Optimizing the last time buy decision at the IBM Service Part Operation organization

Masters Thesis

by

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Management Summary

Introduction Within Service Parts Operation (SPO) of International Business Machines (IBM), the Product life cycle management (PLCM) is responsible for executing an last time buy (LTB). An LTB has the goal to obtain as many spare parts needed to mitigate the risk of running out of spare parts during the remaining service period (RSP). An LTB is initiated when a supplier stops supplying the spare part. The LTB is a decision that balances between buying too few spare parts and buying too many spare parts.

Motivation & Approach Significant improvement possibilities were discovered by a study in the Lenovo laptop division. This study and pressure on cost trigged management to investigate other divisions as well. The objective is to research what the current LTB performance is and which improvements are possible. This is done by studying the LTB process, the LTB model, and interviewing the PLCM team and others who are involved in the LTB calculations.

Conclusions & Results Based on our research we found that the LTB process was unnecessary complicated. The collection of information did involve many people and departments in order to generate accurate and good forecasts. This lead to an information overload and made the LTB decision unnecessary complicated and time consuming. Much of the information was not defined properly, not accurate, and was different used by analysts in the model. This leads to discussion and room for interpretation by the analysts. We showed with numerical analysis that the demand forecast procedure performs better with a simple approach than the currently used complex approach. The new proposed model is based on a demand forecast and a safety stock. It is tested on a dataset of the Power division which is chosen after an initial analysis of all divisions. This initial analysis showed that the Power, Storage and Mainframe divisions are the most promising divisions in terms of financial improvement. The new model is capable of delivering the same service level, defined as the stock out probability, as the original model with 16% less investment. The fill rate will only drop with 0,03 %. The new model is implemented in an Excel sheet and is used by the Power analyst. The safety stock is based on the standard deviation and the length of the RSP. To forecast demand on a standard decline/factor, and the average demand of the last 12 months is

used. The new model uses the parameters of the reutilization department to forecast repair, which are process yield, verification yield, and return rate. In total there are now 6 parameter automatically determined by a fixed process. The analyst can focus on exception management and discussion about the service level in stead focus on the parameter values.

The model must been seen as a first step, it is only applied to a specific group and more testing is needed to check if the model will be valid for larger/other groups. We think the framework still will be valid for larger groups only the values for the factor and the relation between goal and safety stock may change. The model can be optimized when more data becomes available and extended by including more dependencies between demand, repair, dismantling, and including costs such as carrying cost.

Next to the new model and the delivered result we also showed that current inventory levels are rather high. Many LTBs do not need additional supply, and the forecast generated for stock level setting is structural too high. More research should be done on this subject. Another observation was that many LTBs are about cheap common items, such as keyboards and cables. We challenge if an LTB was really necessary. More research is needed to extend this model to the full product and project range of IBM. Better forecasting based on more information, such as commodities, and global risk sharing will be an interesting topic to research in more detail. As last we have the following recommendations to IBM.

- Make a global SPO calculation to reduce the LTB investment. The forecasts can be more accurate, and risk can be spread amongst the geographical areas (GEOs).
- Mitigate an LTB when possible; avoid an LTB on easy replaceable items such as keyboards because alternatives can be easily found.
- Monitor the LTB spare parts to timely avoid expensive stock out solutions. Time is essential in the LTB, when a stock out situations can be foreseen IBM can act proactively.
- Use the new Excel sheet, with the new model for the LTB process and calculation, and use to storage function to be able to analyze decisions taken.
- Put more effort in the data management, and use correct information. Much time is lost by just checking if data is correct.
- Store all information about, demand, repair, dismantling, demand plans, supply plans, assumptions accurate and for a long period in as structured format. When this is done IBM is able to improve forecasting and the LTB decision.

Preface

Now I am finished with my Thesis it is time to look back. It was a long period with ups and downs but I always liked to research this subject. It was a fun and nice time at the office of IBM, SPO with nice colleagues. I did not only learn a lot about the last time buy, but also how a multinational organization works. It was a great experience and I am very great full towards IBM for this opportunity. In particular I would like to thank Laurens Neomagus for his guidance, tips and nice games for on my I-phone. Off course Danielle, Corinne, Hans, Ron, Jaap, Harry, Roelof, Dennis, Agnes, Melle, and all the others, also thanks with helping me and being such nice persons! From the university side, Matthieu and Ahmad did a great Job in challenging me to do that step extra. Every meeting the read my report and had sharp comments. Every time they did a careful review of my thesis even with my horrible writing. Ahmad and Matthieu, thanks!

The persons who are coming last but are the most important, are my parents and family, I was privilege, in some way, to live with them (again) for more than half a year. They took good care of me when I was arriving late and tired at home, dinner was ready and my clothes were washed the next morning. Besides this they always supported me with my choices and activities during my study and that is a great gift. Mom, dad, thanks for all that good care!

Cees Willem Koopman

Breda, 9 November 2011

List of Acronyms

AFR available for repair.

CB central buffer.

CE customer engineer.

CRV central repair vendor.

CSP certified spare part.

CSR country stock room.

DOA dead on arrival.

DROM dynamic reutilization & opportunity management.

EMEA Europe, Middle East and Africa.

EOLN end of life notification.

EOP end of production.

EOS end of service.

GARS global asset recovery service.

GEO geographical area.

GN gross need.

IB installed based.

IBM International Business Machines.

IT information technology.

KPI key performance indicator.

LRD last request date.

LTB last time buy.

MEF monthly error factor.

MF monthly forecast.

MSE mean square error.

MTM machine type model.

NDF no defect found.

OEM original equipment manufacturer.

OS operating system.

PAL parts availability level.

PIB parts installed base.

PLCM product life cycle management.

PS part sales.

QMF query management facility.

ROHS regulation of hazards substance.

RSP remaining service period.

SL service level.

SMA slow mover adjustment.

SPO Service Parts Operation.

STO stock take over.

UCL used class stock.

WAC weighted average cost.

List of Definitions

available for repair Broken spare parts that are suitable for repair and are on stock at the central repair vendor. IBM can issue a repair order for these broken spare parts.

blue money Money of IBM which internally transferred between organizations of IBM, for example money between the Service Part Operation and Manufacturing, both of IBM.

central buffer The main warehouse in Venlo (NL). Stock from Central Buffer is replenished to local warehouses.

central repair vendor The company that executes the complete repair process. The CRV executes the initial verification, holds the available for repair stock and manages the actual repair process.

certified spare parts Spare parts that are classified by IBM equal to '*new*' after repair. These spare parts may be redistributed within the IBM network.

dynamic reutilization & opportunity management Automatic process which determines if it is economically attractive to return a broken spare part and have it repaired.

end of service The moment IBM officially discontinues service for a product or specific spare part.

installed base The number of products that are used by the customers in the field.

last time buy The last option to buy a quantity of spare parts to mitigate the risk of running out of stock during the RSP.

part sales An order where spare parts are sold to a customer, usually a third party service provider. No detailed information about the usage is available and these spare parts are not returned for repair.

parts installed base The number of spare parts that are used by the customer in the field. This is derived from the installed based.

remaining service period The time between the date of a last time buy and the date IBM discontinues service, end of service date.

stock take over A special kind of last time buy. In this case the supplier is an IBM factory and not an external supplier. IBM also use the name *transfer* for stock take overs.

used class stock Spare parts in inventory that are not certified (CSP). These spare parts cannot be redistributed in the EMEA network. For example a spare part that is used temporary in solving a problem. When the problem is solved it is returned to the warehouse. The '*seal*' of this new spare part is now broken. IBM only allows usage in the country it is used in the first time.

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1 Introduction

1.1 IBM, products and services

Started in 1911, International Business Machines (IBM) evolved to be one of the largest companies in the information technology (IT) business. At this moment IBM employs 420.000 people and is operating in 174 different countries. The annual revenue in 2010 was $ 99,9 billion and the profit was $ 19,7 billion. The revenue is split between the three main products of IBM. These products are IT related Service (57%), computer software (23%) and computer hardware (18%). Global financing is responsible for the remaining 2% of revenue.

1.2 Service Parts Operation organization

This research is executed at the Service Parts Operation (SPO) organization, region Europe, Middle East and Africa (EMEA). The responsibility of SPO is to deliver spare parts, in time, on the correct location at minimal cost. The EMEA region is one of the four regions besides the United States, Latin America and Asia-Pacific, Figure 1.1. Each area has their own SPO organization. The central organization office of SPO EMEA is located in Amsterdam where 40 % of the employees work. The other 60 % is working in supporting offices located in the countries within EMEA. Some key figures of the SPO EMEA organization are:

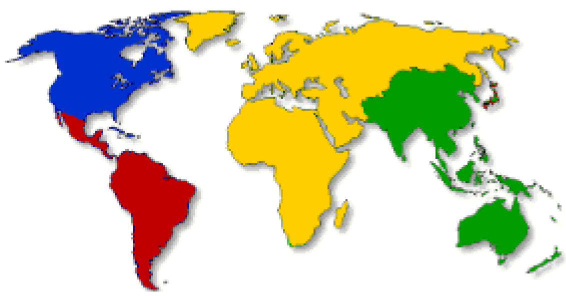


Figure 1.1: The four geographical areas of IBM. EMEA in yellow, Asia Pacific in green, United States in blue and Latin America in red.

- 200 storage locations in 61 countries
- Support for over 34.000 spare parts

- Support of 2500 machine types (IBM and non IBM)
- $\pm$ 160 employees
- Physical delivery and storage is outsourced

The customer of SPO can be a customer engineer (CE) of IBM or an external customer. The customer can have three reasons to request a spare part.

1. Service contracts – IBM has a contract with customers to maintain and repair their machines.
2. Warranty – When a product is broken within the warranty period, IBM is obligated to replace or repair the machine. For this repair spare parts are needed.
3. Part sales – Third party service providers maintain IBM machines. IBM needs to supply spare parts to these service providers by legal regulations.

The main reason for a spare part request in the low-end market is warranty, while in the high end market the main reason is a service contract between IBM and the customer. These service contracts are the most profitable for IBM.

SPO consists out of departments with their own responsibility. One of these departments is Planning, other examples are the Delivery-, Unit Cost-, and the Repair Vendor Management department. This research is executed in the Planning department. Planning is responsible for setting and maintaining the correct stock levels in warehouses. Their operation is to find the optimal balance between the following three key performance indicators (KPIs):

- Service level – Measured in fill rate (parts availability level (PAL)) and parts delivery time.
- Stock control – Total monetary value of the inventory on hand.
- Costs – All costs related to handling of spare parts, e.g. transportation costs, scrap costs, handling costs.

The Planning department consists out of the following four teams:

- Central Buffer Planning – They ensure that the central buffer in Venlo has sufficient stock to replenish the local warehouses in the countries.
- Country Demand Planning – Responsible for setting *reorder* and *keep on stock levels*, and facilitate redistribution in and between countries. In cooperation with the *Service Planning* department they ensure that stock levels meet the service requirements.

- Product Life Cycle Management – Responsible for the coordination of initial stock setting and last time buys (LTBs).
- Inventory Management – Responsible for controlling the overall stock value by reviewing financial figures, making stock outlooks and budgets.

A complete overview of the organizational structure is described in Appendix A. This research is conducted under supervision of the product life cycle management (PLCM) team.

1.3 Last time buy

1.3.1 Challenge

Risk – To provide customers with spare parts within reasonable time, stock is needed in local warehouses. When a spare part is used the stock will decrease and needs to be replenished. This is done by buying a new spare part or order repair for a broken spare part. When new spare parts, *New Buy*, can be ordered, stock levels in the warehouses are maintained and spare parts will be provided to the customer in time. At some moment the supplier will stop producing the spare part, mostly due to economical reasons. Now the supplier is sending an end of life notification (EOLN) to IBM. This notification provides IBM a chance to mitigate the risk of running out of stock in the future by ordering one last quantity of spare parts, also known as an last time buy (LTB). This LTB quantity of spare parts needs to be sufficient to cover the demand during the remaining service period (RSP). The RSP is the period between the moment an LTB is executed until the moment IBM will discontinue service to the customer, *end of service (EOS) date*.

Decision – The LTB decision balance between the costs of buying too much and the costs of an out of stock situation. Out of stock situations usually requires expensive alternatives, for example buying a spare part on the open market from a broker, a *broker buy*, and/or face a penalty cost for violating the service contract. The decision of an LTB quantity is difficult because the RSP tends to be a period of several years. Therefore all forecasts related to costs and quantities are difficult to make. A basic LTB calculation exists of a forecast of future demand (*demand plan*) and a plan on how to supply this future demand (*supply plan*). This research shows how these LTB decisions are made, how they are preforming and how these can be improved. In Figure 1.2 a stock scenario is displayed which gives an overview of terms related to the LTB.

1.3.2 Project types

Every LTB is placed in a work package, called a project. A project is usually based on spare parts in a specific machine or from a specific supplier. A project consists out of

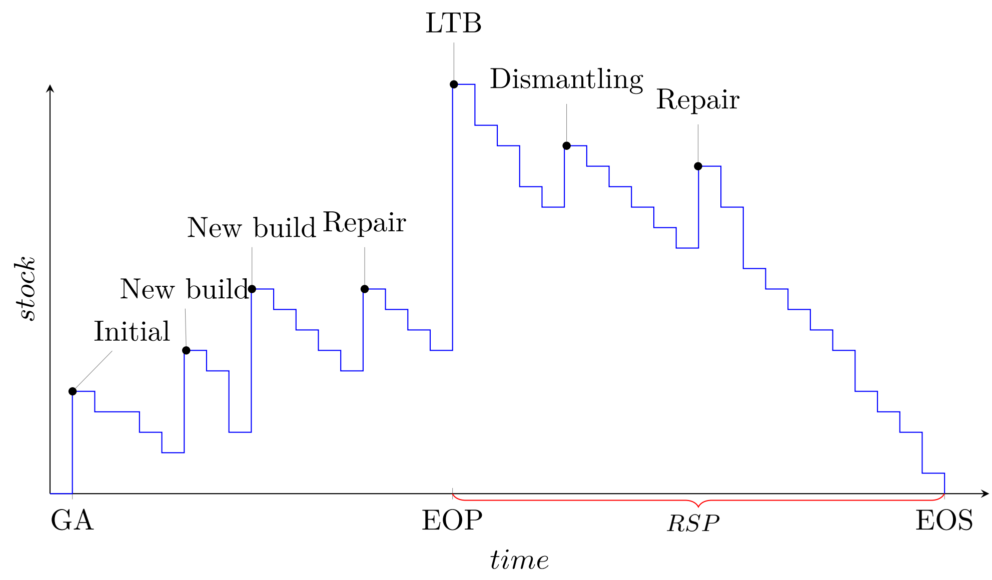


Figure 1.2: A stock scenario for a spare part. A product becomes *general available* (GA) and initial stock is ordered. Requests for spare parts are delivered and the stock is decreasing. *New build* and *Repair* orders replenish the stock to a sufficient level to reach the agreed service level with the customers. At a certain moment in time the supplier stops producing the spare part (EOP). An LTB is done to cover the future demand during the RSP. During the RSP other possible supply sources are *Repair* and/or *Dismantling*

one or more LTB spare parts and is classified as *pre*, stock take over (STO) or *post*. The classification is depending on the status of the supplier. In case the supplier is an IBM factory the project is classified as *STO*. When the supplier is external and the spare part is still used in production by the Manufacturing department of IBM the project is classified as *pre*. If the spare parts is not used in production by Manufacturing, and thus used only for service by SPO, the project is classified as *post*. This classification is important because every type has different characteristics, these characteristics can be related to a life cycle. A *pre* project occurs in the early phases of a life cycle, a *STO* in the end of the maturity phase and *post* in the final phase, see Figure 1.3 The main

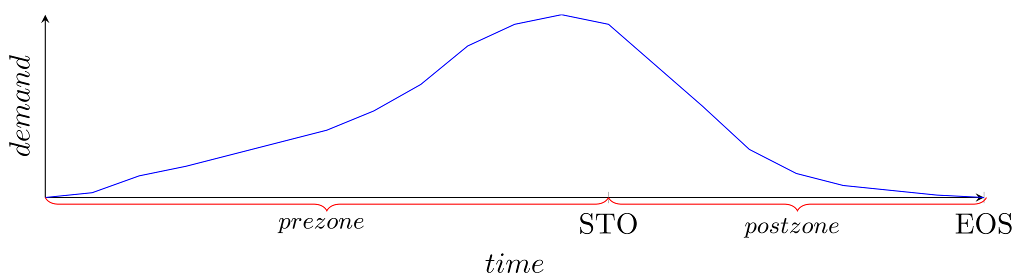


Figure 1.3: A life cycle of a product, if the Manufacturing department still uses the part in production of a machine it is a *pre* LTB, if Manufacturing stops production of the machine it is a *STO*, is the spare part only used by SPO it is a *post* LTB.

difference is that the RSP is longer for *pre* projects compared to STO and *post* projects.

Since the RSP is longer the need will be larger and therefore also the investments will larger for *pre* projects. Another difference is that for a *STO* the money involved is IBM money (blue money). The money is internal transferred between IBM organizations, (SPO buys the product from the Manufacturing department) and no money is spent to an external supplier. The last important difference is the number of spare parts in the type of project. A STO is initiated when complete machines go out of production. In a machine are many spare parts resulting in many LTB calculations for a STO project, compared to a *pre* or *post* project, where only a few LTB calculations are needed. In Table 1.1 an overview of the differences is given.

Type	**Projects**	**Average parts/project**	**RSP**	**% spent value**
Pre Post	1209	4	Long Short	65
STO	215	31	Average	35

Table 1.1: The general characteristics per project type based on historical LTB figures from 2005 up and including 2010. The data does not distinguish between *pre* and *post* projects and therefore no split in numbers is available.

Conclusion – A quick introduction to what an LTB is and which types of LTBs are present. LTB decisions are difficult because forecasts have to be made for different demand and supply sources and the period tend to be very long. The goal of an LTB is to mitigate out of stock risk. Next chapters will describe the research and will go into more details of the LTB.

2 Research

2.1 Motivation and objective

The product life cycle management (PLCM) team executed an last time buy (LTB) for almost 12.000 unique spare parts in the last six years. These 12.000 spare parts have a spend value over $ 100 million (Appendix B). A study in the laptop division on these LTB decisions shows possible reductions up to 40% of the investments. This can be done by using historic sales information and splitting the demand for spare parts in warranty, maintenance, and part sales requests. This improvement potential in combination with financial figures trigged management to investigate if there is also improvement possible in other divisions. The main objectives are to determine the current performance and to quantify improvement potential in these divisions. The new findings should be incorporated in the development of an information technology (IT) tool which is supporting PLCM in reducing the workload and improving the quality of the LTB decision.

2.2 Scope

The scope of the research is limited to the divisions Lenovo (Laptop), RSS (Retail), X Systems (Modular), P Systems (Power), and Z Systems (Mainframe). Appendix C contains a detailed description of these divisions. To limit the complexity the following aspects are not considered.

- Allocation of stock in the network. The total Europe, Middle East and Africa (EMEA) network is seen as one stock location. The main consequence is that it is possible that a spare part cannot be delivered in time to the customer. It is available in the network, but not on the correct location.
- Minimal or maximal order quantities of the LTB, which may arise from supplier or financial perspective.

The research is limited by the availability of data. Historic data about demand is available for six years in the past but for repair there is only six months of historic data available. LTB calculations are available from six year ago but are stored locally in different formats, which make it difficult to compare and analyze. For the Power division the LTB data was the best available. This is one of the reasons detailed numeric analysis is done on this division. Most of the data is coming from the internal planning system (CPPS/Location planning) used to plan spare parts in the EMEA network. This data is not free from errors an exceptional cases are present. An overview of the issues with the data are described in Appendix E.

2.3 Questions

The main research question is derived from the motivation, objective, and scope. This is combined with the key performance indicators used by the planning department, such as service level (fill rate / parts availability level (PAL)), stock control and costs. Given in Section 1.2

How can International Business Machines (IBM) improve the LTB decision by reducing investments and costs while maintaining the desired service level?

First the current situation has to be known and should be compared to existing literature about the subject.

1. How is the current LTB decision made?
   (a) How is the demand plan constructed?
   (b) How is the supply plan constructed?
   (c) What are the assumptions, methods and rules in determining and matching the supply and demand plan?
2. What literature is available about LTB?
   (a) Which different scientific theories about LTB are present in literature?
   (b) What are the general assumptions, parameters and outcomes of these theories?
   (c) What theories can be applied to the IBM situation?

To evaluate and improve the LTB decisions the current performance has to be established. After testing a new or improved model we advise about the implementation.

3. What is the most promising division for improvement?
4. What is the performance of the LTB calculation?
   (a) What is the current performance of the division?
   (b) How does the performance vary over different LTBs, spare parts, and time?

   (c) What is the performance of the forecast?

5. What can be improved to get a better performance?
   (a) What are the possible improvements?
   (b) What will be the results of the improvements?
   (c) What is impact of the improvements on the KPI?
   (d) How should the improvements be implemented?

Approach – To answer these questions and reach the objectives of this research the following approach was used. First knowledge about the LTB process at IBM was acquired. After an initial assessment of a sample of executed LTB decisions a larger, more detailed dataset was collected. Combined with literature review new methods and ideas are developed and statistical analysis on this dataset with real demand data was executed. Unconstrained interviews with employees from different departments were used to get information, test, and evaluate ideas and improvements.

2.4 Thesis outline

The first two chapters are an introduction to IBM, the LTB, and the research. Chapter three describes the current LTB model and process used by IBM. In chapter four there is an overview of available literature. Aspects of models in literature are discussed and compared to the IBM model. Chapter five shows a comparison between divisions and selects the division with the most potential. This division is analyzed in chapter six. Chapter seven describes improvements and the results of these improvements. Chapter eight highlights the practical aspects and implementation. Chapter nine gives the final conclusion, recommendations and future research opportunities.

