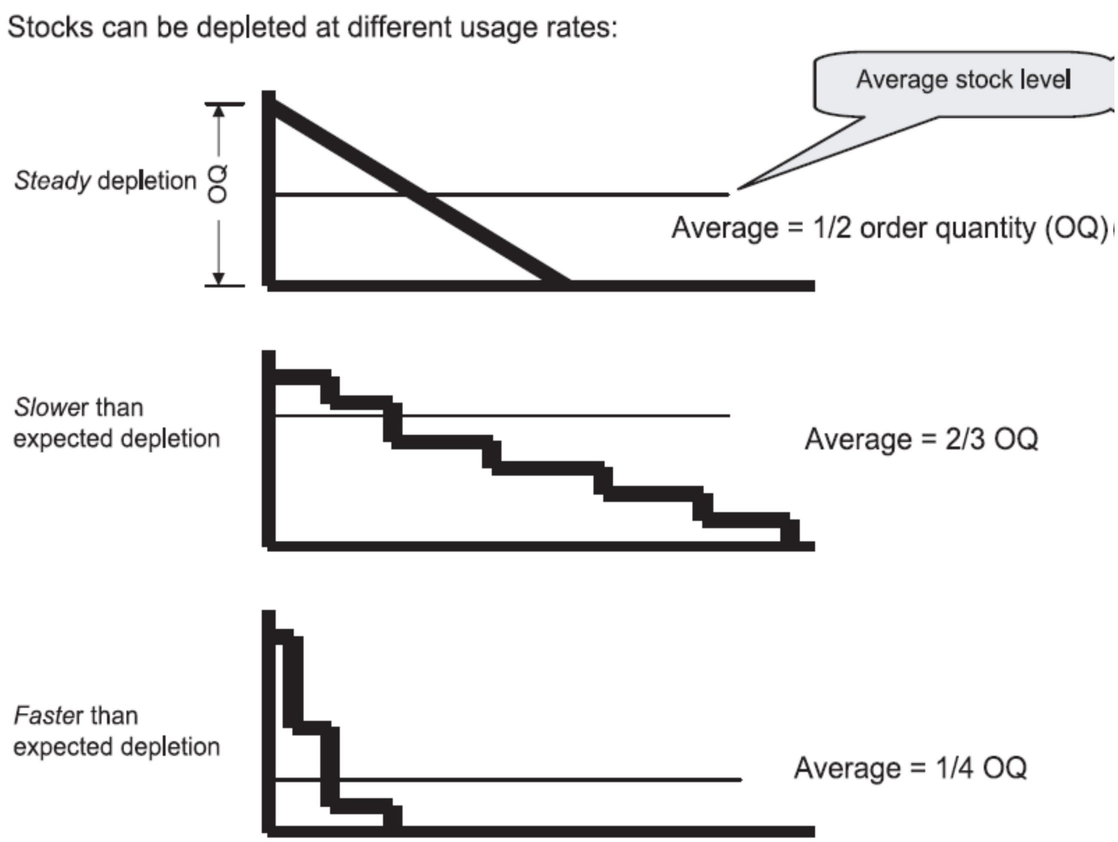
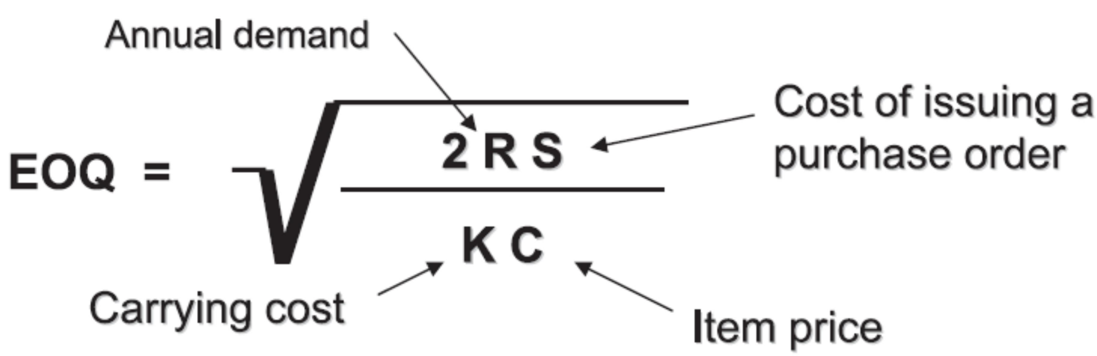


Fig 2.6: The Effect of Different Usage Rates

2.2.5 Factors influencing the EOQ



Four major factors influence the calculation:

1) the annual demand for the item, 2) the cost to issue a purchase order, 3) the carrying cost factor, and 4) the price of the item.

Of the four, only demand is a common factor in setting both the reorder point and the reorder quantity. Because the terms within the square root are a quotient, any combination of values that causes the numerator to increase, or the denominator to decrease, will cause the EOQ to increase.

a. Annual Demand

The annual demand for an item is usually obtained by looking at the usage history of the item captured in the plant material management system. In most cases, the value shown is the total demand, or issues from the storeroom, without consideration of whether the need was to replace a failed part, for a scheduled overhaul, or for some other reason. When setting stocking levels for safety stock, which is what we are mainly concerned about for rarely-used items, we prefer to only consider that part of total demand that relates to part failure. However, most plant material systems do not distinguish between failure demand and other demand. As a result, we typically have to include the total demand when applying the EOQ formula, even though it tends to inflate the reorder quantity.

b. Cost of Issuing a Purchase Order

Determining the cost of processing a purchase order can be tricky.

Should the calculation include both blanket orders and stand-alone purchases? Should it factor-in obsolescence? What about expediting costs? All of these considerations will affect the final value used for Sin the EOQ equation.

To arrive at a value for S, an analysis of the last year or two of purchasing history is necessary. Most companies tend to include in that analysis the following cost components: 1) purchasing department overhead for managers, buyers, and clerical personnel, 2) expediting, 3) receipt and inspection, 4) accounts payable, 5) freight and shipping, 6) computer expense, and 7) obsolescence.

Once the annual cost for these components are determined, the sum is divided by the number of purchase orders processed during the year to arrive at a Naira value per average purchase order. In most cases, blanket orders are not included in the computation because they use only a small part of the above cost components.

c. Carrying Cost Factor

Determining the value to use for the carrying cost factor K in the EOQ formula can be subjective. Usually the value used is the one determined by the chief financial officer (CFO) or the comptroller, and is used company-wide. A number of factors may or may not be used in determining the factor including: 1) local taxes on inventory, 2) warehouse and inventory insurance, 3) storeroom depreciation, 4) obsolescence of inventory, 5) warehouse salaries and overhead, and 6) interest costs on the money tied up in storeroom stocks.

d. The Item Price

One would think that the price of the item one is buying should be the least controversial of all the formula factors. In most cases, it is.

Yet other factors must still be considered when selecting the value for C in the EOQ equation: 1) whether to use the current vendor price or The Company's average unit price in the material system, 2) whether to include or exclude any discounts, and 3) whether to include or exclude freight costs and sales taxes. These decisions are usually made by the financial people; it probably doesn't matter too much what they include or exclude as long as the decision is consistent from year to year.

2.2.6 Systems thinking

Systems' thinking is a way of seeing the connections, links, or relationships between things. Instead of seeing parts and pieces of how things happen, it allows the interdependent whole to be appreciated. It is a process for understanding the interrelationships among key components of a system, such as: hierarchical relations, process flow, attitudes and perceptions, product quality, sales, production, just in time delivery, cash flow, customer service, delivery, research and development, how decisions are made, and hundreds of other factors [Senge, 1990].

This discipline draws on perceptions and experiences of people from different levels and functions in the organization, providing diverse perspectives for improving the quality of systems thinking. Using feedback loops, reinforcing loops, and balancing mechanisms helps to map out systems and the outcomes desired.

To play with employing systems thinking, you can start conversations around openers like,

"We do x that way because …"

"What are your reasons for doing it that way?"

"What works and doesn't work about doing it that way?"

"Can you imagine doing it in some completely different way – and what value might that add?"

"What is going on upstream (policies, systems, practices, habits, traditions, etc.) that affects how and why we are doing things this way?"

"How does doing something this way affect people and stakeholders, things, systems, practices and outcomes downstream?"

"How can we look for synergies with other systems?"

Look at places where there may be a duplication of efforts. Notice how parts of a system may not be seen broadly – overlooking how it could benefit or impact another system. Where might there be waste and how could awareness of that waste be an opportunity for saving human and financial resources? You might begin to see links between what were thought previously to be unrelated variables. Observing at a systems level will enable self-corrections, a balancing of forces, regained stability, self regulation, and generative adaptations.

Systems thinking helps to uncover the living connections between things large and small. After a while, what emerges is recognition of underlying structures to a complex situation – and that often shows up in the form of archetypes. Mapping and analyzing at the systems level allow a careful tracking of factors affecting input, processes, output and outcomes that might otherwise have remained invisible or misunderstood.

CHAPTER THREE

RESEARCH METHODOLOGY

This section gives an insight into the way and manner in which this research was carried out. This includes the mode of data collection, how these data were analyzed and the research design.

3.1.1 Methods

To decouple and structure my work, I make use of the work break down structure (WBS) tool. The main WBS element is my main research topic which is ‘The effects of spare parts inventory control on the productivity of a manufacturing company’. And smaller elements of the WBS will be the sub objectives which at the end of this work provide an answer to my main research topic.

My main objective, which corresponds to my main research topic, is to study the effects of spare parts inventory control on the productivity of a manufacturing firm used in the research.

The figure below shows: Work break down structure.

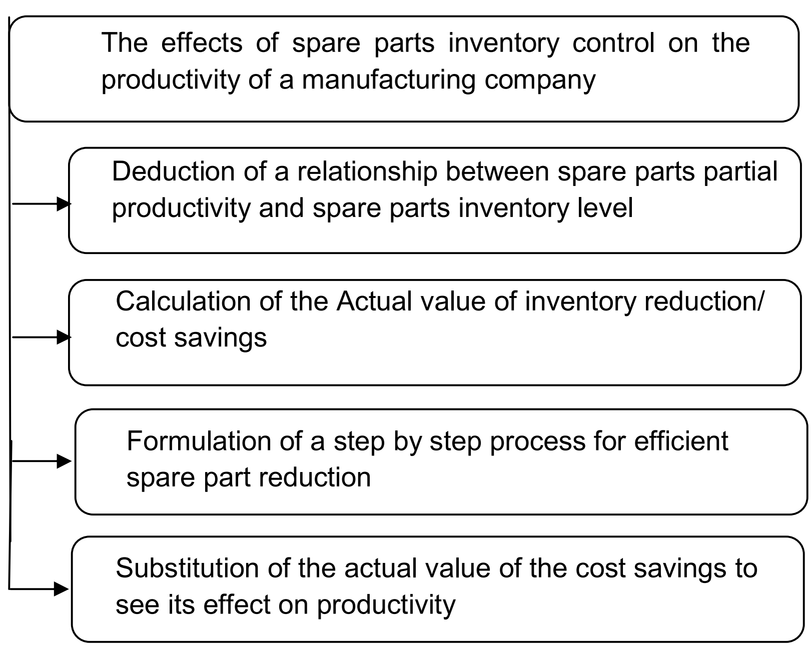


Figure 3.1: Work break down structure. [Florence, 2012].

