Optimization of Inventory through an integrated system Approach for Repairable Spare parts

(The case of Ethiopian Airlines Maintenance, Repair and Overhaul Division)

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A Thesis Submitted to:
The School of Mechanical and Industrial Engineering

Presented in Partial Fulfillment of the Requirements for the Degree of Master of Science in Mechanical Engineering (Industrial Engineering Stream)

Addis Ababa University

Addis Ababa, Ethiopia

October 2019

Addis Ababa University
Addis Ababa Institute of Technology
School of Mechanical and Industrial Engineering

This is to certify that the thesis prepared by Zelalem Eresi, entitled: **Optimization of Inventory through an integrated system Approach for Repairable Spare parts** and submitted in partial fulfillments of the requirements for the degree of Master of Science (Mechanical and Industrial Engineering) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Declaration

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ABSTRACT

Repairable spare parts inventory optimization deals with special type of inventories that are repaired and returned to usable conditions rather than discarding. Surplus repairable spare parts lead to a high carrying cost, whereas inadequate spare parts can result into aircraft down time. This is always a problem and it is the trade- off between the size of spare parts inventory and carrying cost.

There have been numerous studies performed concerning repairable spare parts optimization. However, literatures that consider no fault found (NFF) and scrap rate (S) as an input variable for repairable inventory systems is, to the best of the author's knowledge, lacking. Because the existing literatures assume negligible no fault found and negligible scrap rate which actually deny the reality encountered by maintenance organizations in practice.

This study deals with repairable spare parts optimization in Ethiopian Maintenance repair and Overhaul division. In order to reach that goal, multi stage purposive sampling technique including cluster sampling and sequential sampling to determine sample size of repairable spares. Poison distribution, diminishing Marginal Returns and mixed integer linear programming (MILP) were applied to four different scenarios to study the impact of maintenance turnaround time (TAT), no fault found (NFF) and scrap rate on repairable inventory size. Finally, mixed integer linear programming (MILP) model developed that minimizes overall inventory costs and improves service level.

The quality assurance of all the data inputs were verified by using sensitivity analysis and overall comparison of model out puts. Sensitivity analysis is by transposition of mixed integer linear programming equations and by varying service level. Model outputs were validated by comparison of the model output with the actual existing system and the results of other research findings.

The finding of the study shows better cost saving, compared to the current actual cost. Mixed integer linear programming model gives largest aggregate inventory cost saving result of 19.57% by considering Scrap Rate and No fault found**.** Sensitivity analysis indicates that total inventory cost saving of 4% can be achieved by reducing the shop repair cycle time by 20% without affecting no fault found impact. Combined total inventory saving of 37% can be achieved by reducing the repair cycle time by 20% and by reducing no fault found by 10% without affecting the service level. Financial Impact of No fault found (NFF) is about 5 % (4.936%) when compared to baseline scenario based on mixed integer linear programming (MILP). The Combined Financial Impact of No fault found (NFF) and Scrap Rate (SR) for marginal analysis and mixed integer programming models are 13.483% and 29.066% higher respectively when compared to baseline scenario. Based on the cost saving result and the financial impact of NFF and SR, it is concluded that mixed integer linear programming (MILP) results superior cost saving as compared to diminished marginal returns and poisson distribution under consideration of NFF and SR as input variable.

Keywords: mixed integer linear programming, diminishing Marginal Returns, No fault found, Sensitivity analysis, maintenance turnaround time, scrap rate

ACKNOWLEDGEMENT

I would like to thank Mr. Yared Lemma (my advisor) and my co-advisor Haileliul Mamo (PHD) for their support and assistance that have proved to be invaluable in making this research realized. Their support has transformed the quality of my work and subsequently contributed towards to my career advancement.

Their continuous and unreserved support, encouragement and professional advices were sources of strength through this research program. Their experience assisted me through my study. In addition, their insight and patience helped me to identify interesting study problems. Further acknowledgement also goes to Aboma Tariku and Wakweya Gobena for their contribution and kind words of encouragement through this research process.

Finally, this research will not have been possible but for the motivation, support and strength of other dear friends and family. I am eternally thankful for my wife Alganesh Takele for her constant encouragement. I also appreciate my sons Hawas and Moa whose patience has been truly important.

Thank you and God bless you all!

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ABBREVIATIONS

AAM	Aircraft Availability Model
ABC	Always better control
DMR	Diminishing Marginal Returns
FSN	Fast moving Slow moving and Non-moving
HQ	Holding Quantity
IAEA	International Atomic Energy Agency
IATA	International Air Transport Association
METRIC	Multi-echelon technique for recoverable Items Control
MILP	Mixed Integer Linear Programming Model
MTBR	Mean Time between Removals
MTBUR	Mean Time between Unscheduled Removals
NFF	No Fault Found
QPA	Quantity per Aircraft
REMS/YR	Removals per Year
SIC	Statistical Inventory Control
SIM	Selected Inventory Management
SL	Service Level
TAT	Turnaround Time
WIP	Work in process
VED	Vital, essential and desirable

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Chapter One

Introduction

1.1. Background and Justification

Aircraft operation is a high cost activity in terms of both equipment down time and spare parts inventory cost[CITATION PSa02 \l 1033]. Surplus spare parts inventory leads to a high carrying cost, whereas inadequate spare parts can result in equipment down time. Repairable spare part management is different from conventional manufacturing inventory management[CITATION Mic08 \l 1033]. In traditional manufacturing, orders are placed to meet the production schedules. This type of inventory planning model is described as "Purchase to Consume" (P2C) model[CITATION www19 \l 1033]. For the repair service provider, this is called "Repair to Reuse" (R2R) model. Repairable inventory is more complex than consumable inventories. Because inventories of repairable spare depend on operation reliability as well as maintenance process performance.

Therefore, considerable research works have been done to identify different inventory optimization techniques for different problem contexts. During commencement of this research and literature review, it was recognized that main inventory optimization techniques such Selective Inventory Management (SIM) Techniques, Time-Series Models, Poison distribution, Linear Programming Variants, Diminishing Marginal Returns, Rationing Model, Single Echelon and METRIC Model, AHP analysis were used in repairable spares planning and optimization. Although the literatures have provided a range of improved optimization models and techniques, an integrated (interfaced) approach that addresses some realistic industry problems is lacking.

Therefore, the focus of this paper is to contribute to the existing literatures with two main perspectives.

The first focus is to interface (integrate) the techniques (methodologies) so that to encompass the positive contribution of each optimization techniques. Therefore, four inventory management tools selective inventory management (SIM), poison distribution, marginal analysis and mixed integer linear programming are interfaced and utilized in this research.

The second focus of this paper is application of inventory optimization techniques to two main special situations. The special situations are no fault found (NFF) and scrap rate (SR). No fault found is known industry problem, when repairable spares are failed they are sent to a repair shop for testing, but failure may not be confirmed[CITATION htt05 \l 1033]. That means the only cost in no found fault situation is the logistics (transportation) cost. Because of this NFF, events artificially inflate the inventory balance. Therefore, this no found fault will be one of the inputs for this repairable inventory optimization research. The reliability of the repairable spare parts depends on the environment in which they are operated; the environment (geographical region or geographical locations) also affects the design of repairable inventory [CITATION MEl05 \l 1033].

In this paper, mixed sampling techniques is utilized. Purposive sampling, cluster sampling and sequential sampling techniques are used. In-house repairable spare parts are clustered into eight (8) groups based on their similarity in technology and working principles. Similar technology and working principle, implies that the spare parts follow similar failure characteristics. After that, sequential sampling by using ABC-VED analysis is used to determine the sample size.

To analyze Poisson distribution, Microsoft excel built in cumulative distribution function is utilized. For marginal distribution, Microsoft excel descriptive statistics is used. Finally, Mixed Integer Linear Programming (MILP) solver is used to solve the integer linear programming. This software is selected because it does not need complex syntax or programming skill. The syntax writing is compatible with other commonly used Microsoft office to easily generate and export the reports.

1.2. Problem Statement

Unlike other consumable inventories, repairable (reusable) inventory system design involves many complicating decision factors[CITATION RVD97 \l 1033]. Some of the complicating factors are the nature of demands, inventory policies, scrap rate, location of supplies. No found fault is also another complicating factor [CITATION Wim15 \l 1033]. Since the reliability of the repairable spare parts depends on the environment in which they are operated, the environment (geographical region) also affects the design of repairable inventory [CITATION MEl05 \l 1033]. The main objective of repairable inventory is to maximize aircraft availability subjected to budget constraint [CITATION RVD97 \l 1033].

International Air Transport Association (IATA)'s Maintenance Cost Task Force analysis of 2013 indicates that maintenance cost takes up about 13% of the total operating cost and it can be reduced by a good planning[CITATION Kle13 \l 1033]. IATA Airline Maintenance Cost Executive Summary report of 2014 reveals that spare parts maintenance cost make up the second largest portion (24%) of airlines' direct maintenance costs[CITATION Chr12 \l 1033].

Ethiopian Airlines is not an exception to this, in 2017 fiscal year, the company had expense of more than 1.6 million USD for emergency part purchases. Out of this, 79.7% of this expense was for repairable (reusable) spare parts and 20.3% was for consumable parts. This Emergency spare part purchase has double business impact on airlines. On one hand emergency spare part, purchasing has its own additional expedite cost greater than normal purchase. On the other hand, emergency purchase means the airplane is out of service. This again means the customer service level gets affected negatively. Emergency purchase were because of the challenges imposed by repairable spare attributes such as repair turn-around time(TAT), removal rate, scrap rates, no fault found(NFF) etc.

Therefore, this paper will try to investigate scientific techniques related to Inventory optimization modeling for Repairable Spares in the context of Maintenance and Reliability Performance and propose recommendations.

1.3. Research Questions

Based on the research problems, the following are main research questions:

- What is the comparative evaluation between different inventory optimization models with reference to aircraft repairable inventory?
- How do we formulate inventory optimization model for repairable (reusable) aircraft spare part based on maintenance and reliability to maximize service level and minimize all related costs?
- How does maintenance turnaround time (TAT), No Fault Found (NFF) and scrap rate (disposal rate) affect inventory level of repairable spare parts?

1.4. Objective

1.4.1. General objective

The main objective of this paper is to formulate inventory optimization model for repairable aircraft spare parts based on maintenance and reliability.

1.4.2. Specific objectives

- To investigate repairable inventory optimization models with the objective of service level improvement and overall inventory cost minimization
- To determine the optimal repairable spare part ordering strategy that minimizes overall inventory costs
- To perform comparative analysis between different repairable inventories optimization models under different operation scenarios.
- To research the impact of maintenance turnaround time (TAT), no fault found (NFF) and scrap rate on repairable inventory provisioning.
- To propose decision-making Framework for inventory optimization of repairable aircraft spare parts based on reliability.

1.5. Significance of the Study

This research study output will be used as reference to the researchers and decision makers working in industries with heavy utilization of repairable spare parts like airline operators, defense systems, chemical processing, railway system, heavy construction, electrical/electronic industries etc. It will be helpful in finding the better inventory optimization models and alternatives, in assisting the managerial decision making for purchase of repairable items and in determining the capacity requirements. More specifically, this work has greater cost saving initiative for aviation sector repairable inventories.

1.6. Scope of the study

The scope of this research is limited to repairable aircraft spare parts that are relatively expensive. It does not include inventory of life-limited parts, consumables and other expendables. Moreover, this paper considers only repairable components, which are in the scope of maintenance capability of Ethiopian Airlines maintenance, repair and overhaul scope. Therefore, it does not consider components, which are maintained by other foreign repair organizations. In addition, the scope does not include investigation of root causes and safety implications of inventory optimization inputs (variables).

Chapter Two

Literature Review

2.1. Basic Concepts of Inventory

2.1.1. Repairable Spares Defined

Repairable are inventory items, which are repaired and returned to usable conditions rather than discarded [CITATION RVD97 \l 1033]. Some literatures use the term rotables and repairable interchangeably[CITATION Mar89 \l 1033], while other literatures differentiate this two terms only based on their prices[CITATION Azi15 \l 1033]. The term rotable is used because these spare parts can be rotated among any types of aircraft[CITATION Azi15 \l 1033]. [CITATION Leo99 \l 1033], defines repairable item as recoverable items.

Therefore, we can say that repairable spare are reusable spares after maintenance unlike conventional consumable spare parts that get out of the population after single use. Therefore, this study uses the term ''repairable'' instead of rotable and recoverable.

2.1.2. Inventory Classification.

Standard industry definitions also indicate that the difference between rotables and repairable is the scrap rate. Reparable have higher scrap rate than rotables. The classification is based three main distinctions. The first one is based scrap rate. Rotable, repairable and recoverable are classified based on the scrape rate. Rotable has the least scrap rate and recoverable have the high scarp rate and repairable are in between these two. Expendables have 100% scrap rate. They are one time used. Other classification is based on financial class. Rotable, repairable and recoverable are classified as assets and is depreciated on the book value. Expendables are classified as consumables and they are not classified as assets. The third classification is based on their life cycle. Life limited parts have restriction on their life cycle. They should be replaced after a given defined service life. But clear differences of this inventory classification are usually based on internal company policies. For example, some literatures indicate that rotable spare parts are repairable spare parts[CITATION Mar89 \l 1033]. Therefore, in some companies there is no clear distinction between rotables and repairable. But the recoverable have very high scrap rate and therefore they are different from rotable and repairable.

In the case company, the classification shown above exists based on initial provisioning. But there is no clear cut line between repairable spares and rotable parts. That means there is no defined scrap rate for each of these differently. For example, we can classify scrap rate less or equal to one percent (1%) as rotable and more than one percent as repairable. Therefore, this paper assumes rotables and repairable as repairable.

According to Silver (as cited in Willemain, Smart, & Schwarz, 2004), random demands with large proportion of zero values are called intermittent demands. These items are often called 'slow moving'. Such intermittent is often also 'lumpy', meaning large variability among the values. Inventory classifications of aviation spare are shown in figure 1[CITATION Wim15 \l 1033].

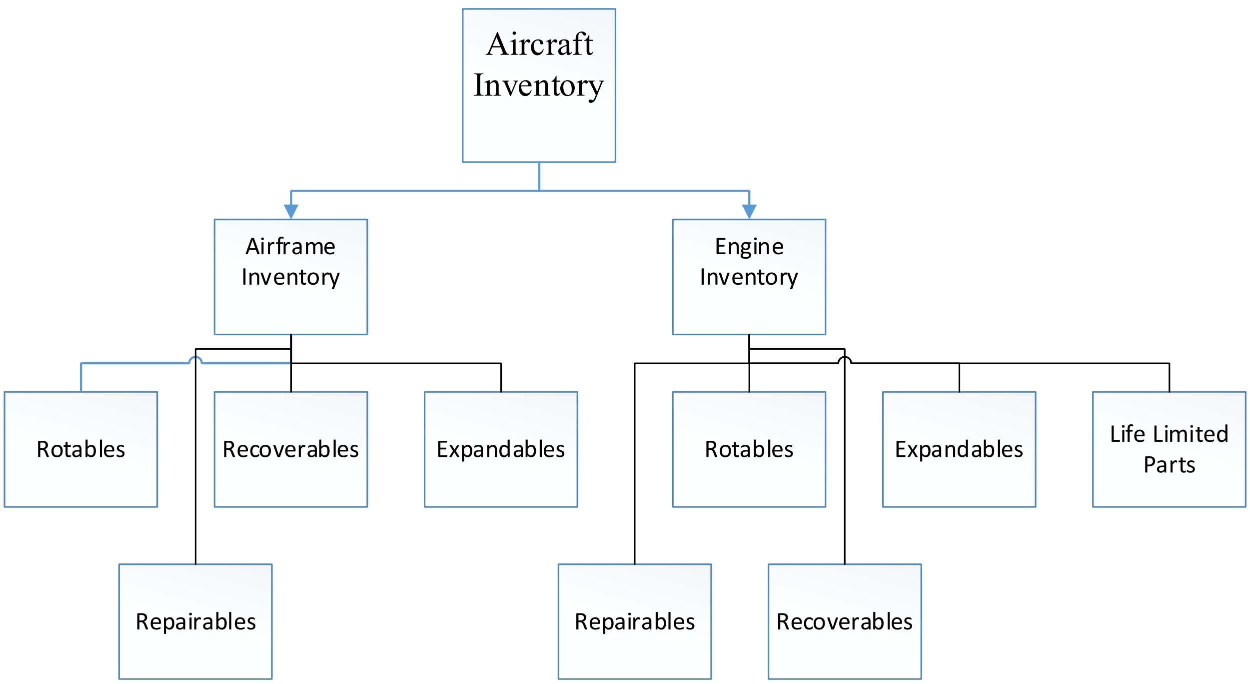

Figure 1: Inventory Classification (Wimer, 2015)

2.2. Inventory Policies

Different scholars classify inventory models differently even though the basic concepts are similar. Inventory policies are operating framework while implementing an inventory model. Vrat (2004) classify inventory policies into three, Economic Order Quantity (EOQ), Periodic Review Inventory Policy or (S, T) policy and Optional Replenishment Policy or (s, S) policy or (s, S, T). Tempelmeier (2007) Classifies inventory policies into four types by modifying (s, S) policy. He added (S-1, S) policy by modifying (s, S) replacing s=S-1 to indicate the order is placed when the stock size falls to one unit lower than the maximum stock size.

Inventory policies are classified into two, P-system and Q-system [CITATION Gho05 \l 1033]. Q-system is reorder point (ROP) system and P-system is fixed interval reorder or periodic reorder system.

Some literatures use ‘inventory model’ in-place of inventory policy[CITATION Azi15 \l 1033].

2.3. Inventory Optimization and Supply Chain

In this section, different inventory optimization literatures utilized in other sector other than aviation sectors are discussed. In addition, related literatures on inventory supply chain are discussed.

The demand for repairable spares follows uncertainty. One alternative to address this uncertainty is to seek for supply chain flexibility[CITATION Ste03 \l 1033]. According to [CITATION Ste03 \l 1033], inefficiencies of supply chain created by lead-time can be tackled by designing different flexible manufacturing system.

The concept of Closed-Loop Supply Chain in Product remanufacturing[CITATION RCa04 \l 1033] is applicable to maintenance. Supply chain coordination frameworks can reduce inventory-holding cost[CITATION Pip05 \l 1033].

Maintenance management of fleet of machines (equipment) like vehicle is a complex task because of many reasons [CITATION Cas98 \l 1033]. One of the complicating factors is the risk associated with failure of each component (spare part) of the equipment. Based on the functions of the equipment, the risk may extend to pool the equipment out of service or it may allow operating with limitations. [CITATION Che05 \l 1033], used genetic algorithms (GA) to plan aircraft servicing. [CITATION PSa02 \l 1033], used unitary software structure comprising of critical path method (CPM), material requirement planning and Production activity control (PAC) to plan aircraft maintenance. Maintenance management literatures are very limited [CITATION Ami06 \l 1033].

In conclusion, we can say that there is dependency between supply chain and inventory. Piplani (2005), identified supply chain inventory dependencies along three dimensions. The dimensions are demand, lead-time and service. These three dependencies represent the interactive relationships among the different decision-makers. Hence, if there is misalignment between the supply chain and the inventory planning, it is difficult to support critical operations such as airline operations.

2.4. Repairable Inventory Optimization models and Control Techniques

Different literatures use different approaches and techniques in different industries such as mining, utilities, defiance, transportation, construction to model inventory of repairable spare parts.

In this section, relevant aircraft repairable (reusable) optimization models are discussed. Some literatures are quantitative and some of the literatures are descriptive. However, all literatures in this section are used in specific reference to aviation sector unlike the literatures discussed under section 2.3.1 of this paper.

2.4.1. Selective Inventory Management (SIM) Techniques

Most organizations have large number of inventory items that should be managed. Zomerdijk and de Vries (as cited in Buxey, 2006) states Pareto's Law is applicable to this situation. At least three distinct groups are formed according to descending annual usage value. The three distinct groups are A, B and C. Accurate stock records are mandatory for class A, but not the same concern for class C. The top 20 per cent accounts for 80 per cent of total usage value. That means even though the company must control inventory of all items, the focus given for each items cannot be equal. Because some inventory items have high values and high business impact while some of them have low value and low business impact.

Naylor (as cited in Buxey, 2006), agrees that maintenance follows different logic than production. He mentioned that spares are classified based on the safety criticality. A is assigned for critical spare parts, whereby shortages shut down operation, B for less severe operations and Class C for substitute parts. This Nayor classification is similar to VED analysis, where V is assigned for vital, E for essential and D for desirable.

[CITATION Uma11 \l 1033], classified around forty (40) different types of carpet by using ABC analysis and then proposed inventory policy only for Class A products. They indicated that only Seven (7) types of carpet are included in this A category (17.5%). From this, we can understand that ABC classification is somewhat elastic. That means the result we get may not be exactly 20-70-10 by quantity or by value. While classifying the spares into ABC groups, the literatures almost followed the same procedure. First, items arranged in the descending order with the highest usage value at the top based on the annual usage value. Class A items constitute about 10% of the total consumption and contribute about 75% of the total value. Class B items constitute about 20% of the total items and contribute about 20% of the total value. Lastly, class C items constitute about 70% of the total items and contribute for about 5% of the total value.

[CITATION Azi15 \l 1033], used ABC methods to classify consumable spare parts to categorize them based on their money value contribution and demand frequency. Their research was focused on spare parts on class C. They used ABC-FSN combined. Demand frequency is to mean that if it is fast moving (F) or slow moving(S) or not moving (N).

Ruud H Teunter (2010), also used four system parameters i.e. demand volume, price, criticality and quantity in order to classify the stocks. Rajarajan (2013) also used ABC-FSN matric for inventory analysis.

Based on the above literatures on SIM utilization, it can be concluded that the SIM tools can be used to make selective focus on vital spare categories. These tools can be used one by one or in combination. To incorporate the advantage of each tool is recommended to use the combination of the tools.

In this research paper, the combination of three selective inventory management tools will be used to classify the total inventory population.

2.4.2. Time-Series Models

Garg J (2013) presented statistical inventory control (SIC) tool such as simple mean (average), simple moving average, weighted moving average, exponential smoothing, and single exponential smoothing. He also explained Croston"s method, Syntetos –Boylan approximation, additive Winter, multiplicative winter, Bootstrap methods with their limitations. Faccio et al (as cited in Garg J, 2013) identified that all the above listed methods are deterministic models. That means they have limitations to be used as an optimization tool for stochastic demands like repairable inventories.

Willemain, Smart, & Schwarz (2004) used bootstrap method for forecasting. They concluded that the bootstrapping method gives more accurate forecasts than do exponential smoothing and Croston's method.

Croston (1972) argued that time series methods, such as exponential smoothening; do not give reliable forecasts for intermittent demand.

Repairable spare closed loop system is similar to Kanban production system because of the fact that both are ‘’pull’’ system[CITATION Jam02 \l 1033]. This Kanban system is a pull system where materials are drawn from stock based on customer order unlike the ‘’push’’ system which is based on forecasting[CITATION NSi90 \l 1033]. The push system is traditional material requirement planning (MRP), which depends on master production schedule. That means push system is based on forecasting not on actual customer order.

When compared to general inventory policies[CITATION Tem \l 1033], the literatures on optimization based on service level constraint are not adequate and structured[CITATION Sri98 \l 1033]. Literatures have also ignored inventory of service parts or maintenance spare parts[CITATION Leo99 \l 1033].

2.4.3. OEM Recommendations (Model-1)

Original equipment manufacturers (OEMs) recommend simple calculations as shown below [CITATION Air97 \l 1033].

$E=(fh*n*N*TAT)/(MTBUR*365)$

Where E = the expected number of removals resulting from the calculation, fh = the flight hours per year per aircraft, n = the number of units per aircraft, N = the number of aircraft operating, and TAT = the turnaround time.

From the above formula, we can understand that E is proportional to repair turnaround time. TAT divided by 365 is the unavailability factor (UF).

$UF=TAT/365$

From the above formula the product of the three variables, fh, n and N is called total component hour (TCH) i.e. $TCH=fh*n*N$.

$E=¿$

The ratio of TCH to MTBUR is equal to number of total removals per unit time(R).

$R=TCH/MTBUR$

Therefore $E=\left(\frac{R*TAT}{365}\right)----(1)$

The TAT is therefore a very important parameter. The number of spares needed could be minimized by managing the maintenance cycle that are removed for repairs. The cycle time of the operators, include the removal time, shipping time to repair station, and the return time to store after repairs. Hence, there is an opportunity to reduce the spares through controlling the Shop Processing Time. Airbus (1997) recommends using the value of E to find the spares requirement based on poison process.

Equation (1) above assumes the scrap rate of repairable spares as zero. Melo (as cited in Melo, 2016) included the scrap rate into the above formula as shown in equation (2)

$$D_{TAT} = D_{annual} * \left[\left(\frac{TAT}{365} \right) * (1 - SR) + SR * \left(\frac{¿ + AT}{365} \right) \right] - - - (2)$$

Where D_{annual} isannual demand;

SR is scrap rate (fraction of components that cannot be repaired);

LT: supply lead-time (number of days necessary for the supplier to deliver a replacement Component) and AT is administration time (number of days required to handle the process of replacing a scrapped Component).

In addition to scrap rates, some industry best practices take no fault found (NFF) events into account when calculating annual demands. International Air Transport Association (2015), recommends to use equation (3) when calculating the annual demand.

$$E = \frac{(R - NFF) * T}{365} + \frac{NFF * T2}{365} + S - - - (3)$$

Where T is the turnaround time for repair (maintenance) and T2 is the turnaround time for no fault found event (false failure events). R is the total number of removals per year for each item. NFF is the total number of no found fault per year. In addition, S is the scrap per year

In this research, we use this formula to determine the value of E and then use this value as an input into poison formula.

Other means of reducing the cost of initial provisioning are through commonality, reliability and punctuality (Airbus, 1998). In this context, reliability refers to mean time between unscheduled removals (MTBUR). The impact of systems integration upon spares provisioning was studied and concluded that it is necessary to calculate the reliability of the system as a whole than individual spare part.

$$system\,Reliability=\frac{1}{\sum(Nu\,A/MTBUR\,A+Nu\,B/MTBUR\,B+Nu\,C/MTBUR\,C\,....)}$$

Where, Nu = number of units

Punctuality is about the turnaround time (TAT) and it includes combination of the transit time and the repair processing time. Again, transit time has two components, airline administrative efficiency and efficiency of freight forwarder (Airbus1998). Airline administrative efficiency deals with removal, shipping out and shelving when the spare part turns back. Efficiency of freight forwarder deals with transporting the spare parts.

Less inventory holding was obtained between 1995 to 2000, by shortening the average Shop processing Time (SPT) by more than 26%[CITATION Air97 \l 1033]. SPT is the total number of days from receipt of the part at the repair shop until its release from the repair shop. It was even possible to shorten the SPT by 32% for ten (10) most expensive items. Airbus guarantees a maximum SPT of 10 (ten) days for avionics and fifteen (15) days for non-avionics components.

Time between Failure (MTBF) and Mean Time between Unscheduled Removal (MTBUR) are indicators of reliability that affects the spare of equipment[CITATION Bén051 \l 1033].

MTBUR is used to indicate all unscheduled removals and MTBF shows confirmed failures. These authors also mentioned that No Fault Found (NFF) rate is often used as measurement of testability. And the NFF rate is given by: -

$$NFF=1-\left(\frac{MTBUR}{MTBF}\right)$$

2.4.4. Poison distribution (Model-2).

Poisson distribution is fit or applicable for repairable inventory problem[CITATION WJK02 \l 1033]. Poisson function is available in Microsoft excel built in function and will be used later in this research paper.

The cumulative Poisson formula is: -

$$E(x)=\sum_{k=0}^{x}\frac{e^{-\rho}\rho^{k}}{k!}$$

Where E(x) is expected probability, $e=¿2.718$, K=0, 1, 2,3…x is discrete integer value ranging from zero up to x and ρ is mean expected value. The (r,S) policy under compound Poisson demand was applied to coordinated inventory [CITATION RYK01 \l 1033]. This compound Poisson demand some time denoted as (T, S) model, to show that an order size of 'S' to be ordered after time 'T'. It also indicates that (s, S) has superior performance than the (r, S) model.

The failure rate of repairable spares changes over time. That means the more they do shop visit, the less they become reliable[CITATION MEl05 \l 1033]. For simplicity, this research paper assumes that the reliability of repairable spares is steady and steady Poisson process will be used to predict the demand.

[CITATION GRW01 \l 1033], used weibull statistical rather than stationary poison process to model the reliability of modules (sub-assemblies). This weibull process helps to capture the reliability changes over time. This is because reliability is changed with equipment life cycle. In this research paper, it is assumed that the failure of repairable components follows poison process.

Keizers, Bertrand, & Wessels (2003) and Kim, Kim, & Hur (2007) also recognized that failure of repairable spare parts follow Poisson distribution.

If given system (equipment) has many spare parts, then its operational performance is governed by aggregate availability of spares but not by item level availability of each spare[CITATION Tho02 \l 1033]. Aggregate inventory planning is also called system approach and it ensures low inventory investment than item level approach. Therefore, this research paper uses system level inventory approach.

It is possible to improve reliability of equipment by using preventive maintenance [CITATION KAT02 \l 1033]. This preventive maintenance includes traditional periodic preventive maintenance and predictive maintenance. However, this research paper assumes that the failures of the parts follow unscheduled failure or stochastic demand distribution.

2.4.6. Diminishing Marginal Returns (Model-3)

Marginal analysis is the process of identifying the benefits and costs of different alternatives by examining the incremental effect on total revenue and total cost caused by a very small (just one unit) change in the output or input of each alternative [CITATION Bus16 \l 1033].

Marginal analysis was first developed by Sherbrooke (1968) in METRIC Model. Zorn (1996) used diminishing marginal returns as an alternate form of the aircraft availability model (AAM). According to [CITATION Chr04 \l 1033], item level optimization level gives more amount of stock than the actual amount of spares required when compared with system level optimization. They used two optimization techniques, marginal analysis and genetic algorithm. Marginal analysis gives suboptimal solution while genetic algorithm gives global optimal solutions. Raytheon genetic algorithm application software (commercial software) used. Diminishing marginal returns (DMR) is utilized to develop inventory model [CITATION Way96 \l 1033]. DMR states as the level of inventory increases the marginal return i.e. benefit to cost ratio decreases. Therefore, the inventory level should not go above the previous inventory level that gives largest benefit to cost ratio. This paper has utilized marginal analysis and this method shall be illustrated in the analysis section of this term paper.

Aircraft Availability model (AAM) is used in US Air force based on standard probabilistic and marginal analysis concepts of inventory systems theory [CITATION TJO83 \l 1033], . He also states that the AAM is a steady-state model. The failure processes are random but stationary. Marginal analysis technique helps to increases the availability of the system and decreases the inventory cost [CITATION Tin16 \l 1033]. Trung (2016) used Excel and special algorithm in Python software. The objective of this research paper is to improve the service level the system level. Therefore, diminishing marginal return will be utilized. But since DMR does not give global optimal solution.

2.4.7. Linear Programming Variants (Model-4)

Combined linear programming and linear programming-split are applied to repairable spare parts optimization [CITATION Mic08 \l 1033]. He also used Poisson distribution and marginal analysis method in the same paper. In his research, the scrap rates are assumed negligible. It also assumes that any repairable spare part that visits, repair shop undergoes maintenance. That means there is issue of no found fault (NFF). Rohit Kapoor and Sudhir Ambekar (as cited in Brick and Uchoa, 2009) explained Mixed integer linear programming is considered as more comprehensive when compared to other methods and can be solved in reasonable time using any commercial solvers. The Combined linear programming is as follows[CITATION Mic08 \l 1033]:-

$$Minimize \sum (Ci * Qi * Xij)$$

Subjected to: -

$$\sum (Ri * SLi * Xij) \geq SL * \sum Ri \text{-----} (1)$$

$$\sum Xij = 1 \text{--------} (2)$$

$$Xij \in (0,1) \text{-------} (3)$$

Where, Ci=inventory cost of product 'i', Qi=the stock size of spare part 'I' and xij=dummy variable.

Ri=removal rate per year for unit 'i', SLi=Service level for unit 'i' and SL is the target service level.

The objective function is to minimize the total inventory cost. Equation (1) indicates the summation of each spare part removal multiplied by its corresponding service level and dummy variable (xij) is at least equal to the target service level multiplied by the summation of all removals. Equation (2) shows the summation of dummy variables for integer programming. For each single unit, we select exactly one quantity. Equation (3) is to indicate the dummy variables take only integer values but not fractional values; this is based on basic concepts on integer programming.

Lonardo, Anghinolfi, Paolucci, & Tonelli (2008) optimized First Fill Rate Value (FFRV) optimization by a stochastic linear programming (SLP). It is described as 'stochastic' because it is applied to random or variable demands. First Fill Rate Value (FFRV) is the ratio of orders satisfied by the available inventory to the total number of order. Lonardo et. al (2008) concluded that SLP is effective and resulted in 15.11% cost saving.

Loo Hay Lee (2008) used genetic algorithm to solve problem of multi-locations. However, it is limited to item level. [CITATION Mor86 \l 1033], concluded that branch and bound algorithm showed 8.5% average error level relative to an LP integer solution.

Lye & Chan (2006) applied Simulation Tool for Aerospace Rotables Management determines the percentages of failed components to get replacements. Again, this does not use the system approach. Computer World (2005) states that Southwest Airline implemented supply chain optimization project (SCOP).

In this research mixed integer programming (MIP) will be used interfaced with poison process and marginal analysis.

2.4.8. Rationing Model (Model-5)

The concept of inventory sharing and inventory rationing has provided fewer inventories[CITATION Hui05 \l 1033]. Inventories are shared between decentralized customers, which control their own costs. This inventory-sharing model is described as (S, k) model, where S represents the stock size to be held and k represents the rationing stock size. Therefore $0 \leq k \leq S$.

Researches also showed that on average 6% reduction can be obtained in spare parts provisioning costs if stocks for different groups are shared[CITATION AAK07 \l 1033].

[CITATION WJK02 \l 1033], indicated the cost of spare engines for major airlines is more than $11 billion per year. The airlines spare parts costs are $45 billion per year. Intensive reduction of spares inventories by leasing, pooling inventories, reducing repair times and eliminating non-productive inventory are proposed. The review also indicates that partitioning techniques such as ABC Analysis, FSN analysis and VED analysis are utilized.

This research paper does not consider inventory sharing and rationing. This is because the case company doesn't use any inventory sharing system at the base location. Therefore, the inventory sharing is not the focus of this research paper.

2.4.5. Single Echelon and METRIC Model

A multi-echelon technique for recoverable Items Control (METRIC) model was first introduced by (Sherbrooke, 1968). The same researcher also develops the improved version of METRIC model, MODI-METRIC and VARI-METRIC after eighteen years to better model expected back order rates (Sherbrooke, 1986). Klenger (as cited in Zorn, 1996) presented Reparable Item Inventory Models as shown in figure 2. As shown on the figure, the aircraft availability model (AAM) is part of Reparable Item Inventory Models based on the METRIC (Multi-echelon Technique for Recoverable items control) philosophy. Zorn (1996) used diminishing marginal returns as an alternate form of the AAM. The other models are METRIC model, Mod-METRIC, Vari-METRIC, Dyna-METRIC and the Aircraft Sustainability Model (ASM).

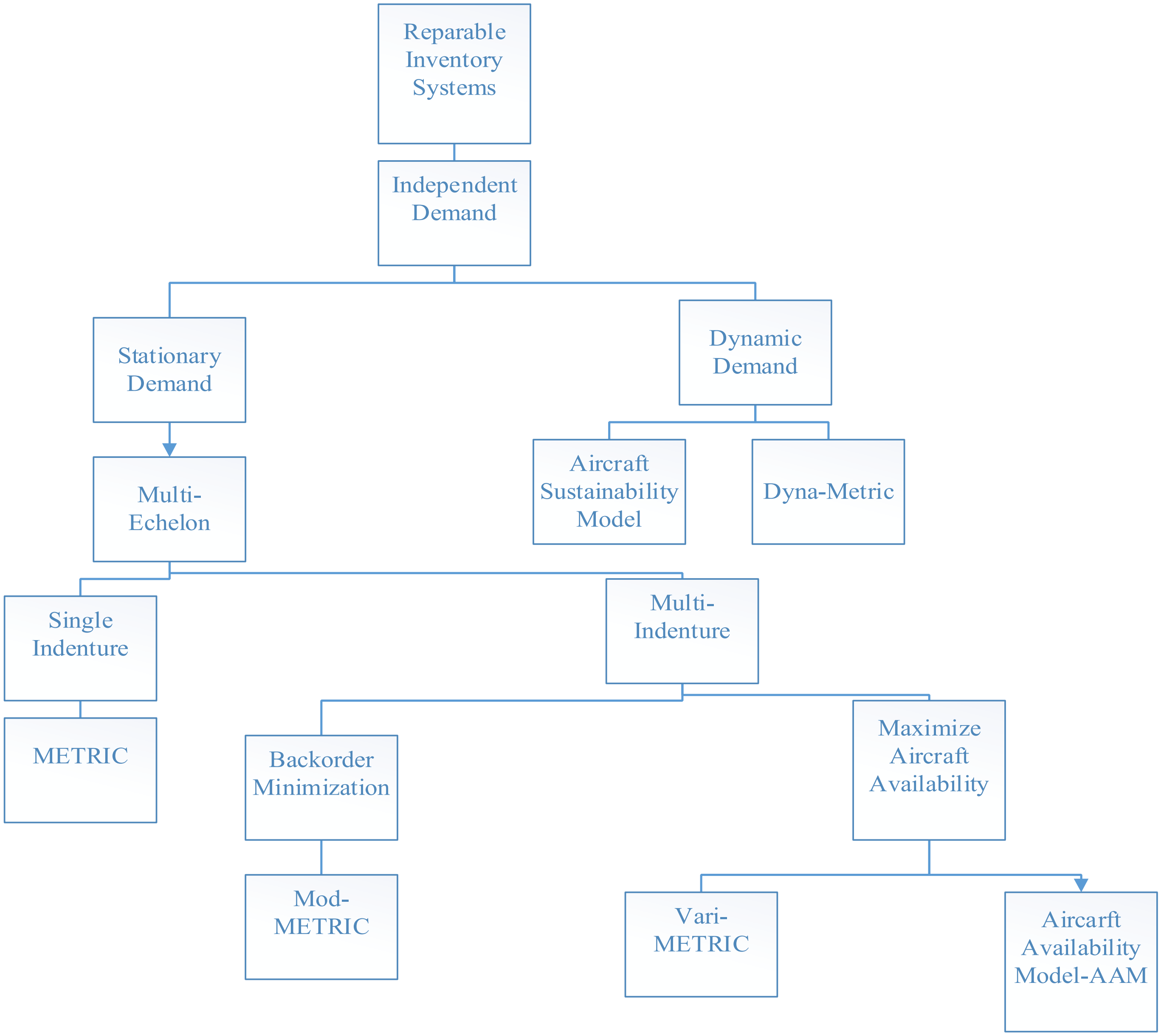

Figure 2: Development of Reparable Item Inventory Models [Klenger (as cited in Zorn 1996)]

Christer (2002) developed model for a hierarchical (or indentured) repairable inventories with multi-echelon. This is also similar to METRIC model.

[CITATION Mor86 \l 1033], developed a comprehensive model of a stochastic, multi-echelon inventory system. They used branch and bound algorithm to obtain a solution for a multi-item service constrained (S, s) system in multi echelon for low usage items.

Vrat (2014) presented the overview of inventory models (Taxonomy of inventory models) as shown on figure 2 and the explanation follows. Some inventory purchases are not repetitive and the decision are made only once with in the planning period. Such type of inventory model is called static models. For example, the decision to purchase news magazine and sale to the end users is made once. When the purchase is repetitive and the decisions are made many times with in the planning period, we call it dynamic inventory models. Based on the demand, inventory models are gain further classified as deterministic or probabilistic. If the nature of the demand is uncertain or intermittent or lumpy we call it probabilistic otherwise it is called deterministic. Again based on the location of the stores we can classify inventories as single location or multi echelon. If we have two or more stores, it is multi echelon inventory system and the supply store is one it is called single location. Single item inventory and multi item inventory is based on the level of bill of materials. When our objective is to deal with the end item, it is called single item or single indenture. When we deal with lower levels of bill of materials, we call it multi item or multi indenture.

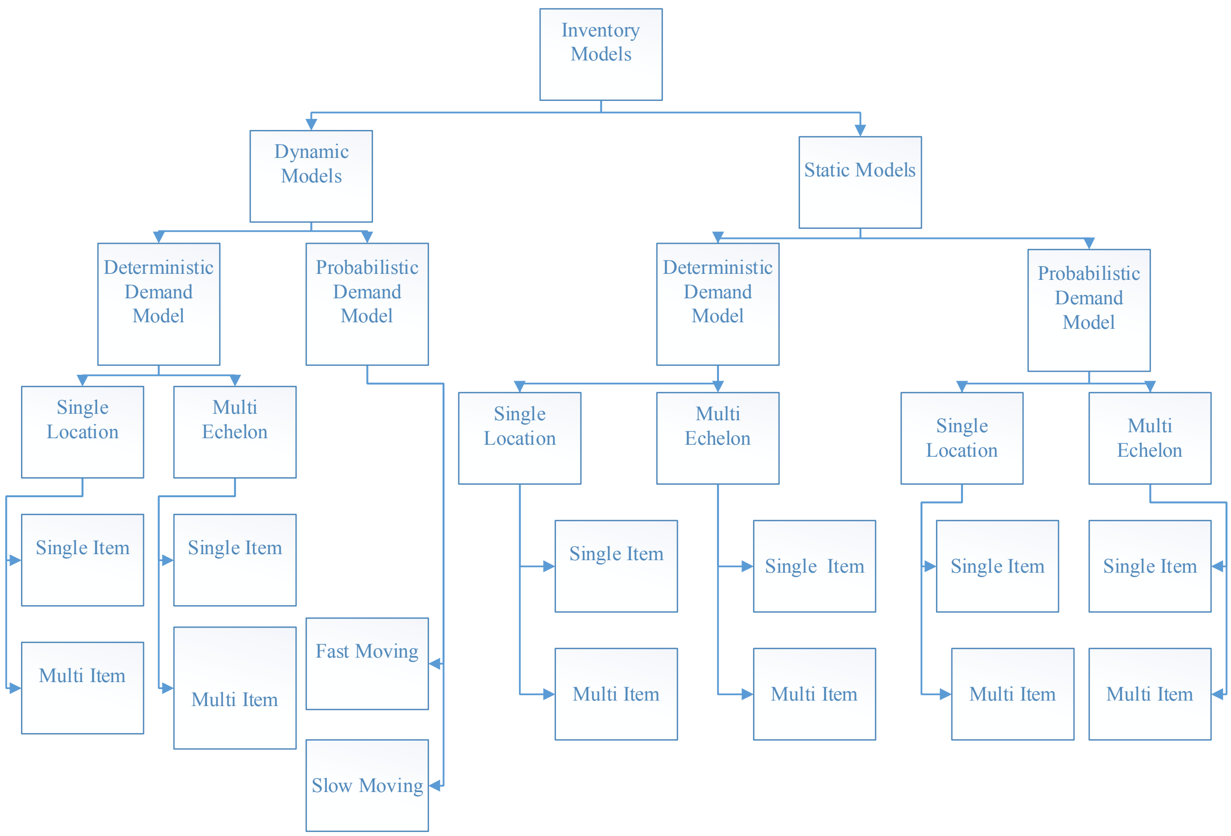

Figure 3: Taxonomy of inventory models[CITATION PVr14 \l 1033]

[CITATION DLo11 \l 1033], used Markov process to determine optimal stock size in mining industries. In this literature, combinations of four optimization criteria are utilized as shown in the figure below. Since the Focus of this paper on optimization of repairable spare parts, let us explain each of the optimization criteria used for repairable. The inventory models for repairable as shown of figure-4 are risk model, cost model and availability model.

When we say risk model, it is to indicate the risk of running out of stocks. This risk models can be instantaneous reliability model or interval reliability model. Instantaneous reliability is the probability that a spare is available at any given moment in time. This literature defines instantaneous reliability as fill rate. Interval reliability is the probability of not running out of stock at any moment over a specified period. For example, let our time reference is one year. In case of interval reliability, the inventory should be availability with in this one year at any moment. However, in case of instantaneous reliability, it should always be available. Each of Instantaneous and interval reliability models again further classified based on the capability of the repair shop. The capacity of the repair shop is said to be limited if it the shop has limitation to repair all parts (components) that fails with in a given time the shop, otherwise it is called repairable. From figure-4, this paper excluded limited repair capacity and used the other four methods for repairable, generated four different results.

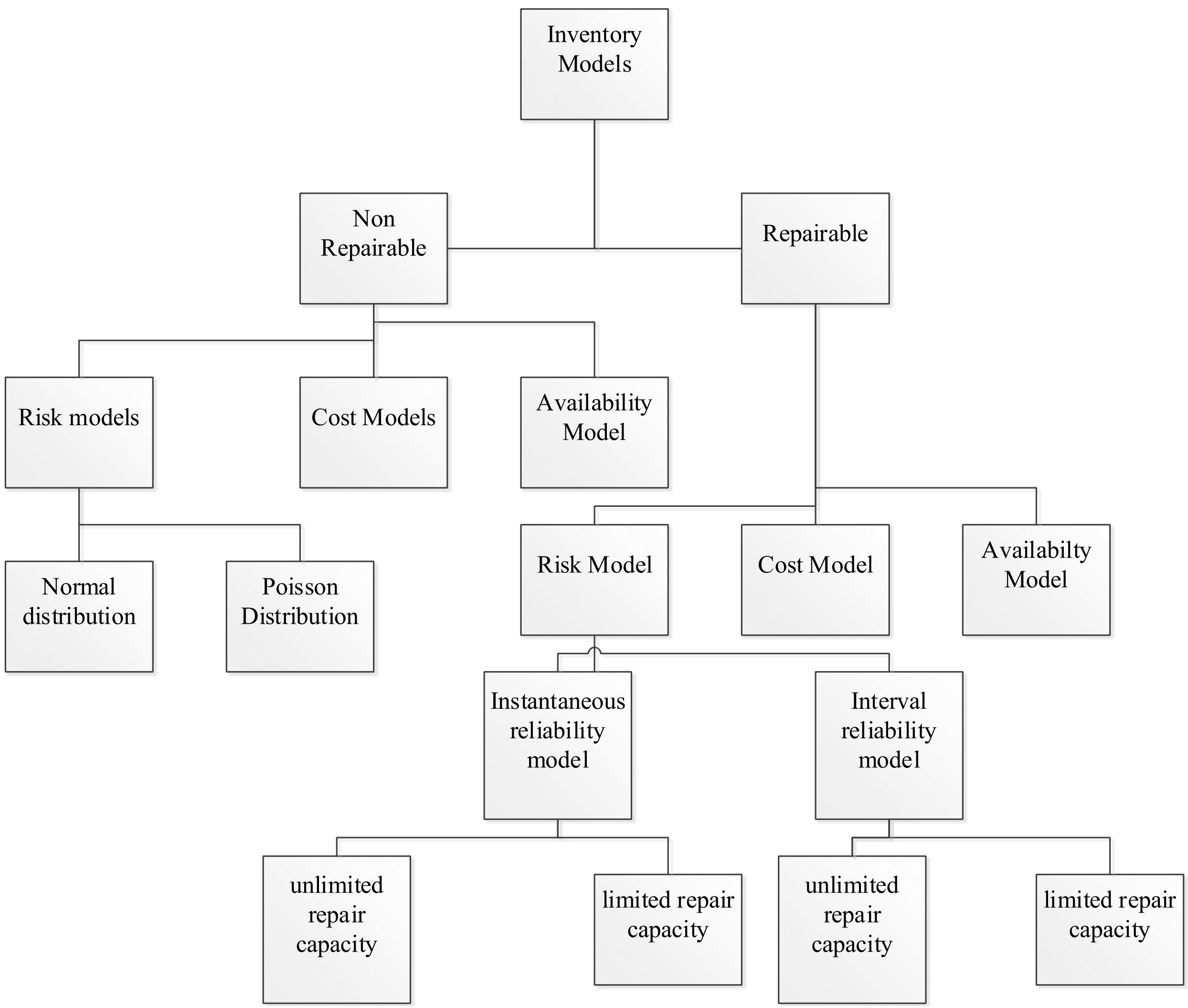

Figure 4: Inventory optimization Models [CITATION DLo11 \l 1033]

The inventory policies of spare parts are different from inventory policies that we use for work in process (WIP) and final product inventories [CITATION WJK02 \l 1033].

Spare parts inventories are different from WIP and final product inventories because of two main reasons. First, the functions of spare part inventory and final product inventory or WIP inventory are very different. Final product inventories are kept to compensate unforeseen irregularities that may happen due to capacity, production rate, labor issue, raw material supply etc. However, spare part inventories kept to kept equipment in operation. Spare part inventories are not WIP or final products. Second, the policies used to manage spare part inventories and WIP or final products are different. Final product inventory or WIP inventory are determined based on the production rate, customer demand, production lead-time etc. However, inventory of spare parts is a function of how the equipment is used and how it is maintained. For example, if the equipment is to be operated for longer hour, the deterioration of the spares increases. Moreover, it needs more frequent replacement of spares. More detail Unique characteristics of maintenance inventories are as follows[CITATION WJK02 \l 1033]:-

- Maintenance policies Driven rather than customer Demand driven. For example, we may repair or replace to restore the functionality of failed equipment. The decision to replace or repair has direct implications on the inventory level. Another decision is whether the failed spare is GO item or NO GO item. If the failed spare part has some redundancy, it is considered as GO item and can be replaced at another convenient time. However, if the failed spare is NO GO item, it is mandatory to replace the part immediately.

- Reliability Information is not Predictive. Especially when equipment is new, it is a challenge to predict the time of failure. Hence, it is a matter of personnel experience and probability.

- Failures are always dependent. The failure of equipment is a function of other systems, environment, operation rate etc.

- Demands can be met through different means for example cannibalization, pooling agreements, loans etc.

- Difficult to quantify stock out Costs. This point is opposed by [CITATION Ade03 \l 1033]

- Obsolescence may be a problem.

Further factors are also discussed in the above literature[CITATION WJK02 \l 1033] like multi-echelon, multiple location inventory supply.

This research paper considers (assumes) single echelon location based on observations. Because all spare parts are first received at one main base (depot) and then distributed to many other locations as necessary. However, entry into the organization is only at one location i.e. Addis Ababa main base.

Americans Airlines developed and used rotables allocation and planning system to manage its spare parts[CITATION Mar89 \l 1033]

The relationship between four business performance indicators, cost, quality, delivery time and flexibility are studied [CITATION Mic04 \l 1033]. This study shows that companies with low quality performance have low financial performance. Thus, companies who managed their quality badly went bankruptcy while those companies who managed their quality well survived the same difficult periods and even decreased their operating costs. The research also shows quality gains come before cost gains. Based on these research findings, we can infer that companies that manage their inventories can better support operation of their aircrafts leading to decreased costs and increased service level.

In this research paper, METRIC model will not be utilized. Since the case, company has single location (not multi-echelon). However, Marginal analysis model that was utilized by other researchers in METRIC model will be used.

2.5. Framework for Repairable Spares Inventory Control.

Different literatures present different conceptual frameworks for repairable spare parts management. Managing spare parts requires integrating the logistics and maintenance perspectives, which motivates the need to follow five sequential decision making framework as shown on figure 5 (Cavalieri, Garetti, Machi, & Pinto, 2008). As shown on figure 5, the first step is coding of the parts in a way it gives specific information about the part. The next step is classification of the parts based on their criticality. The criticality analysis can be based on quantitative methods (ABC, FSN) and qualitative methods (VED).

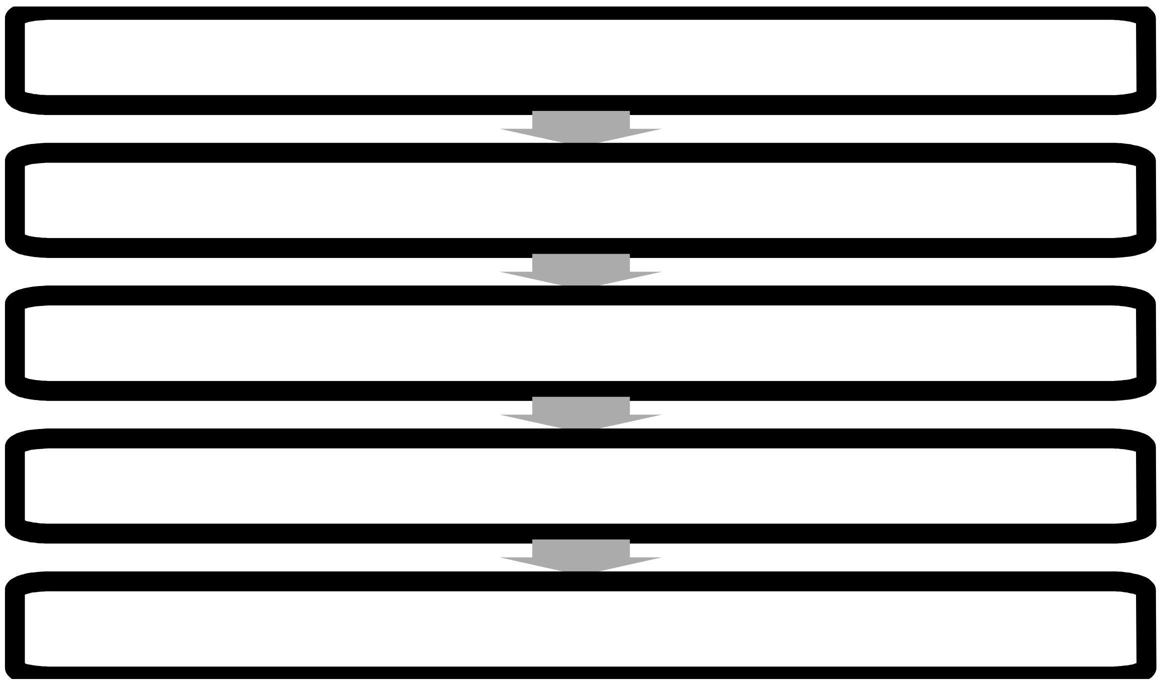

Figure 5: Five Stage sequential decision making framework (Cavalieri, Garetti, Machi, & Pinto, 2008)

International Atomic Energy Agency (IAEA, 2001), used general approach (framework) to determine spare parts optimization as shown in figure 6.