3 Last time buy model and process

IBM executes approximately 1900 last time buy (LTB) calculations a year. All the calculations use the same model and follow the same process. This chapter will explain the LTB model and the LTB process. We will start with the model and continue with the process that leads to the specific parameters values.

3.1 Model - Overview

The LTB model of International Business Machines (IBM) is based on 5 parameters. Three parameters are used by the analyst to make a Demand forecast, this Demand Forecast together with the two other parameters make a Repair Forecast. These two forecasts combined with the actual stock information determine the LTB quantity. An overview is given in Figure 3.1. The five parameters are:

1. EOS date, the date IBM discontinues service of the spare part
2. Factor or Decline, a percentage which should reflect the in- or decrease of spare part demand over the remaining years.
3. monthly forecast (MF), the expected demand of next month.
4. Return Rate, percentage of broken spare parts that are returned.
5. Yield, percentage of returned spare parts that are successfully repaired.

In Figure 3.1 the terms Demand and Supply Plan are used. In the Demand Plan the future demand is stated, given by the Demand Forecast. In the Supply Plan the supply sources and their supply quantities are stated. All supply sources together should equal the total demand in the Demand Plan. Supply sources are for example future repair, current stock, and an LTB.

3.2 Model - Demand Plan

Currently the Demand Plan exists only out of the Demand Forecast. The Demand Forecast is based on three parameters, the end of service (EOS) date, the factor (f) or

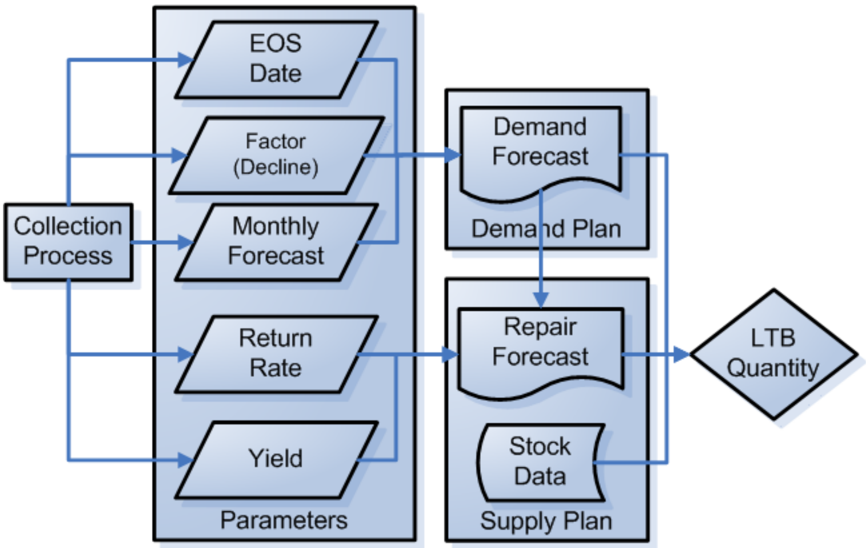


Figure 3.1: An overview of the LTB model. The dismantling forecast is left out for simplicity reason, this forecast is given by an other department and cannot be influenced by the PLCM team.

decline, and the MF. The outcome of the Demand Plan is the *gross need* (GN). The *gross need* states how many spare are required for service until the EOS date. The MF is provided by the Location Planning system (CPPS). The factor is based on a forecast of the *installed base* provided by the Service Planning department. This factor is given by year (y) and should reflect a demand decrease or increase in that specific year after the calculation date. The EOS date is provided by the WDCC information technology (IT) system. The *gross need* (GN) is calculated by the sum of demand over the years until the EOS date. Where demand in a year is given by the number of months (m) (usually 12) times the MF times the factor (f), see Equation 3.1.

$$GN = \sum_{y=1}^{Y} MF \times m_y \times f_y = MF \times \sum_{y=1}^{Y} m_y \times f_y \tag{3.1}$$

3.2.1 End of service date

The EOS date is the date IBM discontinues service for the specific spare part. The EOS date is fixed and set by the Service Planning department. The EOS date determines the number of years y in the remaining service period (RSP) and the months m_y in a specific year. For every full year that is possible after the calculation date the $m_y = 12$. The last year in the RSP m_y will probably be not a full year and thus the $m_y =$ remaining months. The current calculation only looks to full months, not to the number of days in a month.

An EOS date of August 1 will result in the same LTB quantity as an EOS date of August 31.

3.2.2 Factor (decline)

The factor (*decline*) is a percentage that should reflect the increase or decrease in demand in a specific year. The factors f_y are determined by the *installed base forecast* provided by the Service Planning department. This forecast is the number of product installs in the current year i_0 and the installs in the coming years i_y until the EOS date (3.2). When determining this factor the aspect of commonality is important, this is explained in the next section.

$$f_y = \frac{i_y}{i_0} \quad \forall y \tag{3.2}$$

Commonality is a term that states that a spare part is used in different products. Products are identified by a unique *machine type model (MTM)* combination. The *installed base forecast* of Service Planning is given per *Machine Type* (MT), so not by a specific model. As a result one spare part can have multiple installed base forecasts, because it is used in different machine types. Two different methods are used to deal with commonality. The analyst decides self which to use. Method one is the sum of all installed base forecasts of the machine types, $z = 1, \ldots, Z$ and models, $m = 1, \ldots, M$. The sum of all installed base forecasts is seen as one general installed base forecast (3.3) and used to determine the factor as in Equation 3.2. The other method is to weigh every installed base forecast according to their demand percentage. Every demand is registered to a *machine type* d_z (not to the specific model) and from this a *where used percentage* w_z is calculated (3.4). This weight is applied to the sum of the installed base forecasts for all models of a specific type and the sum will lead to a weighted installed base forecast (3.5) which can be used to determine the factor in Equation 3.2.

$$i_y = \sum_{z=1}^{Z} \sum_{m=1}^{M} i_{y,mz} \quad \forall y \tag{3.3}$$

$$w_z = \frac{d_z}{\sum_{z=1}^{Z} d_z} \tag{3.4}$$

$$i_y = \sum_{z=1}^{Z} w_z \times \sum_{m=1}^{M} i_{y,mz} \quad \forall y \tag{3.5}$$

Remarks – The factor is based on an installed base forecast of the Machine Type, assumed is that the installed base forecast of the machine type is one on one linked to the demand of spare parts. We think this is a reasonable assumption. The quality of the installed base forecast is now very important for the quality of the Demand Forecast of the spare part. The weighted method to address the aspect of commonality should deliver, in theory, better result as the sum method and should be preferred.

3.2.3 Monthly forecast

The monthly forecast is used to establish a '*base*' demand number. To this base demand the factor is applied. The monthly forecast is original generated and used by the Location Planning system of IBM to plan inventory levels and allocate inventory in different warehouses, and is not specific generated for an LTB decision. This monthly forecast MF is given by a forecasting process based on single exponential weighted smoothing average of 18 periods ($t = 1, 2, \ldots, 18$), where period one is the most recent period. Each period contains four weeks (28 days) of spare part demand d_t. The four week aggregation level is chosen from practical point of view in relation to the data storage. The weights w_t of the periods are determined by α (3.6a). The α is based on yearly demand and determined by linear interpolation between thresholds, set by the planning analyst. After this the weights are normalized, $w_t^{'}$ (3.6b) and the outcome is adjusted for monthly usage, instead of four weeks (3.6c). In special cases adjustments are made and other types of forecasting are used, this occurs rarely for spare parts that show up in an LTB. A description about these adjustments and a detailed description about this forecasting process can be found in Appendix D.

$$w_t = \alpha(1-\alpha)^{t-1} \tag{3.6a}$$

$$w_t^{'} = w_t / \sum_{t=1}^{18} w_t \tag{3.6b}$$

$$MF = \frac{13}{12} \times \sum_{t=1}^{18} w_t^{'} \times d_t \tag{3.6c}$$

Substitution is important in determining the MF. Simply explained substitution is a newer version of the spare part which is preferred over the old version. The MF is different for the new and old version, because it is determined per version. When only the MF of the new spare part is used this will lead to underestimation because the demand of the older version will shift to the new version. Therefore the forecast of the old version is added to the new version, but only when no stock is present for the old version. If there is stock of the old versions only 25% of the old version will be added to the MF of the new version and subtracted from the MF of the old version. This is done because from Planning perspective old stock is used up first. There are complex substitution situations possible, for example the new version may only be used in specific products. Currently the MF of the newest version only includes full substitution relationships, so valid for all products and not the complex cases. More specific information about substitution can be found in Appendix G and how the forecasting algorithm handles substitution in Appendix D.

Remarks – The forecasting process is complicated but the assumptions are logic and the approach seems right. The MF is intended to use for stock level setting an order policies and unclear is if this MF is a good method for determining the LTB quantity. No statement about the quality of the MF is available because no forecast accuracy measurement is available. In the LTB calculation the MF is multiplied by 12 and used for yearly calculation which can amplify an error. Complex substitution is not covered by the standard LTB calculation, and are usually left out completely.

3.3 Model - Supply plan

The Supply Plan is an overview of all the supply sources and the quantity each source supplies. Some supply sources, such as current stock, are determined by real time information from IT systems, other supply sources are forecasts based on parameters. The order for supply sources is predefined. This supply priority is defined in Table 3.1. This priority is based on the rule that IBM invested money should be used first. Supply is coming from current inventories, future repair, future dismantling and additional buys. The LTB quantity is given by subtracting the *gross need* minus all current and future supplies.

3.3.1 Stock Data

The first supply sources are the current SPO stock and are real time numbers out of the CPPS information system, updated daily. The *EOS need*, (EN) is the *gross need* (GN) minus the stock in the EMEA SPO organization. This is stock on hand s^{oh} , stock on order s^{oo}, repair on order s^{ro}, and used class stock, s^{ucs} (3.7).

$$EN = GN - s^{oh} - s^{oo} - s^{ro} - s^{ucs} \tag{3.7}$$

When $EN > 0$, more spare parts are required, first IBM global inventory is checked. This is global inventory surplus from other geographical areas (GEOs), s^{geo} and surplus from the IBM factories s^{fa}. This information is provided by the other GEOs and the IBM Manufacturing department. The two future supplies are added, forecasted repair, s^{rep} and the forecasted dismantling, s^{dis}, see next paragraphs. After the forecasts possible substitutions s^{sub} are added. This results in the *net need* (NN) (3.8).

Priority	Forecast	Owner	Supply Source	Example
	Y		**Gross Need** , GN	700
1	N	SPO	Stock on hand , s^{oh}	200
2	N	SPO	Stock on order , s^{oo}	10
3	N	SPO	Repair on order , s^{ro}	10
4	N	SPO	Used Class Stock , s^{ucs}	10
			EOS Need , EN	470
5	N	IBM	Other GEO stock surplus , s^{geo}	50
6	N	IBM	Factory stock surplus , s^{fa}	200
7	N	IBM	Repairable parts on stock , s^{afr}	20
8	Y		Future repair , s^{rep}	100
9	Y	IBM	Dismantling , s^{dis}	10
10	N	IBM	Substitution , s^{sub}	30
			Net Need , NN	60
11	N	Supplier	Continuous Supply	-
12	N	Supplier	LTB	60
			Open Need	0

Table 3.1: An overview of all possible supply sources. All supply together should cover the gross need. Used Class (UCL) stock is stock that is not free distributable in the EMEA network. In an LTB usually one or only a few sources are used.

$$NN = EN - s^{geo} - s^{fa} - s^{rep} - s^{dis} - s^{sub} \tag{3.8}$$

The *net need* (NN) is the quantity of spare parts that needs to be procured (LTB) or manufactured by IBM. A possibility is that IBM negotiates with the supplier that the supply of spare part is continued, called *Continuous Supply*. Now no LTB is done. Another case is that current inventories are sufficient to supply future demand and thus no LTB is needed.

Remarks – The supply order is based on the rule of 'blue money' first, but additional cost factors are not used such as holding cost and the price of a supply source. Maybe a buy on the open market is cheaper than repairing a spare part. Other consequence of this rule is that a surplus in the IBM factory must be taken over by the Service Parts Operation (SPO) department, while they could have sufficient repair opportunity. In this case the SPO department is 'punished' for stock surplus at the IBM factory. Another remark is that *Continues Supply* is seen as a last option but can make the LTB decision unnecessary. The decision is now only a cost effective decision comparable to an optimal order quantity decision, it is a decision between the cost of ordering and maintaining the supplier contract versus the holding cost. This is a different problem than the LTB problem.

3.3.2 Repair forecast

The repair forecast has to deal with two stages of the repair process. The repair process is a *pull* process, which means that broken spare parts are collected but only repaired when repair is ordered. More details about the specific repair process will follow later, but the forecast needs to deal with broken spare part that are already on stock and spare parts that will be arriving later. To calculate this the repair forecast uses two parameters, the *return rate*, rr (3.9) and the repair *yield*, ry (3.10). The *return rate* states the percentage of broken spare parts that are returned from the field. The *yield* states the percentage of returned spare parts that are successfully repaired in the repair process. Besides these two parameters also real time information about the broken spare parts on stock, available for repair (AFR), is needed to know how much certified spare part (CSP) will be delivered from AFR stock. All this information is used to make the repair forecast. The known AFR is netted against the *yield* and the GN is netted against the *return rate* and the *yield*. Both the *return rate* and *yield* are derived from six months of historical data. When historic data is not available contracted *return rate* and *yield* with the central repair vendor (CRV) will be used. On average the ry and rr are 80 %. The total repair forecast is given by Equation 3.11.

$$rr = \frac{\text{spare parts arrived at CRV}}{\text{spare parts demand}} \tag{3.9}$$

$$ry = \frac{\text{spare parts repaired}}{\text{spare parts ordered for repair}} \tag{3.10}$$

$$s^{rep} = GN \times rr \times ry + s^{AFR} \times ry = ry \times \left(GN \times rr + s^{AFR}\right) \tag{3.11}$$

3.3.3 Dismantling forecast

The global asset recovery service (GARS) department provides, per year, the number of spare parts they can supply s_y^{dis} to SPO. These spare parts are coming from machines that are returned from lease contracts. The total number of supply trough GARS is determined by sum over these years (3.12).

$$s^{dis} = \sum_{y=1}^{Y} s_y^{dis} \tag{3.12}$$

Remarks – Product life cycle management (PLCM) considers the dismantled parts as one quantity which is available directly at the beginning, which in reality is not true. This could result in negative stock levels for some moment in time such that demand cannot be fulfilled on that specific moment. This problem is called the performance gap and is explained in detail in Chapter 4.

3.4 Model - Conclusion

The model is mathematical correct, but deterministic. It does not include any uncertainty, or timing aspects, in both demand and supply. On the other hand it is simple and not difficult to calculate. When there is substitution and commonality involved it is up to the analyst what kind of approach to use for calculating the input parameters. This will not result in the same LTB quantity when executed by different analysts. A cause is that the parameters used are not defined properly. As result it cannot be stated if the parameters and their values values are suitable for making correct LTB calculations. It is important to investigate what the assumptions and process behind these parameter are and to check if these assumptions result in correct and accurate LTB calculations.

3.5 Process - Overview

An LTB calculation is initiated on request of the Manufacturing department of IBM or an external supplier. An external supplier usually does this by an end of life notification (EOLN). This LTB request is first processed by a global coordinator who sends the calculation request to the EMEA PLCM team and the other GEOs. The PLCM analyst sends a request to the Service Planning department to provide an installed base forecast, to the GARS department to provide a dismantling forecast, and to the PLCM Hungarian support team to do a first model run. The task of the Hungarian team is to extract data and information from different IT systems and order it so that the PLCM analyst can use this information easy. When all information is collected the analyst constructs the Demand Plan followed by the Supply Plan. These plans are sent to the Global Coordinator and this Coordinator combines the Demand and Supply plans from all the GEOs. The Global Coordinator divide the available IBM factory stock and redistributes possible GEO surplus stock. The updated Supply Plan is sent back to the GEOs where they update this information in their local plans, they also update their Demand Plans with actual data because stock levels are changed during the time needed to process all plans. When new plans are changed significantly they are resent to the global coordinator to divide the surplus stock again. When there is consensus about the Demand and Supply plans they are offered for a sign off to all responsible departments. When this meeting is successful the LTB orders are placed, when not successful, the Demand and Supply plans are adjusted. An overview of the process is displayed in Figure 3.2

An overview of the global process is given. Now we zoom into the EMEA PLCM process, we will focus on the repair process and the related repair forecast, the demand forecast parameters, the stock data information collection process, and briefly address the dismantling forecast.

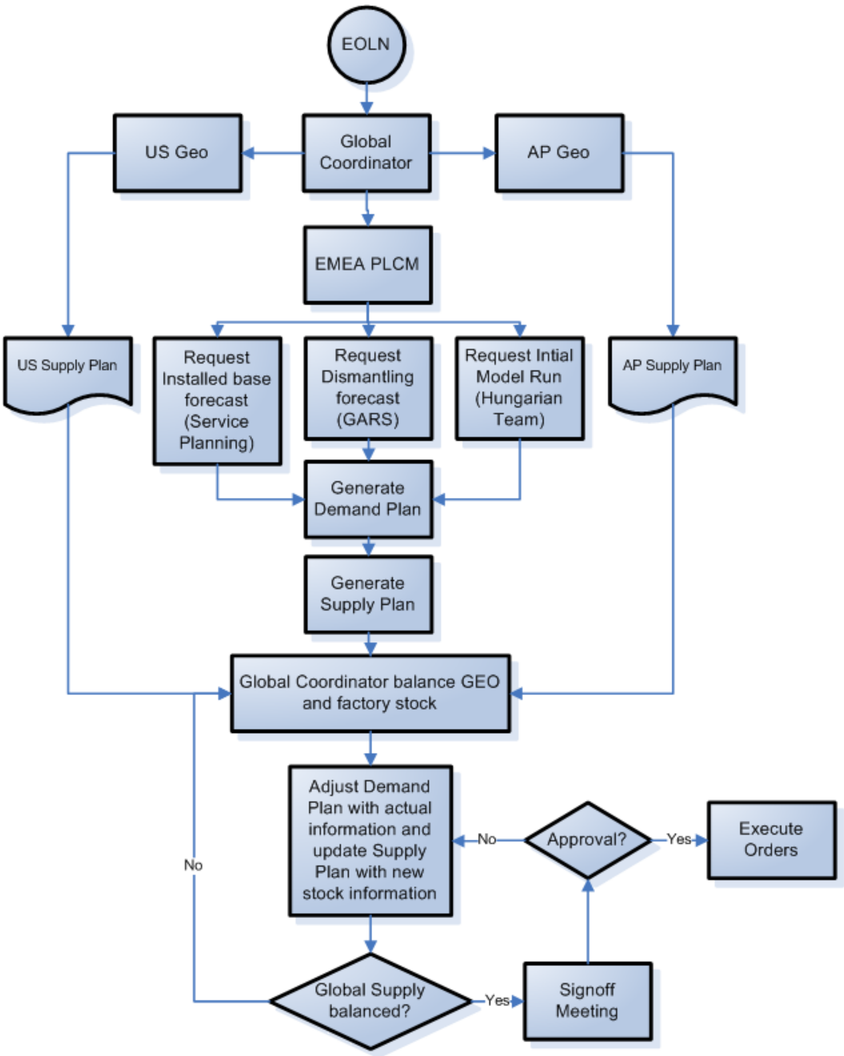


Figure 3.2: An overview of the global LTB process.

3.5.1 Demand Forecast Parameters

EOS date – The EOS date is different for each GEO and therefore it could be case that the EOS date mentioned in the global list in not correct for the EMEA region. Therefore the WDCC information system is used to check the correct EOS date. When there are different dates know in the CPPS, WDCC and/or global list, Service planning is asked what the correct date is, see Figure 3.3. Discussion about this input parameter is limited but costs unnecessary time and work. In an optimal process only the correct date should be communicated and should be the same in every system.

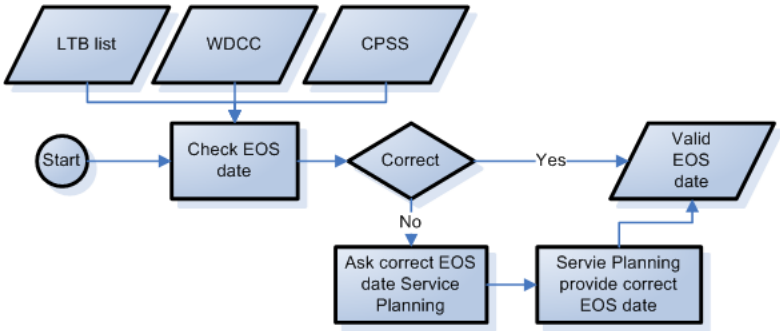


Figure 3.3: The actions needed to verify the correct EOS date

Factor – The factor is based on the installed base forecast. Based on the LTB spare part list, PLCM makes a list of products the spare part is in. These products are identified by the Machine Type code. This list is send to the Service Planning department which determines a forecast for every Machine Type. These installed base forecasts are sent back to PLCM which uses one of the two methods (sum or weigh based) to determine the factor. See Figure 3.4 .

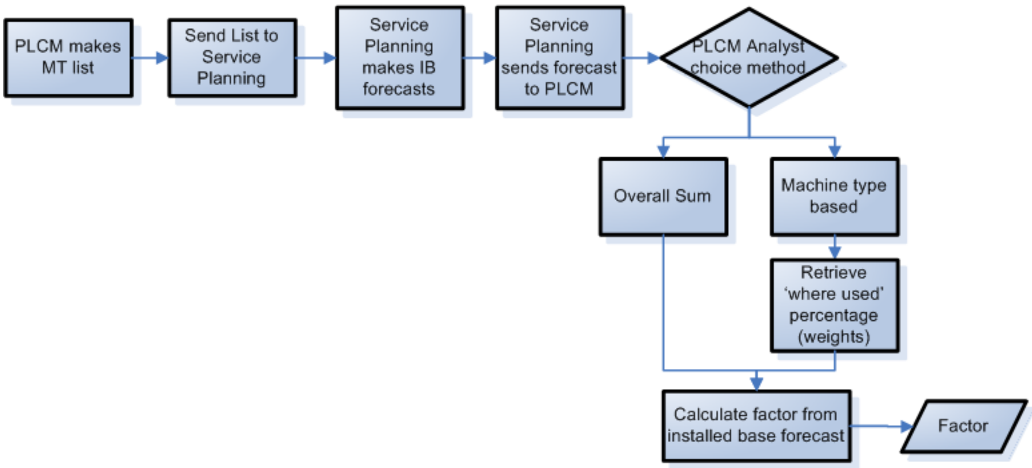


Figure 3.4: The steps in the process to determine the factor needed for the demand forecast.