Having structured my work, I now treat each of the sub objectives in details which in the end provide an answer to the main WBS element.

3.1.2 Deduction of the relationship between spare parts partial productivity and spare parts inventory level.

This sub element of the WBS deduced from Craig and Haris model of productivity equation a relationship between spare parts inventory level and spare parts partial productivity. The deduced equation shows that reduction in spare parts inventory leads to an increase in productivity

According to Martand, [1998], Productivity can be expressed as:

$$\text{Productivity} = \frac{\text{Output}}{\text{Input}} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \quad 3.1.1$$

Using Craig and Harris model of productivity,

$$\text{Total productivity(P)} = \frac{\text{O}}{\text{L} + \text{C} + \text{R} + \text{Q}} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 3.1.2$$

Where L = Labour input factor

C = Capital input factor

R = Raw materials and purchased spare parts

Q = Other misc, goods and services

O = Total output

Let L + C + Q = y

$$\Rightarrow \text{P} = \frac{\text{O}}{\text{R} + \text{y}}$$

But Raw materials + Purchased spare parts + Work in progress = Total inventory

$$\Rightarrow \text{I}_\text{V} = R_M + \text{WIP} + \text{S} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 3.1.3$$

But before the beginning of production, WIP = 0

$$\Rightarrow \mathrm{I_V} = R_M + \mathrm{S} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.1.4$$

Where,

R_M = Raw materials

S = Purchased spare parts

WIP = work-in-progress

$\mathrm{I_V}$ = Total inventory

$$\Rightarrow \mathrm{P} = \frac{\mathrm{O}}{\mathrm{I_V} + \mathrm{y}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.1.5$$

From equation 3.1.4 above, $\mathrm{I_V}$ depends on the variables R_M and S.

In this work, R_M will be left constant. This is because it is assumed that the quantity of raw material is predetermined in relation to the quantity of product demand and that the processing system is design to minimise waste.

Therefore, the total inventory ($\mathrm{I_V}$) reduces to be only a function of the purchased spare parts.

In order to find the relationship between the two variables $\mathrm{I_V}$ and S, I employed the concept of correlation.

The following sets of data as shown below were collected from Nestle Nig. Plc.

Table 3.1: Summary of Nestle's total inventory versus purchased spare parts

Year	I_v ('0000000) (₦)	S ('0000000)(₦)	I_v^2('0000000)(₦)	S^2('0000000)(₦)	I_v*S('0000000)(₦)
2002	140	78	19600	6084	10920
2003	160	86	25600	7396	13760
2004	134	72	17956	5184	9648
2005	144	82	20736	6724	11808
2006	180	80	32400	6400	14400
2007	176	86	30976	7396	15136
2008	174	84	30276	7056	14616
2009	178	89	31684	7921	15842
2010	128	68	16384	4624	8704
2011	132	71	17424	5041	9372
	ΣI_v=1546	ΣS=796	ΣI_v^2=243036	ΣS^2=63776	ΣI_v*S=1242069

Where I_V = Total inventory in naira

S = Purchased spare parts

Coefficient of correlation $r = \frac{n\sum I_V.S - \sum I_{V.}\sum S}{\sqrt{(n\sum I_V^2 - (\sum I_V)^2(n\sum S^2 - (\sum S)^2}}$

$$r = \frac{10(1242069) - (796)(1546)}{\sqrt{[(10)63776 \quad (796)^2][(10)(243036) - (1546)^2]}}$$

$$r = \frac{11444}{\sqrt{(1144)(40244)}} = 0.5966$$

Construction of scattered diagram

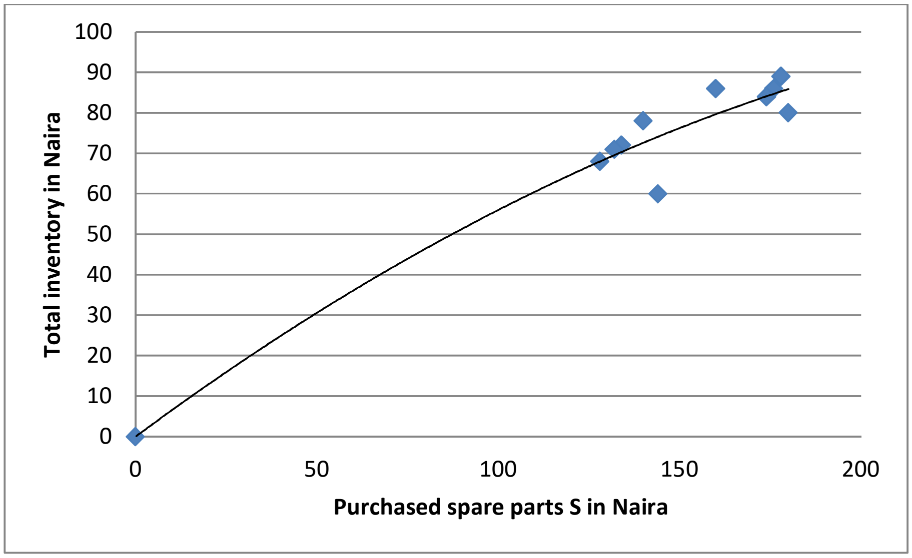


Figure 3.2: A graph of total inventory against purchased spare parts

From the scattered diagram and coefficient of correlation, it shows a positive and strong correlation respectively. This shows that a decrease in S will cause a great decrease in I_V. Hence, to boost productivity, I will focus on the inventory reduction of the purchased spare parts (S).

$$\Rightarrow P = \frac{O}{S + y}$$

Since the total inventory level I_V, is independent of the components of y (i.e. Labour input, Capital input and Other misc. goods and services), y – components factors will be isolated and kept constant.

Therefore, partial productivity of spare parts inventory (P_s) is:

$$P_s = \frac{O}{S} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 3.1.6$$

Where S = spare parts inventory level or purchased spare parts

From equations (3.1.6) above, decrease in the spare parts inventory level S, increases the productivity. Hence, spare parts inventory reduction leads to a productivity increase. This can be further extended to:

$$Spare\ parts\ partial\ productivity = \frac{\text{Total worth of output (ProductionVolume)}}{\text{OriginalWorth of spareparts in store}}$$

$$\Rightarrow \mathrm{P_S} = \frac{T_O}{\mathrm{W_O}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.1.7$$

Where $\mathrm{P_S}$ = Spare parts partial productivity

T_O= Total worth of output (Production volume)

W_O= Original worth of spare parts in store before reduction

Since spare parts inventory reduction increases productivity, the improvement in the productivity achieved can be calculated as:

$$\text{Spare parts partial productivity achieved} = \frac{\text{Total worth of output (ProductionVolume)}}{\text{Current worth of spareparts after inventory reduction}}$$

$$\Rightarrow P_{SA} = \frac{\mathrm{To}}{\mathrm{W_C}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.1.8$$

Where P_{SA} = Spare parts partial productivity achieved

T_O= Total worth of output (production volume)

W_C= Current worth of spare parts after inventory reduction

NOTE: The value of the cost reduction achieved from inventory reduction is dependent upon several factors:

- The inventory reduction achieved
- The cost of financing the working capital; the capital invested in the spare parts may have come from different sources (e.g. Loan from

bank, shareholders, etc) and hence interest and dividends must be paid back.

- The cost of obsolescence, spoilage, and managing, and storing inventory. These factors will vary from inventory and company.

$$\Rightarrow \text{Spareparts partial productivity achieved}$$
$$= \frac{\text{Totaloutput (ProductionVolume)}}{\text{Actual worth of spareparts after inventory reduction}}$$

$$\Rightarrow P_{SA} = \frac{T_O}{W_A} \quad \ldots\ldots 3.1.9$$

Where;

P_{SA}= Spare parts productivity achieved

T_O= Total worth of output (production volume)

W_A= Actual worth of spare parts after inventory reduction

In the light of the above, let the actual value of inventory reduction achieved in cash be C_S.

Therefore,

Actual worth of spare parts inventory after reduction in store (W_A) (in Naira) = Original worth of spare parts (W_O) (in Naira) minus Actual value of inventory reduction in cash (C_S)

$$\Rightarrow W_A = W_O - C_S \ldots\ldots 3.2.1$$

3.1.3 Calculation of the actual value of inventory reduction (C_S)

This will be done by mathematical procedure borrowed from business finance as shown below:

Let:

(i) the original worth of spare parts in store being considered for this process = W_O

(ii) Estimated annual weighted average cost of capital (WACC), adopting 10% = A

(iii) Estimated annual % cost of obsolescence, spoilage, managing and storing inventory (conservatively we assumed 10%) = B

(iv) Inventory cost ratio = C = A + B

(v) Total Annual cost of inventory = C x W_O

This is how much it cost to hold this inventory each and every year.

Potential cash release and ongoing savings

(vi) The average inventory reduction = D

(vii) Potential cash release (E) = original Inventory value (W_O) x Average reduction (D)

$$\Rightarrow \mathrm{E} = \mathrm{W_o} \times \mathrm{D}$$

(viii) Actual value of inventory reduction (C_S) = Cash release (E) * Inventory cost ratio (C)

$$\Rightarrow \mathrm{C_S} = \mathrm{E} \times \mathrm{C} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.2.2$$

It is imperative to note that the cost of financing working capital is much more than just the interest rate the business pay on borrowings. In business finance, there is a term called the weighted average cost of capital (or WACC, pronounced wacc). The WACC will be different for every company because it is based on the sources of capital. Sources of capital include Shareholders fund, borrowings from banks, bond issues, and so on. As this is not a business finance Thesis, I won't be explaining this concept further except to say that for most companies the WACC is generally between 10-15%. To be conservative, I used 10% in this work.

3.1.4 Formulation of a step by step process for efficient spare part reduction

Having established that spare parts inventory reduction increases productivity, it is then necessary to sort for ways to reduce the cash investment in spare parts inventory, which I did by the establishment of an inventory reduction process that ensures that the inventory risk profile is not altered. To do this, I studied in details the spare parts inventory policies, procedures, measures, and reporting used in Nestle which is the case study. A questionnaire to this effect was developed as shown in the appendix. For the inventory reduction process, I developed six steps of inventory reduction that provides a systematic approach to identify the vital few items (that carry higher percentage of inventory value) for attention. After which I apply one (or more) of the established 7 Actions for inventory reduction where necessary. The establishment of the 7 actions for inventory reduction and six steps of inventory reduction were borne out of the application of some managerial principles and models on the spare parts inventory systems operational in Nestle. The principles and models include: The Bath-tub principle, Single and Double Loop learning model, System thinking and MECE principle.

The spare parts inventory reduction process involves collation of appropriate data, step by step application of the developed six steps of inventory reduction and some decision making based on the 7 Actions for inventory reduction. Typically, Spreadsheet is to be developed to lay out the relevant data and record the action(s) to be taken. Consequently, projected value of the inventory will be estimated, thereafter the inventory reduction in naira is calculated.