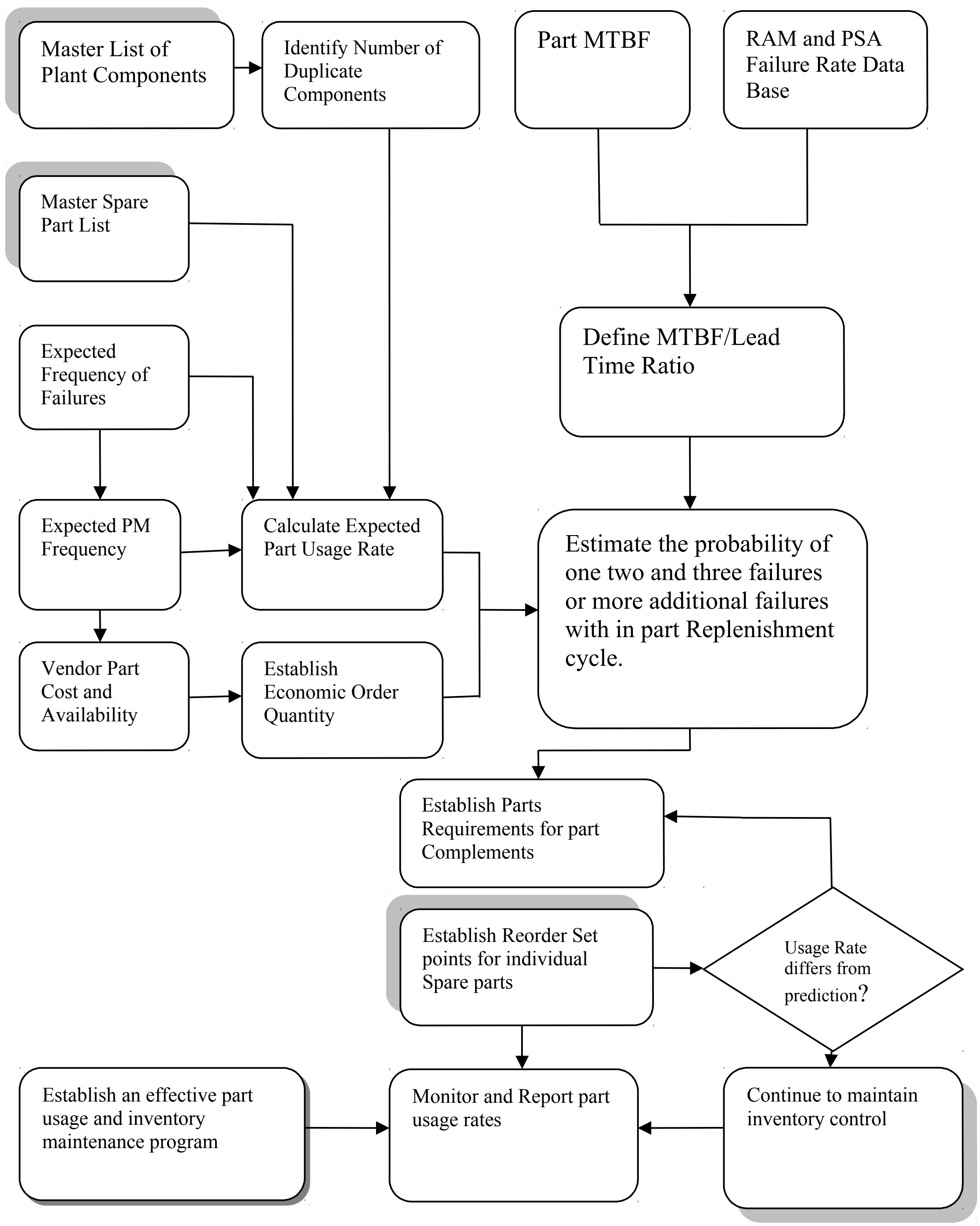

Figure 6: Spare parts optimization Frame Work (determination of complement) [CITATION IAE01 \l 1033]

There are different strategic and tactical decisions related to inventory planning and control[CITATION Art13 \l 1033]. The writer identified three main steps (Process) to control inventories as shown in figure 7.

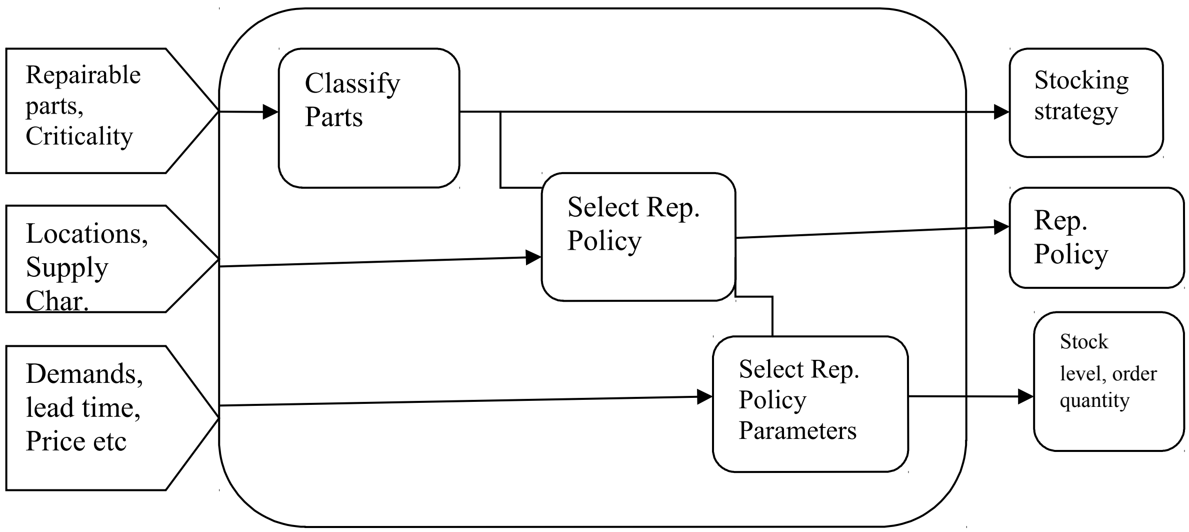

Figure 7: Process overview of controlling inventories[CITATION Art13 \l 1033]**.**

As shown on figure 7, the first step is to classify the spare parts into critical spare parts and non-critical spare. This classification is based on the contribution of the parts for the availability of the product. We use SIM tools listed in section 2.4 of this paper to classify the parts. The next step is to select the inventory policies i.e. (R, S)-policy an (R, s, S) or (R, s, Q)-policy. The last main process is to select policy parameters such as multi-echelon, multi-item, multi-indenture structure, lateral etc. Inputs for this model are demand forecasts and information like lead times, price.

According to Wimer (2015), airlines can follow nine-step model shown on figure 8 to support the operations with Inventory provisioning.

Step-1 understands the operational goal. This means the stock mangers should first know the technical dispatch reliability goal that the organization seeks to meet, say for example 95% dispatch reliability. Step is collection of necessary data such as mean time between removals (MTBR), quantity per aircraft (QPA) of each spare parts, aircraft utilization, expected turnaround time (TAT), scrap percentages etc. The fourth step is to classify (designate the parts) based on their criticality and estimated annual demand.

Based on their criticality the parts are classified as No-Go items (essentiality-1) and go if items (essentiality-2 or 3).

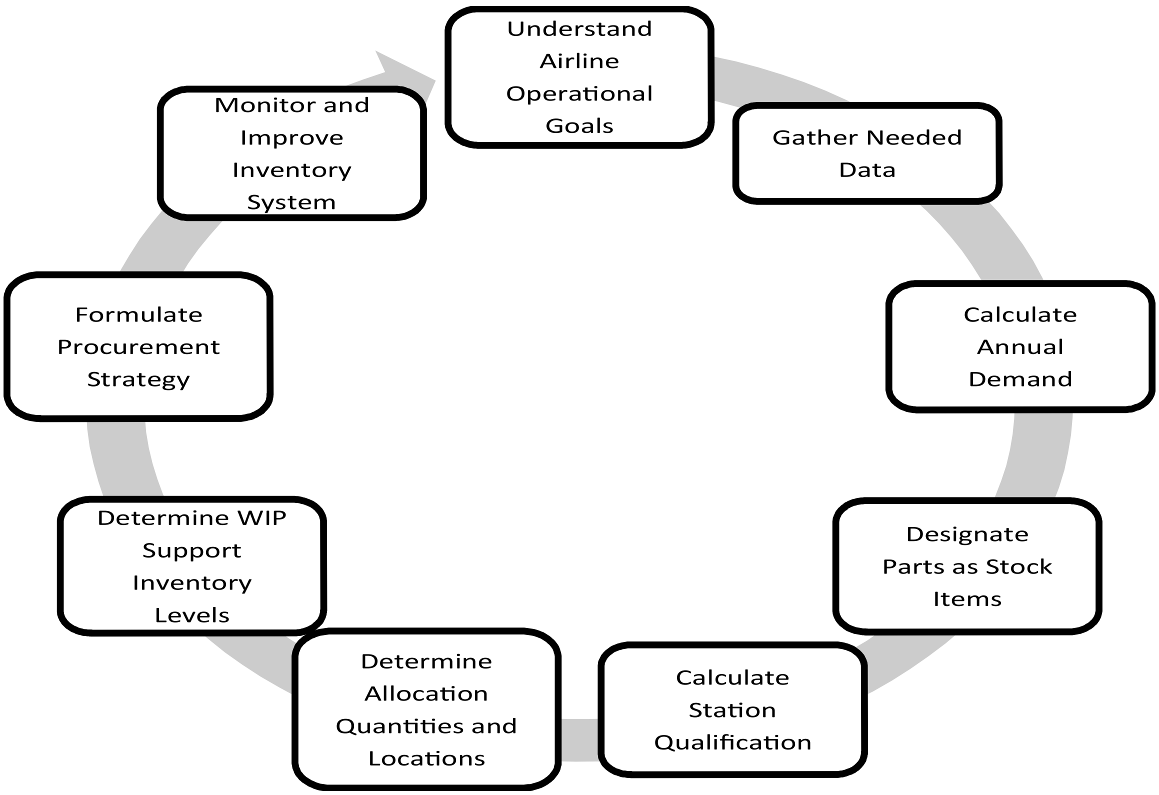

Figure 8: Nine Step Inventory Provisioning Model[CITATION Wim15 \l 1033]

1. Understand Airline Operational Goals 2. Gather Needed Data

3. Calculate Annual Demand 4. Designate Parts as Stock Items

5. Calculate Station Qualification 6. Determine Allocation Quantities and Locations

7. Determine WIP Support Inventory Levels 8. Formulate Procurement Strategy

9. Monitor and Improve Inventory System.

Based on the estimated annual demand the parts are classified as follows: -

Demand	<0.5	0.5≤demand< 1	≥1	Very High Demand Parts
Remark	Not A Stock Item (NASI)	1unit/2 years		

The attention given for each class of demand gets increases as the demand increases. Step-5 and step-6, are applicable t multi-location supplies. Since this research paper is limited to single location supply, these steps are neglected. Step-7 deals with how to calculate work in process inventory that used to support the repair process. WIP is also called pipeline inventory. Step-8 is related to strategy to obtain the spares. The options are own, lease, loan, exchange, robbing. The scope of this research paper does not include this step-8.

Comparison between the frame works shown on figures 6, 7 and 8 show some similarities and differences. The one shown in figure 7 is less comprehensive as compared to the others. The steps shown in figure 7 are all included in Figure 6 and 8. The IAEA framework shown in Figure 6 is more detailed and it is applicable for both single echelon and multi echelon. However, it is more complicated as compared to IATA model shown on figure 8.

it is now possible to modify the framework to further elaborate the steps for inventory optimization as shown on figure 8.

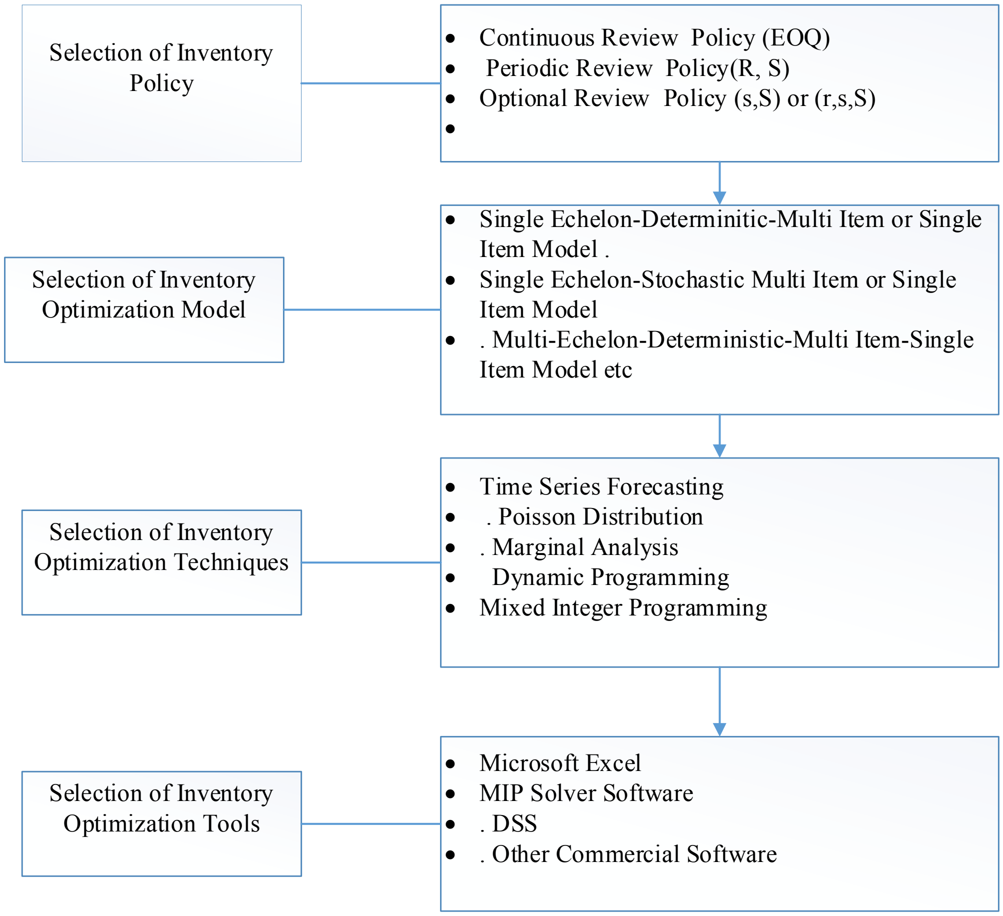

Figure 9: Major Steps of Repairable Inventory Optimization (Adapted from [CITATION Art13 \l 1033]

Inventory model to be developed depends upon the choice of inventory policy. Hence, we have to first determined the inventory policy to be utilized before we develop an inventory model for optimal choice of the decision variables. Again, the optimization technique we use depends on the selected optimization model. The tools (software) that we use for optimization again depend on the techniques we use. Therefore, it is helpful to follow the steps mentioned on figure 9. Other literatures have almost followed the steps shown in figure 9 during inventory optimization.

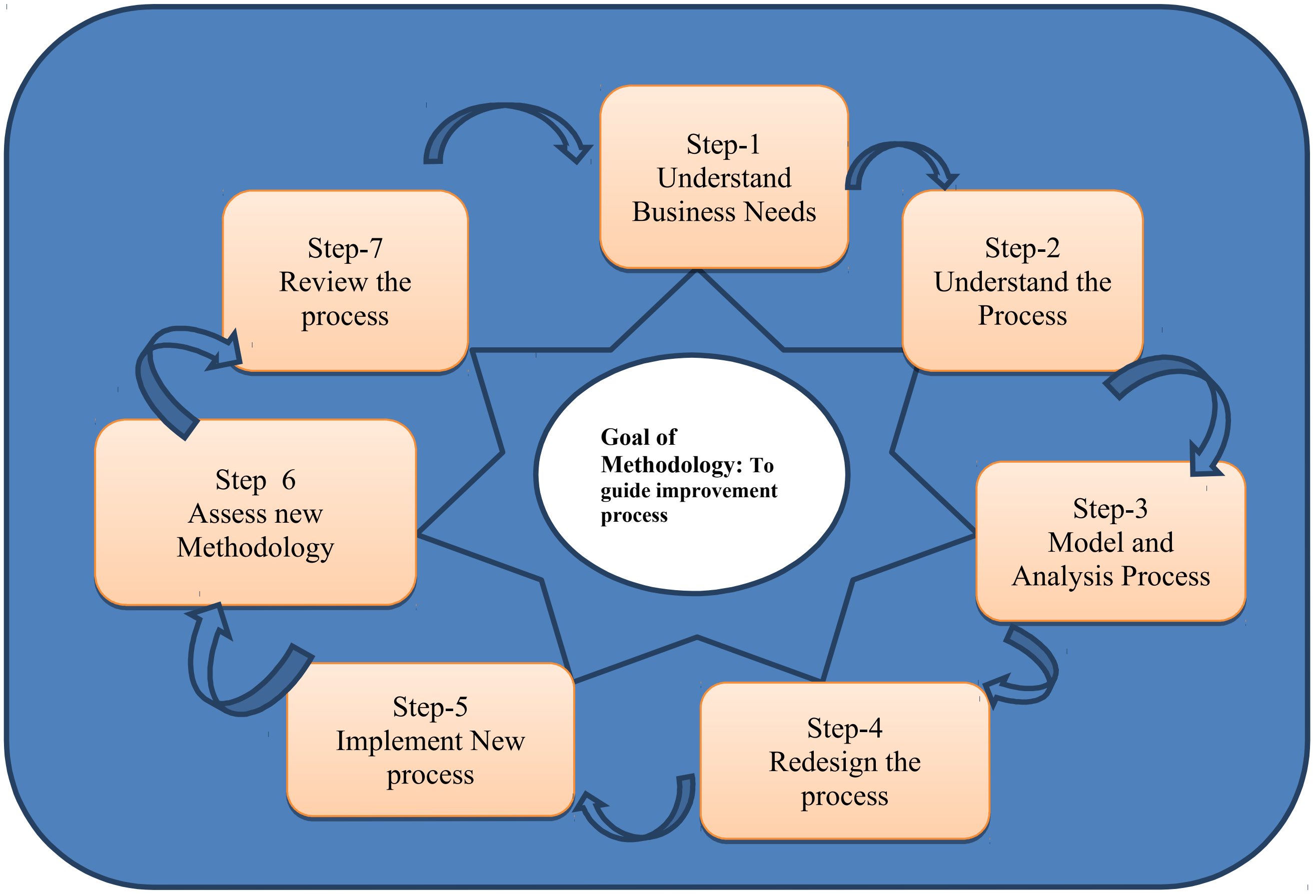

Figure 10: Generic model for business process improvement [CITATION Sol05 \l 1033]

Sola Adesola and Tim Baines (2005) presented generic model for business process improvement as shown on figure 10. They called this model-based and integrated process improvement (MIPI).

Table 1: Sample Literatures on Single and Multi-Echelon Inventory Models

No	Author	Inventory Policy	Inventory Model	Problem
1	[CITATION Ste03 \l 1033]	(s- 1,s)	Single Echelon-Deterministic	
2	[CITATION MCM02 \l 1033]	Modified EOQ	Single Echelon	
3	[CITATION Pre94 \l 1033]	Echelon-ABC analysis, FSN analysis, VED analysis,	Single	
4	[CITATION Che05 \l 1033]	(s- 1,s)		Multiple failures, cannibalization allowed
5	[CITATION Jon07 \l 1033]	(s- 1,s)		Quadratic shortage cost function
6	[CITATION She68 \l 1033]	(s- 1,s)	METRIC	METRIC formulation
7	[CITATION She86 \l 1033]	(s- 1,s)	VARI-METRIC	Multi-indenture model, pipeline variance
8	[CITATION Vin78 \l 1033]	(T,Q) modified	Theory Development-Stochastic	Optimal replenishment quantities
9	[CITATION NSi90 \l 1033]	(s- 1,s)		Bus fleet spares-Failure rates based on geographic area of route and average mileage
10	[CITATION Mar89 \l 1033]	(s- 1,s)		Commercial aircraft availability-Incorporates shortage costs which consider the cost of a canceled flight
11	[CITATION Mor86 \l 1033]	(s- 1,s)		

The basic economic order quantity approach (EOQ) and economic order period (EOP) types ignores random variations in the usage rate or supplier performance[CITATION Geo06 \l 1033]. It also explains how ABC classification was implemented. The study does not show the utilization of these approaches for repairable spare parts. This indicates the impact of system level availability as compared to item level availability[CITATION Chr04 \l 1033]. There are supply chains models for handling of recovery or recycling of products[CITATION Fle00 \l 1033].

However, unlike repairable spares, the models for recycling of products are not closed loop. This is because the recycled products go to different customers than the original customers.

Table 2: Classification of Literatures

No	Authors	Title	Inventory Optimization Method	Tools Used	Gaps
1	[CITATION Chr04 \l 1033]	Inventory Optimization Techniques, System vs. Item Level Inventory	Poisson Distribution(for item level), Marginal Analysis and Genetic Algorithm(Multi-objective Optimization)	Raytheon genetic algorithm, Commercial Software	
2	[CITATION DLo11 \l 1033]	Optimization models for critical spare parts inventories—a reliability approach	Stochastic- Queuing based models(Markov process)		Not considered maintenance turnaround time and assumes that all removed parts are always repaired. -Scrap rate not considered -Does not consider system level availability it considers item level reliability.
3	[CITATION Ade03 \l 1033]	Evaluation of forecasting methods for intermittent parts demand in the field of aviation: a predictive model	Deterministic Model -Statistical analysis by time Series Models	Excel Spread sheet	*Does not consider system availability or service level. Only considers item availability. *The focus is on forecasting not on optimization
4	[CITATION Jat13 \l 1033]	Maintenance: Spare Parts Optimization	Deterministic- Statistical analysis by time Series	Excel Spread sheet built in functions	Focus on forecasting not on optimization. -Not considered maintenance reliability, scrap rate. Does not consider system availability

5	[CITATION Mic08 \l 1033]	Aircraft Rotable Inventory Optimization, Development of New solutions	-Deterministic-Linear Programming and Marginal analysis -Stochastic-Poisson Process -Heuristic-Cost wise skewed holding	LP Solve Excel	Assumes zero scrap rate -Assumes no NFF
6	[CITATION GuJ15 \l 1033]	Efficient aircraft spare parts inventory management under demand uncertainty	Deterministic-non-linear programming (NLP). Iteration method and GAMS are used	GAMS	Does not integrate inventory size, maintenance turnaround time turnaround time, and reliability. -Does not consider system availability
7	[CITATION Pet12 \l 1033]	Initial provisioning and spare parts inventory network optimization in a multi maintenance base environment	simulation-based optimization,	D-SIMSPAIR software package	TAT and Scrap rate not considered.

2.6. Comparison and Selection of Inventory Optimization Models

The inventory models presented in the previous section are compared in this sub-section. After comparison of the models, best-fit optimization techniques are selected. The criteria of comparison are objective of the research, approach (system level approach or item level approach), nature of the spare part, optimality of the intended solution.

Now the next logical question is, how can we select the policies, models, techniques and tools? The best policy options should be selected among the three inventory policies. [CITATION PVr14 \l 1033], states that the best option is (s, S) policy or (s, S, T) if the three decision variables s, S and T are optimized. However, he identified that optimization of these three decision variables simultaneously leads to a very complex model of inventory for stochastic demands demand and lead times. For practical purposes, EOQ-ROP policy is a good choice for high usage value items, while (S, T) policy is good for low usage value items. (s, S) policy may be employed for very high usage value items. We have already discussed that repairable spare parts are classified as slow moving items. In addition, the slow moving items are best handled by (S-1, S), special inventory policy of (s, S) where s=S-1. Therefore, (S-1, S) policy is selected for this research paper.

Selection of inventory model depends on the decision at hand. Now, inventory models shall be selected from the inventory optimization models shown on figure 3. For example, the case company of this research paper is of single site (single echelon model). Since the demand of repairable spares is probabilistic, we use probabilistic inventory model. Hence, single echelon model with probabilistic demand model selected.

Different researchers have used different optimization techniques. [CITATION WJK02 \l 1033], has made an extensive literature review on inventory optimization models. He mentioned inventory control and optimization techniques like statistical control, probability distribution, and queuing analysis, poison distribution, marginal allocation, mixed integer programming (branch and bound algorithm), linear programming integer solution. They identified that the optimization tool used depends on the choice of the objective. For example, if the objective of the research is to study the repairable inventory optimization in relation to repair capacity, we use queue analysis. The scope of this research paper does not include the repair capacity of the shops. It does not take into account the capacity of man-hour availability, machinery availability or other resource requirements (server requirements). Hence, queue analysis shall not be potential optimization technique for this paper.

According to [CITATION Art13 \l 1033], the inventory optimization framework depends on the inputs we have. [CITATION Mor86 \l 1033], concluded that branch and bound algorithm showed 8.5% average error level relative to an LP integer solution. It yields a near optimal (S, s) policy for a multi-echelon spare parts system. Based on this, this research paper has selected LP integer solution approach.

The other techniques like marginal and poison distribution gives suboptimal solution but not optimal solution[CITATION WJK02 \l 1033].

Application of Conventional statistical inventory control (SIC) techniques is not enough for slow moving items like repairable spares[CITATION Leo99 \l 1033]. Because repairable spares are classified as slow moving items, statistical inventory control (SIC) techniques cannot give optimum solutions.

Based on the above comparison, this research paper will use mainly four techniques. First, selective inventory management tools-ABC-VED-FSN will be used to classify the tools. Second, poison distribution will be used to find the sub-optimal stock size for the repairable. Third, the output from poison distribution shall be used to further optimize the results. Lastly, integer linear programming will be used to obtain the final optimal solution.

2.7. Literature Gaps

The literature review show that a huge body of literatures exists regarding repairable spare planning, control and optimization. Nevertheless, the literatures are limited to models that assume negligible no fault found (NFF) and scrap rate (S) which actually deny the reality encountered by maintenance organizations in practice. Literature that follow integrated approach for repairable inventory systems is, to the best of our knowledge, lacking. This paper studies such an integrated optimization approach which takes reliability variables (Mean Time Between Unscheduled Removal-MTBUR, Mean Time Between Failure-MTBF), cost variables, maintenance turnaround time (TAT), No fault found (NFF), Scrap rate (S) and service level as an input. The major gaps are explained as follows: -

1. **Scrap Rates(S) and No Fault Found(NFF) Variables Not Considered**:

For easily understanding of the literatures gaps, existing repairable spare part flow is shown on Figure 11. All literatures included in the literature review in chapter two, assume (consider) that all repairable spare parts that are removed (claimed failed) always need repair before returning to operation. However, practical experiences show that there are situations in which most of the removed components are returned to service without repair activity[CITATION htt05 \l 1033]. Such situations are known as no fault found (NFF) and they are known industry problems.

As shown on Figure 11, then such NFF parts are tested and returned to inventory without any maintenance action. To make clear NFF meaning, this spare part is removed and sent to the repair shop for test. If the spare part passes the test, then it is returned to service. The failure has not been confirmed in shop. In this case, the removal is counted as a NFF. Because of this, NFF events artificially inflate the inventory balance.

:

Wimer (2015) also states that scrap rates and no found fault should be considered as critical measurement inputs into inventory management system.

As shown on Figure 11, scrap rate or condemnation rate or disposal rate is the amount of spare parts that are removed from the inventory population because of permanent damage (beyond economic repair). However, all literatures included in literature review assume that the scrap rate as zero while real experiences indicate that the scrap rates exist.

In section 2.4.3 and 2.4.4, it was explained that

$E = R * TAT / 365$

Where E = the expected number of spares, TAT is turnaround time and R total number of removals per year. Now, the gap is related the above calculation. Scrap Rates and No Fault Found (NFF) are not considered in 'E' calculation. That means these two factors are not used as an input variable while formulating inventory optimization model. Since the result of E will be used as an input for poison distribution, it will affect the out puts of diminishing Marginal Returns and mixed integer Linear Programming. Because the result Poisson distribution is used as an input for diminishing marginal returns and mixed integer linear programming.

Therefore, this research considered scrap rate and NFF as an input to expected mean (E) requirement for each item as follows: -

$$E = \frac{(R - NFF) * T}{365} + \frac{NFF * T2}{365} + S --- (1)$$

Where T is the turnaround time for repair (maintenance) and T2 is the turnaround time for no fault found event (false failure events). R is the total number of removals per year for each item. NFF is the total number of no found fault per year and S is the scrap per year

2. **Operational Environment**

The reliability (such as MTBUR) of the repairable spare parts depends on the environment in which they are operated. The environment (geographical locations) also affects the design of repairable inventory [CITATION MEI05 \l 1033]. Because working environment such as temperature, humidity, dust etc. differs from one area to the other operational area. As shown in model-1, the stock size of repairable is a function of each part reliability (MTBUR).

Considering geographical location, no literature was found that has been researched in Ethiopia or Africa. Therefore, the researcher believes that there is still potential room to be researched in this area.

In addition, repairable spares are depreciated depending on the firm's goals and mode of business. That means Spare part requirements are dependent on utilization of the airplane (the higher assembly). Hence, there is again literature gap regarding how the local business circumstances such as experience and utilization affects the size of repairable stocks.

3. Optimization Frameworks Not Fully Interfaced

Methodology wise, the techniques used for item classification, inventory optimization are not interfaced (integrated). Regarding the sampling techniques, random samplings were used to decide the sample size. That means the criticality level of the spare parts is not considered while determining sample size. Equal importance was given for all spare parts. In this research, selective inventory management tools such (ABC-VED-FSN) are used to determine the sample size of the spare parts. Another major observed gap is that the spare parts are not identified based on their similar technology and operating principle. This is because similarity in technology indicates similarity in reliability characteristics. In this research paper, cluster sampling is used by grouping the components into eleven (8) different groups based on the concept of similar technology. In all reviewed literatures, no integrated model is recommended regarding repairable inventory management. This paper will endeavor to propose an **integrated framework** for repairable inventory optimization.

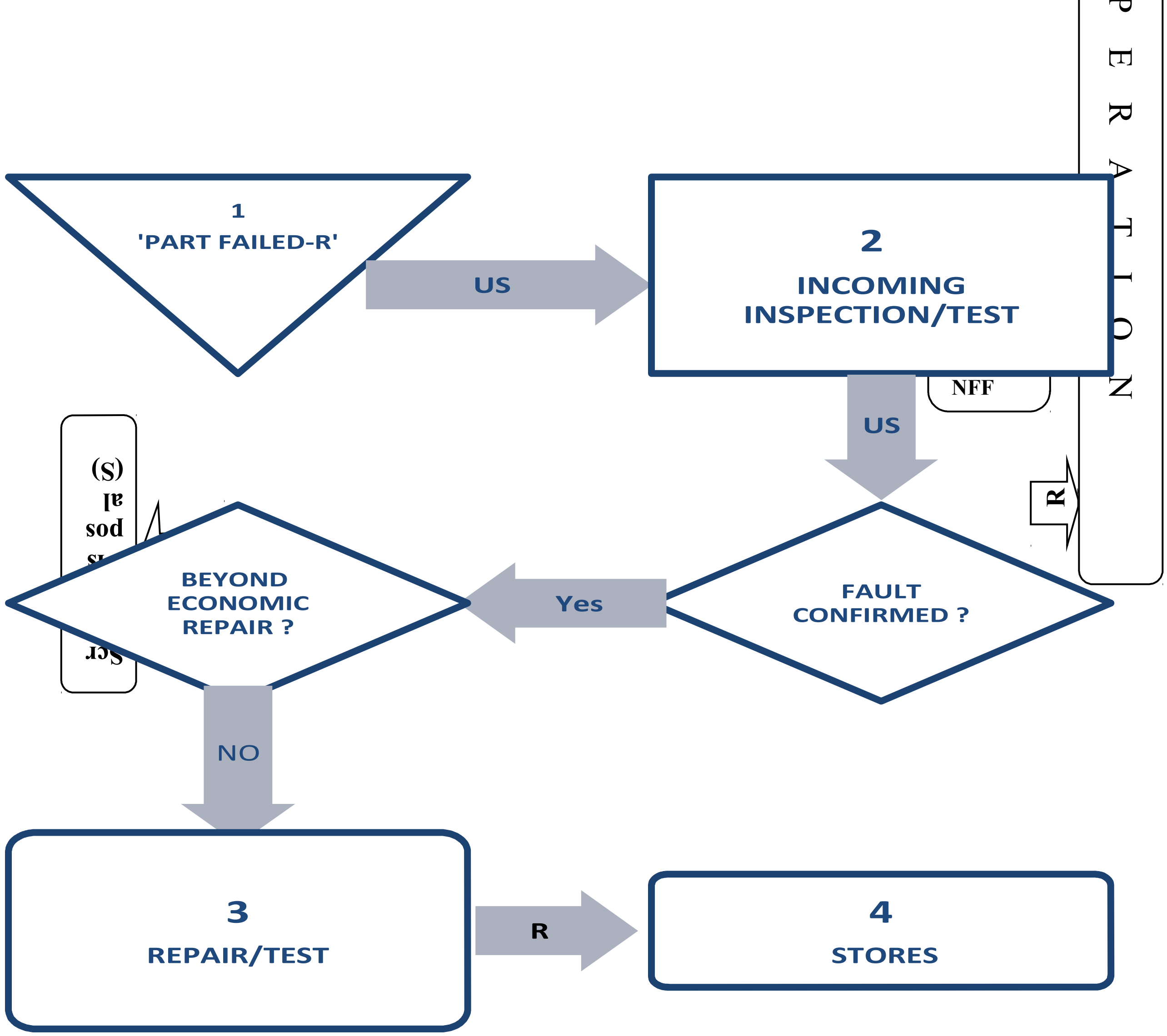

Figure 11: Schematic Flow of Repairable Spare Parts in the case company (Author)

Chapter Three

Research Design and Methodology

In this chapter, research design, sampling techniques, sample sizes, methods of data analysis and scenarios are presented.

3.1. Research Design

Since the objective of this research paper is to maximize the service level and minimize the overall inventory costs, it is very important to select one aircraft model. When the availability improves, it means the dispatch reliability is improved. The major steps to determine final sample size are as shown in Figure 12.

First Boeing B737NG aircraft model is selected by using purposive sampling techniques. Different criteria (factors) considered during purposive sampling to select a model aircraft are explained under section 4.1. Next, the sample size of repairable B737 spares is selected. To select the sample size, let us first discuss all possible options.

Option-1: To select all repairable spares those repaired in foreign repair shops

Option-2: To select all repairable spares those repaired in in-house repair shops.

Option-3: To select combination of option-1 and option-2.

Considering improvement opportunity and research objective, this research paper has selected option-2. In this option, many improvement factors are internal to the case company. Some of the improvement factors or parameters are maintenance turnaround time, control of no fault found events, scrap rate control, maintenance cost control, reliability improvement factors etc. However, if we select option-1 and option-3, all the above listed factors are not under the case company control. Hence, there is less improvement opportunity relative to option-2. Therefore, all repairable spare parts of B737 included in in-house capability list are selected as the focus of this research paper. There are 201 repairable spare parts of B737 included in the list.

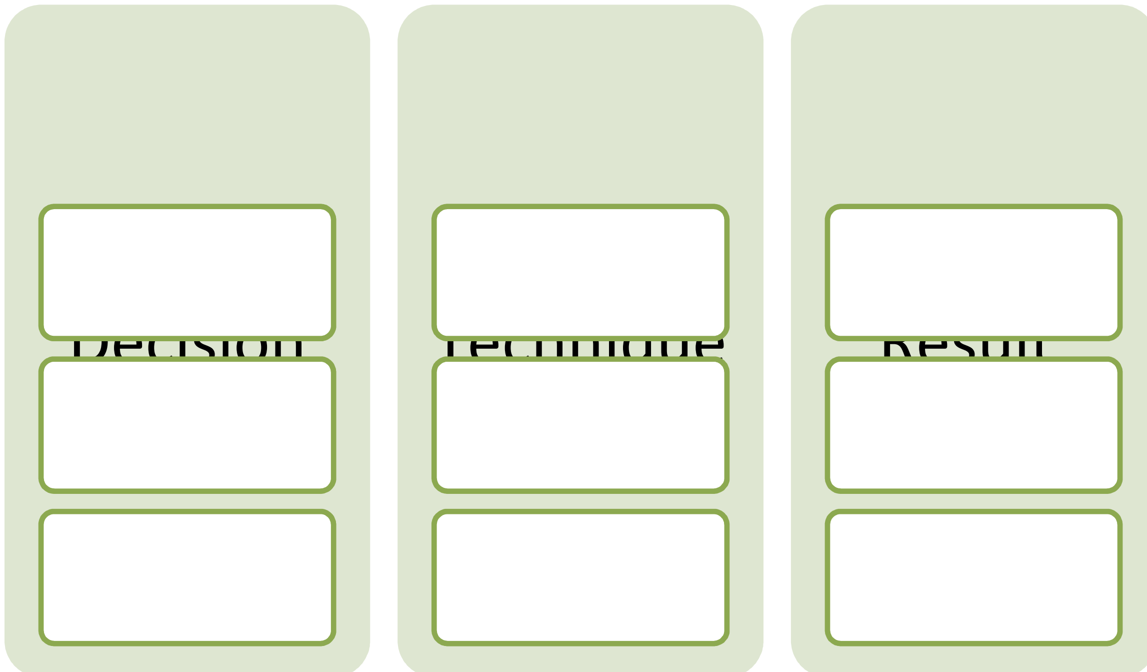

Figure 12: Schematic to show Sampling Techniques and Major Sampling steps

3.2. Sample Size and Sampling Techniques

In this research, mixed sampling technique is utilized. Because three sampling techniques are used together, purposive sampling, cluster sampling techniques and sequential sampling technique. In Purposive Sampling, participants (samples) are selected based on preselected criteria based on the research question[CITATION Mal01 \l 1033]. Stephanie (2015) also states that purposive sample is non-probability sampling technique where the researcher selects a sample based on their knowledge about the study and population. The participants are selected based on the purpose of the sample. Purposeful sampling strategies in implementation research are Criterion sampling, typical case sampling and homogeneity[CITATION Law16 \l 1033]. Criterion is the most common purposeful sampling strategies. Cluster sampling is grouping (clustering) the whole population into groups and then select the groups rather than individual elements for inclusion in the sample[CITATION CRC04 \l 1033].

3.2.1. **Justification for Selecting Sampling Techniques**

A) Justification for Selecting Purposive Sampling

Main criterions (factors) used for purposive sampling are developed by considering research question and research purpose. The criteria are shown in table 3. Some of the criteria are related to each other. Now let us explain how each criterion affects the indicators in relation to fitness.

As shown on table 3, the two main criteria used for purposive sampling are fitness for research question and fitness for research objectives. Based on the research question, one specific research objective is to study the impact of No Fault Found (NFF) and scrap rate (disposal rate) on inventory level of repairable spare parts. These two factors are dependent on personnel training, NFF management policies, organizational cultures etc. [CITATION Joh16 \l 1033]. That means NFF and disposal rate are dependent on organizational experience. Organizations having less experiences can experience abnormal NFF events or scrap rates. However, as experience of the organizations improves, the NFF events and scrap rates gets more normal. This is because NFF event data get more and more reliable. Compared to other model aircrafts, the case company has more experience with B7373 aircraft model. Therefore, with respect to fitness for research question, fitness for research objectives, organizational experience, data availability and data reliability, B737 is the best fit. This model aircraft has been longer time in the world airline industry. Other fleets such as B777, B787 and A-350 have stayed less in airline industry relative to B737. This indicates, the fleet has relatively better maturity level than others. This means the secondary data will be more reliable and healthy.

Regarding maintenance capability, the case company has full maintenance capability for B737. But it has limited maintenance capability for other models such as B777, B787, and A350. To study the whole maintenance process B737 having full gives more opportunity for improvement. Therefore, B737 is best fit as compared to other models. Narrow-body (example B737) aircraft are forecasted to grow fastest when compared to other model aircrafts with an average annual rate of 4.9% between 2017 up to 2027 globally [CITATION Tom \l 1033]. Therefore, B737 model has greatest future global demand when compared to other models. Therefore, again B737 is best fit with respect to future world demand forecast. Based on the above purposive comparison, B737 is selected as sample product.

The record of other model aircrafts is not included this analysis. But, by solving the inventory problems of this fleet it is possible to improve the overall service provision of the case company. Thus the existing operation data are collected and analyzed. The data collected include average repair cycle time (turnaround time-TAT) of each spare, total number of removals(failures) per year, total number of false failures (no fault found-NFF) per year, cycle time for NFF per spare part, number of scrap(condemnation) rates per year, price per spare part and criticality index of each repairable spares.

Therefore, B737 aircraft model is selected as the sample product.

Table 3: Criteria (Factors) used for purposive sampling (Source: The Author)

No	Criterion	Indicators	Fitness or Non Fitness to Criterion	Decision
1	Fitness for Research Question	Research Question	NFF and scrap rate are related to company experience.	B737 is best fit
2	Fitness for Research Objective	Research Objective	One of the objectives is to recommend framework. It needs to see all processes including NFF and disposal rates	B737 is best fit
3	Maintenance Capability	Scope of repair.	Since the other fleets are new, the maintenance capability of the case company is limited. For 737 there is full capability.	B737 is best fit
4	Company Experience with the Product	Number of years the product was operated by the company.	Both Scrap rate and NFF are affected by company experience.	B737 is best fit
5	Data Availability	Number of years in operation	The larger the number of years in operation, the better data availability	B737 is best fit
6	Data Reliability	Product Maturity	The more the company has experience, the more the data are reliable.	B737 is best fit
7	Future World Business Impact	Future Demand Forecast	Industry surveys indicate that B737 has largest demand forecast growth([CITATION Tom \l 1033]	B737 is best fit

B) Justification for Selecting Cluster Sampling

Some researchers suggest that a multistage purposive sampling strategy can be used for some specific nature researches[CITATION Gla781 \l 1033] . This writer presents three different multistage sampling. He mentioned that Several qualitative researchers recommend sampling for variation before sampling for commonalities. Such type of sampling is also known as a “funnel approach”. Other researchers also indicated that variation sampling is used to ensure representativeness [CITATION Bru08 \l 1033]. Therefore, it is possible to consider cluster sampling as one stage of purposive sampling. Schematic diagram of purposive sampling funnel approach is shown on figure 13.

To ensure representativeness, the spare parts are clustered into two (2) main groups, mechanical and avionics parts. Then they are further classified based on their similarity in technology and working principles into eight (8) sub-groups. These eight sub groups are

i. Wheel Components and Brake Components (Cluster group C-I),
ii. Pneumatic components (Cluster group C-II)
iii. Hydraulic Components (Cluster group C-III)
iv. Instrumental components (Cluster group C-IV)
v. Radio and Navigation Components (Cluster group C-V)
vi. Battery Components (Cluster group C-VI)
vii. Electrical/Electronic components (Cluster group C-VII)
viii. other mechanical components (Cluster group C-VIII)

Because of similar technology concept, components classified in each group have similar behavior regarding their reliability, maintenance cycle time, scrap rate etc. Similar technology and working principle, implies that the spare parts follow similar failure characteristics. [CITATION WJK02 \l 1033], also identified that other researchers have used this method of grouping (clustering) concept based on similar technology.

C) **Justification for Sequential Sampling**

In Sequential sampling, the sample size is not fixed in advance but is determined according to mathematical decisions based on information yielded as survey progresses[CITATION CRC04 \l 1033]. Now, based on option-2, selected under section 3.1, our population size is 201. Then the next logical step is to determine the sample size. Here in this research, selective inventory management (SIM) tools are used to determine the sample size. ABC-VED matrix will be used to determine the sample size.

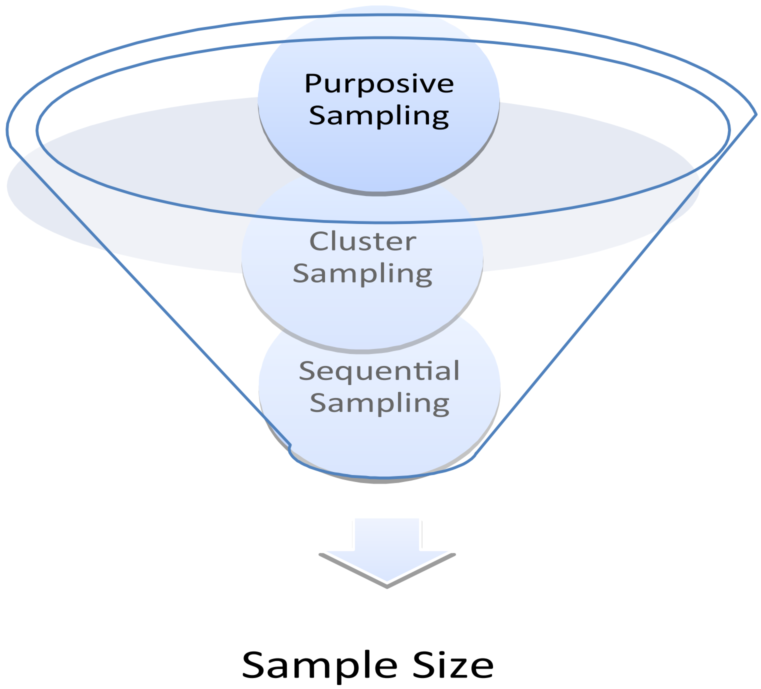

Figure 13: Multistage purposive sampling-Funnel Approach (Source: Adopted from Glaser, 1978)

Data Collection: The Secondary data collected from the company published and unpublished documents. Published documents are documents like company magazines. Moreover, various records that are relevant to the study are collected from websites. Secondary data such as Repair turnaround time in days, number of removals per year, turnaround time for no found fault (false failure), total number of no found faults per year, number of scraps per year, Price per unit, Criticality Code, quantity per aircraft (QPA) and other relevant data.

This paper has not used primary data sources such as interviews or questionnaires. The researcher used secondary data instead of collecting Primary data because of number of reasons.

First, primary data sources have a lot of limitations. For example, the primary data sources are limited to specific time frame. It is impossible to capture important data inputs like repair turnaround time in days, number of removals per year, turnaround time for no found fault (false failure), total number of no found faults per year, number of scraps per year from two years back by using only primary data sources.

Second, the primary data collected by using interviews or questionnaires cannot meet the intended research objectives. Since the main objective of this research is to formulate inventory optimization model, it is impossible to use data that are collected by primary data collection techniques such as interviews or questionnaires as an input. That means the nature of data inputs cannot be captured by primary data collection methods.

3.2. Methods and Tools of Data Analysis

Based on the comparison of the inventory optimization techniques under section 2.4, optional inventory policy or (S-1, S) and four inventory optimization techniques is utilized. First, selective inventory management (SIM) tools ABC-VED-FSN is used to determine the sample size. Second, poison distribution is used to get sub-optimal solution. Third, based on the solution obtained from second step, marginal analysis will be used to further optimize the solution. Finally, integer programming technique shall be used to get final optimal solution. To analyze Poisson distribution, Microsoft excels built in cumulative distribution function will be utilized. For marginal distribution, Microsoft excel descriptive statistics will be used. Finally, Mixed Integer Linear Programming (MILP) solver is used to solve the integer linear programming. Because it does not need complex syntax or programming skill. The syntax writing is compatible with other commonly used Microsoft office to easily generate and export the reports.

3.3. Scenarios to be tested

This research paper follows concepts of empirical research or experimental type research. Empirical research is data based research, coming up with conclusions that are capable of being verified by observation or experiment[CITATION CRC04 \l 1033]. The scenarios to be tested (experimented) are shown on the table 4. This table shows the matrix between the three models and four cases (scenarios) to be tested. The baseline is used as critical reference for other scenarios. Comparative assessment of other scenarios relative to the baseline indicates the impact of the variables such as no fault found and scrap rate.

Scenario-I: is used to study the normal baseline based on the collected empirical data. In this case, both no found fault (NFF) and disposal rate are considered negligible. This baseline scenario clearly shows the point of departure against which other scenarios are compared. That means it will be used as critical reference point for assessing the impact of no fault found and disposal rate. Comparative study between Poison Distribution, Marginal Diminishing Returns and Mixed Integer Linear Programming models will be done under this scenario as shown on table-4. These three models are designated by P1, M1 and LP-1 for this scenario.

<u>Scenario-II:</u> is the case when no found fault (NFF) is considered negligible. It is used to study the impact of disposal rate in comparison to Scenario-I. The three models are designated by P2, M2 and LP-2 for this scenario as shown on table-4.

<u>Scenario-III</u>: is the case when the disposal rate (scrap rate) is considered negligible. This is used to study the impact of NFF in comparison to Scenario-I. The three models are designated by P3, M3 and LP-3 for this scenario as shown on table-4.

<u>Scenario-IV:</u> This case is used to study the impact of turnaround time (TAT) on aircraft repairable parts inventory management. In this scenario, the average TAT for each cluster is used. P4, M4 and LP-4 are used to denote the models for this scenario.

Table 4: Scenarios to be tested

Model	Scenario-I: Baseline (SR=0, NFF=0)	Scenario-II: (SR≠0, NFF=0)	Scenario-III: (NFF≠0, SR=0)	Scenario-IV: (NFF≠0, SR≠0)
Poison Distribution	P1	P2	P3	P4
Marginal Diminishing Returns	M1	M2	M3	M4
Mixed Integer Linear Programming	LP-1	LP-2	LP-3	LP-4

Justification for Selecting the Scenarios

The scenarios were selected based on the research questions and the objectives of the research. Table 5 shows list of scenarios to be tested with their corresponding research questions.

Table 5: Justification For Selection of the Scenarios to be Tested.

No.	Scenario	Why the Scenario is Selected (Research Objective)
1	Scenario-I	• To perform comparative analysis between different repairable inventories optimization models.
2	Scenario-II	• To research the cost impact of scrap rate on repairable inventory

		provisioning. • To perform comparative analysis between different repairable inventories optimization models under consideration of Scrap rate.
3	Scenario-III	• To research the cost impact of no fault found (NFF) on repairable inventory provisioning. • To perform comparative analysis between different repairable inventories optimization models under consideration of Scrap rate.
4	Scenario-IV	• To research combined cost impact of no fault found (NFF) and scrap rate on repairable inventory provisioning. • To perform comparative analysis between different repairable inventories optimization models under consideration of both Scrap rate (SR) and no fault found (NFF).

Chapter Four

OVERVIEW OF THE CASE COMPANY

4.1. Company Profile

Ethiopian Airlines Enterprise started its operation in 1946 G.C as Ethiopian Air Lines Inc. as a joint venture with Trans World Airlines-TWA (American airline). It initially started its operation with five US Government manufactured C-47 aircrafts. The first scheduled flight took place to Cairo via Asmara. Ethiopian currently operates 96 of the young and most modern fleet, with less than five years of age, and has 62 fleet on order. These fleets are operated in more than 100 international destinations in five continents. More than 58 destinations are operated in Africa. It has currently more than 20 domestic destinations.

Table 6: Ethiopian Fleet Summary as of March 2018 [CITATION Eth18 \l 1033]

Type	Model	Fleet Number	Fleet (%)
Passenger	Airbus - A350-900	7	7.3
	Boeing 787-9	2	21.9
	Boeing 787-8	19	
	Boeing 777-300ER	4	10.4
	Boeing 777-200LR	6	
	Boeing 767-300ER	6	6.3
	Boeing 737-800NG	16	25
	Boeing 737-700NG	8	
	Bombardier Q400	20	20.8
Freighter	Boeing 777F Boeing 757-200F	8	8.3
	Total	96	100

4.2. Current Status of Ethiopian MRO

Ethiopian Airlines Maintenance repair and Overhaul was established in 1957in Addis Ababa, with the objective of reducing the need for maintenance from abroad[CITATION His19 \l 1033]. Then after the facility expanded into center for maintenance, overhaul and modification work on aircraft, engines and component systems, not only for the airlines alone, but also for other customers.

The major services provided by Ethiopian maintenance, repair and overhaul (MRO) are Line Maintenance, Base maintenance for Airframe Heavy Maintenance, Engine overhaul, components Overhaul and Modifications. It currently employs over 2,800 employees.

4.3. Facilities and Approvals of Ethiopian MRO

Ethiopian MRO has six main hangars used for airframe maintenance. Four main large hangars are used for maintenance of transport category aircrafts such as B737, B757, B777, B767/B787s A350, Turboprop or Q400s model aircrafts while one hangar is used for pilot training aircrafts maintenance hangar. The other hangar is dedicated for paint hangar. In addition to the aircraft hangars, the MRO has engines and aircraft component maintenance, repair, overhaul and modification workshops. It is the largest MRO service in Africa and serves Africa and the

Middle East. The facility is fully equipped with Hangars, Engine and Component Maintenance workshops with all equipment needed to repair/ overhaul aircraft, engines and components. Ethiopian MRO provides Line Maintenance services at stations where Ethiopian flies and extends the services to other operators at some of the stations.

The company has local Ethiopian Civil Aviation authority (ECAA) maintenance organization approvals as well as many internal civil aviation authorities' approvals. It has approvals from American Federal Aviation Administration (FAA) and European Aviation safety Agency (EASA). It has also many approvals from around the globe from other African Country Civil Aviation, Middle East, Asia, South American countries civil aviation. Ethiopian MRO offers world-class services to its customers and helps make Ethiopian one of the most dependable and safest airlines in the world.

4.4. Existing Inventory System

The case company uses two maintenance sources for its repairable maintenance, overhaul and repair. The first one is the local (in house) repair shops and the other one is foreign repair sources. All new or maintained parts pass through in-coming receiving inspection at Addis Ababa base station and then dispatched to other operational areas based on the demand requirements. Therefore, we can say that the company follows single echelon supply system.

The company uses its own internal IT system to manage all inventory management issues including inventory forecasting based on original equipment manufacturers recommendations. In addition to its own spares parts, the company also uses other spare parts pooling arrangements such as component exchange and loans. However, when compared to the number of owned components, the number of components obtained by pooling is very small.

4.5. Flow of Repairable Spare Parts within the Company System

Figure 11 shows the flow of repairable spare parts with in the case company system. The flow starts from failure event of parts as shown on Figure 11. When the part is reported as failed, this spare part is removed and sent to the repair shop for test/inspection. If the part passes the test, then it is returned to service. In this case, the shop staffs do not confirm the failure. Therefore, the removal is counted as a NFF

These repairable spare parts are unserviceable (US) parts and the parts must be inspected or repaired and released serviceable before installation on the aircraft. Then the shop specialized staff will perform in-coming test or inspection before starting any repair or maintenance. During in-coming inspection, the part that was initially removed from the aircraft as unserviceable (US) may or may not be confirmed as faulty (i.e. needs maintenance). Sometimes the spare parts pass initial test and then released to service without any repair or maintenance function performed. Such phenomena are called no fault found (NFF) events.

If the component is confirmed as unserviceable, it need actual maintenance or repair actions and it needs longer turnaround time (TAT) and additional resources such as piece parts, labor, consumables, utilities etc.

As shown on Figure 11, the next decision is regarding economic aspect of the repair or test. Evaluations are performed to decide if the repair is beyond economic repair or not. If the repair is beyond economic repair, the spare part is scrapped or disposed. Component repair or test and certifications are performed whenever the repair is economically feasible.

Whenever the part fails, another repairable spare part shall be issued from stores and installed on the aircrafts to avoid down time of the aircraft. Every time part is removed, another part replaces the removed part. The amount of work in process inventory or work in process stock size that must be retained inside the stock is affected by no fault found and scrap rates. This research work considers no fault found (NFF) and scrap as an input parameter for inventory optimization model to determine work in process inventory or work in process stock size.

Chapter Five

DATA ANALYSIS AND DISCUSSION

5.1. Introduction

The case company currently operates nine model aircrafts, B737, B757, B767, B777, B787, A350, bombardier, diamond and piper aircrafts constituting a total of 100 commercial aircrafts. Diamond and piper models are training airplanes and are not considered as the member of the population of this research. Hence, the sample product shall be selected from the rest seven models. Purposive sampling technique based on main criterions (factors) shown in table 3 is used to select the sample product. Some of the criteria are related to each other. Accordingly, B737 aircraft which is the largest fleet having 24 number of airplanes is selected as the sample product.

Based on the collected data four repairable inventory control and optimization tools are interfaced to determine the optimal number each repairable spare required to serve the expected service level. First, selected inventory management tools ABC-VED-FSN is used to determine the population of the spares to be included into the other optimization tools. Next, poison distribution (model-1) is used to determine the stock size for each spare part. Third, marginal diminishing analysis (model-2) will be used by taking the result of model-1. Lastly mixed integer linear programming-MILP (model-3) is used to obtain the optimum inventory size of each spare part.

5.2. Data Preparation

Before proceeding to data analysis, it would be helpful to first define and describe all input data. The input data are explained based on sample data shown on table 7. The whole list of data is presented in Appendix-I.

Sequence number (S/N) is used to show the index of each repairable spare. Description is to show the technical naming of the spares. It is the part number is distinct label given for each part and unique for each part number. In the analysis, the part number or the sequence number can be used because each of them are unique for each part description. Repair TAT is the average repair turnaround time for each spare part. REMS/YR is the total number of removals per year for each repairable spare. NFF-TAT is the turnaround time of no fault found event (false failure) for each part number. Total NFF/yr. is the total number of NFF events per year for each corresponding part number. Scrap/yr. is the total number of scraps (condemnations) recorded per year for each spare part. Price is the price value of each repairable spares as new in dollars. This price does not reflect the book value, meaning the salvage value of the spares.

Criticality also called essentiality, are used to show the service level targets. According major manufacturers specially Boeing, criticality codes V, E and D represent service level of 95%, 93% and 90 % respectively. This percentage is assigned by experts. For this current data, the percentage is assigned by the aircraft manufacturer, Boeing. The manufacturers usually use 1,2 and 3 to represent V, E and D codes respectively. In this paper, VED codes are used for easy communication with other literatures because most literatures use VED codes. Quantity per aircraft (QPA) the number of each repairable spare installed on a single product.

To justify representativeness of the collected that all repairable spare parts from each cluster are included into the sample data. As shown on Appendix-I (and table 7), all repairable spare parts from all cluster groups are included into the sample data. The data also consists of all repairable spare parts from all criticality levels.