Service Planning does not use a generic method for all divisions to determine the forecast of the *installed base*. One method is based on a fixed table that contains a decline percentage for every remaining year in the RSP. This percentage indicates how much (in percentage) the install base will decrease in a specific year. This fixed decline percentage is depending on the length of the RSP. This method is used by the Storage division, no explanation is given about the assumptions or logic used in this process, this remains a black box. Another method is based on contract information, used by the RSS division. The Service Planner reviews how many contracts are related to warranty and how many to maintenance. After a warranty period has ended a certain percentage transfer from warranty to maintenance, the rest will be removed from the *installed base*. This percentage was determined by the knowledge of the service planner and varies every time. When asked a statement about the reliability of the current information, and the forecasts of installed base, the service planners were not able to give that. They only stated that the reliability of the current installed base information was more accurate for the high segment compared to the low segment, how accurate they could not state. Our conclusion is that reliability of the installed base forecasts is unclear and the process, assumptions of these forecasts are vague and not properly defined. Therefore different service planners would deliver different installed base forecasts and this is not a good base for the LTB calculation.

Monthly Forecast –The Hungarian team provides the analyst with two forecasts. One forecast is the 'original' MF generated by the CPPS System and extracted by the PANDA IT tool, the second forecast is the forecast generated by the Xelus IT system used for ordering. The analyst looks to both forecasts and makes a choice which one to use, and discuss this number with others analysts. In practice this often means that the analyst take the average of the two forecasts. Usually the Xelus forecast is lower.

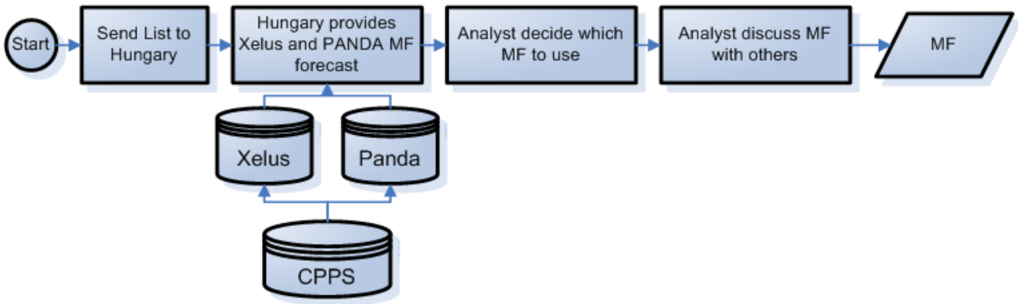


Figure 3.5: Steps in the MF process

What can be seen in Figure 3.5 is that the Xelus and Panda tool use the same input data, but use a different forecasting process. Therefore the outcome is different. Both predict the demand of next month and if the procedures are correct and accurate they should deliver the same forecast. Now the MF is not determined by a fixed process and two sources of change are present, the analyst that chose the MF based on Xelus and PANDA, and there is a discussion with other employees of planning such as the Central Buffer planner and the Inventory manager which give there view on a '*correct*' MF figure. What a '*correct MF figure*' is, is not clear for IBM.

3.5.2 Stock Information & Dismantling Forecast

The basic stock information is provided by the first model run executed by the Hungarian support team. This basic stock information is for example, total on hand inventory, outstanding orders for new spare parts and repair orders for broken spare parts, the used class stock (UCL) stock and the AFR stock at the CRV. This information is updated each day in the CPPS IT system and is regular refreshed in the Supply Plans, with the goal to give an accurate view of the current situation. Because lead times for calculations are several weeks these updates of the supply plans with the latest stock levels cause extra work. When the process is speed up this should take less time and should be needed less frequent.

Dismantling forecast – The analyst asks the GARS department to provide a forecast of dismantled spare parts. GARS is part of the finance division of IBM. GARS is responsible for selling machines which are returned from lease contracts. Spare parts provided by GARS need a specific testing process to become a *CSP*, this testing procedure is comparable to a repair process. Occasionally GARS can support SPO with spare parts. The reason assumed by PLCM why GARS cannot provide spare parts more often is that the CSP process and devaluation of a machine by taking out specific spare parts is more expensive than buying new spare parts. GARS provides SPO with the number of spare parts they can provide in a specific year.

3.5.3 Remarks global LTB process

Every GEO executes it own process and the global coordinator combines these different Demand and Supply plans to one global plan. The main task of the Global Coordinator is to prevent that two GEOs use the same surplus (either surplus from another GEO or a factory). It is only about sharing information while this process could be more efficient. This could be done by creating the Demand and Supply plan only on global level. The process will be much easier because one EOS date is set for the global calculation, only one analyst has to look into substitution and commonality (not an analyst for every GEO) and no concurrence about the different GEO Supply Plans is needed. Besides a process improvement this will also improve the model because risk can be shared between GEOs, and probably better forecasting is possible. The definition and discussion about the parameters should be avoided by the use of right procedures and right IT systems with correct data, in the end all the information is coming from the same source data and the discussion should go about the risk and rewards and not about the values of the parameters. The dismantling forecast is a potential supply source, currently this process and information is rather limited and more discussion between GARS and SPO should take place to investigate potential benefits.

3.6 Process - Repair

IBM outsourced their repair to a central repair vendor (CRV). This is a company that manages the repair process for IBM and is the central actor in this process. The CRV collects broken spare parts and take care of the actual repair process when repair is ordered. Every requested spare part initiates a reverse logistic process for the broken spare part. The objective is to return it in the best way possible. Legal, economic, and process reasons prevent that broken spare parts are returned from the customer to the CRV. Examples of these reasons are that it is not allowed to ship hard disks out of Russia due data sensitivity issues, it is not economically feasible to repair and return cheap parts, or that a spare part is lost in the process. The economic rules are determined by an automatic process called dynamic reutilization & opportunity management (DROM). DROM compares transport, handling and repair costs to the new buy price and decides automatically if this broken spare part should be returned or not. The ratio of spare parts that are demanded and that are returned to the CRV is called the *Return Rate*. When a broken spare part arrives at the CRV it gets classified into a category. Which category depends on the settings set by analyst, and the automatic processes related to the legal and economic rules. Based on the category further actions is taken, see Figure 3.6. The categories are:

1. Warranty – IBM has warranty on the spare part and wants a spare part back from the original equipment manufacturer (OEM). It is sent to the OEM and the OEM sends a new spare part back to IBM. The OEM does not always accept warranty, for example if the damage is customer induced.
2. Repair – The spare parts are repairable based on a quick review of the CRV. The broken spare part is put on stock and is now *available for repair* (AFR). Repair starts when a repair order is issued, this is called a *Pull* policy. Not all AFR will be successfully being repaired. Which results in a loss between ordered and actually delivered repair. The number classified in this category and the warranty category compared to actually repaired and warranty delivered are used in the *yield*.
3. Cash credit – IBM has warranty on the spare part but does not need a spare part in return (for example when there is a stock surplus), or the OEM cannot supply a new spare part. Instead IBM receives money for this spare part and scraps it.
4. Scrap – Spare parts in this category are scrapped. This can be caused by several reasons, for example it is too heavily damaged, it is offered for repair the third time or because it contains forbidden substances (regulation of hazards substance (ROHS)). The age of the spare part is not considered as a reason to put a spare part into this category.
5. Block – A spare parts needs investigation, for example the Engineering department wants to do a failure analysis. The spare part enters a specific process.
6. Unknown – Sometimes the process fails. For example the spare part cannot be identified and thus classified. This classification is made to handle the exceptional cases.

3.6.1 Repair parameters

In the model IBM uses two parameter, *return rate* and *yield*. These numbers are calculated by the CPPS system based on six months of historic data or contracted information.

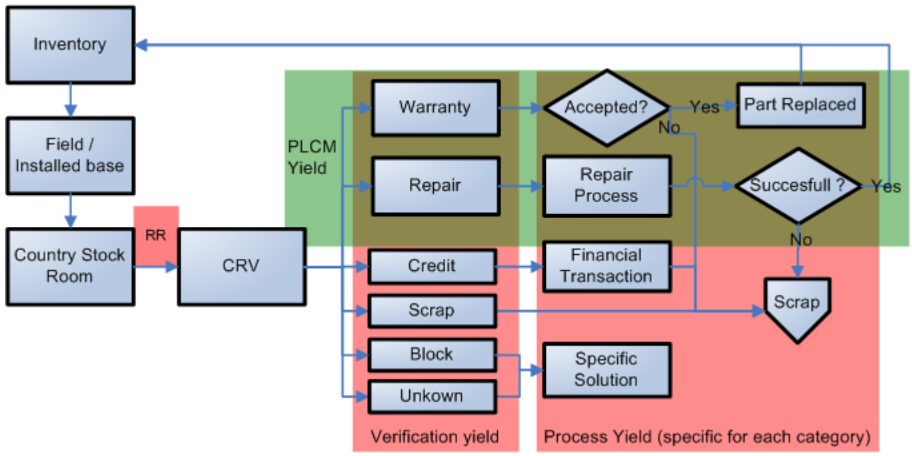


Figure 3.6: The repair process with the return rate and yield as used by PLCM, and the parameters (return rate, verification yield and process yield) used by the reutilization department.

The *repair yield* and *return rate* are provided by the Hungarian team in the first model run. After this run they are sent to the Reutilization department who verifies these repair parameters. The Reutilization adds extra comments if necessary for special cases in the repair or warranty process. A special case is for example that a spare part has a no defect found (NDF) testing procedure.

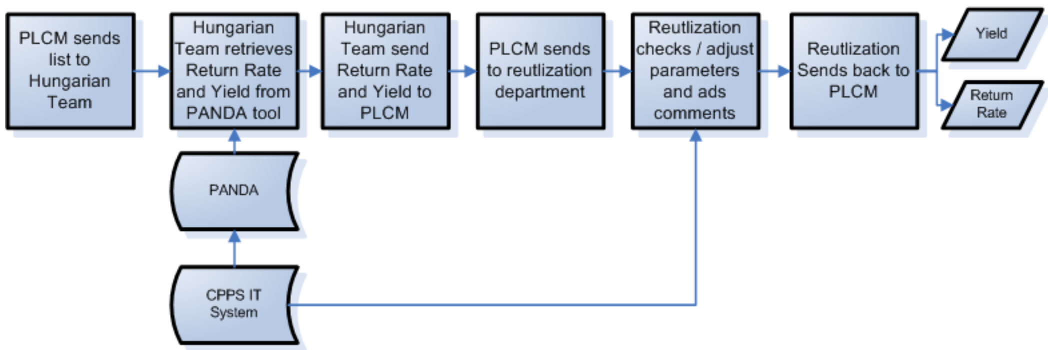


Figure 3.7: Process for obtaining the right return rate and yield figures.

3.6.2 Remarks about repair

IBM uses two parameters, the *return rate* and the *yield*. The reutilization department, who is responsible for the repair process, uses more parameters. They use the *return rate*, the *verification yield* and the *process yield*. The *return rate* is the ratio of spare parts demanded and arrived at the CRV, the *verification yield* is given per category and states the ratio of items arrived at the CRV and classified into a category. The sum of this *verification yield* should be one. The *process yield* is the ratio between the spare parts starting in a category and successful finish the process (as a CSP spare part). See Figure 3.6. The numbers of these ratios and their definition is usually a point of discussion between the two departments because they do not clearly define what the specific parameters mean. The definition of the reutilization department should be used because this tells the analyst more about the losses. It shows where possible improvements in the repair process are possible. In theory the retrieved numbers should be the same since they use the same source data. Since this is not the case somewhere in the process a different method of calculation is used when determining both parameters. We also found an improvement in the process of determining the *return rate*. Currently the six months of historic data are taken, but sometimes the collection process is stopped by an analyst due to some reason (e.g. overstock). When the process is stopped it is logical that no parts will be collected and thus arrive at the CRV. This should not influence the return rate. Therefore the return rate should only be based on the time the process was switched on. For example, if in six months 100 spare parts were demanded, and only 50 are returned, a *return rate* of 50% is used. When the collection process was switched one on just three months ago, probably about 100% was returned when the process would have been on full time. This 100% is a better refelection of the real *return rate*.

3.7 Conclusion

The model IBM uses five main parameters which lead to a simple but straightforward model to calculate the LTB quantity. This model does not take into account uncertainties and timing in both the demand and supply. Many departments and people are involved in determining these parameters. Therefore the process becomes complex and sensitive to personal adjustments, errors, and takes much time to complete. As a result the model will have different outcomes when executed by different analysts. Executing multiple local GEO processes has as a result that much research work is repeated in every GEO and is a source for errors. Based on our observations we advise the following improvements to the model and process:

- Implement a global LTB calculation, this will result in a faster process with less errors, and will make global risk sharing possible. This reduces costs and lower investments trough better risk sharing.
- Include uncertainty in timing and size of demand and supply. When uncertainty in demand and supply is included a balanced and better decision between risk and reward can be made.
- The parameters of the LTB model should have a clear definition such that it is clear to everyone what they represent. When this is done a strict process should lead to the value of these parameters. These values should not be altered by the analyst and no discussion is possible due to the clear strict definition and process. The process should include a manner to deal with commonality and substitution such that accurate figures are used and discussion is avoided.

- Change the repair forecast parameters, *return rate* and *yield* currently used by PLCM, to the parameters used by the Reutilization department. This are the parameters *return rate*, *verification yield* and *repair yield*. These three parameters give more information about the repair process and avoid confusion between departments.

- Make information up to date and accurate between different IT systems, for example the EOS date should be the same in all systems, such that the analyst can trust the information and checks are not needed.

- Includes cost in the model, costs are important for IBM and should be included in the model to make the best LTB decision. Important costs are the different procurement prices for the different supply sources such as repair and new buy, and the holding costs.

4 Theoretical background

In this chapter common aspects of models described in literature are compared with the current International Business Machines (IBM) model and the requirements of IBM. Possible improvements or limitations are discussed and the next research steps are determined.

4.1 IBM model requirements

Discussion with the analysts and management of IBM lgenerated the following model requirements. These requirements are split in *hard* and *soft* requirements. Hard requirements needs to be fulfilled while soft requirements can be partially implemented depending on the available resources.

- **Hard requirements:**
  - Solvable within in reasonable time, e.g. seconds per spare part by a computer, this is necessary because many spare parts needs to be calculated.
  - The outcome of the model should state the last time buy (LTB) quantity and should be able to include repair and dismantling.
  - The model must be easy to understand. Analysts who work with the model must understand what they are doing without expertise in mathematics.
  - Limit the parameters to the only necessary one. More parameters will make the model more difficult to understand and require more resources to store and collect data needed to generate information.
- **Soft requirements:**
  - Introduce a quantified trade off decision between risk and costs such that management can make a balanced and accurate decision regarding the LTB quantity.
  - A possibility to signal out of line situations in an early stage to limit the impact by timely action. The costs of alternatives are usually lower when more time is available to research and execute this alternative.

- Support in making the decision of collecting repairable items. When stock levels are high compared to the usage it could be smart to stop the stocking of repairable items to avoid excessive stocking and collection costs of these broken spare parts.
- The ability to include complex substitution chains and commonality between products, such that older versions are included in LTB model, and that spare parts who are in different products are calculated correctly according to the usage for that products.

4.2 Goal function of the model

An LTB model in literature has a goal function which has an objective. The model tries to find the best possible solution for this objective. The objective in literature is usually defined as a service level or minimum cost given a set of requirements. The service level approach is used by Fortuin (1980, 1981); van Kooten and Tan (2008); Pourakbar, Frenk, and Dekker (2010). In the service level approach a service level (e.g. 95% fill rate) is set and the outcome will be the lowest quantity of spare parts needed to reach that service level. This amount of spare parts represents a certain cost/investement and is the result of the chosen service level. When the objective is minimizing the cost, the minimum cost will be the main result and the service level will seen as secondary output. This cost approach balance between the costs of preforming service versus the costs of not preforming service (penalty). The costs of service are usually the procurement, holding, repair, disposable/scrap costs, sometimes discounted over time. The penalty costs consists out of broker buys, contracted penalty fees, starting new production runs, providing a customer with a new product. Examples of these models are Teunter and Fortuin (1999); Teunter and Haneveld (1998).

We classify the IBM model as a forecast approach, as stated in Pourakbar et al. (2010), because the IBM model does not have any goal function and the model does not make or support in a trade off decision between investment and risk. The goal of this forecast approach is to model demand behavior as precise as possible. See for examples Moore (1971); Ritchie and Wilcox (1977). Hong et al. (2008) developed a forecast approach which includes a stochastic model and links a service level to costs. IBM currently uses deterministic parameters and does not consider any uncertainty in timing and size relating to demand, repair and dismantling. Moreover no clear goal is present. This is a major drawback of the current IBM model. Management cannot make a trade off decision between the LTB quantity and a service criteria because in fact the model does not know what the objective is.

4.3 Information input in the model

To reach the objective a certain relation ship between information is assumed. This information is reflected in parameters which have a certain predefined relationship with each other. For example the sales number is a parameter and the relation with the spare part usage is times 10 percent. Most models do describe the relationship between parameters but do not describe in detail what the best method is to determine the values of these parameters while in practice this is difficult (should we use direct sales, or also included resale, lease, do we subtract returns). In practice the means that information about the appropriate distributions and/or historic data is limited or not available. Every LTB model has in general two forecasts: one forecast about the future demand and one forecast about future supply. The difference is in the parameters they use for determining these forecasts and can be grouped in three categories. Next sections will describe the different categories used in literature, some models use a combination of these parameters.

4.3.1 Demand forecast

Installed base and failure rate – It seems logic that there must be a relation between spare part demand and the *installed base*. A forecast of the installed base times a certain failure rate states the spare part usage. A model who uses the *commonality* aspect is Kaki (2007). He uses the installed base with the known number of spare parts in the machines resulting in a parts installed base (PIB). When the current demand of spare parts is known, and the PIB is known, a failure rate can be calculated, or an engineer can determine the failure rate by analysis. The future spare part demand is now given by a forecast of the PIB and multiplied with the failure rate. This is more less the same as the IBM model. Kaki (2007) does include in the forecast the age aspect related to warranty demand. He does this by assuming that demand related to warranty will drop after several years based on the sales information, in his case almost all request are related to warranty. The main drawback of this method is that a forecast is still needed for the PIB. The PIB will evolve over time as customers discard and replaces their products. Another drawback is that it does not take into account that failure rate change over time due to age of the installed base, and that failure rate is depending on the locations of the PIB, as we observed in our research. For IBM it can be a reasonable approach in the high-end market (Mainframe) because installed base information is accurate. Also the market is better known because it is relative small, but still the major request are related to maintenance and not warranty.

Sales and warranty – Moore (1971) uses sales data as input for the demand forecast. This is an approach suitable for demand caused by warranty claims. Moore (1971) derives three curves, parabola, ellipse, and a linear curve for future demand after the sales has reached its peak demand. This is interesting for the low-end machines of IBM (Lenovo and Modular division). The Lenovo division is now already using sales data to determine the spare part demand. When demand is shifting more to maintenance the sales data is not a reliable estimator for the demand of spare parts because maintenance will also request spare parts for machines out of warranty. Hong, Young, Koo, Chin-Seung, and Ahn (2008) introduced a method that uses besides sales also the failure rate, discard rate and replacement probability. The method of Hong is based on Ritchie and Wilcox (1977) that using renewal theory. The model of Hong requires many parameters and collection of this information is time consuming and it seems difficult to estimate all these parameters reliably. Therefore the method of Hong is not suitable for the IBM model because it will cost too many resources.

Historic demand – In both methods, the installed base and the sales method is based on the assumption that an other variable is better known or can be forecasted better such that it will deliver a good forecast for the spare part demand. Another method is that the historic spare part demand is an estimator of future demand. It is based on the assumption that one specific spare part belongs to a certain reference group that has the same demand pattern, this is called reference forecasting. If the model knows the demand pattern of the reference group the model can use this demand pattern to predict the usage of a specific spare part belonging to that group. The difficulty is how to determine the right groups in such a manner that the predictions are accurate and reliable. The big advantage is that only the historic demand has to be know and analyzed to make such groups and other information is not needed. Teunter and Fortuin (1998, 1999)

4.3.2 Supply forecast

LTB only – In the simplest case the model only needs to calculate an PIB quantity. This is when spare parts are classified as consumable Fortuin and Martin (1999). No repair or dismantling supply is available. The determination of the LTB quantity is the demand forecast minus the current stock. It is a simple case if the demand forecast is deterministic, if it becomes stochastic it is getting more difficult depending on the distribution, but usually easy to solve.

LTB and repair – When repair is introduced the model has to determine how many spare parts will be supplied by repair and what the LTB quantity will be. The repair is given by a forecast and depending how accurate this forecast is, and if is treated deterministic or stochastic will influence the model in complexity and the needed time to solve. Mostly the repair supply is a forecast based on parameters such as *return rate* and *repair yield*. To make it more difficult repair is often depending on the demand so there is interaction between the demand and supply forecast. Important is also the timing of this repair, there are return and repair lead times, push and pull policies, all these timing aspects make the *performance gap* possible, that will be discussed in Section 4.4. In the current IBM model the *return rate* and the *repair yield* are based on six months of historic data and are deterministic which make the models still easy to understand and take little time to solve.

LTB, repair and dismantling – Dismantling adds an extra forecast, and this forecast has the same difficulties as the repair forecast in timing and demand size. The interaction between demand and repair is also present. Dismantling will lower demand and will have interaction with repair. All this is introduce much more complexity in the model resulting in longer solving times.