The six steps of inventory reduction is shown diagrammatically in Figure 3.3 below:

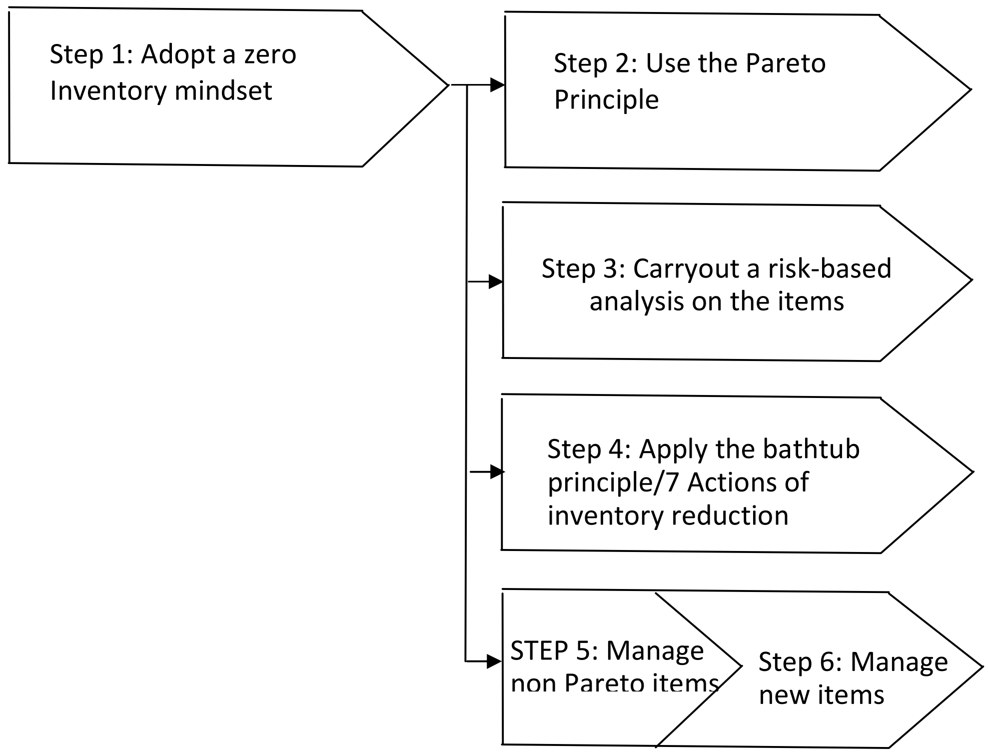


Figure 3.3: Six Steps of inventory reduction

3.1.5 Explanation of the formulated steps

Step 1: Adopt a zero inventory mindset

In an ideal world there would be instant replenishment and zero inventory. Instant replenishment would mean that whenever an item is needed it would be instantly available. But we don't leave in an ideal world and we cannot get instant replenishment. What we can do is to take an approach to inventory that questions the need for inventory or the investment. Adopting a zero inventory mindset is not an action, it is a perspective or framework for all of our future decision making. The key is to ask three questions before making any commitment to inventory holding. The three questions are as follows:

- Question whether stock is really needed – don't automatically assume that it should be held.
- Question who should make the investment
- Determine how planning and process redesign can minimize the investment.

It is by asking and answering these questions every time an inventory decision is made that one start to shape a zero inventory mindset.

To be concise in our work, a more detailed explanation is given in the Appendix.

Step 2: Use the Pareto Principle

For inventory reduction, I focused on the value of inventory held. Put simply, the Pareto principle tells us that the majority of inventory value will be held in a minority of items. That is, a small percentage of inventory items will actually be accountable for the vast majority of the investment. This means that rather than work through the entire catalogue at a detailed level, the greatest impact in achieving an inventory reduction can be achieved by reviewing the vital few items that add most to the naira value invested in inventory. This can be achieved by sorting the spare parts inventory list by Bin value and thereafter, work from top to down the list.

Step 3: Carryout a risk-based analysis on the items

Here, the individual items on the Pareto list are classified based on Active and Rarely-used items. The risk analysis based on Criticality/Availability, Demand pattern, Lead time and Set size of the individual items from top down on the Pareto list is carried out. This is important for inventory reduction that is devoid of cost bias and risk of getting caught short. This is done by carrying out a critical analysis to determine the true position of the individual items relative to the above input parameters. When the true position of the item input parameters are ascertained, I run it on the risk- based decision support tool to set the ROP/MIN, MAX, and EOQ. Thereafter I compare with the existing ROP/MIN, MAX, and EOQ. Whether a variation or no variation is noticed, I apply the 7 Actions of inventory reduction to effect a reduction in the inventory level where need be. But then, the 7actions is applied bearing in mind the risk status of the item under consideration.

Step 4: Apply the Bath tub principle / 7Actions for inventory reduction

Having analysed the items, I went further to take some actions to effect an inventory reduction. By using the bath tub principle as pointed out in my literature review, the focus here is on the two categories of the action which are:

- ❖ Take more out
- ❖ Put less in

Also two other scientific approaches are used to ensure that the actions are mutually exclusive and completely exhaustive (sometimes called MECE). These are hypothesis Driven Analysis and Double Loop Learning model.

Applying a hypothesis driven analysis involves developing hypothesis about the subject and then either proving or disproving the hypothesis. The hypothesis that are proven then form the basis for ongoing development.

Meanwhile, the 7 Actions for inventory reduction are summarised as follows:

1. Have someone else hold it and / or pay for it.
2. Sell excess and obsolete stock
3. Eliminate Duplication

4. Change the factors that drive safety stock
5. Reduce reorder stock
6. More closely match delivery with usage
7. Reduce the value of items held

More on this will be discussed in the Appendix

Step 5: Manage the None Pareto Items That Add No Value

Rather than jumping in and review these items on a one – by – one basis, there is a need to further filter the items to ensure that only those that present real opportunity are reviewed. This filter is to identify these items that add no value.

Primarily, these will be the items that are overstocked; it is also likely that there will be items that are obsolete.

Two ways that overstocked items can be identified:

I. Use inventory management system to generate a 'stock over maximum' report. This report should identify all those items where the stock currently held is in excess of the predetermined maximum.
II. The second is to generate a 'dead stock' report. This report identifies where the SKU in question has never reached zero in stock.
Potentially obsolete stock is identified by reviewing those items with no turnover for some period.

After generating either (or both) reports, I can then apply almost exactly the same process as for the Pareto inventory. Here I can sort the list by bin value (as for the Pareto inventory) or I can sort it by the size of the opportunity, that is, the amount of overstock or dead stock. Thereafter, I can once again begin working from the high value/opportunity items and

Once the items that are overstocked are identified, the approach to managing down can be determined. The approach could include allowing natural attrition, preferential use, or sales of excess stock. As always, prioritise the items to work on, based on total Naira value.

Step 6: Manage New Items

Managing new items as they come could be challenging. After all, most organizations will add new inventory every year. This inventory could be new stock lines in sales, new spares for new stock lines for an OEM, or new engineering inventory for new capital equipment. The problem is that, when deciding what items to put into inventory, many companies limit their thinking; limiting their thinking results in their being overstocked.

Therefore, I have designed a Spare parts decision checklist that can help solve this problem. It is as shown below:

SPARE PARTS DECISION CHECKLIST

KEY ISSUE	YES	NO
1. Availability on short notice		
If failure, is there an alternative which does not jeopardize ➢ Safety ➢ The Environment ➢ The supply promise ➢ Quality		
Could the potential failure be detected and managed in a cost efficient manner before actual failure occur?		
Could the item be repaired in a suitable timeframe?		
Could the item already be supplied rapidly by a local vendor?		
Can we use something that we already have? ➢ Substitution ➢ Duplication ➢ Rationalization		
If we answer yes to any of the above, then follow that option before progressing If we answer no to all the above, be aware that this where most thinking stops-continue on and review the next two issues		
2. Who makes the investment		
Can we get someone else to pay for the item? ➢ Consignment ➢ VMI		
If we answer yes to this, then follow that option before progressing; otherwise review how we can minimize the investment		
Minimize the investment		
It seems that we must make an investment. Can we minimize the investment by:		
Reviewing the factors that impact safety stock		
Reducing the reorder quantity		
Closely matching delivery with usage		
Reducing the valueof the item		
If we answer yes to any of the above, then we follow that option when creating a new stock item		

Figure 3.4: Spare parts decision checklist

3.1.6 Substitution of the actual value of the cost savings

The worth of spare parts in the store in Naira before reduction (W_O) = #6,541,608,000 as collected from Nestle Nig. Plc

Estimated WACC (A) = 10%

Estimated % cost of obsolescence, spoilage, managing and storing inventory (B) = 10%

Inventory cost ratio (C) = A+B

= 10+10

=20%

(i) Total Annual cost of inventory = C x W_O

= 20% x 6,541,608,000

= 1,308,321,600

Average Inventory reduction from the spreadsheet (D) = 29.4% as shown in Table 4.5

Potential Cash Release (E) = W_O x D

= 6541608000 * 29.4%

= 1923232752

Actual value of cash savings (C_S) = E x C

= 1923232752 x 20%

= 384646550.4

Substitute C_S into equation (8)

$$W_A = W_O - C_S \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2.1)$$

$$\Rightarrow W_A = 6541608000 - 384646550.4$$

$$= \#6156961449.6$$

3.1.7 Computation of total output and productivity

NOTE: To compare productivity, indices are to be adjusted to the base year and must be stated in terms of base year naira value. This is referred to as deflating the input and output factors. Deflators are used to nullify the effect of changing price from one year to another.

$$\text{Deflatorforyear 2012} = \frac{\text{Currentyearprice (2012)}}{\text{Baseyearprice (2011)}}$$

Total output for year 2012 = total finished goods produced + total work–in–process + total dividend

- Total finished goods produced (refer to table 1);

$$Deflator = \frac{4400}{3800} = 1.16$$

$$\text{Totalfinishedgoodsproduced} = \frac{6500000 \times 4400}{1.16}$$

$$= 2.465517241 \times 10^{10}$$

Work In Process (WIP);

$$Deflator = \frac{4400}{3800} = 1.16$$

$$WIP = \frac{6500000 \times 0.2 \times 4400}{1.16}$$

$$= 4931034483$$

- *Total Dividend*

  $Deflator = 1.16$

$$Totaldividend = \frac{290000000}{1.16}$$

$$= 250000000$$

$$Totaloutputfor\ 2012 = 2.465517241 \times 10^{10} + 4931034483 + 250000000$$

$= 2.983620689 \times 10^{10}$Spare part productivity before reduction

Using equation 3.1.7 above

$$\Rightarrow P_S = \frac{T_O}{W_O} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.1.7$$

$$= \frac{2.983620689 \times 10^{10}}{6541608000}$$

$$= 4.56$$

Spare part productivity achieved (using equation 3.1.9 above)

$P_{SA} = \frac{To}{W_A} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.1.9$

$$\Rightarrow P_{SA} = \frac{2.983620689 \times 10^{10}}{6156961449.6}$$

$$= 4.85$$

Therefore, % Productivity increase = $\frac{4.85-4.56}{4.56} * 100\%$

= $\frac{0.29}{4.56} = 6.35\%$

3.1.8 Taking action

Before embarking on an implementation process, there are three questions that we need to know the answers to:

1. Do we have the right level of support from the management for an inventory reduction process?
2. Do we have systems capable of generating the required data?
3. Do we know much investment the company has invested in inventory

If we can answer 'yes' to all three questions, then we are in a position to undertake an inventory reduction process.

