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Extending the Aircraft Availability Model to a Constrained Depot Environment Using Activity-Based Costing and the Theory of Constraints

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THESIS

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Abstract

The Aircraft Availability Model (AAM) assists managers in the selection of an optimal list of items to repair in order to attain the best aircraft availability rate. The model considers procurement or repair costs for the components as if the costs were unit variable as a price, instead of a repair cost representing a mix of both fixed and variable cost.

This research used the AAM in conjunction with Activity Based-Costing (ABC) and The Theory of Constraints (TOC) methodologies to investigate the relationships between price, product mix, Aircraft Availability (AA) and total cost. This approach explicitly recognizes that the Air Force Material Command uses its own resources in repairing components, and that it is always operating in a constrained environment in which resources' practical capacities are exceeded by requirements that limit the attainable AA.

The results of this investigation shows that the choice of the optimal mix of reparable items is sensitive to the pricing method used as well as environmental factors like repair cycle time, fleet size, and the intensity and balanced of shop resource load. In addition, the research found that the performance of the repair center should be evaluated under the metric Aircraft Availability per System Total Cost, following the rationale under the TOC methodology that considers labor costs as operational expenses, fixed in the period, and only raw materials as variable costs.

To my wife Adriana and
my children Matías, Belén, and Milagros.

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Gerardo Acosta Voegeli

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EXTENDING THE AIRCRAFT AVAILABILITY MODEL TO A CONSTRAINED DEPOT ENVIRONMENT USING ACTIVITY-BASED COSTING AND THE THEORY OF CONSTRAINTS

I. Introduction

Background

During the last two decades of the 20th century, global competition and technological innovation have developed a new competitive environment, triggering private industry to look for more relevant cost and performance information about organization's activities, processes, products, services, and customers in order to remain competitive in the market (Kaplan, 1998:1).

This global movement affecting industries all over the world has focused the emphasis in managing business and processes on the basis of costs, productivity, quality, time, product introduction time, operational efficiency, and technological advantage (Krajeswki, 2002:18; Hitt, 2003:14; Colander, 2001:36).

In the same way, the service environment has undergone a transformation, becoming as challenging and demanding as for manufacturing firms. Service companies have been pushed to enhance the functionality of their services, improve productivity, and reduce costs (Brimson, 1994:1-3; Fitzsimmons, 2004:5).

The deregulation of industries such as transportation and communication has altered the rules of pricing, product mix, and geographic and competitive restrictions in the service industry. Nowadays, even the government has to compete on price, quality and service with private companies, developing a new strong trend toward privatization and changing the rules for former government companies that now must be competitive entities (Kaplan, 1998:231). More than ever managers of government organizations require information to improve the quality, timeless, and efficiency of the activities they perform, and to understand accurately the costs of the services they produce (Kaplan, 1998:231).

Managers need ***relevant information*** to make right decisions. Many managers are drowned in data that not always is relevant for this purpose. Supplier data, prices of items, product's design, and warehouses' contents, all are organization's data. However, information is that portion of data that will influence managers' decisions, or if missing would negatively influence them. In this new context, it is crucial for organizations to pinpoint which is relevant information for managers' decision making (Goldratt, 1990:4).

Managers should determine in advance the decisions they will face in the future. Information Systems (ISs) should be developed to provide only relevant data for those decisions and not data from all the organization's functions, which brings managers to the situation of struggling with countless data not useful to achieve the main purpose of the organization (Goldratt, 1990:4-6). Therefore, if "information" is not defined as the answer to the questions posed by managers, the decision making process itself should be embedded in the organization's IS and the first purpose should be to deeply analyze the managerial decision making process to incorporate it into the organization's IS (Goldratt, 1990:7).

Organizational Performance Measures

Every organization was built to achieve a purpose, and the only way to evaluate any action taken by managers is measuring the impact of that action on achievement of the overall purpose of the organization (Goldratt, 1990:10). Managers have organizational resources to achieve this purpose and they perform the main functions of management, planning, organizing, coordinating, directing and controlling, to optimize the allocation of those resources to tasks in order to maximize achievement of the purpose of the organization.

Under the traditional management approach, Operational Expenses (OE) is the most important measure to be controlled by managers in the organization. The Theory of

Constraints (TOC) states that under this standpoint, every resource in the organization is a possible point where money leaks out of the system (OE), and thus a point to be controlled. Managers therefore have to be focused on a vast amount of information where all pieces of information are important (Goldratt, 1990:52-53), but when all information is equally important, nothing is important. Such a system where all variables are important is called by TOC the "Cost World".

TOC defines Throughput (T) as "the rate at which the organization achieves its goal" (Goldratt, 1984:60). T becomes the prevalent measure and all functions should be performed in synchronism with the sales function in for-profit organizations. TOC refers this situation as the "T World" (Goldratt, 1990:53). However, both approaches, the traditional and TOC recognize that the final purpose for each for-profit organization is to make money now and in the future.

For non-profit organizations such as the military, the goal can not be defined as making money (Goldratt, 1990:14) but in other terms. This research will be focused on the Air Force Materiel Command (AFMC) that is the supporting organization in the Air Force (AF) that performs maintenance services on weapon system (WS) components such as aircraft and reparable items for the purpose of providing combat capability (CC) to the operational levels (OLs) so that they can carry out their missions.

A comparison of performance plans recommended by The Logistic Management Institute (LMI), the Air Force Logistics Management Agency, and the Headquarters Air Force Materiel Command reveals that both the level of performance measures reporting and the scope of the measurement objectives differ. The AFMC and the AFLMA use "aircraft availability" (AA) as the ultimate measure of organizational performance. Moreover, the LMI includes "Weapon System Not Mission Capable Rates" (inverse of AA) as one of the nine measures considered at strategic level (Leonard, 2004:53).

Sherbrooke asserts that AA is the primary measure to be used by managers when they want to asses the AFMC's performance level. This is achieved by the AFMC performing Aircraft Inspections (AIs) and Reparable Inspections (RIs) through its Depots (Ds) to support aircraft operations at OL (Sherbrooke, 1992:27).

The concept can be extended by proposing that the AFMC is providing the material part of CC, and that AA can be used as a proxy measure for the AFMC in providing material support for CC at OL (Swartz, 2004a). However, AA is not a perfect measure for CC since (Swartz, 2004d):

1. The AFMC provides AA that will be consumed by pilot training at the OL. This loss of AA does not directly convert into CC.

2. AA is in itself a proxy measure since different WSs perform different types of missions, which contribute varying amounts of CC per available aircraft. The AA provided by the AFMC at OL could be measured more as a weighted sum according to the WS's contribution to OL CC.

3. The AA measure does not take into consideration the situation of aircraft at OL that can be full mission capable (FMC), partial mission capable (PMC) or non mission capable (NMC), each of which contribute different amounts of CC.

An alternative measure for the AFMC could be thought as the number of flying hours (FHs) provided for the next year. FHs is the metric commonly used in the AFMC where the budget for the next period is calculated as the current budget times the rate FHs expected to fly in the next period to FHs planned for the current period.

The underlying assumption of this approach is that there is a direct relationship (correlation) between the number of FH planned for the next period and the total costs of operating the AFMC, which is not true since many of the costs to operate the Ds are fixed (Swartz, 2004c).

O'Malley developed the rationale of the Aircraft Availability Model (AAM) (O'Malley, 1983:3-2) based on the fact that the AFMC has a limited budget to buy repairable items (RITs) and managers need to allocate that budget to obtain the best overall system AA. However, the AFMC does not buy all RITs but repairs them at Depot level with the purpose of maximizing the AA for the system. The constraint for the system is not therefore presented in terms of limited budget for buying RITs but may instead be the resources available to support the maintenance operations at D level in the time frame considered.

TOC and ABC for Decision Making

Activity Based Costing (ABC), identified with the traditional management approach, allocates resources to activities and after that to organization' products and services in the purpose of depicting the way the organization consumes its resources.

An ABC model provides the company an economic map of the flow of the organization's expenses and their operations by revealing relevant information with respect to the existing and forecasted costs of activities and business process. An ABC model gives managers insight about the existence, creation, and deployment of used and unused capacity of organization's resources and allows them to know how much of available resources are used in performing organization's activities for producing product and services (Kaplan, 1998:80,111).

ABC is only good data for managers so that they can understand the economic map of their organizations and improve the decision making process (Cokins, 1992:2). It focuses on activities that people and equipment perform to satisfy customer needs. Organizations buy resources to perform activities to fulfill their purposes or goal. Resources in the organization are limited and consumed performing activities. The main difference between ABC and other cost accounting systems is that it is based on the activities performed in the organization (Cokins, 1992:2-12).

The TOC methodology bases its rationale in recognizing that every organization has limited resources and that one of these resources is a constraint that restricts the whole output achieved by the organization and consequently the resource that should closely be controlled by managers. The TOC considers three relevant measures (T, Inventory, and Operational Expenses) that should be used in the management decision making process. Every decision should be measured in terms of its impact on those three measurements, and lead to increasing T and/or decreasing I and OE.

Authors such as Kaplan and Kee have an integrated vision of both ABC and TOC methodologies. On the one hand, the TOC approach considers OE as fixed during the time period analyzed and over the "relevant range" (RR) of production for the product mix. According to Kaplan and Kee it is therefore seen as a short term decision tool to maximize short-term NP and ROI. On the other hand, ABC can provide supporting information for a dynamic optimization of resources supply for the organization, product mix, and pricing for long-term profitability. Both TOC philosophy and ABC methodology have been recognized as pursuing the same purpose; maximize the organizational profits (Kaplan, 1998:135). Kee completes this concept saying "TOC and ABC may be used to measure the component's short and long-run production costs" (Kee, 1998:35).

However, several authors asserts that management decisions of product mix under ABC and TOC methodologies could lead to dramatically different results in for-profit environments (Noreen, 1995:144). Corbett referring to an actual example concludes:

> ABC did not identify the maximum profit mix, and therefore it did not fulfill one management accounting's goals. The information provided (of the product's contribution to the company's profitability) was not correct. Therefore, the only possible conclusion is that ABC has a conceptual error in its formation (Corbett, 1998:92).

It is therefore an open question as to the role of TOC and ABC formulations in making better management decisions.

Problem and Purpose Statements

Since the purpose of the AFMC is not to make money, a primary challenge in the research will be to define the AFMC's purpose in a way that allows managers to measure it so that decisions made under both methodologies can be measured in terms of their impact on the organizational goal.

During peace time the demand posed on the AFMC for aircraft inspections (AIs) and repairable items inspections (RIs) does not depend on unpredictable external sources.

Therefore, the AFMC can establish the annual maintenance plan and program in advanced that will determine the expected mix of AIs and RIs to be performed and an estimation of the opportunity for each inspection.

The focus of this research is the AFMC environment, and whether the new measurement scale stated by TOC is suitable for our environment. Goldratt developed his measurement rationale base on a scenario of a company whose goal is to make money now and in the future. However, he believes that for other types of organizations, though the exact analysis does not apply, "the logical process or method is probably the same" (Goldratt, 1990:14).

Therefore, the overarching purpose for the research is twofold:

1. Extend (expand) the AAM using ABC and TOC principles to account for organizational constrained resources and to use the rationales under both methodologies to determine the mix of RIs to be incorporated to the AFMC D maintenance RIs plan in order to maximize the expected system's AA in the time frame considered.

2. Determine which methodology, the traditional (ABC) or the TOC approach, used to determine the mix for the AFMC D's maintenance RIs plan allows managers to obtain the best performance of the system measured in terms of AA per dollar spent.

In this purpose the researcher will determine if significant differences exist in the decision making process under ABC and TOC methodologies to define the mix for the maintenance RIs plan. Then, the research will establish which methodology leads managers to obtain the best system's performance.

The problem for the research is to obtain the mix of RIs, to be used for developing the D's Maintenance RIs plan that maximizes the expected system's AA per dollar spent in the time frame considered recognizing the D level as a constrained environment.

Research and Investigative Questions

Research Question.

How does different cost accounting approaches (ABC and TOC) and other factors affect the optimal mix of RIs (funding allocation) to be used in building the maintenance RIs plan and the expected performance of the AFMC at Depot level (AA/STC)?

Investigative Questions (IQs).

1. Which are the factors that most impact the AFMC Depot metrics AA and AA/STC achieved by selecting the optimal mix of RIs for the maintenance RIs plan under both methodologies ABC and TOC?

2. Which is the amount of effect of each factor in the metrics AA and AA/STC under ABC and TOC approaches?

3. Are there significant differences between decisions made under the traditional approach (ABC) and the TOC approach in defining the optimal mix for the AFMC Depot maintenance RIs plan?

4. Which is the approach that defines the mix for the AFMC Depot maintenance RIs plan that maximize the metrics AA and AA/STC?

5. Under which circumstances decisions made under ABC and TOC approaches differs?

Scope of the Research

The research focused first on developing an ABC model in the AFMC considering the most relevant functions performed by the organization. In a second face the ABC model is enhanced with the logic used in the AAM so that managers can determine the appropriate mix of RIs to be repaired at Depot level to obtain the best system's response.

The AFMC performs two basic functions at Depot level, AIs and RIs. However, for simplicity purpose, the research will only focus on RIs at Depot level. In this context, both primary and secondary maintenance functions will be treated in the model. Primary maintenance functions are those that are performed directly on the RITs while secondary are usually known as supporting functions necessary to complete the process of reparation. Primary activities on aircraft and RIs are performed only at Depot level.

However, at Depot level there are also support (indirect) activities to sustain primary ones.

All tasks performed at the headquarters level are indirect logistics functions since none of them are performed over aircraft or RITs. These activities are not considered in the development of the ABC model.

Based on the differences between ABC and TOC methodologies, the research will study if the methods lead managers to select different mixes of RIs to be included in the AFMC D maintenance RIs plans.

Research Methodology

A literature review will determine the metric to be used to evaluate the performance of the AFMC at Depot level that will lead managers in the decision making process of determining the mix of RIs for the AFMC Depot maintenance RIs plan.

Literature review of the methodologies AAM, ABC and TOC will provide the basis to build an integrated model among these approaches and to fill it with reasonable data. The integrated model will consider the most important activities performed at Depot level to fulfill the RITs maintenance plan. The forecasted RITs' demand for the period used to determine levels of resources utilization will be estimated to cover a relevant range of RIs for a WS. The cost incurred for each RIs will be calculated based on the ABC rationale and finally the model will be validated.

Before exercising the model, the researcher will set its parameters based on expert opinions and personal experience.

The experimental design (ED) layout will determine the combination of factors that the researcher will use to exercise the model to collect data from the response of the system in terms of AA and STC. The procedure will lead the researcher to conduct a reduced or fractional factorial experimental design that considers the main combination of levels of factors in order to evaluate their main effects in the system's response.

Eventually, treatment of the data will be developed both by visual inspection and statistical analysis in order to determine significant differences in responses under both different cost accounting methodologies and other main factors affecting the system's response.

Limitations and Assumptions of the Research

The limitations and assumptions for the research rely on the characteristics of the AAM, ABC, and TOC approaches.

Under the AAM.

Only one WS. The model will be developed to measure AA for a particular WS. This assumption can be also considered as if all WSs contribute with the same weight to OL's CC.

Stationary Demand Environment. The Depot considered in the AFMC is operating under a stationary demand environment. No peaks in RITs' demand are caused by war situations.

Single Echelon. The system modeled will be designed on a single echelon and location. This simplification means that all the aircraft that intervene in the computation of system's AA are considered operating at Depot level. This environment is referred by Sherbrooke as the Single Inventory Site Model (SSIM) (Sherbrooke, 1992:19). The SSIM entails the following characteristics (Anderson, 2003):

1. Stationary demand. The demand is calculated according to available past data.
2. Multiple Items. Several RITs will be considered affecting the system's AA.
3. Single, location, echelon, and indenture. The ABC model will be based on modeling primary and secondary maintenance activities for a Depot.
4. Backorder minimization. The minimization of backorders for deciding the mix of RITs to repair is coincident with system's AA maximization.

5. No transportation costs and times. In the SSIM all aircraft are at one base that in this case is considered to be a Depot.

Only First Indenture Items (FII). The model considers only RIs of FII developed within the Depot. RIs processed outside the AFMC (outsourced inspections), higher levels of RITs such as second or third indentures items, and consumable FII are not treated in the model and should be considered in future researches. The rationale for this limitation relies on the fact that the researcher is interested in developing a integration among ABC, TOC, and AAM methodologies where unitary variable costs calculated under the ABC approach will be used as inputs in the SSIM for the purpose of calculation of system's AA. Therefore, this purpose excludes items repaired or bought (consumable items) outside the organization since their costs can not be associated to the use of organizational resources and therefore they would not be calculated through the ABC model.