4.3.3 Conclusion about the input

The input of models in literature have a demand and a supply forecast. Models differ in the parameters and assumptions they include in their forecasts. For the demand forecast three types are found. Forecast based on *installed base*, based on *sales* and based on *historic information*. For the supply forecast there are models who only calculate an LTB amount and models who do include other source of supply such as repair and dismantling. The current IBM does include all sources of supply and base their forecasts on historic information and expert knowledge of the Service Planning department. The models found in literature are all stochastic for at least one parameter. In literature there is lacking how to determine the parameter values reliable such that it can be used by IBM.

4.4 Performance gap

The IBM model does not consider timing. The model treats the remaining service period (RSP) as one interval and therefore does not consider lead time for repair and dismantling. Now the performance gap arises when more demand is earlier in time then the supply needed for this demand. In Table 4.1 an example is given. In this example repair lead time is two periods, all spare parts will be repaired, and unfulfilled demand is backordered. From Table 4.1 we see that demand cannot be met in period two and five while if the RSPis seen as one one period this will go unnoticed as displayed in the last column.

To deal with this problem most models in literature use a dynamic solving approach. This dynamic approach splits a complex problem into smaller simple sub problems. Solving all the smaller, simple problems, solves the complex problem. A drawback of dynamic programming is the computational burden of all the possible states. Also it is not easy to understand for an analyst. The heuristic method tries to limit the computational burden of a dynamic approach. This done by a set of 'simple' rules or steps to calculate a near optimal value of the model. The heuristic improves the calculation speed but delivers a close to optimal value. When discussing this problem with IBM, it is decided that the *performance gap* is ignored for the following reasons.

Period	**1**	**2**	**3**	**4**	**5**	**6**	**One interval**	
Stock begin	3	1	-1	1	5	-2	3	
Demand	2	2	0	1	7	2	14	-
Repair Supply			2	2	0	1	5	
Dismantling supply				3	0	5	8	
Stock end	**1**	**-1**	**1**	**5**	**-2**	**2**	**2**	

Table 4.1: This table shows that in periods 2 and 5 not all demand can be full filled from stock. If the RSP is seen as one interval this happens unnoticed, as seen in the last column. Lead time for repair is two periods, demand is back ordered, and all spare parts will be repaired.

- Dismantling is not used often for supply. An analyst can judge if dismantling supply will be available in time.
- Repair lead time is relatively small compared to the RSP. It is usually about six weeks compare to several years for the RSP. The return time is usually about two weeks.
- Newly bought spare parts will be used first, combined with a *pull* repair policy this will diminish the lead time impact. By using new buy first, broken spare parts will be stocked first and can be order on time such that repair lead time can be covered, now the performance gap only show up at the end of the RSP, where stock level are low. The experience of IBM is that at the end of the RSP the customer accepts longer service times.
- Model needs to solve calculations quick, within seconds, and this possible if a suitable heuristic is present.
- Model needs to be understandable for analysts.
- Also it can be considered as a problem similar to the allocation problem, which currently is also not taken into account. The spare parts are available in the IBM stock network but are not available in time. In the allocation problem this is due to the spare parts that are at the wrong location and in the case of repair it is because the spare parts still need time to be repaired. In both cases the consequence is that a customer cannot be serviced in time, but in the end the spare part will be available, only not on time.

4.5 Alternatives to the LTB

A model should support in making a decision. In most models this is the LTB quantity. A few models, such as Cattani and Souza (2003), compare other solutions (e.g. continue production, a commercial solution such as a new product or paying a penalty) of mitigating the out-of-stock risk. To include a comparison to other solutions is not practical. This is because these other solutions involve various IBM departments and it is therefore difficult and time consuming to collect the information of these alternative solutions. Only in exceptional cases the effort of collecting this information is justified if for example the investment is very high.

4.6 Other decisions

Their are models that support in making extra decisions during the RSP. For example remove down to levels, or switching to other policies. Other policies such as a new product to the customer instead of repairing the old product Pourakbar et al. (2010); Teunter and Fortuin (1999). IBM has the soft requirement of deciding when to start or stop the collection of repairable items. Currently this is decided by the dynamic reutilization & opportunity management (DROM) process with manual overrides for LTB spare parts. During this research a modification took place on this DROM process to cope with LTB spare parts. This modification reviews the repair collection decision every week based on actual information and a straight line forecast from current spare part usage now, to zero at the end of service (EOS) date, and some other criteria to limit the collection of available for repair (AFR). Therefore it is not necessary to include it in the LTB model. Also IBM is not very willing to remove stock while they are still providing service for that specific spare part and such remove down to decision will probably not being executed. This is in line with Pourakbar et al. (2010) states "*...the company is loathe to scrap parts.*". The determination of the LTB quantity is sufficient for IBM.

4.7 Conclusion

The main conclusions when comparing the IBM model with the models found in literature are:

- The IBM model lacks a clear goal and therefore no trade off decision is possible. Is the goal to reach a certain service level or does IBM want minimal costs? When an objective is chosen and the uncertainty aspects of the forecasts are included it could be a decision support model for management.
- The IBM model is deterministic for all parameters while in literature at least one or more parameters are stochastic.
- The IBM model includes all relevant supply sources found in literature.
- Models in literature do not clearly explain how they determine the value of the parameters used in their model.
- The IBM model is classified as a forecast approach which implicit goal is to model the demand and supply as precise as possible. Other approaches seem to be more

suitable. These models forecast demand and supply not deterministic but stochastic and use a safety stock to cover their uncertainty in the forecast. On this manner they try to reach a certain goal expressed in service or cost level.

- Most models in literature do not fit the need for IBM, because they require much information, are too complex for analysts, or include not all aspects.

In the next chapters we will determine a focus division to measure performance and see how well the current model is performing and if changes are required.

5 Improvement potential divisions

This chapter will show which division has the best improvement potential. We used five indicators to identify the division where improvement will have the most financial impact and thus the best result for International Business Machines (IBM). To calculate these indicators a split is made in the current inventory between normal and LTB spare parts. This is done by using the flag *setid* in the information system. Spare parts are flagged by PLCM with a *setid* in the planning system if they have been subjected to an last time buy (LTB) calculation.

5.1 Indicators

The five indicators used for this research are:

1. **Total investment** – The amount of money spent on LTBs. Improvements will reduce the investments and therefore divisions with high investments are the most interesting. This indicator does not take into account the number of LTBs executed per division.
2. **Stock value per unique spare part** – When a division has high stock value per unique spare part this can be due to: spare parts have high value and/or high inventory levels. In both cases, IBM would like to have fewer of these spare parts. This number includes the difference in the number of executed LTB calculation between divisions and makes them better comparable.
3. **Total reserve value** – A financial indicator that shows the value of spare parts with a high chance to be scrapped. The scrapping of spare parts, can be caused by an earlier LTB decision. High chance is defined within three categories A, B and C. In which category a spare part belongs is determined by a set of questions. This process with questions is displayed in Figure 5.1.
   - *Category A:* Spare parts are obsolete mainly because they are technical obsolete or passed the EOS date. All these spare parts will be scrapped. All inventory value falling in this category is added to the financial reserve.
   - *Category B:* Spare parts in this category had no usage in the last 18 months and therefore it is unlikely that they will have usage in the future. This

results in a high chance they will be left over after end of service (EOS) and eventually will be scrapped. Their total inventory value is also added to the reserve value.

- *Category C:* For spare parts in this category only a part of their value will be added to the reserve value. Only the value of spare parts in inventory above the excess level, defined as 5 times the yearly usage, is defined as a high chance to be scrapped. The assumption is that the EOS date will be within 5 years and that a constant demand will occur these 5 years. This is a conservative approach because in most cases the demand will drop and the EOS date will be earlier.
- *Category D:* Spare parts in this category are young spare parts and are not reserved because they will be used for normal business.
- *Category E:* Inventory of the spare part is not above the excess level and thus just regular inventory. They have a medium to low chance to be scrapped and therefore not added to the reserve value.

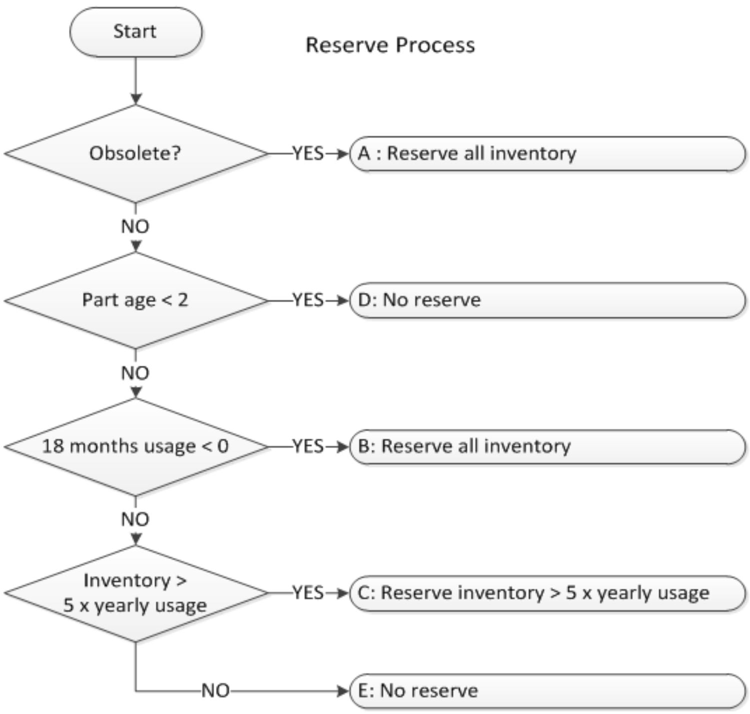


Figure 5.1: Reserve value decision tree

4. **Total scrap value** – The value of scrapped LTB spare parts in the last 12 months. An LTB decision can cause the scrapping of excessive spare parts from inventory, but also high stock levels are potential reasons for scrapping.

5. **Forecast accuracy of the demand forecast** – Less accurate forecasts indicate more improvement potential. Forecast accuracy is given by the percentage error (pe) based on actual demand. F denotes the forecasted demand and A the actual demand (5.1). This error was calculated for a small sample dataset collected. The forecast error was determined for the period of the RSP that has been passed. This is the moment of calculation until the date of 31-12-2010. Therefore the pe is a mix based one to six years of forecasting length. More information about this dataset can be found in appendix F.

$$pe = \frac{F - A}{A} \quad \forall \quad LTB \tag{5.1}$$

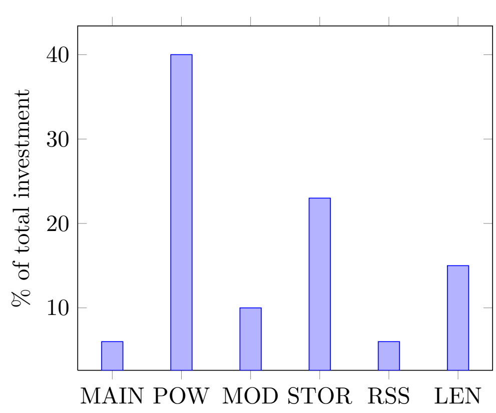
5.2 Results

Figure 5.2 displays the results of the indicators. These indicators show that Power has the most potential for financial improvement, a second best is Storage. Both have high investments (a), large forecast errors (e,f), high reserves(c), high new buy scrap (d), and high value per unique spare part (b). Mainframe and Lenovo are in the middle. Lenovo is doing well compared to other divisions. It has an average investment but the other indicators are rather low. The $ per unique spare part of Lenovo is high, but 50% is caused by one spare part. RSS and Modular do not play a significant role in terms of improvement potential, because all indicators are low.

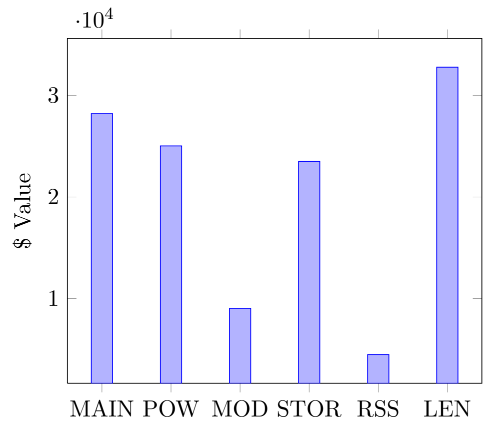
The forecast accuracy indicator shows that Power and Mainframe are the most interesting divisions. These divisions have the biggest errors and the widest dispersion. Storage and Modular show smaller dispersion and a lower median. Modular is showing more underestimation compared to the other divisions, a smaller dispersion and a lower error. This is caused by a standard factor of 80, 60, 40, 20 % in the forecast. The reasons found for incorrect forecasts are:

- Inaccurate factors
- Inaccurate monthly forecast
- Substitution relationships
- Part sales orders
- Spare parts with no, or very low demand.

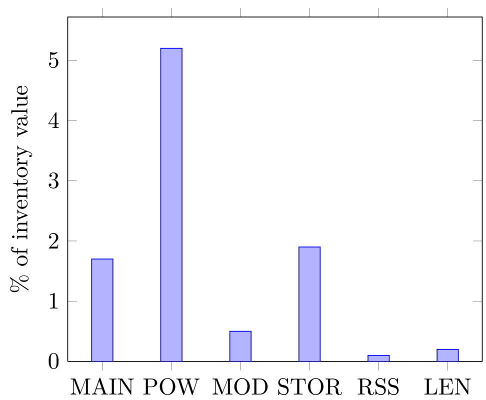
Best division Based on the indicators the Power division is chosen to be researched in detail. After the Power division the Storage and Mainframe division are the most interesting for IBM.



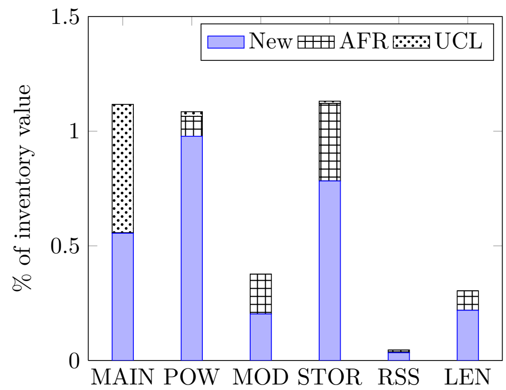
(a) Money invested



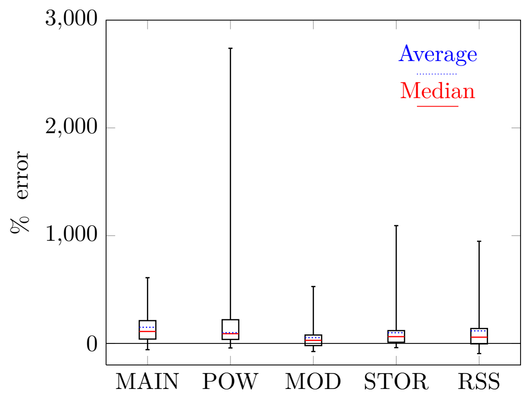
(b) Value per unique spare part



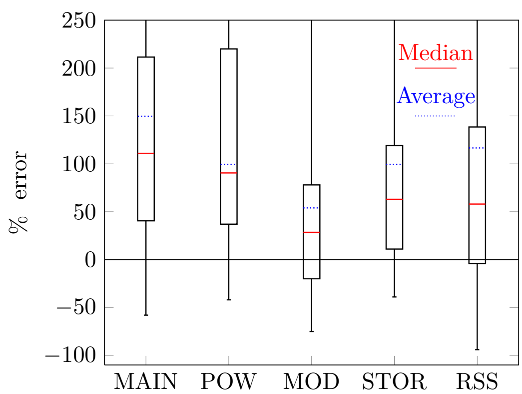
(c) Reserves



(d) Scrap



(e) Box plot of forecast error



(f) Box plot of forecast error - **Zoomed**

Figure 5.2: The five indicators show that Power has the most improvement potential. Figure e and f are the forecast accuracy indicator. MAIN = Mainframe, POW = Power, MOD = Modular, STOR = Storage, RSS = Retail Store Solutions, LEN = Lenovo

5.3 Data set: Power Stock Take Overs

For the Power division a large detailed dataset was collected, because the data are the best available for stock take over (STO) we focused on the STO. The dataset consist out of all STO that have been executed in the period between 2005 up and including 2010. Important notes about the dataset are:

- **Different Prices** – For IBM it is common to use the weighted average cost (WAC) price for a spare part in all calculations of the SPO organization. This is the weighted (against volume) average price of spare parts bought, and will change over time when new spare parts are bought. For supply sources used in the LTB calculation the average internal price of the IBM is used. This price is used to price every supply source, so also repair, dismantling and current stock. As a result the data has different prices for the same spare part, and the prices used are the same for all supply sources, in practice this is not the case. We tried to use the WAC price as much as possible but it was not always clear which one was used in the data.

- **Sources** – Not all LTB calculation have the same source, we use screens hot, Excel sheets, Lotes Notes files, etcetera. Therefore it was not always exactly clear if information was the same, it was not always consistent, and information was missing. As a result the number of samples can be different from one analysis to the other because that particular data was missing.

- **Spent value** – The prices used in the calculation, as mentioned in the first item, do not reflect the real new price for a spare part. This is a first difference in calculated and spent value. Second the value used is the same for all supply sources, and delivers a second difference between calculated and spent value. Third, in the calculation also future spending is calculated such as repair and dismantling but this spending do not have to occur (yet). For example when there is overstock no repair will be done, and thus no spending on repair. Another example is that Service Parts Operation (SPO) will only transfer spare parts between geographical areas (GEOs) if SPO Europe, Middle East and Africa (EMEA) needs these spare parts. This makes real performance evaluation difficult.

Although there are some difficulties with the data, the data is sufficient and is used to analyze the STOs of the Power division, real accurate financial impact cannot be given but estimations are made. In the next chapter the analysis will be executed and first conclusions about the performance are given.

6 Current performance

In this chapter a detailed numerical analysis is executed for the Stock Take Overs between 2005 up and including 2010 in the Power division. We start with discussing the overall performance and will take a closer look to the Demand forecast and its parameters. After this we will discuss some general observations.

6.1 Overall

To evaluate the current performance key performance indicators (KPIs) are needed. The Planning Department uses three KPIs: costs, service level, and inventory value, see also Section 1.2. Costs of the process are small compared to the investments and they are difficult to measures, therefore these costs are not considered. When an last time buy (LTB) is ended, passed it is end of service (EOS) date, the performance is expressed in the service level, and the costs needed for this service level.

Difficulties – When analyzing multiple LTB decisions together there are several issues which make the comparison difficult. It is important to know these issues because this influences the analysis. The main issues are:

- *Demand sizes* – One LTB has a demand of hundreds or even thousands while another LTB only has a demand of several spare parts. In general this is the difference between slow and fast movers. This makes the analysis difficult because absolute values are difficult comparable, and percentage values are significantly influenced by small numbers. There is no direct solution to overcome this and some cut off values are chosen to make appropriate groups.
- *Spare part price* – Is a spare part of \$ 10 less important then a spare part of \$10.000. In the end, the money is what counts for International Business Machines (IBM), thus the focus should be on the expensive spare part. Since the price differences are large the influence of one or a few LTB is great and we have to be careful with using price as a weight. Therefore it should be only applied when the value is important and relevant.
- *Sample size* – To make a meaningful conclusions the sample size should not be too

small e.g. several spare parts, a large dataset will generate stronger conclusions. We used datasets of at least 100 spare parts to make a meaningful conclusion. If these dataset are large enough to be applied to the general case should be researched later.

6.1.1 Service Level

We use two measures for the service level. The fill rate and the percentage of LTB that has a stock out. The fill rate because it is used by IBM as an KPI and the percentage of stock because it is important to know how many spare part run out of stock, and thus require extra action. This extra action starts different processes and escalation to higher echelons, consequently increase the workload and stress level. Besides this there are extra costs of obtaining more spare parts, offer other solutions, pay penalties etcetera. In Silver, Pyke, and Peterson (1998) this is are P_1 and P_2 service criteria were P_1 has to be interpret slightly different. Every LTB is seen as one order cycle. This P_1 service criteria can thus only be calculated for a set of LTBs.

Missing data – The fill rate is defined as the percentage of orders that directly can be fulfilled from stock. If we know over time which requests could be satisfied directly from stock the actual fill rate over a time period can be calculated, but no data about actual stock levels or how the stock levels changed over time is available. For example when repair orders arrived is not available. Therefore the actual fill rate cannot be measured. Another problem is that the stock level in the beginning of the remaining service period (RSP) will be high, due to the LTB quantity. Therefore the fill rate will be 100 % and cannot be used to measure ongoing performance if the LTB has to go for several years longer. To overcome this we selected a set of 122 spare parts which initial EOS date was before 2011, and these spare should be EOS now. If later the EOS date was extended we do not consider this. Still data of stock levels over time are missing, but an approximation is made by expecting that the initial forecasted demand is supplied (we do not care how it is supplied) and subtract from the real demand. By this assumption deviation in repair (29 LTBs) and dismantling forecast (5 LTBs) is not considered. The same data issues are present for calculating the percentage of stock out, we do not know how many stock outs did occur for a specific LTB over time because we do not know the stock levels over time. We can only assume that a stock out did occur when the demand was larger then the Gross Need. See also or comment above in the service level section about the P_1 criteria. We assume that the action taken on a stock out moment was sufficient to prevent another stock out during the RSP.