To achieve a result that can be sustained in a company over the long term, the inventory reduction processes need to have the following goals. These are:

- Need to educate the team on inventory reduction techniques
- Kick start the application of these techniques
- Establish the principles, policies, measures, and reporting to make the inventory reduction sustainable.

3.1.9 Inventory cost reduction process flow chart

Having gone through the processes and its implementation requirements, it is important to present a comprehensive flow chart that can facilitate easy application of the techniques. This chart is shown in figure 3.5 below.

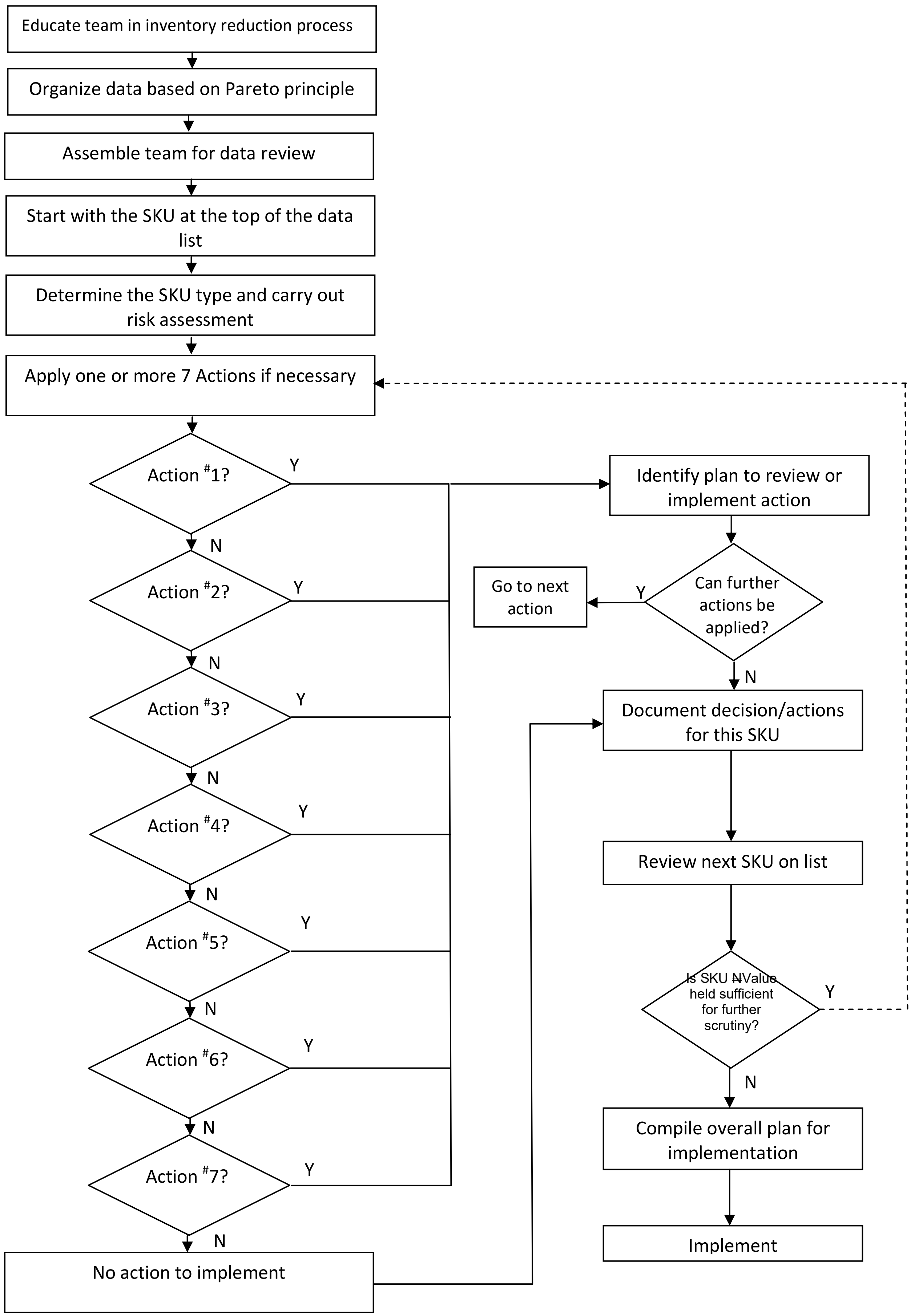


Figure 3.5: Inventory cost reduction process flow chart

CHAPTER FOUR

RESULT AND DISCUSSION

4.1. Inventory review

The data for the validation of the process were collected from Nestle Nig. Plc Agbara, Ogun State. Through the Technical store supervisor, I was able to get hold of the most current spare parts inventory and its worth in Naira. The summary of production volume (output) data for the year 2011 and 2012 of the company was also collected through the Production manager. The collections of these data were possible through the use of the company's business software called 'System Application Procedures' (SAP).

For the spare inventory, due to space limitation, I reviewed only the top 30 items in the Pareto list generated from Nestle's spare inventory. But in a normal case the number could be top 250 or more.

Table 4.1: A spreadsheet containing the top 30 items in the spare parts inventory list and for the purpose of this example. Table 4.1 is sorted by both stock code and item value

Typical Inventory Review Spread Sheet - Sorted by Item Value or Stock Code						
Item No	**Stock Code**	**Description**	**MIN**	**MAX**	**Qty on Hand**	**Item Value (#)**
1	AA1234	Intercooler	1	2	1	3,000,000
2	AA1236	Motor	1	2	2	1,350,000
3	AA1237	Motor	0	1	1	1,275,000
4	AA1238	Gearbox	1	2	2	975,000
5	AA1239	Clutch	0	1	1	840,000
6	AA1240	Pump	1	3	3	675,000
7	AA1241	Spindle	1	3	3	405,000
8	AA1242	Pinion	1	2	3	375,000
9	AA1243	Delivery Valve	15	24	24	300,000
10	AA1244	Suction Valve	20	28	24	292,500
11	AA1235	Delivery Valve Type A	7	10	8	290,000
12	AA1245	Flange	0	1	1	270,000
13	AA1246	Load Cell	1	3	3	255,000
14	AA1247	Hydraulic Cylinder	2	5	5	240,000
15	AA1248	Coupling	5	10	8	225,000
16	AA1249	Casing	0	1	1	225,000
17	AA1250	Impeller	0	1	1	225,000
18	AA1251	Chain Assembly	0	1	1	187,500
19	AA1252	Support Pipe	0	1	1	180,000
20	AA1253	Cylinder Hydraulic	1	3	3	112,500
21	AA1254	Piston and rod	2	4	4	86,250
22	AA1255	Thyristor Equip	40	60	56	52,500
23	AA1256	Hose assembly	3	6	6	45,000
24	AA1257	Sensor	25	40	35	41,250
25	AA1258	Hydraulic Fitting	10	18	15	37,500
26	AA1259	Bearing, tapered	2	10	10	37,500
27	AA1260	Cartridge Filter	2	7	6	37,500
28	AA1261	Cylinder Bushing	10	18	16	12,000
29	AA1262	Circuit Breaker	20	30	25	11,250
30	AA1263	Grinding Wheel	22	30	25	7,500

Note that sorting by stock code and assigning a review based on this sort, potentially results in the review of low value items or stock where there is only a small inventory investment. As it takes as much time to review items with a low inventory investment as it does to items with a high inventory investment, we should focus our time and limited resources where the higher investment exists.

However, sorting by item value is not the answer; it can result in looking at the cost of each item rather than the total investment. Again the use of time and resources in this way will be less efficient.

Table 4.2: Generated list for inventory cash release process

Using the Inventory cash release process generate a list like this one - sorted by bin value							
Item No	**Stock Code**	**Description**	**MIN**	**MAX**	**Qty on Hand**	**Item Value (#)**	**Bin value(#)**
1	AA1243	Delivery Valve	15	24	24	300,000	7200000
2	AA1244	Suction Valve	20	28	24	292,500	7020000
3	AA1234	Intercooler	1	2	1	3,000,000	3000000
4	AA1255	Thyristor Equip	40	60	56	52,500	2940000
5	AA1236	Motor	1	2	2	1,350,000	2700000
6	AA1235	Delivery Valve Type A	7	10	8	290,000	2320000
7	AA1240	Pump	1	3	3	675,000	2025000
8	AA1238	Gearbox	1	2	2	975,000	1950000
9	AA1248	Coupling	5	10	8	225,000	1800000
10	AA1257	Sensor	25	40	35	41,250	1443750
11	AA1237	Motor	0	1	1	1,275,000	1275000
12	AA1241	Spindle	1	3	3	405,000	1215000
13	AA1247	Hydraulic Cylinder	2	5	5	240,000	1200000
14	AA1242	Pinion	1	2	3	375,000	1125000
15	AA1239	Clutch	0	1	1	840,000	840000
16	AA1246	Load Cell	1	3	3	255,000	765000
17	AA1258	Hydraulic Fitting	10	18	15	37,500	562500
18	AA1259	Bearing, tapered	2	10	10	37,500	375000
19	AA1254	Piston and rod	2	4	4	86,250	345000
20	AA1253	Cylinder Hydraulic	1	3	3	112,500	337500
21	AA1262	Circuit Breaker	20	30	25	11,250	281250
22	AA1245	Flange	0	1	1	270,000	270000
23	AA1256	Hose assembly	3	6	6	45,000	270000
24	AA1249	Casing	0	1	1	225,000	225000
25	AA1250	Impeller	0	1	1	225,000	225000
26	AA1260	Cartridge Filter	2	7	6	37,500	225000
27	AA1261	Cylinder Bushing	10	18	16	12,000	192000
28	AA1251	Chain Assembly	0	1	1	187,500	187500
29	AA1263	Grinding Wheel	22	30	25	7,500	187500
30	AA1252	Support Pipe	0	1	1	180,000	180000

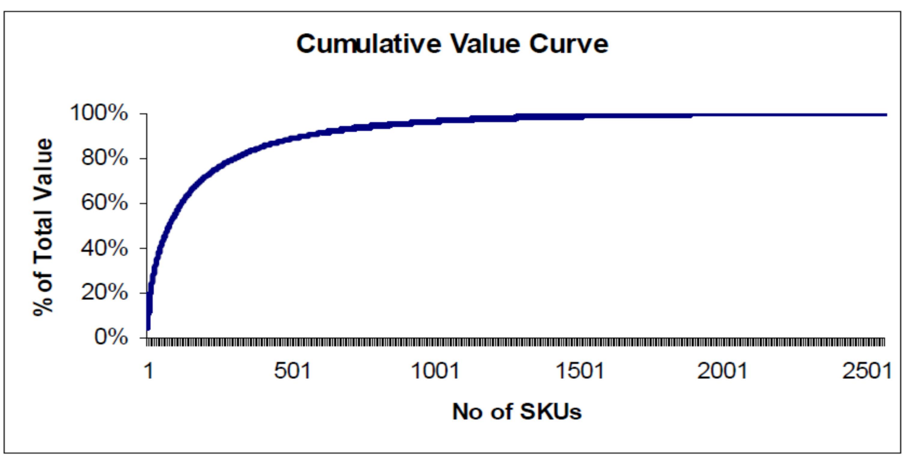
The above table shows the inventory cash release process list – sorted by Bin value.