Table 7: Data Preparation (Sample data from Appendix-I)

S/N	PN	Description	(R)REMS/	Price(P)	VED Code	Repair TAT	SparesTotal	NFF TAT	Total NFF	Scrap/Yr.	QPA	Cluster Group
1	5653215001	WHEELAS SY	113	14,011.00	V	3.78	26	1.25	13	2	4	C-I
8	5653230462	WHEEL NLG	9	1,641.00	V	0.63	8	0.5	1	0	2	C-I
9	5742410005	BATTERY	75	4,905.51	V	1.2	48	0.39	7	3	3	C-VI
33	5742511462	PANEL ASSY	3	5,393.00	D	0.5	1	0.16	0	0	3	C-VII
76	57547H0015	SWITCH-NGS	1	4,005.52	E	5	1	1.67	0	0	1	C-IV
85	5732320058	ACARS CMU	2	34,823.00	E	0.47	2	0.04	1	0	1	C-V
108	5662511417	LIFE RAFT	4	34,994.00	E	8.6	4	5.25	1	0	3	C-VIII
111	5633210006	BRAKE	29	25,705.00	E	6.4	23	3.2	2	1	4	C-III
132	5642110018	SEPARATO R ASSY-AIR COND	1	13,380.00	V	0.5	1	0.42	0	0	2	C-II

5.3. ABC-Analysis and VED Analysis

Sample data of ABC, VED and ABC-VED analysis is as shown in table 8. The whole list is shown on appendix-II. To do ABC analysis, the number of removals per year(R), the service level (SL) and the price per unit (P) shall be used.

$SL = \frac{E}{R}$, Where E is expected demand to be satisfied from stock. Sample Data to show ABC, VED and ABC-VED analysis are as shown in table 8.

Then the total cost (C) for each spare is calculated as follows and shown in table 8.

$C = E * P = SL * R * P$. After that the percentage shares of each stock and cumulative is calculated to arrange. As per the literatures, the lists of stock are arranged in decreasing value of C. The overall result of ABC analysis is shown on table 9.

In similar manner, VED analysis is also performed for all list of repairable spares and shown in table 10.

Table 8: Sample Data to show ABC, VED and ABC-VED analysis

S/N	PN	Description	REMS/YR((R)	Price/unit (P)	VED Code	evel(SL)Service	E=(R*SL)	C=(R*SL*P)	%	Cumulative %	ABC- Code	ABC-VED
16	57425H0004	B/E STEAM OVEN	15	141,261.71	V	0.90	13.50	1907033.1	15.3	15.33	A	AV
2	5653210008	WHEEL AND TIRE ASSY	110	14,011.00	V	0.95	104.50	1464149.5	11.8	39.19	A	AV
5	5653216062	WHEEL AND TIRE ASSY-Main	542	1,641.00	V	0.95	514.90	844950.9	6.79	45.99	A	AV
92	5733420040	TRANSCEIVER	4	109,952.00	E	0.93	3.72	409021.44	3.29	69.49	A	AE
9	5742410005	BATTERY	75	4,905.51	V	0.95	71.25	349517.59	2.81	72.3	A	AV
35	5742310112	BATTERY PACK ASSY	3	80,336.49	V	0.95	2.85	228959	1.84	74.14	A	AV
84	5732310023	MONITOR-RETRACTOR LCD 10.4 IN.	16	15,960.00	D	0.90	14.40	229824	1.85	75.98	A	AD
119	5642610005	BOTTLE ASSY	21	7,044.35	E	0.93	19.53	137576.16	1.11	83.55	B	BE
108	5662511417	LIFE RAFT	4	34,994.00	E	0.93	3.72	130177.68	1.05	84.6	B	BE
74	5753520008	CYLINDER ASSY	44	2,455.21	V	0.95	41.80	102627.78	0.83	85.42	B	BV
121	5642610007	BOTTLE ASSY-FIRE EXT	10	9,673.78	E	0.93	9.30	89966.154	0.72	86.15	B	BE
7	5653230461	MLG-WHEEL AND TIRE ASSY	41	2,118.00	V	0.95	38.95	82496.1	0.66	86.81	B	BV
91	5732310024	MONITOR-RETRACTOR LCD 10.4 IN.	15	15,960.00	D	0.90	13.50	215460	1.73	77.72	B	BD
25	5743310067	PANEL ASSY - MAP/CHART LT	7	4,325.00	D	0.90		27247.5	0.2	95.12	C	CD

		CONT P23-1					6.30		2			
103	5662511377	LIFE RAFT-46 PERSON	35	813.18	E	0.93	32.55	26469.009	0.21	95.33	C	CE
116	5632910001	PUMP ASSY	1	27,700.00	V	0.95	0.95	26315	0.21	95.54	C	CV
37	5745220114	MODULE ASSY - CHIME CONTROLLER	3	9,164.95	D	0.90	2.70	24745.365	0.2	95.74	C	CD

Table 9: ABC-Analysis Result

Code	Number of Items	% Items	Values($)	Percentage value (%)
A	12	9.1	9667066.604	75.98
B	32	24.2	2352596.017	18.92
C	88	66.7	12438822.51	5.1
Total	132	100	12438822.51	100

In similar manner, VED analysis is also performed for all list of repairable spares and shown in table 10.

Table 10: VED analysis Result

Code	**Number of Items**	**% Items**	**Values($)**	**Percentage value (%)**
V	41	31.1	8547023.286	68.7
E	50	37.9	2737495.78	22
D	41	31	1154303.442	9.3
Total	**132**	**100**	**12438822.51**	**100**

5.4. ABC-VED Matrix Analysis

ABC-VED matrix analysis is obtained by tabulating the results of ABC-analysis and VED-analysis. The combined result is then classified into Category-I, category-II and category-III as per the classification shown in table figure 11. The value for each matrix box value of figure is obtained by sorting each value from table 8. The ABC-VED matrix analysis result is shown in table 10.

As we can from table 11, Category-I items constitute 34.1 %(45) items and 84.35 % (10492599.15) values. Category-II items constitute 43.2 %(57) items and 14.4 %(1791189.82) value wise. Category-III items contain 22.7 %(30) items and 1.246 %(155033.53) values.

From this analysis result we can understand that Category-I items have largest value contribution and needs closer (tight) inventory control.

Therefore, this paper has considered the number of Category-I items as the sample size and such type of sample size determination is known as sequential sampling as described in chapter-3.

Based on this, the data of items included in Category-I will be used as an input for poison distribution, marginal analysis and mixed integer linear programming. The list of items included in Category-I are presented under Appendix-I.

Table 11: ABC-VED Matrix Analysis Result.

Codes	V	E	D		
A	AV	AE	AD		Category-I
B	BV	BE	BD		Category-II
C	CV	CE	CD		Category-III

Code	Number of Items	% Items	Values($)	Percentage value (%)	Category	Number of Items	% Items	Values($)	Percentage value (%)
AV	8	6.06	7506030.7	60.3	I	45	34.1	10492599.15	84.35
BV	9	6.82	783931.9	6.3					
CV	24	18.2	257060.65	2.07					
AE	3	2.27	1715751.9	13.8					
AD	1	0.76	229824	1.85					
BE	13	9.85	799218.19	6.43	II	57	43.2	1791189.82	14.4
BD	10	7.58	769445.93	6.19					
CE	34	25.8	222525.7	1.79					
CD	30	22.7	155033.53	1.25	III	30	22.7	155033.53	1.246

5.5. Baseline Comparative Study

In this section, comparative study between Poison Distribution, Marginal Diminishing Returns and Mixed Integer Linear Programming models will be done. First, each of these models will be studied based on empirical collected data. Next, the result of each model under Scenario-I (i.e. baseline scenario) will be compared to each other.

5.5.1. Baseline Study Based on Poison Distribution Model (Scenario-I, P-I)

In this section, the expected number of stock size that should be held is calculated based on the concept of poison distribution. Sample result of the poison distribution is shown in table 12. The whole result is presented on appendix-III. In the table, the holding quantity (HQ) is obtained based on the service level. This method calculates the holding quantity of each repairable spare part based on the item inventory system concept. That means the calculation is made for each item without considering the other spare part.

Expected **mean (E) requirement** for each item is calculated based on equation (1).

$$E = \frac{(R - NFF) * T}{365} + \frac{NFF * T2}{365} + S --- (1)$$

Where T is the turnaround time for repair (maintenance) and T2 is the turnaround time for no fault found event (false failure events). R is the total number of removals per year for each item. NFF is the total number of no found fault per year. And S is the scrap rate per year. For Scenario-I, both NFF and S are considered negligible.

Therefore, the expected mean (E) is calculated as follows.

$$E = \frac{R * T}{365} = \frac{(113) * 3.78}{365} = 1.17$$

Since the failure is stochastic, we can apply poison distribution because number of failures is relatively small in number.

$$E(x) = \sum_{k=0}^{x} \frac{e^{-\rho} \rho^{k}}{k!}$$

Where **E(x) is expected probability**, $e = 2.718$,
K=0, 1, 2, 3…x is discrete integer value ranging from zero up to x and ρ is mean expected value. In this paper, excel built in function shown in equation (2) is used to calculated the holding quantity.

$$HQ = Poison(E, K, TRUE) --- (2)$$

For example, for item number one, holding quantity (HQ) is calculated as follows

HQ=poison (1, 1, true) =0.736 (73.6%), poison (1, 2, true) =0.92(92%), poison (1, 3, true) = 0.981(98.1%) etc.

Interpretation: If the mean requirement is 1 and if 1 items are stocked as a holding quantity, the probability to meet the demand is 73.6%. If we keep 2 items, the probability to meet the demand is 92%. But since the item criticality code is vital (95% service level), it is required to again increase the holding quantity. If the mean requirement is 1 and if 3 items are stocked the probability to meet the demand is 98.1%, which is greater than 95%. Therefore, we should keep 3 units to meet the stochastic demand of this repairable spare. The corresponding service level is highlighted on Table 12 for other items. The ratio T/365 is called unavailability factor (UF).

Table 12 : Poison Distribution Result

S/N	REMS/YR(R)	Price(P) USD	Service Level(SL)	Repair TAT(T) in days	Holding Quantity (HQ)	E=(R)*T/365	Expected Holding Quantity (HQ) and Service Level(probability)									Total cost=P*HQ ($)
							1	**2**	**3**	**4**	**5**	**9**	**10**	**11**	**12**	
1	113	14011	0.95	3.78	3	1	0.736	0.920	0.981	0.996	0.999	1.000	1.000	1.000	1.000	42033
2	110	14011	0.95	6.03	5	2	0.406	0.677	0.857	0.947	0.983	1.000	1.000	1.000	1.000	70055
3	133	4086	0.95	2	3	1	0.736	0.920	0.981	0.996	0.999	1.000	1.000	1.000	1.000	12258
5	542	1641	0.95	4.79	12	7	0.007	0.030	0.082	0.173	0.301	0.830	0.901	0.947	0.973	19692
8	9	1641	0.95	0.625	1	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1641
9	75	4905.51	0.95	1.2	3	1	0.736	0.920	0.981	0.996	0.999	1.000	1.000	1.000	1.000	14716.53
13	17	3558.85	0.95	5.2	2	1	0.736	0.920	0.981	0.996	0.999	1.000	1.000	1.000	1.000	7117.7
58	1	22914	0.95	2.6	1	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	22914
73	86	2455.21	0.95	7.7	5	2	0.406	0.677	0.857	0.947	0.983	1.000	1.000	1.000	1.000	12276.05
125	5	1123	0.95	9.32	3	1	0.736	0.920	0.981	0.996	0.999	1.000	1.000	1.000	1.000	3369
Total Cost (USD)																**1216879**

The total cost based on this poison distribution is **1,216,879** US dollar.

The combined service level can be calculated as follows: -

$$Sl=\frac{(R1*SL1+R2*SL2+R3*SL3+\ldots Ri*SLi)}{\sum_{1}^{45} Ri}$$

$$SL=\frac{(113*0.95+110*0.95+\ldots 1*0.95)}{\sum_{1}^{45} Ri}=\frac{1669.88}{1761}=94.83\%$$

5.5.2. Baseline Study Based on Diminishing Marginal Returns Model (Scenario-I, M-I)

In this sub-section, required stock quantities are calculated based on diminishing marginal returns model. Unlike poison distribution, this model calculates the holding quantities based on system based approach as explained in the literature review. That means the objective of this model is to satisfy aggregate demand of the entire inventory system than to satisfy the demand of each item line by line. This model uses the output of poison distribution. Sample results of marginal distribution analysis are shown in table 13. Full table is presented on appendix-III. Let us explain the main steps for marginal distribution model by taking illustrative example from table 13.

Now let us take part number – 75. First we calculate poison distribution as per section 4.5.

Step-1: Calculate fills for each item.

$Fills(i) = ¿ Ri * SL_{ik = ¿¿}$

, where Ri is total removals per yr. and $SL_{ik}$is the service level of item (i) for the corresponding holding quantity and

$SL_{ik = ¿ POISSON(6,1,TRUE) = 0.0223 ¿}$

$Fills(1) = ¿ 279 * 0.0223_{¿} 6.32$

Step-2: Calculate delta fillsΔF

$\Delta F = F(k) - F(k-1) = F(2) - F(1) = 21.62 - 6.32 = 15.2$, where F(k) is the fill rate for corresponding holding quantity k.

Step-3: Calculate the Marginal Contribution (MC).

$MCi = \frac{\Delta F}{Ci} = \frac{15.3}{47.52} = 0.321$, where Ci is the cost of item (i) and MCi is the marginal cost of item (i).

Step-4: Arrange the items according to decreasing order of marginal contributions and calculate the cumulative service level and cumulative cost and compare it with the target service level.

$$Target\ SL = \frac{\sum_{1}^{45} Ri * SLi}{\sum_{1}^{45} Ri} = \frac{1668.93}{1761} = 0.95$$

From table 13, we can observe that the total cost using this model is 272457.8 USD when its corresponding aggregate service level is 95.5%. For this aggregate service level, items with serial number 115,39,46,6,129,130,16,132,51,133,131,58,35,92 and 116 are considered zero (0) holding quantity. But as mentioned in literature review, holding quantity is less realistic. Based on this it is assumed to hold single unit of each of these items mentioned items.

As shown on table 13, the total cost using this model becomes 974760.8 USD and its corresponding aggregate service level increases to 99.8%.

Diminishing marginal return model total holding cost decreases by 19.9 percent compared to poison distribution result. And its overall service level increases from 94.83% to 99.8. The comparison between diminished marginal returns holding quantity (HQ-DMR) and poison distribution holding quantity is shown on Figure 14.

Based on Figure 14, DMR tends to overstock less cost items when compared to poison distribution. It under stocks more cost items when compared to poison distribution. Average holding quantity for both models is less than 2 units. But maximum holding quantity for poison distribution is 11 units while maximum holding quantity for DMR models is 16 units. HQ-DMR and HQ-PD represents holding quantity based on diminishing marginal returns and holding quantity based on poison distribution respectively.

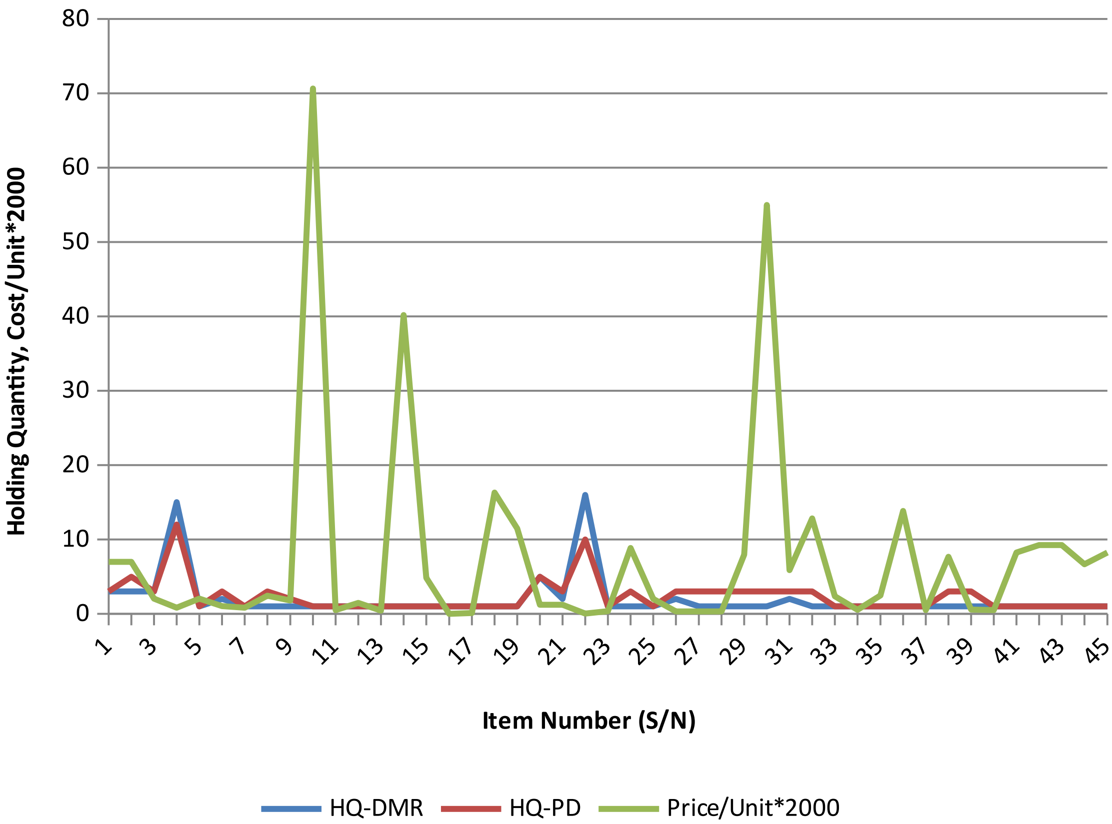

Figure 14: Comparison of poison Distribution (PD) and diminished marginal returns (DMR)

Table 13: Marginal distribution Analysis result

S/N	REMS/YR(R)	Price(P)	HQ	Fills	MC	Delta Fills (ΔF ¿	Cumulative fills(=F	Service Level(F/ $\sum Ri$)	Cumulative Cost($)
75	279	47.52	5	138.709	0.987	46.882	46.882	0.027	47.52

75	279	47.52	6	183.146	0.935	44.436	91.318	0.052	95.04
82	12	661.77	1	11.576	0.017	11.576	914.969	0.520	19632.3
5	542	1641	3	41.230	0.016	26.480	941.449	0.535	21273.3
73	86	2455.21	1	39.441	0.016	39.441	980.889	0.557	23728.51
115	3	4975.31	1	3.000	0.001	3.000	1,683.921	0.956	277433.1
58	1	22914	1	1.000	0.000	1.000	1,749.587	0.994	756772.3
35	3	80336.5	1	2.999	0.000	2.999	1,752.586	0.995	837108.8
92	4	109952	1	3.980	0.000	3.980	1,756.565	0.997	947060.8
116	1	27700	1	1.000	0.000	1.000	1,757.565	0.998	**974760.8**

5.5.3. Baseline Study Based on Mixed Integer Linear Programming Model-MILP (Scenario-I, LP-I)

In this sub-section, mixed integer programming model is used to determine the stock size of each repairable item. Similar to diminishing marginal returns, this method also considers system level availability and not item level availability. The concepts of item level availability and system level availability are explained in the literature section. The entire inventory system performance is measured by treating all items as aggregate demand. But unlike the diminishing marginal returns, this model gives global optimal solution while DMR gives sub-optimal solution. The objective of this method is to determine the optimal size of each repairable stock which can minimize the overall holding inventory cost.

The main steps of mixed integer linear programming model are as follows: -

1. Calculate the service level and holding quantity of each repairable based on poison distribution.

In the previous poison distribution method table 12(Poisson distribution Result), it was known that all repairable spares have holding quantity less than 5(five), except item number 5 and item number 75. Item number 5 has holding quantity of 12 and item number 75 has holding quantity of 10.

2. Formulate the mixed integer linear programming model with the objective of total cost minimization subjected to constraints.

Now the minimization is done without separating (segregating) the parts into their essentiality codes, because the objective is to study the overall inventory performance.

5.5.4. Formulation of Mixed Integer Linear Programming (Scenario-I, LP-I)

5.5.4.1. Mixed Integer Linear Programming Objective function

The objective function is to minimize the total system level cost required to provide expected overall service level. As represented in Equation (1), the objective function is minimizing the total combined cost of the overall inventory.

5.5.4.2. Mixed Integer Linear Programming Constraints

a) Service Level constraint

Service level constraint is represented by equation (2) is to show the combined service level of the intended inventory system should meet minimum target service level.

b) Holding Quantity Constraint

Equation (3) is used to indicate each repairable item must choose only one holding quantity.

c) Integer Constraint

Equation (4) shows the dummy variables that shall take only binary values.

$$Min\,Z = \sum_{\square}^{\square} ((C_i * HQ_i) * X_{ij}\text{¿}) - - - - - (1)\text{¿}$$

$$\sum ((R\text{¿¿}SL_{ij}) * X_{ij}) \geq Target\ SL * \sum R_i - - - - - (2)\text{¿}$$

$$\sum X_{ij} = 1 - - - - - - - - - - - (3)$$

$$X_{ij \in [0,1]} - - - - - - - - - - - (4)$$

Where C_i is unit price for item number ‘i’, HQ_i is holding quantity for item number ‘i’, R_i is the number of removals per year for item number ‘i’, SL_{ij} is the service level for item number ‘i’ corresponding to holding quantity ‘j’ and X_{ij} is the dummy variable assigned for item number ‘i’ corresponding to holding quantity ‘j’.

To make the procedure more convenient, let us represent the dummy variables X_{ij} by making the matrix between the item number and the holding quantity as sample shown on table 14.

Since the largest holding quantity is 12 (for item number 5), let us assume that our holding quantities are represented by letters as follows, which is equal to 12 in number i.e. from letter A up to letter L.

$\{A, B, C, D, E, F, G, H, I, J, K, L\}$

Except for item number 5 and 75, the rest have maximum holding quantity of 4. To accommodate item 5 and item 75, let us represent the dummy variables from letter A up to letter L as shown on table 14.

And let the item number $i \in \{1,2,3,4,5,6,7 \ldots 45\}$

Table 14: Sample Dummy Variables Matrix

Item # (i)	Dummy Variables (Holding Quantities)											
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**
1	A1	B1	C1	D1	E1	F1	G1	H1	I1	J1	K1	L1
2	A2	B2	C2	D2	E2	F2	G2	H2	I2	J2	K2	L2
3	A3	B3	C3	D3	E3	F3	G3	H3	I3	J3	K3	L3
4	A4	B4	C4	D4	E4	F4	G4	H4	I4	J4	K4	L4
5	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
42	A42	B42	C42	D42	E42	F42	G42	H42	I42	J42	K42	L42
43	A43	B43	C43	D43	E43	F43	G43	H43	I43	J43	K43	L43
44	A44	B44	C44	D44	E44	F44	G44	H44	I44	J44	K44	L44
45	A45	B45	C45	D45	E45	F45	G45	45H	I45	J45	K45	L45

Therefore, the equation is formulated as follows. Since Model size contains 540 variables and 62 constraints, only sample equation is shown here. The full equation is shown on appendix III(C).

/* Objective function */

```
min: 14011 A1 +28022 B1 +42033 C1 +56044 D1 +84066 F1 +98077 G1 +112088 H1 +126099 I1 +140110 J1
+154121 K1 +168132 L1 +14011 A2 +28022 B2 +42033 C2 +56044 D2 +84066 F2 +98077 G2 +112088 H2 +
126099 I2 +140110 J2 +154121 K2 +168132 L2 +4086 A3 +8172 B3 +12258 C3 +16344 D3 +24516 F3 +
28602 G3 +32688 H3 +36774 I3 +40860 J3 +44946 K3 +49032 L3 +1641 A4 +3282 B4 +4923 C4 +6564 D4 +
9846 F4 +11487 G4 +13128 H4 +14769 I4 +16410 J4 +18051 K4 +19692 L4 +4086 A5 +8172 B5 +12258 C5 +
…………...+4005.52 A25 +8011.04 B25 +12016.56 C25 +16022.08 D25 +24033.12 F25 +28038.64 G25
+32044.16 …..+18520 A43 +37040 B43 +55560 C43 +74080 D43 +111120 F43 +129640 G43 +148160 H43
+166680 I43 +185200 J43 +203720 K43 +222240 L43 +13380 A44 +26760 B44 +40140 C44 +53520 D44
+80280 F44 +93660 G44 +107040 H44 +120420 I44 +133800 J44 +147180 K44 +160560 L44 +16511 A45
+33022 B45 +49533 C45 +66044 D45 +99066 F45 +115577 G45 +13208845 H +148599 I45 +165110 J45
+181621 K45 +198132 L45;

/* Constraints */
```

```
R1: +76.094959972 A1 +100.10382198 B1 +109.46925149 C1 +112.20921694 D1 +112.97558131 F1
+112.99649149 G1 +112.99955025 H1 +112.99994797 I1 +112.99999452 J1 +113 K1 +113 L1 +50.349312793
A2 +79.859423993 B2 +97.735274914 C2 +105.85654335 D2 +109.70223373 F2 +109.93432348 G2
+109.98704442 H2 +109.99768972 I2 +109.99962424 J2 +109.9 K2 +110 L2 +110.94011086 A3 +A40
+3.9997610397 B40 +3.9999956948 C40 +3.9999999379 D40 +4 F40 +4 G40 +4 H40 +4 I40 +4 J40 +4 K40
+4 L40 +A41 +1.9998638103 B41 +1.9999974353 C41 +1.9999999613 D41 +2 F41 +2 G41 +2 H41 +2 I41 +2
J41 +2 K41 +2 L41 +A42 +1.9998487741 B42 +1.9999970493 C42 +1.9999999539 D42 +2 F42 +2 G42 +2 H42
+2 I42 +2 J42 +2 K42 +2 L42 +A43 +0.9999920951 B43 +0.9999999279 C43 +0.9999999995 D43 +F43 +G43
+H43 +I43 +J43 +K43 +L43 +A44 +0.9999999996 B44 +C44 +D44 +F44 +G44 +H44 +I44 +J44 +K44 +L44 +A45
+0.9999999919 B45 +C45 +D45 +F45 +G45 +145 H +I45 +J45 +K45 +L45 >=1672.95;
A1+B1+C1+D1+E1+F1+G1+H1+I1+J1+K1+L1=1;
A2+B2+C2+D2+E2+F2+G2+H2+I2+J2+K2+L2=1;
A3+B3+C3+D3+E3+F3+G3+H3+I3+J3+K3+L3=1;
+…………
A44+B44+C44+D44+E44+F44+G44+H44+I44+J44+K44+L44=1;
A45+B45+C45+D45+E45+F45+G45+45H+I45+J45+K45+L45=1;

/* Integer definitions */
int
A1,B1,C1,D1,F1,G1,H1,I1,J1,K1,L1,A2,B2,C2,D2,F2,G2,H2,I2,J2,K2,L2,A3,B3,C3,D3,F3,G3,H3,I3,J3,K3,L
3,A4,B4,C4,D4,F4,G4,H4,I4,J4,K4,L4,A5,B5,C5,D5,F5,G5,H5,I5,J5,K5,L5,A6,B6,C6,D6,F6,G6,H6,I6,J6,K6
J40,K40,L40,A41,B41,C41,D41,F41,G41,H41,I41,J41,K41,L41,A42,B42,C42,D42,F42,G42,H42,I42,J42,K42,L
42,A43,B43,C43,D43,F43,G43,H43,I43,J43,K43,L43,A44,B44,C44,D44,F44,G44,H44,I44,J44,K44,L44,A45,B4
5,C45,D45,F45,G45,I45,J45,K45,L45,E1,E2,E3,E4,E5,E6,E7,E8,E9,E10,E11,E12,E13,E14,E15,E16,E17,E18,
E19,E20,E21,E22,E23,E24,E25,E26,E27,E28,E29,E30,E31,E32,E33,E34,E35,E36,E37,E38,E39,E40,E41,E42,E
43,E44,E45;
```

Next, the above equation is directly entered (logged) into LPSolve software as shown on Figure 15 and application is run. The result of the LPsolve is shown on Figure 16. After that the solution is exported to rich text file, converted to excel and then the items having binary value of one (1) are sorted out. The holding quantity, service level and overall performance cost calculated.

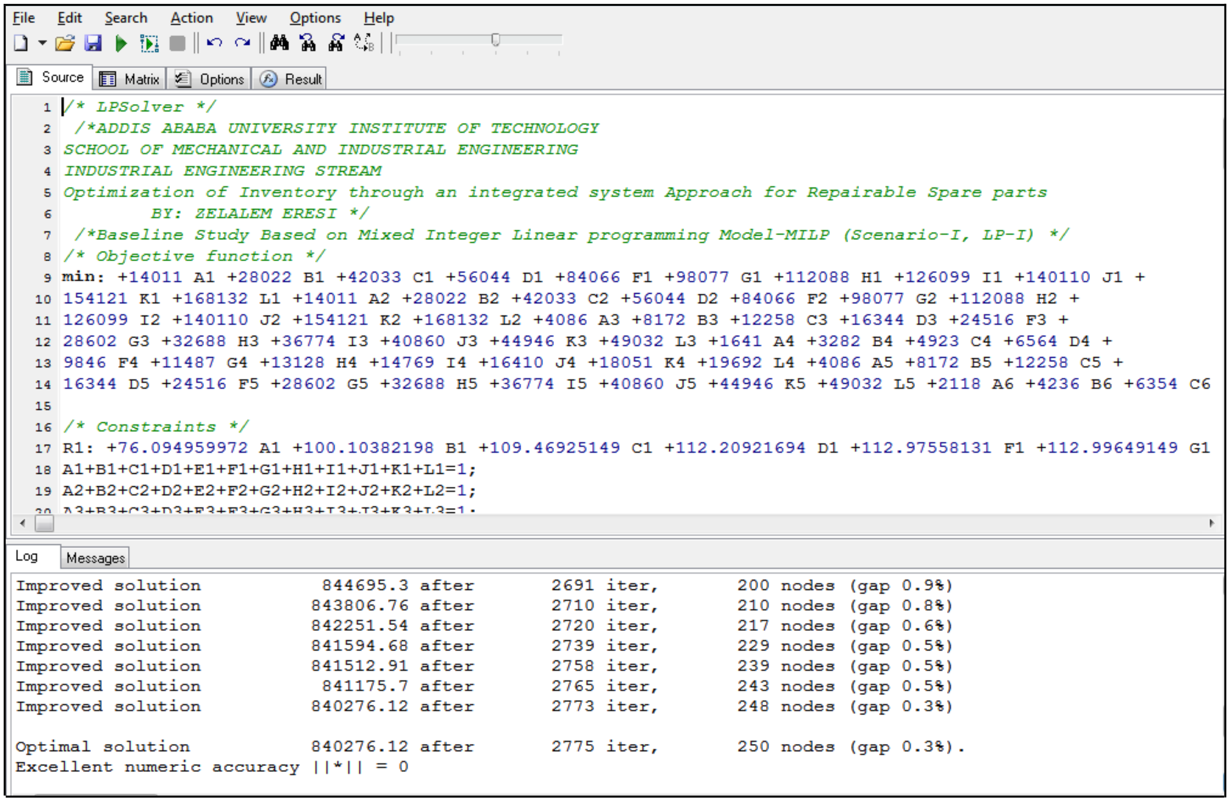

Figure 15: MILP Formulation Loaded into LPSolve Software

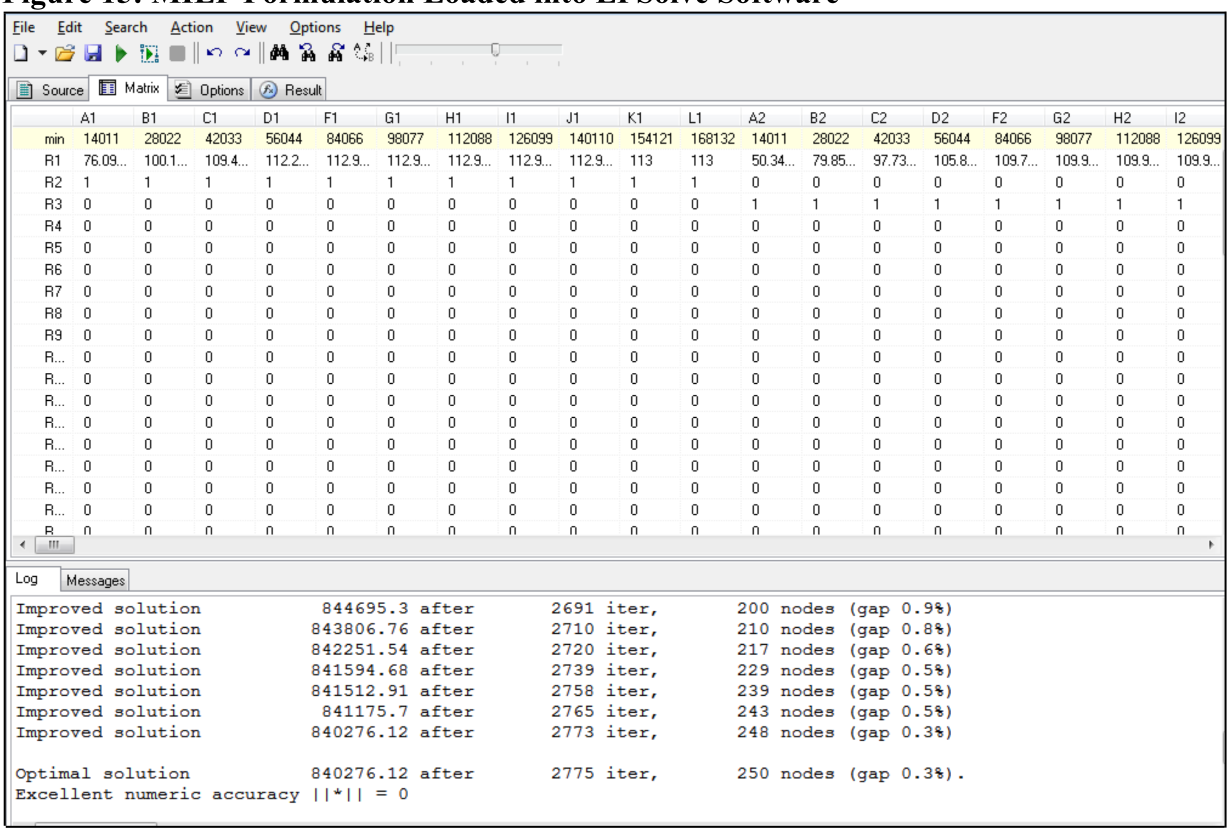

Figure 16: LPSolve Software Result.

From Figure 16, the total cost of the optimal solution is 840,276.12 USD. Compared to the poison distribution model, mixed integer linear programming model has shown 30.95% decrement with regards to total cost. And it has shown 13.8% total cost decrement as compared to marginal diminishing return model.

5.5.5. Comparison of the Models with Minimum NFF (Scenario-II)

In this sub section, the three inventory optimization models poison distribution, marginal diminishing returns and mixed integer linear programming will be compared under consideration of minimum no fault found(NFF). As shown on table 4, the representations are shown as P2, M2 and Lp2. Since one of the objectives of this paper is to investigate the impact of no found fault (NFF) on repairable inventory, NFF is considered negligible (i.e. NFF=0) in equation (1). Hence, equation (1.1) is used for this scenario to calculate expected mean value i.e. E.

$$E^{\square} = \frac{(R-NFF)*T}{365} + \frac{NFF*T2}{365} + S---(1)$$

Considering NFF=0, equation (1) will be written as equation 1.1 below.

$$E^{\square} = \frac{(R)*T}{365} + S---(1.1)$$

Table 4: Scenarios to be Tested

Model	Scenario-I: Baseline (SR=0, NFF=0)	Scenario-II: (SR≠0, NFF=0)	Scenario-III: (NFF≠0, SR=0)	Scenario-IV: (NFF≠0, SR≠0)
Poison Distribution	P1	P2	P3	P4
Marginal Diminishing	M1	M2	M3	M4

Returns				
Mixed Integer Linear Programming	LP-1	LP-2	LP-3	LP-4

a) Poison distribution with Minimum NFF (Scenario-II, P2)

In this section, the expected number of stock size that should be held is calculated based on the concept of poison distribution under consideration of minimum no fault found (NFF) based on equation 1.1. The sample result of the poison distribution is shown in table 15. In the table, the holding quantity (HQ) is obtained based on the service level. The whole table is shown on appendix-IV. The highlighted shows the holding quantity and the corresponding service level.

Table 15: Sample Poison Distribution Result with Minimum NFF (P2).

S/N	REMS/YR(R)	Service Level(SL)	Price-P ($)	Repair TAT	NFF TAT	Total NFF	Scrap/Yr. (SR)	E=(R)*T/365+SR	Expected Holding Quantity (HQ) and Service Level(probability)											(HQ) Holding Quantity	Total cost=HQ*P
									1	2	3	4	5	6	7	8	21	22	23		
1	113	0.95	14,011.00	3.78	1.25	13	2	3	0.2	0.4	0.7	0.8	0.9	1	1	1	1	1		6.00	84066
5	542	0.95	1,641.00	4.79	1.52	86	9	16	0	0	0	0	0	0	0	0	0.9	0.9	96	23.00	37743
6	1	0.95	4,086.00	4	1.2	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1.00	4086
7	41	0.95	2,118.00	3.1	2.1	3	1	2	0.4	0.7	0.9	1	1	1	1	1	1	1		3.00	6354
8	9	0.95	1,641.00	0.63	0.5	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1.00	1641
9	75	0.95	4,905.51	1.2	0.39	7	3	4	0.1	0.2	0.4	0.6	0.8	0.9	95					7.00	34338.57
13	17	0.95	3,558.85	5.2	1.5	2	1	2	0.4	0.7	0.9	1	1	1	1	1	1	1	1	4.00	14235.4
39	3	0.95	9,668.00	1.50.	0.45	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1.00	9668
46	2	0.95	30.96	3.3	1	0	0	1	0.7	0.9	1	1	1	1	1	1	1	1	1	3.00	92.88
58	1	0.95	22,914.00	2.6	0.3	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1.00	22914

73	86	0.95	2,455.21	7.7	5.62	10	2	4	0.1	0.2	0.4	0.6	0.8	0.9	1	1	1	1		7.00	17186.47
74	44	0.95	2,455.21	4.86	3.55	5	1	2	0.4	0.7	0.9	1	1	1	1	1	1	1		4.00	9820.84
75	279	0.95	47.52	7.44	5.43	31	6	12	0	0	0	0	0	0.1	0.1	0.2	1	1		21.00	997.92
79	3	0.95	4,005.52	6.3	4.6	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1.00	4005.52
92	4	0.93	109,952.00	9.55	1.76	1	1	1	0.7	0.9	1	1	1	1	1	1	1	1	1	3.00	329856
110	62	0.95	11,733.00	5.6	2.8	3	2	3	0.2	0.4	0.7	0.8	0.9	1	1	1	1	1	1	6.00	70398
116	1	0.95	27,700.00	1	0.48	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1.00	27700
123	15	0.95	1,010.00	8.1	6.8	1	1	2	0.4	0.7	0.9	1	1	1	1	1	1	1	1	4.00	4040
124	43	0.93	15,340.50	4.1	3.44	2	2	3	0.2	0.4	0.7	0.8	0.9	1	1	1	1	1	1	6.00	92043
125	5	0.95	1,123.00	9.32	7.83	0	0	1	0.7	0.9	1	1	1	1	1	1	1	1	1	3.00	3369
Total Cost																					1764825

On table 15, holding quantity (HQ) is the holding quantity based on mean inventory value (E). From this table, we can observe that the total cost based on poison distribution with minimum NFF is 1,764,825 USD. Compared to the baseline poison distribution of previous total cost of **1,216,879** USD, the poison distribution with minimum no found fault shows 31 % higher. Therefore, the economic impact of condemn rate (scrap rate) on repairable spare part is 31% based on poison distribution when no found fault is considered as negligible.

$$SL=\frac{(113*0.95+110*0.95+\ldots 1*0.95)}{\sum_{1}^{45} Ri}=\frac{1669.88}{1761}=94.83\%$$

b) Marginal Analysis with Minimum NFF (Scenario-II, M2)

In this section, the amount of work in process inventory under consideration of minimum no fault found will be calculated (i.e. M2 on table 13.). The sample result of this analysis is shown on table 16. The whole result is shown on appendix-5. As shown on table 16, the corresponding cumulative cost for service level of 95% is 632974.44 USD. On the same table, assuming minimum holding quantity of one (1) for each repairable item that were not included into 95% service level, the overall service level will increase to 96.7% with corresponding total cost of 1,131,175.640 USD. Compared to baseline previous baseline marginal analysis result of 974760.8, the current marginal analysis result with minimum NFF shows 13.83% higher. Therefore, the economical (financial) impact of condemn rate or scrap rate (SR) on repairable spare parts is 13.83%% based on marginal analysis when no found fault is considered as negligible.

Table 16: Sample Marginal Analysis Result With minimum NFF (**Scenario-II** , M2)

S/N	(100th)Service	Fills	**tionMarginal**	**Delta Fills (** $\Delta F i$	Removals/YR	Unit cost ($)	**Cumulative F**	**Cumulative**	**Cumulative Cost($)**
75	0.4978	138.8912	0.6866	32.6274	279.0000	47.5200	32.6274	0.0185	47.52
75	0.6117	170.6675	0.6687	31.7764	279.0000	47.5200	64.4037	0.0366	95.04
75	0.3809	106.2638	0.6462	30.7094	279.0000	47.5200	95.1131	0.0540	142.56
75	0.7141	199.2345	0.6012	28.5670	279.0000	47.5200	123.6801	0.0702	190.08
75	0.2708	75.5544	0.5530	26.2765	279.0000	47.5200	149.9566	0.0852	237.6
75	0.7996	223.0819	0.5018	23.8473	279.0000	47.5200	173.8040	0.0987	285.12
75	0.1766	49.2779	0.4258	20.2352	279.0000	47.5200	194.0391	0.1102	332.64
5	0.0736	39.9072	0.0108	17.7110	542.0000	1641.0000	810.0957	0.4600	24776.67
5	0.9382	508.4984	0.0107	17.5105	542.0000	1641.0000	827.6062	0.4700	26417.67
48	1.0000	2.0000	0.0103	2.0000	2.0000	193.3600	829.6062	0.4711	26611.03
81	0.9939	4.9693	0.0078	4.9693	5.0000	640.7000	931.8206	0.5291	38888.94
5	0.9608	520.7655	0.0075	12.2671	542.0000	1641.0000	944.0877	0.5361	40529.94
3	0.7077	94.1294	0.0072	29.4111	133.0000	4086.0000	973.4988	0.5528	44615.94
73	0.4706	40.4694	0.0071	17.5415	86.0000	2455.2100	991.0404	0.5628	47071.15
75	0.9990	278.7083	0.0069	0.3271	279.0000	47.5200	991.3675	0.5630	47118.67
123	0.9882	14.8235	0.0005	0.5202	15.0000	1010.0000	1619.0381	0.9194	466899.14
23	0.9802	7.8416	0.0005	0.5034	8.0000	1012.5000	1619.5416	0.9197	467911.64
1	0.9572	108.1598	0.0005	6.6909	113.0000	14011.0000	1626.2325	0.9235	481922.64
3	0.9930	132.0648	0.0005	1.9413	133.0000	4086.0000	1628.1738	0.9246	486008.64
9	0.9818	73.6380	0.0004	2.2011	75.0000	4905.5100	1630.3749	0.9258	490914.15
6	0.9999	0.9999	0.0002	0.9999	1.0000	4086.0000	1668.2773	0.9473	603003.44
84	0.8383	13.4128	0.0002	3.8329	16.0000	15960.0000	1672.1102	0.9495	618963.44

1	0.9840	111.1900	0.0002	3.0303	113.0000	14011.0000	1675.1405	0.9512	632974.44
129	0.9973	1.9946	0.0001	1.9946	2.0000	16511.0000	1677.1350	0.9524	649485.440
131	0.9993	0.9993	0.0001	0.9993	1.0000	18520.0000	1695.0130	0.9625	890273.150
58	1.0000	1.0000	0.0000	1.0000	1.0000	22914.0000	1696.0130	0.9631	913187.150
35	0.9997	2.9990	0.0000	2.9990	3.0000	80336.4900	1699.0119	0.9648	993523.640
116	1.0000	1.0000	0.0000	1.0000	1.0000	27700.0000	1700.0119	0.9654	1021223.640
92	0.6973	2.7893	0.0000	2.7893	4.0000	109952.0000	1702.8012	0.9670	**1131175.640**

C. **Mixed Integer Linear Programming with Minimum NFF (Scenario-II, LP-2)**

Here Mixed Integer Linear Programming formulation is performed in similar manner as previously done under section 4.7 of this paper. The general procedure followed is the same as described under section 4.7. The dummy variables are defined in similar fashion also. In this scenario, the numbers of dummy variables are twenty-three (23) multiplied by number of repairable items i.e. 45 as shown on the next table. This is because poison distribution of scenario-II indicates that the maximum holding quantities are 23. In this scenario fault found is considered as negligible in calculated expected amount of stock (E) that will be further used as an input for mixed integer linear programming. Sample mixed integer linear programming is below and full formulation of the equation is shown on Appendix-V (C).

Item # (i)	**Dummy Variables (Holding Quantities)**												
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**→**	**Z**
1	A1	B1	C1	D1	E1	F1	G1	H1	I1	J1	K1	L1	→	Z1
2	A2	B2	C2	D2	E2	F2	G2	H2	I2	J2	K2	L2	→	Z2
3	A3	B3	C3	D3	E3	F3	G3	H3	I3	J3	K3	L3	→	Z3
4	A4	B4	C4	D4	E4	F4	G4	H4	I4	J4	K4	L4	→	Z4
5	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	→	Z
42	A42	B42	C42	D42	E42	F42	G42	H42	I42	J42	K42	L42	→	Z42
43	A43	B43	C43	D43	E43	F43	G43	H43	I43	J43	K43	L43	→	Z43
44	A44	B44	C44	D44	E44	F44	G44	H44	I44	J44	K44	L44	→	Z44

45	A45	B45	C45	D45	E45	F45	G45	45H	I45	J45	K45	L45	→	Z45

Then the equation is loaded into LP solve software and figure 17 shows MILP Formulation Loaded into LPSolve Software. Figure 18 shows the result of LP solve software. The full LP result is shown on Appendix-V.

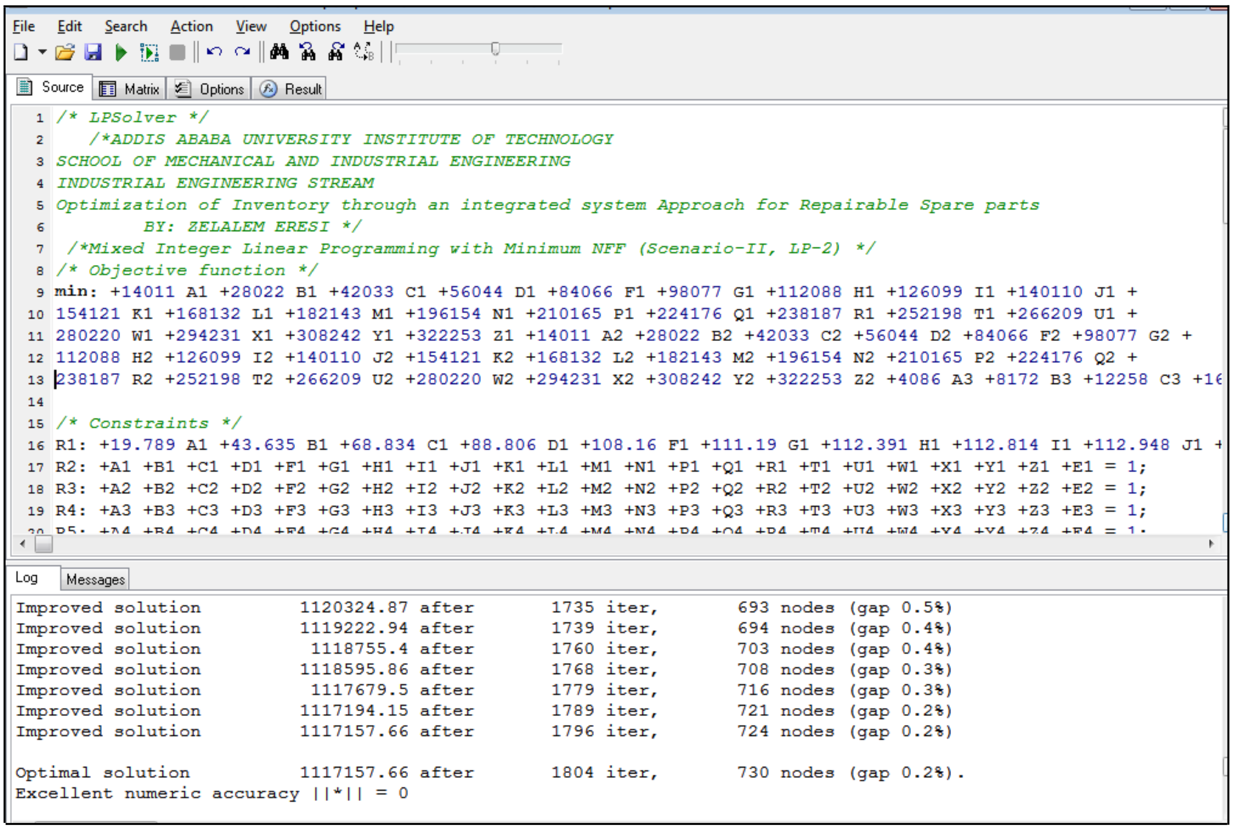

Figure 17: MILP Formulation Loaded into LPSolve Software (Scenario-II, LP-2**)**

As shown on figure 17 and Figure 18, the total cost for feasible solution is 1,117,157.66 USD. Compared to baseline MILP result of 840,276.12, scenario-II has shown 24.78% increment. Visual comparison of scenario-II results is shown on figure 19. As shown on the figure, mixed integer linear programming gives the most optimal solution.

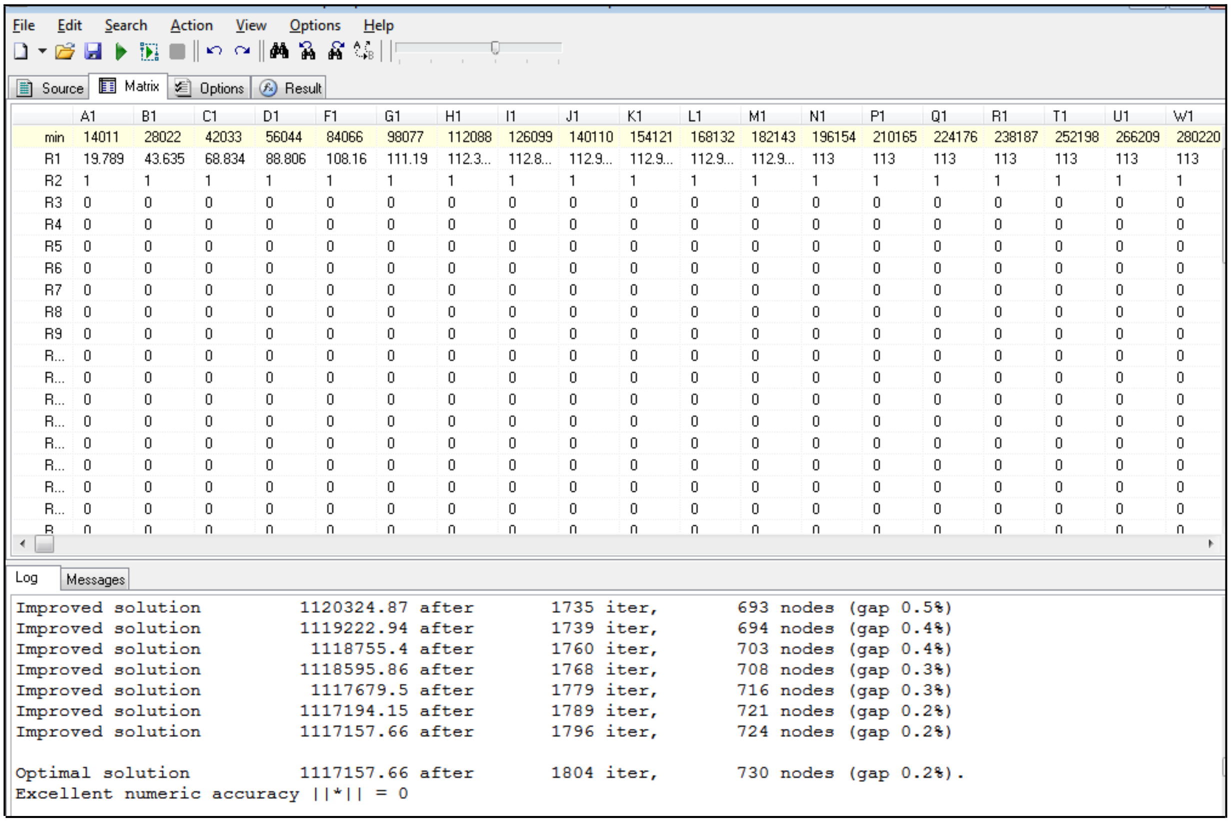

Figure 18: LP solve software Result (Scenario-II, LP-2)

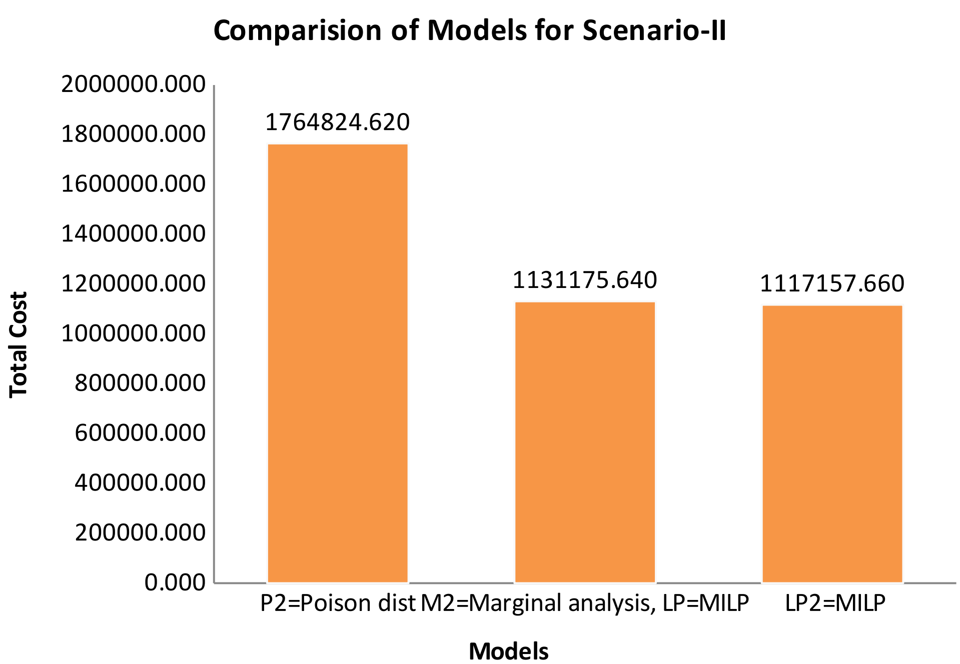

Figure 19: Visual Comparison of Scenario-II Results

5.5.6. Comparison of the Models with Minimum Scrap Rate (Scenario-III)

One of the objective of this paper is to investigate (study), the impact of disposal rates (scrap rates) on repairable aircraft spare parts. In this scenario, the three inventory optimization models poison distribution; marginal diminishing returns and mixed integer linear programming are compared under consideration of minimum scrap rate (S). As shown on table 4, the representations are shown as P3, M3 and Lp3. Since one of the objectives of this paper is to investigate the impact of scrap rate on repairable inventory, scarp rate(S) is considered negligible (i.e. S=0) in equation (1).

$$E^{\square} = \frac{(R-NFF)*T}{365} + \frac{NFF*T2}{365} + S---(1)$$

Considering S=0, equation (1) will be written as equation 1.2 below.

$$E^{\square} = \frac{(R-NFF)*T}{365} + \frac{NFF*T2}{365}---(1.2)$$

Where T is the turnaround time for repair (maintenance) and T2 is the turnaround time for no fault found event (false failure events). R is the total number of removals per year for each item. NFF is the total number of no found fault per year.