RITs equally important. Each RIT has the same impact on AA which means that a backorder caused by the lack of a RIT causes to ground an aircraft and then it is equally serious for the system (Sherbrooke, 1992:19).

No Repair Time Interactions. There is no interaction in the repair times for several RITs (Sherbrooke, 1992:21).

Under the ABC model.

D level activities. The model considers primary and secondary (support) RIs' activities at D level. Activities for AIs should be treated separately and secondary or support activities from headquarter level are not included in the ABC model.

Main Resources. The basic resources included in the ABC model are direct labor, support labor and raw materials (RMs).

Other Costs. Depreciation costs due to facilities or special equipment as well as inventories carrying costs are not included in the model. Transportation costs are not also considered according to the characteristics for the AAM detailed above.

Time Frame. The time frame in which the model is exercised allows managers to adjust labor resources capacities so that they can be treated as incremental costs for determining RIs' unitary variable costs.

Total Repair Time. The total repair time for every RIs is the sum of the times of all activities performed for a particular RIT. These activities are considered in the ABC model and it is assumed that they are sequentially performed (No resources contention).

However, it is assumed that there are enough funds to face wages of labor resources in the time frame considered, thus they are limited by their own practical hour capacities in the period. No funding limitations are posed for acquiring RMs for the RITs' restorations and the researcher is also assuming infinite number of carcasses at Depot to cover the forecasted demand to be repaired. Therefore, the only limitation that can happen in the period is reduced to labor resources hours.

From the standpoint of the research both TOC philosophy and ABC methodology are considered consistent theories, both free from conceptual flaws. The decision making process under both theories, ABC known as the traditional approach and TOC, should not be led managers to antagonist decisions. Although ABC appears to be a tool to be applied in longer time frames than TOC, long term decisions can also be seen as aggregate short term decisions.

Summary

The general purpose for the study have been defined to determine which of both methodologies, ABC or TOC, will lead managers to define the optimal mix of RIs for the AFMC D's maintenance RIs plan to obtain the best system's performance in terms of AA reached per resources consumed. The scope, assumptions and limitation for the research were established in order to simplify and focus the model on answering the IQs proposed.

Since it is accepted that the purpose for the AFMC through its Depots is to provide AA to the OL, the following objective of the research will be to analyze the integration between ABC, TOC and the AAM to allow managers measuring the differences between decisions made under ABC and TOC.

II - Literature Review

Introduction

Chapter 1 provided the problem statement, research questions, and an overview of the methodology. This chapter provides the conceptual foundation for the research analysis through a review of the TOC and ABC literature to pinpoint their similarities and differences in the reported cost information provided to managers. The chapter is divided into 6 sections. Section 1 describes the conditions in the new market environment that trigger special requirements for managerial accounting information. A brief description of how managerial accounting classifies costs is developed in Section 2. Sections 3, 4 and 5 focus on a description of the main concepts and principles that sustain Standard or Traditional Costs Systems (SCSs), ABC, and TOC methodologies. Section 6 describes the differences and similarities between ABC and TOC methods. Finally, Section 7 describes performance measures in the AFMC and how the AA is a suitable metric for use in this study.

Section 1 – New Competitive Production Environment

Expanding Role for Managerial Accounting.

Without relevant information managers cannot make appropriate decisions, and they would also be incapable of improving the performance of the organization. An important part of the information used by managers is provided by the organization structure itself. However, managers also depend on specialists such as economists, marketing specialists, organization behavior specialist, accountants, and others to obtain a large part of the organization's information necessary.

Accounting information is usually a key factor when managers make decisions since different alternatives usually have different costs and benefits associated that can be measured and used as inputs for the decision making process. An accounting system handles an enormous amount of detailed data as a result of day-to-day transactions, but managers' need for information is not detailed but rather summarized.

Financial accounting is used to provide mandatory reports to external accountant information consumers such as banks, owners, and government regulators. In contrast, the focus of this section is on managerial accounting (MA) information that is used for managers and employees teams in the decision making process (Cokins, 2001:33, Garrison, 2000:6-7).

Increasing Need for Cost Information.

At the beginning of the century the information used by management was focused mainly on material and labor costs, with less attention to other organization's costs such as power, depreciation, and factory facilities. After the turn of the 20th century, when companies looked for expanding their capacities through capital stocks from the markets, auditors began to allocate power, depreciation and other costs to value work in process (WIP) inventories so that what was called "accurate financial" statement was shown in the markets (Garrison, 1994:16).

Increasing business competition, worldwide in scope, a severe cost-price squeeze, rapid developing technology and a movement towards deregulation of service-type industries triggered the development of MA since the increasing management's need for internal rather than financial information. Garrison states the following changes produced by this new market environment (Garrison, 1994:17):

1. Production automation methods through computer integrated manufacturing where many products were virtually untouched by human hands. Oil refineries controlled by massive computers and entire plants monitored, and with workers monitoring them by instrumental panels.

2. Widespread use of computers causing a remarkable reduction in the costs to record, store and analyze information.

3. An increasing and changing in form overhaul costs in many industries. Automation has caused a significant reduction in labor costs over total costs in both manufacturing and services. Overhead factors of companies have grown

from ratios of 0.1 to factors of five and eight in the last century. Direct labor expenses at the time cost accounting was invented was ten times greater than overhead and the current situation tends to be one tenth of overhead (Goldratt, 1990:34). Cokins attributes the tendency to complexity of products and services, increasing quality levels, varying customer service levels (CSL) requirements, and compliance with regulations. Figure 1 shows the pattern (Cokins, 2002:25-26).

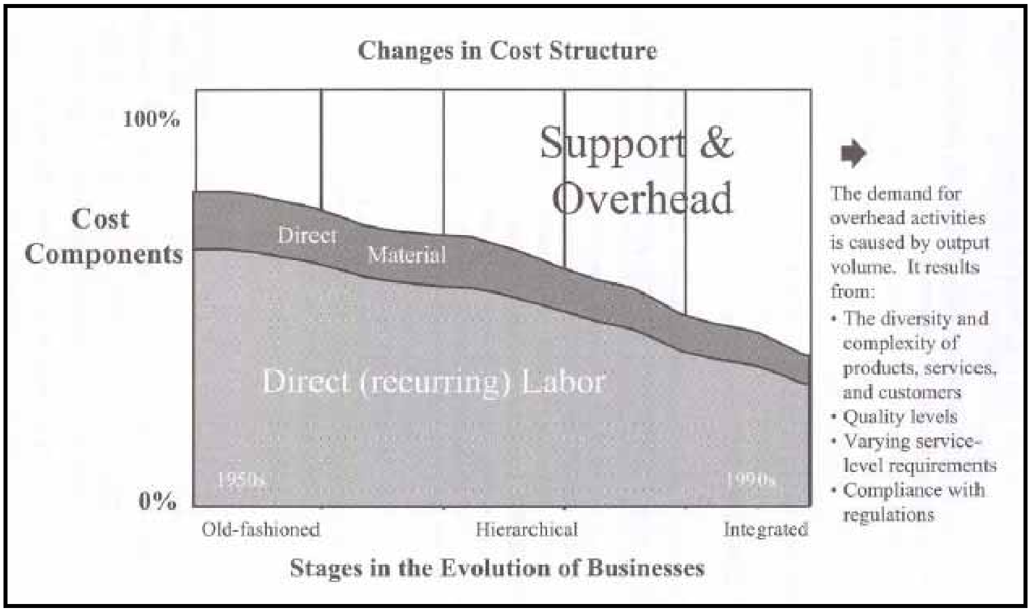


Figure 1. Overhead Costs Displacing Direct Costs

4. Movement towards more flexible manufacturing system that allows companies to respond quicker to customer's demands, total quality control techniques to reduce the defects in outputs, and innovative inventory techniques to allow lower inventory levels.

These changes are considered so important for many observers that they have referred them as a second industrial revolution. As a consequence of these changes the role of MA has expanded greatly from early years. Nowadays, managers are focused on Cost Accounting (CA) that gives them information to evaluate how effectively resources are being used to create, market, and distribute products and services to customers (Garrison, 1994:18).

The freer international market over the last 30 years caused by reductions in commercial barriers has provided an excellent opportunity for companies to be transformed into world-class competitors. However, this transformation would be very difficult using a second class MA system (Garrison, 1994:19).

Implication for Costs Accounting Systems.

The increasing competitive environment particularly since the 1980s has created important pressures over MA systems requiring accurate knowledge of product costs, better costs control, and coherent performance measurement (Pohlen, 1993:33). For many decades prior to 1980 the errors made by SCSs were small. Companies with narrow product lines, many labor intensive processes could use SCSs without worrying about distortions. The introduction of automated processes, elimination of direct labor, variety of product lines, much higher levels of batch activities and product-sustaining activities increased the errors introduced by SCSs (Kaplan, 1998:103).

Section 2 - Cost and Resource Classification

What are Costs?

Cost is an intangible and abstract concept. Costs cannot be seen or hold in one's hand. We know they exist because we can measure the effects caused by the changes in workload of resources used to perform activities within an organization. Costs are measures of resources' use, whereas expenses can be thought as measures of spending (Cokins, 2001:10,302). Managers measure how many resources are used to perform activities and they can cost those activities since they know the costs of the resources involved.

Changes in organization's activity levels are triggered by different events and costs react as effects. We can properly say that managers cannot manage costs; they only manage what generates those costs, their causes, the effective and efficient use of the resources involved in the organization's operations (Cokins, 2001:10). There are several classifications of costs according to the objective pursued by managers.

Variable and Fixed Costs.

Variable costs vary in total or in direct proportion to changes in the level of activity. Direct materials are the most common example of variable cost. Although quantity discounts, managers usually consider unitary costs as constant within the relevant range of the operating activity. Relevant range is defined as the range of activity within which assumptions related to variable and fixed cost behavior are valid (Garrison, 1992:44-45).

Fixed costs are those that remain constant, regardless of changes in the activity's level of activity within the relevant range. As the activities raise or fall they remain constant in total amount unless influenced by some outside forces such as prices changes. Expressed as unitary bases, they will react inversely with changes in activity. Rents and fees the government charges to a firm for making business are the most common examples (Carlton, 2000: 28).

Direct and Indirect Costs.

This classification makes sense when it is related to a particular organization's segment such as a production line, a sales territory, a division, or some other sub-organization.

Direct costs are defined as those that can be physically connected to the organization's segment or product/service considered. Material and labor involved within a manufacturing line are the most common examples of direct costs.

An indirect cost must be allocated in order to be assigned to the segment into consideration. It is not attached physically to the organization's segment. Overhead is not physically attached to a particular product line but is a consequence of general, overall operating activities (Garrison, 1994:46-47).

Controllable and Non-Controllable Costs.

All costs are controllable at some level or another in the organization. Only at lower levels of management some costs can be considered non-controllable. Top management

(TM) has enough power to contract facilities, hire or fire personnel, or exercise control over any cost as desired. Lower management levels do not have authority to control the incurrence of some costs that will therefore be considered non-controllable at that level. Therefore, a cost is considered controllable at a particular level of management if the management at that level has power to authorize the cost. There is a time frame dimension associated with the controllability of costs. Some costs that are controllable in the long time frame can be considered non-controllable in a shorter time frame.

Other Costs (Differential, Opportunity, Avoidable, and Sunk Costs).

Managers consider differential costs in decision making to compare alternatives. Costs present is one alternative and not in the other, are differential costs. This accountant concept is compared with the economics concept of marginal cost and revenue, the costs and revenues for producing one more unit of product or services.

Opportunity costs can be defined as the potential benefit that is lost or sacrificed when the selection of one course of action makes it necessary to give up a competing course of action. They are not registered in the organization's books but they are considered in the decision making process.

Avoidable costs are those, including fixed costs, that are not incurred if operations cease (Carlton, 2000:28).

Sunk costs are those that have already been incurred and that cannot be changed by any decision made now or in the future. They are not differentials and should not be considered in decision making (Garrison, 1994:49). The portion of a fixed cost that is not recoverable or avoidable is a sunk cost (Carlton, 2000:28).

Resource Classification.

Krajewski states that processes have inputs and customer outputs. Inputs are considered the resources used by processes to produce products and services. Resources include human resources as labor (workers and managers), capital such as equipment, facilities and land, purchased materials and services, and energy (Krajewski, 2002:4).

Section 3 – Standard (Traditional) Costs Systems (SCSs)

Fry states that Price Waterhouse in a study developed during 1989 stated that 85% of manufacturing companies in the United States (US) reported using SCSs and that 80% of overhead costs are allocated to each product according to direct labor (Fry, 1998:506). In an SCS:

1. Managers are encouraged to control budget variances since they are considered important to assess managerial performance.

2. Managers are also encouraged to control direct labor variances since overhead costs are allocated bases on direct labor basis.

3. Production volumes are encouraged since they generated less unit product costs and favorable variance.

The remarkable success of General Motors during the 1920s triggered other companies to adopt SCSs practices. These systems were particularly appropriate in specific environments with standardized processes, similar and limited product lines, high direct costs, and a mature stage in the product cycle and where companies tried to optimize the performance of every division as if they were separate sub-companies (Fry, 1998:506-507).

Baker states that most of the causes why SCSs do not provide in time information about inefficiencies to managers is attributed to the product life cycle in today's manufacturing environment. He explains that the phases of the life cycle of a product (introductory, growth, maturity and decline) affect the suitable use of SCSs. During the introductory and growth phases, where standards must be set before management has actual data, SCSs cannot be expected to work well. However, SCSs are more suitable where production volumes are consistent and management and workers have had time to learn and refine the production process (Baker, 1989: 23).

Fry citing Horngren (1989) suggests a similar concept saying that considerations of product life cycle are essential for designing a MA system. An SCS can be effective when:

1. The product has reached the maturity stage.
2. The ratio of direct cost (labor and material) is high compared to overhead expenses.
3. Direct labor is an important factor of production.

SCSs work properly in today's competitive environment where products become often obsolete without reaching their maturity and companies produce products in the growth stage and compete in a market based on quality and delivery (Fry, 1998:507).

Most of the literature agrees that SCSs need to be reviewed to make them useful to provide accurate information to managers in the new competitive environment. In a traditional production environment, managers try to avoid unfavorable price and efficiency variances, buying materials to maintain key workers busy, leading to increase unnecessary inventories. A revised SCS should be focused on inputs and outputs and encourage managers to use Just in Time (JIT) practices (Cheatham, 1990:58; Cheatham, 1996:30; Shillinglaw, 1989:44; Malcom; 1991:77, Boyd and Cox, 2002:1879)

Section 4 – Activity Based Costing (ABC) Methodology

Introduction.

In the new competitive environment managers of organizations, whose overhead rates can reach 500-1000% of direct labor, demand more relevant and accurate information of activities, processes, products, services, and customers than what they obtain from SCSs. External users are not affected by distorted information that could come from SCSs as long as the reported inventory numbers are correct in the aggregate. Many companies have adopted the use of direct costing systems (DCSs) in facilitating managerial decisions. However, DCSs ignore overhead entirely assigning only material and direct labor for calculating costs of products. They would be correct if the fraction of indirect and support resources were a small portion of the total costs or if they were fixed. Organizations in the last years have experienced that indirect and support costs have behaved as super-variable, since they have grown at much higher rate than production or sale volume (Kaplan, 1998:2-3).

ABC has emerged in the mid-1980 to meet the need for accurate information about cost of resource demands by products, services, customers, and channels. ABC systems allow tracing indirect and support expenses, first to organization's activities and processes, and after that to product, services, and customers. Several definitions can be obtained from the literature about ABC. Some mentions by Pohlen are (Pohlen, 1993:47):

1. Cooper identifies ABC as a product costing technique representing an evolutionary extension of the two-stage allocation procedures underlying most modern cost systems.

2. Turney defines ABC as "A method of measuring the cost and performance of activities and cost objects. It assigns costs to activities based on their use of resources, and assigns cost to cost objects based on their use of activities. ABC recognizes the causal relationship of cost drivers to activities".

3. Computer Aided Manufacturing-International, Inc. published a similar definition in the Journal of Cost Management "A methodology that measures the cost and performance of activities, resources, and cost objects. Resources are assigned to activities, then activities are assigned to cost objects based on their use. Activity-based costing recognizes the causal relationship of cost drivers to activities".