Calculation – The RSP for every LTB $n, n = 1, .., N$ is divided in T time periods (t) of 28 days. The first period ($t = 1$) is equal to 28 days after the calculation date. T Identifies the last period, which is the EOS date. The real demand in period t is given by d_t, where d_t is the demand of customer engineers (CEs), together with the demand of third party maintainers, the part sales (PS) demand. The error ϵ_n is the actual demand minus the forecasted demand (6.1), shortage SH_n is the size of the underestimated demand (6.2) and the fill rate, P_2, is given by one minus the shortage divided by the real demand (6.3). To make one KPI for a set of LTB we have to add the fill rate together somehow. We take the mean and also a value weighted mean. The weighted mean shows if expensive spare parts perform better than cheap spare parts. The price of a spare part is give by the weighted average cost (WAC). A volume weighted mean is not calculated because the demand size vary too much and this does not add much information for IBM about the overall performance.

$$\epsilon_n = \left(\sum_{t=1}^{T} d_{t,n} \right) - \left(\frac{12}{13} \times MF_n \times \sum_{t=1}^{T} f_{t,n} \right) \tag{6.1}$$

$$SH_n = \begin{cases} \epsilon_n & \text{if } \epsilon_n > 0 \\ 0 & \text{if } \epsilon_n \leq 0 \end{cases} \tag{6.2}$$

$$P_{2,n} = 1 - \frac{SH_n}{\sum_{t=1}^{T} d_{t,n}} \tag{6.3}$$

$$\text{Mean}\,(P_2) = \frac{1}{N} \sum_{n=1}^{N} P_{2n} \tag{6.4}$$

$$\text{Value}\,(P_2) = \frac{1}{\sum_{n=1}^{N} WAC_n} \sum_{n=1}^{N} P_{2n} \times WAC_n \tag{6.5}$$

$$\text{stock out occurred}_n = \begin{cases} 1 & \text{if } \epsilon_n > 0 \\ 0 & \text{if } \epsilon_n \leq 0 \end{cases} \tag{6.6}$$

$$\text{percentage of LTB with stock out} = \frac{\sum_{n=1}^{N} \text{stock out occurred}_n}{N} \tag{6.7}$$

6.1.2 Cost

The LTB is a decision related to costs. The major costs are the investment, the cost of additional action, the cost of scrap, and the carrying costs. There are also minor costs for example costs related to the execution and monitoring of the LTB. In theory these costs are a measure of performance and can be used in practice also. In the IBM case there are problems with the data.

- *Investment* – We define the investment as the number of expected spare parts needed times the procurement price. In the current IBM model this is the gross need (GN) times the spare price, the WAC value, WAC_n. The investment does not reflect the real spent money. For example half of the GN is already on stock and the rest will be supplied by repair. This spent money is important for the financial impact of the optimization. It is possible that current stock levels are so high that an optimization of the LTB does not have any financial impact on the performance because no extra spare parts are bought and first the problem of high inventory levels should be addressed. The data provides us with the amount of spare parts that are supposed to bought at an external supplier, this can been seen as the real spent money.

- *Additional action* – The cost of additional action is difficult to determine. The cost can be a penalty, higher (or lower) price for the spare part, escalation costs, offering a new product, etcetera. The costs of these alternatives are difficult to estimate and vary heavy according to interviews. Prices can rise with more than 300%. Unfortunately there is no data available about these costs of extra actions executed in the past. Therefore we do not consider these costs in our performance analysis.

- *Carrying costs* – Holding or carrying cost play an important role in the LTB decision. They include the cost of the warehouse, damage, theft, taxes, storage space, etcetera. According to Silver et al. (1998) the largest proportion of carrying cost is the opportunity costs. At IBM this percentage is 8 % of the stock value. Data about stock levels over time is not available and thus holding costs are difficult to calculate. When we assume that the LTB spare are hold for five years and demand is declining straight to zero over these five years the carrying cost will be 20% of the investment value. In this analysis the carrying cost are not taken into account due to the data issues but these cost can drive improvement even more.

- *Scrap costs* – Spare parts that are left over on the EOS date, the surplus, *SU* are usually scrapped, which on itself costs money, but this is not considered. The value of spare parts that are left over is the WAC price times the number of spare parts in stock at the EOS date is the expected scrap costs (ESC). Because we do not know, due to insufficient data, the stock level at the EOS date we cannot determine the scrap value. The best approximation is to assume that the inventory level at the beginning is equal to GN and the inventory at the EOS date is the GN minus the demand. IBM usually does not scrap spare parts direct after the EOS date, causing a delay in the real scrap data. This real scrap data is available for two years in the past, this data shows us how much was scrapped in practice, but probably this number will rise in the future since not all spare parts are scrapped yet. Also it often happens that an EOS date is extended when sufficient spare parts are available, resulting not in scrapping, and spare parts leftover based on the initial EOS date do not show up in real scrap data. This is resulting in data which is not reflecting our definition of scrap. The reserve value as discussed in chapter five is an indicator of future scrap and can be used to shows us how many will be scrapped in the future related to these LTBs. For scrap we have a theoretic expected scrap value, and a value from practice. This is the real scrap value plus the reserve value.

$$I = \sum_{n=1}^{N} \left(\frac{12}{13} \times MF_n \times \sum_{t=1}^{T} f_{t,n} \right) \times WAC_n \tag{6.8}$$

$$SU_n = \begin{cases} 0 & \text{if } \epsilon_n \geq 0 \\ |\epsilon_n| & \text{if } \epsilon_n < 0 \end{cases} \tag{6.9}$$

$$ESC = \sum_{n=1}^{N} SU_n \times WAC_n \tag{6.10}$$

6.1.3 Results

Table 6.1 contains the result of the 122 LTB calculation regarding their performance.

From these figures we conclude the following:

- The fill rate is low compared to the target of 95%, which is used for normal inventory decisions. Because it so high their is no clear difference between the value and the mean of P_2, but the value is somewhat higher than the mean and maybe this is an indication that high value do perform better. More research is needed here to make a solid conclusion.
- The P_1 is 4,1 % which is rather high compared to the fill rate. This shows that even if there is a very high fill rate, 4,1 % of the spare parts run out of stock and require extra action. Probably only a few extra spare parts are needed, looking to the fill rate.
- The expected scrap cost are rather high, about 42% (5,68/12,69) of the investment value.
- The calculated need (12,69) is much higher than the real spent money (1.46), the cause of this is in the repair supply and high initial inventory levels. Much of the investment is supplied by repair supply and/or already on stock.
- Of the spent money about 64% $(0,71 + 0,23)/1,46$ is already or will be scrapped, based on the reserve value. Considering that some spare parts have extended EOS dates and are not included in this number, this number is even larger. For example available for repair (AFR) on stock is not included and stopping of repair is not included. The scarp is not cause only due to the LTB, but can be caused by high initial stock levels.

Remark – It is difficult to generate accurate correct performance figures with the actual data. The numbers above do give some feeling about the performance but we also see big difference between the real and expected values. This is caused by the lack of data and business practice such as extending EOS dates and not scrapping at the EOS date. Therefore it will difficult to analyze, evaluate and improve overall performance.

	Measure	Value
Service	P_1	4,10 %
	Mean P_2	99,22 %
	Value P_2	99,60 %
Costs	Investment	12,69
	ESC	5,68
Data	Spent	1,46
	Scrap	0,71
	Reserve	0,23

Table 6.1: Performance figures. The values are in million dollar.

6.2 Demand Forecast

In the IBM model the demand forecast is the equal to the Demand Plan, while models in literature use a forecast plus a certain safety amount to cover the uncertainty in a forecast. To check how accurate the forecast currently used by IBM is, a group of spare parts that has a demand of ten or more for the year after the LTB calculation date is analyzed.

6.2.1 Bias and error size

The performance of the demand forecast is measured by the bias and by the size of the forecast error. The bias is a structural under or over estimation. A good forecast method should have no bias and the size of the error should be as small as possible. To measure the bias over different time periods and over different LTB calculations several methods are available. None of these methods is able to cope with different demand sizes e.g. compare spare parts that have large and small demand. Therefore a relative and an absolute measure are used. Let F be the forecast, and F_y the forecast for a specific year. A_y is the actual demand in year $y, (y = 1, \ldots, 6)$. The error is $E_y = A_y - F_y$ and is an absolute measure, the $P_y = E_y/A_y$ is a relative measure. The P_y and the E_y are calculated for every LTB. The bias is given by the sum over all LTBs and the error size is given by the average over all LTBs, N.

$$\text{Absolute Bias year y} = \sum_{n=1}^{N} E_{y,n} = \sum_{n=1}^{N} A_{y,n} - F_{y,n} \quad \forall y \tag{6.11}$$

$$\text{Relative Bias year y} = \sum_{n=1}^{N} P_{y,n} = \sum_{n=1}^{N} \frac{E_{y,n}}{A_{y,n}} \quad \forall y \tag{6.12}$$

$$\text{Error size} = \frac{1}{N} \sum_{n=1}^{N} |E_{y,n}| \quad \forall y \tag{6.13}$$

$$\text{Percentage Error size} = \frac{1}{N}\sum_{n=1}^{N}|P_{y,n}| \quad \forall y \tag{6.14}$$

Results – Table 6.2 displays a structural error in the forecast methodology because the absolute as well the relative biases are not close to zero. In fact they are very large, it is now obvious that the forecasting is not done properly. The errors do increase when compared to the average demand, which indicate that the forecasting is better for shorter periods, which seem logical. This table clearly show the current forecast procedure needs to be adjusted.

Year	1	2	3	4	5	6
Sample Size N	262	231	202	140	132	35
Average demand	81	62	44	20	12	8
Absolute bias	-7775	-9349	-9364	-3563	-1975	-318
Relative bias	-15867%	-35966%	-50984%	-27111%	-29144%	-3592%
Error	33,53	42,95	49,4	29,6	19,1	14,06
Percentage Error	67%	160%	278%	218%	263%	186%

Table 6.2: The results of the forecast performance in absolute and relative values. A negative value is an overestimation.

In a new forecast method the bias should be around zero and the error size should be smaller. To investigate what the cause is of this over forecasting the two parameters, the monthly forecast and the factor are checked.

6.2.2 Parameter - Monthly forecast

The monthly forecast (MF) should reflect the spare part demand for the next month. To check the forecasting procedure of MF the value of MF used in the LTB calculation is compared with the average demand of a certain period. The date of the forecasted demand is in the middle of this period. The MF is compared with the average demand of 3, 7 and 13 periods. The date of the forecasted period is still in the middle of these periods. The average demand of the interval is taken and multiplied by $\frac{13}{12}$ to convert it to a monthly figure. (Periods are in 28 days and the MF is in months) The monthly error factor (MEF) is determined by dividing the MF by the average demand of the specific interval. The average error is determined by taking the average of the errors over N.

$$\text{Average } MEF = \frac{1}{N}\sum_{n=1}^{N} MEF_n = \frac{1}{N}\sum_{n=1}^{N}\frac{MF_n}{\frac{13}{12}\times\frac{1}{X}\times\sum_{x=1}^{X} d_{x,n}} \tag{6.15}$$

Table 6.3 displays that the MF is overestimated based on the average of 3, 7 and 13 periods. A value of one for the MEF is a perfect forecast, below one is a underestimation, above is an over estimation. How longer the period the better the MF but still the best case forecasted on average 49% too much of the actual average usage (33% too much of the forecast). The increase of the MEF in small periods is because the demand is volatile in small periods. For a part of the dataset overrides set by the analyst are know. Table 6.3 displays a comparison between the analyst and the algorithm. It displays that 12 to 14 % better forecast for the MF is made by the analyst based on 65 samples when compared to algorithm. Most overrides made by the analysts are lower than the original algorithm outcome resulting in better performance. Implicitly this also shows that the analyzer judges the MF as too high, most overrides are set based on visual inspection of the demand pattern.

	MEF (N=265)	**MEF (N = 65)**	
Periods	*Algorithm*	*Algorithm*	*Analyst*
3	1,89	2,04	1,90
7	1,57	1,44	1,30
13	1,49	1,36	1,24

Table 6.3: MEF figures based on three different lengths. A value of one will state that as much is over forecasted as under forecasted. The last two columns display the difference between the analyst overrides and the algorithm

Causes – The MF is constructed by a complicated forecast algorithm which seems to be based on sound assumptions. One of the causes can be a trend in the data, this is not included in the algorithm. Probably the demand is already declining while the forecasting algorithm assumes a stable demand. Still the deviation is a high percentage and cannot be clarified only by a trend in the data. Figure 6.1 displays a plot of the MEF error against the average of 13 periods. From this plot you can see that the MEF is large for low values. The algorithm has problems to estimate parts which a have a demand between one and five a month.

Other ideas about the causes cannot be tested due time and data constrains but can be explained. One idea is that slow mover adjustment (SMA) used in the forecasting process is a cause. SMA is applied on cluster level. When SMA is applied a small addition is done to the cluster forecast. When many cluster have this addition on Europe, Middle East and Africa (EMEA) level this can be significant large. Another idea is that the alpha is too low, alpha is responsible for determining how heavy recent buckets weigh, it does this on cluster level. Because demand will be low on cluster level much history will be taken into account. For a cluster this can be the right approach but on EMEA level a trend is much more visible and therefore older observations should weigh less. The impact of this assumption cannot be measured. Therefore we suggest to apply forecast accuracy measurement in the planning system on cluster and EMEA level to measure the accuracy of the MF and monitor the performance. This should be done by comparing current method to a simple alternative method such as setting the forecast equal to the last period.

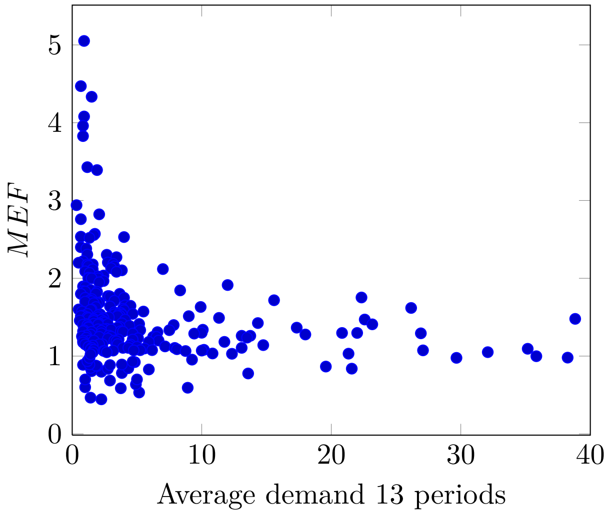


Figure 6.1: The average demand of 13 periods plotted against the MEF. When demand is small this error becomes larger. The algorithm seems to perform worse for small demand values.

Conclusion MF – The MF figure is too high for the LTB calculation. Overrides do improve the MF but if this is based correct reasons cannot be determined. The MF algorithm has problems to estimate the right MF figure especially for spare parts with an average demand of one to five a month. To improve the forecasting algorithm for planning purposes forecast performance measuring should be implemented.

6.2.3 Parameter - Factor

The factor is based on a forecast of Service Planning, we are not able to obtain the right data to measure the performance of this forecast. An alternative method uses a fixed value for the year zero (y=0). In the current method this is the MF times 12. We want a fixed input variable for MF to clear out the influence of the overestimation of the MF variable. The real demand of 13 periods before the calculation date generates the base year, y=0. A stable demand is assumed in these 12 months and thus no trend is present. If the demand is not completely available due to data issues for one year before the calculation date (this when the calculation is done in 2005), one year from first moment the data is available, is used. The factor is compared per year to see the time influence. The PD (6.17) is the difference between the used factor f_y, and the actual factor percentage, AP, in year y, where AP_y is given by Equation 6.16.

$$AP_y = \frac{\sum_{t=1+(y-1)13}^{t=13+(y-1)13} d_t}{\sum_{t=-12}^{t=0} d_t} \quad \forall y \tag{6.16}$$

$$PD_y = AP_y - f_y \quad \forall y \tag{6.17}$$

We take the *average* and the *median* of PD of all stock take over (STO) calculations. The *median* limits the influence of large outliers. If the difference between the average and the median is large this is an indicator of large/many outliers. From Table 6.4 we conclude that the factors are overestimated and especially in year two, three and four. More than 20% is overestimated these years. The current factors used are not declining fast enough. This can be seen in Figure 6.2. In the dataset there are some spare parts that are underestimated heavily and these are the main source for the difference between the average and the median. About 50 spare parts have an inclining factor in the first year compared to year zero, and only 15 of the 50, have also an incline in the second year compared to the first year.

Percentage difference ($PD_y = AP_y - f_y$)							
N	265	265	232	203	140	131	265
Year	1	2	3	4	5	6	Total
Average	-8,5	-24,6	-29,9	-21,7	-12,4	-15,1	-112,2
Median	-15,2	-29,8	-32,6	-20	-11,8	-15,9	-125,3

Table 6.4: The result of the evaluation of the factors. The factor is estimated the worse in year 2, 3 and 4. Large outliers are present especially in the first year two years because the median and the average differs the most.

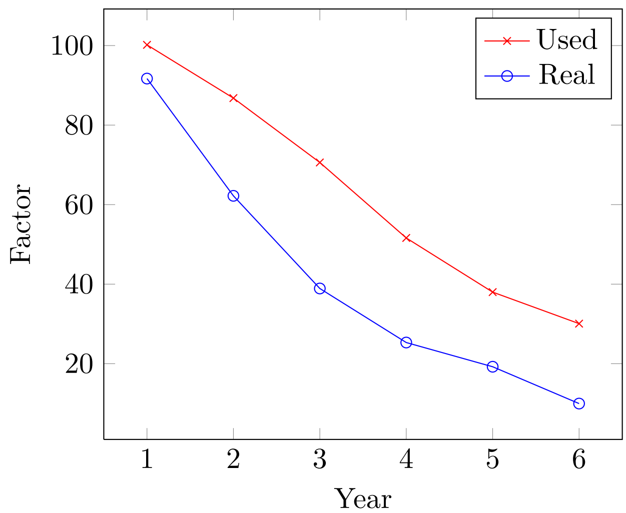


Figure 6.2: In this graph the difference can be seen between the real and used yearly factor. The space between the two lines will be overestimated.

6.3 Other observations

When analyzed the dataset we did also other observation which will be discussed next.

- **High current stock** – Several figures showed that current inventory on IBM, global Service Parts Operation (SPO) and SPO EMEA level are high. A cause can be the allocation aspect. The following indicates a high stock level:
  - From the 2572 calculated spare parts only 872 (34%) needed extra supply. The average RSP was 5,6 years. 2572 - 872 = 1700 spare parts did have enough inventory to cover on average 5,6 years. This is also included slow movers who had no need at all. Table 6.5
  - The value of these 872 spare parts is 67,5 % of the total needed value which indicates that high volume and high priced spare parts are present in this group, resulting in high value. Table 6.5
  - Other geographical areas (GEOs) are used for 5% of the spare parts as supply source, for 188 spare parts, indicating surplus in an other GEO. Table 6.6
  - Manufacturing is used to deliver supply for 23% of the spare parts and provides many spare part looking to the value. This indicates inventory left over at the IBM factory. 6.6
- **Not many real LTB** – In Table 6.6 only 4,7% of the spare parts require a procurement from an external supplier. The other 95,3% are provided by IBM itself or by making a continue supply contract with a supplier.
- **Repair is important** – When repair is used this represent much value (32,3 %) and/or volume. From business perspective this logical because it is only useful to set up repair for expensive spare parts or for high volume spare parts, for these spare parts repair can be financial efficient, and thus if repair is possible it is for much volume or expesive spare parts, resulting in high value.
- **Continuous Supply** – Continuous supply is a different decision than an LTB. Therefore this option should not be approached as an LTB decision. Continuous supply is a decision between the cost of maintaining a supplier and keeping stock. It is not a decision where the spare part is not procurable anymore as with an LTB
- **Specific Items** – We question if it is needed to do a LTB for all spare parts calculated. IBM did LTBs on keyboards and USB cables, we think alternative or other solutions were available here and an LTB could be avoided.

	LTB calculations	%	**% of GN value**
in STO projects	2572	100	100,0
with no need	798	31	0,0
with gross need	1774	69	100,0
gross need with sufficient stock	902	35	32,5
gross need with extra supply	872	34	67,5

Table 6.5: This table shows that 2572 spare parts are calculated over the period 2005 up and including 2010. Only 1774 spare parts had a need and the current stock could cover 905 of these spare parts. Therefore only 872 needed additional supply, this mix of supply sources is shown in Table 6.6. The value is expressed in a percentage of the total gross need value.

Source	**STO that use source**	**% of GN value**
Other GEOs	118 (4.6%)	0,8
IBM factory	**594 (23.1%)**	**13,2**
Repair	211 (8.2%)	32,3
Substitution	11 (0.4%)	4,6
Dismantling	27 (1.0%)	1,9
Continuous Supply	79 (3.1%)	6,6
Last Time Buy	**121 (4.7%)**	**8,2**
Total		67,5

Table 6.6: The supply sources of all the STO of Power executed between 2005 - 2010. Spare parts can have multiple sources and therefore the spare parts cannot be summed. Money is directly spend by SPO when using the source IBM factory or LTB source.

6.4 Conclusion

Due to missing data only an approximation of the performance can be given. The expected service levels are very high, fill rate is above the 99%, almost 5% of the spare parts have a stock out situation. The expected scrap value is 46 % percent of the calculated investment and much of the real investment (64%) is scrapped. In future this will be even more. A statement in terms of good or bad cannot yet be made but looking to the demand forecast which is too high it is probably not good. It has a structural bias and the error is large. Both parameters used for this forecast are overestimated and the analyst implicit lower the MF parameter indicating it was too high. A new procedure for the parameters is needed to determine the correct value. Observations show that the current stock levels are high, and many LTB calculations do not result in the buying of additional spare part. The challenge will be to make a good forecast and determine an appropriate safety stock to cover the uncertainty in the demand forecast.

7 Improved method

This chapter will implement advises and remarks given in the previous chapters. First the new approach is discussed and after this an unbiased forecast procedure will be created. A method for safety stock setting is researched and evaluated.