Table 4: Scenarios to be Tested

Model	Scenario-I: Baseline (SR=0, NFF=0)	Scenario-II: (SR≠0, NFF=0)	Scenario-III: (NFF≠0, SR=0)	Scenario-IV: (NFF≠0, SR≠0)
Poison Distribution	P1	P2	P3	P4
Marginal Diminishing Returns	M1	M2	M3	M4
Mixed Integer Linear	LP-1	LP-2	LP-3	LP-4

Programming				

a) Poison distribution with Minimum Scrap rate (Scenario-III, P3)

In this section, the expected number of stock size that should be held is calculated based on the concept of poison distribution under consideration of minimum scrap (S) based on equation 1.2. The procedure is similar to the explanation given under section 4.7.2 of this paper. The only difference is that the scrap rate is considered negligible(S=0) in equation (1). The sample result of the poison distribution is shown in table 17. In the table, the holding quantity (HQ) is obtained based on the service level. The whole table is shown on appendix-6

Table 17: Sample result for Poison distribution With Minimum Scrap rate (Scenario-III , P3)

S/N	REMS/YR(R)	Price(P)	Service Level(SL)	Repair TAT	NFF TAT	Total NFF	HQ	E"=(R-NFF)*12/365+J2*K2/365	Expected Holding Quantity (HQ) and Service Level(probability)						Total cost=HQ*P
									1	2	3	4	5	10	
1	113	14,011.00	0.95	3.78	1.25	13	3	1	0.706	0.904	0.976	0.995	0.999	1.000	42,033.00
2	110	14,011.00	0.95	6.03	2.43	17	4	2	0.509	0.770	0.914	0.973	0.993	1.000	56,044.00
3	133	4,086.00	0.95	2.00	1.49	21	3	1	0.844	0.966	0.994	0.999	1.000	1.000	12,258.00
5	542	1,641.00	0.95	4.79	1.52	86	10	6.00	0.017	0.062	0.151	0.285	0.446	0.957	16,410.00
58	1	22,914.00	0.95	2.60	0.30	0	1	0.01	1.000	1.000	1.000	1.000	1.000	1.000	22,914.00
73	86	2,455.21	0.95	7.70	5.62	10	5	2.00	0.406	0.677	0.857	0.947	0.983	1.000	12,276.05
74	44	2,455.21	0.95	4.86	3.55	5	3	1.00	0.736	0.920	0.981	0.996	0.999	1.000	7,365.63
75	279	47.52	0.95	7.44	5.43	31	10	6.00	0.017	0.062	0.151	0.285	0.446	0.957	475.20
79	3	4,005.52	0.95	6.30	4.6	1	1	0.05	0.999	1.000	1.000	1.000	1.000	1.000	4,005.52
80	35	661.77	0.95	4.92	3.59	4	3	1.00	0.736	0.920	0.981	0.996	0.999	1.000	1,985.31

123	15	1,010.00	0.95	8.10	6.8	1	1	0.33	0.956	0.995	1.000	1.000	1.000	1.000	1,010.00
124	43	15,340.50	0.93	4.10	3.44	2	3	1.00	0.736	0.920	0.981	0.996	0.999	1.000	46,021.50
Total Cost(USD)															889,956.51

b) Marginal Analysis with Minimum Scrap rate (Scenario-III, M3)

As shown on table 4, scenario-III is the case when minimum scrap rate is considered. The amount of work in process inventory under consideration of minimum scrap rate will be calculated (i.e. M3 on table 4.). The sample result of this analysis is shown on table 18. The whole result is shown on Appendix-VI (B). As shown on table 18, the corresponding cumulative cost for service level of 95% is 459546.60($). On the same table, assuming minimum holding quantity of one (1) for other repairable items which fall outside of 95%, the service level will increase to 95.9% with corresponding total cost of 845295.09($).

Table 18: Marginal Analysis Result with Minimum Scrap rate (Scenario-III, M3)

SN	Holding Qty (HQ)	Service Level	Fills(unit)	(MC)Marginal Contribution	Delta Fills (ΔF)	Removals/yr.(Ri)	cost	Cumulative fills($\sum \Delta F$)=F	Service Level(F/ $\sum Ri$)	Cumulative Cost($)
75	6	0.6063	169.1585	0.9431	44.8139	279	47.52	44.81386	0.02545	47.52
75	5	0.4457	124.3446	0.9431	44.8139	279	47.52	89.62771	0.0509	95.04
75	7	0.7440	207.5704	0.8083	38.4119	279	47.52	128.0396	0.07271	142.56
75	4	0.2851	79.53076	0.7859	37.3449	279	47.52	165.3845	0.09392	190.08
9	1	1.0000	75	0.0153	75	75	4905.51	951.1341	0.54011	23430.00
5	11	0.9467	513.0845	0.0149	24.4828	542	1641.00	975.6168	0.55401	25071.00
123	1	1.0000	15	0.0149	15	15	1010.00	990.6168	0.56253	26081.00
7	1	0.7358	30.16611	0.0142	30.1661	41	2118.00	1020.783	0.57966	28199.00
73	1	0.4060	34.9165	0.0142	34.9165	86	2455.21	1055.699	0.59949	30654.21
82		0.7358	8.829107	0.0133	8.82911	12	661.77	1064.529	0.6045	31315.98
74	1	0.7358	32.37339	0.0132	32.3734	44	2455.21	1096.902	0.62289	33771.19

75	14	0.9986	278.6093	0.0131	0.62165	279	47.52	1097.524	0.62324	33818.71
7	2	0.9197	37.7076	0.0036	7.5415	41.0000	2118.00	1395.8502	0.7926	87020.67
82		0.9197	11.0364	0.0033	2.2073	12.0000	661.77	1398.0575	0.7939	87682.44
74	2	0.9197	40.4667	0.0033	8.0933	44.0000	2455.21	1406.1508	0.7985	90137.65
80	3	0.9810	34.3354	0.0032	2.1460	35	661.77	1408.297	0.800	90799.42
2	1	0.4060	44.6606	0.0032	44.6606	110	14011.00	1452.957	0.825	104810.42
73	4	0.9473	81.4718	0.0032	7.7592	86	2455.21	1460.717	0.829	107265.63
114	1	1.0000	3.0000	0.0027	3.0000	3	1101.00	1463.717	0.831	108366.63
82		0.9963	11.9561	0.0003	0.1839	12.0000	661.77	1649.8886	0.9369	248878.68
2	4	0.9197	14.7152	0.0002	2.9430	16	15960.00	1652.8316	0.9386	264838.68
84		0.9197	14.7152	0.0002	2.9430	16	15960.00	1655.7746	0.9402	280798.68
129	1	1.0000	2.0000	0.0001	2.0000	2	16511.00	1657.7746	0.9414	297309.68
73	7	0.9989	85.9057	0.0001	0.2956	86	2455.21	1658.0702	0.9416	299764.89
130	1	1.0000	2.0000	0.0001	2.0000	2	18520.00	1660.0702	0.9427	318284.89
16	1	1.0000	15.0000	0.0001	15.0000	15	141261.71	1675.0702	0.9512	459546.60
132	1	1.0000	1.0000	0.0001	1.0000	1	13380.00	1676.070	0.952	472926.60
51	1	1.0000	2.0000	0.0001	2.0000	2	32595.00	1678.070	0.953	505521.60
133	1	1.0000	1.0000	0.0001	1.0000	1	16511.00	1679.070	0.953	522032.60
131	1	1.0000	1.0000	0.0001	1.0000	1	18520.00	1680.070	0.954	540552.60
6	1	1.0000	16.0000	0.0000	0.0000	16	15960.00	1689.365	0.959	**845295.09**

C. **Mixed Integer Linear Programming with Minimum Scrap rate (Scenario-III, LP-3)**

Based on the result of poison distribution of scenario-III (refer section 4.7.3 table 15), the largest holding quantity is ten (10) i.e. for item number five (5) and for item number 75. Therefore, let us assume that our holding quantities are represented by letters as follows, which is equal to ten (10) in numbers.

$\{A, B, C, D, E, F, G, H, I, J\}$

Except for item number 5 and 75, the rest have maximum holding quantity of 5. That means the letter representation is up to J as shown on table 19.

And let the item number $i \in \{1,2,3,4,5,6,7 \ldots 45\}$

Table 19: Sample Dummy variables formed by matrix between item number and holding quantity (for Scenario-III, LP-3)

	Dummy Variables (Holding Quantities)									
Item # (i)	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
1	A1	B1	C1	D1	E1	F1	G1	H1	I1	J1
2	A2	B2	C2	D2	E2	F2	G2	H2	I2	J2
3	A3	B3	C3	D3	E3	F3	G3	H3	I3	J3
↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
44	A44	B44	C44	D44	E44	F44	G44	H44	I44	J44
45	A45	B45	C45	D45	E45	F45	G45	H45	I45	J45

The general procedure followed is the same as described under section 4.7. The dummy variables are defined in similar fashion also. The only difference here is minimum scrap rate (negligible scrap rate) is considered in calculating expected amount of stock (E) that will be further used as an input for mixed integer linear programming. Sample MILP equation is as shown below. The whole equation is shown on Appendix-VI (C).

/*Mixed Integer Linear Programming with Minimum Scrap rate (Scenario-III, LP-3) */

/* Objective function */

Min 14011 A1 +28022 B1 +42033 C1 +56044 D1 +84066 F1 +98077 G1 +112088 H1 +126099 I1 +140110 J1 +14011 A2 +28022 B2 +42033 C2 +56044 D2 +84066 F2 +98077 G2 +112088 H2 +126099 I2 +140110 J2 +4086 A3 +8172 B3 +12258 C3 +16344 D3 +24516 F3 +28602 G3 +32688 H3 +36774 I3 +40860 J3 +1641 A4 +3282 B4 +4923 C4 +6564 D4 +9846 F4 +11487 G4 +13128 H4 +14769 I4 +16410 J4 +4086 A5 +8172 B5 +12258 C5 +16344 D5 +24516 F5 +28602 G5 +32688 H5 +36774 I5 +40860 J5 +2118 A6 +4236 B6 +6354 C6 +8472 D6 +12708 F6 +……+26760 B44 +40140 C44 +53520 D44 +80280 F44 +93660 G44 +107040 H44 +120420 I44 +133800 J44 +16511 A45 +33022 B45 +49533 C45 +66044 D45 +99066 F45 +115577 G45 +132088 H45 +148599 I45 +165110 J45;

/* Constraints */

79.813 A1 +102.195 B1 +110.254 C1 +112.43 D1 +112.985 F1 +112.998 G1 +113 H1 +113 I1 +113 J1 +55.997 A2 +84.751 B2 +100.563 C2 +107.083 D2 +109.826 F2 +109.965 G2 +109.994 H2 +109.999 I2 +110 J2 +112.305 A3 +128.468 B3 +132.237 C3 +132.896 D3 +132.999 F3 +……

5 C39 +5 D39 +5 F39 +5 G39 +5 H39 +5 I39 +5 J39 +A40 +4 B40 +4 C40 +4 D40 +4 F40 +4 G40 +4 H40 +4 I40 +4 J40 +A41 +2 B41 +2 C41 +2 D41 +2 F41 +2 G41 +2 H41 +2 I41 +2 J41 +A42 +2 B42 +2 C42 +2 D42 +2 F42 +2 G42 +2 H42 +2 I42 +2 J42 +A43 +B43 +C43 +D43 +F43 +G43 +H43 +I43 +J43 +A44 +B44 +C44 +D44 +F44 +G44 +H44 +I44 +J44 +A45 +B45 +C45 +D45 +F45 +G45 +H45 +I45 +J45 >= 1672.95;

A1 +B1 +C1 +D1 +F1 +G1 +H1 +I1 +J1 +E1 = 1;

+A2 +B2 +C2 +D2 +F2 +G2 +H2 +I2 +J2 +E2 = 1;

A3 +B3 +C3 +D3 +F3 +G3 +H3 +I3 +J3 +E3 = 1;

A4 +B4 +C4 +D4 +F4 +G4 +H4 +I4 +J4 +E4 = 1;

A5 +B5 +C5 +D5 +F5 +G5 +H5 +I5 +J5 +E5 = 1;

R46: +A45 +B45 +C45 +D45 +F45 +G45 +H45 +I45 +J45 +E45 = 1;

/* Integer definitions */

int
A1,B1,C1,D1,F1,G1,H1,I1,J1,A2,B2,C2,D2,F2,G2,H2,I2,J2,A3,B3,C3,D3,F3,G3,H3,I3,J3,A4,B4,C4,D4,F4,G4,H4,I4,J4,A5,B5,C5,D5,F5,G5,H5,I5,J5,A6,B6,C6,D6,F6,G6,H6,I6,J6,A7,B7,C7,D7,F7,G7,H7,I7,J7,A8,B8,C8,D8,F8,G8,H8,I8,J8,A9,B9,C9,D9,F9,G9,H9,I9,J9,A10,B10,C10, ….. , A45, B45, C45, D45, F45, G45, H45, I45, J45;

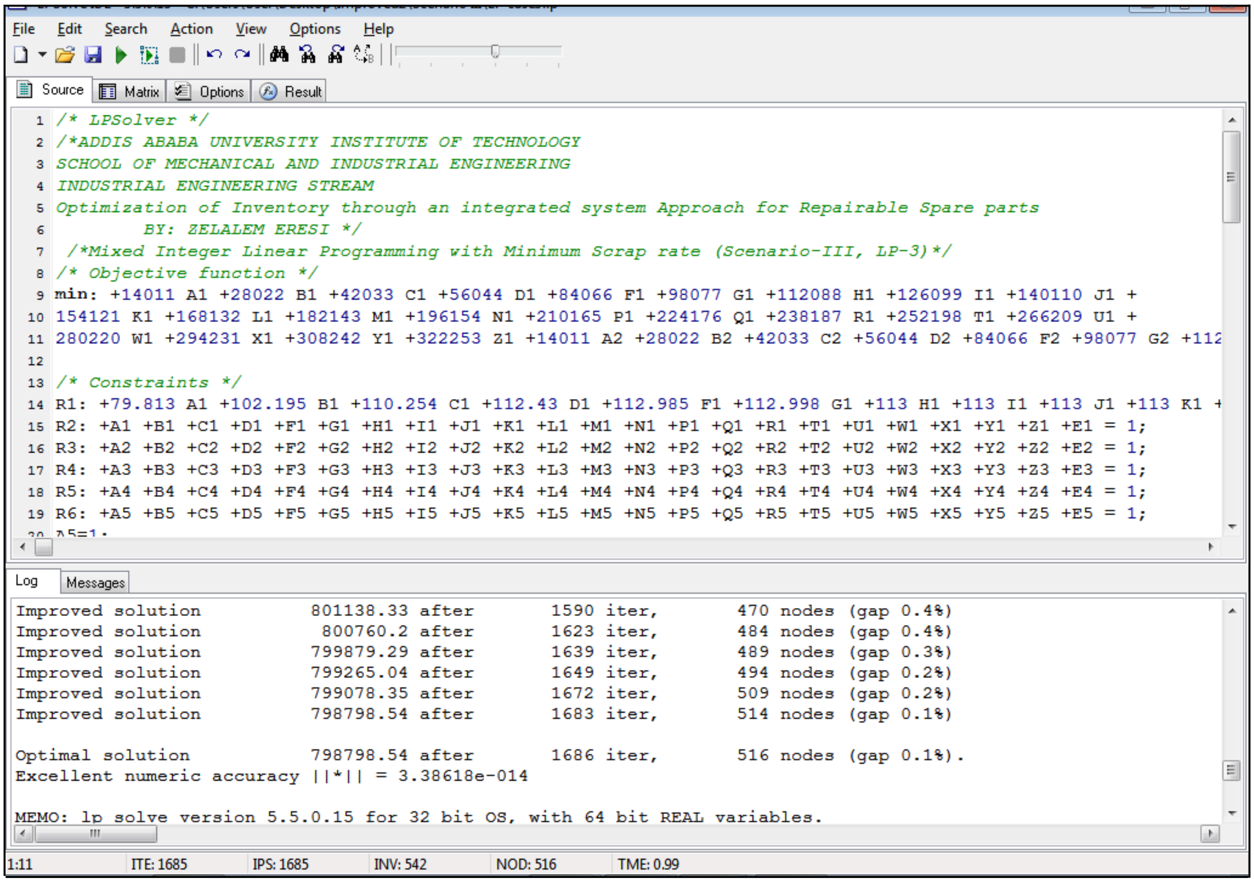

Figure 20: LP solve software Result (Scenario-III, LP-3)

Sample LP solve software result is as shown on figure 20. In this case, the optimal value is 798798.54($).

5.5.7. Comparison of the Models with Minimum Scrap Rate and No Fault Found (Scenario-IV)

This test scenario is specifically designed to investigate (study), the combined impact of disposal rates (scrap rates) and no found fault on repairable aircraft spare parts. The three inventory optimization models poison distribution; marginal diminishing returns and mixed integer linear programming are compared by taking both condemnation rate or scrap rate and no found fault as an input. Unlike scenario-II and scenario-III, this case considers both condemnation rate and no found fault as they are not negligible. As shown on table 4, the representations are shown as P4, M4 and Lp4.

Table 4: Scenarios to be Tested

Model	Scenario-I: Baseline (SR=0, NFF=0)	Scenario-II: (SR≠0, NFF=0)	Scenario-III: (NFF≠0, SR=0)	Scenario-IV: (NFF≠0, SR≠0)
Poison Distribution	P1	P2	P3	P4
Marginal Diminishing Returns	M1	M2	M3	M4
Mixed Integer Linear Programming	LP-1	LP-2	LP-3	LP-4

$$E^{\square}=\frac{(R-NFF)*T}{365}+\frac{NFF*T\,2}{365}+S---(1)$$

Where T is the turnaround time for repair (maintenance) and T2 is the turnaround time for no fault found event (false failure events). R is the total number of removals per year for each item. NFF is the total number of no found fault per year.

a) Poison distribution with Combined NFF and Disposal Rate (Scenario-IV, P4)

In this section, the expected number of stock size that should be held is calculated based on the concept of poison distribution under consideration of condemn rate or scrap rate(S) and no fault found different from zero based on equation 1.1. The procedure is similar to the explanation given under section 4.7.2 of this paper. The only difference is that the scrap rate and no found fault are considered not negligible (S≠0, NFF≠0). The sample result of the poison distribution is shown in table 21. In the table, the holding quantity (HQ) is obtained based on the service level. The whole table is shown on appendix-VII.

As shown on table 21, the total cost for this scenario is 1,611,357($).

Table 20: Sample result for Poison distribution With Combined NFF and Disposal Rate (Scenario-IV , P4)

SN	REMS/YR(R)	Price(P)	Repair TAT(T)	NFF TAT (T2)	Total NFF(NFF)	Scrap/Yr. (S)	E=(R-NFF)*T/365+NFF*T2/365+S	Expected Holding Quantity (HQ) and Service Level(probability)									Total Cost=P*HQ
								1	2	4	5	6	7	18	22	Holding Qty-HQ	
1	113	14011	3.78	1.25	13	2	3	0.187	0.405	0.802	0.908	0.962	0.986	1.000	1.000	6	84066
2	110	14011	6.03	2.43	17	2	4	0.121	0.294	0.697	0.837	0.923	0.967	1.000	1.000	7	98077
5	542	1641	4.79	1.52	86	9	15	0.000	0.000	0.001	0.002	0.006	0.015	0.794	0.960	22	36102
9	75	4905.51	1.2	0.39	7	3	3	0.167	0.373	0.775	0.891	0.953	0.982	1.000	1.000	6	29433.1
13	17	3558.85	5.2	1.5	2	1	1	0.655	0.875	0.992	0.998	1.000	1.000	1.000	1.000	3	10676.6
16	15	141261.71	0.67	0.22	2	1	1	0.727	0.915	0.996	0.999	1.000	1.000	1.000	1.000	2	282523
23	8	1012.5	0.6	0.2	1	1	1	0.731	0.917	0.996	0.999	1.000	1.000	1.000	1.000	3	3037.5
30	4	2905	4.2	1.6	1	1	1	0.721	0.912	0.996	0.999	1.000	1.000	1.000	1.000	3	8715
32	4	856	0.6	0.2	0	1	1	0.733	0.918	0.996	0.999	1.000	1.000	1.000	1.000	3	2568
46	2	30.96	3.3	1	0	0	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1	30.96
73	86	2455.21	7.7	5.62	10	2	4	0.111	0.276	0.676	0.822	0.913	0.962	1.000	1.000	7	17186.5
74	44	2455.21	4.86	3.55	5	2	3	0.274	0.527	0.882	0.953	0.984	0.995	1.000	1.000	5	12276.1
75	279	47.52	7.44	5.43	31	6	12	0.000	0.001	0.011	0.027	0.060	0.113	0.974	0.998	18	855.36
80	35	661.77	4.92	3.59	4	1	1	0.572	0.820	0.983	0.996	0.999	1.000	1.000	1.000	4	2647.08
81	5	640.7	8.4	6.1	1	0	0	0.994	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1	640.7
82	12	661.77	8.9	5.6	2	1	1	0.636	0.863	0.990	0.998	1.000	1.000	1.000	1.000	3	1985.31
110	62	11733	5.6	2.8	3	2	3	0.210	0.439	0.827	0.923	0.970	0.990	1.000	1.000	3	35199
111	29	25705	6.4	3.2	2	1	1	0.561	0.811	0.982	0.996	0.999	1.000	1.000	1.000	6	154230
112	5	4759.78	0.5	0.24	1	1	1	0.734	0.919	0.996	0.999	1.000	1.000	1.000	1.000	3	14279.3
114	3	1101	0.4	0.19	0	0	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1	1101
123	15	1010	8.1	6.8	1	1	1	0.616	0.850	0.988	0.998	1.000	1.000	1.000	1.000	3	3030
124	43	15340.5	4.1	3.44	2	2	2	0.292	0.549	0.894	0.959	0.986	0.996	1.000	1.000	5	76702.5
133	1	16511	1.33	1.12	0	0	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1	16511
												Total Cost (USD)					1611357

b) Marginal Analysis With Combined NFF and Disposal Rate (Scenario-IV , M4)

As shown on table 4, scenario-IV is the case when both no found fault and scrap rate are considered. The amount of work in process inventory under consideration of this scenario will be calculated (i.e. M4 on table 4.). The sample result of this analysis is shown on table 22. The whole result is shown on Appendix-VII. As shown on table 22, the corresponding cumulative cost for service level of 95% is 584,279.4($). On the same table, assuming minimum holding quantity of one (1) for other repairable items which fall outside of 95%, the service level will increase to 96.7% with corresponding total cost of 1,106,188 USD.

Table 21: Result for Combined NFF and Disposal Rate (Scenario-IV, M4)

S/N	Holding Qty (HQ)	Service Level	Fills(unit)	Marginal Contribution (MC)	Delta Fills (ΔF ¿	Removals/yr.(Ri)	Cost/Unit($)	Cumulative fills($\sum \Delta F$ ¿ =F	Service Level(F/ $\sum R$)	Cumulative Cost($)
75	11	0.5179	144.4869	0.6927	32.9174	279	47.52	32.917	0.019	47.52
75	12	0.6311	176.0774	0.6648	31.5906	279	47.52	64.508	0.037	95.04
74	5	0.9945	43.7583	0.0003	0.7244	44	2455.21	1666.370	0.946	557718.4
32	3	0.9806	3.9224	0.0003	0.2485	4	856	1666.618	0.946	558574.4
111	2	0.8111	23.5223	0.0003	7.2575	29	25705	1673.876	0.951	584279.4
6	1	0.9999	0.9999	0.0002	0.9999	1	4086	1674.876	0.951	588365.4
129	1	0.9973	1.9946	0.0001	1.9946	2	16511	1676.870	0.952	604876.4
114	22	1.0000	3.0000	0.0000	0.0000	3	1101	1702.581	0.967	1087668
131	23	1.0000	1.0000	0.0000	0.0000	1	18520	1702.581	0.967	**1106188**

C) **Mixed Integer Linear Programming with Combined NFF and Disposal Rate (Scenario-IV, LP4)**

Based on the result of poison distribution of scenario-IV (refer section 4.5.7 table 22), the largest holding quantity is ten (22) i.e. for item number five (5). Therefore, let us assume that our holding quantities are represented by letters as follows, which is equal to ten (23) in numbers.

$\{A, B, C, D, E, F, G, H, I, J, K, L, M, N, P, Q, R, T, U, W, X, Y, Z\}$

Except for item number 5 and 75, the rest have maximum holding quantity of 5. That means the letter representation is up to Z as shown on table 23.

And let the item number $i \in \{1,2,3,4,5,6,7 \ldots 45\}$

Table 22: Sample Dummy variables formed by matrix between item number and holding quantity (for Scenario-IV, LP-4)

Item # (i)	**Dummy Variables (Holding Quantities)**													
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	→	**Z**
1	A1	B1	C1	D1	E1	F1	G1	H1	I1	J1	K1	L1	→	Z1
2	A2	B2	C2	D2	E2	F2	G2	H2	I2	J2	K2	L2	→	Z2
3	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	→	Z
43	A43	B43	C43	D43	E43	F43	G43	H43	I43	J43	K43	L43	→	Z43
44	A44	B44	C44	D44	E44	F44	G44	H44	I44	J44	K44	L44	→	Z44
45	A45	B45	C45	D45	E45	F45	G45	45H	I45	J45	K45	L45	→	Z45

The general procedure followed is the same as described under section 4.7. The dummy variables are defined in similar fashion also. The difference here is both condemn rate and no found fault are considered in calculating expected amount of stock (E) that will be further used as an input for mixed integer linear programming. Sample MILP equation and the LP solver result is shown on figure 21. The whole equation is shown on Appendix-IVII(C). As shown on figure 21, the optimal result for this sub-case (LP-4) is 1,084,511.78($).

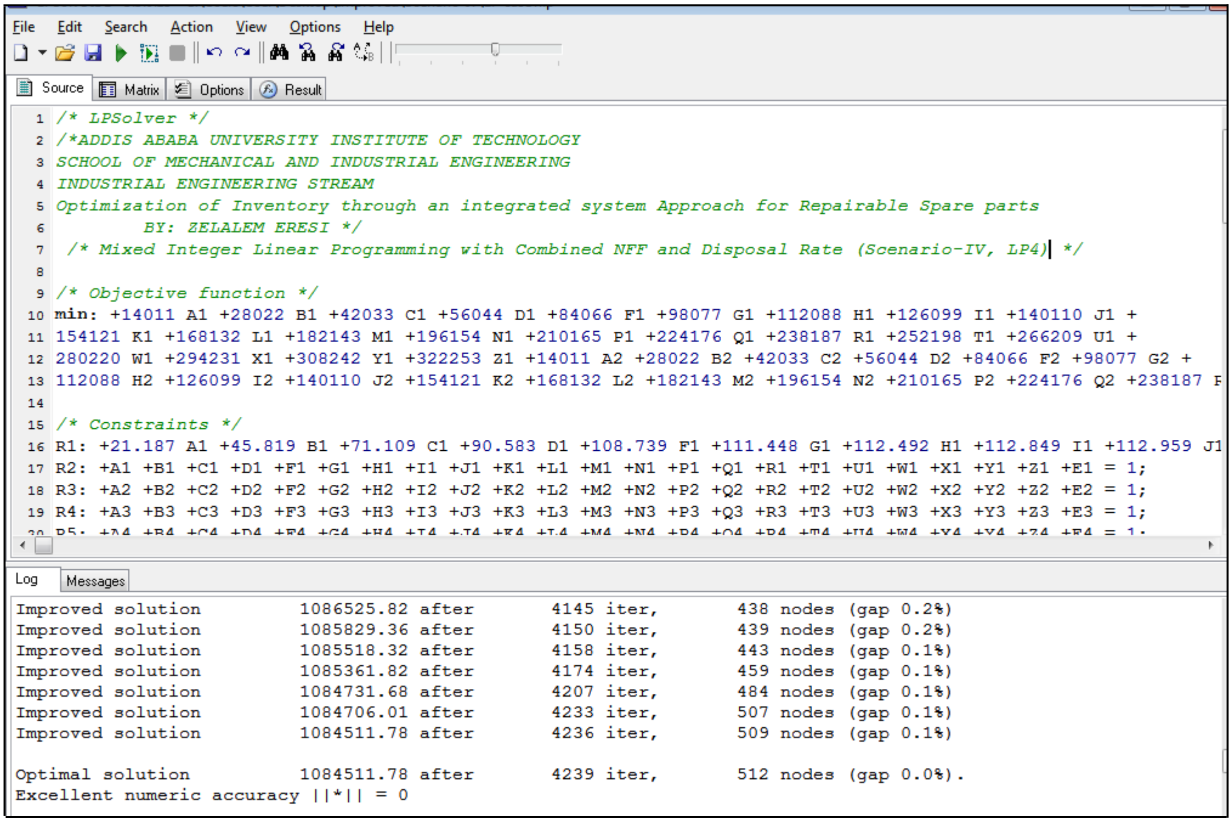

Figure 21: LP Software Result for Combined NFF and Disposal Rate (Scenario-IV, LP4)

The visual comparison of scenario-IV results is shown on figure 22.

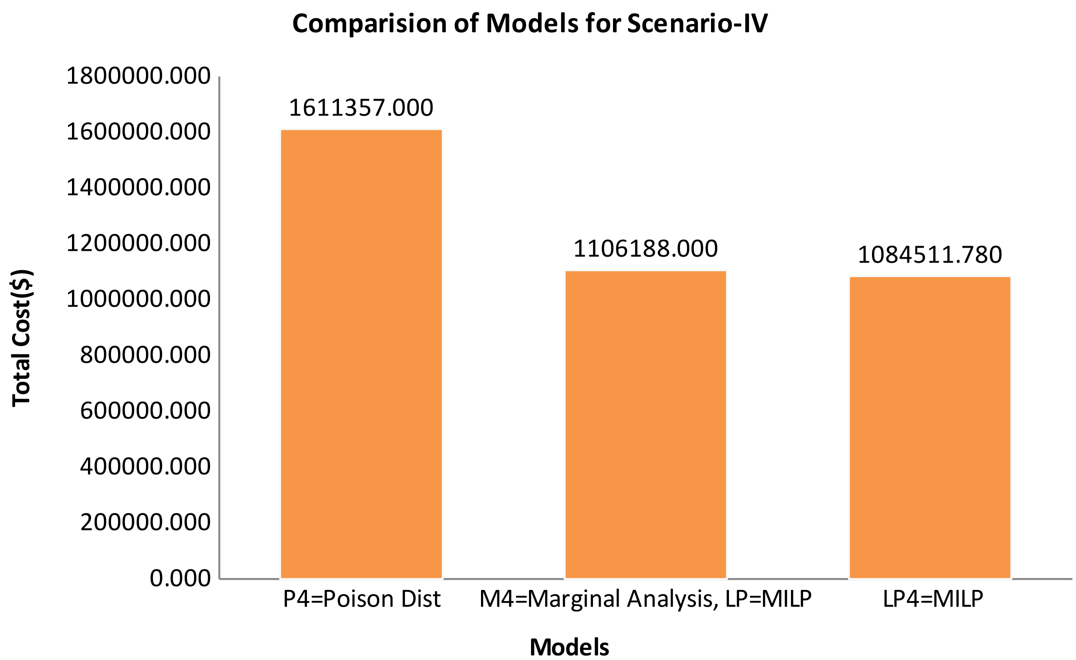

Figure 22: Visual Comparison of Scenario-IV Results

5.5.8. Summary of Analysis Results (Findings)

The summary of optimal results for each model and corresponding scenarios are shown on table 24. Figure 23 also shows the summary results. The holding quantity of each repairable item for each models and scenarios are also shown on Appendix-VII.

Table 23: Summary Results, Total Cost for Each Scenario

Scenario	Total cost For Each Scenario			MILP Cost Saving Vs Poisson Dist. (%)	MILP Cost Saving Vs Marginal Dist. (%)
	Poisson Dist.	Marginal Dist.	MILP		
Scenario-I	1216879	974760.8	840276.1	30.948	13.797
Scenario-II	1764825	1131175.64	1117158	36.699	1.239
Scenario-III	889956.5	845295.09	798798.5	10.243	5.501
Scenario-IV	1611357	1106188	1084512	32.696	1.960

Based on table 24, mixed integer linear programming gives the least cost for each models and scenario. Mixed integer linear programming model gives minimum of 10.243% and 1.239 % cost saving when compared to Poisson distribution and marginal diminishing results respectively. As explained previously, Scenario-I for each model is considered as a baseline against which to measure improvements. Scenario-II for each model is to study the financial impact of scrap rate (disposal rate) and scenario-III is used to study the financial impact of no fault found events.

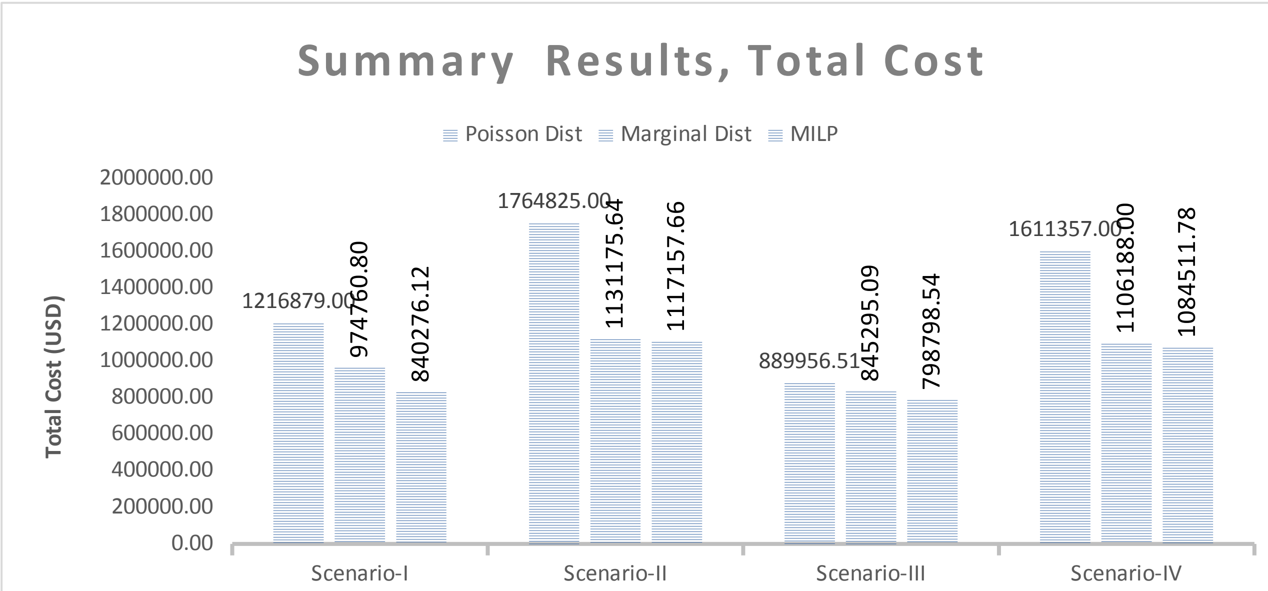

Figure 23: Summary Results (Total Cost)

Scenario-IV is used to study the combined financial impact of no fault found and scrap rates. Based on the above results, diminishing marginal returns model provides better performance as compared Poisson distribution model. Table 25 shows the financial Impact of No fault found (NFF) and Scrap Rate (SR) as compared to baselines.

As shown on table 25, financial Impact of No fault found (NFF) is 13.282% when compared to baseline scenario based on marginal analysis model (scenario-III). What is the interpretation for this result? This tells us how big the financial impact of no fault found is. It shows the difference between optimal total cost results when no fault found (NFF) is considered as an input (decision variable) and when it is not considered as an input (i.e. when it is considered as negligible). Considering no fault found (NFF) as an input for optimization gives 13.282% lower total inventory value based on marginal analysis model. Another way of saying this is no fault found is artificially inflating the inventory balance because no fault found (NFF) is the planning opposite of inflated repair turnaround time (TAT).

Table 24: Financial Impact of No fault found (NFF) and Scrap Rate (SR) Vs Baseline

Model	Scenarios	Total Cost	Financial Impact of No fault found (NFF) and Scrap Rate (SR) Vs Baseline in percentage		
			No fault found (NFF)	Scrap Rate(SR)	Combined (NFF and SR)
Marginal Analysis	**Scenario-I (Baseline)**	974760.8			
	Scenario-II	1131175.64		16.046	
	Scenario-III	845295.09	-13.282		
	Scenario-IV	1106188			13.483
Mixed Integer Linear Prog (MILP)	**Scenario-I (Baseline)**	840276.12			
	Scenario-II	1117157.66		32.951	
	Scenario-III	798798.54	-4.936		
	Scenario-IV	1084511.78			29.066

As shown on table 25, the impact of no fault found falls to 4.936% based on mixed integer linear programming (MILP). The impact of scrap rate (disposal rate) is 16.046% and 32.951% higher as compared to baseline scenario based on marginal analysis and mixed integer programming respectively. The Combined Financial Impact of No fault found (NFF) and Scrap Rate (SR) for marginal analysis and mixed integer programming models are 13.483% and 29.066% higher respectively when compared to baseline scenario.

Chapter Six

VALIDATION AND VERIFICATION OF THE MODELS

6.1. Introduction

This section focuses on Verification and validation (V & V) of the optimization models. The quality assurance of all the data inputs will be checked through overall verification of the models used in chapter-5. Model verification is used to give assurance that all data collection, data preparation, data entry and analysis are correct. For Model, validation output will be compared with the actual system to study the improvements.

6.2. Overall Verification of the Models

6.2.1. Comparison of Model Results (Total cost)

Based on the literature review results, the total cost obtained by using poison distribution is usually larger than both marginal analysis result and mixed integer linear programming results. Moreover, the total cost result for mixed integer linear programming is smaller than marginal analysis result. Based on this anticipation, we will compare the total cost of each model for all the four scenarios. As shown on figure 24, the total cost obtained for poison distribution is the largest value for each scenario. The total cost for MILP is also smaller than the total cost result of marginal distribution result for all scenarios.

These results agree with the anticipation of literature review, which verifies or assures the data collection, data entry and data analysis methodologies are in agreement with existing theories or literatures.

Figure 24: Graphical Comparison of Model Outputs for Each Scenario

6.2.2. Verification by Transposition of the MILP Equations

In the previous section, MILP was used to optimize by cost minimization. The service level was included as one constraint. In this section, the previous equations transposed with the objective of service level maximization and total cost as constraint.

Transposed Mixed Integer Linear Programming Objective function

As represented in Equation (1), the objective function is to maximize the system service level constrained to defined budget (C_t).

Transposed Mixed Integer Linear Programming Constraints

a) Total system Inventory Cost constraint

The total cost constraint is represented by equation (2) is to show the combined total cost of the intended inventory system should not exceed predefined total cost (C_t¿

b) Holding Quantity Constraint

Equation (3) is used to indicate each repairable item must choose only one holding quantity.

c) Integer Constraint

Equation (4) shows the dummy variables that shall take only binary values.

$$Max\,Z=\sum\left(\left(R\text{¿¿}SL_{ij}\right)*X_{ij}\right)------(1)\text{¿}$$

$$\sum_{\square}^{\square}\left(\left(C_i*HQ_i\right)*X_{ij}\text{¿}\leq C_t\right)------(2)\text{¿}$$

$$\sum X_{ij}=1-----------(3)$$

$$X_{ij\in[0,1]}-----------(4)$$

Where R_i is the number of removals per year for item number ‘i’, SL_{ij} is the service level for item number ‘i’ corresponding to holding quantity ‘j’ and X_{ij} is the dummy variable assigned for item number ‘I’ corresponding to holding quantity ‘j’, C_t is the total system inventory cost. And C_i is unit price for item number ‘i’, HQ_i is holding quantity for item number ‘I’.

Now the bode transposed equation is solved for each scenario following similar procedure as described in section 4.7. The results obtained for transposed equation (i.e. service level optimization) and the original equation (Cost minimization) are shown on table 26.

Table 25: Objective & Constraint Comparison of Original Equation and Transposed Equations

MILP Objective	**Scenarios**	**Objective (Optimal Result-in USD/ Percentage)**	**Constraint (Max-in USD/percentage)**
Cost Minimization (Original Equation)	I	$840276.12=C_t$	$1672.95=SL*\sum R_i$
	II	$1117157.66=C_t$	$1672.95=SL*\sum R_i$
	III	$798798.54=C_t$	$1672.95=SL*\sum R_i$
	IV	$1084511.78=C_t$	$1672.95=SL*\sum R_i$
Service Level Maximization (Transposed Equation)	I	$1672.98=SL*\sum R_i$	$840276.12=C_t$
	II	$1672.981=SL*\sum R_i$	$1117157.66=C_t$
	III	$1673.239=SL*\sum R_i$	$798798.54=C_t$
	IV	$1673.095=SL*\sum R_i$	$1084511.78=C_t$

Based on table 26, the comparison between service level of the original equation (cost minimization) and transposed equation (service level maximization). The maximum difference is 0.289 (i.e. 1672.95-1673.239=0.289). This is to mean that the service level percentage difference is 0.016%.

In some typical companies, the data error rates can range between 1% to 5% [CITATION Uyi16 \l 1033].

Therefore, the above percentage service level difference (0.016%) verifies that the data inputs used for this optimization model have consistent data quality (i.e. low data error rates). Because the result obtained by both original equation (total cost minimization) and transposed equation (service level maximization) are almost the same.

6.2.3. Sensitivity Analysis Based on Service Level

This sensitivity analysis has dual purposes. On one hand it is used to check the financial impact of the model by changing the service level. On the other hand, it is used to verify the consistency behavior of the model. Table 27 shows the model outputs of each scenario for each corresponding service level ranging between 89% to 97%.

Table 26: Sensitivity Analysis Result

Service Level	Total Cost For Each Scenario By using MILP (USD)			
	Baseline	**Scenario-II**	**Scenario-III**	**Scenario-IV**
89	695662.7	884495.09	697129.75	871737.36
90	705682.7	909737.32	712068.26	895778.05
91	718471.47	941813.88	733566.71	923353.82
92	742935.12	981502.9	767666.73	960139.97
93	772937.45	1021913.88	796809.04	996648.11
94	805426.03	1065139.28	831377.61	1037694.24
95	840276.12	1117157.66	874652.21	1084511.78
96	880917	1192249.62	956939.76	1143665.94
97	958960.81	1336841.68	INFEASIBLE	1251574.99

Graphical representations of sensitivity analysis result are also shown on figure 25. The results of table 27 are transposed version of results explained under section 5.2.2. When the results do not get coincide each other, it verifies that the quality of the input data, data preparation and data analysis with respect to consistency.

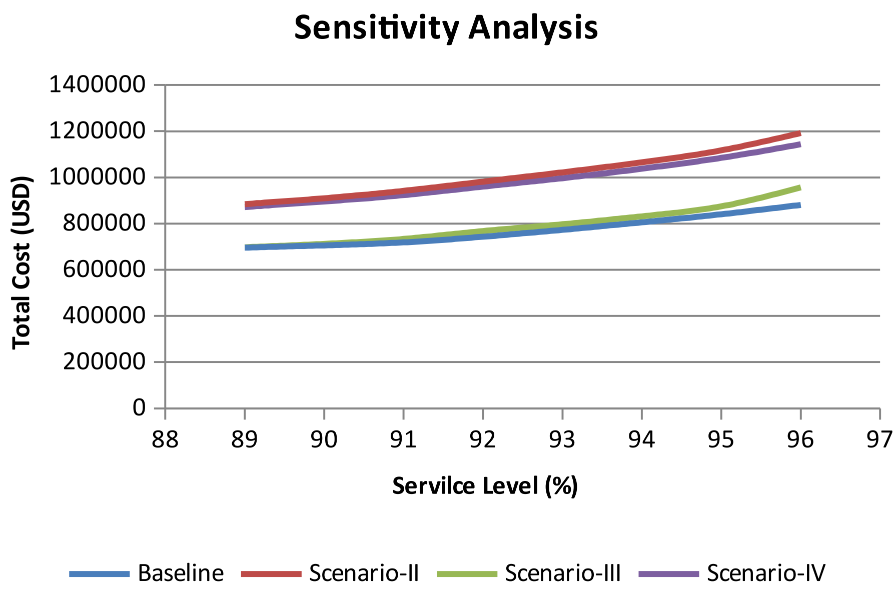

Figure 25: Sensitivity Analysis Result for Mixed Integer linear Programming

6.2.4. Sensitivity Analysis Based on Repair Cycle Time (TAT) and No Fault Found (NFF).

In this section, the impact of three important input variables, repair shop turnaround time (TAT), no fault found (NFF) and scrap rate will be assessed in comparison to the baseline and actual existing system. The amount of training given to the maintenance personnel directly impact the TAT of maintenance services [CITATION Gon17 \l 1033]. Northrop Aircraft Inc. achieved many positive results after consistent training of all employees. One of the improvements was that scrap rate reduction by 27%. The technical trainings given by Northrop Aircraft Inc. are aircraft model training, special services such as Non-Destructive Inspections, borescope inspections and maintenance practices while non-technical training are aviation regulations, lean manufacturing, Safety Management System and Human Factors.

Based on some original equipment manufacturers recommendation [CITATION Air97 \l 1033], let us assume 20% repair turnaround time reduction for this sensitivity analysis. Different literatures mention different figures for percentage of no fault found NFF. Minimum no fault found of 10% was reported by Royal Air France [CITATION Sam14 \l 1033]. The technical trainings given by Air France–KLM engineering are basic maintenance training, Aircraft Maintenance Type Training, Specialized Trainings (such as Borescope inspection), Human Factors, Fuel Tank Safety, EASA regulations and Refresher or Continuation courses[CITATION KLM17 \l 1033]. KLM engineering and Maintenance has EASA Part 145 FAR 145 and FAA approved part 145 Repair Station approvals. Since the case company has similar technical and non-technical trainings as well as approvals with Air France–KLM engineering and maintenance, this research intends to use this no fault found reduction to assess the expected gains due to NFF reduction.

Therefore, the financial impact of repair cycle (turnaround time reduction-TAT) by 20% and no fault found reduction by 10% is assessed by using mixed linear integer programming following similar procedure for scenario-IV. Formulation of the mixed integer programming and execution are similar to section 4.5.7 of this paper.

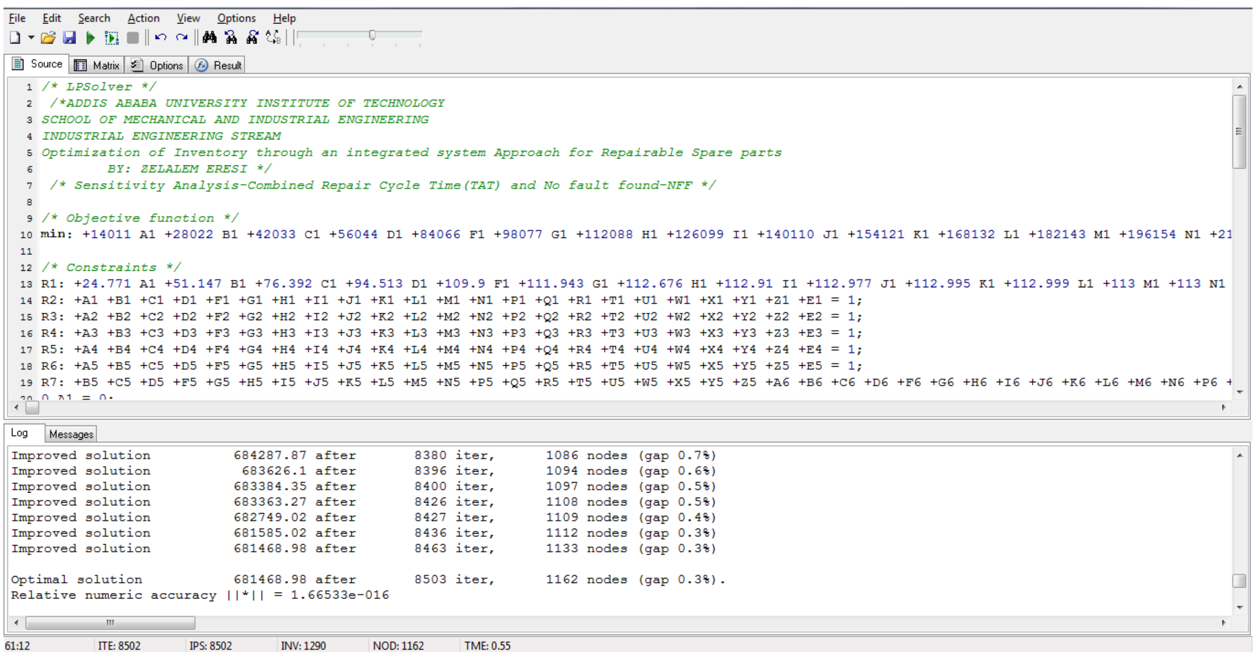

Figure 26: Sensitivity Analysis Result (Combined TAT and NFF)

As shown on figure 26, the optimal total cost by considering 20% turnaround time reduction and 10% no fault found reduction is 681468.98($), which shows 37% reduction as compared to scenario-IV result obtained under section 4.5.7.

But by considering only 20% reduction of repair turnaround time, the optimal total cost becomes 1038868.91($) as shown on figure 27 below. This shows 4.2% total cost reduction can be attained by reducing the repair cycle time by 20%.

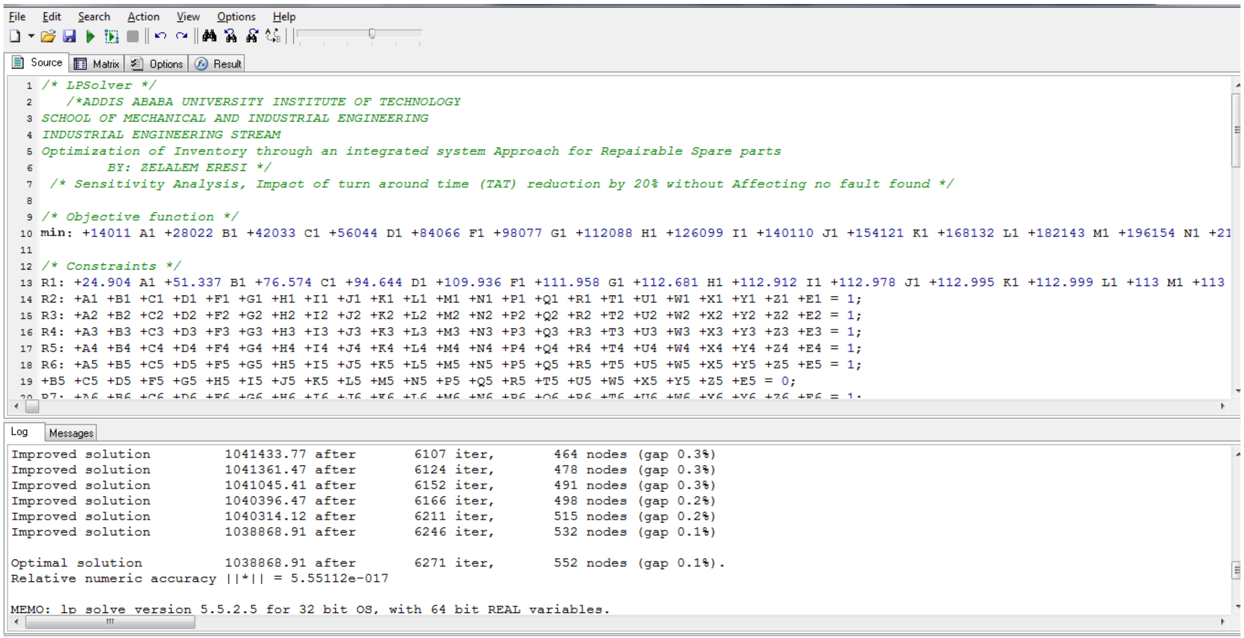

Figure 27: Sensitivity Analysis, Impact of turnaround Time (TAT)

6.3. Model Validation

The objective of this section is to validate (evaluate) the degree to which the optimization model represents the real existing system. Two methods of model validations are used during this research.

The first method is by comparison of the model output with the actual existing system and baseline results. In doing so, recent demand history or actual holding quantity (AHQ) during one-year time (2018) was collected for each repairable spare part. As shown on table 28, the total actual cost is 1,348,391.94 (USD). The actual holding quantities data collected for each repairable item are shown on Appendix VII. Cost saving compared to actual system for each scenario also shown on table 28. Based on table 28, all scenarios for each model have shown an improvement over the actual total cost except poison distribution model. As explained in chapter-2 (literature review), Poisson distribution may not always result into an improved result because of its inherent behavior. Considering mixed integer linear programming results of table 28, it has shown 19.57% improvement as compared to actual results (MILP, scenario-IV). Scenario-II and III indicates the impact of no fault found and Scrap when compared to actual system.

Mixed integer linear programming has shown 10.88% improvement when compared to baseline Poisson distribution result. Further comparison of marginal distribution result, mixed integer linear programming (MILP) result and Poisson distribution indicates that MILP has superior performance. Therefore, these results provide evidence that the model works properly.

Table 27: Model Validation, Comparison of Model Results and Actual System

Model Name	Scenarios	Total Cost(USD)	(%)Service Level	(%)Total Holding	Saving Compared to	Saving (%)Compared to Poisson Dist.	Saving (%)Compared to
Actual	**Actual**	1,348,391.94		144		(10.81)	
Poison Distribution	Scenario-I (Baseline)	1216879	94.83	84	9.75		
	Scenario-II	1764825	94.83	167	(30.88)	(45.03)	
	Scenario-III	889,956.51	94.83	84.00	34.00	26.87	
	Scenario-IV	1611357	94.83	151	(19.50)	(32.42)	
Marginal Dist.	Scenario-I	974760.8	99.8	88	27.71	19.90	19.8967
	Scenario-II	1131175.64	96.7	155	16.11	7.04	35.9044
	Scenario-III	845295.09	95.9	86	37.31	30.54	5.0184
	Scenario-IV	1106188	96.7	151	17.96	9.10	31.3505
MILP	Scenario-I	840276.12	95	112	37.68	30.95	30.9483
	Scenario-II	1117157.66	95	172	17.15	8.19	36.6987
	Scenario-III	798798.54	95	114	40.76	34.36	10.2430
	Scenario-IV	1084511.78	95	170	19.57	10.88	32.6957

The second approach utilized for model evaluation is by Validation of models' results against the results or behavior of other research findings.

[CITATION Alt11 \l 1033], mentioned that southwest airlines used supply chain optimization project, which reduced budget for repairable spare parts by 46.15%, while increasing service level (SL) from 92 to 95%. The company identified excess of 25million US dollar and avoided maintenance costs of two (2) million US dollar.

[CITATION Cle07 \l 1033], used a mixed integer linear programming model (MILP) to decide optimum levels inventory for set of repairable spare parts. This model version was tested in SR Technics, one of the world leading maintenance repair and overhaul service provider. But an issue that remained not addressed by this model is that some important decision variables such as scrap rate, no fault found events were not considered.

SR Technics, witnessed that their inventory investment decreased by 40% and 25% annual inventory savings obtained [CITATION www19 \l 1033]. This result shows 5.43% percentage over which is more significantly different from the research finding of this paper, which indicated inventory cost savings of 19.57 % based on mixed integer programming.

It was also mentioned that the management attained unparalleled management control. This is because stock levels managed to right levels, inventory turn is faster and overall profit performance improved. The company indicated that a 2-day reduction in component turnaround time (TAT) or repair cycle time enabled reduction of 7.5 million USD.

Chapter Seven

CONCLUSIONS AND RECOMMENDATIONS

7.1. CONCLUSIONS (RESEARCH FINDINGS)

This research indicates that there is a clear benefit in optimizing repairable inventories by taking no fault found and scrap rate as an input. Very significant cost savings were achieved without decreasing the service level when compared with current practice.

Comparative Evaluation of Repairable Spares Inventory optimization models under consideration of Scrap Rate and No fault found indicates that Poisson Distribution model provides least inventory saving. The overall service level achieved by this model is 94.83% and inventory cost savings of 9.75%. This is because this model operates at item level (not system level) which results into an excessive combined result. Mixed integer linear programming gives better improvement result as compared to Marginal Analysis model under consideration of scrap rates(SR) and no fault founds(NFF) as input variables. This models resulted into maximum

Inventory cost saving of 17.96% resulted while mixed integer linear programming model gives largest aggregate inventory cost saving result of 19.57%.

Regarding the effect Turn Around Time(TAT) on Repairable Inventory Cost, Sensitivity analysis indicates that total inventory cost saving of 4% can be achieved by reducing the shop repair cycle time by 20% without affecting no fault found impact. Combined total inventory saving of 37% can be achieved by reducing the repair cycle time by 20% and by reducing no fault found by 10% without affecting the service level.