4. Brimson uses the term activity accounting and defines it as "The collection of financial and operational performance information about significant activities of an enterprise".

5. Computer Aided Manufacturing, Inc. developed the following definition for ABC accounting, "[Activity-based accounting is] a collection of financial and operational performance information dealing with significant activities of the business. Activities represent repetitive tasks performed by each specialized group within a company as it executes its business objectives".

However, Cokins, Stratton and Hebling clarify that ***ABC is only data*** that can be very powerful to trigger project teams or decision makers to take new steps or draw innovative conclusions. Also ABC can be used as an enabler for Process of Ongoing Improvement (POOGI), Process Business Reengineers (PBR), and decision support making (Cokins, 1992:1). The same author also states that it is a mistake to refer ABC or Activity Based Management (ABM – ABC/M) as an improvement program or a change initiative. The ABC/M data are simply used as means for an end. ABC/M could be thought as an IS supporting organization's managers in effectively managing their business. ABC/M only restacks organization's costs but it does not root them out (Cokins, 2001:2-3).

ABC systems are designed to define the activities performed by a company's resources, determine the costs to perform those organization's activities, and measure how much of every activity performed by the organization is used in every organization's product, service, and customers. ABC presents an activity/operation-based economic map of the organization's expenses (Kaplan, 1998:79-80).

ABC/M was developed as a practical solution for problems associated with SCSs. SCSs usually treat indirect and support (ISR) expenses in a too aggregate form and these large groups causes inaccuracy in costing system's reports. Cost allocation for SCSs usually relies on sales-related, volume-based factor or basis such as direct labor or department expenses that rarely reflects a cause-effect relationship between the resources consumed the output produced. Under SCSs some costs objects are over-costed while others under-costed.

Kaplan explains the phenomenon of over-costed and under-costed using an example of a "complex factory" that produces one million pens per year but of many colors, sizes, and varieties in contrast with a "simple factory" that processes also one million of pens but of only one color. Evidently, the complex factory that produces a variety of products will use more ISRs to produce the same output. Complexity increases overhead in the company.

But within the complex factory, products "A" represent 10% of the production while product "B" represents only 1% of the production.

Under SCSs cost allocation, product "A" will receive 10% of the overhead expenses while product "B" will receive only 1% of the expenses according to their production volumes. The SCSs allocation of costs based on volume will cause the same unitary cost for both products.

However, clearly product “B” will use on a per-unit basis more resources from the company. Considering that the same machine produces all products and the set up costs for this machine are the same for both product line, the per unit-basis set up cost for product “B” (low volume) will be higher since they will be divided into less amount of products. Therefore, SCSs reporting the same unitary costs for all products will underestimate the unitary costs for low volume products (product “B”) and overestimate the unitary costs for high volume products (products “A”) (Kaplan, 1998:82). Figure 2 shows the phenomenon in the diagram called ABC/M’s “S-curve” (Cokins, 2001:14).

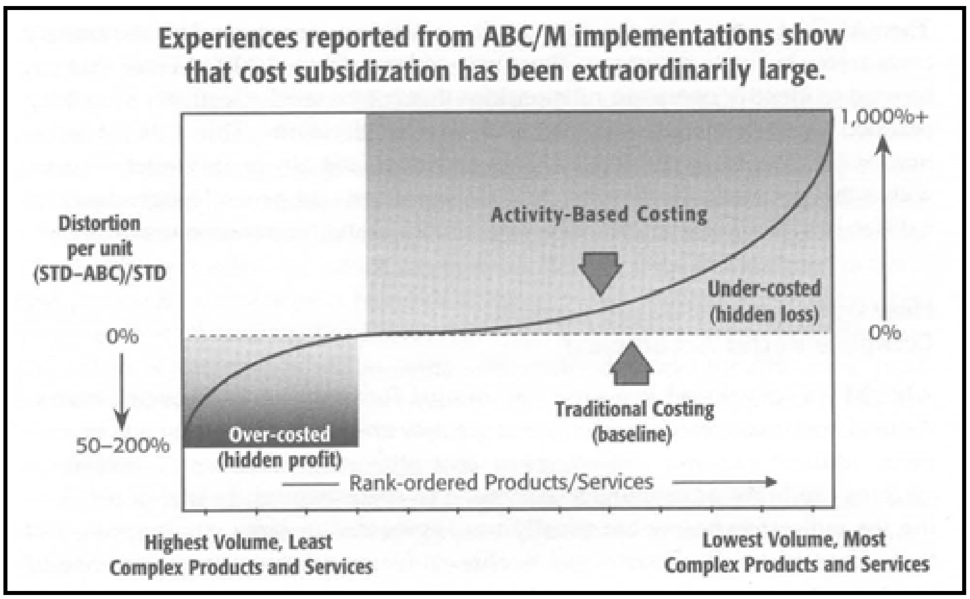


Figure 2. Products and Services Costs Distortion

The use of ABC/M logic assignment of expenses eliminates the use of averages values for tracing or allocating costs to products or services and corrects these flaws identifying the work activities responsible for those costs. The use of a cost flow assignment network allows work activity costs to be continually assigned or passed downwards only if the products or services use those costs (Cokins, 2001:15).

The ABC’s Cross View.

The ABC’s cross shows that work activities are essential to report both the costs of the products or services (objects) and the costs of the processes. Therefore activities are located at the center of the ABC cross. Costs objects receive the benefits of performing the activities and they can be persons or things that benefit when the organization uses its resources. Objects are those for *to* "what and for whom" work is done. The vertical view explains "what specific things cost" and the horizontal view, referred as Activity Based Management (ABM), explains "what causes cost to exist and to fluctuate" (Cokins, 2001:15). Figure 3 displays the traditional two-step allocation view and the process view of the ABC/M cross (Cokins, 2001:15).

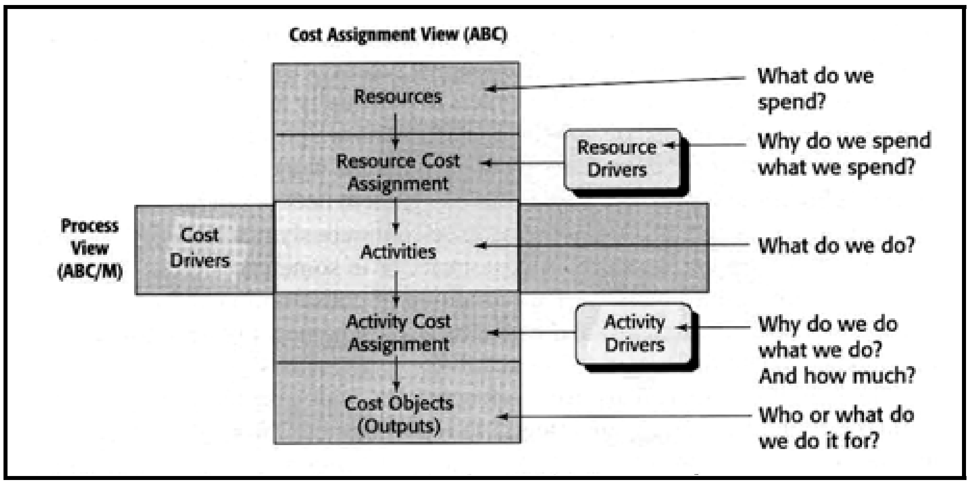


Figure 3. ABC Two Step Allocation View and Process View.

The "vertical axis" reflects the costs that are sensitive to demand mix of products or services. Activities performed consume organization's resources and the mix demand for products and services consumes activities. All resources expenses are aggregated into products and services when each cost is traced downwards based on its driver. The system is called "pull and remember" based on its activity drivers that work as pumps and valves in the costs assignment network.

The "horizontal axis" of the ABC/M cross represents the business process view. A business process can be defined as two or more activities or a network of activities with a common purpose. Across the process activities costs are sequential and additive. Activity costs in this orientation can be used for modeling flow-charting.

ABC Design.

ABC systems are identified with two basic concepts: "drivers and activities". A cost driver (CD) can be described in words but not always in numbers. As Cokins mentions, a storm could be a driver that causes the increment of the cleaning activity and the increment of costs. However, an activity driver (AD) must be quantitative. In the vertical cost assignment the model presents the following quantitative types of drivers (Cokins, 2001:17):

1. Resource drivers (RD) or CDs trace expenditures or cost resources (general ledgers cash outlays) to activities.
2. Activity drivers (AD) trace activity costs to costs objects, products and/or services.
3. Cost object drivers (COD) trace cost object costs to other cost objects.

An AD relates an activity to products or services, it meters out the work activity used according with the mix of objects that consume the activity. An AD has to trace the relative proportion of the activity cost to its cost object (Cokins, 2001:17).

RDs or CD are drivers of higher order than AD. They can affect multiple activities and can be described as triggering events. They do not need to be measurable.

ABC uses AD to trace activity costs to products but both driver data (CD and AD) together are useful to trigger root-cause analysis combined with quality management measuring the variance of these drivers over time it is possible to determine trends of per-unit costs activities and eventually of products. Figure 4 shows the location for RDs and ADs (Cokins, 2001:18).

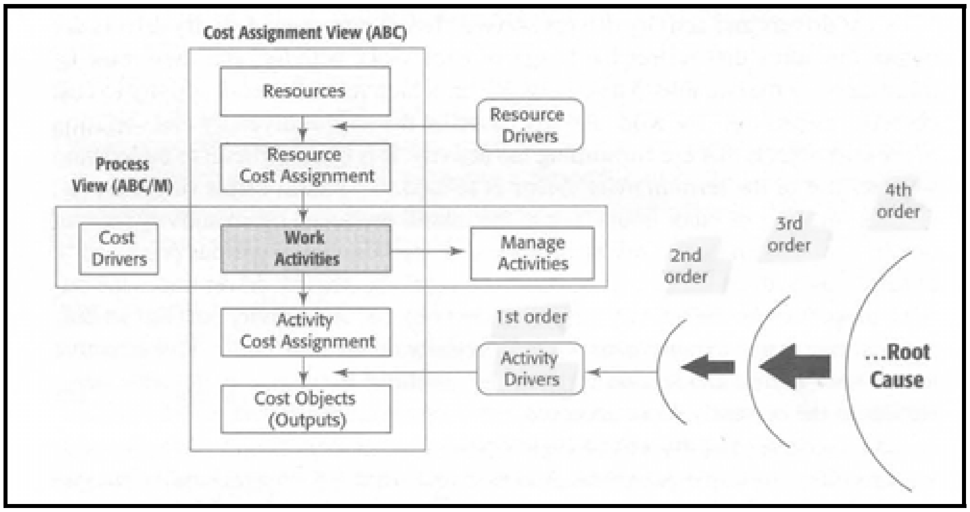


Figure 4. Resource and Activity Drivers.

The third category of costs drivers considered (CODs) is applied to cost objects after all activity costs have already been logically assigned to them. It is important to note that cost object can be consumed by another cost objects given place to a "multistage costs assignment scheme" known as "Expanded ABC/M Cross". Cokins distinguishes four categories of drivers: costs driver, resource driver, activity costs driver, and cost object driver (Cokins, 2001:19).

Expanded ABC's Cross.

According to the simplistic presentation of the two steps ABC/M cross, it appears that there is only a single and direct costs assignment between resource and activities and activities and objects. However, in practice there is multiple assignments for every CD and intra-module costs assignment prior to the cost assignment at the exit of a module entering to the next one.

The ABC/M Cross includes intermediate activities, which means that some activity outputs are inputs to other successive (downward) work activities. These intermediate activities cannot be traced directly to objects since they do not have a direct/logical cause-effect relationship with them. Therefore, these activities are removed two or more stages from the final objects. Organization's complexity explained in section one, creates support organizational activities, overhead, acting on other primary or core activities. For these activities is almost impossible to determine how much of them are consumed by products because the work is too indirect and it does not have any logical connection with a too remote product or service produced. Figure 5 describes the situation (Cokins, 2001:51).

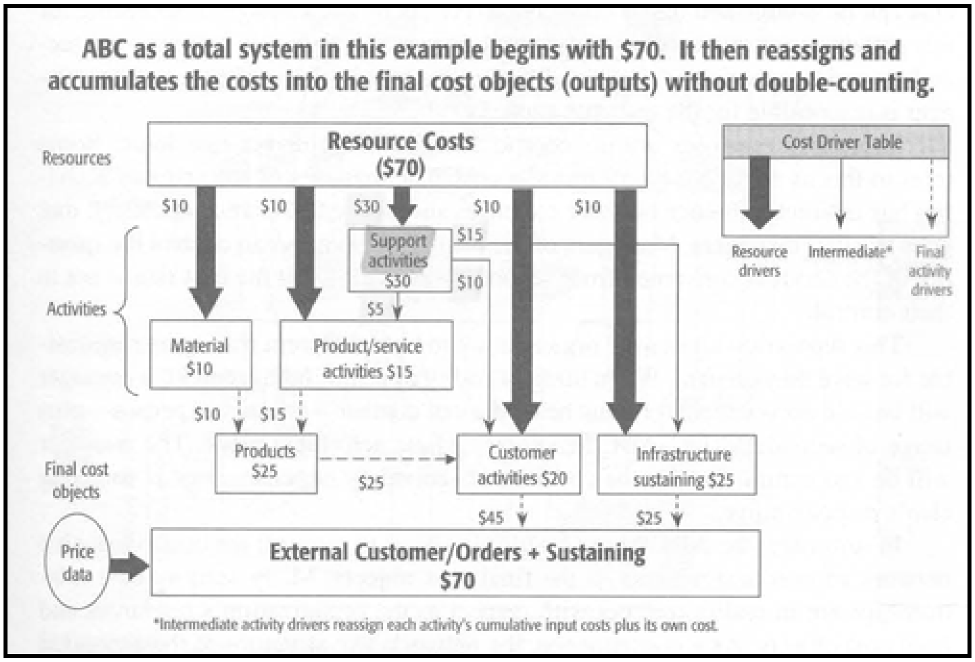


Figure 5. Support Activities in ABC.

The Vertical Cost Assignment View.

This view deals with the costs assignment view of the ABC/M model. It consists of three modules and two costs assignments. This view is a picture of the business conducted and represents the structure and rules for the cost assignment for some specific time period that can be a month, a quarter, or any other period. The costs assignment shows how resources and activities relate to objects in that specific time period (Cokins, 2001:47).

The available resources employed by the organization to perform the work (activities) are located in the "resource module" at the top of the scheme. These resources articulate all the period's expenditures (expenses for the time period considered) incurred by the organization that are summarized in the general ledger (GL). They are salaries, operating supplies, electrical power, and others, representing not only the period's cash outlays but also amortization outlays such as depreciation's from a prior period (Cokins, 2001:47-48).

At that point, a differentiation between expenses and costs has to be done. Expenses occur at the point of resources' acquisition from third parties, including employee wages. These transactions do not vary their values; they are permanently recorded in the general ledger. However, from these expenses, costs are calculated representations of how these resource costs are consumed by the organization' objects through activities (Cokins, 2001:48).

In the "activity module" is where the work is performed and resources are converted into outputs. The activity costs assignment contains the structure to assign costs activities to cost objects. In the object module, at the bottom of the cross are located all the cost objects. They are people or things that benefits for performing the activities. Examples are products, services lines, distribution channels, customers, and outputs of internal processes.

The Horizontal Process View.

The horizontal view in contrast with the vertical view, displays in costs terms the flowchart-like sequence of work activities. This view allows calculating the costs of business processes, which are the two or more activities linked in a particular sequence. The events that cause activities to be performed are the cost drivers. Sales or work orders can be thought as cost drivers since they trigger the use of work activities to produce outputs. Activities' costs are accumulated in sequence in order to obtain the processes' costs. In the horizontal axis therefore, is displayed the sequential or time-based relationship of how activities relate to each other and not to costs objects (Cokins, 2001:49).

Primary and Secondary Expenses.

Primary expenses are generated and incurred in a particular activity cost center. Salary expenses from employees are assigned to this activity according to the time employees spend performing the activity (RD). In contrast, secondary expenses originate elsewhere but can be traced to primary activities as input costs for them. Secondary expenses are costs for primary activities and they are tracing based on activity drivers.

Managers who are responsible for the consumption of primary expenses, can control them since they are closely tied to measures of capacity. Secondary expenses arrive at primary activities as costs and managers of primary activities have only indirect control over them since they can only control the quantity of services received but secondary AD rates are not under their control. This hierarchy in activities allows companies to differentiate manager's responsibilities. A manager can be held accountable only for primary expenses but not by secondary expenses. Figure 6 shows a scheme of an expanded ABC/M model (Cokins, 2001:53).