7.1 New Process

All suggestions in previous chapters are combined into a new process displayed in Figure 7.1. All the parameters are collected automatically and use the same source data, no discussion should take place about the parameters because a good and specific process is set up. The forecast procedure is defined and should be adjusted based on the forecast measurement which compares actual data with produced forecasts. This can be done for the demand forecast but also for the repair and dismantling forecast. After that the forecasts are generated the analyst and management has to decide which service level they want to offer for this specific spare parts. The service level will require a certain safety stock which should be added to the forecast. This is the needed amount and based on the repair forecast, dismantling forecast and current stock information a last time buy (LTB) quantity is determined. The analyst only has to check if this spare part has some exceptional behaviour, for example a special repair processes or a high part sales percentage. When this is the case, it can be dealt with by adding or subtracting an amount of spare parts from the safety stock and provide a specific reason for this adjustment. A reason should be compulsory to do able to analyze the taken decision afterwards. When management judge the investment as too high, they should lower their service goal, which will result in lower safety stock and less investment. To calculate an accurate LTB quantity a good forecast procedure is needed and a relationship between the service level and the safety stock must be quantified. The safety stock assumption check is needed to determine if the relationship used for safety stock and service level is still valid or need to be adjusted. Currently there are two measures for service, P_1, stock out probability and P_2, fill rate. For service parts fill rate is less attractive because service is time depended and thus cannot be backordered as in normal stock situations. Having spare parts available in time is the main service provided. The stock out probability is therefore more suitable for the service industry, especially for the LTB where in principle no demand can be backordered. A disadvantage is that, P_1 needs much higher stock levels, or safety stocks. Therefore our primary service level measure is the stock out probability, our secondary is the fill rate. To test the new process and model we use the same performance measures as in chapter six. A small change is that the safety stock is added to the gross need (GN). If the same stock out probability can be reached with less investment it is an improvement.

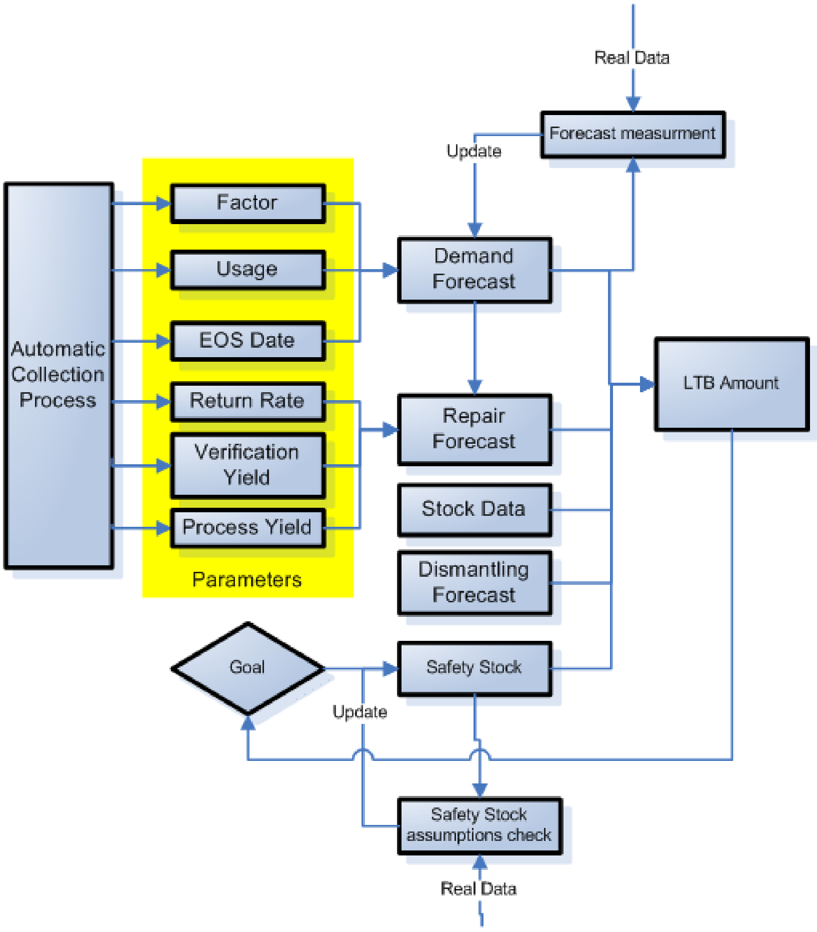


Figure 7.1: The proposed new process

7.2 Demand forecast

For the new process a good forecasting procedure is needed. This new method is based on the old forecast procedure, but refined. We redefine the two parameters used for the demand forecast:

- **Current usage** – This parameter should reflect the usage of a specific period before the calculation date, comparable to the monthly forecast (MF) figure but without a comprehensive forecasting procedure. The research of the MF in chapter six showed that it is better to use a longer period for generating a current usage figure. The choice of the length of the period is a decision between including a trend when taking a long period and the sensitivity to exceptional demand when taking a small period. Based on our observations and interviews we use a 12 month, 13 periods, historic demand figure. Part sales (PS) demand is excluded. PS demand is sporadic and lumpy and disturbs the demand pattern. PS should be handled in the safety stock.

- **Factor** – The factor should reflect the increase or decrease in demand compared to the CU figure. As seen in the previous chapters the performance of the factor is not good, it is overestimated. The forecasting procedure of the installed base, provided by the Service Planning Department, is questionable and complicated, and thus not suitable. Standardized factors based on historic observations, are easy in use, and probably give a better performance. To determine this standard factor, used for all LTBs, the absolute error E_y is minimized sequentially for every year. Chosen is for every year and not in total because we do not want to compensate an error in one year with the other year. This is because it is unknown how long an LTB is ongoing and if it possible to compensate one year by the year after. The optimization is given in Equation 7.1.

$$\underbrace{min}_{f_y}(E_y) = (\sum_{t=-12}^{t=0}(d_t) \times f_y) - A_y \quad \forall y \tag{7.1}$$

Table 7.1 shows the results of the optimization. Still the absolute bias is relative large when compared to the average demand. This has to do with spare parts that have high demand, and a one percentage difference in the factor makes a big difference in the absolute bias. Also the percentage biases are not close to zero. Therefore we did a minimization of the percentage bias to see what the influence is on the factor. A naive method is also calculated, this naive method is a straight line from the current usage to zero on to end of service (EOS) date. The different factors resulting from this scenarios are displayed in Figure 7.2.

Year	**1**	**2**	**3**	**4**	**5**	**6**
N	262	231	202	140	132	35
Average demand	81	62	44	20	12	8
Absolute bias	102	78	-95	30	-32	-5
Relative bias	123%	-5809%	-9654%	-6111%	-7314%	-911%
Error	17,31	18,8	15,2	9,7	6,52	3,4
Percentage Error	30%	56%	87%	83%	98%	68%

Table 7.1: The result of the optimization based on the absolute bias. The percentage bias is still large, also the error size is large.

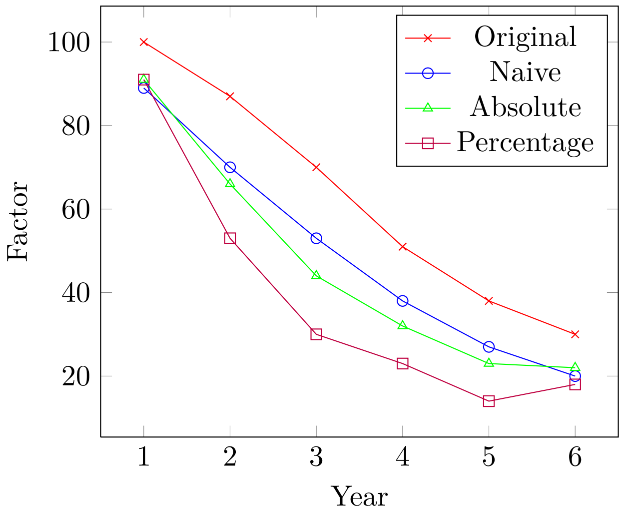


Figure 7.2: Different factors belonging to different scenarios. The original factors used, the naive straight line fore each spare part, optimization over the absolute and relative bias.

Conclusion The new forecast method should use a standard factor of 91, 66, 44, 32, 23, 22, percent, based on minimizing the absolute values. The basic value, the current usage (CU), should be the total demand of the last 12 months. In absolute measures this will be the best general forecast procedure for all spare parts. Still the sizes of the errors are significant which indicates that the individual spare parts can still deviate significant from the forecast.

7.3 Safety stock

The forecasting procedure is now a fixed procedure. In theory, when assumed that the demand is normally distributed, this will deliver a forecasted demand which will be sufficient in 50% of the time, the other 50 % it will not be sufficient, as result the stock out probability is 50 %. The P_1 service measure should be much higher for International Business Machines (IBM) and therefore a safety stock is added. A relationship must be found which relates a service level, or goal, to a specific amount of safety stock. When the goal changes the safety stock should be adjusted accordingly. First we need to quantify this relationship before management can decide which goal they want to use and how much that will cost.

The safety stock is based on Silver et al. (1998). This is used for determining the safety stock amount such that you do not run out of stock during a replenishment cycle. This safety stock is given by Equation 7.2. In this Equation three variables are present; one is the safety factor k, which is the relation between the goal, the service level (SL), and the safety stock quantity SS. The value of the SL is given by the inverse of the normal distribution, in case the stock out probability is 5% the service level is $1-0,05 = 0,95\%$. The standard deviation over the remaining service period (RSP) should be an indication of the forecast quality, high deviation should lead to high safety stock. The σ_{rsp} is a combination of the standard deviation for one period, σ_t times the square root of the number periods, T. The square root is taking to share risks between periods. The standard deviation for one period is usually chosen by using past forecasts and taking the mean square error (MSE). There are no past forecasts available and as alternative it is estimated with the standard deviation of the last 12 months (13 periods). The main assumption here is that the forecast error is normal distributed.

$$\begin{aligned} ss &= k \times \sigma_{rsp} \\ &= \Phi(\mathrm{SL})^{-1} \times \sigma_t \times \sqrt{T} \\ &= \Phi(\mathrm{SL})^{-1} \times \sqrt{\sum_{t=-12}^{t=0} d_t - \frac{1}{13} \sum_{t=-12}^{t=0} d_t}^{\,2} \times \sqrt{T} \end{aligned} \quad (7.2)$$

The first analysis did not deliver the desired result, Table 7.2, column one. The goal stock out probability of 5 % delivers in our model a 22,95 % stock out probability. Therefore we conclude the relationship between safety stock and service level is not defined properly. Silver et al. (1998) also states that $\sigma_{rsp} = \sigma_t T^c$ were c=0.5 is usually a good approximation, but not always. Specific when the RSP, or lead time, becomes longer. To find a good value for C rewrite $\sigma_{rsp} = \sigma_t T^c$ to $\log(\sigma_{rsp}/\sigma_t) = c \log T$. With this equation and the available data we can determine the value of c by taking the forecast error as σ_{rsp}. When plotting these values in a plot, and draw line trough the origin (0,0) the slope is equal to c. Figure 7.3 displays this plot. From this plot a value of $c = 0.6$ is found and applied to the model. Still our goal service level is not the same as we get out of the model performance. We changed the C value manual to 0,7 and found that is a very good value for this specific data set. The results can be found in Table 7.2, the $P_1 = 5\%$. We used the performance measure of chapter six, but left out value weighted P_2 and the real data. The overall new Demand Plan is given by the Demand Forecast plus the safety stock, SS.

$$GN = \sum_{t=-12}^{t=0} d_t \times \sum_{y=0}^{Y} f_y \times m_y + SS \quad (7.3)$$

To check if this relationship between the service level and the safety stock is valid for all values of the service level the goal service level is changed to different values and compared the outcome service level. This is displayed in Figure 7.4.

Based on Figure 7.4 the model is also valid for other service levels. Now we are able to compare the current performance with the model performance and see if the model generates lower investment. Current performance has a stock out probability of 4,1 % which means a service level on 95,9 %. Now the model is run with this service level goal

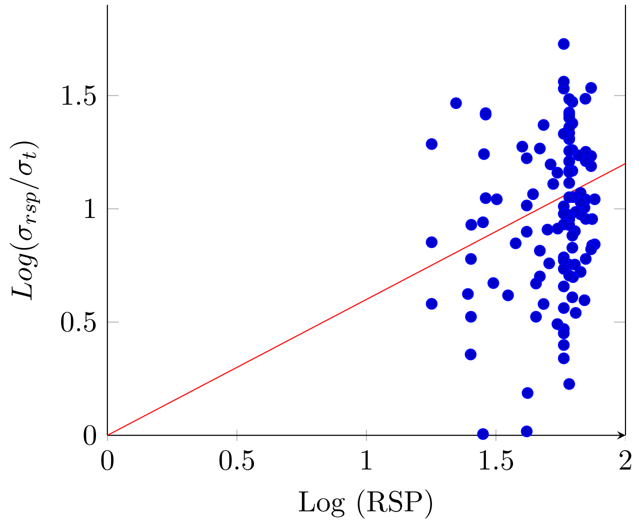


Figure 7.3: Based on this plot, c=0,6 by Log(RSP)=1

C, goal P_1 = 95 %	**0,5**	**0,6**	**0,7**
Fill rate P_2	96,35%	98,01%	99,10 %
Stock out probability P_1	22,95%	12,30%	4,92 %
Investment	8,64	9,52	10,82
ESC	1,94	2,64	3,81

Table 7.2: Result of different c values for the determination of the safety stock where c= 0,7 gives the best result.

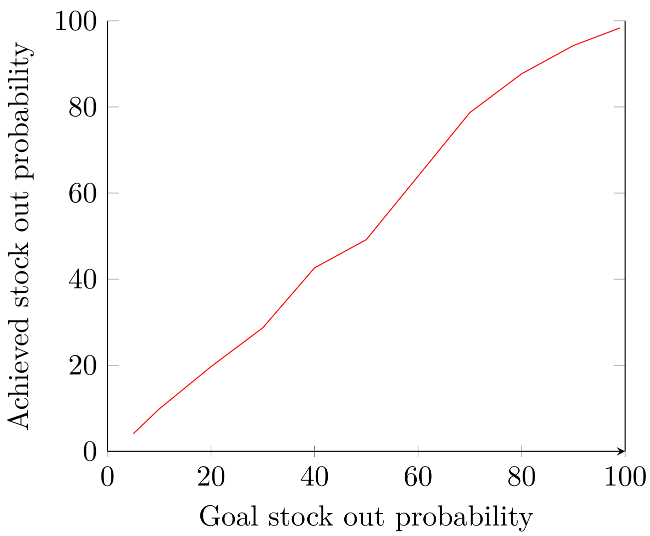


Figure 7.4: The relationship between the desired service level, and the achieved service level of the model.

C	Original	Model
Fill rate P_2	99,22%	99,19%%
Stock out probability P_1	4,10 %	4,10 %
Investment	12,69	11,05
ESC	5,68	4,04

Table 7.3: The model reach the same stock out probability for less costs.

of 4,1%. In Table 7.3 are the results. It is clear that the same service level is delivered against less costs, and thus can be conclude that the model does perform better than the initial IBM model. 12,69 - 11,05 = 1.64 million dollar is saved, this about 13% of the calculated investment while maintaining the same stock out probability, or service level. The fill rate drops with 0,03 % which means if extra actions is taken it has to be for more spare parts that in the original model, but the drop of 0,03 % is not much.

Remarks and improvements – From the result the model seems to perform good, still some remarks can be made and improvements idea are present.

- **Sample size** – The model performs good for these 122 LTB, which are from the type stock take over (STO) and have a relatively short RSP, and a minimal demand of ten. It would be good to extend this group to a large number and check if the model works for a larger group as well.
- **C value** – Currently the value of c cannot be determined exactly, when more data will become available this can be better tested, maybe this c has to be adjusted downwards as seen in the scatter plot.
- **Forecasting** – The factors are based on a larger data set but still this is not very large. Also these factors are probably different per commodity which is based on Figure 7.5. The forecasting can be more specific resulting in better forecasts and lower safety stocks needed.
- **Slow movers** – We did not test the method on slow movers. The forecasting procedure will not work for slow movers. Slow mover will probably have many periods with zero demand, and therefore the average of last year can be zero and the safety stock should be determined different. The forecasting procedure should be adjusted and the determination of the safety stock should be adjusted. Our model will be suitable if the demand is 10 or more in the past year. Also carrying cost will reduce significant and the new process will take away a lot of workload, at first the Hungarian support team is not needed anymore.
- **Repair** – When there is repair possible, there is uncertainty in the demand and repair forecast, which are probably positive correlated, when demand is higher the repair will probably also deliver more spare parts. Therefore safety stock can be

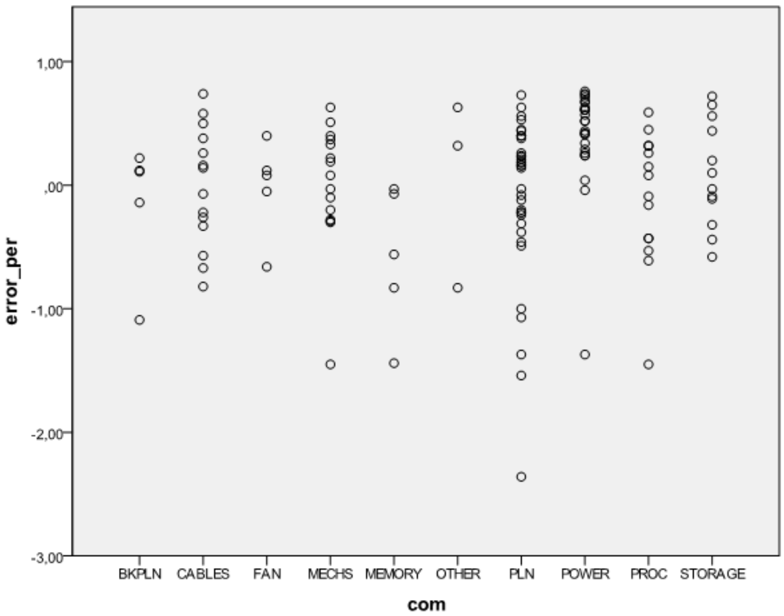


Figure 7.5: Error per commodity, showing that commodity do behave different.

smaller than when no repair is available, because repair is reducing the effect on supply when demand increases. This can be a extension to the current model.

- **Financial impact** – It is very difficult to determine the financial impact, as seen in chapter of the current performance only a small fraction about 8% of the gross need value is spend to LTB. Will this reduction of 13% completely remove the spending regarding the LTB, probably not, but it will demise the spending for sure.

7.4 Conclusion

For the dataset of 122 LTBs, of the type STO, the model was able to improve the performance of the LTB. Based on fixed process of handling input data, transform this data to parameter values, and use a standardized forecast method for demand, it was able to deliver the same service level in terms of stock out probability (4,1%) for about 13 % less costs. A test with more spare parts will make the model more reliable and additions for repair and dismantling should have effect on the required safety stock.When the process of the LTB is followed, the forecasting will become more accurate trough forecast performance measurement, and the safety stock can be adjusted over time to optimize the model.

8 Implementation

Our suggestions and improvements can only deliver result if they are implemented. Currently a full automated tool is developed, the product life cycle management (PLCM) support Application. The development of this application is not sure for budget reasons and therefore an intermediated solution is necessary. This intermediated also provide some useful insights for the development of the PLCM Support Application, and could been seen as a prototype.

8.1 PLCM application

While developing already takes place we suggest that the developing team implement our advisees.

- Data storage
  - Store all data related to the forecasts and the actual data over time, the goal is to improve the forecasting methodologies.
  - Store all overrides and assumption to be able to track what was done.
  - Store the demand and supply plans to track responsibilities.
- Usability
  - Display information visually. Demand patterns can be easily seen when displayed and use all historic information available in this visualization.
  - Display substitution changes such that it is easy to see how this structure is build up. This should provide better insight in alternatives and which stock, demand etc. could be used in the supply sources.
  - Include all correct information from other IT systems to avoid manually checking the data.
  - Implement a review possibilities for other departments, such that communication and transfers of data out and in the system is not necessary.
- Methodology

- Implement the simple proposed forecast methodology combined with the safety stock relation and a process to update these values based on real data.
- Allow only overrides on the trend and safety factor / service level
- Implement forecasting monitoring with a tracking signal to signal when a forecast is out of line so that timely action can be taken.

8.2 Intermediate solution in Excel

We developed an intermediate solution between the current situation and the PLCM Support application in Excel. We used an external program, query management facility (QMF) for Windows to extract all the information from the IT system. We wrote several procedures/queries to extract all information at once from the information technology (IT) systems. By QMF for windows all information was possible to import to Excel. In the Excel sheet all kind of actions are applied automatically which deliver a standard analyze tab which the analyst can use to check the first estimation. The sheet is able to:

- Process all data such that is easy to analyze. The analyst does not have to look into several different IT systems.
- Interaction with the Repair department is in a generic format and is generated automatic; also the return sheet from the Repair department can be imported automatically.
- The interaction with the Global coordinator is automated and a generic format is used such that manual work is very limited.
- The storage of all the relevant data is processed automatically to a generic format ready to store in a database, this can later used to evaluate the LTB calculations.
- The signoff reports are generated automatically.
- High investment spare parts are highlighted.

While much work is automated this also limited the chance off errors. We started to implement this in one division. We educated two employees with the Excel sheet and the QMF for windows program. Next steps to take are:

- Educate more employees in the use of the excel sheet and the QMF for windows program.
- Expend the use of the sheet to other divisions.
- Educate people in the principle of forecasting and safety stock principles.
- Regular analyze the information produced in last time buy (LTB) calculations, this can give valuable information and make it possible to increase the quality of the forecasting procedure or the safety stock decision.

8.3 Conclusion

Most part of the implementation is already done. Important is that the new process and model is also implemented in the PLCM Support Application. Also the storage of information, and analysis done, is very important. This information is needed for performance figures and continuous improvement of the model. This can improve the quality of the forecasts and the better safety stock relationships can be found.

9 Conclusions & Recommendations

9.1 Conclusions

The main question that this research answers is *How can IBM improve the last time buy (LTB) decision by reducing investments and costs while maintaining the desired service level?*. The answer to this questions is: by applying the new LTB model and process, this will result in the same service level with 16% less investments.