Financial Impact of No fault found (NFF) on repairable inventory cost is about 5 % (4.936%) when compared to baseline scenario based on based on mixed integer linear programming (MILP). The interpretation of this percentage shows the difference between optimal total inventory cost results when no fault found (NFF) is considered as an input (decision variable) and when it is not considered as an input (i.e. when it is considered as negligible). Considering no fault found (NFF) as an input into mixed integer linear programming (MILP) model gives 5% lower total inventory value based as compared to baseline. Financial Impact of No fault found (NFF) is 13.282% based on marginal analysis model (scenario-III) as compared to baseline scenario. The impact of scrap rate (disposal rate) is on Repairable Inventory Cost is16.046% and 32.951% higher as compared to baseline scenario based on marginal analysis and mixed integer programming respectively. The Combined Financial Impact of No fault found (NFF) and Scrap Rate (SR) for marginal analysis and mixed integer programming models are 13.483% and 29.066% higher respectively when compared to baseline scenario.

7.2. Recommendations (Framework for Implementation)

Repairable spare parts inventory optimization framework is simplified and presented as shown on figure 28. The implementation framework is prepared by modifying and/or combining inventory optimization models discussed under section 2.5 of this work. Mainly inventory optimization frameworks of International Atomic Energy Agency (shown on figure 6), IATA Nine Step Inventory Provisioning Model (figure 8),inventory control framework(figure7),generic model for business process improvement [CITATION Sol05 \l 1033]and the five decision-making steps (Cavalieri et al, 2008) are modified and/or combined to develop the implementation framework.

As shown on figure 28, three implementation phases are identified. The first step is preparation phase, which includes procedure preparation, and training of employees regarding overall repairable spares inventory management. Then the next phase is inventory demand planning which mainly includes data collection and data analysis. Final phase is inventory utilization monitoring and reporting phase. Figure 28 also shows methods or approaches used for each phase and expected results.

Preparation of procedures and training are the main activities during preparation phase. Responsibilities are also established and forms or templates are also developed at this phase.

After preparation phase, reliability based demand planning are performed based on important reliability data such as mean time between failures(MTBF) and no fault found, repair cycle etc. The methods used for data collection or data analysis could be manual based or supported by commercial soft wares. After determining stock size, it must be monitored.

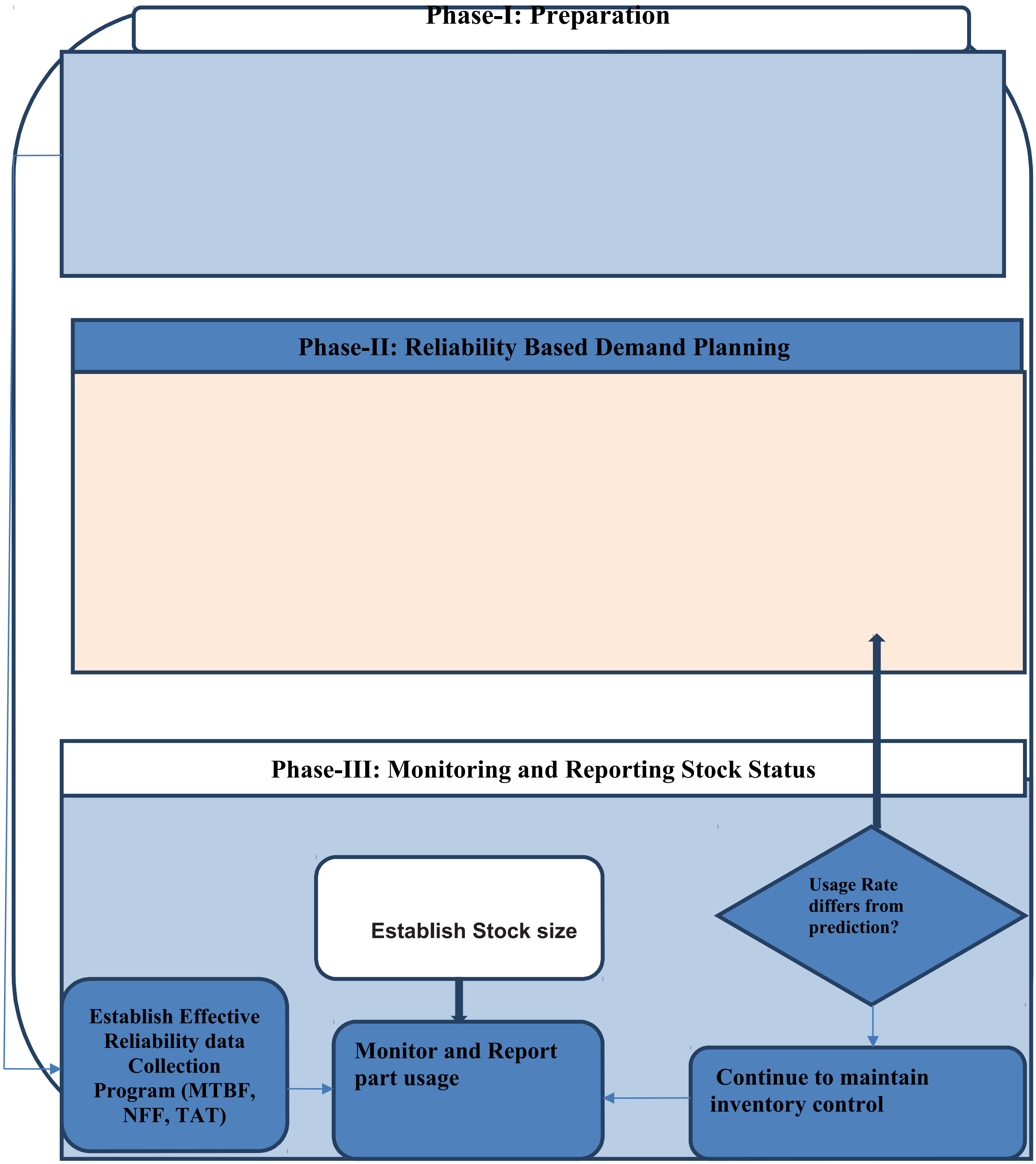

Figure 28: Aircraft Repairable Spare Parts Optimization Framework (Author)

7.3. Opportunities for Further Study

- ❖ To obtain supply chain system-wide optimization, there is a research opportunity to combine other factors that affect repairable spare parts supply chain performance like external logistics, fleet commonality, service life and other factors i.e. moving beyond optimization is needed.

- ❖ There is also an opportunity to extend the scope of this research to other industries.

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Appendixes

Appendix-I

S/N	PN	Description	REMS/YR(	Price(P)	VED Code	TATRepair	SparesTotal	NFF TAT	Total NFF	Scrap/Yr.	QPA	Cluster Group
1	5653215001	WHEEL AND TIRE ASSY	113	14,011.00	V	3.78	26	1.25	13	2	4	C-I
2	5653210008	WHEEL AND TIRE ASSY	110	14,011.00	V	6.03	23	2.43	17	2	4	C-I
3	5653210054	WHEEL AND TIRE ASSY	133	4,086.00	V	2	32	1.49	21	2	2	C-I
5	5653216062	WHEEL AND TIRE ASSY-Main	542	1,641.00	V	4.79	94	1.52	86	9	2	C-I
6	5653210054	WHEEL AND TIRE ASSY	1	4,086.00	V	4	1	1.2	0	0	2	C-I
7	5653230461	MLG-WHEEL AND TIRE ASSY	41	2,118.00	V	3.1	37	2.1	3	1	2	C-I
8	5653230462	WHEEL AND TIRE INSTL-NLG-01	9	1,641.00	V	0.63	8	0.5	1	0	2	C-I
9	5742410005	BATTERY	75	4,905.51	V	1.2	48	0.39	7	3	3	C-VI
10	5742518001	B/E OVEN - STEAM	22	10,250.88	D	0.7	20	0.23	2	1	4	C-VII
11	5742511457	OVEN	20	679.13	D	0.5	15	0.16	2	1	6	C-VII
12	5742520004	COFFEE MAKER	19	107.77	D	0.45	16	0.15	2	1	3	C-VII
13	5743516000	MASK ASSY - OXY FULL FACE	17	3,558.85	V	5.2	17	1.5	2	1	3	C-VII
14	57425H0001	B/E COFFEE MAKER	16	3,728.81	D	2.4	16	0.8	2	1	3	C-VII
15	57425H0013	B/E WATER BOILER	15	3,226.58	D	3.5	1	1.5	2	1	4	C-VII
16	57425H0004	B/E STEAM OVEN	15	141,261.71	V	0.67	15	0.22	2	1	6	C-VII
17	5743310331	LIGHT ASSY-LOGO	15	2,990.00	D	0.3	12	0.1	2	1	1	C-VII
18	5743310068	LIGHT ASSY-LOGO	12	2,990.00	D	0.3	9	0.1	2	1	1	C-VII
19	5743310005	POWER SUPPLY-EMER	10	3,784.00	E	4.1	9	1.2	1	1	8	C-VII
20	5742710036	MODULE ASSY - STAB. TRIM AND CAB. DOOR	10	5,212.00	E	0.4	6	0.13	1	1	1	C-VII
21	5742520009	BOILER-WATER	9	4,440.00	D	0.5	7	0.16	1	1	2	C-VII

22	5743310126	PANEL ASSY - MAP/CHART LT	8	4,930.00	D	0.46	6	0.15	1	1	1	C-VII
23	5743520006	PBE	8	1,012.50	V	0.6	8	0.2	1	1	5	C-VII
24	5743310006	LIGHT ASSY-(LIGHTS ONLY)	8	5,268.45	E	0.35	6	0.11	1	1	1	C-VII
25	5743310067	PANEL ASSY - MAP/CHART LT CONT P23-1	7	4,325.00	D	0.5	6	0.16	1	1	1	C-VII
26	5743310234	LIGHT ASSY - NON-LED	6	2,248.80	E	0.3	6	0.1	1	1	1	C-VII
27	5743310378	LIGHT	5	10,469.13	E	1.6	5	1.75	1	1	1	C-VII
28	5742520004	COFFEE MAKER	5	8.98	D	0.5	5	0.16	1	1	3	C-VII
29	5743520006	SMOKE HOOD - PBE	5	1,012.50	E	2	5	0.66	1	1	5	C-VII
30	5742410067	BATTERY ASSY	4	2,905.00	V	4.2	3	1.6	1	1	1	C-VI
31	5742526000	OVEN	4	730.83	D	0.67		0.22	0	1	4	C-VII
32	5742410005	BATTERY	4	856	V	0.6	3	0.2	0	1	1	C-VI
33	5742511462	PANEL ASSY	3	5,393.00	D	0.5	1	0.16	0	0	3	C-VII
34	5743318001	LIGHT ASSY - 35 IN	3	1,508.34	D	1.5	3	0.5	0	0	1	C-VII
35	5742310112	BATTERY PACK ASSY	3	80,336.49	V	3.2	2	1	0	0	1	C-VI
36	5743310133	LIGHT ASSY	3	848	D	0.4	3	0.13	0	0	12	C-VII
37	5745220114	MODULE ASSY - CHIME CONTROLLER	3	9,164.95	D	0.55	3	0.18	0	0	4	C-VII
38	5742511446	FLASHLIGHT	3	5,025.49	D	0.25	3	0.08	0	0	6	C-VII
39	5742210009	SWITCHPACK ASSY	3	9,668.00	V	1.50 .	2	0.45	0	0	1	C-VII
40	57433H0142	BALLAST	3	834	D	3.6	3	2.1	0	0	3	C-VII
41	5743310296	LIGHT ASSY	3	470.27	E	4.3	3	1.3	0	0	1	C-VII
42	5742526000	OVEN	3	31.78	D	0.55	3	0.18	0	0	4	C-VII
43	5743515001	MASK-FULL FACE OXY	3	1,874.04	E	2.7	3	0.9	0	0	5	C-VII
44	5744716004	SWITCH-THERMAL	2	143.61	E	4.8	2	2.1	0	0	4	C-VII
45	5742539019	B/E OVEN	2	329.97	D	1.92	2	0.6	0	0	1	C-VII

		CONTROL MODULE										
46	5743510001	MASK ASSY	2	30.96	V	3.3	2	1	0	0	3	C-VII
47	5743310001	LIGHT ASSY-(LIGHTS ONLY)	2	5,562.08	E	0.6	2	0.2	0	0	1	C-VII
48	5743310236	LIGHT ASSY - WING POSITION NAV RED	2	193.36	V	0.08	1	0.03	0	0	2	C-VII
49	5742511457	OVEN	2	77.61	D	0.5	2	0.16	0	0	6	C-VII
50	5743360148	LIGHT ASSY	2	337.77	D	1.74	2	1.2	0	0	4	C-VII
51	5742410004	MAIN(AUXILIARY) BATTERY CHARGER	2	32,595.00	V	1.2	2	0.39	0	0	2	C-VI
52	5742511446	FLASHLIGHT	2	337.77	D	0.3	2	0.1	0	0	6	C-VII
53	5744910092	LEAD-IGNITER PLUG	2	558.5	E	3.5	2	0.72	0	0	1	C-VII
54	5743310199	print board	2	786.87	D	4.1	2	2.1	0	0	2	C-VII
55	5742610006	DETECTOR ASSY-SMOKE CARGO COMPT	2	2,160.93	E	4.43	2	1.78	0	0	10	C-VII
56	5743310033	LIGHT ASSY-(LIGHTS ONLY)	1	6,895.06	E	1.6	1	0.8	0	0	1	C-VII
57	5747410002	SWITCH	1	3,844.00	E	4.3	1	1.2	0	0	2	C-VII
58	5743110008	MODULE ASSY	1	22,914.00	V	2.6	1	0.3	0	0	1	C-VII
59	5742120018	SWITCH ASSY	1	1,693.00	E	0.17	1	0.05	0	0	2	C-VII
60	5743310179	LIGHT ASSY	1	1,366.66	D	2.3	1	0.85	0	0	1	C-VII
61	57425H0637	B/E OVEN CONTROL MODULE	1	1,996.91	D	4.36	1	1.9	0	0	4	C-VII
62	5742610001	DETECTOR ASSY	1	10,120.00	E	0.33	1	0.11	0	0	2	C-VII
63	5742410013	MODULE ASSY	1	39,756.00	E	2.1	1	0.5	0	0	1	C-VII
64	5743310197	LIGHT SUBASSY	1	1,725.40	E	3.8	1	2	0	0	1	C-VII
65	5742510360	SERVICE UNIT ASSY-PASS. WITH	1	5,393.00	D	0.42	1	0.14	0	0	3	C-VII

		2K SPKR AND GASPER										
66	5743110029	MODULE ASSY	1	5,035.00	E	0.33	1	0.11	0	0	1	C-VII
67	5742110037	OUTLET	1	104	D	7.2	1	3.1	0	0	7	C-VII
68	5743310002	LIGHT ASSY	1	37,663.00	E	0.5	1	0.16	0	0	1	C-VII
69	5743310191	HOUSING ASSY - EXIT SIGN LWR CLG	1	1,270.00	D	5.2	1	1.82	0	0	1	C-VII
70	57425H0451	B/E Oven Control Module	1	1,996.91	D	9.8	1	5.1	0	0	6	C-VII
71	5743310076	LIGHT ASSY-THRESHOLD	1	673.02	D	0.17	1	0.05	0	0	1	C-VII
72	5743310050	LIGHT ASSY	1	165.32	D	0.33	1	0.11	0	0	126	C-VII
73	5753520008	CYLINDER ASSY	86	2,455.21	V	7.7	27	5.62	10	2	1	C-IV
74	5753520008	CYLINDER ASSY	44	2,455.21	V	4.86	17	3.55	5	1	1	C-IV
75	5753520016	BOTTLE ASSY-OXY	279	47.52	V	7.44	59	5.43	31	6	1	C-IV
76	57547H0015	SWITCH-NGS	1	4,005.52	E	5	1	1.67	0	0	1	C-IV
77	5753520008	CYLINDER ASSY	4	697.84	V	2.66	2	1.94	1	0	1	C-IV
78	5753520020	CYLINDER ASSY-OXYGEN CYLINDER	11	17,674.52	V	4.47	7	3.26	0	1	1	C-IV
79	5753416002	INDICATOR-INTEGRATED STBY FLIGHT DISPLAY	3	4,005.52	V	6.3	3	4.6	1	0	1	C-IV
80	5753520008	CYLINDER ASSY	35	661.77	V	4.92	12	3.59	4	1	1	C-IV
81	5753220136	SWITCH ASSY-PRESSURE	5	640.7	V	8.4	5	6.1	1	0	1	C-IV
82	5753520020	BOTTLE ASSY-OXY	12	661.77	V	8.9	6	5.6	2	1	6	C-IV
83	5757310014	SWITCH	7	582.4	E	1.43	3	0.13	2	1	1	C-IV
84	5732310023	MONITOR-RETRACTOR LCD 10.4 IN.	16	15,960.00	D	8.67	14	0.78	4	1	8	C-V
85	5732320058	ACARS CMU - ACARS COMM	2	34,823.00	E	0.47	2	0.04	1	0	1	C-V

		MANAGEMENT UNIT										
86	5732318007	SERVER	5	1,628.00	D	1.49	3	0.13	1	0	6	C-V
87	5733420055	ANTENNA ASSY	4	431	E	8.71	1	1.68	1	0	1	C-V
88	5732310035	SEB	10	535.73	D	0.69	10	0.06	2	1	170	C-V
89	5732531123	MEGAPHONE	46	1,068.00	E	1.52	38	0.5	11	2	2	C-V
90	5733010002	CONTROLLER ASSY-WINDOW HEAT CONT UNIT	2	8,140.00	E	9.04	2	1.71	1	0	4	C-V
91	5732310024	MONITOR-RETRACTOR LCD 10.4 IN.	15	15,960.00	D	3.14	13	0.28	5	1	8	C-V
92	5733420040	TRANSCEIVER	4	109,952.00	E	9.55	3	1.76	1	1	1	C-V
93	5732316001	CONTROL UNIT-SYSTEM	3	17,942.00	D	9.65	3	1.77	1	0	1	C-V
94	5732310105	PRINTER-ARINC 740 MULTI-INPUT	9	7,556.10	D	11.3	8	1.02	2	1	2	C-V
95	5732310067	MICROPHONE	18	148.5	E	0.17	13	0.01	4	1	3	C-V
96	5732318010	DPCU	44	321.88	E	0.08	40	0.01	10	2	3	C-V
97	5732310001	PANEL-AUDIO SELECTOR CONT CAPT AND FIRST OFFICER	1	7,087.00	E	3.54	1	0.32	0	0	3	C-V
98	5733430078	ANTENNA	5	408	E	12.15	4	1.09	1	0	4	C-V
99	5732315007	DPCU	13	250.03	E	0.08	12	0.01	3	1	6	C-V
100	5732316003	RH DPCU	1	296.66	E	0.08	1	0.01	0	0	3	C-V
101	5732310003	PANEL	1	432.85	E	8.6	1	0.77	0	0	1	C-V
102	5732310057	CRADLE ASSY	1	3,584.00	D	1.2	1	0.82	0	0	3	C-V
103	5662511377	LIFE RAFT-46 PERSON	35	813.18	E	7.1	1	4.33	3	1	3	C-VIII
104	5662510008	SLIDE ASSY-ESCAPE	33	507	D	11.4	30	6.95	2	1	2	C-VIII
105	56625H0708	INFANT LIFE VEST	13	108.99	E	4.2	13	2.4	1	1	10	C-VIII
106	5662511370	LIFE VEST-CREW	5	201.85	E	9.7	5	5.92	1	0	9	C-VIII

107	56625H0821	LIFE VEST - INFANT	4	13.99	E	5.3	4	15.43	1	0	10	C-VIII
108	5662511417	LIFE RAFT	4	34,994.00	E	8.6	4	5.25	1	0	3	C-VIII
109	5662511350	LIFE VEST	1	144.7	E	1	1	0.61	0	0	10	C-VIII
110	5633210050	BRAKE ASSY - CARBON MESSIER-BUGATTI	62	11,733.00	V	5.6	54	2.8	3	2	2	C-III
111	5633210006	BRAKE ASSY-BENDIX HIGH CAPACITY	29	25,705.00	E	6.4	23	3.2	2	1	4	C-III
112	5632760525	FUSE	5	4,759.78	V	0.5	5	0.24	1	1	1	C-III
113	5637810015	ACTUATOR-FAN DUCT COWL	1	11,954.00	E	4.3	1	2.5	0	0	4	C-III
114	5632910082	VALVE-DRAIN	3	1,101.00	V	0.4	3	0.19	0	0	2	C-III
115	5632720153	FUSE	3	4,975.31	V	0.55	2	0.26	0	0	1	C-III
116	5632910001	PUMP ASSY	1	27,700.00	V	1	1	0.48	0	0	2	C-III
117	5632910005	PUMP ASSY	4	5,147.00	E	1	3	0.48	1	1	2	C-III
118	5642620009	EXTINGUISHER ASSY-HALON	81	296.75	E	2.87	74	2.41	3	4	3	C-II
119	5642610005	BOTTLE ASSY	21	7,044.35	E	3.4	20	2.86	1	1	3	C-II
120	5642630057	EXTINGUISHER ASSY-FIRE	25	953.13	E	8.86	24	7.44	1	1	1	C-II
121	5642610007	BOTTLE ASSY-FIRE EXT	10	9,673.78	E	1	10	0.84	1	1	2	C-II
122	5642630043	LAVATORY EXTINGUISHER	15	296.75	D	0.4	15	0.34	1	1	3	C-II
123	5642115006	VALVE-PACK TEMP CONTROL	15	1,010.00	V	8.1	15	6.8	1	1	4	C-II
124	5642110051	EXCHANGER ASSY	43	15,340.50	E	4.1	33	3.44	2	2	4	C-II
125	5642115006	VALVE ASSY-TEMP CONT	5	1,123.00	V	9.32	4	7.83	0	0	4	C-II
126	5643010018	BLADE ASSY	4	988	V	6.6	4	5.54	0	0	1	C-II
127	5644716003	EXCHANGER-HEAT	4	15,340.50	E	7.4	4	6.22	0	0	4	C-II

128	5642660049	LAVATORY EXTINGUISHER	2	16,360.50	E	1.2	2	1.01	0	0	4	C-II
129	5645610069	WINDSHIELD ASSY	2	16,511.00	V	13.8	2	11.59	0	0	1	C-II
130	5645616001	WINDSHIELD ASSY	2	18,520.00	V	14.3	2	12.01	0	0	4	C-II
131	5645616000	WINDSHIELD ASSY	1	18,520.00	V	13.33	1	11.2	0	0	4	C-II
132	5642110018	SEPARATOR ASSY-AIR COND	1	13,380.00	V	0.5	1	0.42	0	0	2	C-II
133	5645610016	WINDSHIELD ASSY	1	16,511.00	V	1.33	1	1.12	0	0	1	C-II

S/N	PN	Description	REMS/YR(R)	Price(P)	VED Code	Repair TAT	Total Spares	NFF TAT	Total NFF	Scrap/Yr.	QPA
1	5653215001	WHEEL AND TIRE ASSY	113	14,011.00	V	3.78	26	1.25	13	2	4
2	5653210008	WHEEL AND TIRE ASSY	110	14,011.00	V	6.03	23	2.43	17	2	4
3	5653210054	WHEEL AND TIRE ASSY	133	4,086.00	V	2.00	32	1.49	21	2	2
5	5653216062	WHEEL AND TIRE ASSY-Main	542	1,641.00	V	4.79	94	1.52	86	9	2
6	5653210054	WHEEL AND TIRE ASSY	1	4,086.00	V	4.00	1	1.2	0	0	2
7	5653230461	MLG-WHEEL AND TIRE ASSY	41	2,118.00	V	3.10	37	2.1	3	1	2
8	5653230462	WHEEL AND TIRE INSTL-NLG-01	9	1,641.00	V	0.63	8	0.5	1	0	2
9	5742410005	BATTERY	75	4,905.51	V	1.20	48	0.39	7	3	3
10	5742518001	B/E OVEN - STEAM	22	10,250.88	D	0.70	20	0.23	2	1	4
11	5742511457	OVEN	20	679.13	D	0.50	15	0.16	2	1	6
12	5742520004	COFFEE MAKER	19	107.77	D	0.45	16	0.15	2	1	3
13	5743516000	MASK ASSY - OXY FULL FACE	17	3,558.85	V	5.20	17	1.5	2	1	3
14	57425H0001	B/E COFFEE MAKER	16	3,728.81	D	2.40	16	0.8	2	1	3
15	57425H0013	B/E WATER BOILER	15	3,226.58	D	3.50	1	1.5	2	1	4
16	57425H0004	B/E STEAM OVEN	15	141,261.71	V	0.67	15	0.22	2	1	6
17	5743310331	LIGHT ASSY-LOGO	15	2,990.00	D		12	0.1	2	1	1

						0.30					
18	5743310068	LIGHT ASSY-LOGO	12	2,990.00	D	0.30	9	0.1	2	1	1
19	5743310005	POWER SUPPLY-EMER	10	3,784.00	E	4.10	9	1.2	1	1	8
20	5742710036	MODULE ASSY - STAB. TRIM AND CAB. DOOR	10	5,212.00	E	0.40	6	0.13	1	1	1
21	5742520009	BOILER-WATER	9	4,440.00	D	0.50	7	0.16	1	1	2
22	5743310126	PANEL ASSY - MAP/CHART LT	8	4,930.00	D	0.46	6	0.15	1	1	1
23	5743520006	PBE	8	1,012.50	V	0.60	8	0.2	1	1	5
24	5743310006	LIGHT ASSY-(LIGHTS ONLY)	8	5,268.45	E	0.35	6	0.11	1	1	1
25	5743310067	PANEL ASSY - MAP/CHART LT CONT P23-1	7	4,325.00	D	0.50	6	0.16	1	1	1
26	5743310234	LIGHT ASSY - NON-LED	6	2,248.80	E	0.30	6	0.1	1	1	1
27	5743310378	LIGHT	5	10,469.13	E	1.60	5	1.75	1	1	1
28	5742520004	COFFEE MAKER	5	8.98	D	0.50	5	0.16	1	1	3
29	5743520006	SMOKE HOOD - PBE	5	1,012.50	E	2.00	5	0.66	1	1	5
30	5742410067	BATTERY ASSY	4	2,905.00	V	4.20	3	1.6	1	1	1
31	5742526000	OVEN	4	730.83	D	0.67		0.22	0	1	4
32	5742410005	BATTERY	4	856	V	0.60	3	0.2	0	1	1
33	5742511462	PANEL ASSY	3	5,393.00	D	0.50	1	0.16	0	0	3
34	5743318001	LIGHT ASSY - 35 IN	3	1,508.34	D	1.50	3	0.5	0	0	1
35	5742310112	BATTERY PACK ASSY	3	80,336.49	V	3.20	2	1	0	0	1
36	5743310133	LIGHT ASSY	3	848	D	0.40	3	0.13	0	0	12
37	5745220114	MODULE ASSY - CHIME CONTROLLER	3	9,164.95	D	0.55	3	0.18	0	0	4
38	5742511446	FLASHLIGHT	3	5,025.49	D	0.25	3	0.08	0	0	6
39	5742210009	SWITCHPACK ASSY	3	9,668.00	V	1.50.	2	0.45	0	0	1
40	57433H0142	BALLAST	3	834	D	3.60	3	2.1	0	0	3
41	5743310296	LIGHT ASSY	3	470.27	E	4.30	3	1.3	0	0	1
42	5742526000	OVEN	3	31.78	D		3	0.18	0	0	4

						0.55					
43	5743515001	MASK-FULL FACE OXY	3	1,874.04	E	2.70	3	0.9	0	0	5
44	5744716004	SWITCH-THERMAL	2	143.61	E	4.80	2	2.1	0	0	4
45	5742539019	B/E OVEN CONTROL MODULE	2	329.97	D	1.92	2	0.6	0	0	1
46	5743510001	MASK ASSY	2	30.96	V	3.30	2	1	0	0	3
47	5743310001	LIGHT ASSY-(LIGHTS ONLY)	2	5,562.08	E	0.60	2	0.2	0	0	1
48	5743310236	LIGHT ASSY - WING POSITION NAV RED	2	193.36	V	0.08	1	0.03	0	0	2
49	5742511457	OVEN	2	77.61	D	0.50	2	0.16	0	0	6
50	5743360148	LIGHT ASSY	2	337.77	D	1.74	2	1.2	0	0	4
51	5742410004	MAIN(AUXILIARY) BATTERY CHARGER	2	32,595.00	V	1.20	2	0.39	0	0	2
52	5742511446	FLASHLIGHT	2	337.77	D	0.30	2	0.1	0	0	6
53	5744910092	LEAD-IGNITER PLUG	2	558.5	E	3.50	2	0.72	0	0	1
54	5743310199	print board	2	786.87	D	4.10	2	2.10	0	0	2
55	5742610006	DETECTOR ASSY-SMOKE CARGO COMPT	2	2,160.93	E	4.43	2	1.78	0	0	10
56	5743310033	LIGHT ASSY-(LIGHTS ONLY)	1	6,895.06	E	1.60	1	0.8	0	0	1
57	5747410002	SWITCH	1	3,844.00	E	4.30	1	1.20	0	0	2
58	5743110008	MODULE ASSY	1	22,914.00	V	2.60	1	0.30	0	0	1
59	5742120018	SWITCH ASSY	1	1,693.00	E	0.17	1	0.05	0	0	2
60	5743310179	LIGHT ASSY	1	1,366.66	D	2.30	1	0.85	0	0	1
61	57425H0637	B/E OVEN CONTROL MODULE	1	1,996.91	D	4.36	1	1.9	0	0	4
62	5742610001	DETECTOR ASSY	1	10,120.00	E	0.33	1	0.11	0	0	2
63	5742410013	MODULE ASSY	1	39,756.00	E	2.10	1	0.5	0	0	1
64	5743310197	LIGHT SUBASSY	1	1,725.40	E	3.80	1	2	0	0	1
65	5742510360	SERVICE UNIT ASSY-PASS. WITH 2K SPKR AND GASPER	1	5,393.00	D	0.42	1	0.14	0	0	3
66	5743110029	MODULE ASSY	1	5,035.00	E	0.33	1	0.11	0	0	1
67	5742110037	OUTLET	1	104	D		1	3.10	0	0	7

						7.20					
68	5743310002	LIGHT ASSY	1	37,663.00	E	0.50	1	0.16	0	0	1
69	5743310191	HOUSING ASSY - EXIT SIGN LWR CLG	1	1,270.00	D	5.20	1	1.82	0	0	1
70	57425H0451	B/E Oven Control Module	1	1,996.91	D	9.80	1	5.1	0	0	6
71	5743310076	LIGHT ASSY-THRESHOLD	1	673.02	D	0.17	1	0.05	0	0	1
72	5743310050	LIGHT ASSY	1	165.32	D	0.33	1	0.11	0	0	126
73	5753520008	CYLINDER ASSY	86	2,455.21	V	7.70	27	5.62	10	2	1
74	5753520008	CYLINDER ASSY	44	2,455.21	V	4.86	17	3.55	5	1	1
75	5753520016	BOTTLE ASSY-OXY	279	47.52	V	7.44	59	5.43	31	6	1
76	57547H0015	SWITCH-NGS	1	4,005.52	E	5.00	1	1.67	0	0	1
77	5753520008	CYLINDER ASSY	4	697.84	V	2.66	2	1.94	1	0	1
78	5753520020	CYLINDER ASSY-OXYGEN CYLINDER	11	17,674.52	V	4.47	7	3.26	0	1	1
79	5753416002	INDICATOR-INTEGRATED STBY FLIGHT DISPLAY	3	4,005.52	V	6.30	3	4.6	1	0	1
80	5753520008	CYLINDER ASSY	35	661.77	V	4.92	12	3.59	4	1	1
81	5753220136	SWITCH ASSY-PRESSURE	5	640.7	V	8.40	5	6.1	1	0	1
82	5753520020	BOTTLE ASSY-OXY	12	661.77	V	8.90	6	5.6	2	1	6
83	5757310014	SWITCH	7	582.4	E	1.43	3	0.13	2	1	1
84	5732310023	MONITOR-RETRACTOR LCD 10.4 IN.	16	15,960.00	D	8.67	14	0.78	4	1	8
85	5732320058	ACARS CMU - ACARS COMM MANAGEMENT UNIT	2	34,823.00	E	0.47	2	0.04	1	0	1
86	5732318007	SERVER	5	1,628.00	D	1.49	3	0.13	1	0	6
87	5733420055	ANTENNA ASSY	4	431	E	8.71	1	1.68	1	0	1
88	5732310035	SEB	10	535.73	D	0.69	10	0.06	2	1	170
89	5732531123	MEGAPHONE	46	1,068.00	E	1.52	38	0.5	11	2	2
90	5733010002	CONTROLLER ASSY-WINDOW HEAT CONT UNIT	2	8,140.00	E	9.04	2	1.71	1	0	4
91	5732310024	MONITOR-RETRACTOR LCD 10.4 IN.	15	15,960.00	D	3.14	13	0.28	5	1	8
92	5733420040	TRANSCEIVER	4	109,952.00	E	9.55	3	1.76	1	1	1
93	5732316001	CONTROL UNIT-SYSTEM	3	17,942.00	D	9.65	3	1.77	1	0	1
94	5732310105	PRINTER-ARINC 740 MULTI-INPUT	9	7,556.10	D	11.3	8	1.02	2	1	2
95	5732310067	MICROPHONE	18	148.5	E	0.17	13	0.01	4	1	3

96	5732318010	DPCU	44	321.88	E	0.08	40	0.01	10	2	3
97	5732310001	PANEL-AUDIO SELECTOR CONT CAPT AND FIRST OFFICER	1	7,087.00	E	3.54	1	0.32	0	0	3
98	5733430078	ANTENNA	5	408	E	12.15	4	1.09	1	0	4
99	5732315007	DPCU	13	250.03	E	0.08	12	0.01	3	1	6
100	5732316003	RH DPCU	1	296.66	E	0.08	1	0.01	0	0	3
101	5732310003	PANEL	1	432.85	E	8.6	1	0.77	0	0	1
102	5732310057	CRADLE ASSY	1	3,584.00	D	1.2	1	0.82	0	0	3
103	5662511377	LIFE RAFT-46 PERSON	35	813.18	E	7.10	1	4.33	3	1	3
104	5662510008	SLIDE ASSY-ESCAPE	33	507	D	11.40	30	6.95	2	1	2
105	56625H0708	INFANT LIFE VEST	13	108.99	E	4.20	13	2.4	1	1	10
106	5662511370	LIFE VEST-CREW	5	201.85	E	9.70	5	5.92	1	0	9
107	56625H0821	LIFE VEST - INFANT	4	13.99	E	5.30	4	15.43	1	0	10
108	5662511417	LIFE RAFT	4	34,994.00	E	8.60	4	5.25	1	0	3
109	5662511350	LIFE VEST	1	144.7	E	1.00	1	0.61	0	0	10
110	5633210050	BRAKE ASSY - CARBON MESSIER-BUGATTI	62	11,733.00	V	5.60	54	2.8	3	2	2
111	5633210006	BRAKE ASSY-BENDIX HIGH CAPACITY	29	25,705.00	E	6.40	23	3.2	2	1	4
112	5632760525	FUSE	5	4,759.78	V	0.50	5	0.24	1	1	1
113	5637810015	ACTUATOR-FAN DUCT COWL	1	11,954.00	E	4.30	1	2.50	0	0	4
114	5632910082	VALVE-DRAIN	3	1,101.00	V	0.40	3	0.19	0	0	2
115	5632720153	FUSE	3	4,975.31	V	0.55	2	0.26	0	0	1
116	5632910001	PUMP ASSY	1	27,700.00	V	1.00	1	0.48	0	0	2
117	5632910005	PUMP ASSY	4	5,147.00	E	1.00	3	0.48	1	1	2
118	5642620009	EXTINGUISHER ASSY-HALON	81	296.75	E	2.87	74	2.41	3	4	3
119	5642610005	BOTTLE ASSY	21	7,044.35	E	3.40	20	2.86	1	1	3
120	5642630057	EXTINGUISHER ASSY-FIRE	25	953.13	E	8.86	24	7.44	1	1	1
121	5642610007	BOTTLE ASSY-FIRE EXT	10	9,673.78	E	1.00	10	0.84	1	1	2
122	5642630043	LAVATORY EXTINGUISHER	15	296.75	D	0.40	15	0.34	1	1	3

123	5642115006	VALVE-PACK TEMP CONTROL	15	1,010.00	V	8.10	15	6.8	1	1	4
124	5642110051	EXCHANGER ASSY	43	15,340.50	E	4.10	33	3.44	2	2	4
125	5642115006	VALVE ASSY-TEMP CONT	5	1,123.00	V	9.32	4	7.83	0	0	4
126	5643010018	BLADE ASSY	4	988	V	6.60	4	5.54	0	0	1
127	5644716003	EXCHANGER-HEAT	4	15,340.50	E	7.40	4	6.22	0	0	4
128	5642660049	LAVATORY EXTINGUISHER	2	16,360.50	E	1.20	2	1.01	0	0	4
129	5645610069	WINDSHIELD ASSY	2	16,511.00	V	13.80	2	11.59	0	0	1
130	5645616001	WINDSHIELD ASSY	2	18,520.00	V	14.30	2	12.01	0	0	4
131	5645616000	WINDSHIELD ASSY	1	18,520.00	V	13.33	1	11.2	0	0	4
132	5642110018	SEPARATOR ASSY-AIR COND	1	13,380.00	V	0.50	1	0.42	0	0	2
133	5645610016	WINDSHIELD ASSY	1	16,511.00	V	1.33	1	1.12	0	0	1

Appendix-II

S/N	PN	Description	REMS/YR(R)	Price(P)	VED Code	Service Level(SL)	R*SL	R*SL*P	%	Cumulative %	ABC- Code	ABC-VED
1	5653215001	WHEEL AND TIRE ASSY	113	14,011.00	V	0.95	107.35	1504080.9	12.1	27.42	A	AV
2	5653210008	WHEEL AND TIRE ASSY	110	14,011.00	V	0.95	104.50	1464149.5	11.8	39.19	A	AV
3	5653210054	WHEEL AND TIRE ASSY	133	4,086.00	V	0.95	126.35	516266.1	4.15	66.2	A	AV
5	5653216062	WHEEL AND TIRE ASSY-Main	542	1,641.00	V	0.95	514.90	844950.9	6.79	45.99	A	AV
6	5653210054	WHEEL AND TIRE ASSY	1	4,086.00	V	0.95	0.95	3881.7	0.03	99.45	C	CV
7	5653230461	MLG-WHEEL AND TIRE ASSY	41	2,118.00	V	0.95	38.95	82496.1	0.66	86.81	B	BV
8	5653230462	WHEEL AND TIRE INSTL-NLG-01	9	1,641.00	V	0.95	8.55	14030.55	0.11	97.76	C	CV
9	5742410005	BATTERY	75	4,905.51	V	0.95	71.25	349517.59	2.81	72.3	A	AV
10	5742518001	B/E OVEN - STEAM	22	10,250.88	D	0.90	19.80	202967.42	1.63	79.35	B	BD
11	5742511457	OVEN	20	679.13	D	0.90	18.00	12224.34	0.1	98.37	C	CD
12	5742520004	COFFEE MAKER	19	107.77	D	0.90	17.10	1842.867	0.01	99.83	C	CD
13	5743516000	MASK ASSY - OXY FULL FACE	17	3,558.85	V	0.95	16.15	57475.427	0.46	88.78	B	BV
14	57425H0001	B/E COFFEE MAKER	16	3,728.81	D	0.90	14.40	53694.864	0.43	89.67	B	BD
15	57425H0013	B/E WATER BOILER	15	3,226.58	D	0.90	13.50	43558.83	0.35	91.56	B	BD
16	57425H0004	B/E STEAM OVEN	15	141,261.71	V	0.90	13.50	1907033.1	15.3	15.33	A	AV
17	5743310331	LIGHT ASSY-LOGO	15	2,990.00	D	0.90	13.50	40365	0.32	91.89	B	BD
18	5743310068	LIGHT ASSY-LOGO	12	2,990.00	D	0.90	10.80	32292	0.26	94.18	B	BD
19	5743310005	POWER SUPPLY-EMER	10	3,784.00	E	0.93	9.30	35191.2	0.28	93.07	B	BE
20	5742710036	MODULE ASSY - STAB. TRIM AND CAB. DOOR	10	5,212.00	E	0.93	9.30	48471.6	0.39	90.45	B	BE
21	5742520009	BOILER-WATER	9	4,440.00	D	0.90	8.10	35964	0.29	92.79	B	BD
22	5743310126	PANEL ASSY - MAP/CHART LT	8	4,930.00	D	0.90	7.20	35496	0.29	93.64	B	BD
23	5743520006	PBE	8	1,012.50	V			7695	0.06	98.86	C	CV

						0.95	7.60					
24	5743310006	LIGHT ASSY-(LIGHTS ONLY)	8	5,268.45	E	0.93	7.44	39197.268	0.32	92.2	B	BE
25	5743310067	PANEL ASSY - MAP/CHART LT CONT P23-1	7	4,325.00	D	0.90	6.30	27247.5	0.22	95.12	C	CD
26	5743310234	LIGHT ASSY - NON-LED	6	2,248.80	E	0.93	5.58	12548.304	0.1	98.28	C	CE
27	5743310378	LIGHT	5	10,469.13	E	0.93	4.65	48681.455	0.39	90.06	B	BE
28	5742520004	COFFEE MAKER	5	8.98	D	0.90	4.50	40.41	0	100	C	CD
29	5743520006	SMOKE HOOD - PBE	5	1,012.50	E	0.93	4.65	4708.125	0.04	99.29	C	CE
30	5742410067	BATTERY ASSY	4	2,905.00	V	0.95	3.80	11039	0.09	98.64	C	CV
31	5742526000	OVEN	4	730.83	D	0.90	3.60	2630.988	0.02	99.74	C	CD
32	5742410005	BATTERY	4	856	V	0.95	3.80	3252.8	0.03	99.6	C	CV
33	5742511462	PANEL ASSY	3	5,393.00	D	0.90	2.70	14561.1	0.12	97.41	C	CD
34	5743318001	LIGHT ASSY - 35 IN	3	1,508.34	D	0.90	2.70	4072.518	0.03	99.36	C	CD
35	5742310112	BATTERY PACK ASSY	3	80,336.49	V	0.95	2.85	228959	1.84	74.14	A	AV
36	5743310133	LIGHT ASSY	3	848	D	0.90	2.70	2289.6	0.02	99.78	C	CD
37	5745220114	MODULE ASSY - CHIME CONTROLLER	3	9,164.95	D	0.90	2.70	24745.365	0.2	95.74	C	CD
38	5742511446	FLASHLIGHT	3	5,025.49	D	0.90	2.70	13568.823	0.11	97.86	C	CD
39	5742210009	SWITCHPACK ASSY	3	9,668.00	V	0.95	2.85	27553.8	0.22	94.9	B	BV
40	57433H0142	BALLAST	3	834	D	0.90	2.70	2251.8	0.02	99.8	C	CD
41	5743310296	LIGHT ASSY	3	470.27	E	0.93	2.79	1312.0533	0.01	99.93	C	CE
42	5742526000	OVEN	3	31.78	D	0.90	2.70	85.806	0	100	C	CD
43	5743515001	MASK-FULL FACE OXY	3	1,874.04	E	0.93	2.79	5228.5716	0.04	99.17	C	CE
44	5744716004	SWITCH-THERMAL	2	143.61	E	0.93	1.86	267.1146	0	99.99	C	CE
45	5742539019	B/E OVEN CONTROL MODULE	2	329.97	D	0.90	1.80	593.946	0	99.98	C	CD
46	5743510001	MASK ASSY	2	30.96	V	0.95	1.90	58.824	0	100	C	CV
47	5743310001	LIGHT ASSY-(LIGHTS ONLY)	2	5,562.08	E	0.93	1.86	10345.469	0.08	98.73	C	CE
48	5743310236	LIGHT ASSY - WING POSITION NAV RED	2	193.36	V	0.95	1.90	367.384	0	99.99	C	CV
49	5742511457	OVEN	2	77.61	D	0.90	1.80	139.698	0	100	C	CD
50	5743360148	LIGHT ASSY	2	337.77	D	0.90	1.80	607.986	0	99.97	C	CD

51	5742410004	MAIN(AUXILIARY) BATTERY CHARGER	2	32,595.00	V	0.95	1.90	61930.5	0.5	87.83	B	BV
52	5742511446	FLASHLIGHT	2	337.77	D	0.90	1.80	607.986	0	99.97	C	CD
53	5744910092	LEAD-IGNITER PLUG	2	558.5	E	0.93	1.86	1038.81	0.01	99.96	C	CE
54	5743310199	print board	2	786.87	D	0.90	1.80	1416.366	0.01	99.91	C	CD
55	5742610006	DETECTOR ASSY-SMOKE CARGO COMPT	2	2,160.93	E	0.93	1.86	4019.3298	0.03	99.39	C	CE
56	5743310033	LIGHT ASSY-(LIGHTS ONLY)	1	6,895.06	E	0.93	0.93	6412.4058	0.05	99.09	C	CE
57	5747410002	SWITCH	1	3,844.00	E	0.93	0.93	3574.92	0.03	99.57	C	CE
58	5743110008	MODULE ASSY	1	22,914.00	V	0.95	0.95	21768.3	0.18	96.63	C	CV
59	5742120018	SWITCH ASSY	1	1,693.00	E	0.93	0.93	1574.49	0.01	99.9	C	CE
60	5743310179	LIGHT ASSY	1	1,366.66	D	0.90	0.90	1229.994	0.01	99.94	C	CD
61	57425H0637	B/E OVEN CONTROL MODULE	1	1,996.91	D	0.90	0.90	1797.219	0.01	99.84	C	CD
62	5742610001	DETECTOR ASSY	1	10,120.00	E	0.93	0.93	9411.6	0.08	98.8	C	CE
63	5742410013	MODULE ASSY	1	39,756.00	E	0.93	0.93	36973.08	0.3	92.5	B	BE
64	5743310197	LIGHT SUBASSY	1	1,725.40	E	0.93	0.93	1604.622	0.01	99.87	C	CE
65	5742510360	SERVICE UNIT ASSY-PASS. WITH 2K SPKR AND GASPER	1	5,393.00	D	0.90	0.90	4853.7	0.04	99.21	C	CD
66	5743110029	MODULE ASSY	1	5,035.00	E	0.93	0.93	4682.55	0.04	99.33	C	CE
67	5742110037	OUTLET	1	104	D	0.90	0.90	93.6	0	100	C	CD
68	5743310002	LIGHT ASSY	1	37,663.00	E	0.93	0.93	35026.59	0.28	93.92	B	BE
69	5743310191	HOUSING ASSY - EXIT SIGN LWR CLG	1	1,270.00	D	0.90	0.90	1143	0.01	99.95	C	CD
70	57425H0451	B/E Oven Control Module	1	1,996.91	D	0.90	0.90	1797.219	0.01	99.86	C	CD
71	5743310076	LIGHT ASSY-THRESHOLD	1	673.02	D	0.90	0.90	605.718	0	99.98	C	CD
72	5743310050	LIGHT ASSY	1	165.32	D	0.90	0.90	148.788	0	100	C	CD
73	5753520008	CYLINDER ASSY	86	2,455.21	V	0.95	81.70	200590.66	1.61	80.96	B	BV
74	5753520008	CYLINDER ASSY	44	2,455.21	V	0.95	41.80	102627.78	0.83	85.42	B	BV
75	5753520016	BOTTLE ASSY-OXY	279	47.52	V	0.95	265.05	12595.176	0.1	98.17	C	CV
76	57547H0015	SWITCH-NGS	1	4,005.52	E	0.93	0.93	3725.1336	0.03	99.55	C	CE
77	5753520008	CYLINDER ASSY	4	697.84	V	0.95	3.80	2651.792	0.02	99.72	C	CV
78	5753520020	CYLINDER ASSY-	11	17,674.52	V			184698.7	1.48	82.45	B	BV

		OXYGEN CYLINDER				0.95	10.45	3				
79	5753416002	INDICATOR-INTEGRATED STBY FLIGHT DISPLAY	3	4,005.52	V	0.95	2.85	11415.732	0.09	98.47	C	CV
80	5753520008	CYLINDER ASSY	35	661.77	V	0.95	33.25	22003.853	0.18	96.46	C	CV
81	5753220136	SWITCH ASSY-PRESSURE	5	640.7	V	0.95	4.75	3043.325	0.02	99.68	C	CV
82	5753520020	BOTTLE ASSY-OXY	12	661.77	V	0.95	11.40	7544.178	0.06	98.92	C	CV
83	5757310014	SWITCH	7	582.4	E	0.93	6.51	3791.424	0.03	99.49	C	CE
84	5732310023	MONITOR-RETRACTOR LCD 10.4 IN.	16	15,960.00	D	0.90	14.40	229824	1.85	75.98	A	AD
85	5732320058	ACARS CMU - ACARS COMM MANAGEMENT UNIT	2	34,823.00	E	0.93	1.86	64770.78	0.52	87.33	B	BE
86	5732318007	SERVER	5	1,628.00	D	0.90	4.50	7326	0.06	98.98	C	CD
87	5733420055	ANTENNA ASSY	4	431	E	0.93	3.72	1603.32	0.01	99.88	C	CE
88	5732310035	SEB	10	535.73	D	0.90	9.00	4821.57	0.04	99.25	C	CD
89	5732531123	MEGAPHONE	46	1,068.00	E	0.93	42.78	45689.04	0.37	91.21	B	BE
90	5733010002	CONTROLLER ASSY-WINDOW HEAT CONT UNIT	2	8,140.00	E	0.93	1.86	15140.4	0.12	97.18	C	CE
91	5732310024	MONITOR-RETRACTOR LCD 10.4 IN.	15	15,960.00	D	0.90	13.50	215460	1.73	77.72	B	BD
92	5733420040	TRANSCEIVER	4	109,952.00	E	0.93	3.72	409021.44	3.29	69.49	A	AE
93	5732316001	CONTROL UNIT-SYSTEM	3	17,942.00	D	0.90	2.70	48443.4	0.39	90.84	B	BD
94	5732310105	PRINTER-ARINC 740 MULTI-INPUT	9	7,556.10	D	0.90	8.10	61204.41	0.49	88.32	B	BD
95	5732310067	MICROPHONE	18	148.5	E	0.93	16.74	2485.89	0.02	99.76	C	CE
96	5732318010	DPCU	44	321.88	E	0.93	40.92	13171.33	0.11	97.97	C	CE
97	5732310001	PANEL-AUDIO SELECTOR CONT CAPT AND FIRST OFFICER	1	7,087.00	E	0.93	0.93	6590.91	0.05	99.04	C	CE
98	5733430078	ANTENNA	5	408	E	0.93	4.65	1897.2	0.02	99.81	C	CE
99	5732315007	DPCU	13	250.03	E	0.93	12.09	3022.8627	0.02	99.7	C	CE
100	5732316003	RH DPCU	1	296.66	E	0.93	0.93	275.8938	0	99.99	C	CE
101	5732310003	PANEL	1	432.85	E	0.93	0.93	402.5505	0	99.99	C	CE
102	5732310057	CRADLE ASSY	1	3,584.00	D	0.90	0.90	3225.6	0.03	99.63	C	CD
103	5662511377	LIFE RAFT-46 PERSON	35	813.18	E	0.93	32.55	26469.009	0.21	95.33	C	CE
104	5662510008	SLIDE ASSY-ESCAPE	33	507	D	0.90	29.70	15057.9	0.12	97.3	C	CD
105	56625H0708	INFANT LIFE VEST	13	108.99	E	0.93		1317.689	0.01	99.92	C	CE

							12.09	1				
106	5662511370	LIFE VEST-CREW	5	201.85	E	0.93	4.65	938.6025	0.01	99.96	C	CE
107	56625H0821	LIFE VEST - INFANT	4	13.99	E	0.93	3.72	52.0428	0	100	C	CE
108	5662511417	LIFE RAFT	4	34,994.00	E	0.93	3.72	130177.68	1.05	84.6	B	BE
109	5662511350	LIFE VEST	1	144.7	E	0.93	0.93	134.571	0	100	C	CE
110	5633210050	BRAKE ASSY - CARBON MESSIER-BUGATTI	62	11,733.00	V	0.95	58.90	691073.7	5.56	57.12	A	AV
111	5633210006	BRAKE ASSY-BENDIX HIGH CAPACITY	29	25,705.00	E	0.93	26.97	693263.85	5.57	51.56	A	AE
112	5632760525	FUSE	5	4,759.78	V	0.95	4.75	22608.955	0.18	95.92	C	CV
113	5637810015	ACTUATOR-FAN DUCT COWL	1	11,954.00	E	0.93	0.93	11117.22	0.09	98.55	C	CE
114	5632910082	VALVE-DRAIN	3	1,101.00	V	0.95	2.85	3137.85	0.03	99.65	C	CV
115	5632720153	FUSE	3	4,975.31	V	0.95	2.85	14179.634	0.11	97.64	C	CV
116	5632910001	PUMP ASSY	1	27,700.00	V	0.95	0.95	26315	0.21	95.54	C	CV
117	5632910005	PUMP ASSY	4	5,147.00	E	0.93	3.72	19146.84	0.15	96.79	C	CE
118	5642620009	EXTINGUISHER ASSY-HALON	81	296.75	E	0.93	75.33	22354.178	0.18	96.1	C	CE
119	5642610005	BOTTLE ASSY	21	7,044.35	E	0.93	19.53	137576.16	1.11	83.55	B	BE
120	5642630057	EXTINGUISHER ASSY-FIRE	25	953.13	E	0.93	23.25	22160.273	0.18	96.28	C	CE
121	5642610007	BOTTLE ASSY-FIRE EXT	10	9,673.78	E	0.93	9.30	89966.154	0.72	86.15	B	BE
122	5642630043	LAVATORY EXTINGUISHER	15	296.75	D	0.90	13.50	4006.125	0.03	99.42	C	CD
123	5642115006	VALVE-PACK TEMP CONTROL	15	1,010.00	V	0.95	14.25	14392.5	0.12	97.53	C	CV
124	5642110051	EXCHANGER ASSY	43	15,340.50	E	0.93	39.99	613466.6	4.93	62.05	A	AE
125	5642115006	VALVE ASSY-TEMP CONT	5	1,123.00	V	0.95	4.75	5334.25	0.04	99.13	C	CV
126	5643010018	BLADE ASSY	4	988	V	0.95	3.80	3754.4	0.03	99.52	C	CV
127	5644716003	EXCHANGER-HEAT	4	15,340.50	E	0.93	3.72	57066.66	0.46	89.24	B	BE
128	5642660049	LAVATORY EXTINGUISHER	2	16,360.50	E	0.93	1.86	30430.53	0.24	94.68	B	BE
129	5645610069	WINDSHIELD ASSY	2	16,511.00	V	0.95	1.90	31370.9	0.25	94.43	B	BV
130	5645616001	WINDSHIELD ASSY	2	18,520.00	V	0.95	1.90	35188	0.28	93.35	B	BV
131	5645616000	WINDSHIELD ASSY	1	18,520.00	V	0.95	0.95	17594	0.14	96.93	C	CV
132	5642110018	SEPARATOR ASSY-AIR COND	1	13,380.00	V	0.95	0.95	12711	0.1	98.07	C	CV

133	5645610016	WINDSHIELD ASSY	1	16,511.00	V	0.95	0.95	15685.45	0.13	97.05	C	CV

Appendix-III

A) Poison Distribution Result

S/N	REMS/	Price(P) USD	Service	Repair	Holding	E=(R)*T/365	Expected Holding Quantity (HQ) and Service Level(probability)	Total cost=P*HQ ($)