I have added another column – bin value. The value in this column is calculated by multiplying the quantity on hand by the item value.

From Table 4.2, it can be seen that the first two items have significantly lower individual item values than the third item, but involve a larger number of components and subsequently a higher total investment. It is now clear that we are focusing on the items where our cash is tied up.

Now I can generate a cumulative value curve. To do this I added another column, that is, cumulative and percentage of total value of the complete inventory list as collected from Nestle which is too big to be displayed on this work. But the curve as generated in Microsoft Excel is shown in figure 4.1.

Figure 4.1 below demonstrates clearly that Pareto inventory is where to focus attention.



In this example, 80% of the inventory value is held in just 12% of SKUs

Figure 4.1: Pareto graph

Table 4.3: Classification of Pareto Items

Item No	Stock Code	Description	MIN	MAX	Qty on Hand	Item Value (#)	Bin value(#)	Category
1	AA1243	Delivery Valve	15	24	24	300,000	7200000	Low Turnover
2	AA1244	Suction Valve	20	28	24	292,500	7020000	Low Turnover
3	AA1234	Intercooler	1	2	1	3,000,000	3000000	Slow Moving
4	AA1255	Thyristor Equip	40	60	56	52,500	2940000	High Turnover
5	AA1236	Motor	1	2	2	1,350,000	2700000	Slow Moving
6	AA1235	Delivery Valve Type A	7	10	8	290,000	2320000	Slow Moving
7	AA1240	Pump	1	3	3	675,000	2025000	Slow Moving
8	AA1238	Gearbox	1	2	2	975,000	1950000	Slow Moving
9	AA1248	Coupling	5	10	8	225,000	1800000	Low Turnover
10	AA1257	Sensor	25	40	35	41,250	1443750	High Turnover
11	AA1237	Motor	0	1	1	1,275,000	1275000	Low Turnover
12	AA1241	Spindle	1	3	3	405,000	1215000	Obsolete
13	AA1247	Hydraulic Cylinder	2	5	5	240,000	1200000	Low Turnover
14	AA1242	Pinion	1	2	3	375,000	1125000	Low Turnover
15	AA1239	Clutch	0	1	1	840,000	840000	Obsolete
16	AA1246	Load Cell	1	3	3	255,000	765000	Low Turnover
17	AA1258	Hydraulic Fitting	10	18	15	37,500	562500	High Turnover
18	AA1259	Bearing, tapered	2	10	10	37,500	375000	High Turnover
19	AA1254	Piston and rod	2	4	4	86,250	345000	Low Turnover
20	AA1253	Cylinder Hydraulic	1	3	3	112,500	337500	Obsolete
21	AA1262	Circuit Breaker	20	30	25	11,250	281250	High Turnover
22	AA1245	Flange	0	1	1	270,000	270000	Slow Moving
23	AA1256	Hose assembly	3	6	6	45,000	270000	High Turnover
24	AA1249	Casing	0	1	1	225,000	225000	Slow Moving
25	AA1250	Impeller	0	1	1	225,000	225000	Slow Moving
26	AA1260	Cartridge Filter	2	7	6	37,500	225000	Low Turnover
27	AA1261	Cylinder Bushing	10	18	16	12,000	192000	Low Turnover
28	AA1251	Chain Assembly	0	1	1	187,500	187500	Low Turnover
29	AA1263	Grinding Wheel	22	30	25	7,500	187500	High Turnover
30	AA1252	Support Pipe	0	1	1	180,000	180000	Slow Moving

Now looking at table 4.3, I have added one more columns: ‘Category. The first step in working through the list is to identify which category the item fits. As per the discussion above, identifying the category helps guide us in knowing whether the item under review is active or rarely-used spare. This is to enable us carry out risk-based analysis. Thereafter, we consider which action to apply to each item. Remember, it is possible that we can apply more than one action to an item. For here, as I have stated earlier, this process requires the right level of support from the management, team work and so on. I have applied only one action to each item to facilitate it.

Working from the top down, each item has been considered in turn and the appropriate action determined.

4.2 Case studies

a) The item with stock code AA1235 (Delivery valve Type A) is a critical spare use in the production line. It was found that Nestle had 2000 of this valve currently installed throughout the factory. Its failure without available spare for replacement will cause serious production loss. It has an average lead time of three weeks. Through a study of past failures, the probability of any one Valve failing during the year was determined to be 0.002 or one chance in every 500 Valves. The current MIN/MAX was 7/10 and the quantity-on- hand was 8.

In order to carry out inventory reduction on it, I used the Poisson’s formula to calculate Poisson probabilities for different n values, to determine the probability that 0, 1, 2, up to 10 Valves would fail during the year. The procedure is shown below:

Poisson formula; $Poisson = \frac{\lambda^x e^{-\lambda}}{x!}$

Where λ = np

n = number of units in service

p = probability of units failing during the year

x = number of units failing during the year

Therefore, p = 0.002, n = 2000, λ = 0.002* 2000 = 4

For n = 0, λ = 4

⇒ Poisson probability $= \frac{4^{(0)} * e^{-(4)}}{0!} = 0.018$

For n = 1, λ = 4

⇒ Poisson probability $= \frac{4^{(1)} * e^{-(4)}}{1!} = 0.073$

The result is summarized on the table 4.4 below

Table 4.4: Results of Poisson's Probability Distribution

0	1	2	3	4	5	6	7	8	9	10
0.018	0.073	0.147	0.195	0.196	0.156	0.104	0.06	0.03	0.013	0.005

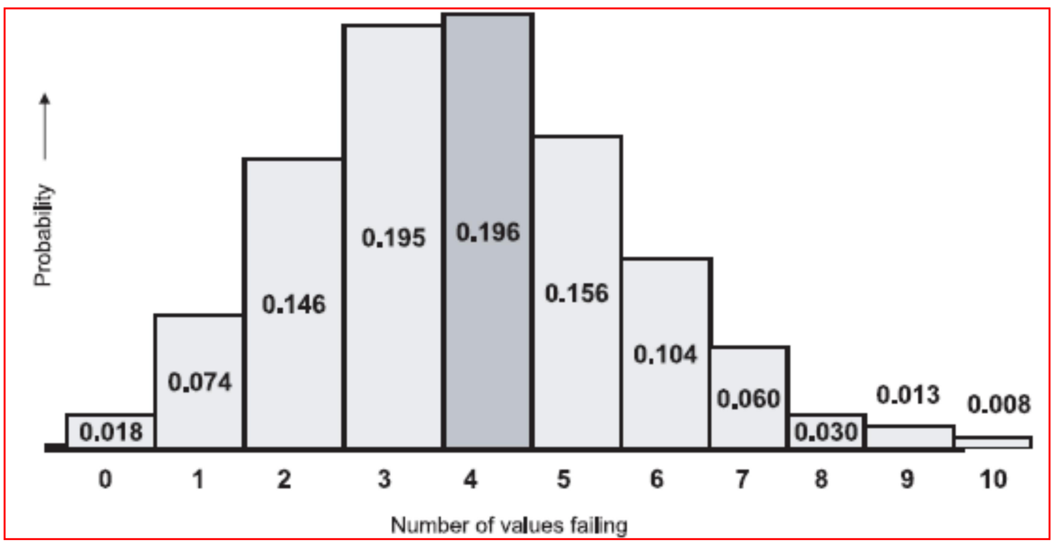


Figure 4.2: Histogram showing Poisson Probabilities

Now, when the histogram is plotted, the results showed a skewed distribution with a peak failure probability of 0.196 for four Valves failures.

Notice that immediately after five valves failure from the histogram, the probabilities continued to decrease and decrease.

From the above result, it shows that the maximum number of valve that can fail in a year is four.

This is the risk-based analysis stage. Thereafter, we considered each of the seven actions of inventory reduction to arrive at an optimal stocking level. We recommended that the MIN/MAX which was set at 7/10 be adjusted to 4/5. This action releases three valves for disposal thereby by reducing the quantity on hand from 8 to 5. This is noted in the table 4.5.

Again, item 1 is a Delivery valve where the turnover is low. But in this case, the full set of 24 is considered as critical. It was decided to take no action on item1. The same goes for items 2 and 3.

Item 4 is a Thyristor device. This is a high turnover item and so may be suitable for consignment stocking from the vendor. This is noted in the table.

Item 5 is again an item that is thought to be OK in terms of inventory level. Item 7 is a pump that is categorized as slow moving. We noticed that there are three of them in stock. Holding three may be too many and so this item is noted as likely to be sold as overstocked.

And so on.

It is obvious that the combination of classifying and deciding which action to apply can help us assign to the appropriate team members the tasks for reviewing the inventory and negotiating with suppliers.

In table 4.5, I have added four more columns: Action to apply, Comment, Projected value and inventory reduction.

Table 4.5: Completed Spreadsheet

Item No	Stock Code	Description	MIN	MAX	Qty on Hand	Item Value (#)	Bin value(#)	Category	Action to apply	Comment	Projected Value	Inventory Reduction
1	AA1243	Delivery Valve	15	24	24	300,000	7200000	Low Turnover	Nil	Critical spare with no alternate	7200000	-
2	AA1244	Suction Valve	20	28	24	292,500	7020000	Low Turnover	Nil	Critical spare with no alternate	7020000	-
3	AA1234	Intercooler	1	2	1	3,000,000	3000000	Slow Moving	Nil	Critical spare with no alternate	3000000	-
4	AA1255	Thyristor Equip	40	60	56	52,500	2940000	High Turnover	1	Put on consignment	-	2940000
5	AA1236	Motor	1	2	2	1,350,000	2700000	Slow Moving	Nil	Repairable Item	2700000	-
6	AA1235	Delivery Valve Type A	7	10	8	290,000	2320000	Slow Moving	Nil	Follow Poisson and reduce qty on hand by 3	1450000	870000
7	AA1240	Pump	1	3	3	675,000	2025000	Slow Moving	2	Sell one pump and adjust MAX to 2	1350000	675000
8	AA1238	Gearbox	1	2	2	975,000	1950000	Slow Moving	Nil	Repairable Item	1950000	-
9	AA1248	Coupling	5	10	8	225,000	1800000	Low Turnover	6	Coordinate delivery with supplier & reduce qty on hand by 6	450000	1350000
10	AA1257	Sensor	25	40	35	41,250	1443750	High Turnover	1	Put on consignment	-	1443750
11	AA1237	Motor	0	1	1	1,275,000	1275000	Low Turnover	Nil	Critical spare with no alternate	1275000	-
12	AA1241	Spindle	1	3	3	405,000	1215000	Obsolete	2	Remove Item	-	1215000
13	AA1247	Hydraulic Cylinder	2	5	5	240,000	1200000	Low Turnover	4	Reduce maximum to 3 due to supplier changes	720000	480000
14	AA1242	Pinion	1	2	3	375,000	1125000	Low Turnover	5	Reduce Reorder by 1	750000	375000
15	AA1239	Clutch	0	1	1	840,000	840000	Obsolete	2	Remove Item	-	840000
16	AA1246	Load Cell	1	3	3	255,000	765000	Low Turnover	5	Reduce Reorder by 1	510000	255000
17	AA1258	Hydraulic Fitting	10	18	15	37,500	562500	High Turnover	4	Reduce maximum to 5 due to supplier changes	187500	375000
18	AA1259	Bearing, tapered	2	10	10	37,500	375000	High Turnover	3	Duplicated with item AA3456-remove this item	-	375000
19	AA1254	Piston and rod	2	4	4	86,250	345000	Low Turnover	4	Reduce maximum to 2 due to supplier changes	172500	172500
20	AA1253	Cylinder Hydraulic	1	3	3	112,500	337500	Obsolete	2	Remove Item	-	337500
21	AA1262	Circuit Breaker	20	30	25	11,250	281250	High Turnover	1	Put on consignment	-	281250
22	AA1245	Flange	0	1	1	270,000	270000	Slow Moving	Nil	Critical spare with no alternate	270000	-
23	AA1256	Hose assembly	3	6	6	45,000	270000	High Turnover	1	Put on consignment	-	270000
24	AA1249	Casing	0	1	1	225,000	225000	Slow Moving	Nil	Critical spare with no alternate	225000	-
25	AA1250	Impeller	0	1	1	225,000	225000	Slow Moving	Nil	Critical spare with no alternate	225000	-
26	AA1260	Cartridge Filter	2	7	6	37,500	225000	Low Turnover	6	Coordinate usage with PM	112500	112500
27	AA1261	Cylinder Bushing	10	18	16	12,000	192000	Low Turnover	5	Reduce Reorder so max is 8	96000	96000
28	AA1251	Chain Assembly	0	1	1	187,500	187500	Low Turnover	Nil	Critical spare with no alternate	187500	-
29	AA1263	Grinding Wheel	22	30	25	7,500	187500	High Turnover	7	Purchase from new supplier at half price	93750	93750
30	AA1252	Support Pipe	0	1	1	180,000	180000	Slow Moving	Nil	Critical spare with no alternate	180000	-
						Total	**42682000**			Potential	30124750	12557250
										Inventory reduction	**29.40%**	