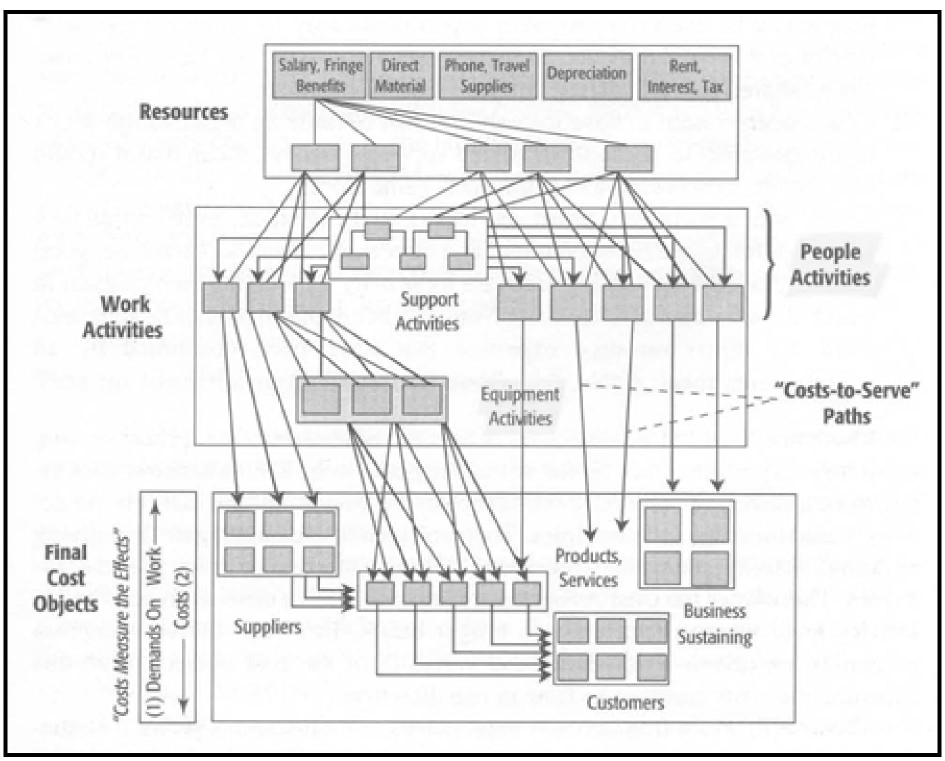


Figure 6. The Expanded ABC Model.

Hierarchy of Activities.

Kaplan describes the important insight obtained by managers after resources have been traced to activities and critical attributes of activities allow classifying cost by activities' hierarchy. He identifies unit, batch, and product, customer, and facility-sustaining dimensions and describes this hierarchy as follows (Kaplan, 1998: 89):

> Unit-level activities are activities that have to be performed for every unit of product or service produced….. Batch-level activities are the activities that have to be performed for each batch or setup of work performed…. Product-sustaining activities are performed to enable the production of individual products or services to occur. (Kaplan, 1998:90)

Steps in Developing an ABC/M Model.

Kaplan suggests four sequential steps to construct an ABC system (Kaplan, 1998:85-98):

1. Develop the activity dictionary. The organization identifies activities performed by indirect and support resources and a dictionary of indirect activities described by a verb and an associated object. Some companies use front-line employees to define the activity dictionary. Selecting too many activities is expensive and confusing. ABC teams usually ignore activities that use less than 5% of an individual's time or a resource capacity.

2. Determine how much the organization is spending on each of its activities. RDs link spending and expenses to activities. The GL categorizes expenses by spending codes (salaries, fringe benefits, overtime, utilities, indirect materials, travel, telecommunications, computing, maintenance, and depreciation) and the ABC model drives them to activities. In this task usually the organization recognizes, for the first time, how much it is spending on activities. Employees surveys can be performed to establish the time every employee spend doing activities that appears in the activity dictionary. For non-personal resources the ABC team can rely either on direct measurements (how much power, computer, or telecommunications time) or estimate the percentage of the resources used by the activity in the dictionary. ABC/M instead of driving expenses only to production centers as SCSs, drives expenses also to activities that are not primarily involved in converting materials into intermediate or finished goods such as setup machines, schedule productions runs, performing engineering change notices and maintenance.

3. Identify the organization's product, services, and customers. An organization performs activities in order to design, build, and deliver products and services to

its customers who are the ultimately beneficiaries of them. In this step the organization can realize if the activities are worth doing and if it is getting paid adequately for performing them.

4. Selecting ADs. Kaplan differentiates three sorts of *activity drivers*: transaction, duration, and intensity.

    - Transaction activity drivers (TAD). This kind of AD counts how often an activity is performed and they assume that the same amount of resources is consumed every time the activity is performed. Scheduling production run, processing a purchase order, maintaining a unique part number may demand the same amount of resource consumed independently of the product schedules, purchased or maintained.

    - Duration activity drivers (DAD). This kind of ADs represents the amount of time required to perform an activity. They have to be used when products require different amount of time from resources performing activities. They include set up hours, inspection hours, and direct labor hours. They are more accurate but more expensive to implement.

    - Intensity activity drivers (IAD). This AD is defined every time a special product or service requires an activity that involves the use of special resources such as special machines, controls or special setups due to the complexity of the product. IADs are the most accurate AD but the most expensive to implement.

Suitable Environment for Developing ABC Systems.

Two basic rules define a suitable environment for high-potential ABC development (Kaplan, 1998:100):

1. The Willie Sutton rule looks for areas where indirect and support expenses have increased in the past. Areas of large proportion of direct materials and labors are not suitable for ABC developments.

2. The high diversity rule looks for areas where large variety of products has been developed. This rule includes areas where high, low, standard and custom products are produced.

Resources' Capacity.

Kaplan mentioned as flexible resources those that are typically purchased from outside suppliers and can be acquired as needed. They are typically RM, energy, telecommunications services, temporary workers hired on a daily basis, employees paid on a piece-work basis, and overtime authorized as needed. The cost of acquiring these resources equals the cost of using them. There is not unused capacity in these resources in the period considered since they are purchased in the quantities needed.

ABC recognized that almost all organizational costs except those flexible resources mentioned above are not variable in the short run due to changes in demand. However, Kaplan states that committed resources become variable in longer period of time according to a two step process:

1. The demand for supply of resources changes (up or down) if activity levels required change. In case of batches and sustaining resources changes are due to changes in the mix of product or services.

2. The organization changes the supply of committed resources (up or down) to match the new level of the activities required for the new mix of product or services.

If for some management's actions, the efficiency of performing some activities improves, requiring fewer resources to produce the same outputs, the demand for batch or sustaining resources decreases. However, the total spending in the organization will not decrease since it will spend the same amount of money for those resources but the unused capacity of those resources will increase and the used capacity of them will decrease. The only way the organization would reduce its spending is getting rid off the organization's unused capacity. The unused capacity of committed resources will become variable in the downward direction only if the organization' management can handle it out of the system. Therefore, what makes a resource variable in a time period is a function of management decisions and rely on the power of organizations' managers in lowering the spending of unused resources. Kaplan states that this issue of measuring and managing used and unused capacity is the central focus of ABC methodology (Kaplan, 1998:122).

In measuring used and unused capacity of committed resources ABC can help managers to identify those resources that are currently at, or expected to reach, capacity constraints, allowing POOGIs such as Total Quality Management (TQM) and BPR focus on those activities performed by these expected constraint resources. Applying POOGI to activities that do not require constraint resources will lead to increase unused capacity of the system but not to increase NP. Unused capacity can be eliminated only in two ways. On the one hand, managers can reduce supplied resources to perform activities. On the other hand, managers can increase revenues increasing sales that will increase the demand of activities and resource utilization (Kaplan, 1998:123).

Making decisions only based on resources used can be problematic because it is not guaranteed that resources supplied will match the new levels of resources demanded in the future. Before making decisions and with the insight of ABC, managers should analyze the resource supply implications of their decisions (Kaplan, 1998: 126).

Section 5 – New Management Philosophies and TOC

New Management Philosophies.

The 1980s are seen as a decade in which a second industrial revolution, which impacts the basic procedures used by managers to run their business, has occurred. TQM, JIT and TOC, referred to as "new management philosophies", challenged almost all the management rules accepted in the past (Goldratt, 1990:6-7; Cokins, 1996:118; Krajewski: 2002:243; Garrison, 2000:10).

Goldratt asserts that the new management philosophies differentiate from the traditional management approaches because these movements addressed major issues and changes for the organization that only can be evaluated by:

1. The way organizations define their purpose.
2. The way organizations measure the impact of every management decision on their goal (Goldratt, 1990:9).

Purpose of For-Profit Organizations.

Since every organization has been created to fulfill a purpose, mission or goal, every management's decision should be evaluated in terms of the impact it causes on the organization's purpose.

There is a common understanding in management thinking that the purpose for profit organization is to make money (Goldratt, 1990:12; Gomez-Bezares, 1998:36). The goal for every company that has shares in the market has been clearly defined. Investors invest their money through the market in order to make more money now and in the future. The enterprise has to maximize its value in the market in order to maximize the money invested by their shareholders.

Goldratt concludes that the deep difference between traditional management approaches and these new philosophies is not in the way they define their organization purpose but it relies on the treatment of performance measures (Goldratt, 1990:13).

Basic Concepts of TOC.

TOC was developed in the 1970s by Eliyahu Goldratt when he was involved with logistics problems in production. Without previous background in business, he used his knowledge in physics to solve production logistics problems but he also created solutions to other areas such as distribution logistics and project management (Corbett, 1998:23). TOC is divided into two fields, the Thinking Process (TP) and the Specific Applications (SA).

<u>Thinking Process (TP).</u>

The TP is a collection of logical-based tools that help people in diagnosing problems, finding solutions, and producing implementation plans. Noreen says that Goldratt argues that TP can be used to develop a successful plan to deal with any organizational, personal, or interpersonal problem that can be solved. Noreen, Smith and Mackey, from the standpoint that problems have causes, recognize that some sort of logical system is required to deal effectively with problems (Noreen, 1995:52).

They have observed that TP is not an infallible tool and that bad decisions can be made using it. As any other decision tool, it relies on the quality of the information used. However, they emphasize that the process forces discipline in decisions and can yield important new insights for the organization (Noreen, 1995:57). The basic assumption under the TP is that in any system only few causes explain most of the effects. The TP relies on the laws of cause and effect, appears after the development of the SA, and still has not been widely promoted (Corbett, 1998:24).

Specific Application Field.

TOC sees any company as a system, a set of element in an interdependent relationship, where each element depends on the others in some way. The global performance for the system depends on the combined efforts of all the elements of the system. TOC claims as a core concept the critical role played by the system's constraint. TOC emphasizes that every system was build to fulfill a purpose and every action or decision made by managers has to be aligned and judged by its impact on that purpose.

In order to evaluate every decision focused on a local improvement within a sub-organization, managers have to define the system's global goal and the measurements that will enable them to judge the impact of that local improvement / decision on the organization's goal. Anything limiting the system from achieving higher performance in terms of its goal is considered a system's constraint under TOC (Corbett, 1998:25).

Every system has to have at least one constraint. If it did not have a constraint limiting its performance, it would be possible to increase the system's performance until the infinite. The process of TOC POOGI consists of five steps:

1. Identify the constraint.

   Every plant will always have at least one resource that is limiting its maximum flow. This resource is considered the weakest link in the flow of production, which is considered as a chain. This internal resource is called Capacity Constraint Resource (CCR), to differentiate it from the possible external constraints such as market constraint. After detecting the company's constraint, managers need to focus their attention on it since it is limiting the performance of the entire system. Goldratt believes that in most of the cases the constraint is inside the company and it usually consists in a company's policy (Noreen, 1995:43; Corbett, 1998:26).

2. Decide how to exploit the System's Constraint(s).

   After detecting the constraint managers need to obtain the most of it. Any minute lost in the constraint is a minute lost for the entire system. Managers need to guarantee that there will always be a security buffer in front of the constraint so that it will not stop due to lack of work to process (Corbett, 1998:27). The constraint can be overstaffed to reduce lost time due to setups and routine maintenance can be done after normal hours of operation. Prioritizing the jobs where the system constraint is working through scheduling is the corollary of this step. First priority will have the potential jobs that have more contribution for the entire system (Noreen, 1995:44).

3. Subordinate everything else to the above decision.

   The rest of the non constraint resources have to be balanced so that they provide to the constraint everything it needs and not more. The other resources should work to the CCR pace, neither faster nor slower. If the other resources work at lower pace the CCR will run out of material damaging the performance of the entire system. On the other hand, if they run faster the effect will be an accumulation of WIP at the entrance of the CCR **(**Corbett, 1998:27).

   The balance of non-constraint operations is made through the Drum Buffer Rope (DBR) scheduling system in which the constraint sets the pace for the entire system. Noreen, Smith and Macket consider this step a major change from MA's perspective since the focus is posed on the question: "What must this non-constraint area or resource do to protect the exploitation decision?" instead of "What can this area do by itself to increase the bottom line?". The important conclusion is that the performance of non-constraint areas/resources should be measured in terms of how well they support the CCR and definitely not on local cost minimization actions (Noreen, 1995:45).

4. Elevate the System's Constraint(s).

   Elevate means lift the restriction. Goldratt warns that this is not the second step saying:

> So many times we have witnesses a situation where everybody was complaining about a huge constraint, but when they exercised the second step of exploitation, of just not wasting what was available, it turned out that there was more than enough. So let's not hastily run to approve subcontracting, or lunch a fancy advertising campaign, etc. When the

second and third steps are completed and we still have a constraint, that is the time to move to the fourth step, unless we are talking about crystal-clear cases, where the constraint is out of proportion to everything else. (Goldratt, 1990:61)

In this step the company centers on many investing alternatives that will increase the capacity of the CCR. Alternatives such as more shifts or the use of another identical resource are the most common. However, if we add more and more capacity to a CCR it will sometimes have enough capacity and it will not be a CCR anymore. Since the system cannot reach infinitive performance, another CCR will appear in another area of the organization (Goldratt, 1990:62).

5. If in the previous steps a Constraint has been broken, go back to step 1, but do not allow inertia to cause a System Constraint.

Due to the existence of the CCR we develop rules in the company – some formally, some intuitively -. When the CCR is broken, we go back to the first step but the company does not review those policies and since they stay behind, now we have policy constraint. Goldratt emphasizes the importance of reviewing prior company's policies since in most of the companies he analyzed he never saw physical or market constraint. What he encountered were companies with policy constraints such as marketing, production, and logistical policy constraints (Goldratt, 1990:62-63).

Performance Measures in For-Profit Organizations.

In order to describe how our organization operates we should define core measurements that represent or describe it. Measurements are the direct results of the organization's goal and they can be selected only after the organization's purpose is clearly defined. After defining the goal, every organization can be thought as a machine spending money in resources to accomplish its purpose (Goldratt, 1990: 15-16).

Corbett paraphrasing Goldratt says that before managers focus on local sub-organization's improvements, they need to establish the purpose of the whole system and define the key measurements that will allow them to determine the impact of every local decision on the global purpose of the system (Corbett; 1998:25). Goldratt poses three basic questions in order to define key measurements:

1. Which is the rate at which the organization generates its goal or purpose?

2. How much money is captured by our organization?

3. How much money do we have to spend to operate it? He defines three measurements as answers

He, therefore, defines 3 measures (T, I and OE) to evaluate the whole performance of the system, the company (Goldratt, 1990:15-18):

1. T is defined as the rate at which the organization achieves its goal.

   For every company whose goal is to make money, managers want to know how much money it generates over time. For a for-profit organization T is the rate at which the organization generates money through sales and only when the company sells products it increases (Goldratt, 1984:60).

2. I is considered as all the money the system invests in purchasing things the system intends to sell.

   Inventory definition departs drastically from convention when it refers to material inventory. The value added to a product before it is sold only entails the materials and purchased parts that went into the product and not even the direct labor. This is another important difference that contradicts any conventional method of valuing inventory. The concept of adding value to a product is considered by TOC as a distorted local optimum since the moment in which the company gets money from a product is the moment when the product is sold and not a minute before. Since I considers all the money the system invest, it also entails machines and buildings that in conventional terms are considered assets (Goldratt, 1990:23-24).