	YR(R)		Level(SL)	TAT(T) in days	Quantity (HQ)		**1**	**2**	**3**	**4**	**5**	**9**	**10**	**11**	**12**	
1	113	14011	0.95	3.78	3	1	0.736	0.920	0.981	0.996	0.999	1.000	1.000	1.000	1.000	42033
2	110	14011	0.95	6.03	5	2	0.406	0.677	0.857	0.947	0.983	1.000	1.000	1.000	1.000	70055
3	133	4086	0.95	2	3	1	0.736	0.920	0.981	0.996	0.999	1.000	1.000	1.000	1.000	12258
5	542	1641	0.95	4.79	12	7	0.007	0.030	0.082	0.173	0.301	0.830	0.901	0.947	0.973	19692
6	1	4086	0.95	4	1	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	4086
7	41	2118	0.95	3.1	3	1	0.736	0.920	0.981	0.996	0.999	1.000	1.000	1.000	1.000	6354
8	9	1641	0.95	0.625	1	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1641
9	75	4905.51	0.95	1.2	3	1	0.736	0.920	0.981	0.996	0.999	1.000	1.000	1.000	1.000	14716.53
13	17	3558.85	0.95	5.2	2	1	0.736	0.920	0.981	0.996	0.999	1.000	1.000	1.000	1.000	7117.7
16	15	141261.7	0.9	0.67	1	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	141261.7
23	8	1012.5	0.95	0.6	1	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1012.5
30	4	2905	0.95	4.2	1	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	2905
32	4	856	0.95	0.6	1	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	856
35	3	80336.49	0.95	3.2	1	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	80336.49
39	3	9668	0.95	1.5	1	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	9668
46	2	30.96	0.95	3.3	1	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	30.96
48	2	193.36	0.95	0.083	1	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	193.36
51	2	32595	0.95	1.2	1	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	32595
58	1	22914	0.95	2.6	1	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	22914
73	86	2455.21	0.95	7.7	5	2	0.406	0.677	0.857	0.947	0.983	1.000	1.000	1.000	1.000	12276.05
74	44	2455.21	0.95	4.86	3	1	0.736	0.920	0.981	0.996	0.999	1.000	1.000	1.000	1.000	7365.63
75	279	47.52	0.95	7.44	10	6	0.017	0.062	0.151	0.285	0.446	0.916	0.957	0.980	0.991	475.2
77	4	697.84	0.95	2.66	1	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	697.84
78	11	17674.52	0.95	4.47	3	1										53023.56

							0.736	0.920	0.981	0.996	0.999	1.000	1.000	1.000	1.000	
79	3	4005.52	0.95	6.3	1	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	4005.52
80	35	661.77	0.95	4.92	3	1	0.736	0.920	0.981	0.996	0.999	1.000	1.000	1.000	1.000	1985.31
81	5	640.7	0.95	8.4	3	1	0.736	0.920	0.981	0.996	0.999	1.000	1.000	1.000	1.000	1922.1
82	12	661.77	0.95	8.9	3	1	0.736	0.920	0.981	0.996	0.999	1.000	1.000	1.000	1.000	1985.31
84	16	15960	0.9	8.67	3	1	0.736	0.920	0.981	0.996	0.999	1.000	1.000	1.000	1.000	47880
92	4	109952	0.93	9.55	3	1	0.736	0.920	0.981	0.996	0.999	1.000	1.000	1.000	1.000	329856
110	62	11733	0.95	5.6	3	1	0.736	0.920	0.981	0.996	0.999	1.000	1.000	1.000	1.000	35199
111	29	25705	0.93	6.4	3	1	0.736	0.920	0.981	0.996	0.999	1.000	1.000	1.000	1.000	77115
112	5	4759.78	0.95	0.5	1	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	4759.78
114	3	1101	0.95	0.4	1	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1101
115	3	4975.31	0.95	0.55	1	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	4975.31
116	1	27700	0.95	1	1	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	27700
123	15	1010	0.95	8.1	1	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1010
124	43	15340.5	0.93	4.1	3	1	0.736	0.920	0.981	0.996	0.999	1.000	1.000	1.000	1.000	46021.5
125	5	1123	0.95	9.32	3	1	0.736	0.920	0.981	0.996	0.999	1.000	1.000	1.000	1.000	3369
126	4	988	0.95	6.6	1	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	988
129	2	16511	0.95	13.8	1	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	16511
130	2	18520	0.95	14.3	1	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	18520
131	1	18520	0.95	13.33	1	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	18520
132	1	13380	0.95	0.5	1	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	13380
133	1	16511	0.95	1.333	1	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	16511
Total Cost (USD)																**1216879**

B) Marginal distribution Analysis result

S/N	REMS/YR(R)	Price(P)	HQ	Fills	MC	Delta Fills ($\Delta F ¿$	=F Cumulative fills(	Service Level(F/ $\sum Ri$)	Cumulative Cost($)
75	279	47.52	5	138.709	0.987	46.882	46.882	0.027	47.52
75	279	47.52	6	183.146	0.935	44.436	91.318	0.052	95.04
75	279	47.52	4	91.827	0.867	41.218	132.537	0.075	142.56
75	279	47.52	7	219.247	0.760	36.101	168.638	0.096	190.08
75	279	47.52	3	50.609	0.610	28.991	197.629	0.112	237.6
75	279	47.52	8	244.911	0.540	25.664	223.293	0.127	285.12
75	279	47.52	9	261.127	0.341	16.217	239.510	0.136	332.64
75	279	47.52	2	21.617	0.322	15.293	254.803	0.145	380.16
75	279	47.52	10	270.350	0.194	9.222	264.026	0.150	427.68
75	279	47.52	1	6.324	0.133	6.324	270.350	0.154	475.2
75	279	47.52	11	275.118	0.100	4.768	275.118	0.156	522.72
5	542	1641	7	315.394	0.049	80.687	355.805	0.202	2163.72
80	35	661.77	1	32.138	0.049	32.138	387.943	0.220	2825.49
5	542	1641	6	234.707	0.048	79.407	467.350	0.265	4466.49
75	279	47.52	12	277.377	0.048	2.260	469.609	0.267	4514.01
5	542	1641	8	387.133	0.044	71.739	541.348	0.307	6155.01
5	542	1641	5	155.300	0.041	66.984	608.332	0.345	7796.01
5	542	1641	9	443.829	0.035	56.696	665.028	0.378	9437.01
5	542	1641	4						11078.01

				88.317	0.029	47.087	712.115	0.404	
3	133	4086	1	110.940	0.027	110.940	823.055	0.467	15164.01
5	542	1641	10	484.156	0.025	40.327	863.382	0.490	16805.01
75	279	47.52	13	278.366	0.021	0.989	864.370	0.491	16852.53
7	41	2118	1	39.022	0.018	39.022	903.393	0.513	18970.53
82	12	661.77	1	11.576	0.017	11.576	914.969	0.520	19632.3
5	542	1641	3	41.230	0.016	26.480	941.449	0.535	21273.3
73	86	2455.21	1	39.441	0.016	39.441	980.889	0.557	23728.51
5	542	1641	11	510.233	0.016	26.076	1,006.966	0.572	25369.51
74	44	2455.21	1	38.840	0.016	38.840	1,045.806	0.594	27824.72
9	75	4905.51	1	73.062	0.015	73.062	1,118.868	0.635	32730.23
123	15	1010	1	14.332	0.014	14.332	1,133.201	0.643	33740.23
5	542	1641	12	525.689	0.009	15.456	1,148.657	0.652	35381.23
73	86	2455.21	2	62.505	0.009	23.064	1,171.721	0.665	37836.44
75	279	47.52	14	278.767	0.008	0.402	1,172.123	0.666	37883.96
23	8	1012.5	1	7.999	0.008	7.999	1,180.122	0.670	38896.46
81	5	640.7	1	4.969	0.008	4.969	1,185.092	0.673	39537.16
5	542	1641	2	14.750	0.007	11.168	1,196.260	0.679	41178.16
77	4	697.84	1	3.998	0.006	3.998	1,200.258	0.682	41876
73	86	2455.21	3	76.453	0.006	13.948	1,214.207	0.689	44331.21
8	9	1641	1	8.999	0.005	8.999	1,223.206	0.695	45972.21
1	113	14011	1	76.095	0.005	76.095	1,299.300	0.738	59983.21
5	542	1641	13	534.146	0.005	8.457	1,307.757	0.743	61624.21
32	4	856	1	4.000	0.005	4.000	1,311.757	0.745	62480.21
13	17	3558.8	1				1,328.332		66039.06

		5		16.575	0.005	16.575		0.754	
125	5	1123	1	4.963	0.004	4.963	1,333.295	0.757	67162.06
3	133	4086	2	127.981	0.004	17.041	1,350.336	0.767	71248.06
126	4	988	1	3.990	0.004	3.990	1,354.326	0.769	72236.06
110	62	11733	1	46.729	0.004	46.729	1,401.055	0.796	83969.06
80	35	661.77	2	34.568	0.004	2.430	1,403.485	0.797	84630.83
2	110	14011	1	50.349	0.004	50.349	1,453.834	0.826	98641.83
75	279	47.52	15	278.920	0.003	0.152	1,453.987	0.826	98689.35
114	3	1101	1	3.000	0.003	3.000	1,456.987	0.827	99790.35
5	542	1641	14	538.442	0.003	4.297	1,461.283	0.830	101431.4
73	86	2455.21	4	82.780	0.003	6.326	1,467.609	0.833	103886.6
124	43	15340.5	1	39.341	0.003	39.341	1,506.950	0.856	119227.1
5	542	1641	1	3.582	0.002	3.582	1,510.532	0.858	120868.1
2	110	14011	2	79.859	0.002	29.510	1,540.042	0.875	134879.1
1	113	14011	2	100.104	0.002	24.009	1,564.051	0.888	148890.1
74	44	2455.21	2	43.043	0.002	4.203	1,568.254	0.891	151345.3
30	4	2905	1	3.996	0.001	3.996	1,572.250	0.893	154250.3
2	110	14011	3	97.735	0.001	17.876	1,590.126	0.903	168261.3
5	542	1641	15	540.480	0.001	2.037	1,592.163	0.904	169902.3
75	279	47.52	16	278.974	0.001	0.054	1,592.218	0.904	169949.8
112	5	4759.78	1	5.000	0.001	5.000	1,597.217	0.907	174709.6
111	29	25705	1	26.309	0.001	26.309	1,623.526	0.922	200414.6
3	133	4086	3	132.121	0.001	4.140	1,627.666	0.924	204500.6
84	16	15960	1	15.099	0.001	15.099	1,642.766	0.933	220460.6
73	86	2455.2	5				1,645.061		222915.8

		1		85.075	0.001	2.296		0.934	
110	62	11733	2	57.564	0.001	10.835	1,655.896	0.940	234648.8
7	41	2118	2	40.777	0.001	1.755	1,657.651	0.941	236766.8
79	3	4005.52	1	2.996	0.001	2.996	1,660.647	0.943	240772.3
1	113	14011	3	109.469	0.001	9.365	1,670.012	0.948	254783.3
78	11	17674.5	1	10.909	0.001	10.909	1,680.921	0.955	272457.8
115	3	4975.31	1	3.000	0.001	3.000	1,683.921	0.956	277433.1
39	3	9668	1	3.000	0.000	3.000	1,699.930	0.965	312494.9
46	2	30.96	1	3.000	0.000	3.000	1,702.929	0.967	312525.9
6	1	4086	1	1.000	0.000	1.000	1,708.059	0.970	330800.1
129	2	16511	1	1.995	0.000	1.995	1,719.973	0.977	396400.6
130	2	18520	1	1.994	0.000	1.994	1,722.364	0.978	418527
16	15	141262	1	14.994	0.000	14.994	1,737.358	0.987	559788.7
132	1	13380	1	1.000	0.000	1.000	1,740.967	0.989	602632.7
51	2	32595	1	2.000	0.000	2.000	1,744.969	0.991	665098.6
133	1	16511	1	1.000	0.000	1.000	1,745.969	0.991	681609.6
131	1	18520	1	0.999	0.000	0.999	1,747.005	0.992	700791.4
58	1	22914	1	1.000	0.000	1.000	1,749.587	0.994	756772.3
35	3	80336.5	1	2.999	0.000	2.999	1,752.586	0.995	837108.8
92	4	109952	1	3.980	0.000	3.980	1,756.565	0.997	947060.8
116	1	27700	1	1.000	0.000	1.000	1,757.565	0.998	974760.8