The comment column allows us to put in a comment or define the action required.

The projected value column is the predicted value of the inventory once the tasks assigned for reducing the inventory are complete.

The inventory reduction column is the difference between the bin value and the projected value; it tells us by how much the inventory is projected to reduce.

Obviously, this spreadsheet is simplified. For our purpose, this spreadsheet sets out to show how the process is applied. When working through a real spreadsheet though, there are many numbers of other columns that could be added. They might include:

- More details on the action to be taken by who and when
- The potential timing of the impact of the action
- Whether the action will affect the book value of the inventory.

Finally, look at the bottom right corner of Table 4.5, it is seen that after the inventory reduction tasks take effect, the projected value of these 30 items is N30124750, which is a reduction of N12557250. This is a 29.4% reduction in inventory holdings for those few items.

At this point, it is important to realise that zero risk inventory reduction does not mean that every item must be reduced as we can see that the inventory reduction was achieved despite the fact that for 12 out of 30 items no action was taken.

Now, as mathematically shown in section 3.1.7 comparing productivity before and after inventory reduction, notice a significant increase from 4.56 to 4.85 even though a small portion of the spare list was analysed.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This work has to a large extent contributed in establishment of efficient process for Spare parts inventory reduction. A Six step of inventory reduction were formulated. Risk- based decision support tool immense benefit in analysing the factors that affect Spare parts inventory level and factors that causes excess inventory was discussed. Manual processes, flow chart that can facilitate easy application of the techniques, and algorithms which enhances accurate decision making as well as maximises efficient use of time and resources have also been formulated.

On the application of inventory reduction processes, notice a significant improvement in Nestle's Spare parts partial productivity from 4.56 to 4.85 even though a small portion of the list was analysed implying release of cash, less overstock and cost reduction.

Analysis of the data extracted from Nestle spare parts list, has shown clearly the fact that zero risk inventory reduction does not mean that every item must be reduced as we can see that the inventory reduction was achieved despite the fact that for 12 out of 30 items no action was taken.

Finally, I have been able to show that sorting by item value could result in looking at the cost of each item rather than the total investment. Again the use of time and resources in this way will be less efficient. By sorting with Bin value, we are focusing on the items where the cash is tied up.

5.2 Contribution to knowledge

(ii) An inventory reduction process that maximises efficient use of time and resources; enhances accurate decision making and also drives a lasting and sustainable improvements, has been developed.

(iii) A measurement for spare parts partial productivity which can be used to evaluate breakthrough improvements achieved in spare parts inventory reduction has been established.

(iv) This work provides a conceptual framework. A framework is useful because it provides rules of thumbs facilitating management decision-making process. It also gives a general comprehension by showing the connection between the decisions taken in different sub-processes within spare parts management overall processes.

5.3 Recommendations

1. Companies should not see spare parts inventory reduction as a project that is completed after a specified period. Spare parts inventory reduction should be a culture—an attitude—and it needs to be integrated with the ongoing inventory management and should become part of the way companies do business.

2. Finally, further research is required in the use of the Internet communication. Since many years, more and more business transactions are conducted over the Internet. The term E-business refers to those activities. The term E-maintenance – referring the E-business conducted in maintenance activities – has recently started to be used in the literature. E- maintenance need further research on how it can effectively supports day-to-day activities related with spare parts management. According to Kennedy et al. (2002), the internet has the potential to change the relationship between the maintenance logistic organizations and the spare parts suppliers by increasing communication. Increased communication means greater frequency of communication as well as faster communication. Campbell et al. (2006, p. 149) argue in the same direction on the potential benefits of Internet: —E-business allows the customer to identify, order, specify shipping, and pay for items online on the supplier's website. Efficient systems working in tandem with e-business substantially reduce the transaction costs associated with these purchases. Even if E-maintenance may seem challenging to set, savings and reward are very large – even more for worldwide global companies. The paper by Levrat et al.(2008) presents a framework for E-maintenance and can be considered as a starting point for further work.

REFERENCES

Eugene, C. M., Ronald, M. S., &Michael, P. R. (2006).Production spare parts: optimizing the MRO inventory asset. New York, Industrial Press Inc. pp.325-330

Martang, T. (1998).Industrial Engineering and production Management(1sted.). New Delhi, S. Chand &Comp. pp.16-20

Gupta, S.P. (2011). Statistical Methods (Rev. ed.).New Delhi, Sultan Chand &Sons.pp.415-420

Tagaras, G., Vlachos, D., (2001). A periodic review inventory system with emergency replenishments. Management Science, pp.415–429.

Koudalo, P.(2006). The service revolution in global manufacturing industries. Deloitte Research. pp.110-117

Flint, P. (1995). Too much of a good thing: better inventory management could save the industry millions while improving reliability. Air Transport World 32, 103–107.

Heather H. (2004) Keeping an eye on all your parts, Info world (http://www.inforworld.com/article/02/01/04)

Cohen, M.A., Y-S.Zheng and V. Agrawal, 1997."Service parts logistics: a benchmark analysis", IIE Transactions 29, 627-639.

Senge, Peter (1990). The fifth discipline: the art and practice of the learning organization. New York: Doubleday. pp.110-117

Aberdeen Group, 2005. The service parts management solution selection report, SPM strategy and technology selection handbook, Aberdeen Group, Boston (MA).

Veinott, A. F. (1965). Optimal Policy in a Dynamic, Single Product, Non-stationary Inventory Model with Several Demand Classes. Operations Research, 13, 761-778.

Akçay,Y., & Xu, S.H. (2004). Joint inventory replenishment and component allocation optimization in an assemble-to-order system. Management Science , 50 (1), 99-116.

Alfredsson, P. (1997). Optimization of multi-echelon repairable item inventory systems with simulataneous location of repair facilities. European Journal of Operational Research , 99, pp. 584-595.

Basten, R. J. I., Schutten, J. M. J., & Van der Heijden, M. C. (2009a). An efficient model formulation for level of repair analysis. Annals of Operations Research , 172 (1), 119-142.

Basten, R. J. I., Van der Heijden, M. C., & Schutten, J. M. J. (2009b). An iterative method for the simultaneous optimization of repair decisions and spare parts stocks. beta working paper 295 .

Basten, R.J.I., Heijden, M.C. Van der, & Schutten, J.M.J. (2010). A minimum cost flow model for level of repair analysis. International Journal of Production Economics .

Cavalieri, S. ,Garetti, M. , Macchi, M., & Pinto, R. (2008). A decision-making framework for managing maintenance spare parts. Production Planning & Control , 19 (4), pp. 379-396.

Croston, J.D. (1972). Forecasting and stock control for intermittent demands. Operational Research Quarterly , 23 (3), pp. 289-303.

Damme, D.A.v,& Amstel, M.J. P. v. (1996). Outsourcing Logistics Management activities. The International Journal of LogisitcsManagment , 7 (2), 85-95.

Dekker, R., Kleijn, M.J., & de Rooij, P.J. (1998). A spare parts stocking policy based on equipment criticality. International Journal of Production Economics , 56/57 (3), 69-77.

Driessen, M.A., Arts, J.J., Houtum, G.J.van, Rustenburg, W.D., &Huisman, B. (2010). Maintenance spare part planning and control : a framework for control and agenda for future research. Beta working research paper series .

Gajpal, P.P., Ganesh, L.S., & Rajnedran, C. (1994). Criticality analysis of spare parts using the analytic hierarchy process. International Journal of Production Economics , 35 (1/3), 293-297.

Gilley,K.M.,&Rasheed,A. (2000). Making more by doing less: an analysis of outsourcing and its effects on firm performance. Journal of management , pp. 26 (4): 763-790.

Guide Jr, V.D.R.,& Srivastava, R. (1997). Repairable inventory theory: models and applications. European Journal of Operational Research , 102 (1), pp. 1-20.

http://www.portek.com/publications/Maintenance_Outsourcing_New_Trend.pdf.

Huiskonen, J. (2001). Maintenance spare parts logistics: Special characteristics and strategic choices. International Journal of Production Economics , pp. (71) 125-133.

Jardine, A.K.S.,& Tsang, A.H.C. (2006). Maintenance, replacement and reliability: theory and applications (1sted.). Boca Raton: CRC Press.

Karsten, F. (2009). Cost allocation and cooperation stability in spare parts inventory pooling. Eindhoven: Operations management and logisitics, Eindhoven University of Technology.

Kennedy, W.J., Patterson, J.W., & Fredendall, L.D. (2002).An overview of recent literature on spare parts inventories. International Journal of Production Economics , 76 (2), pp. 201-215.

Kranenburg, A. (2006). Spare Parts Inventory Control under System Availability Constraints. Eindhoven: Technische Universiteit Eindhoven.

Law, A.M.,& Kelton, W.D. (1991). Simulation modelling and analysis (2 ed.). New York: McGraw-Hill.

Muckstadt, J.A. (1973). A model for a multi-item, multi-echelon, multi-indenture inventory system. Management Science , 20 (4), pp. 472-481.

Muckstadt,J.A. (2005). Analysis and algorithms for service part supply chains. Berlin: Springer.

Schultz, C.R. (2004). Spare parts inventory and cycle time reduction. International Journal of Production Research, 42 (4), 759-776.