3. OE is defined as all the money the system spends in turning I into T (Goldratt, 1990:29).

   OE concept includes not only direct labor but also the personnel that is not touching the product but that are working for the product such as salespersons, foremen, managers, secretaries, and others. All money invested in the system is considered I but the money spent is considered OE. The purchase price of a new machine is considered I but as we use the machine and scrap it because of wear and tear, we remove this value from I and passes it to OE. This phenomenon is known as depreciation (Goldratt: 1990: 29).

When managers need to evaluate local decisions they should measure the impact of such decision in all these three measures. The final judgment for the decision should be evaluated in terms of the relationship between the three measures. TOC introduces two known relationships established between T, I and OE, net profit (NP) and return on investment (ROI) that he refers as the company's bottom line (Goldratt, 1990:32).

TOC says that these three measurements are sufficient to bridge the gap between NP and ROI and the managers' daily actions and to figure out the impact of every decision in the company's bottom line (Corbett, 1998: 32). The relationships are:

$$NP = T - OE \qquad (1)$$

$$ROI = \frac{(T - OE)}{I} \qquad (2)$$

An ideal decision is one that increases T and reduces OE and I. However, since in ROI all the measures are included, it is considered the final judge to evaluate decisions (Corbett, 1998:32). Two more relationships, currently used by conventional management practices, can be established by the three measures set up by TOC:

$$P = \frac{T}{OE} \qquad (3)$$

$$TU = \frac{T}{I} \qquad (4)$$

Where P = Productivity

TU = Turns

However, Goldratt does not appreciate any significant difference in the above treatment of measurements between traditional management practices and the new philosophies since:

1. Only TOC addresses the distinctions stated above. TQM and JIT do not consider such distinctions.
2. T, I and OE are terms actually used by conventional management as well.

Goldratt states that the only possible reason to detect a significant difference between traditional approaches and new philosophies in making decisions has to underlie on the scale of importance given to these measurements (Goldratt, 1990:47).

The New Paradigm.

In conventional management OE are considered as the most important measurements since they are more tangible than T. Nowadays, in every position for every company minimization of OE is required as the first goal to achieve. T then is left to a secondary position, and I occupies the last place in the scale.

All these new management philosophies are considered POOGIs. The underlying idea of these approaches is that it is always possible to obtain an improvement in the performance of the company. Under this consideration the measurement scale of importance totally changes from the conventional approach.

T is located in the first place of importance. The reason is that T does not recognize any limitation in the possibility of growing; the limitation would be in the ability of the company in obtaining more business. I and OE are considered measures that restrict the management's action freedom since they are limited in their minimum by zero. Managers have more power for reaching improvement over T than over I and OE. I is given the secondary position before OE since clearly all three new philosophies have identified secondary effects that cause increments in T reducing I (Goldratt, 1990:47-51).

This new scale of importance (T, I, and OE), has significant implications in every management's decision making. Actions that make perfect sense under conventional approaches are considered absurd or even destructive under the new management philosophies (Goldratt, 1990:51).

Foundation of Cost Accounting – Cost Accounting Paradigm.

Another way to express T and OE is defining the components that comprise them. T of a company is composed by the sum of all Ts from all company's products; we can express this relationship as:

$$T = \sum_{p} Tp \qquad (5)$$

Where Tp = T generated for every product

The same procedure can be used to express OEs that is the money spent to convert I into T. The company pays this money to the resources involved in performing the activities to produce products and services. One of the points that Goldratt emphasizes is that this money cannot be paid to products. Therefore, products are not feasible categories of OEs. The total OE of a company is simply the summation of the individual categories of OE:

$$OE = \sum_{c} OEc \qquad (6)$$

Where c = all categories for expenses

Therefore, the company's NP, a company's bottom line measurements, can be expressed as follows:

$$NP = \sum_{p} Tp - \sum_{c} OEc \qquad (7)$$

Another way to express the above formula is:

$$NP = \sum_{p} Rp - \sum_{p} RMp - \sum_{c} OEc \qquad (8)$$

Where Rp = revenue for every product

RMp = raw materials used for producing a unit of product

This formula (Corbett, 1998:19) basically expresses the same concept than the above but divides T into revenues (R) and RMs for every product. The first two summations are carried out over products. Every product as it is sold generates money (T) for the company. However, the last term is performed over every category of operational expenses. The conclusion is that while both summations are performed separately the result will be correct. However, when managers wanted to analyze a decision such as launching a new product, they desired to know how much profit the new product will create for the company. Under the above approach this question does not have an answer since both summations have to be computed in an aggregate manner.

Goldratt states that cost accounting was created to answer this important question (Goldratt, 1990:38). Cost accounting breaks the second summation instead of categories of expenses into categories of products. Cost accounting questioned to itself: Why does the company pay money to its resources? The answer is: Because it uses its resources to produce products and services. Therefore, a relationship between the resources to which the company pays money and the use of them in producing products and services would be established.

At the beginning of the century when this procedure was invented, direct labor was paid by pieces of work or number of products produced. At that moment there was a logical and direct relationship between this expenses and products produced. The rest of the expenses were grouped into a whole category called overhead entailing the rest of labor and expenses apart from direct labor, expended by the company to allow production. At that moment these expenses represented a minimum percentage in comparison with direct labor. They were spread into products according to their percentage of direct labor used, introducing little deviations. This method was called allocation and it is referred as a way to assign OE to products by SCSs. Therefore, the new mathematical expression for NP used by SCSs was:

$$NP = \sum_{p} (T - OE)\, p \qquad (9)$$

These new approximation allowed managers to make decisions of incorporating new line of products. The allocation of OE to the various products was created to be able to quickly answer the very important question of evaluating the introduction of a new product without looking to the rest of the products and to be able to evaluate and make local decisions that would result in global optimization (Corbett, 1998:19).

Obsolescence of Cost Accounting Models.

The distortion in product cost introduced by allocation was small since the proportion of OEs was insignificant compared with direct labor. However, as we have mentioned in Section 1 the new production environment since the 1950s significantly increases OEs in relationship to direct labor. Corbett says that in today's environment direct labor's participation in total costs is decreasing and no more than ten percent in many cases. Direct labor is no longer paid by piece of product, and overhead is the most significant OE. Nowadays, most of the OEs do not vary directly to production volumes; RMs are usually the only resources that vary directly with production volumes. Even so, most companies continue to use production volumes as a base for allocation (Corbett, 1998:20).

Goldratt says that the problem of abandoning cost accounting practices lies on the fact that managers are so accustomed to this nomenclature that they are not willing to give it up. Moreover, he refers the terms OE and NP of a product as mathematical phantoms that do not have any support in reality. He says:

> Net profits exits only for the company, not for the products. This means that all the following terms, product profit, product margin, and product cost, must be omitted from our vocabulary at the minute that the approximation is recognized to be no longer valid. … Unfortunately, these terms have very deep roots in our decision process. …Every conglomerate in United States and Europe reports its performances according to the original formula: total throughput minus operating expenses. Nevertheless, if we dive into these same conglomerates, to division level, and certainly to the plant level and down, you will find another mechanism … the diabolic creature called BUDGET. … It is just the construction of the original P&L formula through the approximation (Goldratt, 1990:43).

Throughput Accounting (TA).

Noreen, Smith, and Mackey develop a clear explanation how excess inventory in the form of WIP inventories can cause increase in cycle time, decrease due date performances, increase defects rates, increase operating expenses, reduce the ability to plan, and ultimately reduce sales and profits (Noreen, 1995:9-12).

Because excess WIP can create so many problems, Goldratt is in opposition to CA. Full absorption (allocation) costing capitalizes fixed cost in inventories creating incentives to build and manipulate inventories to smooth incomes.

Since absorption costing encourages managers to build inventories, Goldratt creates TA as a variation of variable costing (VC). Noreen explains that TA is based on three building blocks: T, OE, and assets (A). The official definition for T is revenues less "totally variable costs" (TVC). Most of the literature uses revenue less direct materials. However, some companies deduct other variable costs such as subcontracting work, variable selling costs, and variable shipping costs (Noreen, 1995:13).

Noreen replaces I for the term A. A in TA is the same than A in SCSs except for inventories that are considered totally variable costs. OE are all the rest of the expenses that are not deducted in calculating T.

T in TA expresses exactly the same concept that contribution margin in VC, the only formal difference consists in that TA calls TVC instead of variable costs as it is called in VC. However, there is an important difference in the treatment of costs. TA considers labor costs as part of the OE (fixed costs), without using them in computing T. Instead, VC considers labor costs as variable costs. Noreen following the same reasoning that Goldratt considers that labor costs were variable when labor was paid in pieces rates. However, in the new production environment since the 1980s where managers are particularly reluctant to lay off skilled direct labor, except in dire conditions, he argues that direct labor is essentially a fixed cost particularly in the short run (Noreen, 1995:15).

Noreen, Smith and Mackey studies several cases where several organization applying TOC principles ignored Goldratt's advise that direct labor should not be deducted in calculating T. In one case the manager uses a radical downsizing prior to apply TOC and the company slowly adjusted its remain workforce. The manager argued that direct labor is a variable cost and should be a deduction in the calculation of T (Noreen, 1995:15).

Goldratt advocates VC since it is closer to cash flow, can be used more easily than absorption costing to estimate relevant costs and benefits, and does not contain incentives to build inventories. The study of Noreen reported managers using TOC have greater freedom in pricing decisions since margins are much larger under TA than under absorption accounting (Noreen, 1995:16-17).

Section 6 – TOC and ABC Differences and Similarities

Corbett refers economists Adam Smith and Barker to define a paradigm. For Smith a paradigm represents "A shared set of assumptions" and for Barker it can be thought as a set of rules and regulations that establishes boundaries and defines how people should behave to be successful. Since different paradigms are based on significantly different assumptions, understanding the underlying assumptions under both ABC and TOC methodologies will contribute to a better comprehension of their differences and complementarily (Corbett, 138).

ABC's Assumptions.

A synthesis of the underlying assumptions on ABC methodology stated by Fritzch and Holmes are (Fritsch, 1997/1998:84-85; Holmen, 1995:38-39):

1. Activities consume resources and products or customers consume activities.
2. Costs of resources associated with an activity pool (a set of activities that can be considered together for cost analysis purpose) must be highly correlated with each other and must be traceable to products or services using the same activity driver (AD).
3. Costs associated to activity pools must vary proportionately to ADs. All costs of resources assigned to activities vary linearly with respect to ADs.

   Holmen considers only ***"facility-level"*** costs as fixed costs since they do not depend on some type of fluctuating activity. When more tasks are aggregated into an activity, the ability of a unique AD to trace costs to product accurately decreases.

4. ABC models the consumption of resources rather than expenditure of them.

   Holmen thinks that one of the most important implications from this assumption is that for costs to decrease there must be a change in the company's spending. Although consumption of resources (what ABC measures) can change in the short run, spending of resources (the resources supply by the company for operations) can only be aligned with their consumption in the long run (Holmen, 1995:38).

5. There are several causes for the consumption of resources. Therefore, a wide arrange of activities can be identified and measured.

According to the assumptions Holmen states that ABC methodology appears to be a tool primarily intended for long term analysis since only in the long run the expenditures can be aligned with consumption of resources (Holmen, 1995:39).

Based on the above assumptions ABC could be synthesized as a product costing methodology that provides information of financial and operational performance data of activities, resources, and costs objects (products and services) from the entire organization, to support organization's managers so that they can optimize the decision making process in the use of organizational resources and draw innovative conclusions leading project teams in the quest of POOGI.

TOC's Assumptions.

Kee and Holmen identify the following assumptions under TOC methodology (Kee, 1995:50; Holmen, 1995:39-40):

1. TOC recognizes the interdependent nature of production activities. The most limited activity in resources assignment/consumption limits the performance of the system.

2. TOC focuses on how to manage the activity constraining the whole process.

3. TOC is a process of continuous removing bottlenecks from subsystems of the firm, which leads to a cultural change in the organization.

4. The goal of the system is to make money. This assumption comes from the fact that TOC was developed to help for-profit organization's managers in the decision making process.

5. T is the measure used by TOC for measuring money. It is revenue minus the variable costs of raw material and energy.

6. Labor, overhead and all other costs except RMs and energy are considered fixed costs under the TOC approach.

7. There is always at least one constraint on each product produced by the company that limits the company's revenue.

8. There are three types of resources in a company: bottleneck resources, non-bottleneck resources and CCRs, which are not bottlenecks in the present but can become one of them if they are not carefully treated.

9. Most manufacturing operations have only few CCRs and they are not easily controllable.

10. The production process is a sequence of dependent events that result in interactions between resources and their statistical fluctuations that randomly emerge.

11. The order product mix is stable with respect to given resources, resource capacity is fixed for the time frame (production period) considered. Bottlenecks are detected at any given time and they are unavoidable.

Based on the assumptions, the objective of TOC is to maximize the goal of an organization which is limited by a constraint resource. The whole performance of the system will depend on the performance of that constraint. Managers should expend resources to release the system from that constraint and after it is removed, the system will be able to be moved to a higher level of performance. In this situation a new constraint will eventually appear and managers will face a new cycle in managing the system based on the new constraint. TOC is defined as a methodology or systematic approach whereby a decision is made to identify and manage that which limits the performance of the entire system (Swartz, 2003).

At this point we would like to know which the best approach under particular conditions is. To answer the question we will first develop an analysis of the relevant costs that influence cost making decision process.

Relevant Costs in Decision Making Process.

According to Fritzsch, economists classify costs decision making both into short-run and long-run based on the managers' ability to change the factors of production, the resources used in the production process, in a particular time frame. In the short run, most capital related inputs are considered fixed and others such as labor and RMs are deemed variable. On the other hand, in a longer time frame (long run) all resources, even capital intensive, can be changed and thus they can be considered variable. Other economists add the "very short run" concept to this classification where all costs are deemed fixed and the "very long run" in which even technology and regulatory policies can be modified (Fritzsch, 1997/1998:86).

However, very few costs are completely fixed. When managers refer to costs as fixed in a time frame, they mean the costs are fixed within some RR or production quantity. The relevant range is the range of activity within which the assumptions about variable and fixed costs are valid (Garrison, 2000:58) and since different resources perform different activities within the organization, the relevant range is different for every resource. Considering a RI, the relevant range for RM would be a unit of RM since for some RIs it is necessary to use only a unit of RM. On the other hand, the RR for a planning personnel resource could be very large since only when the output of the organization exceeds the capacity of this resource will it need to purchase another unit of it. Therefore, the concept of fixed costs of a resource is only valid within the RR for this particular resource.

A company operating at a particular level of output will have in its costs structure a value for UVC and a value for fixed costs that summed will constitute the total costs of the company operating at a specific level of output. If managers want to increase or decrease the level of production, there will be an increase or decrease in total costs according to the variable costs only. However, if the new level of output exceeds the RR range for those resources considered fixed in the initial position, managers would need to hire or buy more of these resources in order to meet the new level of production. The result would be increments not only in variable costs but in those costs considered fixed in the initial RR and eventually in OE (Swartz, 2004e). The TOC explicitly recognize this increment of OE in its fourth step "Elevate the System's Constraint(s)" (Goldratt, 1990:61).

Holmes states that "the economic concept of short run versus long run focuses on whether the capacity of the production facility can be expanded or contracted" (Holmen, 1995:40). However, the time frame in which the production facilities can be expanded or contracted depends on the ability and talent of organization's management in overcoming internal and external company's constraints.

There is not a specific time frame that clearly divides short run from long run decisions since costs are consequences of the use of resources and they can be changed in different time frames. The time period for classifying a decision as short or long run will depend on the kind of resources involved in that decision but eventually it will rely on the managers' ability to modify the resources committed by the organization in that period. This ability, limited by the nature of the resources (e.g. capital versus flexible resources such as RM, energy and even labor), could be also affected by internal and/or external factors such as internal company's policies, governmental regulations and even the market.

In the relevant-cost decision making approach, costs that ***change*** as the result of the decision are considered ***incremental costs*** for that decision and should be compared with the incremental revenues obtained from that decision. If the expected incremental revenues are greater than expected incremental costs the decision should be deemed convenient (Kennedy, 1995:27).