C) Mixed integer Linear Programming Equation (Scenario-I, LP1)

```
/* LPSolver */
 /*ADDIS ABABA UNIVERSITY INSTITUTE OF TECHNOLOGY
SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING
INDUSTRIAL ENGINEERING STREAM
```

```
Optimization of Inventory through an integrated system Approach for Repairable Spare parts
       BY: ZELALEM ERESI */
 /*Baseline Study Based on Mixed Integer Linear programming Model-MILP (Scenario-I, LP-I) */
/* Objective function */
min: 14011 A1 +28022 B1 +42033 C1 +56044 D1 +84066 F1 +98077 G1 +112088 H1 +126099 I1 +140110 J1
+154121 K1 +168132 L1 +14011 A2 +28022 B2 +42033 C2 +56044 D2 +84066 F2 +98077 G2 +112088 H2 +
126099 I2 +140110 J2 +154121 K2 +168132 L2 +4086 A3 +8172 B3 +12258 C3 +16344 D3 +24516 F3 +
28602 G3 +32688 H3 +36774 I3 +40860 J3 +44946 K3 +49032 L3 +1641 A4 +3282 B4 +4923 C4 +6564 D4 +
9846 F4 +11487 G4 +13128 H4 +14769 I4 +16410 J4 +18051 K4 +19692 L4 +4086 A5 +8172 B5 +12258 C5 +
16344 D5 +24516 F5 +28602 G5 +32688 H5 +36774 I5 +40860 J5 +44946 K5 +49032 L5 +2118 A6 +4236 B6
+6354 C6 +8472 D6 +12708 F6 +14826 G6 +16944 H6 +19062 I6 +21180 J6 +23298 K6 +25416 L6 +1641 A7
+3282 B7 +4923 C7 +6564 D7 +9846 F7 +11487 G7 +13128 H7 +14769 I7 +16410 J7 +18051 K7 +19692 L7
+4905.51 A8 +9811.02 B8 +14716.53 C8 +19622.04 D8 +29433.06 F8 +34338.57 G8 +39244.08 H8
+44149.59 I8 +49055.1 J8 +53960.61 K8 +58866.12 L8 +3558.85 A9 +7117.7 B9 +10676.55 C9 +14235.4
D9 +21353.1 F9 +24911.95 G9 +28470.8 H9 +32029.65 I9 +35588.5 J9 +39147.35 K9 +42706.2 L9
+141261.71 A10 +282523.42 B10 +423785.13 C10 +565046.840001 D10 +847570.26 F10 +988831.97 G10
+1130093.68 H10 +1271355.39 I10 +1412617.1 J10 +1553878.81 K10 +1695140.52 L10 +1012.5 A11 +2025
B11 +3037.5 C11 +4050 D11 +6075 F11 +7087.5 G11 +8100 H11 +9112.5 I11 +10125 J11 +11137.5 K11
+12150 L11 +2905 A12 +5810 B12 +8715 C12 +11620 D12 +17430 F12 +20335 G12 +23240 H12 +26145 I12
+29050 J12 +31955 K12 +34860 L12 +856 A13 +1712 B13 +2568 C13 +3424 D13 +5136 F13 +5992 G13 +6848
H13 +7704 I13 +8560 J13 +9416 K13 +10272 L13 +80336.49 A14 +160672.98 B14 +241009.47 C14
+321345.96 D14 +482018.94 F14 +562355.43 G14 +642691.92 H14 +723028.41 I14 +803364.9 J14
+883701.390001 K14 +964037.88 L14 +9668 A15 +19336 B15 +29004 C15 +38672 D15 +58008 F15 +67676
G15 +77344 H15 +87012 I15 +96680 J15 +106348 K15 +116016 L15 +30.96 A16 +61.92 B16 +92.88 C16
+123.84 D16 +185.76 F16 +216.72 G16 +247.68 H16 +278.64 I16 +309.6 J16 +340.56 K16 +371.52 L16
+193.36 A17 +386.72 B17 +580.08 C17 +773.44 D17 +1160.16 F17 +1353.52 G17 +1546.88 H17 +1740.24
I17 +1933.6 J17 +2126.96 K17 +2320.32 L17 +32595 A18 +65190 B18 +97785 C18 +130380 D18 +195570
F18 +228165 G18 +260760 H18 +293355 I18 +325950 J18 +358545 K18 +391140 L18 +22914 A19 +45828 B19
+68742 C19 +91656 D19 +137484 F19 +160398 G19 +183312 H19 +206226 I19 +229140 J19 +252054 K19
+274968 L19 +2455.21 A20 +4910.42 B20 +7365.63 C20 +9820.84 D20 +14731.26 F20 +17186.47 G20
+19641.68 H20 +22096.89 I20 +24552.1 J20 +27007.31 K20 +29462.52 L20 +2455.21 A21 +4910.42 B21
+7365.63 C21 +9820.84 D21 +14731.26 F21 +17186.47 G21 +19641.68 H21 +22096.89 I21 +24552.1 J21
+27007.31 K21 +29462.52 L21 +47.52 A22 +95.04 B22 +142.56 C22 +190.08 D22 +285.12 F22 +332.64 G22
+380.16 H22 +427.68 I22 +475.2 J22 +522.72 K22 +570.24 L22 +697.84 A23 +1395.68 B23 +2093.52 C23
+2791.36 D23 +4187.04 F23 +4884.88 G23 +5582.72 H23 +6280.56 I23 +6978.4 J23 +7676.24 K23
+8374.08 L23 +17674.52 A24 +35349.04 B24 +53023.56 C24 +70698.08 D24 +106047.12 F24 +123721.64
G24 +141396.16 H24 +159070.68 I24 +176745.2 J24 +194419.72 K24 +212094.24 L24 +4005.52 A25
+8011.04 B25 +12016.56 C25 +16022.08 D25 +24033.12 F25 +28038.64 G25 +32044.16 H25 +36049.68 I25
+40055.2 J25 +44060.72 K25 +48066.24 L25 +661.77 A26 +1323.54 B26 +1985.31 C26 +2647.08 D26
+3970.62 F26 +4632.39 G26 +5294.16 H26 +5955.93 I26 +6617.7 J26 +7279.47 K26 +7941.24 L26 +640.7
A27 +1281.4 B27 +1922.1 C27 +2562.8 D27 +3844.2 F27 +4484.9 G27 +5125.6 H27 +5766.3 I27 +6407 J27
+7047.7 K27 +7688.4 L27 +661.77 A28 +1323.54 B28 +1985.31 C28 +2647.08 D28 +3970.62 F28 +4632.39
G28 +5294.16 H28 +5955.93 I28 +6617.7 J28 +7279.47 K28 +7941.24 L28 +15960 A29 +31920 B29 +47880
C29 +63840 D29 +95760 F29 +111720 G29 +127680 H29 +143640 I29 +159600 J29 +175560 K29 +191520 L29
+109952 A30 +219904 B30 +329856 C30 +439808 D30 +659712 F30 +769664 G30 +879616 H30 +989568 I30
+1099520 J30 +1209472 K30 +1319424 L30 +11733 A31 +23466 B31 +35199 C31 +46932 D31 +70398 F31
+82131 G31 +93864 H31 +105597 I31 +117330 J31 +129063 K31 +140796 L31 +25705 A32 +51410 B32
+77115 C32 +102820 D32 +154230 F32 +179935 G32 +205640 H32 +231345 I32 +257050 J32 +282755 K32
+308460 L32 +4759.78 A33 +9519.56 B33 +14279.34 C33 +19039.12 D33 +28558.68 F33 +33318.46 G33
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/ Constraints */*

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+261.12731649 I22 +270.34974392 J22 +275.11775038 K22 +277.37739355 L22 +A23 +3.9999838428 B23
+3.9999998824 C23 +3.9999999993 D23 +4 F23 +4 G23 +4 H23 +4 I23 +4 J23 +4 K23 +4 L23 +A24
+10.9959474 B24 +10.999864446 C24 +10.999996364 D24 +10.999999998 F24 +11 G24 +11 H24 +11 I24 +11
J24 +11 K24 +11 L24 +A25 +2.9999332221 B25 +2.9999991378 C25 +2.9999999911 D25 +3 F25 +3 G25 +3
H25 +3 I25 +3 J25 +3 K25 +3 L25 +0.406 A26 +34.568154098 B26 +34.950314632 C26 +34.995388634 D26
+34.999976059 F26 +34.999998598 G26 +34.999999927 H26 +34.999999997 I26 +35 J26 +35 K26 +35 L26
+0.736 A27 +4.9988350257 B27 +4.9999666817 C27 +4.9999992362 D27 +4.9999999998 F27 +5 G27 +5 H27
+5 I27 +5 J27 +5 K27 +5 L27 +0.406 A28 +11.959703543 B28 +11.997096465 C28 +11.999831783 D28
+11.999999661 F28 +11.999999988 G28 +12 H28 +12 I28 +12 J28 +12 K28 +12 L28 +0.406 A29
+15.889613323 B29 +15.98971738 C29 +15.999228637 D29 +15.99999739 F29 +15.999999877 G29
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+61.999953539 H31 +61.999995621 I31 +61.999999624 J31 +62 K31 +62 L31 +0.406 A32 +28.563845557
B32 +28.9460241 C32 +28.994607893 D32 +28.999967534 F32 +28.999997952 G32 +28.999999885 H32
+28.999999994 I32 +29 J32 +29 K32 +29 L32 +0.736 A33 +4.9999997336 B33 +4.9999999995 C33 +5 D33
+5 F33 +5 G33 +5 H33 +5 I33 +5 J33 +5 K33 +5 L33 +A34 +2.9999999823 B34 +3 C34 +3 D34 +3 F34 +3
G34 +3 H34 +3 I34 +3 J34 +3 K34 +3 L34 +A35 +2.999999954 B35 +2.9999999999 C35 +3 D35 +3 F35 +3
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+K36 +L36 +0.406 A37 +14.928007979 B37 +14.994111368 C37 +14.999612438 D37 +14.999998992 F37
+14.999999958 G37 +14.999999999 H37 +15 I37 +15 J37 +15 K37 +15 L37 +0.199 A38 +42.435298761 B38
+42.933523588 C38 +42.993685942 D38 +42.999965657 F38 +42.999997941 G38 +42.99999989 H38
+42.999999995 I38 +43 J38 +43 K38 +43 L38 +0.736 A39 +4.9984236727 B39 +4.9999500117 C39
+4.9999987291 D39 +4.9999999995 F39 +5 G39 +5 H39 +5 I39 +5 J39 +5 K39 +5 L39 +A40 +3.9997610397
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+J43 +K43 +L43 +A44 +0.9999999996 B44 +C44 +D44 +F44 +G44 +H44 +I44 +J44 +K44 +L44 +A45
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B36+C36+D36+E36+F36+G36+H36+I36+J36+K36+L36=0;
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B43+C43+D43+E43+F43+G43+H43+I43+J43+K43+L43=0;
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Int
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A24,B24,C24,D24,E24,F24,G24,H24,I24,J24,K24,L24,
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A26,B26,C26,D26,E26,F26,G26,H26,I26,J26,K26,L26,
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/* Integer definitions */
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43,E44,E45;
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Appendix-IV

A) Poison Distribution Result With Minimum NFF (P2).

S/N	REMS/YR(R)	Service Level(SL)	Price-P ($)	Repair TAT	NFF TAT	Total NFF	Scrap/Yr.	E=(R)*T/365+S	Expected Holding Quantity (HQ) and Service Level(probability)											(HQ) Holding Quantity	Total cost=HQ*P
									1	2	3	4	5	6	7	8	21	22	23		
1	113	0.95	14,011.00	3.78	1.25	13	2	3	0.2	0.4	0.7	0.8	0.9	1	1	1	1	1		6.00	84066
2	110	0.95	14,011.00	6.03	2.43	17	2	4	0.1	0.2	0.4	0.6	0.8	0.9	1	1				7.00	98077
3	133	0.95	4,086.00	2	1.49	21	2	3	0.2	0.4	0.7	0.8	0.9	1	1	1	1	0.7		6.00	24516
5	542	0.95	1,641.00	4.79	1.52	86	9	16	0	0	0	0	0	0	0	0	0.9	0.9	96	23.00	37743
6	1	0.95	4,086.00	4	1.2	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1.00	4086
7	41	0.95	2,118.00	3.1	2.1	3	1	2	0.4	0.7	0.9	1	1	1	1	1	1	1		3.00	6354
8	9	0.95	1,641.00	0.63	0.5	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1.00	1641

9	75	0.95	4,905.51	1.2	0.39	7	3	4	0.1	0.2	0.4	0.6	0.8	0.9	95					7.00	34338.57
13	17	0.95	3,558.85	5.2	1.5	2	1	2	0.4	0.7	0.9	1	1	1	1	1	1	1	1	4.00	14235.4
16	15	0.9	141,261.71	0.67	0.22	2	1	1	0.7	0.9	1	1	1	1	1	1	1	1	1	2.00	282523.4
23	8	0.95	1,012.50	0.6	0.2	1	1	1	0.7	0.9	1	1	1	1	1	1	1	1	1	3.00	3037.5
30	4	0.95	2,905.00	4.2	1.6	1	1	1	0.7	0.9	1	1	1	1	1	1	1	1		3.00	8715
32	4	0.95	856	0.6	0.2	0	1	1	0.7	0.9	1	1	1	1	1	1	1	1	1	3.00	2568
35	3	0.95	80,336.49	3.2	1	0	0	1	0.7	0.9	1	1	1	1	1	1	1	1	1	3.00	241009.5
39	3	0.95	9,668.00	1.50.	0.45	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1.00	9668
46	2	0.95	30.96	3.3	1	0	0	1	0.7	0.9	1	1	1	1	1	1	1	1	1	3.00	92.88
48	2	0.95	193.36	0.08	0.03	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1.00	193.36
51	2	0.95	32,595.00	1.2	0.39	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1.00	32595
58	1	0.95	22,914.00	2.6	0.3	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1.00	22914
73	86	0.95	2,455.21	7.7	5.62	10	2	4	0.1	0.2	0.4	0.6	0.8	0.9	1	1	1	1		7.00	17186.47
74	44	0.95	2,455.21	4.86	3.55	5	1	2	0.4	0.7	0.9	1	1	1	1	1	1	1		4.00	9820.84
75	279	0.95	47.52	7.44	5.43	31	6	12	0	0	0	0	0	0.1	0.1	0.2	1	1		21.00	997.92
77	4	0.95	697.84	2.66	1.94	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1.00	697.84
78	11	0.95	17,674.52	4.47	3.26	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1.00	17674.52
79	3	0.95	4,005.52	6.3	4.6	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1.00	4005.52
80	35	0.95	661.77	4.92	3.59	4	1	2	0.4	0.7	0.9	1	1	1	1	1	1	1	1	4.00	2647.08
81	5	0.95	640.7	8.4	6.1	1	0	1	0.7	0.9	1	1	1	1	1	1	1	1	1	3.00	1922.1
82	12	0.95	661.77	8.9	5.6	2	1	2	0.4	0.7	0.9	1	1	1	1	1	1	1	1	4.00	2647.08
84	16	0.9	15,960.00	8.67	0.78	4	1	2	0.4	0.7	0.9	1	1	1	1	1	1	1	1	4.00	63840
92	4	0.93	109,952.00	9.55	1.76	1	1	1	0.7	0.9	1	1	1	1	1	1	1	1	1	3.00	329856
110	62	0.95	11,733.00	5.6	2.8	3	2	3	0.2	0.4	0.7	0.8	0.9	1	1	1	1	1	1	6.00	70398
111	29	0.93	25,705.00	6.4	3.2	2	1	2	0.4	0.7	0.9	1	1	1	1	1	1	1	1	4.00	102820
112	5	0.95	4,759.78	0.5	0.24	1	1	1	0.7	0.9	1	1	1	1	1	1	1	1	1	3.00	14279.34
114	3	0.95	1,101.00	0.4	0.19	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1.00	1101
115	3	0.95	4,975.31	0.55	0.26	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1.00	4975.31
116	1	0.95	27,700.00	1	0.48	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1.00	27700
123	15	0.95	1,010.00	8.1	6.8	1	1	2	0.4	0.7	0.9	1	1	1	1	1	1	1	1	4.00	4040
124	43	0.93	15,340.50	4.1	3.44	2	2	3	0.2	0.4	0.7	0.8	0.9	1	1	1	1	1	1	6.00	92043
125	5	0.95	1,123.00	9.32	7.83	0	0	1	0.7	0.9	1	1	1	1	1	1	1	1	1	3.00	3369
126	4	0.95	988	6.6	5.54	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1.00	988
129	2	0.95	16,511.00	13.8	11.6	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1.00	16511
130	2	0.95	18,520.00	14.3	12	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1.00	18520
131	1	0.95	18,520.00	13.3	11.2	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1.00	18520
132	1	0.95	13,380.00	0.5	0.42	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1.00	13380
133	1	0.95	16,511.00	1.12	0	0	0	1	1	1	1	1	1	1	1	1	1	1		1.00	16511
Total Cost																					1764825

B) Marginal Analysis Result With minimum NFF (**Scenario-II** , M2)

S/N	(100^{th})Service	Fills	(C) Marginal Contribution	Delta Fills (ΔF¿	Removals/YR	Unit cost ($)	Cumulative $\sum \Delta F$ =F	Cumulative Service Level(F/	Cumulative Cost($)
75	0.4978	138.8912	0.6866	32.6274	279.0000	47.5200	32.6274	0.0185	47.52
75	0.6117	170.6675	0.6687	31.7764	279.0000	47.5200	64.4037	0.0366	95.04
75	0.3809	106.2638	0.6462	30.7094	279.0000	47.5200	95.1131	0.0540	142.56
75	0.7141	199.2345	0.6012	28.5670	279.0000	47.5200	123.6801	0.0702	190.08
75	0.2708	75.5544	0.5530	26.2765	279.0000	47.5200	149.9566	0.0852	237.6
75	0.7996	223.0819	0.5018	23.8473	279.0000	47.5200	173.8040	0.0987	285.12
75	0.1766	49.2779	0.4258	20.2352	279.0000	47.5200	194.0391	0.1102	332.64
75	0.8662	241.6621	0.3910	18.5803	279.0000	47.5200	212.6194	0.1207	380.16
75	0.1041	29.0427	0.2915	13.8514	279.0000	47.5200	226.4708	0.1286	427.68
75	0.9148	255.2339	0.2856	13.5718	279.0000	47.5200	240.0425	0.1363	475.2
75	0.9483	264.5641	0.1963	9.3302	279.0000	47.5200	249.3727	0.1416	522.72
75	0.0544	15.1914	0.1746	8.2964	279.0000	47.5200	257.6691	0.1463	570.24
75	0.9700	270.6220	0.1275	6.0579	279.0000	47.5200	263.7270	0.1498	617.76
75	0.0247	6.8950	0.0896	4.2593	279.0000	47.5200	267.9862	0.1522	665.28
75	0.9833	274.3482	0.0784	3.7262	279.0000	47.5200	271.7125	0.1543	712.8
46	0.9998	1.9997	0.0646	1.9997	2.0000	30.9600	273.7122	0.1554	743.76
75	0.9911	276.5257	0.0458	2.1774	279.0000	47.5200	275.8896	0.1567	791.28
75	0.0094	2.6357	0.0383	1.8222	279.0000	47.5200	277.7118	0.1577	838.8
5	0.5548	300.6853	0.0328	53.7546	542.0000	1641.0000	331.4664	0.1882	2479.8
5	0.4556	246.9307	0.0325	53.3782	542.0000	1641.0000	384.8447	0.2185	4120.8
5	0.6488	351.6347	0.0310	50.9493	542.0000	1641.0000	435.7940	0.2475	5761.8
5	0.3571	193.5525	0.0303	49.6917	542.0000	1641.0000	485.4857	0.2757	7402.8
80	0.5673	19.8560	0.0300	19.8560	35.0000	661.7700	505.3417	0.2870	8064.57
5	0.7329	397.2423	0.0278	45.6076	542.0000	1641.0000	550.9493	0.3129	9705.57
5	0.2654	143.8608	0.0263	43.1758	542.0000	1641.0000	594.1251	0.3374	11346.57
75	0.9955	277.7375	0.0255	1.2118	279.0000	47.5200	595.3369	0.3381	11394.09
5	0.8043	435.9195	0.0236	38.6772	542.0000	1641.0000	634.0141	0.3600	13035.09
5	0.1858	100.6850	0.0212	34.8347	542.0000	1641.0000	668.8488	0.3798	14676.09
5	0.8618	467.0795	0.0190	31.1600	542.0000	1641.0000	700.0088	0.3975	16317.09
5	0.1215	65.8503	0.0158	25.9431	542.0000	1641.0000	725.9519	0.4122	17958.09
5	0.9059	490.9879	0.0146	23.9083	542.0000	1641.0000	749.8602	0.4258	19599.09
75	0.9978	278.3812	0.0135	0.6437	279.0000	47.5200	750.5040	0.4262	19646.61
80	0.8159	28.5564	0.0131	8.7004	35.0000	661.7700	759.2044	0.4311	20308.38
75	0.0029	0.8135	0.0131	0.6237	279.0000	47.5200	759.8280	0.4315	20355.9

7	0.6098	25.0034	0.0118	25.0034	41.0000	2118.0000	784.8314	0.4457	22473.9
82	0.6294	7.5534	0.0114	7.5534	12.0000	661.7700	792.3847	0.4500	23135.67
5	0.0736	39.9072	0.0108	17.7110	542.0000	1641.0000	810.0957	0.4600	24776.67
5	0.9382	508.4984	0.0107	17.5105	542.0000	1641.0000	827.6062	0.4700	26417.67
48	1.0000	2.0000	0.0103	2.0000	2.0000	193.3600	829.6062	0.4711	26611.03
74	0.5295	23.2984	0.0095	23.2984	44.0000	2455.2100	852.9047	0.4843	29066.24
123	0.6152	9.2283	0.0091	9.2283	15.0000	1010.0000	862.1330	0.4896	30076.24
3	0.2435	32.3838	0.0079	32.3838	133.0000	4086.0000	894.5168	0.5080	34162.24
3	0.4866	64.7183	0.0079	32.3345	133.0000	4086.0000	926.8513	0.5263	38248.24
81	0.9939	4.9693	0.0078	4.9693	5.0000	640.7000	931.8206	0.5291	38888.94
5	0.9608	520.7655	0.0075	12.2671	542.0000	1641.0000	944.0877	0.5361	40529.94
3	0.7077	94.1294	0.0072	29.4111	133.0000	4086.0000	973.4988	0.5528	44615.94
73	0.4706	40.4694	0.0071	17.5415	86.0000	2455.2100	991.0404	0.5628	47071.15
75	0.9990	278.7083	0.0069	0.3271	279.0000	47.5200	991.3675	0.5630	47118.67
73	0.6651	57.1963	0.0068	16.7269	86.0000	2455.2100	1008.0944	0.5725	49573.88
5	0.0410	22.1963	0.0067	10.9919	542.0000	1641.0000	1019.0862	0.5787	51214.88
80	0.9378	32.8247	0.0064	4.2683	35.0000	661.7700	1023.3546	0.5811	51876.65
23	0.7309	5.8474	0.0058	5.8474	8.0000	1012.5000	1029.2020	0.5844	52889.15
77	0.9996	3.9983	0.0057	3.9983	4.0000	697.8400	1033.2003	0.5867	53586.99
73	0.2666	22.9279	0.0056	13.7968	86.0000	2455.2100	1046.9971	0.5945	56042.2
8	0.9999	8.9989	0.0055	8.9989	9.0000	1641.0000	1055.9961	0.5997	57683.2
73	0.8134	69.9565	0.0052	12.7601	86.0000	2455.2100	1068.7562	0.6069	60138.41
3	0.8586	114.1935	0.0049	20.0640	133.0000	4086.0000	1088.8202	0.6183	64224.41
74	0.7870	34.6282	0.0046	11.3298	44.0000	2455.2100	1100.1500	0.6247	66679.62
7	0.8459	34.6806	0.0046	9.6772	41.0000	2118.0000	1109.8272	0.6302	68797.62
125	0.9925	4.9626	0.0044	4.9626	5.0000	1123.0000	1114.7898	0.6330	69920.62
82	0.8588	10.3058	0.0042	2.7524	12.0000	661.7700	1117.5422	0.6346	70582.39
126	0.9975	3.9900	0.0040	3.9900	4.0000	988.0000	1121.5322	0.6369	71570.39
5	0.0207	11.2044	0.0037	6.1396	542.0000	1641.0000	1127.6719	0.6404	73211.39
73	0.1062	9.1310	0.0037	9.1310	86.0000	2455.2100	1136.8029	0.6455	75666.6
123	0.8495	12.7421	0.0035	3.5138	15.0000	1010.0000	1140.3167	0.6475	76676.6
32	0.7333	2.9334	0.0034	2.9334	4.0000	856.0000	1143.2501	0.6492	77532.6
9	0.5922	44.4126	0.0034	16.6424	75.0000	4905.5100	1159.8925	0.6587	82438.11
75	0.0007	0.1898	0.0034	0.1601	279.0000	47.5200	1160.0526	0.6587	82485.63
73	0.9078	78.0682	0.0033	8.1117	86.0000	2455.2100	1168.1643	0.6634	84940.84
9	0.3703	27.7701	0.0031	15.3784	75.0000	4905.5100	1183.5428	0.6721	89846.35
13	0.6474	11.0064	0.0031	11.0064	17.0000	3558.8500	1194.5491	0.6783	93405.2
9	0.7723	57.9203	0.0028	13.5077	75.0000	4905.5100	1208.0569	0.6860	98310.71
114	1.0000	3.0000	0.0027	3.0000	3.0000	1101.0000	1211.0569	0.6877	99411.71
3	0.9409	125.1435	0.0027	10.9500	133.0000	4086.0000	1222.0069	0.6939	103497.71
9	0.1652	12.3917	0.0025	12.3917	75.0000	4905.5100	1234.3985	0.7010	108403.22
74	0.9231	40.6174	0.0024	5.9892	44.0000	2455.2100	1240.3877	0.7044	110858.43
80	0.9827	34.3952	0.0024	1.5705	35.0000	661.7700	1241.9582	0.7053	111520.2

7	0.9519	39.0296	0.0021	4.3490	41.0000	2118.0000	1246.3072	0.7077	113638.2
5	0.0093	5.0648	0.0019	3.0483	542.0000	1641.0000	1249.3556	0.7095	115279.2
73	0.9592	82.4882	0.0018	4.4200	86.0000	2455.2100	1253.7756	0.7120	117734.41
1	0.6091	68.8339	0.0018	25.1991	113.0000	14011.0000	1278.9747	0.7263	131745.41
82	0.9576	11.4917	0.0018	1.1859	12.0000	661.7700	1280.1606	0.7270	132407.18
9	0.8892	66.6911	0.0018	8.7708	75.0000	4905.5100	1288.9314	0.7319	137312.69
1	0.3861	43.6347	0.0017	23.8459	113.0000	14011.0000	1312.7773	0.7455	151323.69
2	0.4700	51.6956	0.0016	22.4224	110.0000	14011.0000	1335.1997	0.7582	165334.69
123	0.9536	14.3033	0.0015	1.5612	15.0000	1010.0000	1336.7609	0.7591	166344.69
2	0.6645	73.0936	0.0015	21.3980	110.0000	14011.0000	1358.1589	0.7712	180355.69
23	0.9173	7.3381	0.0015	1.4907	8.0000	1012.5000	1359.6496	0.7721	181368.19
1	0.7859	88.8057	0.0014	19.9719	113.0000	14011.0000	1379.6215	0.7834	195379.19
1	0.1751	19.7888	0.0014	19.7888	113.0000	14011.0000	1399.4103	0.7947	209390.19
2	0.2661	29.2732	0.0013	17.6218	110.0000	14011.0000	1417.0321	0.8047	223401.19
3	0.9784	130.1235	0.0012	4.9800	133.0000	4086.0000	1422.0121	0.8075	227487.19
110	0.4342	26.9207	0.0012	14.1145	62.0000	11733.0000	1436.1266	0.8155	239220.19
110	0.6582	40.8057	0.0012	13.8850	62.0000	11733.0000	1450.0116	0.8234	250953.19
2	0.8130	89.4300	0.0012	16.3364	110.0000	14011.0000	1466.3480	0.8327	264964.19
110	0.2066	12.8062	0.0011	12.8062	62.0000	11733.0000	1479.1542	0.8400	276697.19
13	0.8702	14.7936	0.0011	3.7872	17.0000	3558.8500	1482.9414	0.8421	280256.04
30	0.7188	2.8753	0.0010	2.8753	4.0000	2905.0000	1485.8167	0.8437	283161.04
9	0.9525	71.4369	0.0010	4.7458	75.0000	4905.5100	1490.5625	0.8464	288066.55
74	0.9771	42.9919	0.0010	2.3745	44.0000	2455.2100	1492.9370	0.8478	290521.76
1	0.8980	101.4689	0.0009	12.6632	113.0000	14011.0000	1505.6002	0.8550	304532.76
110	0.8234	51.0502	0.0009	10.2445	62.0000	11733.0000	1515.8447	0.8608	316265.76
32	0.9185	3.6739	0.0009	0.7406	4.0000	856.0000	1516.5853	0.8612	317121.76
73	0.9837	84.5955	0.0009	2.1074	86.0000	2455.2100	1518.6926	0.8624	319576.97
2	0.1059	11.6514	0.0008	11.6514	110.0000	14011.0000	1530.3440	0.8690	333587.97
124	0.2908	12.5044	0.0008	12.5044	43.0000	15340.5000	1542.8485	0.8761	348928.47
5	0.0037	2.0165	0.0008	1.3243	542.0000	1641.0000	1544.1728	0.8769	350569.47
112	0.7332	3.6662	0.0008	3.6662	5.0000	4759.7800	1547.8390	0.8790	355329.25
79	0.9987	2.9961	0.0007	2.9961	3.0000	4005.5200	1550.8351	0.8807	359334.77
2	0.9075	99.8233	0.0007	10.3934	110.0000	14011.0000	1561.2284	0.8866	373345.77
124	0.5482	23.5716	0.0007	11.0672	43.0000	15340.5000	1572.2956	0.8928	388686.27
80	0.9959	34.8575	0.0007	0.4623	35.0000	661.7700	1572.7579	0.8931	389348.04
7	0.9877	40.4954	0.0007	1.4659	41.0000	2118.0000	1574.2238	0.8939	391466.04
111	0.5550	16.0946	0.0006	16.0946	29.0000	25705.0000	1590.3184	0.9031	417171.04
75	0.0001	0.0297	0.0006	0.0297	279.0000	47.5200	1590.3481	0.9031	417218.56
115	1.0000	3.0000	0.0006	3.0000	3.0000	4975.3100	1593.3481	0.9048	422193.87
84	0.5987	9.5798	0.0006	9.5798	16.0000	15960.0000	1602.9279	0.9102	438153.87
124	0.7612	32.7316	0.0006	9.1600	43.0000	15340.5000	1612.0879	0.9154	453494.37
82	0.9896	11.8749	0.0006	0.3832	12.0000	661.7700	1612.4711	0.9157	454156.14
110	0.9209	57.0970	0.0005	6.0468	62.0000	11733.0000	1618.5179	0.9191	465889.14

123	0.9882	14.8235	0.0005	0.5202	15.0000	1010.0000	1619.0381	0.9194	466899.14
23	0.9802	7.8416	0.0005	0.5034	8.0000	1012.5000	1619.5416	0.9197	467911.64
1	0.9572	108.1598	0.0005	6.6909	113.0000	14011.0000	1626.2325	0.9235	481922.64
3	0.9930	132.0648	0.0005	1.9413	133.0000	4086.0000	1628.1738	0.9246	486008.64
9	0.9818	73.6380	0.0004	2.2011	75.0000	4905.5100	1630.3749	0.9258	490914.15
13	0.9625	16.3617	0.0004	1.5681	17.0000	3558.8500	1631.9430	0.9267	494473
78	0.6863	7.5498	0.0004	7.5498	11.0000	17674.5200	1639.4928	0.9310	512147.52
2	0.9590	105.4911	0.0004	5.6677	110.0000	14011.0000	1645.1605	0.9342	526158.52
124	0.8934	38.4177	0.0004	5.6861	43.0000	15340.5000	1650.8466	0.9374	541499.02
73	0.9941	85.4887	0.0004	0.8931	86.0000	2455.2100	1651.7397	0.9380	543954.23
39	0.9999	2.9998	0.0003	2.9998	3.0000	9668.0000	1654.7395	0.9397	553622.23
74	0.9942	43.7450	0.0003	0.7531	44.0000	2455.2100	1655.4926	0.9401	556077.44
5	0.0013	0.6922	0.0003	0.4931	542.0000	1641.0000	1655.9858	0.9404	557718.44
32	0.9806	3.9224	0.0003	0.2485	4.0000	856.0000	1656.2342	0.9405	558574.44
111	0.8067	23.3946	0.0003	7.3000	29.0000	25705.0000	1663.5343	0.9447	584279.44
30	0.9110	3.6442	0.0003	0.7688	4.0000	2905.0000	1664.3031	0.9451	587184.44
110	0.9689	60.0712	0.0003	2.9742	62.0000	11733.0000	1667.2773	0.9468	598917.44
6	0.9999	0.9999	0.0002	0.9999	1.0000	4086.0000	1668.2773	0.9473	603003.44
84	0.8383	13.4128	0.0002	3.8329	16.0000	15960.0000	1672.1102	0.9495	618963.44
1	0.9840	111.1900	0.0002	3.0303	113.0000	14011.0000	1675.1405	0.9512	632974.44
129	0.9973	1.9946	0.0001	1.9946	2.0000	16511.0000	1677.1350	0.9524	649485.440
130	0.9971	1.9942	0.0001	1.9942	2.0000	18520.0000	1679.1292	0.9535	668005.440
16	0.7256	10.8845	0.0001	10.8845	15.0000	141261.7100	1690.0137	0.9597	809267.150
132	1.0000	1.0000	0.0001	1.0000	1.0000	13380.0000	1691.0137	0.9603	822647.150
51	1.0000	2.0000	0.0001	2.0000	2.0000	32595.0000	1693.0136	0.9614	855242.150
133	1.0000	1.0000	0.0001	1.0000	1.0000	16511.0000	1694.0136	0.9620	871753.150
131	0.9993	0.9993	0.0001	0.9993	1.0000	18520.0000	1695.0130	0.9625	890273.150
58	1.0000	1.0000	0.0000	1.0000	1.0000	22914.0000	1696.0130	0.9631	913187.150
35	0.9997	2.9990	0.0000	2.9990	3.0000	80336.4900	1699.0119	0.9648	993523.640
116	1.0000	1.0000	0.0000	1.0000	1.0000	27700.0000	1700.0119	0.9654	1021223.640
92	0.6973	2.7893	0.0000	2.7893	4.0000	109952.0000	1702.8012	0.9670	**1131175.640**

C) Mixed Integer Linear Programming with Minimum NFF (Scenario-II, LP-2)

/*Mixed Integer Linear Programming with Minimum NFF (Scenario-II, LP-2) */

/* Objective function */

min: +14011 A1 +28022 B1 +42033 C1 +56044 D1 +84066 F1 +98077 G1 +112088 H1 +126099 I1 +140110 J1 +154121 K1 +168132 L1 +182143 M1 +196154 N1 +210165 P1 +224176 Q1 +238187 R1 +252198 T1 +266209 U1 +280220 W1 +294231 X1 +308242 Y1 +322253 Z1 +14011 A2 +28022 B2 +42033 C2 +56044 D2 +84066 F2 +98077 G2 +112088 H2 +126099 I2 +140110 J2 +154121 K2 +168132 L2 +182143 M2 +196154 N2 +210165 P2 +224176 Q2 +238187 R2 +252198 T2 +266209 U2 +280220 W2 +294231 X2 +308242 Y2 +322253 Z2 +4086 A3 +8172 B3 +12258 C3 +16344 D3 +24516 F3 +28602 G3 +32688 H3 +36774 I3 +40860 J3 +44946 K3 +49032 L3 +53118 M3 +57204 N3 +61290 P3 +65376 Q3 +69462 R3 +73548 T3 +77634 U3 +81720 W3 +85806 X3 +89892 Y3 +93978 Z3 +1641 A4 +3282 B4 +4923 C4 +6564 D4 +9846 F4 +11487 G4 +13128 H4 +14769 I4 +16410 J4 +18051 K4 +19692 L4 +21333 M4 +22974 N4 +24615 P4 +26256 Q4 +27897 R4 +29538 T4 +31179 U4 +32820 W4 +34461 X4 +36102 Y4 +37743 Z4 +4086 A5 +8172 B5 +12258 C5 +16344 D5 +24516 F5 +28602 G5 +32688 H5 +36774 I5 +40860 J5 +44946 K5 +49032 L5 +53118 M5 +57204 N5 +61290 P5 +65376 Q5 +69462 R5 +73548 T5 +77634 U5 +81720 W5 +85806 X5 +89892 Y5 +93978 Z5 +2118 A6 +4236 B6 +6354 C6 +8472 D6 +12708 F6 +14826 G6 +16944 H6 +19062 I6 +21180 J6 +23298 K6 +25416 L6 +27534 M6 +29652 N6 +31770 P6 +33888 Q6 +36006 R6 +38124 T6 +40242 U6 +42360 W6 +44478 X6 +46596 Y6 +48714 Z6 +1641 A7 +3282 B7 +4923 C7 +6564 D7 +9846 F7 +11487 G7 +13128 H7 +14769 I7 +16410 J7 +18051 K7 +19692 L7 +21333 M7 +22974 N7 +24615 P7 +26256 Q7 +27897 R7 +29538 T7 +31179 U7 +32820 W7 +34461 X7 +36102 Y7 +37743 Z7 +4905.51 A8 +9811.02 B8 +14716.53 C8 +19622.04 D8 +29433.06 F8 +34338.57 G8 +39244.08 H8 +44149.59 I8 +49055.1 J8 +53960.61 K8 +58866.12 L8 +63771.63 M8 +68677.14 N8 +73582.65 P8 +78488.16 Q8 +83393.67 R8 +88299.18 T8 +93204.69 U8 +98110.2 W8 +103015.71 X8 +107921.22 Y8 +112826.73 Z8 +3558.85 A9 +7117.7 B9 +10676.55 C9 +14235.4 D9 +21353.1 F9 +24911.95 G9 +28470.8 H9 +32029.65 I9 +35588.5 J9 +39147.35 K9 +42706.2 L9 +46265.05 M9 +49823.9 N9 +53382.75 P9 +56941.6 Q9 +60500.45 R9 +64059.3 T9 +67618.15 U9 +71177 W9 +74735.85 X9 +78294.7 Y9 +81853.5499999 Z9 +141261.71 A10 +282523.42 B10 +423785.13 C10 +565046.840001 D10 +847570.26 F10 +988831.97 G10 +1130093.68 H10 +1271355.39 I10 +1412617.1 J10 +1553878.81 K10 +1695140.52 L10 +1836402.23 M10 +1977663.94 N10 +2118925.65 P10 +2260187.36 Q10 +2401449.07 R10 +2542710.78 T10 +2683972.49 U10 +2825234.2 W10 +2966495.91 X10 +3107757.62 Y10 +3249019.33 Z10 +1012.5 A11 +2025 B11 +3037.5 C11 +4050 D11 +6075 F11 +7087.5 G11 +8100 H11 +9112.5 I11 +10125 J11 +11137.5 K11 +12150 L11 +13162.5 M11 +14175 N11 +15187.5 P11 +16200 Q11 +17212.5 R11 +18225 T11 +19237.5 U11 +20250 W11 +21262.5 X11 +22275 Y11 +23287.5 Z11 +2905 A12 +5810 B12 +8715 C12 +11620 D12 +17430 F12 +20335 G12 +23240 H12 +26145 I12 +29050 J12 +31955 K12 +34860 L12 +37765 M12 +40670 N12 +43575 P12 +46480 Q12 +49385 R12 +52290 T12 +55195 U12 +58100 W12 +61005 X12 +63910 Y12 +66815 Z12 +856 A13 +1712 B13 +2568 C13 +3424 D13 +5136 F13 +5992 G13 +6848 H13 +7704 I13 +8560 J13 +9416 K13 +10272 L13 +11128 M13 +11984 N13 +12840 P13 +13696 Q13 +14552 R13 +15408 T13 +16264 U13 +17120 W13 +17976 X13 +18832 Y13 +19688 Z13 +80336.49 A14 +160672.98 B14 +241009.47 C14 +321345.96 D14 +482018.94 F14 +562355.43 G14 +642691.92 H14 +723028.41 I14 +803364.9 J14 +883701.390001 K14 +964037.88 L14 +1044374.37 M14 +1124710.86 N14 +1205047.35 P14 +1285383.84 Q14 +1365720.33 R14 +1446056.82 T14 +1526393.31 U14 +1606729.8 W14 +1687066.29 X14 +1767402.78 Y14 +1847739.27 Z14 +9668 A15 +19336 B15 +29004 C15 +38672 D15 +58008 F15 +67676 G15 +77344 H15 +87012 I15 +96680 J15 +106348 K15 +116016 L15 +125684 M15 +135352 N15 +145020 P15 +154688 Q15 +164356 R15 +174024 T15 +183692 U15 +193360 W15 +203028 X15 +212696 Y15 +222364 Z15 +30.96 A16 +61.92 B16 +92.88 C16 +123.84 D16 +185.76 F16 +216.72 G16 +247.68 H16 +278.64 I16 +309.6 J16 +340.56 K16 +371.52 L16 +402.48 M16 +433.44 N16 +464.4 P16 +495.36 Q16 +526.32 R16 +557.28 T16 +588.24 U16 +619.2 W16 +650.16 X16 +681.12 Y16 +712.08 Z16 +193.36 A17 +386.72 B17 +580.08 C17 +773.44 D17 +1160.16 F17 +1353.52 G17 +1546.88 H17 +1740.24 I17 +1933.6 J17 +2126.96 K17 +2320.32 L17 +2513.68 M17 +2707.04 N17 +2900.4 P17 +3093.76 Q17 +3287.12 R17 +3480.48 T17 +3673.84 U17 +3867.2 W17 +4060.56 X17 +4253.92 Y17 +4447.28 Z17 +32595 A18 +65190 B18 +97785 C18 +130380 D18 +195570 F18 +228165 G18 +260760 H18 +293355 I18 +325950 J18 +358545 K18 +391140 L18 +423735 M18 +456330 N18 +488925 P18 +521520 Q18 +554115 R18 +586710 T18 +619305 U18 +651900 W18 +684495 X18 +717090 Y18 +749685 Z18 +22914 A19 +45828 B19 +68742 C19 +91656 D19 +137484 F19 +160398 G19 +183312 H19 +206226 I19 +229140 J19 +252054 K19 +274968 L19 +297882 M19 +320796 N19 +343710 P19 +366624 Q19 +389538 R19 +412452 T19 +435366 U19 +458280 W19 +481194 X19 +504108 Y19 +527022 Z19 +2455.21 A20 +4910.42 B20 +7365.63 C20 +9820.84 D20 +14731.26 F20 +17186.47 G20 +19641.68 H20 +22096.89 I20 +24552.1 J20 +27007.31 K20 +29462.52 L20 +31917.73 M20 +34372.94 N20 +36828.15 P20 +39283.36 Q20 +41738.57 R20 +44193.78 T20 +46648.99 U20 +49104.2 W20 +51559.41 X20 +54014.62 Y20 +56469.83 Z20 +2455.21 A21 +4910.42 B21 +7365.63 C21 +9820.84 D21 +14731.26 F21 +17186.47 G21 +19641.68 H21 +22096.89 I21 +24552.1 J21 +27007.31 K21 +29462.52 L21 +31917.73 M21 +34372.94 N21 +36828.15 P21 +39283.36 Q21 +41738.57 R21 +44193.78 T21 +46648.99 U21 +49104.2 W21 +51559.41 X21 +54014.62 Y21 +56469.83 Z21 +47.52 A22 +95.04 B22 +142.56 C22 +190.08 D22 +285.12 F22 +332.64 G22 +380.16 H22 +427.68 I22 +475.2 J22

+522.72 K22 +570.24 L22 +617.76 M22 +665.28 N22 +712.8 P22 +760.32 Q22 +807.84 R22 +855.36 T22 +902.88 U22 +950.4 W22 +997.92 X22 +1045.44 Y22 +1092.96 Z22 +697.84 A23 +1395.68 B23 +2093.52 C23 +2791.36 D23 +4187.04 F23 +4884.88 G23 +5582.72 H23 +6280.56 I23 +6978.4 J23 +7676.24 K23 +8374.08 L23 +9071.92000001 M23 +9769.76 N23 +10467.6 P23 +11165.44 Q23 +11863.28 R23 +12561.12 T23 +13258.96 U23 +13956.8 W23 +14654.64 X23 +15352.48 Y23 +16050.32 Z23 +17674.52 A24 +35349.04 B24 +53023.56 C24 +70698.08 D24 +106047.12 F24 +123721.64 G24 +141396.16 H24 +159070.68 I24 +176745.2 J24 +194419.72 K24 +212094.24 L24 +229768.76 M24 +247443.28 N24 +265117.8 P24 +282792.32 Q24 +300466.84 R24 +318141.36 T24 +335815.88 U24 +353490.4 W24 +371164.92 X24 +388839.44 Y24 +406513.96 Z24 +4005.52 A25 +8011.04 B25 +12016.56 C25 +16022.08 D25 +24033.12 F25 +28038.64 G25 +32044.16 H25 +36049.68 I25 +40055.2 J25 +44060.72 K25 +48066.24 L25 +52071.76 M25 +56077.28 N25 +60082.8 P25 +64088.32 Q25 +68093.84 R25 +72099.36 T25 +76104.8799999 U25 +80110.4 W25 +84115.92 X25 +88121.44 Y25 +92126.96 Z25 +661.77 A26 +1323.54 B26 +1985.31 C26 +2647.08 D26 +3970.62 F26 +4632.39 G26 +5294.16 H26 +5955.93 I26 +6617.7 J26 +7279.47 K26 +7941.24 L26 +8603.00999999 M26 +9264.78 N26 +9926.54999999 P26 +10588.32 Q26 +11250.09 R26 +11911.86 T26 +12573.63 U26 +13235.4 W26 +13897.17 X26 +14558.94 Y26 +15220.71 Z26 +640.7 A27 +1281.4 B27 +1922.1 C27 +2562.8 D27 +3844.2 F27 +4484.9 G27 +5125.6 H27 +5766.3 I27 +6407 J27 +7047.7 K27 +7688.4 L27 +8329.1 M27 +8969.8 N27 +9610.50000001 P27 +10251.2 Q27 +10891.9 R27 +11532.6 T27 +12173.3 U27 +12814 W27 +13454.7 X27 +14095.4 Y27 +14736.1 Z27 +661.77 A28 +1323.54 B28 +1985.31 C28 +2647.08 D28 +3970.62 F28 +4632.39 G28 +5294.16 H28 +5955.93 I28 +6617.7 J28 +7279.47 K28 +7941.24 L28 +8603.00999999 M28 +9264.78 N28 +9926.54999999 P28 +10588.32 Q28 +11250.09 R28 +11911.86 T28 +12573.63 U28 +13235.4 W28 +13897.17 X28 +14558.94 Y28 +15220.71 Z28 +15960 A29 +31920 B29 +47880 C29 +63840 D29 +95760 F29 +111720 G29 +127680 H29 +143640 I29 +159600 J29 +175560 K29 +191520 L29 +207480 M29 +223440 N29 +239400 P29 +255360 Q29 +271320 R29 +287280 T29 +303240 U29 +319200 W29 +335160 X29 +351120 Y29 +367080 Z29 +109952 A30 +219904 B30 +329856 C30 +439808 D30 +659712 F30 +769664 G30 +879616 H30 +989568 I30 +1099520 J30 +1209472 K30 +1319424 L30 +1429376 M30 +1539328 N30 +1649280 P30 +1759232 Q30 +1869184 R30 +1979136 T30 +2089088 U30 +2199040 W30 +2308992 X30 +2418944 Y30 +2528896 Z30 +11733 A31 +23466 B31 +35199 C31 +46932 D31 +70398 F31 +82131 G31 +93864 H31 +105597 I31 +117330 J31 +129063 K31 +140796 L31 +152529 M31 +164262 N31 +175995 P31 +187728 Q31 +199461 R31 +211194 T31 +222927 U31 +234660 W31 +246393 X31 +258126 Y31 +269859 Z31 +25705 A32 +51410 B32 +77115 C32 +102820 D32 +154230 F32 +179935 G32 +205640 H32 +231345 I32 +257050 J32 +282755 K32 +308460 L32 +334165 M32 +359870 N32 +385575 P32 +411280 Q32 +436985 R32 +462690 T32 +488395 U32 +514100 W32 +539805 X32 +565510 Y32 +591215 Z32 +4759.78 A33 +9519.56 B33 +14279.34 C33 +19039.12 D33 +28558.68 F33 +33318.46 G33 +38078.24 H33 +42838.02 I33 +47597.8 J33 +52357.58 K33 +57117.36 L33 +61877.14 M33 +66636.92 N33 +71396.7 P33 +76156.48 Q33 +80916.26 R33 +85676.04 T33 +90435.82 U33 +95195.6 W33 +99955.38 X33 +104715.16 Y33 +109474.94 Z33 +1101 A34 +2202 B34 +3303 C34 +4404 D34 +6606 F34 +7707 G34 +8808 H34 +9909 I34 +11010 J34 +12111 K34 +13212 L34 +14313 M34 +15414 N34 +16515 P34 +17616 Q34 +18717 R34 +19818 T34 +20919 U34 +22020 W34 +23121 X34 +24222 Y34 +25323 Z34 +4975.31 A35 +9950.61999999 B35 +14925.93 C35 +19901.24 D35 +29851.86 F35 +34827.17 G35 +39802.48 H35 +44777.79 I35 +49753.1 J35 +54728.41 K35 +59703.72 L35 +64679.03 M35 +69654.34 N35 +74629.65 P35 +79604.96 Q35 +84580.27 R35 +89555.58 T35 +94530.89 U35 +99506.1999999 W35 +104481.51 X35 +109456.82 Y35 +114432.13 Z35 +27700 A36 +55400 B36 +83100 C36 +110800 D36 +166200 F36 +193900 G36 +221600 H36 +249300 I36 +277000 J36 +304700 K36 +332400 L36 +360100 M36 +387800 N36 +415500 P36 +443200 Q36 +470900 R36 +498600 T36 +526300 U36 +554000 W36 +581700 X36 +609400 Y36 +637100 Z36 +1010 A37 +2020 B37 +3030 C37 +4040 D37 +6060 F37 +7070 G37 +8080 H37 +9090 I37 +10100 J37 +11110 K37 +12120 L37 +13130 M37 +14140 N37 +15150 P37 +16160 Q37 +17170 R37 +18180 T37 +19190 U37 +20200 W37 +21210 X37 +22220 Y37 +23230 Z37 +15340.5 A38 +30681 B38 +46021.5 C38 +61362 D38 +92043 F38 +107383.5 G38 +122724 H38 +138064.5 I38 +153405 J38 +168745.5 K38 +184086 L38 +199426.5 M38 +214767 N38 +230107.5 P38 +245448 Q38 +260788.5 R38 +276129 T38 +291469.5 U38 +306810 W38 +322150.5 X38 +337491 Y38 +352831.5 Z38 +1123 A39 +2246 B39 +3369 C39 +4492 D39 +6738 F39 +7861 G39 +8984 H39 +10107 I39 +11230 J39 +12353 K39 +13476 L39 +14599 M39 +15722 N39 +16845 P39 +17968 Q39 +19091 R39 +20214 T39 +21337 U39 +22460 W39 +23583 X39 +24706 Y39 +25829 Z39 +988 A40 +1976 B40 +2964 C40 +3952 D40 +5928 F40 +6916 G40 +7904 H40 +8892 I40 +9880 J40 +10868 K40 +11856 L40 +12844 M40 +13832 N40 +14820 P40 +15808 Q40 +16796 R40 +17784 T40 +18772 U40 +19760 W40 +20748 X40 +21736 Y40 +22724 Z40 +16511 A41 +33022 B41 +49533 C41 +66044 D41 +99066 F41 +115577 G41 +132088 H41 +148599 I41 +165110 J41 +181621 K41 +198132 L41 +214643 M41 +231154 N41 +247665 P41 +264176 Q41 +280687 R41 +297198 T41 +313709 U41 +330220 W41 +346731 X41 +363242 Y41 +379753 Z41 +18520 A42 +37040 B42 +55560 C42 +74080 D42 +111120 F42 +129640 G42 +148160 H42 +166680 I42 +185200 J42 +203720 K42 +222240 L42

+240760 M42 +259280 N42 +277800 P42 +296320 Q42 +314840 R42 +333360 T42 +351880 U42 +370400 W42 +388920 X42 +407440 Y42 +425960 Z42 +18520 A43 +37040 B43 +55560 C43 +74080 D43 +111120 F43 +129640 G43 +148160 H43 +166680 I43 +185200 J43 +203720 K43 +222240 L43 +240760 M43 +259280 N43 +277800 P43 +296320 Q43 +314840 R43 +333360 T43 +351880 U43 +370400 W43 +388920 X43 +407440 Y43 +425960 Z43 +13380 A44 +26760 B44 +40140 C44 +53520 D44 +80280 F44 +93660 G44 +107040 H44 +120420 I44 +133800 J44 +147180 K44 +160560 L44 +173940 M44 +187320 N44 +200700 P44 +214080 Q44 +227460 R44 +240840 T44 +254220 U44 +267600 W44 +280980 X44 +294360 Y44 +307740 Z44 +16511 A45 +33022 B45 +49533 C45 +66044 D45 +99066 F45 +115577 G45 +132088 H45 +148599 I45 +165110 J45 +181621 K45 +198132 L45 +214643 M45 +231154 N45 +247665 P45 +264176 Q45 +280687 R45 +297198 T45 +313709 U45 +330220 W45 +346731 X45 +363242 Y45 +379753 Z45;

/* Constraints */

R1: +19.789 A1 +43.635 B1 +68.834 C1 +88.806 D1 +108.16 F1 +111.19 G1 +112.391 H1 +112.814 I1 +112.948 J1 +112.987 K1 +112.997 L1 +112.999 M1 +113 N1 +113 P1 +113 Q1 +113 R1 +113 T1 +113 U1 +113 W1 +113 X1 +113 Y1 +113 Z1 +11.651 A2 +29.273 B2 +51.696 C2 +73.094 D2 +99.823 F2 +105.491 G2 +108.195 H2 +109.343 I2 +109.78 J2 +109.9 K2 +110 L2 +109.995 M2 +109.999 N2 +110 P2 +110 Q2 +110 R2 +110 T2 +110 U2 +110 W2 +110 X2 +110 Y2 +110 Z2 +32.384 A3 +64.718 B3 +94.129 C3 +114.193 D3 +130.123 F3 +132.065 G3 +132.727 H3 +132.928 I3 +132.983 J3 +133 K3 +133 L3 +133 M3 +133 N3 +133 P3 +133 Q3 +133 R3 +133 T3 +133 U3 +133 W3 +133 X3 +133 Y3 +133 Z3 +0.001 A4 +0.008 B4 +0.046 C4 +0.199 D4 +2.016 F4 +5.065 G4 +11.204 H4 +22.196 I4 +39.907 J4 +65.85 K4 +100.685 L4 +143.861 M4 +193.552 N4 +246.931 P4 +300.685 Q4 +351.635 R4 +397.242 T4 +435.92 U4 +467.08 W4 +490.988 X4 +508.498 Y4 +520.765000001 Z4 +A5 +B5 +C5 +D5 +F5 +G5 +H5 +I5 +J5 +K5 +L5 +M5 +N5 +P5 +Q5 +R5 +T5 +U5 +W5 +X5 +Y5 +Z5 +25.003 A6 +34.681 B6 +39.03 C6 +40.495 D6 +40.98 F6 +40.997 G6 +41 H6 +41 I6 +41 J6 +41 K6 +41 L6 +41 M6 +41 N6 +41 P6 +41 Q6 +41 R6 +41 T6 +41 U6 +41 W6 +41 X6 +41 Y6 +41 Z6 +8.999 A7 +9 B7 +9 C7 +9 D7 +9 F7 +9 G7 +9 H7 +9 I7 +9 J7 +9 K7 +9 L7 +9 M7 +9 N7 +9 P7 +9 Q7 +9 R7 +9 T7 +9 U7 +9 W7 +9 X7 +9 Y7 +9 Z7 +12.392 A8 +27.77 B8 +44.413 C8 +57.92 D8 +71.437 F8 +73.638 G8 +74.531 H8 +74.853 I8 +74.958 J8 +74.93 K8 +74.98 L8 +74.999 M8 +75 N8 +75 P8 +75 Q8 +75 R8 +75 T8 +75 U8 +75 W8 +75 X8 +75 Y8 +75 Z8 +0.406 A9 +14.794 B9 +16.362 C9 +16.849 D9 +16.995 F9 +16.999 G9 +17 H9 +17 I9 +17 J9 +17 K9 +17 L9 +17 M9 +17 N9 +17 P9 +17 Q9 +17 R9 +17 T9 +17 U9 +17 W9 +17 X9 +17 Y9 +17 Z9 +0.736 A10 +13.718 B10 +14.689 C10 +14.939 D10 +14.999 F10 +15 G10 +15 H10 +15 I10 +15 J10 +15 K10 +15 L10 +15 M10 +15 N10 +15 P10 +15 Q10 +15 R10 +15 T10 +15 U10 +15 W10 +15 X10 +15 Y10 +15 Z10 +0.736 A11 +7.338 B11 +7.842 C11 +7.969 D11 +7.999 F11 +8 G11 +8 H11 +8 I11 +8 J11 +8 K11 +8 L11 +8 M11 +8 N11 +8 P11 +8 Q11 +8 R11 +8 T11 +8 U11 +8 W11 +8 X11 +8 Y11 +8 Z11 +0.736 A12 +3.644 B12 +3.912 C12 +3.982 D12 +4 F12 +4 G12 +4 H12 +4 I12 +4 J12 +4 K12 +4 L12 +4 M12 +4 N12 +4 P12 +4 Q12 +4 R12 +4 T12 +4 U12 +4 W12 +4 X12 +4 Y12 +4 Z12 +0.736 A13 +3.674 B13 +3.922 C13 +3.985 D13 +4 F13 +4 G13 +4 H13 +4 I13 +4 J13 +4 K13 +4 L13 +4 M13 +4 N13 +4 P13 +4 Q13 +4 R13 +4 T13 +4 U13 +4 W13 +4 X13 +4 Y13 +4 Z13 +0.736 A14 +3 B14 +3 C14 +3 D14 +3 F14 +3 G14 +3 H14 +3 I14 +3 J14 +3 K14 +3 L14 +3 M14 +3 N14 +3 P14 +3 Q14 +3 R14 +3 T14 +3 U14 +3 W14 +3 X14 +3 Y14 +3 Z14 +A15 +3 B15 +3 C15 +3 D15 +3 F15 +3 G15 +3 H15 +3 I15 +3 J15 +3 K15 +3 L15 +3 M15 +3 N15 +3 P15 +3 Q15 +3 R15 +3 T15 +3 U15 +3 W15 +3 X15 +3 Y15 +3 Z15 +0.736 A16 +2 B16 +2 C16 +2 D16 +2 F16 +2 G16 +2 H16 +2 I16 +2 J16 +2 K16 +2 L16 +2 M16 +2 N16 +2 P16 +2 Q16 +2 R16 +2 T16 +2 U16 +2 W16 +2 X16 +2 Y16 +2 Z16 +A17 +2 B17 +2 C17 +2 D17 +2 F17 +2 G17 +2 H17 +2 I17 +2 J17 +2 K17 +2 L17 +2 M17 +2 N17 +2 P17 +2 Q17 +2 R17 +2 T17 +2 U17 +2 W17 +2 X17 +2 Y17 +2 Z17 +A18 +2 B18 +2 C18 +2 D18 +2 F18 +2 G18 +2 H18 +2 I18 +2 J18 +2 K18 +2 L18 +2 M18 +2 N18 +2 P18 +2 Q18 +2 R18 +2 T18 +2 U18 +2 W18 +2 X18 +2 Y18 +2 Z18 +A19 +B19 +C19 +D19 +F19 +G19 +H19 +I19 +J19 +K19 +L19 +M19 +N19 +P19 +Q19 +R19 +T19 +U19 +W19 +X19 +Y19 +Z19 +0.092 A20 +22.928 B20 +40.469 C20 +57.196 D20 +78.068 F20 +82.488 G20 +84.596 H20 +85.489 I20 +85.829 J20 +85.92 K20 +85.98 L20 +85.996 M20 +85.999 N20 +86 P20 +86 Q20 +86 R20 +86 T20 +86 U20 +86 W20 +86 X20 +86 Y20 +86 Z20 +0.406 A21 +34.628 B21 +40.617 C21 +42.992 D21 +43.944 F21 +43.989 G21 +43.998 H21 +44 I21 +44 J21 +44 K21 +44 L21 +44 M21 +44 N21 +44 P21 +44 Q21 +44 R21 +44 T21 +44 U21 +44 W21 +44 X21 +44 Y21 +44 Z21 +0.19 B22 +0.814 C22 +2.636 D22 +15.191 F22 +29.043 G22 +49.278 H22 +75.554 I22 +106.264 J22 +138.891 K22 +170.668 L22 +199.235 M22 +223.082 N22 +241.662 P22 +255.234 Q22 +264.564 R22 +270.622 T22 +274.348 U22 +276.526 W22 +277.737 X22 +278.381 Y22 +278.708 Z22 +A23 +4 B23 +4 C23 +4 D23 +4 F23 +4 G23 +4 H23 +4 I23 +4 J23 +4 K23 +4 L23 +4 M23 +4 N23 +4 P23 +4 Q23 +4 R23 +4 T23 +4 U23 +4 W23 +4 X23 +4 Y23 +4 Z23 +A24 +9.827 B24 +10.688 C24 +10.932 D24 +10.998 F24 +11 G24 +11 H24 +11 I24 +11 J24 +11 K24 +11

L24 +11 M24 +11 N24 +11 P24 +11 Q24 +11 R24 +11 T24 +11 U24 +11 W24 +11 X24 +11 Y24 +11 Z24 +A25 +3 B25 +3 C25 +3 D25 +3 F25 +3 G25 +3 H25 +3 I25 +3 J25 +3 K25 +3 L25 +3 M25 +3 N25 +3 P25 +3 Q25 +3 R25 +3 T25 +3 U25 +3 W25 +3 X25 +3 Y25 +3 Z25 +0.406 A26 +28.556 B26 +32.825 C26 +34.395 D26 +34.971 F26 +34.995 G26 +34.999 H26 +35 I26 +35 J26 +35 K26 +35 L26 +35 M26 +35 N26 +35 P26 +35 Q26 +35 R26 +35 T26 +35 U26 +35 W26 +35 X26 +35 Y26 +35 Z26 +0.736 A27 +4.999 B27 +5 C27 +5 D27 +5 F27 +5 G27 +5 H27 +5 I27 +5 J27 +5 K27 +5 L27 +5 M27 +5 N27 +5 P27 +5 Q27 +5 R27 +5 T27 +5 U27 +5 W27 +5 X27 +5 Y27 +5 Z27 +0.406 A28 +10.306 B28 +11.492 C28 +11.875 D28 +11.995 F28 +11.999 G28 +12 H28 +12 I28 +12 J28 +12 K28 +12 L28 +12 M28 +12 N28 +12 P28 +12 Q28 +12 R28 +12 T28 +12 U28 +12 W28 +12 X28 +12 Y28 +12 Z28 +0.406 A29 +13.413 B29 +15.176 C29 +15.784 D29 +15.991 F29 +15.998 G29 +16 H29 +16 I29 +16 J29 +16 K29 +16 L29 +16 M29 +16 N29 +16 P29 +16 Q29 +16 R29 +16 T29 +16 U29 +16 W29 +16 X29 +16 Y29 +16 Z29 +0.736 A30 +3.598 B30 +3.896 C30 +3.978 D30 +3.999 F30 +4 G30 +4 H30 +4 I30 +4 J30 +4 K30 +4 L30 +4 M30 +4 N30 +4 P30 +4 Q30 +4 R30 +4 T30 +4 U30 +4 W30 +4 X30 +4 Y30 +4 Z30 +0.199 A31 +26.921 B31 +40.806 C31 +51.05 D31 +60.071 F31 +61.325 G31 +61.788 H31 +61.939 I31 +61.984 J31 +62 K31 +62 L31 +62 M31 +62 N31 +62 P31 +62 Q31 +62 R31 +62 T31 +62 U31 +62 W31 +62 X31 +62 Y31 +62 Z31 +0.406 A32 +23.395 B32 +27.065 C32 +28.45 D32 +28.972 F32 +28.995 G32 +28.999 H32 +29 I32 +29 J32 +29 K32 +29 L32 +29 M32 +29 N32 +29 P32 +29 Q32 +29 R32 +29 T32 +29 U32 +29 W32 +29 X32 +29 Y32 +29 Z32 +0.736 A33 +4.592 B33 +4.903 C33 +4.981 D33 +5 F33 +5 G33 +5 H33 +5 I33 +5 J33 +5 K33 +5 L33 +5 M33 +5 N33 +5 P33 +5 Q33 +5 R33 +5 T33 +5 U33 +5 W33 +5 X33 +5 Y33 +5 Z33 +A34 +3 B34 +3 C34 +3 D34 +3 F34 +3 G34 +3 H34 +3 I34 +3 J34 +3 K34 +3 L34 +3 M34 +3 N34 +3 P34 +3 Q34 +3 R34 +3 T34 +3 U34 +3 W34 +3 X34 +3 Y34 +3 Z34 +A35 +3 B35 +3 C35 +3 D35 +3 F35 +3 G35 +3 H35 +3 I35 +3 J35 +3 K35 +3 L35 +3 M35 +3 N35 +3 P35 +3 Q35 +3 R35 +3 T35 +3 U35 +3 W35 +3 X35 +3 Y35 +3 Z35 +A36 +B36 +C36 +D36 +F36 +G36 +H36 +I36 +J36 +K36 +L36 +M36 +N36 +P36 +Q36 +R36 +T36 +U36 +W36 +X36 +Y36 +Z36 +0.406 A37 +12.742 B37 +14.303 C37 +14.824 D37 +14.993 F37 +14.999 G37 +15 H37 +15 I37 +15 J37 +15 K37 +15 L37 +15 M37 +15 N37 +15 P37 +15 Q37 +15 R37 +15 T37 +15 U37 +15 W37 +15 X37 +15 Y37 +15 Z37 +0.199 A38 +23.572 B38 +32.732 C38 +38.418 D38 +42.41 F38 +42.825 G38 +42.953 H38 +42.989 I38 +42.998 J38 +43 K38 +43 L38 +43 M38 +43 N38 +43 P38 +43 Q38 +43 R38 +43 T38 +43 U38 +43 W38 +43 X38 +43 Y38 +43 Z38 +0.736 A39 +4.998 B39 +5 C39 +5 D39 +5 F39 +5 G39 +5 H39 +5 I39 +5 J39 +5 K39 +5 L39 +5 M39 +5 N39 +5 P39 +5 Q39 +5 R39 +5 T39 +5 U39 +5 W39 +5 X39 +5 Y39 +5 Z39 +A40 +4 B40 +4 C40 +4 D40 +4 F40 +4 G40 +4 H40 +4 I40 +4 J40 +4 K40 +4 L40 +4 M40 +4 N40 +4 P40 +4 Q40 +4 R40 +4 T40 +4 U40 +4 W40 +4 X40 +4 Y40 +4 Z40 +A41 +2 B41 +2 C41 +2 D41 +2 F41 +2 G41 +2 H41 +2 I41 +2 J41 +2 K41 +2 L41 +2 M41 +2 N41 +2 P41 +2 Q41 +2 R41 +2 T41 +2 U41 +2 W41 +2 X41 +2 Y41 +2 Z41 +A42 +2 B42 +2 C42 +2 D42 +2 F42 +2 G42 +2 H42 +2 I42 +2 J42 +2 K42 +2 L42 +2 M42 +2 N42 +2 P42 +2 Q42 +2 R42 +2 T42 +2 U42 +2 W42 +2 X42 +2 Y42 +2 Z42 +A43 +B43 +C43 +D43 +F43 +G43 +H43 +I43 +J43 +K43 +L43 +M43 +N43 +P43 +Q43 +R43 +T43 +U43 +W43 +X43 +Y43 +Z43 +A44 +B44 +C44 +D44 +F44 +G44 +H44 +I44 +J44 +K44 +L44 +M44 +N44 +P44 +Q44 +R44 +T44 +U44 +W44 +X44 +Y44 +Z44 +A45 +B45 +C45 +D45 +F45 +G45 +H45 +I45 +J45 +K45 +L45 +M45 +N45 +P45 +Q45 +R45 +T45 +U45 +W45 +X45 +Y45 +Z45 >= 1672.95;

R2: +A1 +B1 +C1 +D1 +F1 +G1 +H1 +I1 +J1 +K1 +L1 +M1 +N1 +P1 +Q1 +R1 +T1 +U1 +W1 +X1 +Y1 +Z1 +E1 = 1;

R3: +A2 +B2 +C2 +D2 +F2 +G2 +H2 +I2 +J2 +K2 +L2 +M2 +N2 +P2 +Q2 +R2 +T2 +U2 +W2 +X2 +Y2 +Z2 +E2 = 1;

R4: +A3 +B3 +C3 +D3 +F3 +G3 +H3 +I3 +J3 +K3 +L3 +M3 +N3 +P3 +Q3 +R3 +T3 +U3 +W3 +X3 +Y3 +Z3 +E3 = 1;

R5: +A4 +B4 +C4 +D4 +F4 +G4 +H4 +I4 +J4 +K4 +L4 +M4 +N4 +P4 +Q4 +R4 +T4 +U4 +W4 +X4 +Y4 +Z4 +E4 = 1;

R6: +A5 +B5 +C5 +D5 +F5 +G5 +H5 +I5 +J5 +K5 +L5 +M5 +N5 +P5 +Q5 +R5 +T5 +U5 +W5 +X5 +Y5 +Z5 +E5 = 1;

R7: +A6 +B6 +C6 +D6 +F6 +G6 +H6 +I6 +J6 +K6 +L6 +M6 +N6 +P6 +Q6 +R6 +T6 +U6 +W6 +X6 +Y6 +Z6 +E6 = 1;

R8: +A7 +B7 +C7 +D7 +F7 +G7 +H7 +I7 +J7 +K7 +L7 +M7 +N7 +P7 +Q7 +R7 +T7 +U7 +W7 +X7 +Y7 +Z7 +E7 = 1;

R9: +A8 +B8 +C8 +D8 +F8 +G8 +H8 +I8 +J8 +K8 +L8 +M8 +N8 +P8 +Q8 +R8 +T8 +U8 +W8 +X8 +Y8 +Z8 +E8 = 1;

R10: +A9 +B9 +C9 +D9 +F9 +G9 +H9 +I9 +J9 +K9 +L9 +M9 +N9 +P9 +Q9 +R9 +T9 +U9 +W9 +X9 +Y9 +Z9 +E9 = 1;

R11: +A10 +B10 +C10 +D10 +F10 +G10 +H10 +I10 +J10 +K10 +L10 +M10 +N10 +P10 +Q10 +R10 +T10 +U10 +W10 +X10 +Y10 +Z10 +E10 = 1;

+B10 +C10 +D10 +F10 +G10 +H10 +I10 +J10 +K10 +L10 +M10 +N10 +P10 +Q10 +R10 +T10 +U10 +W10 +X10 +Y10 +Z10 +E10 = 0;

R12: +A11 +B11 +C11 +D11 +F11 +G11 +H11 +I11 +J11 +K11 +L11 +M11 +N11 +P11 +Q11 +R11 +T11 +U11 +W11 +X11 +Y11 +Z11 +E11 = 1;

R13: +A12 +B12 +C12 +D12 +F12 +G12 +H12 +I12 +J12 +K12 +L12 +M12 +N12 +P12 +Q12 +R12 +T12 +U12 +W12 +X12 +Y12 +Z12 +E12 = 1;

R14: +A13 +B13 +C13 +D13 +F13 +G13 +H13 +I13 +J13 +K13 +L13 +M13 +N13 +P13 +Q13 +R13 +T13 +U13 +W13 +X13 +Y13 +Z13 +E13 = 1;

R15: +A14 +B14 +C14 +D14 +F14 +G14 +H14 +I14 +J14 +K14 +L14 +M14 +N14 +P14 +Q14 +R14 +T14 +U14 +W14 +X14 +Y14 +Z14 +E14 = 1;

+B14 +C14 +D14 +F14 +G14 +H14 +I14 +J14 +K14 +L14 +M14 +N14 +P14 +Q14 +R14 +T14 +U14 +W14 +X14 +Y14 +Z14 +E14 = 0;

R16: +A15 +B15 +C15 +D15 +F15 +G15 +H15 +I15 +J15 +K15 +L15 +M15 +N15 +P15 +Q15 +R15 +T15 +U15 +W15 +X15 +Y15 +Z15 +E15 = 1;

R17: +A16 +B16 +C16 +D16 +F16 +G16 +H16 +I16 +J16 +K16 +L16 +M16 +N16 +P16 +Q16 +R16 +T16 +U16 +W16 +X16 +Y16 +Z16 +E16 = 1;

R18: +A17 +B17 +C17 +D17 +F17 +G17 +H17 +I17 +J17 +K17 +L17 +M17 +N17 +P17 +Q17 +R17 +T17 +U17 +W17 +X17 +Y17 +Z17 +E17 = 1;

R19: +A18 +B18 +C18 +D18 +F18 +G18 +H18 +I18 +J18 +K18 +L18 +M18 +N18 +P18 +Q18 +R18 +T18 +U18 +W18 +X18 +Y18 +Z18 +E18 = 1;

+B18 +C18 +D18 +F18 +G18 +H18 +I18 +J18 +K18 +L18 +M18 +N18 +P18 +Q18 +R18 +T18 +U18 +W18 +X18 +Y18 +Z18 +E18 = 0;

R20: +A19 +B19 +C19 +D19 +F19 +G19 +H19 +I19 +J19 +K19 +L19 +M19 +N19 +P19 +Q19 +R19 +T19 +U19 +W19 +X19 +Y19 +Z19 +E19 = 1;

+B19 +C19 +D19 +F19 +G19 +H19 +I19 +J19 +K19 +L19 +M19 +N19 +P19 +Q19 +R19 +T19 +U19 +W19 +X19 +Y19 +Z19 +E19 = 0;

R21: +A20 +B20 +C20 +D20 +F20 +G20 +H20 +I20 +J20 +K20 +L20 +M20 +N20 +P20 +Q20 +R20 +T20 +U20 +W20 +X20 +Y20 +Z20 +E20 = 1;

R22: +A21 +B21 +C21 +D21 +F21 +G21 +H21 +I21 +J21 +K21 +L21 +M21 +N21 +P21 +Q21 +R21 +T21 +U21 +W21 +X21 +Y21 +Z21 +E21 = 1;

R23: +A22 +B22 +C22 +D22 +F22 +G22 +H22 +I22 +J22 +K22 +L22 +M22 +N22 +P22 +Q22 +R22 +T22 +U22 +W22 +X22 +Y22 +Z22 +E22 = 1;

R24: +A23 +B23 +C23 +D23 +F23 +G23 +H23 +I23 +J23 +K23 +L23 +M23 +N23 +P23 +Q23 +R23 +T23 +U23 +W23 +X23 +Y23 +Z23 +E23 = 1;

R25: +A24 +B24 +C24 +D24 +F24 +G24 +H24 +I24 +J24 +K24 +L24 +M24 +N24 +P24 +Q24 +R24 +T24 +U24 +W24 +X24 +Y24 +Z24 +E24 = 1;

R26: +A25 +B25 +C25 +D25 +F25 +G25 +H25 +I25 +J25 +K25 +L25 +M25 +N25 +P25 +Q25 +R25 +T25 +U25 +W25 +X25 +Y25 +Z25 +E25 = 1;

R27: +A26 +B26 +C26 +D26 +F26 +G26 +H26 +I26 +J26 +K26 +L26 +M26 +N26 +P26 +Q26 +R26 +T26 +U26 +W26 +X26 +Y26 +Z26 +E26 = 1;

R28: +A27 +B27 +C27 +D27 +F27 +G27 +H27 +I27 +J27 +K27 +L27 +M27 +N27 +P27 +Q27 +R27 +T27 +U27 +W27 +X27 +Y27 +Z27 +E27 = 1;

R29: +A28 +B28 +C28 +D28 +F28 +G28 +H28 +I28 +J28 +K28 +L28 +M28 +N28 +P28 +Q28 +R28 +T28 +U28 +W28 +X28 +Y28 +Z28 +E28 = 1;

R30: +A29 +B29 +C29 +D29 +F29 +G29 +H29 +I29 +J29 +K29 +L29 +M29 +N29 +P29 +Q29 +R29 +T29 +U29 +W29 +X29 +Y29 +Z29 +E29 = 1;

R31: +A30 +B30 +C30 +D30 +F30 +G30 +H30 +I30 +J30 +K30 +L30 +M30 +N30 +P30 +Q30 +R30 +T30 +U30 +W30 +X30 +Y30 +Z30 +E30 = 1;

+B30 +C30 +D30 +F30 +G30 +H30 +I30 +J30 +K30 +L30 +M30 +N30 +P30 +Q30 +R30 +T30 +U30 +W30 +X30 +Y30 +Z30 +E30 = 0;

R32: +A31 +B31 +C31 +D31 +F31 +G31 +H31 +I31 +J31 +K31 +L31 +M31 +N31 +P31 +Q31 +R31 +T31 +U31 +W31 +X31 +Y31 +Z31 +E31 = 1;

R33: +A32 +B32 +C32 +D32 +F32 +G32 +H32 +I32 +J32 +K32 +L32 +M32 +N32 +P32 +Q32 +R32 +T32 +U32 +W32 +X32 +Y32 +Z32 +E32 = 1;