Silver, E.A.,Pyke, D.F.,& Peterson, R. (1998).Inventory management and production planning and scheduling. John Wiley & Sons.

Stamatis, D. (1995). Failure mode and effect analysis. ASQC Quality press .

Tech, A. C. (2009).Driving out Costs and Adding Value: How Outsourcing Spares and Inventory Planning Drives High Performance.

Teunter, R., & Duncan, L. (2009). Forecasting intermittent demand: a comparative study. Journal of the Operational Research Society (60), pp. 321-329.

Wagner, S. M. and Lindemann, E. (2008).A case study-based analysis of spare parts management in the engineering industry. Production Planning & Control,19:4 , pp. 397 — 407.

Willemain, T.R., Smart, C.N., & Schwarz, H.F. (2004).A new approach to forecasting intermittent demand for service part inventories. International Journal of Forecasting , 20, pp. 375-387.

Krugman P. 1990. The age of diminished expectations, MIT press, Cambridge, MASS. p. 9.

Measuring productivity, OECD manual, Measurement of Aggregate and industry level productivity growth, www.sourceOECD.org

Slack N., S.Chambers and R. Johnston. 2001. Operations Management. 3rd Ed. Harlow: Prentice-Hall.

APPENDIX

Table a: The summary of Nestlé's production volume for the year 2011 and 2012

S/N	OUTPUT	YEAR 2011	YEAR 2012
1	Finished goods produced(in cartons)	3,750,000	6,500,000
2	Work – in – progress (in cartons)	1,800,000	3,000,000
	% of completion	30	20
	Price per carton (naira)	3,800	4,400
3	Dividend from Securities	280,000,000	290,000,000
	Deflector for item (3)	1.5	1.16

Current worth of spare parts in the store as at 31st Dec.2012 is ₦6,541,608,000

THE 7 ACTIONS FOR INVENTORY REDUCTION

Action 1: Have someone else hold it and/or pay for it

The best way to reduce the investment in inventory is to eliminate the investment altogether. Reducing inventory is to eliminate the investment altogether. Reducing inventory in this way can be achieved without risk and with full access to the inventory by having someone else hold and/or pay for the inventory. This approach, sometimes known as consignment stocking; transfers both the ownership and the management of replenishment of the inventory to the vendor, companies only pay for what they use, when it use them.

Consignment stock is however, often thought to be too expensive. The theory is that the vendor will, in time, seek to recover the cost of holding the stock through price increase. But assuming that there is still competition for the business, if that happened companies could still switch vendors or move out of the consignment arrangement. Setting up a consignment arrangement does require careful contract development.

Action 2: Sell excess and obsolete stock

Another great way to eliminate the investment in inventory is simple to sell off items that are excess or obsolete. Operationally, excess and obsolete items generate little interest because they do not create emergencies. The focus has always tends to be on items that stock out, or, at the least, need reordering. Items that are excess or obsolete do not fit either of these categories so only tend to get reviewed if there is a review program such as this. These items add no value to the business and so should be eliminated.

For obsolete items, there are accounting standards that require that any item that becomes obsolete be written down when it is recognized that the item is obsolete. In many cases though, items become obsolete and this is not recognized. When this happens, they add to the business. Also, because accounting standards write down excess and write off obsolete inventory, it is tempting and easy to leave these items on auto pilot and not manage them proactively. While it may seem that the problem will just go away, the reality is that the company has spent its cash on these items and received nothing in return. In effect, this is a complete waste of money.

There are, however, four reasons why removing obsolete items is important.

1. It ensures a discipline that one do not just bury his mistakes by making them obsolete. He can learn from the items that become obsolete and perhaps change his future buying patterns to minimised future obsolescence.
2. It costs money to store, count, and sometimes maintain obsolete items. The fewer items one has, the lower his inventory management costs.
3. If one can sell the item, he can actually retrieve some value. The value may be minimal compared to the original or book cost, but on a cash basis, every naira of income is better than zero sitting in inventory.
4. There may be tax gains from removing obsolete stock. In Australia, a company that removes obsolete stock can gain a tax break equal to 30% of the value of that stock. The tax break is only available when the item is physically removed from the company's premises and ownership. On a cash basis, the tax break is equivalent to an income of 30% of the value.

Therefore, adopting an approach that manages both excess and obsolete stock in a rigorous and timely manner may occasionally result in a need to make difficult decisions and incurring a seemingly otherwise unnecessary expense. However, in the long term, adopting this approach is likely to result in reduced obsolescence and lower holding costs.

Action 3: Eliminate duplication

The third action relating to taking more out is to eliminate duplication. By definition, duplicated items add no value and should be a prime candidate for inventory reduction. There are a number of ways that items can be duplicated in an inventory system. Within a single store, the same or similar items may be held as different item numbers. Across a network of stores, the same or similar items may be duplicated when a shared access might be preferable.

Examples of duplication include:

- Specifying new skills that are only marginally different from those in stock.
- Holding the same item specified by different equipment suppliers using their own inventory codes. This is particularly the case where the OEM supplies the inventory
- Holding stock at two (or more) locations with safety stock at each
- Holding stock when your supplier holds safety stock as well

Despite the advantages of computerization, inventories that consist of thousands of skills can be unwieldy to manage. It is unlikely that anyone knows everything that is held and it is also possible that more than one person is making recommendations on what ought to be held. With this degree of complexity, it is not just possible, it is likely that duplication will occur. The message here is simple, seek to identify and eliminate duplication.

Action 4: Change the factors that drive safety stock

Safety stock has a definite purpose and must be managed to ensure that it fulfils its purpose. Looking at figure a below which represents a series of replenishment cycles for a product.

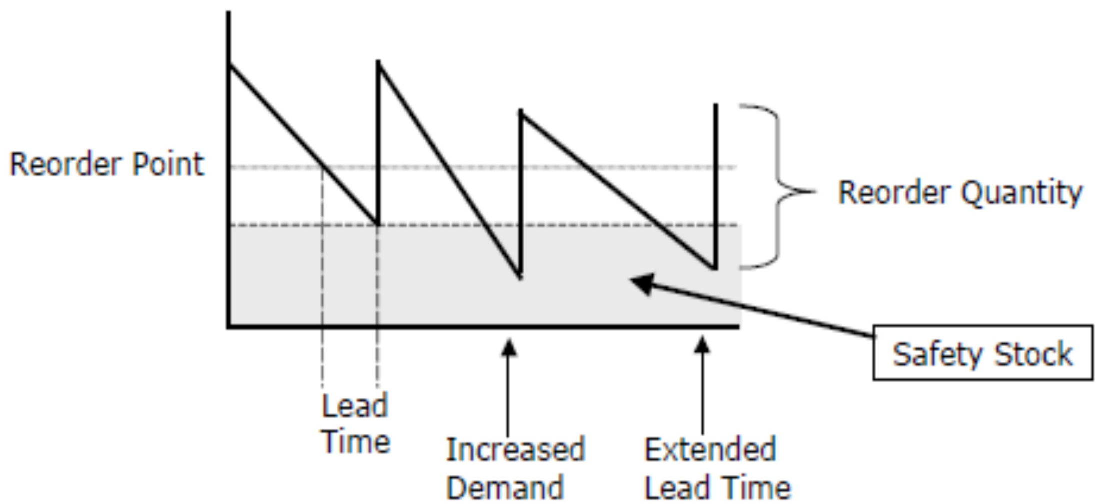


Figure a

In this figure, the shaded area represents the safety stock. The horizontal line represents the reorder point.

In this example, the safety stock is set so that, with the expected lead-time and demand, the stock usage reaches the safety stock level at the time of replenishment. But what happens when demand is greater than expected or lead-time long than expected? As shown, the inventory level goes below the safety stock.

There are ways, however, of reducing the investment in safety stock without impacting the availability of stock or the ability to provide the required buffer. In this work we have enumerated five ways to reduce safe stock:

a) **Increase the speed and reliability of replenishment:** In the example shown in figure a, we can see that extending the lead-time for replenishment results in using safety stock. The replenishment time and the variation in that time partially drive the quantity of safety stock required.

   By taking actions to shorten both the replenishment time and the variation in replenishment time, we can hold less safety stock. These actions could include reviewing our own processes or working with suppliers on improving their response. Increasing the speed and reliability of replenishment has formed the basis of most supply chain improvements in the past ten years. The key difference here is that we know exactly the value of SKU we are seeking to reduce and can easily determine the viability of making any change and at what point it does or does not make sense.

b) **Smooth the demand pattern:** The other driver of safety stock is demand fluctuation, in the figure a above, we saw that an increase in demand resulted in a usage of safety stock.

By taking actions to smooth the demand pattern, we can safely reduce the level of safety stock. This is particularly relevant in situations where demand is driven by artificial factors such as month and accounting and terms of business or, for engineering spares, the usage of items in a factory.

c) **Hold only the right amount of stock:** In the earlier pages we discussed that inventory that does not stock out rarely gets attention for review. Similarly, it is also likely that safety stock levels have been based on an initial estimate of requirements. If that estimate was high and the item never stocks out, it is unlikely that safety stock would be revisited.

One way to minimize the safety is simply to review the required holding based on historical data once sufficient time has passed to provide a sound basis for review.

Depending upon the validity of the product collecting the required data could take anywhere from 6 – 12 months or longer.

d) **Identify changed circumstances:** Supply chain improvement has been the buzz word of industry since the early 1990s. Even if our company has not made major advances in supply chain management, it is entirely likely that our supplier have. They may have a vastly improved capability, but we are not taking advantage of their good work. Of course, if our company has made advances in supply chain management, we are going to make sure that we take advantage of that also. It is also possible that demand patterns have changed. In engineering, there may have been major maintenance improvements aimed at increasing reliability but with the flow-on effect of enabling a reduction of reduction in spares holdings. For direct inventory items such as raw materials and finished goods, the demand may have slowed or changed in characteristic.

By reviewing the current circumstance for an item we can reset the holding parameters and reduce inventory holdings.

e) **Have fever stock holding points:** It has been mentioned a few times that there is a rule of thumb that safety stock increases with the square root of the number of stocking points. For example, if there are two stocking points, 41% more inventory will be required that if there was one. For three points, 73%. In theory, reducing from five stocking point to three would enable a 22% reduction in safety stock.

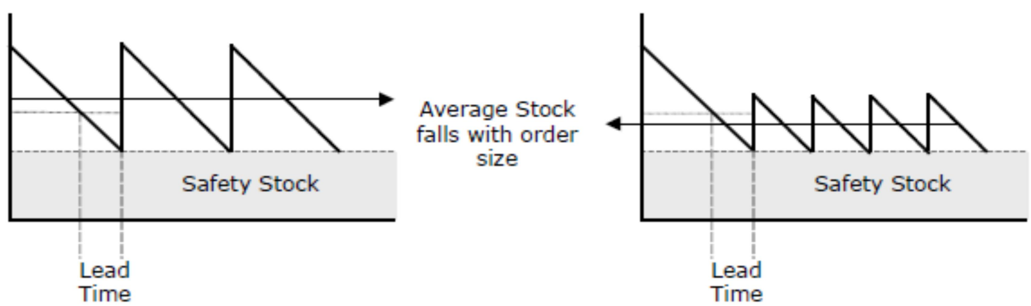
Review the locations at which inventory is held and question whether the number of holding points is still logical.