The new model and process do improve the current model on several ways. The new process simplifies the parameters needed. For example the current usage, or the former monthly forecast, is now given by the average demand of the last year instead of a complicate forecasting procedure. The new model provides a clear definition of these parameters. This eliminates the labour intensive and unnecessary steps currently executed during an LTB, such as the exchange with the Reutilization department and asking the Service Planning for an installed base forecast. It is also avoiding discussion between analysts about the parameters values. A clear split between the forecasting procedure and the safety stock is made. The safety stock is needed to cover the uncertainty in the demand forecast. In the new process the Hungarian support team is not needed anymore by the introduction of the Excel sheet, also the process is become much quicker. As a result throughput time can be decreased with days due too less and standardized communications and the right support from IT systems.

This new model is build based on historic data and observations of the current model. It is tested on a dataset that exists out of stock take over (STO) from the Power division which is according to our research the most promising division, followed by the Storage and Mainframe division. The current forecast performance is bad, almost every LTB is overestimated which is leading to high scrap costs. The current overall performance is high, the service level, defined as stock out probability is 4,1 % and the fill rate is 99,22 %. The new model can reach the same stock out probability of 4,1% and a fill rate of 99,19% which is almost equal but with 16% less costs and much less work and throughput time. An improvement in the model will be if more different costs will be included, such as carrying costs, and real different procurement prices for every supply source. Researching the repair and dismantling forecast and opportunities more and try to integrate this interaction will improve the model too.

Due to data issues we could only approximate the performance, when more data will come available also a detailed analysis about the repair forecast is possible. Data is essential to make a good objective and full analysis of the LTB decision and monitor the performance to timely adjust your forecast and safety stock settings.

Regarding repair the following improvements are made. A consistent definition between the Reutilization department and PLCM is agreed, about the three repair forecast parameters. An improvement of the return rate has been taken place to reflect the reality better. The impact could not be determined due to data issues.

9.2 Recommendations

During this research we observed a lot of issues and based on this we gave the following recommendations:

- The current stock levels are high and a research should take place to investigate why these are high. A root cause must be found because this will also impact daily operations.
- Make a global LTB calculation process that spans all GEOs at once. This will improve the forecasting and makes global risk sharing possible.
- Check if a LTB is needed, if continuous supply or reasonable (for example key boards) alternatives are present do not a last time buy.
- Go discus the opportunities with the global asset recovery service (GARS) organization, our feeling is that more spare parts can be sourced here, it could be a good backup solution.

9.3 Future Research

For future research we suggest three directions:

1. **Forecasting** – The forecast can probably be improved if more research is done for specific commodities of spare parts, such as a life cycle approach. Maybe the use of the installed base can be valuable for forecasting the spare part demand, important will be if the forecasting of the installed base can be accurate.
2. **Safety Stock** – The relation between safety stock and the goal, related to the forecast accuracy and risk taken. What are the (combination) of indicators that can predict upfront what the amount of safety stock must be. For example electronic spare parts need less safety stock than mechanical spare parts.

3. **Risk sharing** – The LTB is a method to mitigate risk of running out of stock during the remaining service period. We think IBM should put more effort in risk sharing, first starting with Global risk sharing between GEOs and as second step research the risk options such dismantling, and repair in more detail. Start first with investigation of the process possibilities and after that try to improve the forecast related to it.

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Appendices

A Organization structure

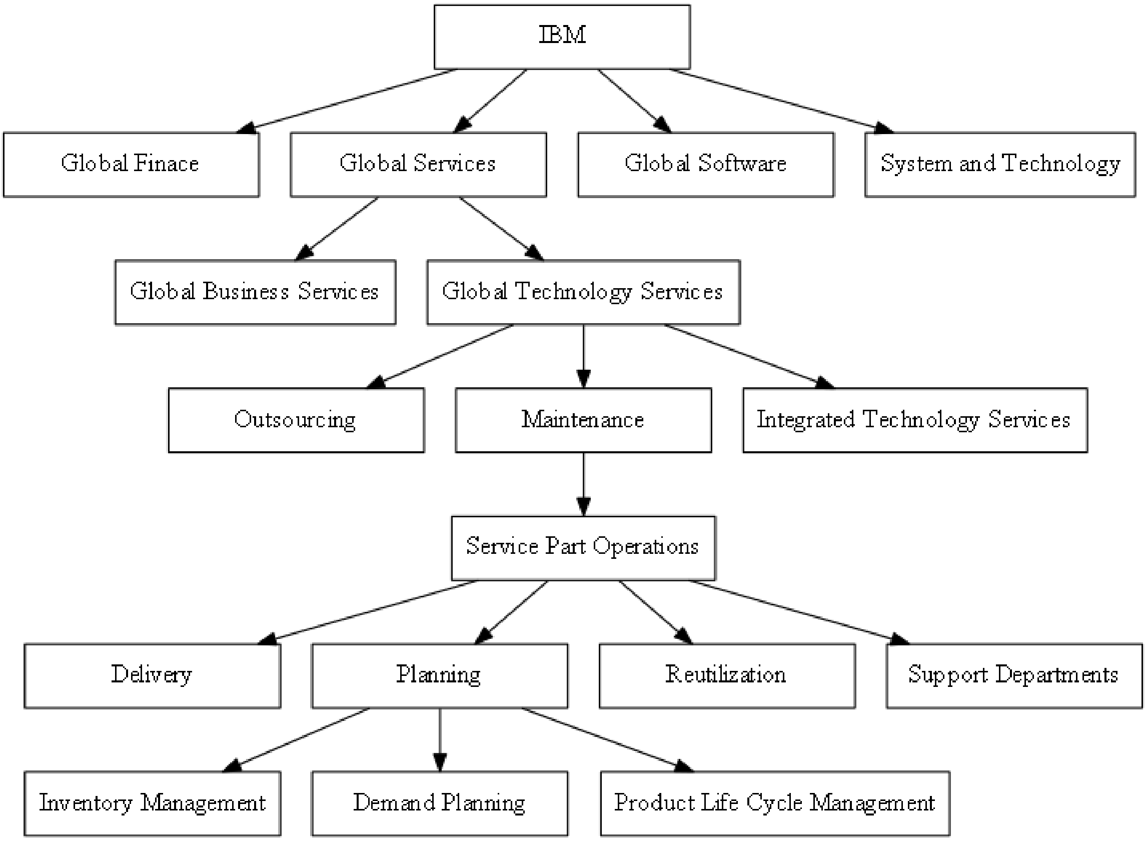

Figure A.1: A simplified structure of the IBM and SPO orginization

B LTB Figures

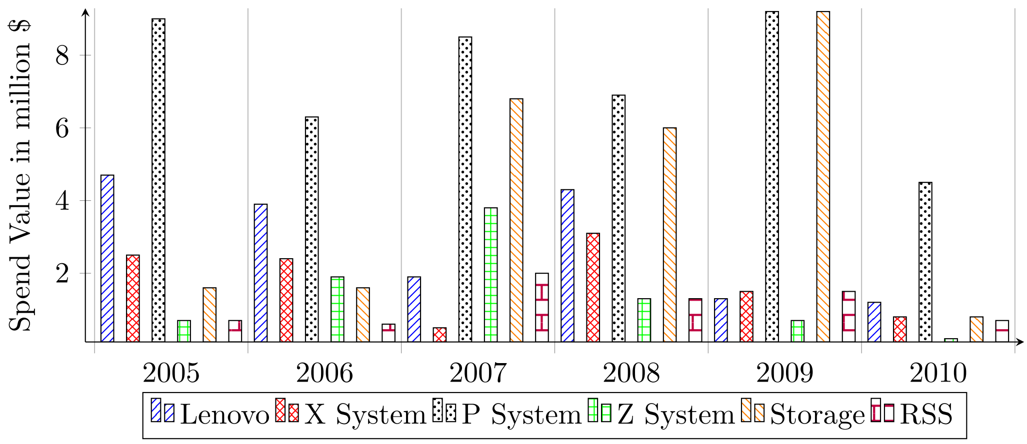

Figure B.1: The total spend value of LTB projects.

	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**Total**
Lenovo	4.7	3.9	1.9	4.3	1.3	1.2	**17.3**
Modular	2.5	2.4	0.5	3.1	1.5	0.8	**10.7**
Power	9.0	6.3	8.5	6.9	9.2	4.5	**44.4**
Mainframe	0.7	1.9	3.8	1.3	0.7	0.2	**6.9**
Storage	1.6	1.6	6.8	6.0	9.2	0.8	**25.8**
RSS	0.7	0.6	2.0	1.3	1.5	0.7	**6.7**
Total	**19.2**	**14.8**	**23.5**	**22.9**	**23.4**	**8.1**	**111.8**

Table B.1: The total spend value of all LTB projects in million $

[1] See table B.6, One project was responsible for more than 4000 calculations, the project itself had almost no value, so no investments were done. The large number was caused by RoHS regulation

	2005	2006	2007	2008	2009	2010	Total
Lenovo	0,08	0,00	0,00	0,00	0,00	0,00	**0,08**
Modular	0,49	0,00	0,00	1,25	0,35	0,22	**2,31**
Storage	0,68	1,09	2,90	3,96	4,23	0,44	**13,30**
Power	2,20	0,16	3,87	3,77	1,71	3,13	**14,83**
Mainframe	0,66	0,10	3,47	1,28	0,63	0,17	**6,30**
RSS	0,18	0,56	0,24	0,38	0,58	0,61	**2,56**
Total	**4,29**	**1,92**	**10,47**	**10,64**	**7,49**	**4,56**	**39,38**

Table B.2: Value of *STO* in million $

	2005	2006	2007	2008	2009	2010	Total
Lenovo	4,64	3,87	1,93	4,35	1,31	1,16	**17,25**
Modular	2,03	2,36	0,50	1,83	1,11	0,60	**8,43**
Storage	0,90	0,47	3,86	2,00	4,96	0,34	**12,54**
Power	6,84	6,10	4,60	3,09	7,53	1,36	**29,52**
Mainframe	0,04	0,09	0,35	0,05	0,06	0,00	**0,60**
RSS	0,48	0,00	1,75	0,90	0,93	0,04	**4,11**
Total	**14,94**	**12,89**	**12,98**	**12,22**	**15,90**	**3,51**	**72,44**

Table B.3: Value of *Pre* and *Post* projects in million $

	2005	2006	2007	2008	2009	2010	Total
Lenovo	1	0	0	0	0	0	**1**
Modular	2	0	0	2	2	4	**10**
Storage	2	5	16	17	16	31	**87**
Power	9	4	11	13	2	17	**56**
Mainframe	2	2	4	7	16	5	**36**
RSS	3	0	2	6	4	10	**25**
Total	**19**	**11**	**33**	**45**	**40**	**67**	**215**

Table B.4: Number of *STO* projects

	2005	2006	2007	2008	2009	2010	Total
Lenovo	53	52	52	72	73	59	**361**
Modular	46	35	10	59	33	26	**209**
Storage	17	19	37	63	70	44	**250**
Power	50	18	61	77	63	46	**315**
Mainframe	8	15	5	13	8	3	**52**
RSS	6	1	2	7	2	4	**22**
Total	**180**	**140**	**167**	**291**	**249**	**182**	**1209**

Table B.5: Number of *Pre* and *Post* projects

	2005	2006	2007	2008	2009	2010	Total
Lenovo	13						**13**
Modular	142			57	37	24	**260**
Storage	31	194	146	101	500	897	**1869**
Power	1262	52	451	345	37	186	**2333**
Mainframe	163	14	83	180	9	46	**495**
RSS	194		234	476	4978 [1]	333	**6215**
Total	**1805**	**260**	**914**	**1159**	**5552**	**1486**	**11185**

Table B.6: Number of spare parts involved in *STO* projects

	2005	2006	2007	2008	2009	2010	Total
Lenovo	194	390	342	399	320	370	**2015**
Modular	154	95	35	277	81	111	**753**
Storage	77	70	97	254	363	151	**1012**
Power	138	71	279	248	240	137	**1113**
Mainframe	11	26	6	18	9	7	**77**
RSS	25	1	6	26	9	9	**76**
Total	**599**	**653**	**765**	**1222**	**1022**	**785**	**5046**

Table B.7: Number of spare parts involved in *Pre* and *Post* projects

C Divisions

IBM defined different divisions based on their characteristics. Figure C.1 shows how these divisions together serve the hardware market. The four divisions are described from a customer perspective, more computing power reliability will result in a 'higher' division. The differentiation is based on 1) the processor (International Business Machines (IBM) / INTEL), 2) the operating system (OS). The OS is not a strict criterion but from historical perspective it is a good criterion to differentiate between divisions. The X System

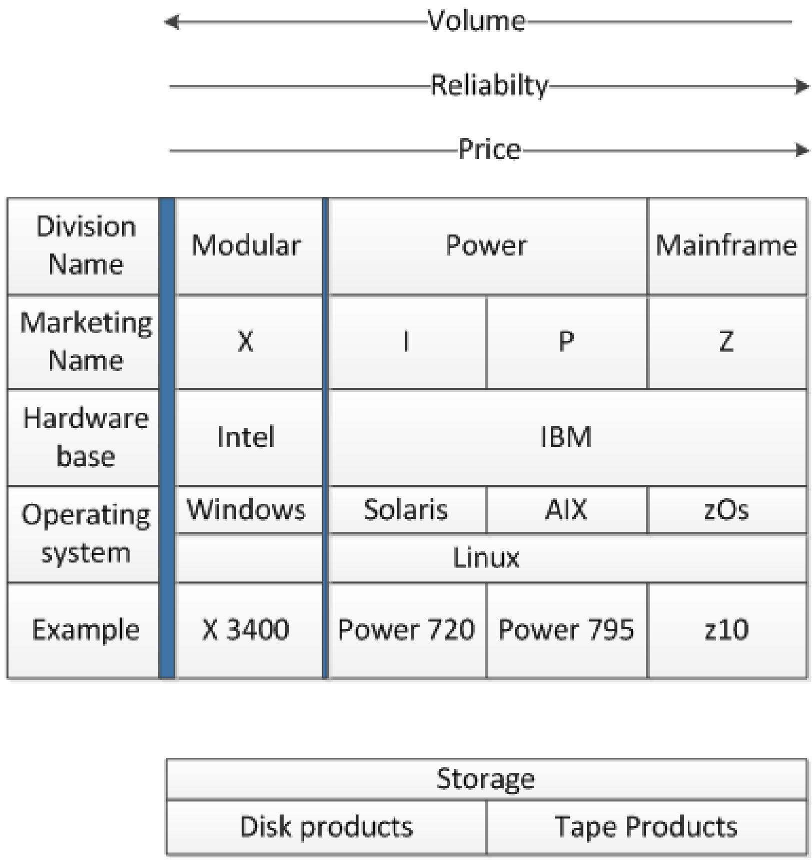

Figure C.1: An overview of the divisions. Modular is the lower segment, Mainframe the highest, Storage provides additional services to these divisions. RSS and Lenovo are not displayed.

machines have an Intel core and operate on Windows, this is often called 'WINTEL'. A higher segment is the Power division who has two different marketing brands. Power I, which means Integrated, and system P, that stands for Power. The hardware is comparable but the systems operate on different operating systems. Power I is intended for businesses that have no in house IT professionals to keep the server up and running. System P is more advanced and needs a professional to keep it running. This required maintenance is related to the software and process monitoring, and not related to the hardware maintenance. System P is used for example in research environment, such as universities. Reliability is here less important but significant computing power is required. Mainframes is the top division and these systems are used where high reliability and much computation power is needed, e.g. a bank where the mainframe has to process many transactions with high reliability. All these systems from the different divisions store data and this is the area of the Storage division. To every machine(park) a storage solution can be attached. It can be *in* the network (Storage Area Network, SAN) or *to* the network (Network Attached Storage, NAS).

In practice a lot of different machines can be present at the costumer site. The customer has a mainframe for a high reliability, high volume, and strategic applications. A System I for a regular HR processes and a Modular system for the print server. Large multinational companies usually have large general maintenance contracts which these kind of configurations and uses machine from different Divisions.

Figure C.2: Lenovo laptop

Lenovo – This is the former laptop division (Thinkpad) of IBM. The division is sold to the Lenovo company eight years ago but IBM still does the spare part management. This division is characterized by large volumes, low prices and mostly warranty demand requests. The laptops are sold to consumers and to companies ranging from small, to large, and are used as workstations.

Modular – Modular systems are based on the Intel processor. The focus is on the low end server market for non-critical applications such a customer relationship management application, local department databases, file and print sharing. The prices of the spare parts are low and the volumes are high. Customers are small to large enterprises. Most requests are warranty related. In large maintenance contracts these machines are usually included in the overall contract but service targets are less important because downtime is not critical.

Power – Systems based on the IBM Power core. These systems provide more reliability and more computing power. Most customers are medium to large enterprise, government

Figure C.3: A Modular, Power, Mainframe and Storage machines. The differences are mostly inside the black boxes.

agencies, and universities. Requests are usually related to service contracts and do not require high service targets. The volume and price is between the Modular and Mainframe division.

Mainframe – The marketing name zSeries, stands for zero downtime. It is the top of computing power and reliability. Mission critical applications and large transactional applications are installed on mainframes. These systems have many users using their capacity. Service is important because the customer accepts no or only very short downtimes. Penalty costs are high because downtime costs the costumer a lot of money. Spare parts are often expensive and the reliability of these spare parts is high. Customers are typical government agencies, financial institutions, and large multinationals.

Storage – Storage provides additional services to the machine park of the customer. This division can be split into tape and disk products. Tapes are cassettes and disks are optical disks like the hard drives most people know. Storage devices can be installed in other systems, such as Power or Mainframe or can be a standalone system in a network (SAN/NAS). Besides tape and disk products it can segmented in low and high end which results in different reliability factors and different demand patterns. A special characteristic is that here are relative more mechanical parts in comparison to electronic parts.

RSS – RSS stands for Retail Store Solutions, this divisions is focused on the retail business. It delivers all kind of point of sales hardware to retailers. Examples are cash machines at the supermarket but also self-check-ins at the airport. The division has one of the biggest market share in this market and a long history in the retail business. For example IBM developed the bar code. The divisions is characterizes by low value items, high serviceability focus, maintenance done by third parties, and big costumers like Carefour and Rynair.

D Forecasting

Introduction The planning is done for whole Europe, Middle East and Africa (EMEA) but within EMEA there are three main planning levels. The whole EMEA region is divided in clusters which represent a country or a set of countries (Germany, Iberia, Benelux) and in these clusters there are stock locations. The planning system make a distinction between two types of demand, demand related to customer engineer (CE) requests and to non CE requests (NCE). CE requests are related to maintenance and warranty, and NON CE requests are related to *Part Sales* and other special requests. The forecast process does include these different planning levels and two demand types. The steps executed for the complete forecast process is in Table D.1.

	Process	**Reason**	**CE**	**NCE**
1	Demand data grouping	Apply demand corrections	x	x
2	Calculate activity level	Needed for alpha process	x	x
3	Determine alpha	Needed for period weight	x	x
4	Determine period weights	Weigh relevant periods	x	x
5	Normalize weights	Prevent underestimation	x	x
6	Rapid user expansion	Adjust for newly parts	x	x
	Raw forecast		x	x
7	Slow mover adjustment	Adjust for slow movers	x	–
8	Substitution adjustment	Adjust for substitution	x	x
	Usage forecast		x	x
9	Parts installed base forecast	Correct for no demand data	x	–
	Initial forecast			
10	Usage or PIB forecast	Choose the best forecast	x	x
11	Redistribution	Installed base but no usage	x	–
12	Allocation processes	Divide forecast over network	x	x
	Ultimate forecast			

Table D.1: All process steps in the forecasting process. Steps 7,9, and 11 are not executed for the NCE demand.

Overview – The weekly forecast process runs for every spare part. The output of this forecasting process is the *ultimate forecasted*, F_0^{ult}, this is the demand for the next four weeks in the EMEA cluster. In the LTB calculation the fixed monthly demand, d^{mnt}, is used which is not the same period as four weeks. This is corrected by $d^{mnt} = \frac{13}{12} F_0^{ult}$.

The algorithm for F_0^{ult} usages 72 weeks of historic demand data grouped into 18 periods n ($n = 1, 2, 3, \ldots, 18$) of fours weeks, where 1 is the most recent period. This period contains demand data, d, of cluster, c ($c = 1, 2, 3, \ldots C, \quad 0 =$ EMEA cluster), location l ($l = 1, 2, 3, \ldots L$), and demand type t ($1 = CE, 2 = NCE$). The periods are multiplied by weight factor, w_{cn}. The weight factor can vary between clusters and is different for each period. The sum over all periods results in a forecast for stock location, l, type demand, t. The sum over all location leads to a cluster forecast, and the sum of all cluster is the EMEA forecast (D.1).

$$F_0^{ult} = \sum_{c=1}^{C} \sum_{n=1}^{18} \sum_{l=1}^{L} \sum_{t=1}^{2} w_{cn} d_{cnlt} = \sum_{c=1}^{C} \sum_{n=1}^{18} w_{cn} \sum_{l=1}^{L} \sum_{t=1}^{2} d_{cnlt} \tag{D.1}$$

1. **Data collection** – Every time the forecast process runs 72 weeks of historic demand data is collected into periods of 4 weeks. This is done again every forecasting cycle because corrections made in the historic data will now be taken into account. 72 Weeks is chosen from a practical point of view in relation to data storage. The output will be 18 periods of 4 weeks with the demand data per location for every type of usage, d_{cnlt}.