Under these considerations, only variable costs in the time frame are expected to change (increase or decrease) due to the decision and should be deemed relevant. Kennedy states that:

> As the timescale over which a decision will have an impact shortens, so the number of costs which are deemed relevant to that decision tend to

> decrease, as costs which may change in the long term may be viewed as fixed in the short term. (Kennedy, 1995:27)

Kennedy emphasizes the fact that costs become variable not as a result of the simple passage of time itself but as a consequence of actions taken by managers to change them over time. In the short run costs that are considered fixed are not relevant and thus they should not be considered for evaluating incremental costs versus incremental revenues. A company evaluating product mix alternatives for the following week will have to consider overhead costs as irrelevant since they cannot be modified in this period. However, if the same company arranges a contract for producing over a six months time frame period, some of the overhead costs, fixed and irrelevant in the short run, will turn out to be relevant (Kennedy, 1995:27).

Common Costs.

Hirsch refers to common costs as those such as common support department, supervisory, and general costs. Common costs should be differentiated from traceable costs to products and services. These costs are attributable to more than one product (e.g. inspection, support department, setup costs) and thus any assignment of them to product and services would involve an allocation. He says that these costs are not incremental or avoidable and if they were allocated to products and services they would be treated as if they were. However, he asserts that when managers want fully allocation of costs to products, ABC methods should differentiate between traceable and allocated costs so that managers could distinguish relevant costs for decision making. Managers in decision making must distinguish among incremental, sunk, and allocated costs (Hirsch, 1992:46).

In a Depot, the salary of the person who is running it, its CEO, should not be considered relevant in decisions related to product mix or outsourcing of products or services since this cost will not be changed by the decision. The salary does not vary according to the number of items repaired in the Depot. It is not possible to imagine an AD that relates the items produced with the consumption of the CEO's salary. There is not a causal-effect relationship between this salary and the number of items produced. This cost should be deemed not relevant for those decisions. However, in a decision considering shutting down the Depot, the CEO's salary should be considered relevant since shutting down the depot will eliminate it (Cunningham, 2004).

On the other hand, the work of the planning staff at the Depot is indirectly related to the number of aircraft or item repaired. Every inspection requires a single plan and the usage of planning resources will depend on the number and type of inspection that the depot is planning to perform in the time frame considered. These costs should be considered relevant in the long run, and only incrementally over the relevant range of production levels causing hiring or firing.

Depreciation of Assets.

Depreciation is not a real cost since it is not money out of the pocket or spent by the organization. It is basically a concept that should be related to how long an asset is going to last, what it is worth at the end of its life, how it loses its value over time or due to usage in a period, and what would the interest rate be to apply measuring the value of depreciation since it uses the concept of net present value (NPV). However, one of the most important and difficult issues to define is how long will the asset last.

Depreciation is a long term concept that is usually thought in a long time frame (ten or fifteen years). In shorter periods of time depreciation does not really matter, it is not relevant, since it is almost nothing in a short period that can change its value. The only alternative to change depreciation in the short run is to sell the entire plant off (Cunningham, 2004).

Managers can allocate depreciation cost of a plant to products and services based on the rationale that they use part of the facilities to be produced, but depreciation is not a real variable cost at least in the short run. However, at some point of time and when managers face the decision of replacing the plant or facilities, depreciation becomes a relevant cost and thus should be considered in the decision.

The matter is whether or not it is necessary to push assets' depreciation down to products and services and if they are relevant. Depreciation of facilities are not affected or changed by how many products or services the company produces. Depreciation of Depots facilities in the military does not depend on how many repairable or aircraft inspections will be performed. Depreciation will be the same value whether or not the Depot repairs few or several items. However, for some assets such special equipment, depreciation could be related to the number of pieces processed since some of these machines have a limited and maximum number of operations available beyond that the machine has to be replaced.

A simple rule to be taken into account when considering tracing down costs to product and services is to ask whether or not those products or services are using resources involved (Cokins, 2002:23-24). "If you do not use the resource, do not charge it to what you are doing. To determine if a cost is relevant or not for a decision, ask the question: "What would the cost driver be"? (Cunningham, 2004).

In a D environment the cost driver for facilities' depreciation could not be the number of engines or aircraft repaired since depreciation's values will not change modifying the number of engines or aircraft repaired. The value of depreciation will not vary with decisions such as defining product mix or product outsourcing. It will depend on payback conditions in the time frame and interest rates used to depreciate the assets, both subjectively under management considerations. If managers cannot think in a cost driver to trace depreciation to products or services, depreciation values should be deemed not relevant for making decisions about mix of items repaired and they should not be driven down to the component level or unit level of production.

Managers sometimes want to trace all assets costs to products and services because they claim that production is using the facilities. In this case, we define the value of depreciation for the time period considered and then allocate it to products and services based on units produced or square foot occupied by the production process in the facility. "But the question remains the same: Should you consider depreciation costs traced to products or services in mix decision making? The answer should be: No" (Cunningham, 2004).

From the standpoint of the traditional cost accounting some costs are considered relevant independently of the time frame in which the decision takes place but on the type of decision at hand. For example, in considering shutting down a Depot, traditional accounting may consider depreciation costs as relevant based on the rationale that they could get rid off through this decision. The analysis would be that in shutting down the plant the company will get back part of the money attached to the investment and the interest rate for the principal and then in such decisions depreciation costs should be deemed as relevant.

Under this rationale, both the type of decision and the time frame involved in the decision will affect what costs should be considered relevant or not for that decision. From an ABC standpoint this means whether or not these costs should be traced down to products and services or whether they should stay in a higher level (Cunningham, 2004).

However, depreciation is not a real cost and thus it will not be relevant under any circumstance since the organization can not save money that is not real. Hirsch emphasizes the same concept saying that depreciation is a sunk cost since it does not have either resale or replacement cost. It could be traced to products and services but should be differentiated as a sunk cost and thus not relevant for making decisions. The assignment of depreciation costs to products can lead managers to think that these costs are relevant in the decision making process (Hirsch, 1992:43).

Limitations.

<u>ABC's Standpoint.</u>

Professor Robert S. Kaplan, a pioneer in advocating the ABC methodology says that the purpose of TOC is to maximize T while keeping steady or preferably reduce OE and I. He says that this means to maximize T when the organization has fixed supply of resources, expenses and spending for the next period (except materials) has already been determined, when its products have already been designed, prices have been set, and customer orders have been received. Consequently, the issue is reduced to solve a linear problem of maximizing the T processed by the bottleneck of the system. In the linear programming set up by TOC with OE assumed to be independent of product mix, it is logical not to assign OE to individual products and customers.

However, in relation to the validity of considering OE as fixed costs, Kaplan asks first how did OE reach the current levels? Why do they reach different levels at different companies, and why are not they fixed at lower levels? Secondly, he states that if they were independent of volume, mix and complexity, all companies in the same industry, with the same line of business, should have the same level of OE. The assumption for considering OE different to zero is that some minimum set or resources and facilities would be necessary to operate. With these minimum set of resources these companies would be able to operate at different mixes, volumes and complexities of products (Kaplan, 1998:133).

Kaplan also says that empirical evidence shows that this is not true. He exemplified in the following way:

> Assume that operating expenses were fixed at a given level of sales, and that sales have increased by a factor of 5 to 10. Were operating expenses to be fixed, their ratio to sales would be only 10-20% of their initial level, a conclusion in sharp conflict with the real world of virtually all organizations. (Kaplan, 1998:134)

Kaplan asserts that the solution proposed by TOC is an excellent approximation for short term decisions and scheduling of bottleneck resources. ABC plays a little role in short term production scheduling decisions, or decision trying to evaluate one-time incremental orders (Kaplan, 1998:134). ABC allows managers address the following set of questions and statements:

1. How does demand for products, services lead to resources' supply?

2. Which products or services are generating revenues in relation to resources' costs used?

3. How do changes in activities management, processes performance, and product mix will affect future demand of resources?

According to Kaplan, ABC provides a dynamic TOC that allows managers to make better decisions today according to their impact in future resources constraints and also to determine resources in excess supply, allowing managers to pursue their reduction or reallocation.

Cokins emphasizes the differences between ABC and TOC stating:

> …In contrast (to TOC), absorption costing proponents look backward in time and observe that different types of products (as well as sales channels, distribution channels, and customers) placed varying demands on time and usage of the resources. Therefore, they see many of the categories of expenses (OE for TOC) as being product-related. …. To managerial accountants, product cost is a logical consequence of the actions of the organization. Product costing is not an artifact of managerial accounting. (Cokins, 2001:301)

Kee, paraphrasing Thomas Johnson, states that one of the critics received by ABC is its inability to identify and remove constraints. He says that a constraint in a production process plays a relevant role in decision such as determining proper mix of products, pricing, make-buy, special orders, opportunity costs of the firms' resources, and where to focus POOGI on (Kee, 1995:49; Johnson, 1992:32).

However, Kaplan and Cooper have clearly defined the differences between the costs associated of used and unused capacity for the resources supplied by top management (TM) to the firm for performing its operations. The implementation of ABC models will allow managers to know how much of every resource supplied is projected to be used by the expected mix of demands of products and services in the prearranged time frame. Therefore, managers will be able not only to determine the resources used above its maximum practical capacity level, but also to make decisions such as resource reallocations and also to determine which resource reaches its maximum practical capacity first determining the constraint resource of the system for this particular mix of product or services in the period considered.

Hirsch asserts that ABC models have expanded the former idea that managers have in relation with incremental costs as those of additional materials needed to process an extra order. Nowadays, ABC focuses managers' attention on incremental costs due to products' complexity of incremental production orders in terms of overhead and specific departments such as engineering and purchasing. However, he emphasizes that some costs traced by ABC models to products or services are not incremental and therefore not relevant for costs based decision making. ABC systems may trace engineering and purchasing costs of resources to products and services based on the consumption that those products make of those resources but these costs cannot be deemed avoidable. If the production of one product or service consumes half the time of one engineer and the company decides to drop the product, the costs related to half of the engineer's time would not disappear, which means that this cost although traced to products is not avoidable. The company needs to pay the whole salary to the engineer yet and thus this cost is not avoidable or incremental related to the decision of dropping the product. However, a percentage of the engineer's time is now available for another use and thus "if and only if" the company can use this time for another purpose "avoiding to hire another employee" the costs should be considered incremental and therefore relevant for this decision (Hirsch, 1995:43).

TOC's Standpoint.

The consideration of Goldratt in relation to SCSs and particularly to ABC could be summarized in his following declaration:

> Today the entire financial community has awakened both to the fact that cost accounting is not longer applicable and that something must be done. Unfortunately they are not going back to the fundamentals, the financial statements logic, and seeking the answers for the important business questions. Instead, the financial community is totally immersed in an attempt to save the obsolete solution. "Cost drivers" and "activity-based costing" are the names of these fruitless efforts. (Goldratt, 1990:39-40)

Noreen states that the strategies of a company involved in TOC can differ dramatically from those companies using ABC (Noreen, 1995:143). Products appear more or less profitable under TOC methodologies than under full allocation costs methods; therefore Noreen says that products will tend to proliferate in a TOC environment. On the other hand, since ABC tends to shifts costs from high-volume products to low-volume products, low-volume products usually appear as losing money. If managers respond dropping those products the company will decrease its offerings. In conclusion TOC encourage variety while ABC reduces (Noreen, 1995:144). However, it should be recognized that TOC methodology considers that products costs do not exist in reality (Goldratt, 1990:42).

While TOC assumes that almost all costs other than materials and energy are fixed within the RR, ABC assumes that nearly all costs are variable since they all are proportional to the ADs used. Fixed costs are not relevant for making decisions unless there is a good reason to believe that they will affect the decision.

Moreover, TOC assumes that product variety (proliferation) and volume have not appreciable effects on OE within the RR. Increments in OE is not budgeted automatically in relation to variety and volume of products. Noreen, Smith and Mackey articulate:

> Managers at almost all the sites we visited claimed that they had been able to reduce or keep operating expenses constant despite increased volume and variety. This fact is surprising given the assertions made in the ABC literature concerning the effects of volume and variety on overhead costs. We believe these companies have been able to hold the line on operating expenses simply saying no to increases. (Noreen, 1995:144-145)

However, the same authors say that ultimately when there is no possibility to reduce fat in the form of non-value activities to liberate resources, product proliferation and increasing activities will likely create pressures to increase overhead. Several managers have pointed out that pressures to increase activities and product variety have expanded support staffs. Some of them have declared that the effect is a change of the CCR from the shop floor to engineering or design departments. In this situation TOC treats these new constraints, overhead constraints, in the same way that a CCR is treated in the shop floor. The new constraint should be elevated after performing steps two and three (TOC methodology) by acquiring more capacity in engineering just as we purchase a new machine in presence of a machine constraint (Noreen, 1995:145).

Product and Services Costs Treatment under ABC and TOC.

According to the explanations and the description of the underlying assumption under TOC and ABC, Fritzch states that "it should be apparent that these two methodologies are based on opposing views of the nature of product costs" (Fritzsch, 1997/1998:85).

Goldratt refers to product costs as a "mathematical phantom," "the outcome of allocation" (Goldratt, 1990:42) and Noreen and others say that Goldratt believes that the term product cost should be purged from our vocabulary (Noreen, 1995:24). He only associates the costs of RMs and energy as incremental to products and services. All the rest of the organization's costs such as direct labor, overhead, machines, and facilities are not affected "within the RR" by the mix of products or services produced and thus they are fixed in the time frame considered (Fritzch, 1997/1998:85; Kee, 1995:50). In this way he eliminates the difficult and controversial issue of allocating and tracing costs to products (Fritzch, 1997/1998:85).

Since almost all costs are considered fixed within the RR except RM and energy under the TOC approach, managers' focus will be reduced on maximizing T (product price minus RM plus energy cost subject to the limited resource capacity assigned to individual production activities in the firm. The constraint will limit the optimal profit of the entire system.

Therefore, on the one hand ABC assumes that all resources costs can be traced to products and services that use those resources in the organization. Under this standpoint, the resource costs traced to products and services are variable or incremental in the time frame considered. On the other hand, under TOC approach almost all costs, except RM and energy, are considered fixed and "sunk" with respect to cost decision making (Fritzch, 1997/1998:86). However, it should be clarified that TOC considers all OE costs to be wholly irrelevant to determining product mix in pursuit of organizational objects. The only "product" or marginal profits are those associated with variable revenue (price) and unit variable costs (RM) with respect to quantity.

Although at the beginning Goldratt advised not to do product cost but only use variable cost to make decisions, there have been some changes proposed in the TOC approach. One alternative for product costing under TOC holds that if it is necessary to take all the fix costs or non-unit-variable-costs (NUVC) of the system into account, they can be allocated to the capacity constraint. If a product does not use the capacity constraint the product will not receive any NUVC. On the other hand, if multiple products go through the capacity constraint, the burden each product receives will be equal to the percentage that every product uses the CCR (Swartz, 2004b). The following example shows the procedure.

Having three products A, B and C and every of them has unit-variable costs (UVC) associated that are the RMs used for every unit of product produced. The company operates at a particular level of OE in the time frame considered. The market demand for the products creates a CCR. The products consume the CCR in the following way:

1. Product A does not use the constraint resource and then it does not load the constraint of the system.
2. Product B uses sixty percent of the constraint resource.
3. Product C uses forty percent of the constraint resource.

Under TOC methodology the company will produce all the quantity demanded by the market for product A first since it does not use the constraint and thus it has the highest priority for production. Products B and C will be produced according to the priority established by the metric "T per constraint usage", the higher the metric the first higher the priority for the product. According to the priorities, the products will be produced in quantities Qi in the time frame considered. TOC would cost products A, B and C in the following way:

$$TCi = RMi + \frac{\frac{CLi}{CLt} \times OE}{Qi} \qquad (10)$$

Where TCi = Total cost of product I ($)

RMi = Unit variable costs (UVC) for product i ($). Equal to the value of RMs used to produce one unit of the product i

CLi = The constraint load due to product A ($)

CLt = Practical capacity of the resource constraint (in hours)

OE = Total NUVC = Operational expenses in the period ($)

Qi = Quantity produced of product i

Under this procedure product A will cost only the value of RMs used to produce it and products B and C will receive the percentage of the total OE according to how much every of them loads the CCR. It must be recognized that this approach results in a different, but still arbitrary, value of "product cost" that traditional/ABC allocation. Under the true TOC philosophy, the concept of product cost is somewhat meaningless and this calculation would only be useful in certain narrow applications including questions of "product profitability".

However, it appears that the differences in product cost treatment and time frame visions under both ABC and TOC methodologies are interrelated. Most of the OE are considered fixed under TOC approach when evaluating decisions in a very short period of time. Most of the examples of decision making under TOC's literature are focused on determining the most profitable product mix for the oncoming week. On the other hand, OEs are deemed variable under ABC approach in a longer period of time when managers gain power to modify the resource committed and traced them to product and services as variable or incremental costs, thus being relevant for decision making.