Action 5: Reduce reorder stock

The average quantity of stock held across a period of time is a function of both the safety stock level and the reorder quantity. Action 5 is to focus on the reorder quantity to reduce the average stock holding.

In figure b below, the shaded area once again represents safety stock. The horizontal line represents the average stock holding under each scenario.

With the replenishment pattern shown, it is simple mathematical calculation to determine the average stock holding. That is, average stock equals the safety plus half the reorder quantity.



Average Stock = Safety Stock + (Reorder Qty/2)

Figure b: Impact of Reducing Reorder Stock

On the left side of figure b, there is a situation similar to that shown for Action 4. On the right side of figure b, the reorder quantity is reduced by half. This change has had the effect of reducing the average stock holding but also increasing the required frequency delivery. Assuming that the delivery increase is not onerous, then changing the inventory ordering in this way is a very effective way to quickly reduce stock holdings with no risk.

Remember that one of the only two strategies that can apply to inventory reduction is to put less in. the point at which we can act on the decision to put less in is when we reorder stock. Therefore, this is the time at which we can have greatest influence over the stock holding. By reducing reorder quantities, we will significantly impact stock holding.

It is also worth considering the logic applied to setting maximum and minimum levels of stock holding.

Many companies set a minimum based on their level of comfort at meeting expected demand with that level of stock. The minimum is based on demand characteristics. They then manage their stock holding to their maximum stock setting, that is, the level of stock they are comfortable holding based on supply characteristics. Managing their stock holding in this way drives their stock holding to the maximum.

Why not change the approach and manage to the minimum? The minimum is the level that meet demand and also minimizes the investment in inventory.

Example of Action 5

The real impact of Action 5 is dependent upon the relative level of safety stock compared to operating stock. Two examples are given to show the relative impact.

Low Safety Stock

This company orders 12 weeks supply of an SKU that takes one week to be restocked. Let's assume that they hold two weeks supply as their safety stock.

The average stock = 2 + (12/12) = 8 weeks stock.

Now, assume that they change the reorder quantity to 4 weeks and reorder every month.

The average is now = 2+ ($4/_2$) = 4 weeks stock.

This simple change produces a 50% reduction in the average holding of that SKU.

High Safety Stock

This company orders 4 weeks supply of an SKU that takes one week to deliver. In this case, the demand is highly volatile and they hold 4 weeks supply as safety stock.

The average is now = 4 + ($4/_2$) = 6 weeks stock now assume that they change their reorder quantity to 2 weeks and every fortnight.

The average is now =4 + ($^4/_2$) = 5 weeks stock

Even in this more extreme example, the average stock reduction is 16%!

Action 6: More closely match delivery with usage

Until now we have been looking at ways to reduce the physical number of items held. However, one of the variables that drive the cost of holding inventory is how long we hold the inventory. This represents the amount of time that we might have to finance the working capital required to buy the inventory.

Reducing the time that we hold inventory has the same impact as putting less in. This is because if we can shorten the length of time in which we hold the inventory, we can significantly reduce the average inventory holding and directly impact the holding cost.

This is shown diagrammatically in Fig (c).

Holding fixed frequency| project materials longer than is necessary increases average inventory holding.

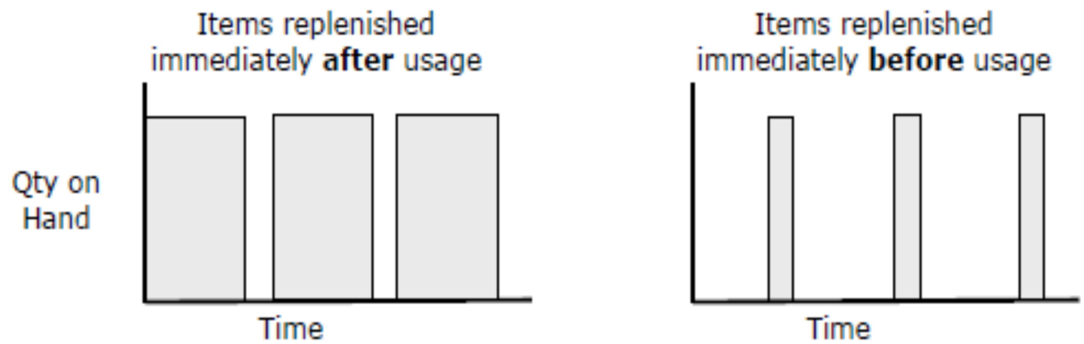


Figure c

In many cases it may be hard enough to predict how much of an item we need, let alone get the timing of delivery right. After all, we hold inventory as a buffer between supply and demand.

There are some cases, however, where we can make decisions about timing without impacting the risk. These are cases where we have project stock regular frequency use in engineering, or sale/ special event stock in retail. In each of these cases, the usage/ requirement date is reasonably well known. By planning the purchasing of that inventory close to the event, the average inventory holding is reduced substantially.

Fig c represents a fixed frequency of usage. On the left, the item is restocked immediately after use. Here we can see that the stock then waits until the next usage before going quickly through a usage/ restock cycle.

On the right of Fig c, the same item is restocked just prior to being used. Here there is no stock for long periods when the item is not required. We can see from the amount of white space on the right that the averages holding will be very much lower. The example below qualifies this.

This philosophy is a central part of a JIT approach to inventory management and often is thought to need sophisticated MRP controls or Kan Ban Systems. The approach can be applied, though, will just a little fore thought on the inventory needs and the requirements of demand.

One warning: Some companies operate reservations systems whereby stock can be held for a particular use or customer. If these systems are applied indiscriminately or don't recognize the acceptable level of risk, they can cause overstocking.

For example, assume that an item will be reordered when it reaches a minimum quantity of 5. This means that it has been previously determined that 5 items are sufficient to cover the restocking cycle. If there are 10 in stock and someone reserves 5, a poorly tuned reservation system will order a restock even though the minimum has not been physically reached. Reordering the stock in this way would result in stock being brought in weeks ahead of when it will be required. If the full quantity of reserved stock is not used (as often happens), then the item will be over stocked and we will have invested in inventory that we do not yet need.

Poorly tuned reservations systems are a common issue in manufacturing and production environments.

Example of Action 6

A company replaces a wearing part in its plant every 12 weeks. The item is held as a store item in order to simplify the planning and ensure availability.

Assume that the item cost ₦1000 and takes one week to be restocked.

Using the pattern on the left of Fig b, the item will be restocked immediately after usage and will be in stock for 11 out of 12 weeks or approximately 47 weeks of the year. At a holding cost of 10%, this would cost the company ₦90.00 per year to hold. [(47/52) x ₦1000 x 10%].

Using the pattern on the right of Fig c, and ordering two weeks before usage, the item will be in stock for 1 out of 12 weeks. The holding cost will now be ₦8.33 pre year, a reduction of 90%!

Now translate the ₦1000 cost to the hundreds of thousands or millions of dollars that might benefit from this approach, and the will be massive.

Action 7: Reduce the value of items held

Reducing the value of items held is the last of the 7 Actions and is probably the most obvious, but perhaps because of that the most overlooked.

Most cost reduction actions one aimed at reducing the price of an item for the obvious profit and loss impact. However, price reductions also have an impact on working capital and the investment required for inventory.

The other six actions discussed in this manual are aimed at reducing the quantity held in stock or the time for which it is held. Action 7 is to work on reducing the purchase price, as per the equation below.

Note: Typically accountants measure the ₦ value held of inventory.

By purchasing at a lower cost (or lower cost items), the total ₦ value held reduces.

Store value	=	No of items	x	cost per item

There is no reason why the approach would be different from a normal cost reductions exercise, just that the initial starting point is different. The target may not even be the actual unit price, but could be consolidated without impacting inventory holdings? Do we pay for fast delivery when slow will do?

Here are some of the approaches that can be applied to review the price of inventory:

- Volume concentration – across sites or with suppliers
- Product specification review
- Joint process improvement
- Building
- Unbundling
- Expanding the supplier base to increase competition
- Concentrating the supplier base to drive greater surety with vendors.

Don't forget that we are only applying this action to our Pareto inventory and to specific items within that subset of our inventory. Action 7 is not advocating a comprehensive strategic souring review, but a targeted price review aimed at specific skills that are high value held items. From this perspective, this action becomes a very manageable task to undertake.

Be wary, however, of trading off inventory holding for price reduction. There is need for a clear economical benefit for any change.

SPARE PARTS INVENTORY QUESTIONAIRE
ORGANIZATION

S/N	QUESTION	Yes	No	N/A	Remarks
1	How many stores locations are there in this company/on this site				2
	Check for different businesses/divisions and different store types.			√	
2	How is inventory classified and organized				
	Machine/process				
	Type: mechanical or electrical				
	Active, inactive, obsolete	√			
	A, B, C	√			
3	What are the organizational structure and responsibilities for inventory				
	Draw out organizational chart—to whom does this function report				Can be found in chapter 2
	What is the relationship with purchasing/supply				
	What are the responsibilities for both financial and customer promise outcomes				
4	What training in stock management have the inventory personnel received				SAP training, Stock counting training, Stock quality management training
5	Is the staff remuneration linked to inventory performance, How	√			Appraisal is based on some predetermined KPIs

MANAGEMENT AND CONTROL

6	How are items added to inventory and how is the recommended holding determined				
	Max–Min	√			
	Reorder point				
	Reorder quantity				
	Safety stock				
	History				
7	What process is used to review stock holding targets and when were the targets last reviewed				
	Cycle count	√			
	Order by order				
	Usage analysis	√			
8	Is there a quality system for inventory management	√			
9	Does your computer system only record stock movements or is it also used to control stock quantities	√			The syetem does both
10	What approach is used to value stock				
	Average	√			Moving Average
	Latest price				
	FIFO/LIFO				
11	How is the stock level and availability controlled				
	Max–Min	√			
	Visual management				

	Cycle count	√			
	A,B,C classification	√			base on criticality
12	How is obsolescence managed	√			It is written-off if detected
13	How are item movements recorded				SAP system captures it
	Is this system followed	√			
14	Who has access to the store				Store keeper and Store Supervisor
15	What KPIs are used to monitor stores performance				
	Availability/service level	√			
	# Value	√			
	Turnover				
	Stock turns	√			
16	What is the current value of these KPIs, actual vs. budget				
17	How and to whom are these KPIs reported				Factory Engineer
18	How is the availability policy set				Base on criticality of the item
19	What current other plans are there to reduce inventory				
	Supply chain initiatives				
	Stores rationalization				
	Spares rationalization	√			

ACTIVITY DATA

20	What is the annual transactional value by store and category				654160800 in naira
21	What is the current value of stock by store and category and how does this compare to budget				6,541,608,000 in naira
22	How many purchase orders are raised per day or week for inventory items				10 per day on average done by three different staff
23	Is there any planned inventory held as stock build for project or marketing initiatives	√			
24	What benchmarking data do you use			√	
	Reordering Process				
25	Are orders 'rolled up' in order to manage purchasing		√		
26	Are local suppliers identified and/or favored	√			But quality is never compromised
27	Are orders shared with other stores	√			
28	What is the process for reordering and restocking stores items				Min/Max