R34: +A33 +B33 +C33 +D33 +F33 +G33 +H33 +I33 +J33 +K33 +L33 +M33 +N33 +P33 +Q33 +R33 +T33 +U33 +W33 +X33 +Y33 +Z33 +E33 = 1;

R35: +A34 +B34 +C34 +D34 +F34 +G34 +H34 +I34 +J34 +K34 +L34 +M34 +N34 +P34 +Q34 +R34 +T34 +U34 +W34 +X34 +Y34 +Z34 +E34 = 1;

R36: +A35 +B35 +C35 +D35 +F35 +G35 +H35 +I35 +J35 +K35 +L35 +M35 +N35 +P35 +Q35 +R35 +T35 +U35 +W35 +X35 +Y35 +Z35 +E35 = 1;

R37: +A36 +B36 +C36 +D36 +F36 +G36 +H36 +I36 +J36 +K36 +L36 +M36 +N36 +P36 +Q36 +R36 +T36 +U36 +W36 +X36 +Y36 +Z36 +E36 = 1;

+B36 +C36 +D36 +F36 +G36 +H36 +I36 +J36 +K36 +L36 +M36 +N36 +P36 +Q36 +R36 +T36 +U36 +W36 +X36 +Y36 +Z36 +E36 = 0;

R38: +A37 +B37 +C37 +D37 +F37 +G37 +H37 +I37 +J37 +K37 +L37 +M37 +N37 +P37 +Q37 +R37 +T37 +U37 +W37 +X37 +Y37 +Z37 +E37 = 1;

R39: +A38 +B38 +C38 +D38 +F38 +G38 +H38 +I38 +J38 +K38 +L38 +M38 +N38 +P38 +Q38 +R38 +T38 +U38 +W38 +X38 +Y38 +Z38 +E38 = 1;

R40: +A39 +B39 +C39 +D39 +F39 +G39 +H39 +I39 +J39 +K39 +L39 +M39 +N39 +P39 +Q39 +R39 +T39 +U39 +W39 +X39 +Y39 +Z39 +E39 = 1;

R41: +A40 +B40 +C40 +D40 +F40 +G40 +H40 +I40 +J40 +K40 +L40 +M40 +N40 +P40 +Q40 +R40 +T40 +U40 +W40 +X40 +Y40 +Z40 +E40 = 1;

B41 +C41 +D41 +F41 +G41 +H41 +I41 +J41 +K41 +L41 +M41 +N41 +P41 +Q41 +R41 +T41 +U41 +W41 +X41 +Y41 +Z41 +E41 = 0;

B42 +C42 +D42 +F42 +G42 +H42 +I42 +J42 +K42 +L42 +M42 +N42 +P42 +Q42 +R42 +T42 +U42 +W42 +X42 +Y42 +Z42 +E42 = 0;

B43 +C43 +D43 +F43 +G43 +H43 +I43 +J43 +K43 +L43 +M43 +N43 +P43 +Q43 +R43 +T43 +U43 +W43 +X43 +Y43 +Z43 +E43 = 0;

B44 +C44 +D44 +F44 +G44 +H44 +I44 +J44 +K44 +L44 +M44 +N44 +P44 +Q44 +R44 +T44 +U44 +W44 +X44 +Y44 +Z44 +E44 = 0;

B45 +C45 +D45 +F45 +G45 +H45 +I45 +J45 +K45 +L45 +M45 +N45 +P45 +Q45 +R45 +T45 +U45 +W45 +X45 +Y45 +Z45 +E45 = 0;

R42: +A41 +B41 +C41 +D41 +F41 +G41 +H41 +I41 +J41 +K41 +L41 +M41 +N41 +P41 +Q41 +R41 +T41 +U41 +W41 +X41 +Y41 +Z41 +E41 = 1;

R43: +A42 +B42 +C42 +D42 +F42 +G42 +H42 +I42 +J42 +K42 +L42 +M42 +N42 +P42 +Q42 +R42 +T42 +U42 +W42 +X42 +Y42 +Z42 +E42 = 1;

R44: +A43 +B43 +C43 +D43 +F43 +G43 +H43 +I43 +J43 +K43 +L43 +M43 +N43 +P43 +Q43 +R43 +T43 +U43 +W43 +X43 +Y43 +Z43 +E43 = 1;

R45: +A44 +B44 +C44 +D44 +F44 +G44 +H44 +I44 +J44 +K44 +L44 +M44 +N44 +P44 +Q44 +R44 +T44 +U44 +W44 +X44 +Y44 +Z44 +E44 = 1;

R46: +A45 +B45 +C45 +D45 +F45 +G45 +H45 +I45 +J45 +K45 +L45 +M45 +N45 +P45 +Q45 +R45 +T45 +U45 +W45 +X45 +Y45 +Z45 +E45 = 1;

/* Integer definitions */

int
A1,B1,C1,D1,F1,G1,H1,I1,J1,K1,L1,M1,N1,P1,Q1,R1,T1,U1,W1,X1,Y1,Z1,A2,B2,C2,D2,F2,G2,H2,I2,J2,K2,L2,M2,N2,P2,Q2,R2,T2,U2,W2,X2,Y2,Z2,A3,B3,C3,D3,F3,G3,H3,I3,J3,K3,L3,M3,N3,P3,Q3,R3,T3,U3,W3,X3,Y3,Z3,A4,B4,C4,D4,F4,G4,H4,I4,J4,K4,L4,M4,N4,P4,Q4,R4,T4,U4,W4,X4,Y4,Z4,A5,B5,C5,D5,F5,G5,H5,I5,J5,K5,L5,M5,N5,P5,Q5,R5,T5,U5,W5,X5,Y5,Z5,A6,B6,C6,D6,F6,G6,H6,I6,J6,K6,L6,M6,N6,P6,Q6,R6,T6,U6,W6,X6,Y6,Z6,A7,B7,C7,D7,F7,G7,H7,I7,J7,K7,L7,M7,N7,P7,Q7,R7,T7,U7,W7,X7,Y7,Z7,A8,B8,C8,D8,F8,G8,H8,I8,J8,K8,L8,M8,N8,P8,Q8,R8,T8,U8,W8,X8,Y8,Z8,A9,B9,C9,D9,F9,G9,H9,I9,J9,K9,L9,M9,N9,P9,Q9,R9,T9,U9,W9,X9,Y9,Z9,A10,B10,C10,D10,F10,G10,H10,I10,J10,K10,L10,M10,N10,P10,Q10,R10,T10,U10,W10,X10,Y10,Z10,A11,B11,C11,D11,F11,G11,H11,I11,J11,K11,L11,M11,N11,P11,Q11,R11,T11,U11,W11,X11,Y11,Z11,A12,B12,C12,D12,F12,G

12,H12,I12,J12,K12,L12,M12,N12,P12,Q12,R12,T12,U12,W12,X12,Y12,Z12,A13,B13,C13,D13,F13,G13,H13,I13,J13,K13,L13,M13,N13,P13,Q13,R
13,T13,U13,W13,X13,Y13,Z13,A14,B14,C14,D14,F14,G14,H14,I14,J14,K14,L14,M14,N14,P14,Q14,R14,T14,U14,W14,X14,Y14,Z14,A15,B15,C15,D
15,F15,G15,H15,I15,J15,K15,L15,M15,N15,P15,Q15,R15,T15,U15,W15,X15,Y15,Z15,A16,B16,C16,D16,F16,G16,H16,I16,J16,K16,L16,M16,N16,P1
6,Q16,R16,T16,U16,W16,X16,Y16,Z16,A17,B17,C17,D17,F17,G17,H17,I17,J17,K17,L17,M17,N17,P17,Q17,R17,T17,U17,W17,X17,Y17,Z17,A18,B
18,C18,D18,F18,G18,H18,I18,J18,K18,L18,M18,N18,P18,Q18,R18,T18,U18,W18,X18,Y18,Z18,A19,B19,C19,D19,F19,G19,H19,I19,J19,K19,L19,M1
9,N19,P19,Q19,R19,T19,U19,W19,X19,Y19,Z19,A20,B20,C20,D20,F20,G20,H20,I20,J20,K20,L20,M20,N20,P20,Q20,R20,T20,U20,W20,X20,Y20,Z
20,A21,B21,C21,D21,F21,G21,H21,I21,J21,K21,L21,M21,N21,P21,Q21,R21,T21,U21,W21,X21,Y21,Z21,A22,B22,C22,D22,F22,G22,H22,I22,J22,K2
2,L22,M22,N22,P22,Q22,R22,T22,U22,W22,X22,Y22,Z22,A23,B23,C23,D23,F23,G23,H23,I23,J23,K23,L23,M23,N23,P23,Q23,R23,T23,U23,W23,X
23,Y23,Z23,A24,B24,C24,D24,F24,G24,H24,I24,J24,K24,L24,M24,N24,P24,Q24,R24,T24,U24,W24,X24,Y24,Z24,A25,B25,C25,D25,F25,G25,H25,I2
5,J25,K25,L25,M25,N25,P25,Q25,R25,T25,U25,W25,X25,Y25,Z25,A26,B26,C26,D26,F26,G26,H26,I26,J26,K26,L26,M26,N26,P26,Q26,R26,T26,U2
6,W26,X26,Y26,Z26,A27,B27,C27,D27,F27,G27,H27,I27,J27,K27,L27,M27,N27,P27,Q27,R27,T27,U27,W27,X27,Y27,Z27,A28,B28,C28,D28,F28,G2
8,H28,I28,J28,K28,L28,M28,N28,P28,Q28,R28,T28,U28,W28,X28,Y28,Z28,A29,B29,C29,D29,F29,G29,H29,I29,J29,K29,L29,M29,N29,P29,Q29,R2
9,T29,U29,W29,X29,Y29,Z29,A30,B30,C30,D30,F30,G30,H30,I30,J30,K30,L30,M30,N30,P30,Q30,R30,T30,U30,W30,X30,Y30,Z30,A31,B31,C31,D3
1,F31,G31,H31,I31,J31,K31,L31,M31,N31,P31,Q31,R31,T31,U31,W31,X31,Y31,Z31,A32,B32,C32,D32,F32,G32,H32,I32,J32,K32,L32,M32,N32,P32
,Q32,R32,T32,U32,W32,X32,Y32,Z32,A33,B33,C33,D33,F33,G33,H33,I33,J33,K33,L33,M33,N33,P33,Q33,R33,T33,U33,W33,X33,Y33,Z33,A34,B3
4,C34,D34,F34,G34,H34,I34,J34,K34,L34,M34,N34,P34,Q34,R34,T34,U34,W34,X34,Y34,Z34,A35,B35,C35,D35,F35,G35,H35,I35,J35,K35,L35,M35
,N35,P35,Q35,R35,T35,U35,W35,X35,Y35,Z35,A36,B36,C36,D36,F36,G36,H36,I36,J36,K36,L36,M36,N36,P36,Q36,R36,T36,U36,W36,X36,Y36,Z3
6,A37,B37,C37,D37,F37,G37,H37,I37,J37,K37,L37,M37,N37,P37,Q37,R37,T37,U37,W37,X37,Y37,Z37,A38,B38,C38,D38,F38,G38,H38,I38,J38,K38
,L38,M38,N38,P38,Q38,R38,T38,U38,W38,X38,Y38,Z38,A39,B39,C39,D39,F39,G39,H39,I39,J39,K39,L39,M39,N39,P39,Q39,R39,T39,U39,W39,X3
9,Y39,Z39,A40,B40,C40,D40,F40,G40,H40,I40,J40,K40,L40,M40,N40,P40,Q40,R40,T40,U40,W40,X40,Y40,Z40,A41,B41,C41,D41,F41,G41,H41,I41
,J41,K41,L41,M41,N41,P41,Q41,R41,T41,U41,W41,X41,Y41,Z41,A42,B42,C42,D42,F42,G42,H42,I42,J42,K42,L42,M42,N42,P42,Q42,R42,T42,U42
,W42,X42,Y42,Z42,A43,B43,C43,D43,F43,G43,H43,I43,J43,K43,L43,M43,N43,P43,Q43,R43,T43,U43,W43,X43,Y43,Z43,A44,B44,C44,D44,F44,G44
,H44,I44,J44,K44,L44,M44,N44,P44,Q44,R44,T44,U44,W44,X44,Y44,Z44,A45,B45,C45,D45,F45,G45,H45,I45,J45,K45,L45,M45,N45,P45,Q45,R45,
T45,U45,W45,X45,Y45,Z45,E1,E2,E3,E4,E5,E6,E7,E8,E9,E10,E11,E12,E13,E14,E15,E16,E17,E18,E19,E20,E21,E22,E23,E24,E25,E26,E27,E28,E29,E3
0,E31,E32,E33,E34,E35,E36,E37,E38,E39,E40,E41,E42,E43,E44,E45;

APPENDIX-V

A) Sample result for Poison distribution With Minimum Scrap rate (Scenario-III , P3)

S/N	REMS/YR(R)	Price(P)	Service Level(SL)	Repair TAT	NFF TAT	Total NFF	HQ	E"=(R-	Expected Holding Quantity (HQ) and Service Level(probability)						Total cost=HQ*P
									1	2	3	4	5	10	

								NFF)*I2/365+J2*K2/36							
1	113	14,011.00	0.95	3.78	1.25	13	3	1	0.706	0.904	0.976	0.995	0.999	1.000	42,033.00
2	110	14,011.00	0.95	6.03	2.43	17	4	2	0.509	0.770	0.914	0.973	0.993	1.000	56,044.00
3	133	4,086.00	0.95	2.00	1.49	21	3	1	0.844	0.966	0.994	0.999	1.000	1.000	12,258.00
5	542	1,641.00	0.95	4.79	1.52	86	10	6.00	0.017	0.062	0.151	0.285	0.446	0.957	16,410.00
6	1	4,086.00	0.95	4.00	1.2	0	1	0.01	1.000	1.000	1.000	1.000	1.000	1.000	4,086.00
7	41	2,118.00	0.95	3.10	2.1	3	1	0.34	0.954	0.995	1.000	1.000	1.000	1.000	2,118.00
8	9	1,641.00	0.95	0.63	0.5	1	1	0.02	1.000	1.000	1.000	1.000	1.000	1.000	1,641.00
9	75	4,905.51	0.95	1.20	0.39	7	1	0.23	0.977	0.998	1.000	1.000	1.000	1.000	4,905.51
13	17	3,558.85	0.95	5.20	1.5	2	1	0.22	0.979	0.998	1.000	1.000	1.000	1.000	3,558.85
16	15	141,261.71	0.89	0.67	0.22	2	1	0.03	1.000	1.000	1.000	1.000	1.000	1.000	141,261.71
23	8	1,012.50	0.95	0.60	0.2	1	1	0.01	1.000	1.000	1.000	1.000	1.000	1.000	1,012.50
30	4	2,905.00	0.95	4.20	1.6	1	1	0.04	0.999	1.000	1.000	1.000	1.000	1.000	2,905.00
32	4	856	0.95	0.60	0.2	0	1	0.01	1.000	1.000	1.000	1.000	1.000	1.000	856.00
35	3	80,336.49	0.95	3.20	1	0	1	0.03	1.000	1.000	1.000	1.000	1.000	1.000	80,336.49
39	3	9,668.00	0.95	1.50	0.45	0	1	0.01	1.000	1.000	1.000	1.000	1.000	1.000	9,668.00
46	2	30.96	0.95	3.30	1	0	1	0.02	1.000	1.000	1.000	1.000	1.000	1.000	30.96
48	2	193.36	0.95	0.08	0.03	0	1	0.00	1.000	1.000	1.000	1.000	1.000	1.000	193.36
51	2	32,595.00	0.95	1.20	0.39	0	1	0.01	1.000	1.000	1.000	1.000	1.000	1.000	32,595.00
58	1	22,914.00	0.95	2.60	0.30	0	1	0.01	1.000	1.000	1.000	1.000	1.000	1.000	22,914.00
73	86	2,455.21	0.95	7.70	5.62	10	5	2.00	0.406	0.677	0.857	0.947	0.983	1.000	12,276.05
74	44	2,455.21	0.95	4.86	3.55	5	3	1.00	0.736	0.920	0.981	0.996	0.999	1.000	7,365.63
75	279	47.52	0.95	7.44	5.43	31	10	6.00	0.017	0.062	0.151	0.285	0.446	0.957	475.20
77	4	697.84	0.95	2.66	1.94	1	1	0.03	1.000	1.000	1.000	1.000	1.000	1.000	697.84
78	11	17,674.52			3.26	0	1		0.992	1.000	1.000	1.000	1.000	1.000	

			0.95	4.47				0.13							17,674.52
79	3	4,005.52	0.95	6.30	4.6	1	1	0.05	0.999	1.000	1.000	1.000	1.000	1.000	4,005.52
80	35	661.77	0.95	4.92	3.59	4	3	1.00	0.736	0.920	0.981	0.996	0.999	1.000	1,985.31
81	5	640.7	0.95	8.40	6.1	1	1	0.11	0.994	1.000	1.000	1.000	1.000	1.000	640.70
82	12	661.77	0.95	8.90	5.6	2	1	0.27	0.969	0.997	1.000	1.000	1.000	1.000	661.77
84	16	15,960.00	0.89	8.67	0.78	4	1	0.29	0.964	0.997	1.000	1.000	1.000	1.000	15,960.00
92	4	109,952.00	0.93	9.55	1.76	1	1	0.08	0.997	1.000	1.000	1.000	1.000	1.000	109,952.00
110	62	11,733.00	0.95	5.60	2.8	3	3	1.00	0.736	0.920	0.981	0.996	0.999	1.000	35,199.00
111	29	25,705.00	0.93	6.40	3.2	2	3	1.00	0.736	0.920	0.981	0.996	0.999	1.000	77,115.00
112	5	4,759.78	0.95	0.50	0.24	1	1	0.01	1.000	1.000	1.000	1.000	1.000	1.000	4,759.78
114	3	1,101.00	0.95	0.40	0.19	0	1	0.00	1.000	1.000	1.000	1.000	1.000	1.000	1,101.00
115	3	4,975.31	0.95	0.55	0.26	0	1	0.00	1.000	1.000	1.000	1.000	1.000	1.000	4,975.31
116	1	27,700.00	0.95	1.00	0.48	0	1	0.00	1.000	1.000	1.000	1.000	1.000	1.000	27,700.00
123	15	1,010.00	0.95	8.10	6.8	1	1	0.33	0.956	0.995	1.000	1.000	1.000	1.000	1,010.00
124	43	15,340.50	0.93	4.10	3.44	2	3	1.00	0.736	0.920	0.981	0.996	0.999	1.000	46,021.50
125	5	1,123.00	0.95	9.32	7.83	0	1	0.13	0.993	1.000	1.000	1.000	1.000	1.000	1,123.00
126	4	988	0.95	6.60	5.54	0	1	0.07	0.998	1.000	1.000	1.000	1.000	1.000	988.00
129	2	16,511.00	0.95	13.80	11.6	0	1	0.08	0.997	1.000	1.000	1.000	1.000	1.000	16,511.00
130	2	18,520.00	0.95	14.30	12	0	1	0.08	0.997	1.000	1.000	1.000	1.000	1.000	18,520.00
131	1	18,520.00	0.95	13.33	11.2	0	1	0.04	0.999	1.000	1.000	1.000	1.000	1.000	18,520.00
132	1	13,380.00	0.95	0.50	0.42	0	1	0.00	1.000	1.000	1.000	1.000	1.000	1.000	13,380.00
133	1	16,511.00	0.95	1.33	1.12	0	1	0.00	1.000	1.000	1.000	1.000	1.000	1.000	16,511.00
Total Cost(USD)															889,956.51

B) Marginal Analysis Result with Minimum Scrap rate (Scenario-III, M3)

SN	Holding Qty (HQ)	Service Level	Fills(unit)	Marginal Contribution (MC)	Delta Fills ($\Delta F ¿$	Removals/yr(Ri)	cost	Cumulative fills($\sum \Delta F ¿¿$ =F	Service Level(F/ $\sum Ri$)	Cumulative Cost($)
75	6	0.6063	169.1585	0.9431	44.8139	279	47.52	44.81386	0.02545	47.52
75	5	0.4457	124.3446	0.9431	44.8139	279	47.52	89.62771	0.0509	95.04
75	7	0.7440	207.5704	0.8083	38.4119	279	47.52	128.0396	0.07271	142.56
75	4	0.2851	79.53076	0.7859	37.3449	279	47.52	165.3845	0.09392	190.08
75	8	0.8472	236.3793	0.6062	28.8089	279	47.52	194.1934	0.11027	237.60
75	3	0.1512	42.18588	0.5239	24.8966	279	47.52	219.09	0.12441	285.12
75	9	0.9161	255.5852	0.4042	19.2059	279	47.52	238.2959	0.13532	332.64
75	2	0.0620	17.2893	0.2620	12.4483	279	47.52	250.7442	0.14239	380.16
75	10	0.9574	267.1088	0.2425	11.5236	279	47.52	262.2678	0.14893	427.68
75	11	0.9799	273.3943	0.1323	6.28558	279	47.52	268.5533	0.1525	475.20
75	1	0.0174	4.841003	0.1019	4.841	279	47.52	273.3943	0.15525	522.72
75	12	0.9912	276.5371	0.0661	3.14279	279	47.52	276.5371	0.15703	570.24
46	1	1.0000	2	0.0646	2	2	30.96	278.5371	0.15817	601.20
5	6	0.4497	243.7434	0.0492	80.7595	542	1641.00	359.2966	0.20403	2242.20
5	7	0.5987	324.5029	0.0492	80.7595	542	1641.00	440.0561	0.24989	3883.20
5	8	0.7291	395.1675	0.0431	70.6646	542	1641.00	510.7207	0.29002	5524.20
5	5	0.3007	162.9839	0.0422	69.2224	542	1641.00	579.9431	0.32933	7165.20
80	1	0.7358	25.75156	0.0389	25.7516	35	661.77	605.6947	0.34395	7826.97
5	9	0.8305	450.1288	0.0335	54.9613	542	1641.00	660.656	0.37516	9467.97
75	13	0.9964	277.9877	0.0305	1.45052	279	47.52	662.1066	0.37598	9515.49
5	4	0.1730	93.76145	0.0301	49.4446	542	1641.00	711.5512	0.40406	11156.49
3	1	0.7358	97.85593	0.0239	97.8559	133	4086.00	809.4071	0.45963	15242.49
5	10	0.9015	488.6017	0.0234	38.4729	542	1641.00	847.88	0.48148	16883.49
5	3	0.0818	44.31686	0.0172	28.2541	542	1641.00	876.1341	0.49752	18524.49
9	1	1.0000	75	0.0153	75	75	4905.51	951.1341	0.54011	23430.00
5	11	0.9467	513.0845	0.0149	24.4828	542	1641.00	975.6168	0.55401	25071.00
123	1	1.0000	15	0.0149	15	15	1010.00	990.6168	0.56253	26081.00
7	1	0.7358	30.16611	0.0142	30.1661	41	2118.00	1020.783	0.57966	28199.00
73	1	0.4060	34.9165	0.0142	34.9165	86	2455.21	1055.699	0.59949	30654.21

82		0.7358	8.829107	0.0133	8.82911	12	661.77	1064.529	0.6045	31315.98
74	1	0.7358	32.37339	0.0132	32.3734	44	2455.21	1096.902	0.62289	33771.19
75	14	0.9986	278.6093	0.0131	0.62165	279	47.52	1097.524	0.62324	33818.71
48	1	1.0000	2	0.0103	2	2	193.36	1099.524	0.62437	34012.07
80	2	0.9197	32.18945	0.0097	6.43789	35	661.77	1105.962	0.62803	34673.84
73	2	0.6767	58.19417	0.0095	23.2777	86	2455.21	1129.239	0.64125	37129.05
5	12	0.9730	527.3661	0.0087	14.2816	542	1641.00	1143.521	0.64936	38770.05
23	1	1.0000	8	0.0079	8	8	1012.50	1151.521	0.6539	39782.55
81	1	1.0000	5	0.0078	5	5	640.70	1156.521	0.65674	40423.25
5	2	0.0296	16.0628	0.0074	12.1089	542	1641.00	1168.63	0.66362	42064.25
73	3	0.8571	73.7126	0.0063	15.5184	86	2455.21	1184.148	0.672	44519.46
3	2	0.9197	122.3199	0.0060	24.4640	133	4086.00	1208.612	0.686	48605.46
1	1	0.7358	83.1408	0.0059	83.1408	113	14011.00	1291.753	0.734	62616.46
77	1	1.0000	4.0000	0.0057	4.0000	4	697.84	1295.753	0.736	63314.30
8	1	1.0000	9.0000	0.0055	9.0000	9	1641.00	1304.753	0.741	64955.30
75	15	0.9995	278.8580	0.0052	0.2487	279	47.52	1305.002	0.741	65002.82
13	1	1.0000	17.0000	0.0048	17.0000	17	3558.85	1322.002	0.751	68561.67
5	13	0.9872	535.0562	0.0047	7.6901	542	1641.00	1329.692	0.755	70202.67
32	1	1.0000	4.0000	0.0047	4.0000	4	856.00	1333.692	0.757	71058.67
125	1	1.0000	5.0000	0.0045	5.0000	5.0000	1123.00	1338.6916	0.7602	72181.67
126	1	1.0000	4.0000	0.0040	4.0000	4.0000	988.00	1342.6916	0.7625	73169.67
110	1	0.7358	45.6171	0.0039	45.6171	62.0000	11733.00	1388.3087	0.7884	84902.67
7	2	0.9197	37.7076	0.0036	7.5415	41.0000	2118.00	1395.8502	0.7926	87020.67
82		0.9197	11.0364	0.0033	2.2073	12.0000	661.77	1398.0575	0.7939	87682.44
74	2	0.9197	40.4667	0.0033	8.0933	44.0000	2455.21	1406.1508	0.7985	90137.65
80	3	0.9810	34.3354	0.0032	2.1460	35	661.77	1408.297	0.800	90799.42
2	1	0.4060	44.6606	0.0032	44.6606	110	14011.00	1452.957	0.825	104810.42
73	4	0.9473	81.4718	0.0032	7.7592	86	2455.21	1460.717	0.829	107265.63
114	1	1.0000	3.0000	0.0027	3.0000	3	1101.00	1463.717	0.831	108366.63
5	1	0.0073	3.9539	0.0024	3.9539	542	1641.00	1467.671	0.833	110007.63
5	14	0.9943	538.9013	0.0023	3.8451	542	1641.00	1471.516	0.836	111648.63
2	2	0.6767	74.4344	0.0021	29.7738	110	14011.00	1501.289	0.853	125659.63
124	1	0.7358	31.6376	0.0021	31.6376	43.0000	15340.50	1532.9270	0.8705	141000.13
3	3	0.9810	130.4746	0.0020	8.1547	133.0000	4086.00	1541.0817	0.8751	145086.13
75	16	0.9998	278.9512	0.0020	0.0932	279.0000	47.52	1541.1749	0.8752	145133.65
1	2	0.9197	103.9259	0.0015	20.7852	113.0000	14011.00	1561.9601	0.8870	159144.65
2	3	0.8571	94.2836	0.0014	19.8492	110.0000	14011.00	1581.8093	0.8982	173155.65
30	1	1.0000	4.0000	0.0014	4.0000	4.0000	2905.00	1585.8093	0.9005	176060.65
73	5	0.9834	84.5755	0.0013	3.1037	86.0000	2455.21	1588.9130	0.9023	178515.86
7	3	0.9810	40.2215	0.0012	2.5138	41.0000	2118.00	1591.4268	0.9037	180633.86
82		0.9810	11.7721	0.0011	0.7358	12.0000	661.77	1592.1626	0.9041	181295.63
74	3	0.9810	43.1645	0.0011	2.6978	44.0000	2455.21	1594.8604	0.9057	183750.84
5	15	0.9976	540.6956	0.0011	1.7944	542.0000	1641.00	1596.6547	0.9067	185391.84

112	1	1.0000	5.0000	0.0011	5.0000	5.0000	4759.78	1601.6547	0.9095	190151.62
110	2	0.9197	57.0213	0.0010	11.4043	62.0000	11733.00	1613.0590	0.9160	201884.62
111	1	0.7358	21.3370	0.0008	21.3370	29.0000	25705.00	1634.3960	0.9281	227589.62
80	4	0.9963	34.8719	0.0008	0.5365	35.0000	661.77	1634.9325	0.9284	228251.39
79	1	1.0000	3.0000	0.0007	3.0000	3.0000	4005.52	1637.9325	0.9301	232256.91
84		0.7358	11.7721	0.0007	11.7721	16.0000	15960.00	1649.7046	0.9368	248216.91
82		0.9963	11.9561	0.0003	0.1839	12.0000	661.77	1649.8886	0.9369	248878.68
2	4	0.9197	14.7152	0.0002	2.9430	16	15960.00	1652.8316	0.9386	264838.68
84		0.9197	14.7152	0.0002	2.9430	16	15960.00	1655.7746	0.9402	280798.68
129	1	1.0000	2.0000	0.0001	2.0000	2	16511.00	1657.7746	0.9414	297309.68
73	7	0.9989	85.9057	0.0001	0.2956	86	2455.21	1658.0702	0.9416	299764.89
130	1	1.0000	2.0000	0.0001	2.0000	2	18520.00	1660.0702	0.9427	318284.89
16	1	1.0000	15.0000	0.0001	15.0000	15	141261.71	1675.0702	0.9512	459546.60
132	1	1.0000	1.0000	0.0001	1.0000	1	13380.00	1676.070	0.952	472926.60
51	1	1.0000	2.0000	0.0001	2.0000	2	32595.00	1678.070	0.953	505521.60
133	1	1.0000	1.0000	0.0001	1.0000	1	16511.00	1679.070	0.953	522032.60
131	1	1.0000	1.0000	0.0001	1.0000	1	18520.00	1680.070	0.954	540552.60
58	1	1.0000	1.0000	0.0000	1.0000	1	22914.00	1681.070	0.955	563466.60
35	1	1.0000	3.0000	0.0000	3.0000	3	80336.49	1684.070	0.956	643803.09
92	1	1.0000	4.0000	0.0000	4.0000	4	109952.00	1688.070	0.959	753755.09
116	1	1.0000	1.0000	0.0000	1.0000	1	27700.00	1689.070	0.959	781455.09
78	1	0.9963	15.9414	0.0000	0.2453	16	15960.00	1689.315	0.959	797415.09
115	1	0.9994	15.9905	0.0000	0.0491	16	15960.00	1689.365	0.959	813375.09
39	1	1.0000	16.0000	0.0000	0.0000	16	15960.00	1689.365	0.959	829335.09
6	1	1.0000	16.0000	0.0000	0.0000	16	15960.00	1689.365	0.959	**845295.09**

C) Mixed Integer Linear Programming with Minimum Scrap rate (Scenario-III, LP-3)

/*Mixed Integer Linear Programming with Minimum Scrap rate (Scenario-III, LP-3) */

/* Objective function */

min: +14011 A1 +28022 B1 +42033 C1 +56044 D1 +84066 F1 +98077 G1 +112088 H1 +126099 I1 +140110 J1 +14011 A2 +28022 B2 +42033 C2 +56044 D2 +84066 F2 +98077 G2 +112088 H2 +126099 I2 +140110 J2 +4086 A3 +8172 B3 +12258 C3 +16344 D3 +24516 F3 +28602 G3 +32688 H3 +36774 I3 +40860 J3 +1641 A4 +3282 B4 +4923 C4 +6564 D4 +9846 F4 +11487 G4 +13128 H4 +14769 I4 +16410 J4 +4086 A5 +8172 B5 +12258 C5 +16344 D5 +24516 F5 +28602 G5 +32688 H5 +36774 I5 +40860 J5 +2118 A6 +4236 B6 +6354 C6 +8472 D6 +12708 F6 +14826 G6 +16944 H6 +19062 I6 +21180 J6 +1641 A7 +3282 B7 +4923 C7 +6564 D7 +9846 F7 +11487 G7 +13128 H7 +14769 I7 +16410 J7 +4905.51 A8 +9811.02 B8 +14716.53 C8 +19622.04 D8 +29433.06 F8 +34338.57 G8 +39244.08 H8 +44149.59 I8 +49055.1 J8 +3558.85 A9 +7117.7 B9 +10676.55 C9 +14235.4 D9 +21353.1 F9 +24911.95 G9 +28470.8 H9 +32029.65 I9 +35588.5 J9 +141261.71 A10 +282523.42 B10 +423785.13 C10 +565046.840001 D10 +847570.26 F10 +988831.97 G10 +1130093.68 H10 +1271355.39 I10 +1412617.1 J10 +1012.5 A11 +2025 B11 +3037.5 C11 +4050 D11 +6075 F11 +7087.5 G11 +8100 H11 +9112.5 I11 +10125 J11 +2905 A12 +5810 B12 +8715 C12 +11620 D12 +17430 F12 +20335 G12 +23240 H12 +26145 I12 +29050 J12 +856 A13 +1712 B13 +2568 C13 +3424 D13 +5136 F13 +5992 G13 +6848 H13 +7704 I13 +8560 J13 +80336.49 A14 +160672.98 B14 +241009.47 C14 +321345.96 D14 +482018.94 F14 +562355.43 G14 +642691.92 H14 +723028.41 I14 +803364.9 J14 +9668 A15 +19336 B15 +29004 C15 +38672 D15 +58008 F15 +67676 G15 +77344 H15 +87012 I15 +96680 J15 +30.96 A16 +61.92 B16 +92.88 C16 +123.84 D16 +185.76 F16 +216.72 G16 +247.68 H16 +278.64 I16 +309.6 J16 +193.36 A17

+386.72 B17 +580.08 C17 +773.44 D17 +1160.16 F17 +1353.52 G17 +1546.88 H17 +1740.24 I17 +1933.6 J17 +32595 A18 +65190 B18 +97785 C18 +130380 D18 +195570 F18 +228165 G18 +260760 H18 +293355 I18 +325950 J18 +22914 A19 +45828 B19 +68742 C19 +91656 D19 +137484 F19 +160398 G19 +183312 H19 +206226 I19 +229140 J19 +2455.21 A20 +4910.42 B20 +7365.63 C20 +9820.84 D20 +14731.26 F20 +17186.47 G20 +19641.68 H20 +22096.89 I20 +24552.1 J20 +2455.21 A21 +4910.42 B21 +7365.63 C21 +9820.84 D21 +14731.26 F21 +17186.47 G21 +19641.68 H21 +22096.89 I21 +24552.1 J21 +47.52 A22 +95.04 B22 +142.56 C22 +190.08 D22 +285.12 F22 +332.64 G22 +380.16 H22 +427.68 I22 +475.2 J22 +697.84 A23 +1395.68 B23 +2093.52 C23 +2791.36 D23 +4187.04 F23 +4884.88 G23 +5582.72 H23 +6280.56 I23 +6978.4 J23 +17674.52 A24 +35349.04 B24 +53023.56 C24 +70698.08 D24 +106047.12 F24 +123721.64 G24 +141396.16 H24 +159070.68 I24 +176745.2 J24 +4005.52 A25 +8011.04 B25 +12016.56 C25 +16022.08 D25 +24033.12 F25 +28038.64 G25 +32044.16 H25 +36049.68 I25 +40055.2 J25 +661.77 A26 +1323.54 B26 +1985.31 C26 +2647.08 D26 +3970.62 F26 +4632.39 G26 +5294.16 H26 +5955.93 I26 +6617.7 J26 +640.7 A27 +1281.4 B27 +1922.1 C27 +2562.8 D27 +3844.2 F27 +4484.9 G27 +5125.6 H27 +5766.3 I27 +6407 J27 +661.77 A28 +1323.54 B28 +1985.31 C28 +2647.08 D28 +3970.62 F28 +4632.39 G28 +5294.16 H28 +5955.93 I28 +6617.7 J28 +15960 A29 +31920 B29 +47880 C29 +63840 D29 +95760 F29 +111720 G29 +127680 H29 +143640 I29 +159600 J29 +109952 A30 +219904 B30 +329856 C30 +439808 D30 +659712 F30 +769664 G30 +879616 H30 +989568 I30 +1099520 J30 +11733 A31 +23466 B31 +35199 C31 +46932 D31 +70398 F31 +82131 G31 +93864 H31 +105597 I31 +117330 J31 +25705 A32 +51410 B32 +77115 C32 +102820 D32 +154230 F32 +179935 G32 +205640 H32 +231345 I32 +257050 J32 +4759.78 A33 +9519.56 B33 +14279.34 C33 +19039.12 D33 +28558.68 F33 +33318.46 G33 +38078.24 H33 +42838.02 I33 +47597.8 J33 +1101 A34 +2202 B34 +3303 C34 +4404 D34 +6606 F34 +7707 G34 +8808 H34 +9909 I34 +11010 J34 +4975.31 A35 +9950.61999999 B35 +14925.93 C35 +19901.24 D35 +29851.86 F35 +34827.17 G35 +39802.48 H35 +44777.79 I35 +49753.1 J35 +27700 A36 +55400 B36 +83100 C36 +110800 D36 +166200 F36 +193900 G36 +221600 H36 +249300 I36 +277000 J36 +1010 A37 +2020 B37 +3030 C37 +4040 D37 +6060 F37 +7070 G37 +8080 H37 +9090 I37 +10100 J37 +15340.5 A38 +30681 B38 +46021.5 C38 +61362 D38 +92043 F38 +107383.5 G38 +122724 H38 +138064.5 I38 +153405 J38 +1123 A39 +2246 B39 +3369 C39 +4492 D39 +6738 F39 +7861 G39 +8984 H39 +10107 I39 +11230 J39 +988 A40 +1976 B40 +2964 C40 +3952 D40 +5928 F40 +6916 G40 +7904 H40 +8892 I40 +9880 J40 +16511 A41 +33022 B41 +49533 C41 +66044 D41 +99066 F41 +115577 G41 +132088 H41 +148599 I41 +165110 J41 +18520 A42 +37040 B42 +55560 C42 +74080 D42 +111120 F42 +129640 G42 +148160 H42 +166680 I42 +185200 J42 +18520 A43 +37040 B43 +55560 C43 +74080 D43 +111120 F43 +129640 G43 +148160 H43 +166680 I43 +185200 J43 +13380 A44 +26760 B44 +40140 C44 +53520 D44 +80280 F44 +93660 G44 +107040 H44 +120420 I44 +133800 J44 +16511 A45 +33022 B45 +49533 C45 +66044 D45 +99066 F45 +115577 G45 +132088 H45 +148599 I45 +165110 J45;

/* Constraints */

R1: +79.813 A1 +102.195 B1 +110.254 C1 +112.43 D1 +112.985 F1 +112.998 G1 +113 H1 +113 I1 +113 J1 +55.997 A2 +84.751 B2 +100.563 C2 +107.083 D2 +109.826 F2 +109.965 G2 +109.994 H2 +109.999 I2 +110 J2 +112.305 A3 +128.468 B3 +132.237 C3 +132.896 D3 +132.999 F3 +133 G3 +133 H3 +133 I3 +133 J3 +7.005 A4 +26.192 B4 +66.757 C4 +131.076 D4 +298.905 F4 +377.045 G4 +438.994 H4 +482.65 I4 +510.338 J4 +A5 +B5 +C5 +D5 +F5 +G5 +H5 +I5 +J5 +39.105 A6 +40.791 B6 +40.983 C6 +40.999 D6 +41 F6 +41 G6 +41 H6 +41 I6 +41 J6 +8.999 A7 +9 B7 +9 C7 +9 D7 +9 F7 +9 G7 +9 H7 +9 I7 +9 J7 +73.281 A8 +74.87 B8 +74.993 C8 +75 D8 +75 F8 +75 G8 +75 H8 +75 I8 +75 J8 +0.406 A9 +16.974 B9 +16.999 C9 +17 D9 +17 F9 +17 G9 +17 H9 +17 I9 +17 J9 +0.736 A10 +15 B10 +15 C10 +15 D10 +15 F10 +15 G10 +15 H10 +15 I10 +15 J10 +0.736 A11 +8 B11 +8 C11 +8 D11 +8 F11 +8 G11 +8 H11 +8 I11 +8 J11 +0.736 A12 +4 B12 +4 C12 +4 D12 +4 F12 +4 G12 +4 H12 +4 I12 +4 J12 +0.736 A13 +4 B13 +4 C13 +4 D13 +4 F13 +4 G13 +4 H13 +4 I13 +4 J13 +0.736 A14 +3 B14 +3 C14 +3 D14 +3 F14 +3 G14 +3 H14 +3 I14 +3 J14 +A15 +3 B15 +3 C15 +3 D15 +3 F15 +3 G15 +3 H15 +3 I15 +3 J15 +0.736 A16 +2 B16 +2 C16 +2 D16 +2 F16 +2 G16 +2 H16 +2 I16 +2 J16 +A17 +2 B17 +2 C17 +2 D17 +2 F17 +2 G17 +2 H17 +2 I17 +2 J17 +A18 +2 B18 +2 C18 +2 D18 +2 F18 +2 G18 +2 H18 +2 I18 +2 J18 +A19 +B19 +C19 +D19 +F19 +G19 +H19 +I19 +J19 +0.092 A20 +63.815 B20 +77.233 C20 +83.128 D20 +85.806 F20 +85.959 G20 +85.992 H20 +85.999 I20 +86 J20 +0.406 A21 +43.117 B21 +43.878 C21 +43.986 D21 +44 F21 +44 G21 +44 H21 +44 I21 +44 J21 +24.377 B22 +55.761 C22 +99.04 D22 +190.689 F22 +225.284 G22 +249.138 H22 +263.759 I22 +271.824 J22 +A23 +4 B23 +4 C23 +4 D23 +4 F23 +4 G23 +4 H23 +4 I23 +4 J23 +A24 +10.996 B24 +11 C24 +11 D24 +11 F24 +11 G24 +11 H24 +11 I24 +11 J24 +A25 +3 B25 +3 C25 +3 D25 +3 F25 +3 G25 +3 H25 +3 I25 +3 J25 +0.406 A26 +34.603 B26 +34.956 C26 +34.996 D26 +35 F26 +35 G26 +35 H26 +35 I26 +35 J26 +0.736 A27 +4.999 B27 +5 C27 +5 D27 +5 F27 +5 G27 +5 H27 +5 I27 +5 J27 +0.406 A28 +11.966 B28 +11.998 C28 +12 D28 +12 F28 +12 G28 +12 H28 +12 I28 +12 J28 +0.406 A29 +15.946 B29 +15.996 C29 +16 D29 +16 F29 +16 G29 +16 H29 +16 I29 +16 J29 +0.736 A30 +4 B30 +4 C30 +4 D30 +4 F30 +4 G30 +4 H30 +4 I30 +4 J30 +0.199 A31 +57.81 B31 +61.076 C31 +61.834 D31 +61.997 F31 +62

G31 +62 H31 +62 I31 +62 J31 +0.406 A32 +28.602 B32 +28.952 C32 +28.995 D32 +29 F32 +29 G32 +29 H32 +29 I32 +29 J32 +0.736 A33 +5 B33 +5 C33 +5 D33 +5 F33 +5 G33 +5 H33 +5 I33 +5 J33 +A34 +3 B34 +3 C34 +3 D34 +3 F34 +3 G34 +3 H34 +3 I34 +3 J34 +A35 +3 B35 +3 C35 +3 D35 +3 F35 +3 G35 +3 H35 +3 I35 +3 J35 +A36 +B36 +C36 +D36 +F36 +G36 +H36 +I36 +J36 +0.406 A37 +14.93 B37 +14.994 C37 +15 D37 +15 F37 +15 G37 +15 H37 +15 I37 +15 J37 +0.199 A38 +42.446 B38 +42.935 C38 +42.994 D38 +43 F38 +43 G38 +43 H38 +43 I38 +43 J38 +0.736 A39 +4.998 B39 +5 C39 +5 D39 +5 F39 +5 G39 +5 H39 +5 I39 +5 J39 +A40 +4 B40 +4 C40 +4 D40 +4 F40 +4 G40 +4 H40 +4 I40 +4 J40 +A41 +2 B41 +2 C41 +2 D41 +2 F41 +2 G41 +2 H41 +2 I41 +2 J41 +A42 +2 B42 +2 C42 +2 D42 +2 F42 +2 G42 +2 H42 +2 I42 +2 J42 +A43 +B43 +C43 +D43 +F43 +G43 +H43 +I43 +J43 +A44 +B44 +C44 +D44 +F44 +G44 +H44 +I44 +J44 +A45 +B45 +C45 +D45 +F45 +G45 +H45 +I45 +J45 >= 1672.95;

R2: +A1 +B1 +C1 +D1 +F1 +G1 +H1 +I1 +J1 +E1 = 1;

R3: +A2 +B2 +C2 +D2 +F2 +G2 +H2 +I2 +J2 +E2 = 1;

R4: +A3 +B3 +C3 +D3 +F3 +G3 +H3 +I3 +J3 +E3 = 1;

R5: +A4 +B4 +C4 +D4 +F4 +G4 +H4 +I4 +J4 +E4 = 1;

R6: +A5 +B5 +C5 +D5 +F5 +G5 +H5 +I5 +J5 +E5 = 1;

B5 +C5 +D5 +F5 +G5 +H5 +I5 +J5 +E5 = 0;

R7: +A6 +B6 +C6 +D6 +F6 +G6 +H6 +I6 +J6 +E6 = 1;

R8: +A7 +B7 +C7 +D7 +F7 +G7 +H7 +I7 +J7 +E7 = 1;

R9: +A8 +B8 +C8 +D8 +F8 +G8 +H8 +I8 +J8 +E8 = 1;

R10: +A9 +B9 +C9 +D9 +F9 +G9 +H9 +I9 +J9 +E9 = 1;

R11: +A10 +B10 +C10 +D10 +F10 +G10 +H10 +I10 +J10 +E10 = 1;

B10 +C10 +D10 +F10 +G10 +H10 +I10 +J10 +E10 = 0;

R12: +A11 +B11 +C11 +D11 +F11 +G11 +H11 +I11 +J11 +E11 = 1;

R13: +A12 +B12 +C12 +D12 +F12 +G12 +H12 +I12 +J12 +E12 = 1;

R14: +A13 +B13 +C13 +D13 +F13 +G13 +H13 +I13 +J13 +E13 = 1;

R15: +A14 +B14 +C14 +D14 +F14 +G14 +H14 +I14 +J14 +E14 = 1;

B14 +C14 +D14 +F14 +G14 +H14 +I14 +J14 +E14 = 0;

R16: +A15 +B15 +C15 +D15 +F15 +G15 +H15 +I15 +J15 +E15 = 1;

B15 +C15 +D15 +F15 +G15 +H15 +I15 +J15 +E15 = 0;

R17: +A16 +B16 +C16 +D16 +F16 +G16 +H16 +I16 +J16 +E16 = 1;

R18: +A17 +B17 +C17 +D17 +F17 +G17 +H17 +I17 +J17 +E17 = 1;

R19: +A18 +B18 +C18 +D18 +F18 +G18 +H18 +I18 +J18 +E18 = 1;

B18 +C18 +D18 +F18 +G18 +H18 +I18 +J18 +E18 = 0;

R20: +A19 +B19 +C19 +D19 +F19 +G19 +H19 +I19 +J19 +E19 = 1;

B19 +C19 +D19 +F19 +G19 +H19 +I19 +J19 +E19 = 0;

R21: +A20 +B20 +C20 +D20 +F20 +G20 +H20 +I20 +J20 +E20 = 1;

R22: +A21 +B21 +C21 +D21 +F21 +G21 +H21 +I21 +J21 +E21 = 1;

R23: +A22 +B22 +C22 +D22 +F22 +G22 +H22 +I22 +J22 +E22 = 1;

R24: +A23 +B23 +C23 +D23 +F23 +G23 +H23 +I23 +J23 +E23 = 1;

R25: +A24 +B24 +C24 +D24 +F24 +G24 +H24 +I24 +J24 +E24 = 1;

R26: +A25 +B25 +C25 +D25 +F25 +G25 +H25 +I25 +J25 +E25 = 1;

R27: +A26 +B26 +C26 +D26 +F26 +G26 +H26 +I26 +J26 +E26 = 1;

R28: +A27 +B27 +C27 +D27 +F27 +G27 +H27 +I27 +J27 +E27 = 1;

R29: +A28 +B28 +C28 +D28 +F28 +G28 +H28 +I28 +J28 +E28 = 1;

R30: +A29 +B29 +C29 +D29 +F29 +G29 +H29 +I29 +J29 +E29 = 1;

R31: +A30 +B30 +C30 +D30 +F30 +G30 +H30 +I30 +J30 +E30 = 1;

B30 +C30 +D30 +F30 +G30 +H30 +I30 +J30 +E30 = 0;

R32: +A31 +B31 +C31 +D31 +F31 +G31 +H31 +I31 +J31 +E31 = 1;

R33: +A32 +B32 +C32 +D32 +F32 +G32 +H32 +I32 +J32 +E32 = 1;

R34: +A33 +B33 +C33 +D33 +F33 +G33 +H33 +I33 +J33 +E33 = 1;

R35: +A34 +B34 +C34 +D34 +F34 +G34 +H34 +I34 +J34 +E34 = 1;

R36: +A35 +B35 +C35 +D35 +F35 +G35 +H35 +I35 +J35 +E35 = 1;

B35 +C35 +D35 +F35 +G35 +H35 +I35 +J35 +E35 = 0;

R37: +A36 +B36 +C36 +D36 +F36 +G36 +H36 +I36 +J36 +E36 = 1;

B36 +C36 +D36 +F36 +G36 +H36 +I36 +J36 +E36 = 0;

R38: +A37 +B37 +C37 +D37 +F37 +G37 +H37 +I37 +J37 +E37 = 1;

R39: +A38 +B38 +C38 +D38 +F38 +G38 +H38 +I38 +J38 +E38 = 1;

R40: +A39 +B39 +C39 +D39 +F39 +G39 +H39 +I39 +J39 +E39 = 1;

R41: +A40 +B40 +C40 +D40 +F40 +G40 +H40 +I40 +J40 +E40 = 1;

B41 +C41 +D41 +F41 +G41 +H41 +I41 +J41 +E41 = 0;

R43: +B42 +C42 +D42 +F42 +G42 +H42 +I42 +J42 +E42 = 0;

R44: +B43 +C43 +D43 +F43 +G43 +H43 +I43 +J43 +E43 = 0;

R45: +B44 +C44 +D44 +F44 +G44 +H44 +I44 +J44 +E44 = 0;

R46:+B45 +C45 +D45 +F45 +G45 +H45 +I45 +J45 +E45 = 0;

R42: +A41 +B41 +C41 +D41 +F41 +G41 +H41 +I41 +J41 +E41 = 1;

R43: +A42 +B42 +C42 +D42 +F42 +G42 +H42 +I42 +J42 +E42 = 1;

R44: +A43 +B43 +C43 +D43 +F43 +G43 +H43 +I43 +J43 +E43 = 1;

R45: +A44 +B44 +C44 +D44 +F44 +G44 +H44 +I44 +J44 +E44 = 1;

R46: +A45 +B45 +C45 +D45 +F45 +G45 +H45 +I45 +J45 +E45 = 1;

/* Integer definitions */

int
A1,B1,C1,D1,F1,G1,H1,I1,J1,A2,B2,C2,D2,F2,G2,H2,I2,J2,A3,B3,C3,D3,F3,G3,H3,I3,J3,A4,B4,C4,D4,F4,G4,H4,I4,J4,A5,B5,C5,D5,F5,G5,H5,I5,J5,A6,B6,C6,D6,F6,G6,H6,I6,J6,A7,B7,C7,D7,F7,G7,H7,I7,J7,A8,B8,C8,D8,F8,G8,H8,I8,J8,A9,B9,C9,D9,F9,G9,H9,I9,J9,A10,B10,C10,D10,F10,G10,H10,I10,J10,A11,B11,C11,D11,F11,G11,H11,I11,J11,A12,B12,C12,D12,F12,G12,H12,I12,J12,A13,B13,C13,D13,F13,G13,H13,I13,J13,A14,B14,C14,D14,F14,G14,H14,I14,J14,A15,B15,C15,D15,F15,G15,H15,I15,J15,A16,B16,C16,D16,F16,G16,H16,I16,J16,A17,B17,C17,D17,F17,G17,H17,I17,J17,A18,B18,C18,D18,F18,G18,H18,I18,J18,A19,B19,C19,D19,F19,G19,H19,I19,J19,A20,B20,C20,D20,F20,G20,H20,I20,J20,A21,B21,C21,D21,F21,G21,H21,I21,J21,A22,B22,C22,D22,F22,G22,H22,I22,J22,A23,B23,C23,D23,F23,G23,H23,I23,J23,A24,B24,C24,D24,F24,G24,H24,I24,J24,A25,B25,C25,D25,F25,G25,H25,I25,J25,A26,B26,C26,D26,F26,G26,H26,I26,J26,A27,B27,C27,D27,F27,G27,H27,I27,J27,A28,B28,C28,D28,F28,G28,H28,I28,J28,A29,B29,C29,D29,F29,G29,H29,I29,J29,A30,B30,C30,D30,F30,G30,H30,I30,J30,A31,B31,C31,D31,F31,G31,H31,I31,J31,A32,B32,C32,D32,F32,G32,H32,I32,J32,A33,B33,C33,D33,F33,G33,H33,I33,J33,A34,B34,C34,D34,F34,G34,H34,I34,J34,A35,B35,C35,D35,F35,G35,H35,I35,J35,A36,B36,C36,D36,F36,G36,H36,I36,J36,A37,B37,C37,D37,F37,G37,H37,I37,J37,A38,B38,C38,D38,F38,G38,H38,I38,J38,A39,B39,C39,D39,F39,G39,H39,I39,J39,A40,B40,C40,D40,F40,G40,H40,I40,J40,A41,B41,C41,D41,F41,G41,H41,I41,J41,A42,B42,C42,D42,F42,G42,H42,I42,J42,A43,B43,C43,D43,F43,G43,H43,I43,J43,A44,B44,C44,D44,F44,G44,H44,I44,J44,A45,B45,C45,D45,F45,G45,H45,I45,J45,E1,E2,E3,E4,E5,E6,E7,E8,E9,E10,E11,E12,E13,E14,E15,E16,E17,E18,E19,E20,E21,E22,E23,E24,E25,E26,E27,E28,E29,E30,E31,E32,E33,E34,E35,E36,E37,E38,E39,E40,E41,E42,E43,E44,E45;

APPENDIX-VI

A) Result for Poison distribution With Combined NFF and Disposal Rate (Scenario-IV , P4)

SN	REMS/YR(R)	Price(P)	Repair TAT(T)	NFF TAT (T2)	Total NFF(NFF)	Scrap/Yr. (S)	E=(R-NFF)*T/365+NFF*T2/365+S	Expected Holding Quantity (HQ) and Service Level(probability)									Total Cost=P*HQ
								1	2	4	5	6	7	18	22	Holding Qty-HQ	
1	113	14011	3.78	1.25	13	2	3	0.187	0.405	0.802	0.908	0.962	0.986	1.000	1.000	6	84066
2	110	14011	6.03	2.43	17	2	4	0.121	0.294	0.697	0.837	0.923	0.967	1.000	1.000	7	98077
3	133	4086	2	1.49	21	2	3	0.249	0.494	0.863	0.943	0.979	0.993	1.000	1.000	6	24516
5	542	1641	4.79	1.52	86	9	15	0.000	0.000	0.001	0.002	0.006	0.015	0.794	0.960	22	36102
6	1	4086	4	1.2	0	0	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1	4086
7	41	2118	3.1	2.1	3	1	1	0.613	0.848	0.988	0.997	1.000	1.000	1.000	1.000	3	6354
8	9	1641	0.63	0.5	1	0	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1	1641
9	75	4905.51	1.2	0.39	7	3	3	0.167	0.373	0.775	0.891	0.953	0.982	1.000	1.000	6	29433.1
13	17	3558.85	5.2	1.5	2	1	1	0.655	0.875	0.992	0.998	1.000	1.000	1.000	1.000	3	10676.6
16	15	141261.71	0.67	0.22	2	1	1	0.727	0.915	0.996	0.999	1.000	1.000	1.000	1.000	2	282523
23	8	1012.5	0.6	0.2	1	1	1	0.731	0.917	0.996	0.999	1.000	1.000	1.000	1.000	3	3037.5
30	4	2905	4.2	1.6	1	1	1	0.721	0.912	0.996	0.999	1.000	1.000	1.000	1.000	3	8715
32	4	856	0.6	0.2	0	1	1	0.733	0.918	0.996	0.999	1.000	1.000	1.000	1.000	3	2568
35	3	80336.49	3.2	1	0	0	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1	80336.5
39	3	9668	1.5	0.45	0	0	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1	9668
46	2	30.96	3.3	1	0	0	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1	30.96
48	2	193.36	0.08	0.03	0	0	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1	193.36
51	2	32595	1.2	0.39	0	0	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1	32595
58	1	22914	2.6	0.3	0	0	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1	22914
73	86	2455.21	7.7	5.62	10	2	4	0.111	0.276	0.676	0.822	0.913	0.962	1.000	1.000	7	17186.5
74	44	2455.21	4.86	3.55	5	2	3	0.274	0.527	0.882	0.953	0.984	0.995	1.000	1.000	5	12276.1
75	279	47.52	7.44	5.43	31	6	12	0.000	0.001	0.011	0.027	0.060	0.113	0.974	0.998	18	855.36
77	4	697.84	2.66	1.94	1	0	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1	697.84
78	11	17674.52	4.47	3.26	0	1	1	0.686	0.893	0.994	0.999	1.000	1.000	1.000	1.000	3	53023.6

79	3	4005.52	6.3	4.6	1	0	0	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1	4005.52
80	35	661.77	4.92	3.59	4	1	1	0.572	0.820	0.983	0.996	0.999	1.000	1.000	1.000	4	2647.08
81	5	640.7	8.4	6.1	1	0	0	0.994	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1	640.7
82	12	661.77	8.9	5.6	2	1	1	0.636	0.863	0.990	0.998	1.000	1.000	1.000	1.000	3	1985.31
84	16	15960	8.67	0.78	4	1	1	0.629	0.859	0.990	0.998	1.000	1.000	1.000	1.000	3	47880
92	4	109952	9.55	1.76	1	1	1	0.705	0.904	0.995	0.999	1.000	1.000	1.000	1.000	3	329856
110	62	11733	5.6	2.8	3	2	3	0.210	0.439	0.827	0.923	0.970	0.990	1.000	1.000	3	35199
111	29	25705	6.4	3.2	2	1	1	0.561	0.811	0.982	0.996	0.999	1.000	1.000	1.000	6	154230
112	5	4759.78	0.5	0.24	1	1	1	0.734	0.919	0.996	0.999	1.000	1.000	1.000	1.000	3	14279.3
114	3	1101	0.4	0.19	0	0	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1	1101
115	3	4975.31	0.55	0.26	0	0	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1	4975.31
116	1	27700	1	0.48	0	0	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1	27700
123	15	1010	8.1	6.8	1	1	1	0.616	0.850	0.988	0.998	1.000	1.000	1.000	1.000	3	3030
124	43	15340.5	4.1	3.44	2	2	2	0.292	0.549	0.894	0.959	0.986	0.996	1.000	1.000	5	76702.5
125	5	1123	9.32	7.83	0	0	0	0.993	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1	1123
126	4	988	6.6	5.54	0	0	0	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1	988
129	2	16511	13.8	11.6	0	0	0	0.997	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1	16511
130	2	18520	14.3	12	0	0	0	0.997	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1	18520
131	1	18520	13.3	11.2	0	0	0	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1	18520
132	1	13380	0.5	0.42	0	0	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1	13380
133	1	16511	1.33	1.12	0	0	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1	16511
																	1611357

B: Result for Combined NFF and Disposal Rate (Scenario-IV, M4)

S/N	Holding Qty (HQ)	Service Level	Fills(unit)	Marginal Contribution (MC)	Delta Fills (ΔF¿)	Removals/yr(Ri)	Cost/Unit($)	Cumulative fills($\sum \Delta F$¿ =F)	Service Level(F/ $\sum R$)	Cumulative Cost($)
75	11	0.5179	144.4869	0.6927	32.9174	279	47.52	32.917	0.019	47.52
75	12	0.6311	176.0774	0.6648	31.5906	279	47.52	64.508	0.037	95.04
75	10	0.3999	111.5695	0.6617	31.4416	279	47.52	95.950	0.054	142.56
75	13	0.7314	204.0625	0.5889	27.9851	279	47.52	123.935	0.070	190.08
75	9	0.2872	80.1278	0.5745	27.3019	279	47.52	151.237	0.086	237.6

75	14	0.8139	227.0829	0.4844	23.0204	279	47.52	174.257	0.099	285.12
75	8	0.1893	52.8260	0.4490	21.3364	279	47.52	195.593	0.111	332.64
75	15	0.8773	244.7569	0.3719	17.6740	279	47.52	213.267	0.121	380.16
75	7	0.1129	31.4895	0.3119	14.8217	279	47.52	228.089	0.130	427.68
75	16	0.9229	257.4780	0.2677	12.7212	279	47.52	240.810	0.137	475.2
75	6	0.0597	16.6678	0.1896	9.0091	279	47.52	249.819	0.142	522.72
75	17	0.9537	266.0957	0.1813	8.6177	279	47.52	258.437	0.147	570.24
75	18	0.9735	271.6093	0.1160	5.5136	279	47.52	263.951	0.150	617.76
75	5	0.0275	7.6587	0.0988	4.6938	279	47.52	268.644	0.153	665.28
75	19	0.9855	274.9511	0.0703	3.3419	279	47.52	271.986	0.154	712.8
46	1	0.9998	1.9997	0.0646	1.9997	2	30.96	273.986	0.156	743.76
75	4	0.0106	2.9649	0.0429	2.0379	279	47.52	276.024	0.157	791.28
75	20	0.9924	276.8754	0.0405	1.9243	279	47.52	277.948	0.158	838.8
5	15	0.5331	288.9213	0.0337	55.3070	542	1641	333.255	0.189	2479.8
5	14	0.4310	233.6143	0.0330	54.0728	542	1641	387.328	0.220	4120.8
5	16	0.6309	341.9550	0.0323	53.0337	542	1641	440.362	0.250	5761.8
80	1	0.5722	20.0287	0.0303	20.0287	35	661.77	460.390	0.261	6423.57
5	13	0.3313	179.5415	0.0301	49.3418	542	1641	509.732	0.289	8064.57
5	17	0.7192	389.8175	0.0292	47.8625	542	1641	557.595	0.317	9705.57
5	12	0.2402	130.1997	0.0255	41.8087	542	1641	599.403	0.340	11346.57
5	18	0.7945	430.6132	0.0249	40.7957	542	1641	640.199	0.364	12987.57
75	21	0.9962	277.9307	0.0222	1.0553	279	47.52	641.254	0.364	13035.09
5	19	0.8553	463.5555	0.0201	32.9422	542	1641	674.197	0.383	14676.09
5	11	0.1631	88.3910	0.0199	32.7006	542	1641	706.897	0.401	16317.09
5	20	0.9019	488.8261	0.0154	25.2706	542	1641	732.168	0.416	17958.09
75	3	0.0033	0.9270	0.0149	0.7078	279	47.52	732.876	0.416	18005.61
5	10	0.1027	55.6904	0.0143	23.4453	542	1641	756.321	0.429	19646.61
80	2	0.8195	28.6828	0.0131	8.6541	35	661.77	764.975	0.434	20308.38
7	1	0.6127	25.1215	0.0119	25.1215	41	2118	790.097	0.449	22426.38
75	22	0.9981	278.4831	0.0116	0.5524	279	47.52	790.649	0.449	22473.9
82	1	0.6359	7.6305	0.0115	7.6305	12	661.77	798.279	0.453	23135.67
5	21	0.9360	507.2884	0.0113	18.4624	542	1641	816.742	0.464	24776.67
48	1	1.0000	2.0000	0.0103	2.0000	2	193.36	818.742	0.465	24970.03
74	1	0.5354	23.5557	0.0096	23.5557	44	2455.21	842.298	0.478	27425.24
5	9	0.0595	32.2451	0.0093	15.2814	542	1641	857.579	0.487	29066.24
123	1	0.6165	9.2471	0.0092	9.2471	15	1010	866.826	0.492	30076.24
3	1	0.2488	33.0857	0.0081	33.0857	133	4086	899.912	0.511	34162.24
3	2	0.4938	65.6708	0.0080	32.5851	133	4086	932.497	0.530	38248.24
5	22	0.9597	520.1637	0.0078	12.8753	542	1641	945.372	0.537	39889.24
81	1	0.9945	4.9725	0.0078	4.9725	5	640.7	950.345	0.540	40529.94
73	3	0.4823	41.4750	0.0072	17.7502	86	2455.21	968.095	0.550	42985.15
3	3	0.7142	94.9911	0.0072	29.3203	133	4086	997.415	0.566	47071.15
73	4	0.6761	58.1481	0.0068	16.6730	86	2455.21	1014.088	0.576	49526.36

80	3	0.9396	32.8865	0.0064	4.2036	35	661.77	1018.292	0.578	50188.13
75	23	0.9991	278.7597	0.0058	0.2766	279	47.52	1018.568	0.578	50235.65
23	1	0.7313	5.8506	0.0058	5.8506	8	1012.5	1024.419	0.582	51248.15
73	2	0.2759	23.7248	0.0058	14.1727	86	2455.21	1038.592	0.590	53703.36
77	1	0.9996	3.9985	0.0057	3.9985	4	697.84	1042.590	0.592	54401.2
8	1	0.9999	8.9990	0.0055	8.9990	9	1641	1051.589	0.597	56042.2
5	8	0.0313	16.9636	0.0055	8.9643	542	1641	1060.554	0.602	57683.2
5	23	0.9756	528.7523	0.0052	8.5886	542	1641	1069.142	0.607	59324.2
73	5	0.8218	70.6771	0.0051	12.5290	86	2455.21	1081.671	0.614	61779.41
3	4	0.8630	114.7781	0.0048	19.7870	133	4086	1101.458	0.625	65865.41
74	2	0.7916	34.8311	0.0046	11.2754	44	2455.21	1112.734	0.632	68320.62
7	2	0.8478	34.7600	0.0046	9.6385	41	2118	1122.372	0.637	70438.62
125	1	0.9925	4.9626	0.0044	4.9626	5	1123	1127.335	0.640	71561.62
82	2	0.8629	10.3553	0.0041	2.7248	12	661.77	1130.059	0.642	72223.39
126	1	0.9975	3.9900	0.0040	3.9900	4	988	1134.049	0.644	73211.39
73	1	0.1111	9.5521	0.0039	9.5521	86	2455.21	1143.601	0.649	75666.6
75	2	0.0008	0.2192	0.0039	0.1844	279	47.52	1143.786	0.650	75714.12
123	2	0.8503	12.7546	0.0035	3.5075	15	1010	1147.293	0.652	76724.12
32	1	0.7333	2.9334	0.0034	2.9334	4	856	1150.227	0.653	77580.12
9	3	0.5956	44.6712	0.0034	16.6615	75	4905.51	1166.888	0.663	82485.63
73	6	0.9131	78.5229	0.0032	7.8458	86	2455.21	1174.734	0.667	84940.84
9	2	0.3735	28.0097	0.0032	15.4701	75	4905.51	1190.204	0.676	89846.35
13	1	0.6547	11.1302	0.0031	11.1302	17	3558.85	1201.334	0.682	93405.2
5	7	0.0148	7.9994	0.0028	4.6743	542	1641	1206.009	0.685	95046.2
9	4	0.7751	58.1297	0.0027	13.4585	75	4905.51	1219.467	0.692	99951.71
114	1	1.0000	3.0000	0.0027	3.0000	3	1101	1222.467	0.694	101052.7
3	5	0.9433	125.4608	0.0026	10.6827	133	4086	1233.150	0.700	105138.7
9	1	0.1672	12.5396	0.0026	12.5396	75	4905.51	1245.689	0.707	110044.2
74	3	0.9255	40.7240	0.0024	5.8930	44	2455.21	1251.582	0.711	112499.4
80	4	0.9834	34.4178	0.0023	1.5314	35	661.77	1253.114	0.712	113161.2
7	3	0.9528	39.0652	0.0020	4.3052	41	2118	1257.419	0.714	115279.2
1	3	0.6293	71.1091	0.0018	25.2901	113	14011	1282.709	0.728	129290.2
9	5	0.8910	66.8267	0.0018	8.6970	75	4905.51	1291.406	0.733	134195.7
1	2	0.4055	45.8190	0.0018	24.6321	113	14011	1316.038	0.747	148206.7
82	3	0.9594	11.5129	0.0017	1.1576	12	661.77	1317.196	0.748	148868.5
73	7	0.9620	82.7341	0.0017	4.2112	86	2455.21	1321.407	0.750	151323.7
2	3	0.5047	55.5197	0.0017	23.1727	110	14011	1344.580	0.764	165334.7
123	3	0.9539	14.3088	0.0015	1.5542	15	1010	1346.134	0.764	166344.7
1	1	0.1875	21.1869	0.0015	21.1869	113	14011	1367.321	0.776	180355.7
2	4	0.6969	76.6624	0.0015	21.1427	110	14011	1388.464	0.788	194366.7
23	2	0.9175	7.3397	0.0015	1.4891	8	1012.5	1389.953	0.789	195379.2
1	4	0.8016	90.5834	0.0014	19.4743	113	14011	1409.427	0.800	209390.2
2	2	0.2941	32.3470	0.0014	19.0482	110	14011	1428.475	0.811	223401.2

5	6	0.0061	3.3251	0.0013	2.1326	542	1641	1430.608	0.812	225042.2
110	2	0.4395	27.2467	0.0012	14.2187	62	11733	1444.826	0.820	236775.2
110	3	0.6633	41.1252	0.0012	13.8785	62	11733	1458.705	0.828	248508.2
3	6	0.9795	130.2670	0.0012	4.8062	133	4086	1463.511	0.831	252594.2
110	1	0.2101	13.0280	0.0011	13.0280	62	11733	1476.539	0.838	264327.2
2	5	0.8372	92.0949	0.0011	15.4324	110	14011	1491.972	0.847	278338.2
13	2	0.8747	14.8699	0.0011	3.7396	17	3558.85	1495.711	0.849	281897
30	1	0.7215	2.8858	0.0010	2.8858	4	2905	1498.597	0.851	284802
9	6	0.9535	71.5101	0.0010	4.6834	75	4905.51	1503.280	0.854	289707.6
2	1	0.1209	13.2988	0.0009	13.2988	110	14011	1516.579	0.861	303718.6
74	4	0.9780	43.0339	0.0009	2.3099	44	2455.21	1518.889	0.863	306173.8
110	4	0.8272	51.2850	0.0009	10.1598	62	11733	1529.049	0.868	317906.8
32	2	0.9185	3.6739	0.0009	0.7406	4	856	1529.790	0.869	318762.8
1	5	0.9078	102.5800	0.0009	11.9967	113	14011	1541.786	0.876	332773.8
124	1	0.2916	12.5367	0.0008	12.5367	43	15340.5	1554.323	0.883	348114.3
73	8	0.9850	84.7119	0.0008	1.9778	86	2455.21	1556.301	0.884	350569.5
112	1	0.7335	3.6675	0.0008	3.6675	5	4759.78	1559.968	0.886	355329.3
79	1	0.9989	2.9968	0.0007	2.9968	3	4005.52	1562.965	0.888	359334.8
75	1	0.0001	0.0348	0.0007	0.0348	279	47.52	1563.000	0.888	359382.3
124	2	0.5491	23.6117	0.0007	11.0750	43	15340.5	1574.075	0.894	374722.8
7	4	0.9880	40.5074	0.0007	1.4422	41	2118	1575.517	0.895	376840.8
80	5	0.9961	34.8642	0.0007	0.4463	35	661.77	1575.963	0.895	377502.6
2	6	0.9226	101.4819	0.0007	9.3870	110	14011	1585.350	0.900	391513.6
111	1	0.5609	16.2648	0.0006	16.2648	29	25705	1601.615	0.909	417218.6
84	1	0.6291	10.0655	0.0006	10.0655	16	15960	1611.681	0.915	433178.6
115	1	1.0000	3.0000	0.0006	3.0000	3	4975.31	1614.681	0.917	438153.9
124	3	0.7620	32.7648	0.0006	9.1531	43	15340.5	1623.834	0.922	453494.4
82	4	0.9901	11.8817	0.0006	0.3688	12	661.77	1624.203	0.922	454156.1
123	4	0.9884	14.8254	0.0005	0.5165	15	1010	1624.719	0.923	455166.1
5	5	0.0022	1.1925	0.0005	0.8340	542	1641	1625.553	0.923	456807.1
110	5	0.9231	57.2350	0.0005	5.9500	62	11733	1631.503	0.926	468540.1
23	3	0.9803	7.8421	0.0005	0.5024	8	1012.5	1632.006	0.927	469552.6
3	7	0.9934	132.1205	0.0005	1.8534	133	4086	1633.859	0.928	473638.6
9	7	0.9823	73.6719	0.0004	2.1617	75	4905.51	1636.021	0.929	478544.2
1	6	0.9623	108.7386	0.0004	6.1586	113	14011	1642.179	0.933	492555.2
13	3	0.9643	16.3931	0.0004	1.5232	17	3558.85	1643.702	0.933	496114
78	1	0.6863	7.5498	0.0004	7.5498	11	17674.52	1651.252	0.938	513788.5
124	4	0.8939	38.4383	0.0004	5.6735	43	15340.5	1656.926	0.941	529129
2	7	0.9671	106.3760	0.0003	4.8941	110	14011	1661.820	0.944	543140
73	9	0.9946	85.5376	0.0003	0.8257	86	2455.21	1662.646	0.944	545595.2
39	1	0.9999	2.9998	0.0003	2.9998	3	9668	1665.645	0.946	555263.2
74	5	0.9945	43.7583	0.0003	0.7244	44	2455.21	1666.370	0.946	557718.4
32	3	0.9806	3.9224	0.0003	0.2485	4	856	1666.618	0.946	558574.4

111	2	0.8111	23.5223	0.0003	7.2575	29	25705	1673.876	0.951	584279.4
6	1	0.9999	0.9999	0.0002	0.9999	1	4086	1674.876	0.951	588365.4
129	1	0.9973	1.9946	0.0001	1.9946	2	16511	1676.870	0.952	604876.4
130	1	0.9971	1.9942	0.0001	1.9942	2	18520	1678.864	0.953	623396.4
16	1	0.7265	10.8981	0.0001	10.8981	15	141261.7	1689.762	0.960	764658.2
132	1	1.0000	1.0000	0.0001	1.0000	1	13380	1690.762	0.960	778038.2
51	1	1.0000	2.0000	0.0001	2.0000	2	32595	1692.762	0.961	810633.2
133	1	1.0000	1.0000	0.0001	1.0000	1	16511	1693.762	0.962	827144.2
131	1	0.9993	0.9993	0.0001	0.9993	1	18520	1694.762	0.962	845664.2
58	1	1.0000	1.0000	0.0000	1.0000	1	22914	1695.762	0.963	868578.2
35	1	0.9997	2.9990	0.0000	2.9990	3	80336.49	1698.761	0.965	948914.6
116	1	1.0000	1.0000	0.0000	1.0000	1	27700	1699.761	0.965	976614.6
92	1	0.7051	2.8206	0.0000	2.8206	4	109952	1702.581	0.967	1086567
114	22	1.0000	3.0000	0.0000	0.0000	3	1101	1702.581	0.967	1087668
131	23	1.0000	1.0000	0.0000	0.0000	1	18520	1702.581	0.967	1106188

C. Summary of Holding Quantities(HQ)

Item #	Unit Price	HQ-PD1	HQ-PD2	HQ-PD3	HQ-PD4	HQ-MD1	HQ-MD2	HQ-MD3	HQ-MD4	HQ-MILP1	HQ-MILP2	HQ-MILP3	HQ-MILP4	Actual HQ
1	14011	3	6.00	3	6	3	7	2	6	3	6	3	6	6.00
2	14011	4	7.00	4	7	3	7	3	7	4	7	3	6	4.00
3	4086	2	6.00	3	6	3	7	3	7	3	7	3	7	6.00
5	1641	12	23.00	10	22	15	23	14	23	12	23	14	23	23.00
6	4086	1	1.00	1	1	1	1	1	1	1	1	1	1	1.00
7	2118	1	3.00	1	3	2	4	2	4	2	4	2	4	3.00
8	1641	1	1.00	1	1	1	1	1	1	1	1	1	1	3.00
9	4905.51	1	7.00	1	6	1	7	1	7	1	8	1	7	6.00
13	3558.85	1	4.00	1	3	1	3	1	3	2	3	2	3	3.00
16	141261.7	1	2.00	1	2	1	1	1	1	1	1	1	1	1.00
23	1012.5	1	3.00	1	3	1	3	1	3	2	3	2	3	3.00
30	2905	1	3.00	1	3	1	2	1	1	5	2	2	2	3.00
32	856	1	3.00	1	3	1	3	1	3	2	2	2	2	3.00
35	80336.49	1	3.00	1	1	1	1	1	1	1	1	1	1	1.00
39	9668	1	1.00	1	1	1	1	1	1	1	5	1	5	1.00
46	30.96	1	3.00	1	1	1	1	1	1	1	2	2	2	1.00
48	193.36	1	1.00	1	1	1	1	1	1	1	2	2	2	1.00
51	32595	1	1.00	1	1	1	1	1	1	1	1	1	1	1.00
58	22914	1	1.00	1	1	1	1	1	1	1	1	1	1	1.00

73	2455.21	7	7.00	5	7	5	9	5	9	6	9	4	8	7.00
74	2455.21	2	4.00	3	5	2	5	2	5	2	4	2	4	4.00
75	47.52	10	21.00	10	18	16	23	16	23	12	23	13	23	17.00
77	697.84	1	1.00	1	1	1	1	1	1	2	2	2	2	1.00
78	17674.52	1	1.00	1	3	1	1	1	1	5	5	5	5	3.00
79	4005.52	1	1.00	1	1	1	1	1	1	5	2	5	2	1.00
80	661.77	2	4.00	3	4	2	5	2	5	2	6	2	4	4.00
81	640.7	1	3.00	1	1	1	1	1	1	2	2	2	2	1.00
82	661.77	1	4.00	1	3	1	4	1	4	2	4	2	4	3.00
84	15960	2	4.00	1	3	1	2	1	1	2	2	5	2	3.00
92	109952	1	3.00	1	3	1	1	1	1	1	1	1	1	3.00
110	11733	3	6.00	3	3	2	6	2	5	2	6	2	6	3.00
111	25705	2	4.00	3	6	1	2	1	2	2	2	2	2	4.00
112	4759.78	1	3.00	1	3	1	1	1	1	5	2	5	2	3.00
114	1101	1	1.00	1	1	1	1	1	1	2	2	2	2	1.00
115	4975.31	1	1.00	1	1	1	1	1	1	1	2	1	5	1.00
116	27700	1	1.00	1	1	1	1	1	1	1	1	1	1	1.00
123	1010	1	4.00	1	3	1	4	1	4	2	4	2	4	3.00
124	15340.5	2	6.00	3	5	1	4	1	4	2	4	2	4	3.00
125	1123	1	3.00	1	1	1	1	1	1	2	2	2	2	1.00
126	988	1	1.00	1	1	1	1	1	1	2	2	2	2	1.00
129	16511	1	1.00	1	1	1	1	1	1	1	1	1	1	1.00
130	18520	1	1.00	1	1	1	1	1	1	1	1	1	1	1.00
131	18520	1	1.00	1	1	1	1	1	1	1	1	1	1	1.00
132	13380	1	1.00	1	1	1	1	1	1	1	1	1	1	1.00
133	16511	1	1.00	1	1	1	1	1	1	1	1	1	1	1.00
Total HQ		84	167	84	151	88	155	86	151	112	172	114	170	144
PD	Poisson Distribution													
MD	Marginal Distribution													
MILP	Mixed integer programming													