Time Frame Under ABC and TOC.

Analyzing the assumption under both methodologies, Holmen declares that "it becomes clear that the cost paradigms are based on different time horizons – ABC has primarily a long-run time horizon, while TOC has primarily a short-run time horizon" (Holmen, 1995:40).

On the one hand, the treatment of costs under TOC approach's assumptions appears to resemble a very short run situation (Fritzsch, 1997/1998:86). In very short run decisions such as defining the mix of products to produce or which line of products to outsource in the next week, almost all costs related to the resources available can be deemed fixed. In this very short period of time TOC considers that only RM and energy are UVC, all resources capacities are fixed within their RR and the resource that first reaches its practical capacity will be the CCR that limits the output of the whole system. The TOC approach focused on obtaining the best efficiency in the CCR will be valid. It is assumed that RM will be available as they are required by our production schedule for the following week. However, even the purchase of RM in such a short period could restrict this assumption under TOC if managers cannot handle the lead time from suppliers.

On the other hand if managers evaluate what to produce in the next year, they can evaluate different alternatives that include major changes in production capacity, methods, and even labor force composition. In the long run with a longer time frame, most resources capacities can be changed and thus more costs, fixed in a shorter time frame, turn out to be variable. In this new situation with adjustable resource capacity, resources supplied can be matched with resources consumed and ABC's assumptions make sense (Holmen, 1995:40).

Holmen concludes that since both methods are based on different sets of assumptions that suppose different time horizons, they are not competing one against each other but there is enough room for both. Selecting one or the other methodology depends on the applicability of the set of assumptions of every methodology to the particular decision under consideration. He states the question of "When does a TOC approach become invalid and ABC become the 'correct' methodology?" In other words, which is the time frame and circumstances under which decisions made under TOC differs from decisions made under ABC (Holmen, 1995:40).

Kee states "ABC and TOC model different aspects of a firm's production structure" (Kee, 1995:50). Since ABC determines how resource costs are transformed and traced to products and services, it represents a long term perspective. On the other hand TOC tries to determine the critical role played by resources in the production process giving a "short term perspective in the relationship between a change in costs and production" (Kee, 1995:51).

However, it must be recognized that discussions involving "times frames" have a different meaning under TOC. With TOC, a cost is not "fixed" or "variable" with respect to time. A cost is either fixed or variable with respect to increments or changes in the production count, and whether capacities are exceeded. Decisions involving product mix and profitability are therefore misinterpreted as being "short term" only; simply because the production level desired can be a short term decision.

Sequential Decisions – Short Versus Long Term Decisions.

An important aspect addressed by Kennedy is related with the validity of making sequential short term optimal decisions as a way to reach an optimal long term decision. He presents the case of a company with excess capacity, due to reduction in demand, where managers face the decision of accepting an incremental order that can be covered by the excess capacity of the company. Kennedy advises that the company undoubtedly should accept the order since the relevant cost from a contribution marginal analysis standpoint will be only the RM and energy needed to complete the order.

A direct extension for this problem addresses whether or not managers should accept sequential special orders that includes customized products for several oncoming periods based on contribution marginal considerations.

He asserts that if the company accepts the orders based on a short run contribution margin approach, costs that appeared to be fixed in each short term contribution marginal analysis (OE such as overhead) will start to increase or at least they will be incapable of being reduced. Kennedy reporting that Kaplan emphasizes the importance of considering long run impact of the decision in the whole performance of the organization, states:

> In the presence of excess capacity managers are exhorted to consider other opportunities which may present themselves in the future before taking an action on the basis of an excess of short term incremental revenue over incremental cost. The technique offers no guidance as to how these future as yet unknown, possibilities should be accounted for. (Kennedy, 1995:28)

Kennedy finally argues that the sum of optimal short term contribution marginal decisions using a relevant costs approach may not lead to an optimal long term optimal decision. The sum of the parts may be less than the whole. He proposes using short term contribution marginal analysis using relevant cost for decision making only if such decisions are unique. Short term contribution marginal analysis using relevant cost may still be valid even if they are not unique but only considerations of future opportunities of cost savings and revenues will determine the validity. He also says that using costing information to provide management with a comprehensible understanding of the long run variable or incremental costs involved in the decision will help managers in the judgment of whether a short term contribution marginal analysis is valid. Finally, he asserts that ABC can provide managers with the information necessary to realize the long term consequences of short term decisions based on contribution marginal analysis and to improve the quality of short term decision making.

Integration between ABC and TOC.

Kaplan asserts that TOC and ABC can be seen as complementary tools. TOC can provide short term optimization to maximize short-term NP and ROI and ABC can provide the support for dynamic optimization of resources supplied for the organization, product mix, and pricing in a long term frame. Both have the same purpose that is to maximize the organization NP and ROI. While TOC is the tool for maximizing profitability within existing resources and constraints, ABC provides the economics of resource supply, giving the map of how to improve resources supply in the future (Kaplan, 1998:135).

Kee complements these concepts with a similar line of reasoning saying that “TOC and ABC may be used to measure a component’s short and long-run production costs” (Kee, 1998:35).

Huang identifies four situations in which ABC and TOC can be integrated to obtain optimal solutions:

1. The situation 1 is related to short-term and long-term decisions. TOC is useful in short run decisions where almost all costs are fixed and thus the only way to improve the performance of the system, its profitability, is through increasing T that in this case is related to effectiveness, obtaining the maximum output and maintaining fixed the system's inputs. On the other hand, a longer time perspective allows managers to change inputs resources (e.g. labor and overhead) in the system to measure performance in terms of efficiency (maximizing T per unit of input). This situation, more related with a long term perspective, is where ABC techniques has been primarily used (Huang, 1999:24)

2. The second situation addresses a mix-integer programming model combining TOC and ABC principles developed by Kee. He addresses the integration between TOC and ABC using a mixed-integer programming model "to represent unit-level cost and resources as continuous variables, while batch-and-product-level activities are represented as discrete variables" (Kee, 1995:51). The solution of this model can determine the non-constraint activities and their unused capacities assisting managers previous to actual production in decisions of resources allocations for other uses (Kee, 1995:51).

3. In the third situation ABC and TOC are used to analyze and optimize cycle time management. Two processes are described to manage cycle time using TOC and ABC. In the first process TOC helps to increase productivity through reducing cycle that increases production and enables timely deliveries without adding capacity to the company. A reduction in cycle time will improve T since it depends on the flow of goods in manufacturing and distribution. Cycle time reduction will allow having less inventory levels in the process reducing average fixed costs for the company. In the second process ABC helps managers in cost-benefit analysis since it can provide information about what activities consume most of the resources or what are the costs of reducing or incrementing some activities will be in order to evaluate TOs to optimize decisions (Huang, 1999:26).

4. In the situation 4 Huang refers to an integrated model using TOC and ABC developed by Baxendale and Gupta for a silk-screen printing business. In the study, Baxendale states that additionally to provide information for the five steps of TOC and process improvement, ABC provides the information on unused capacities of the activities considered and also the profitability of every product (Baxendale, 1998:44).

One of the most important interactions between TOC and ABC comes from the information ABC can provide managers to identify constraint resources. Baxendale states that for machine or labor activities practical capacity is the number of hours that can be reasonable available in the period considered in relationship with the costs of the resources assigned to activities. After managers define practical capacity for an activity, it is possible to determine a charging rate, the AD rate, which is the total costs of the activity divided by its practical capacity in units of AD that can be produced. Baxendale also states that a unique characteristic used by Kaplan and Cooper in ABC is the fact that they use this charging rate to cost the practical capacity not used in the activity, which they named unused capacity. This charging rate remains unchangeable as the number of unit of products produced changes, which allow manages to pinpoint the total amount of resources used and unused for a particular mix of product.

If the ABC model includes all the different activities in the company, those in which resources have direct contact with products or services, which we refer as direct or primary production activities, and those in which resources do not have direct contact with products or services, which we can call indirect or secondary since they are not sequentially dependent with the primary production process but support it (e.g. purchasing, planning, scheduling, sales, secretaries payroll, and marketing), ABC will allow managers to measure the value of used and unused capacity of all resources assigned to activities. Analyzing the load in every resource caused by the product mix it would be possible to obtain information about where the CCR of the system is located (Baxendale, 1998:43).

It is possible for the CCR to change at any instant in time (due to process variability), but also have two resources loaded at approximately the same average percentage according to the product mix. This is unusual but it is possible to happen. When two resources are identically loaded on average, the resource exhibiting the higher variability could be chosen as the actual resource constraint (Swartz, 2004c) as in the following example.

The combined constraint consumption uses the marginal revenue minus marginal costs (TOC T) for every product and divides those for the sum of the minutes used in both constraints. This determines priority of product mix. Look at the variability of resource consumption to choose the resource constraint. Although in average both resources are consumed at the same rate, the variances of both resource consumptions will be different. Therefore, the activity that has the rate of resource consumption with larger variability will determine the CCR of the system since in a longer period of time the probability of reaching the practical capacity of the resource at any instant in time is greater for the activity with greater variance of resource consumption. Schedule according to this “selected” drum resource.

If the variabilities are also approximately equal, break ties by comparing at the location in the sequential flow of products. The first machine or resource in the sequence should be treated as the CCR since if the product does not get through the first machine or resource, it does not get to the second machine to become a problem.

The above procedure of determining the system’s constraint could be simplified by the information provided by the ABC model. However, Baxendale advises being very careful with the analysis of unused capacity. He says that while unused capacity in for production labor maybe considered seriously, unused capacities in administrative activities such as marketing and sales should not be taken quite as seriously. He refers the resources attached to these activities as soft constraints because of the manner in which their capacities were calculated (Baxendale, 1998:43).

Primary Conclusion.

Many of expert opinions in the literature appear to coincide that ABC and TOC are not opposite management tools but complementary in nature. Holmen thinks that both ABC and TOC are useful tools with enough space for their applicability on the accounting management arena. A deep understanding from managers is required so that they can select which tool applies better in every situation (Holmen, 1995:40). According to Kee ABC and TOC can be used to measure a component’s short and long-run production costs (Kee, 1998:35) and their integration will result in a model capturing the interaction among costs, physical resources and capacity of production activities that allows determining the bottleneck of the system (Kee, 1995:48). Schneiderman concludes that the rivalry between advocates of both ABC and TOC methodologies relies on the fact that they fail to recognize that both systems have to be considered together to optimize the decision making process (Schneiderman, 2000:39). Finally, Huang states that ABC may be used to provide the data to support TOC analysis of product mixing (Huang, 1999:21).

It was mentioned that management's decisions are based on the fundamental TO between effectiveness and costs, which implies the optimization of the decision of organization's resources allocation to tasks.

ABC is not a method for decision making, but it provides the economic map of resources consumption in the organization and the possibility to measure the relevant costs of an organization that operates at a particular level of output and time frame. Since management decisions are based on the allocation of resources to organization's requirement, ABC provides powerful data to feed the management's decision making process.

The major difference between ABC and TOC is the treatment of the costs associated to products and services. In other words, both methods differs in which costs are deemed relevant or incremental for a decision making process. However, this significant difference is the consequence of the time frame in which both methods are usually applied.

While ABC is used to trace the costs of resources to activities and after that to products for long periods such as one year or one semester, TOC is oriented to product mix decisions that optimize the profit of the organization in the very short run. Since both times frames are significantly different, a comparative analysis of the methods should recognize that most of the costs that are deemed variable or incremental and therefore relevant for ABC will appear irrelevant for TOC.

This difference is primarily based on the fact that ABC considers all costs associated to resources' usage as UVC in the period and then trace them to evaluate the cost of products and services. On the other hand, TOC considers all costs except RMs and energy as fixed within a RR for every resource and then it does not allocate any "fixed cost" to products and services but RMs and energy and states that product costs are a mathematical phantom or artifact created by traditional accounting.

Goldratt basically uses a two step procedure to evaluate the product mix that generates the maximum profitability for the period analyzed:

1. To calculate the CCR of the system through the technique called capacity load profiling (CLP) (Swartz, 2003).
2. To determine the priority of products in the mix according to the product that generates more profit per unit of constraint.

When TOC uses the CLP technique to pinpoint the system's resource constraint it is using the concept that every product consumes particular quantities of hours of some resources performing the activities to produce that product. Every unit of product consumes resources (through activities) in incremental or variable quantities that represent variable costs until one of the resources (the constraint) reaches first its practical capacity. The procedure basically uses the same AD concept than ABC but the difference relies on the fact that ABC considers not only primary production activities but all indirect or not primary activities and then instead of having only AD in hours of work (the basic AD used in primary activities), it uses other ADs such as transaction or intensity. At this point, it is clear that ABC embraces TOC and expands the CLP procedure to determine the system constraint toward indirect or non primary activities.

Finally, although considers the accountant concept of product costs as a mathematical phantom but he is actually using the concept when considering the UVC, which is the costs of RM and energy associated to the production of an incremental unit of a product in the short time considered by TOC. However, in a longer time frame not only RM but other incremental or relevant costs should be deemed UVC for every product and this is the caveat stated by ABC. This appears to be the most significant difference between both methods but also the connection between them since then ABC is presented as a suitable tool that allows tracing the relevant costs considered in product mix decisions in longer time frames.

Section 7 – Performance Measures for the AFMC

The Fundamental Trade-Off for Any Organization.

Under the general system theory, management is concerned with the decision making process of efficiently assigning available organization's resources to tasks in order to perform the conversion of inputs to outputs for the purpose the organization is trying to achieve. Managers perform planning, organizing, coordinating, directing and controlling functions to assign resources to everyday jobs. The quality of managers' decisions is measured in terms of how much of organization's purpose is achieved, as a measure of effectiveness, per unit of resources expended performing tasks, as a measure of efficiency (Swartz, 2004a).

The fundamental management trade off without importance to what kind of organization managers are leading is recognized in terms of costs, not always in dollar but sometimes as efficiency, and effectiveness. In other words, how much purpose the organization achieves versus how many resources it spends to obtain a particular level of purpose. This inherent trade off between outputs and inputs (resources consumed) is commonly expressed as bang for the back (BFB) that represents a marginal rate of return. Bang in terms of how much of the organization's purpose is reached and back of how many resources the organization consumed to achieve that level of purpose. Therefore management's responsibility is decision making assigning resources to activities to maximize the BFB.

However, there is something unique in providing logistics in the military. Since the output of a logistics system in the military, that can be called supply chain (SC), is a mix of tangible products and intangible services and since the purpose of this SC is not to make money, we can define it as purpose serving output (PSO) (Swartz, 2004).

Looking at OL, a wing basically can be divided into three pieces of sub-organizations: operations, maintenance, and services. The purpose of the OL is basically to have the best trained pilots in order to have the highest CC, defined as pilots highly trained and skilled. However, at OL there is a limited budget available and then there is a TO since to have trained pilots managers must provide aircraft available to fly. For a wing as a whole, CC would mean both trained pilots and AA. Consequently, there is a dynamic tension in defining CC as the synergy between trained pilots and the aircraft ready for fly (AA) (Swartz, 2004).

In general, we consider the PSO for the military as providing certain CC. Therefore, the PSO for the logistics system, generally associated with the AFMC, would be the provision of goods and services that contributes to CC, the material aspect of CC. In providing this material support for CC, the substitute or proxy measure is aircraft availability (AA) or some type of weapon system (WS) uptime.

However, managers will also have to consider that aircraft have both fly systems, those systems that allow them to fly, and mission system, those that allow them to perform particular missions. Some of the parts that compose those systems will affect differently the CC metric. Managers, therefore, have a mix of fly and mission systems. They have to measure not only AA but to add into the mix what are the actual capabilities of the aircraft to support operations. The definition of defining the bang of our system has now several dimensions from a logistics perspective.

As we mention earlier, in for-profit organizations the bang is to make money and the back is cost. In managing a SC private organizations are primarily concerned in defining bang as retail customer service level (CSL). Bottom line for CSL is the product's availability at retail's shelves when they are requested by customers. CSL is usually expressed as a percentage. A 100% of CSL means all customers who requested products at retail obtain what they want. CSL entails the right part, at the right place, at the right time, in the right quantity, and at the right price or cost.

Therefore, managers are constantly making decision about resource allocation throughout the SC involving TOs mainly among resources, inventories, transportation, and warehouses costs but the fundamental TO they face is to achieve the purpose of the system maximizing the BFB. In making these TOs managers operates in a region that can be defined in a plane with "y" axis that measures the total costs of the system and "x" axis that measures AA. Figure 7 describes what is called the "S" curve that defines the region where the fundamental trade off of every organization takes place (Swartz, 2004a).