2. **Activity level** – The activity level, a_c, is used in the determination of α. A higher activity level weighs recent periods heavier than older periods. IBM defines the activity as the demand of one year in a specific cluster. (D.2)

$$a_c = \frac{13}{18} \sum_{n=1}^{18} \sum_{l=1}^{L} \sum_{t=1}^{2} d_{cnlt} \quad \forall c \tag{D.2}$$

3. **Alpha** – a_c is used to determine α_c. Now α_c is used to determine the weight w_{nc} for each period, n, in cluster c. For the determination of α_c four thresholds are set by the planner. These thresholds are specific for one cluster and are the same for every spare part (not spare part specific!). The four thresholds define the range for the value of α_c. The thresholds are $a_c^{min}, a_c^{max}, \alpha_c^{min}, \alpha_c^{max}$. The thresholds must satisfy the conditions $0 \geq a_c^{min} < a_c^{max} < \infty, 0 \geq \alpha_c^{min} < \alpha_c^{max} < 1$. For most clusters the thresholds are set $a_c^{min} = 1, a_c^{max} = 25, \alpha_c^{min} = 0.08, \alpha_c^{max} = 0.25$. α is given by linear interpolation between the thresholds (D.3).

$$\alpha = \frac{a_c^{max} - a_c^{min}}{\alpha_c^{max} - \alpha_c^{min}} (a_c - a_c^{min}) + \alpha_c^{min} \tag{D.3}$$

In Figure D.1 an example is given with $a_c = 15$ for a specific cluster. The dotted lines are the thresholds and define the range for possible values of α_c.

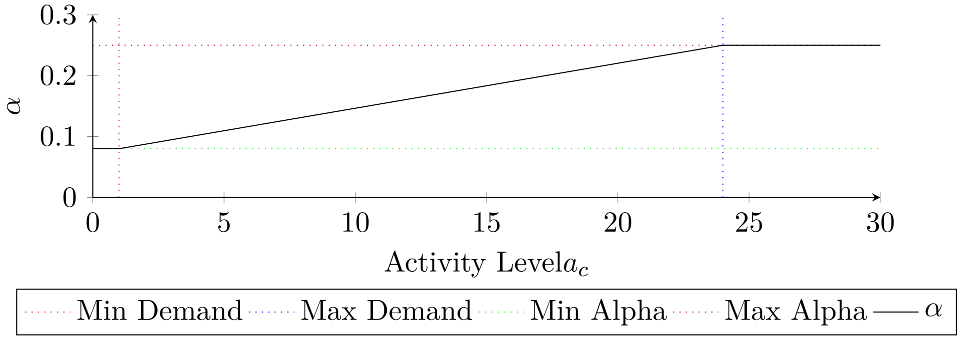

Figure D.1: An overview of the alpha determination. The dotted lines are showing the thresholds set by the planner.

4. **Period weight** – Period weights w_{cn} are determined per cluster and used for both types of demand. As a result each period weight is the same for every stock location in a cluster. The weight determines if recent periods are more important than older periods. When activity of a spare part is high the recent periods weighs more and the forecast reacts quicker to changes in demand. With α_c we can determine the w_{cn} (D.4).

$$w_{cn} = \alpha_c \left(1 - \alpha_c'\right)^{n-1} \quad \forall c, n \tag{D.4}$$

5. **Normalize weights** – When determining the weight, as in Equation D.4, the condition that the sum of all weights is one, is not satisfied. The result is a possible underestimation. Therefore the weights are normalized $w_{cn}^{'}$ by Equation D.5

$$w_{cn}^{'} = \frac{w_{cn}}{\sum_{n=1}^{18} w_{cn}} \quad \forall c, n \tag{D.5}$$

6. **Rapid user expansion** – An adjustment is made for young spare parts. Young spare parts do not have data in all 18 periods to determine an appropriate activity level, which will result in incorrect weights. The number of periods $i = 1, 2, 3 \ldots, I$ a spare part is defined as a young part is set by a parameter $I_c \leq 13$ on cluster level. The adjustment made for these spare parts is that the period weight is multiplied by a factor f_{ic} for each normalized weight $w_{cn}^{'}$ D.6.

$$f_{ic} = 1 + \frac{(p_c + 1 - i)(13 - I_c)}{0.5 I_c (I_c + 1)} \tag{D.6a}$$

$$w_{cn}^{''} = f_{ic} \times \frac{w_{cn}^{'}}{\sum_{n=1}^{18} w_{cn}^{'}} \quad \forall c, n \tag{D.6b}$$

The result of the forecasting process, so far, is the *raw forecast* for the CE and non CE demand, on location, on cluster level and on EMEA level. Every level adds up to the forecast of a higher level. (D.7)

$$F_{0t}^{raw} = \sum_{c=1}^{C} F_{ct}^{raw} = \sum_{c=1}^{C} \sum_{l=1}^{L} F_{clt}^{raw} \quad \forall t \tag{D.7}$$

7. **Slow mover adjustment** – slow mover adjustment (SMA) is executed for spare parts that are defined as slow mover. IBM defines a slow mover when yearly demand is one or less on cluster level $F_{ct}^{raw} \leq 1$ for $t = 1$. The SMA is only executed for the CE forecast. SMA first determines a lower bound (LB) and compares this lower bound with the forecast generated for the CE requests F_{ct}^{raw}. The lower bound is determined based on the last request date (LRD), measured in years.(D.8). The $psma_c$ is a parameter set by the planner to set the value of a minimum forecast, usually this is set to 1.

$$F_{ct}^{lb} = psma_c \begin{cases} 1 & \text{if } (0 \geq LRD \leq 1) \\ 0.5 & \text{if } (1 \geq LRD \leq 2) \\ 0.33 & \text{if } (2 \geq LRD \leq 3) \\ 0 & \text{if } LRD > 3 \end{cases} \text{for } t = 1 \quad \forall c \tag{D.8a}$$

$$F_{ct}^{sma} = \begin{cases} F_{ct} & \text{if } F_{ct} > F_{ct}^{lb} \\ F_{ct}^{lb} & \text{if } F_{ct} \leq F_{ct}^{lb} \end{cases} \text{for} t = 1 \forall c \tag{D.8b}$$

The F_{ct}^{sma} will be assigned to the highest location in the planning hierarchy for that cluster (usually a country stock room). Two cases can happen, a forecast is adjusted, e.g. from 0,1 to 0,33, or a forecast is initiated e.g. from 0 to 0,33. On EMEA level SMA is applied again but now for $c = 0$ (D.8). The forecast added to the EMEA cluster, needs to be allocated back to the clusters. When the $F_{0t}^{raw} = 0$ the lower bound is divided equally between the clusters which have demand in the last three years. If $F_{0t}^{raw} \neq 0$ it is divided between clusters based on their ratio of the original forecast F_{ct}^{raw}.

$$F_{ct}^{sma'} = \begin{cases} F_{ct}^{sma} \frac{F_{0t}^{lb}}{F_{0t}} & \text{if } \sum_{c=1}^{C} F_{c1} > 0 \quad \forall F_{ct} > 0 \quad t = 1 \\ \frac{F_{0t}^{lb}}{COUNT(F_{ct} > 0)} & \text{if } \sum_{c=1}^{C} F_{c1} = 0 \qquad t = 1 \end{cases} \tag{D.9}$$

8. **Substitution adjustment** – Substitution relationships influence the forecast. Adjustments are made both to CE and NON CE demand. The method sums the forecast to the highest *up level* in the substitution chain. When no stock of the *down level* is present at location *l*, the total forecast of location l will be added to the top *up level.* The forecast of the *down level* will be removed. When there is stock of the *down level* at location l a percentage of the *down level* forecast will be added to the *up level* and subtracted from the *down level* forecast. This percentage is a parameter and set on 25%. Only simple substitutions chains are considered.

9. **Parts installed base forecast** – This is a separated forecast method not based on activity data. It is based on the spare *parts installed base* (PIB). This alternative method does not split the demand type in CE and NCE. It is done because spare parts may have no activity data in a cluster. A reason could be that machines are recently new installed in that specific cluster. It is also depending on the age of spare part p^{age}. The definition of newly installed machines is determined by two parameters set per cluster by the planner. The first parameter p^{full} is the number of periods n where the full parts installed base (PIB) forecast is used. After this first period the second parameter $p^{partial}$ defines the number of periods where only a percentage of the PIB forecast is used. In this method the usage based forecast takes over the PIB forecast because IBM thinks it is reflecting the reality better. Figure D.2 displays this method.

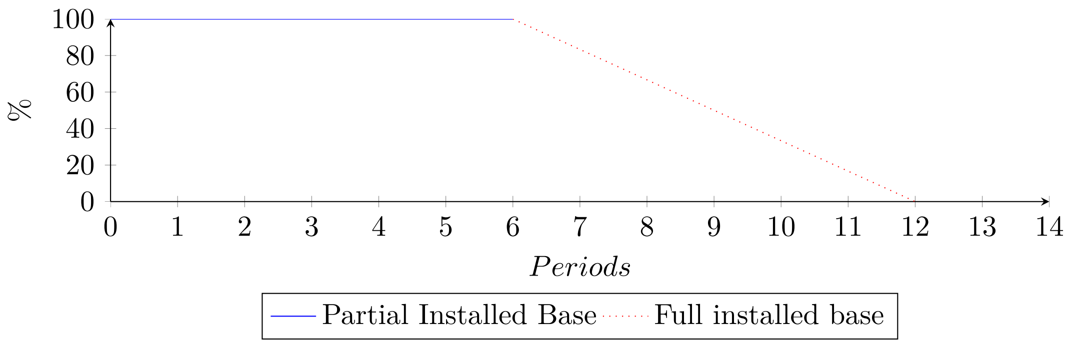

Figure D.2: The first 6 periods full PIB is used for comparison, after six period it is declining from 100 to 0 % in 6 periods. The total periods the PIB is considerd is equal to 12.

A spare part has a removal rate, defined by engineering r^{eng}. The removal rate is defined as "*Quantity of a specific part required per month to support one occurrence of that part within the actual spare parts installed base*". The spare parts installed base times the removal rate is the forecast. Two parameters are set to limit the forecast, one parameter is a maximum on the removal rate r^{max} and one is a maximum on total forecast F_c^{max}.

$$r = \max\left(r^{eng}; r^{max}\right) \tag{D.10a}$$

$$F_c^{pib} = \begin{cases} PIB \times r & \text{if } p^{age} < p^{full} \\ PIB \times r \frac{p^{full}+p^{part}-p^{age}}{p^{full}+p^{part}} & \text{if } p^{age} < p^{full} + p^{part} \end{cases} \tag{D.10b}$$

$$F_c^{pib} = \max\left(F_c^{pib}; F_c^{max}\right) \tag{D.10c}$$

10. **Compare forecast** – The PIB forecast for CE is compared with the CE and NON CE forecast generated based on demand. When the PIB forecast is larger, the PIB is chosen as the CE type forecast and the NCE forecast is set to zero. If the PIB is smaller than the forecast based on demand, the forecast based on demand is chosen. (D.11)

$$F_c^{Fin} = \begin{cases} F_c^{PIB} & \text{if } F_c^{PIB} > F_{c1}^{USAGE} + F_{c2}^{USAGE} \quad \text{, set } F_{c2}^{USAGE} = 0 \\ F_{c1}^{USAGE} & \text{if } F_c^{PIB} \leq F_{c1}^{USAGE} + F_{c2}^{USAGE} \end{cases} \tag{D.11}$$

11. **Redistribution** – If one cluster has no historic data on a specific spare part no forecast will be generated. When new machines are recently installed in this cluster and in other clusters there is demand, it will be likely their will be demand in this cluster also, therefore we apply redistribution. (The SMA adjustment is not applied because no last request date (LRD) is known. It also passes the PIB installed forecast because other regions overrule the PIB forecast). Redistribution is only applied if the sum of all cluster forecasts is larger than zero, and one of the clusters has a forecast between 0 and $0,33 \times psma_c$. $psma_c$ is the parameter value of the SMA adjustment. The redistribution of $F_{c=0}^{Final}$ can be based on 1) *machine type model* or 2) on *PIB* methods. Both methods will produce weights for a specific cluster w_c^{redis}. The method is chosen based on the reliability of the *PIB*. When this is below a certain threshold the *machine type model* redistribution method is used, else the PIB method.

    The adjustment are limited to the SMA adjustment. (D.12)

$$F_c^{re} = \min\left(F_0^{fin} \times w_c^{redis}; 0.33 \times psma_c\right) \tag{D.12}$$

    As a result F_c^{re} can be larger than F_c^{Fin}. When the F_c^{re} is used over estimation can be caused on the EMEA level. Therefore the added value is subtracted from clusters which have a relative high forecast. A relative high forecast is defined as a forecast lager then $1 \times psma_c$. All clusters that participate and have a high forecast are selected for subtracting the added amount. This subtraction is done based on the *ultimate forecast ratio*. To prevent that a large amount will be subtracted from one of the selected clusters some rules apply when subtracting. (1) A forecast in a cluster may not drop below $1 \times psma_c$. (2) The subtracted value may not exceed maximum subtracting threshold set by a parameter.

To demonstrate is this a small numeric example is given. Consider Table D.2, in this example $psma_c = 1 \quad \forall c$. A forecast is added to cluster A and F because the forecast is between 0 and 0,33. G is not selected for addition because it has no PIB and E will be excluded because it has a value smaller than $1 \times psma_c = 1 \times 1 = 1$. The additions are calculated by Equation D.13

$$F_f = \min\left(9.51 \times \frac{20}{220} = 0.86 \ ; \ 0.33\right) \times 1 = 0.33 \tag{D.13a}$$

$$F_a = \min\left(9.51 \times \frac{10}{220} = 0.43 \ ; \ 0.33\right) \times 1 = 0.33 \tag{D.13b}$$

The addition of 0,33 + 0,33 = 0,66 has to be subtracted from the clusters that have a forecast above $1 \times psma_c = 1 \times 1 = 1$. Clusters B, C and D are larger than 1. These clusters are used to subtract the 0,66 and this 0,66 is divided based on the ratio of their original forecast.

$$\Delta_b = 0.66 \times \frac{5}{9.51} = 0.35 \tag{D.14a}$$

$$\Delta_c = 0.66 \times \frac{1.01}{9.51} = 0.07 \tag{D.14b}$$

$$\Delta_d = 0.66 \times \frac{3}{9.51} = 0.21 \tag{D.14c}$$

The delta values may not exceed 10% of their original forecast (maximum subtracting threshold), they all comply. The delta is subtracted from the original forecast where the forecast may not drop below the $1 \times psma_c = 1 \times 1 = 1$ threshold. Only the result of cluster C will drop below the threshold and thus only 0.01 will be subtracted. The result of the redistribution process will always be equal or larger than the forecast before redistribution, in this case an addition of 0,09 is the result.

Cluster	**Forecast**	**PIB**	**Delta**	**New Forecast**
A	0.00	10	0.43	0.33
B	5.00	100	-0.35	4.65
C	1.01	20	-0.07	1.00
D	3.00	60	-0.21	2.79
E	0.50	10	0.00	0.50
F	0.00	20	0.86	0.33
G	0.00	0	0.00	0.00
	9,51	220	0,66	9,60

Table D.2: An example of redistribution

The whole forecast process which determines the actual value needed for the LTB calculation has been explained. Some other processes are applied to redistribute the forecast to specific stock locations, for example adjustments for opening or closing of a stock location. These adjustment have an effect on the allocation of the forecast to different stock locations but do not change the total outcome of the forecast used for whole EMEA cluster.

E Data issues

The data used was not free from errors. Most errors were corrected of removed. There were three sources:

1. Past LTB calculations in Excel & Lotus123 sheets, original PANDA output files, and screen shots from the PANDA application. PANDA is used to gather data and execute LTB calculations.

2. The CPPS planning system, this systems contains all actual data related to inventory, scrap, prices, etcetera, in most cases two years of historic data was available

3. Demand data and corrections, stored in 6 database tables from 01/11/2004 until 31/12/2010, this was much data more than millions of records.

The main issues with this data were:

- Data related to the LTB calculations were not saved in a structured format. This data needed to be transformed to a uniform format. Not for every LTB calculation all information was available or it was not always clear which data was used. It was solved by removing this calculation from the current analysis or make assumption depending on the extra information given in the work files, notes, attachment, sign off presentation, etcetera.

- The demand data was not split accurately in the typically three request types (part sales, maintenance, warranty). Therefore it was not possible to split warranty requests and maintenance request. Part sales request could be split out. Therefore a split between part sales and maintenance plus warranty requests are made.

- In special cases automatic corrections were made on the demand data by the planning system. This happens if the planner flags a request as exceptional. This exceptional demand is not taken into account by the planning system. These corrections could not be filtered out. If an order is canceled, this could lead to negative demand because no correction is made on the exceptional correction. Spare parts with total negative demand over all periods were not considered as correct demand data and these spare parts are removed.

- A return of spare part cannot be tracked back to a specific request. Therefore it is possible that in one period there is a request and the return is next period. This can lead to a negative demand in a specific period. In most cases this is not a problem because of the aggregation level of four periods it will not be noticed in the data. In some cases, mostly slow movers, it can happen that the request was in one period and the return in the other. This results in a negative demand for a specific period. When the demand data is summed it is not a problem but it can give a strange picture, for example in graphs, if there is negative demand in a specific period.

- When a substitution takes place corrections are made manually to the demand data by a planner. Down-level demand is transferred manual to the up-level spare part. The demand in the lower down-level is manual corrected to zero, this is done to remove the planning levels. These corrections were not done for the good returns resulting in negative demand on the lower level. The percentage of spare parts that was possible affected by this was below 1% and therefore we neglected this issue.

- It was not possible to get a freeze of the CPPS planning system therefore some figure can be different because they were taken on different moments in time.

- The CPPS planning system is used for planning, sometimes a work around is implemented to be able to model specific business requirement for the planning environment. This specific need results in sometime strange categorization, or periods of data and therefore it was not always possible to group all information in a correct highly accurate way. When this influences the data significantly it is mentioned.

The data issues do influence some spare part and the calculations although the influence is limited and the results constructed are still valid. Mostly a workaround is found or the special cases are excluded.

F Indicator details

Data set selection

Selection process – The goal of the selection process was to random select the best-analyzed LTB calculations. Random LTBs over project types and divisions. The best analyzed LTB will result in a pessimistic view on the improvement possibilities. This pessimistic view is chosen to minimize the improvement expectations. The steps for the selection are:

- Select for every division at least on type of project calculated between 2005 up to and including 2010.
- Select projects with high value. High value projects draw much attention of management resulting in a detailed, extensive analysis by an analyst.
- Select one or more spare part with at least at positive net need, preferable with a significant value.

These step result in the following dataset, see Table F.1

	LTB calculations	Projects
Mainframe	30	14
Power	63	15
Modular	68	15
Storage	65	19
RSS	96	13
Total	**322**	**76**

Table F.1: The details of the dataset used for the forecast accuracy comparison between divisions. The number of different LTB calculations and the different number of projects

G Substitution and commonality

Substitution

Simply explained substitution is a newer version of the spare part which is preferred above the old version. Substitutions are initiated due to all kinds of reasons. It can be an economic reason, e.g. a supplier change or cheaper production method, it can be a technical reason, e.g. a part with lower failure rate or a better operational performance, and it can be a safety or environmental issue. The replacement should result in an IBM satisfying solution. The satisfying solution differs with every spare part. Preferable it will have the same *Form, Fit and Function*, sometimes *Fit* and *Function* are good enough, in another case only the same *Form* is sufficient. Substitution relationships between spare parts are described a substitution chain. Chains can be combined or connected to each other which results in a substitution hierarchy. This hierarchy can be very large and complex, e.g. multiple levels and split in to multiple branches depending on the kind of substitution.

Terms:

- Up level: A spare part higher in the substitution hierarchy, this the ”newest version” of the spare part
- Down-level: A spare part lower in the substitution hierarchy, this is the older version of the spare part.
- Complexity: A split in the hierarchy e.g. a new chain is started.

When substitution takes place the newly introduced spare part is placed as the highest in the hierarchy and its substitutes are placed below. The new part is the *up level* and the older spare part lower in the hierarchy is the *down level.* The relationship between these two parts can be of five different types.

1. *Fully compatible*, the *down-level* can be used as replacement for the *up level* and vice versa.

2. *Upward compatible*, the *down-level* can only be used as a replacement of the *up level*.

3. *Downward compatible*, the *up level* can only be used as a replacement of the *down level*.

4. *Repair reworkable*, a special case, the *down-level* (older part) can be repaired and modified such that it will be the *up-level*. For example a substitution is initiated because there was a bad mechanical component in the part. The component can be replaced and the part is now the same as the *up level*.

5. *Not compatible*, again a special case, this is a replacement and no substitution.

These relationships can differ between machine type models (MTM). Codes are used to indicate for which MTM combination the relationship can be used. For example a down level and up level spare part may be used in MTM combination A, but only the up level may be used for MTM B.

- G = Generic, the relationship is valid for all occurrences of a part
- M = MT specific, only valid for a specific type of machine

Sometimes substitution relationship exists but these relationships may not be used. This can happen if a part has for example quality issues and therefore may not be installed anymore. Every relationship has another code which indicates if it is allowed. Figure G.1 displays an overview of the relations and codes.

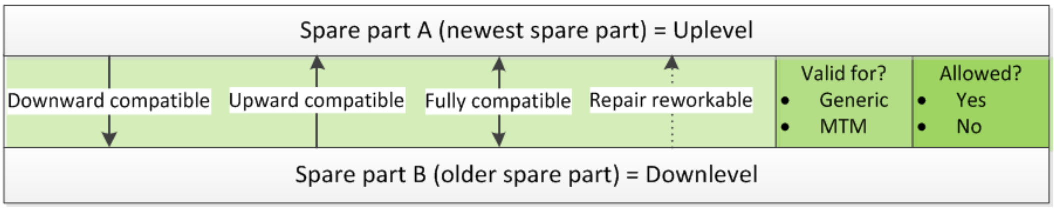

Figure G.1: An overview of all possible substitution relationships. The relationship can be valid for a specific *Machine Type* combination. A relationship can exist but may not be used, this is the allowed flag.

Substitution is usually present in the high volume divisions such as Modular and Lenovo. When the substitution hierarchy is very large and complex it is difficult to get this information correctly. No structured method is found to deal with substitution. Questions that arise are: how should the current stock of the down level be included? How to handle MTM specific substitution? What to do with repair reworkable spare parts? Correctly applied substitution could possible reduce the LTB quantity or prevent stock out situations. To handle this substitution a well designed structured approach is necessary, to be able to deal with all possible situations.