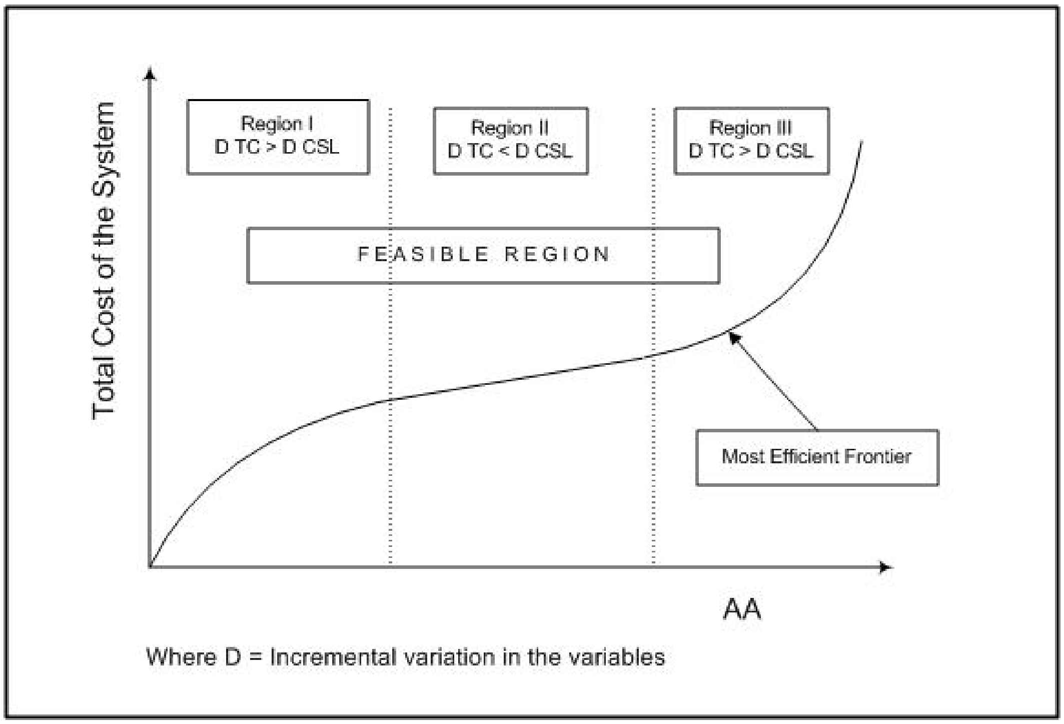


Figure 7. The Fundamental Trade-Off for Any Organization.

TC in the "y" axis goes from zero to infinity and AA in the "x" axis goes from zero to hundred percent. There is a line called the most efficient frontier (MEF) that is the line defined, for every AA value, by the absolute minimum value of TC for which that AA level can be achieved. The feasible region (FR), where we can operate, is defined as the area above the MEF. Every point in the FR is a point of possible trade off.

However, managers making the best decisions and everything right, efficiently and perfectly, will never be able to get the MEF for lots of reasons but the most important is variability in the system.

Along the MEF in the S curve we identify 3 regions:

1. In region I, changes in TC are greater than changes in CSL. Managers are building infrastructure to develop the logistics system at that moment and they incur costs of start up. High fixed costs are incurred in this region.
2. In region II, changes in TC are less than changes in CSL. With small changes in TC managers can achieve large changes in CSL. The zone is called efficient one. The marginal rate of return is high and the BFB is high moving along this region. There are economies of scale in this zone.
3. In the region III, changes in TC are greater than changes in AA as manages are closer to hundred percent of AA. Diseconomies of scale are generated by uncertainty and complexity and this zone is characterized by higher inventories levels that generate high holding costs.

The S curve does not show an absolute but a generic representation of the fundamental TO inhering in every logistic system. The goodness or badness of a particular decision should be evaluated in terms of how it minimizes the system's TC satisfying a particular level of AA, which means to approximate the operational point of the logistic system to the MEF. In the private sector logisticians are given a particular level of CSL and they have to reach this level at minimum system's TC (maximize the BFB). On the other hand, logisticians in the AFMC receive a particular budget number and their objective is to obtain the highest level of system's AA.

However, operationally there are lots of decisions not oriented to contribute to maximize the overall metric BFB. Sometimes, managers' decisions appear not to be focus on the overarching purpose of the system but on optimizing a local work center. The fundamental problem with local optimization is that we do not necessarily have a clearly defined hierarchy from the Purpose of the entirely logistics system through its supporting Goals, Objectives and Activities down until the actual Tasks performed

(PGOAT hierarchy). Theoretically, every agent in the shop floor should know exactly how his /her contribution is in the final purpose of the system, AA or whatever PSO.

Therefore, the purpose of management is global optimization for the entire logistics system. Managers should maximize our BFB of the entire system. They will face lots of local issues that are going to come up since the serial nature or sequence of events in the SC leads to sub-optimizations. So, in order to achieve global optimizations, managers have to think in terms of the whole system and recognize that certain things happen sequentially (Swartz, 2004a).

The Aircraft Availability Model (AAM) for the AFMC.

<u>The environment.</u>

When a failure is diagnosed on an aircraft, the item that causes the failure is removed and brought to a base supply. If an on condition item is available it is installed on the aircraft and if the item that caused the failure is a repairable item, it is sent to the maintenance function to be restored. If there is no availability in the base supply, a backordered is established at that level. Items that are directly replaced or installed from aircraft are called first indenture items (FII) and the literature refers a FII's backorder as a "hole in an aircraft" since there is no availability of an item that is directly installed on the aircraft. The aircraft is grounded until the item is repaired and supplied to be installed in the airplane.

We consider every aircraft as an engineering hierarchical structure referred as indenture structure since some FIIs can be composed by other sub-items that we are going to call second indenture items (SII) and some of them can also be composed by another level of desegregation referred as third, fourth, etc indenture. However, it is necessary to highlight that backorders for SII or third indenture items not necessarily causes holes on aircraft (Sherbrooke, 1992:6).

An FII removed from an aircraft is called a line-replaceable unit (LRU) because the activity of removing and changing these items can be developed in the flight line. If

LRUs removed from the aircraft can be taken apart and repaired in a maintenance shop through changing SII, these SIIs are called shop-replaceable units (SRUs). Repairable LRUs are built up by SRUs or SIIs (Sherbrooke, 1992:8).

Inventory models.

Inventory theory recognizes a primary classification of items in repairable and consumables. Repairable or recoverable items are those that have the possibility of being repaired. On the other hand a consumable item is removed and changed by a new one when it fails since it is commonly considered uneconomical to attempt to repair them. Item managers are basically concerned in answering the following basic questions:

1. When to order or which the optimal reorder point is.
2. How much to order or which the order quantity is.

These two fundamental questions are answered by the fundamental formula of inventory theory, known as Wilson lot-size formula that established the optimal reorder quantity called Economic Order Quantity (EOQ). The formula is based on the TOs between ordering costs, holding costs and stock outs in order to minimize the total costs, the sun of order and holding costs in the period, of the item in the time frame considered. Equation 11 shows the formula for the EOQ (Sherbrooke, 1992:3-4).

$$EOQ = \sqrt{{2 \times O \times M}/{H \times P}} \qquad (11)$$

Where EOQ = the economic order quantity

O = the annual cost to place an order

M = the mean annual demand for the item

H = the annual holding cost rate (e.g. .2 is a common choice for the sum of interest rate, warehousing, and obsolescence

P = the price of the item

The EOQ model can be applied indistinctly for both consumable and repairable (recoverable) items. However, three basic characteristics lead item managers to pay special attention and be focused on repairable items (Sherbrooke, 1992:5):

1. The availability of supported systems is dominated by repairable or recoverable items.
2. Repairable items tend to be expensive and demands from bases usually tend to be low.
3. Recoverable spares tend to have longer lead times than consumable items.

Low values in the numerator and high values in the denominator of equation 11 leads managers to lower values of EOQ. Therefore, the repairable item problem has become easier in this way since the reorder quantity tends to be one and then the problem of the item manager is reduced to know when to reorder (Sherbroobe, 1992:6).

Sherbrooke shows the fundamental contrast between the old method of managing spares, the item approach and the system approach.

The Item Approach.

The item approach uses the traditional inventory theory where the spares for every item are determined by the EOQ model in a simpler way since purchase decisions for every item are made without considering other items. However, the disadvantage of the approach is that managers do not know if their purchase decisions lead to maximize the BFB of the entire system, the relationship between effectiveness and efficiency expressed in terms of AA and system TC.

In this approach AA and the total investment in the systems are uncontrollable outputs for the decision of number of items to buy or repair and this could lead to decisions where either the AA of the system or the investment required could be suboptimal (Sherbrooke, 1992:3). Therefore, the AA target and system's resource constraints such as labor, equipment, RM and money should be considered in the decision making process.

On the other hand, the policy used by the United States Air Force (USAF) to determine the required number of spare parts, characterized as the item approach, has been to buy spares to cover demand during lead time (LT) plus a safety level to protect the system against demand variability, then:

$$S = \mu + k \times \sigma \qquad (12)$$

Where S = Stock level.

μ = average demand during lead time

k = positive constant for the amount of protection

σ = standard deviation of demand during lead time

The value k should have different values for different items. Two items can have the same demand characteristics and the same importance for the operation of the aircraft. However, for the purpose of allocating a budget in order to buy or repair one or the other item, the priority of budget allocation should be put on the item with less cost since managers can obtain the same impact or improvement on AA at less cost. After the failure of the item occur and an aircraft is grounded, the importance of both items is the same and both have the same priority for being repaired. However, when managers are deciding to allocate resources in advance in order to provide the best expected AA in the future, both items are expected to have different impact on AA (Sherbrooke, 1992:13).

In an environment with several echelons (bases and depot level), levels of inventory of items bases, when aircraft are flown, have more impact on AA than the same stock levels at depots. This means that the k value for bases should be higher than for depots.

FII at base level have more impact on AA than second-, third-, or lower-indenture items. The k value should decrease as we move to lower levels in the indenture structure.

The System Approach.

In the system approach Sherbrooke establishes the analysis in terms of how much of the purpose of the system, in our case AA, managers can achieve with the amount of resources available. The trade off is here established as the relationship between effectiveness and efficiency of the whole system. The common questions answered by this approach are how much managers need to change the logistics structure to obtain a particular level of AA more efficiently or if it is convenient to increase our resources capabilities at operational sites or depots to reach the goals of AA.

Managers could be indirectly concerned about particular or local measures of supply system performance such as fill rates or number of backorders for particular echelons in the supply chain, but only as means to obtain optimal system performances (Sherbrooke, 1992:2).

The system approach as described by Sherbrooke introduces an availability-cost curve of efficient system alternatives. However, the present study will develop the most efficient availability curve as a function of the relevant resources in order to determine the efficient investment that maximize availability until the first resource constraint of the system is reached.

Single - Site Inventory Model (SSIM).

The objective of the SSIM is to develop the AA curve as a function of the investment in system's resources. The fundamental assumption in the model is that every FII has the same importance or has the same impact on the aircraft operation. A backorder for every FII will impact the aircraft in the same way. Every backorder for FII will ground the aircraft until the out of stock situation is removed (Sherbrooke, 1992:19).

<u>Palm's Theorem.</u>

The rationale of the AA is based on this theorem that allows managers to determine the steady-state probability distribution of the number of repairable units in repair, called due in (DI), based on two parameters (Sherbrooke, 1992:21), the probability distribution of the demand process since demands are caused by failures of items on aircraft (failure and demand are considered interchangeable terms in the literature), and the mean of the repair time distributions for the RIT.

The theorem expresses that if the demand for a repairable item is Poisson distributed with annual mean "m" and the repair time (RT) for each failed item is independently and identically distributed according to any kind of distribution with mean of "T" years, the steady-state probability distribution for the number of items in repair, DI or sometimes called "in the pipeline", is Poisson distributed with mean $m \times T$ (Sherbrooke, 1992:21).

There is no interaction in RTs for several items and the theorem implies that it is not necessary to determine the shape of the RT distribution but only its mean "m".

Stock Levels.

The purpose of the inventory theory proposed is to determine the optimal stock level (SL) for every item that impact AA in the system and that we are trying to procure or repair. The SL for every item can be thought as the number of units of the item that we want to have in the system. In a single echelon environment, we suppose that every repairable FII can be repaired at the echelon.

The SL for every spare is related with the amount of items in serviceable condition on shelves at the unit. Sometimes, item's SLs are serviceable on the shelves waiting for being replaced by a defective item removed from an aircraft. In other opportunities the SL is divided in some serviceable items on shelves and the other undergoing repair, which means that less than the SL is serviceable on the shelves.

Every time a FII fails in an aircraft it is removed and sent to be repaired in the maintenance function at the echelon. Therefore, a serviceable item is mounted on the aircraft. In this situation, the amount of units due in (DI) from repair increases in one and the amount of stock serviceable decreases in one too. The maximum amount of units of a repairable that can be replaced in an aircraft from the serviceable stock is equal to SL and this is the case where all the SL at the beginning of the time frame considered is on serviceable condition at shelves. Every time in that period, the failure item's rate exceeds the item's SL, the system is in a backorder situation since managers will have a hole in an aircraft until the repair function processes and turn one of the item out of service to a serviceable condition. Whenever the number of DI in a time frame considered is equal or more than the SL, there is no stock on hand and a backorder appears (Sherbrooke, 1992:25).

Since all the spare assets must be in somewhere inside the system, a basic but important equation could be written as:

$$SL = OH + DI - BO \qquad (13)$$

Where SL =Stock level.

OH = On hand inventory (amount of items in serviceable condition on shelves)

DI = Number of units of stock due in from repair and resupply. Number of items in the pipeline

BO = Number of backorders of the system

The number of backorders (BO) is defined as:

$$B(X / SL) = (X - SL) \qquad \text{if X > SL} \qquad (14)$$

and 0 otherwise. Therefore, the expected number of backorders (EBO) in the system will be the expected value that the number of units entering to repair or DI, is greater than the SL:

$$EBO = \Pr(DI = S + 1) + 2 \times \Pr(DI = S + 2) + 3 \times \Pr(DI = S + 3) + ... \qquad (15)$$

Where Pr = Probability distribution for the number of items in the pipeline, DI or entering for repairing

Or in other simpler form:

$$EBO = \sum_{x=S+1}^{\infty} (x - S) \times \Pr(DI = x) \qquad (16)$$

However, Sherbrooke states that using EBOs to evaluate the performance of the system is cumbersome since it will be necessary to track all customers that are requesting spare parts. Therefore, he asserts that for the perspective of a system manager it is more useful to use AA as a meaningful measure since minimization of BO for the system implies maximization of its AA (Sherbrooke, 1992:27).

AA is understood as the “expected percentage of fleet of aircraft that is not down for spares at a random point in time”. If the fleet consists only on one aircraft and only one LRU, AA is the percentage of time the aircraft is operational.

Managers are interested in investing the available budget (resources available in the time frame) to obtain the best AA for the system. This is developing an optimal curve for AA as a function of the investment in the system. Sherbrooke develops an optimal curve for total BOs for the system versus investment and after that shows that minimization of system’s BOs is equivalent to maximization of AA (Sherbrooke, 1992:28).

The technique used by Sherbrooke is called “marginal analysis” because it decides the next item the D in the AFMC is going to invest looking at only one number for every repairable item considered. This number represents the optimal increment in system effectiveness per dollar spent, our BFB metric. This value called by Sherbrooke delta value is calculated as (Sherbrooke, 1992:30):

$$\Delta BFB_i = \frac{[EBO_i(s-1) - EBO_i(s)]}{UVC_i} \qquad (17)$$

Where ΔBFB = Incremental BFB

EBO = Expected BO for repairable item

s = Level of inventory for item

UVC = Unit variable cost for repairable item ($)

i = Repairable item considered

The greater the difference between $EBO_i(s-1)$ and $EBO_i(s)$ per dollar spent the better our investment. Managers would maximize the reduction in EBO per dollar spent. The approach leads to optimize the investment in repairable items minimizing the total BO for the entire system.

Aircraft Availability.

There are three definitions of availability used by logisticians (Sherbrooke, 1992:36):

1. Inherent Availability (IA):

$$IA = \frac{100 \times MTBF}{MTBF + MTTR} \qquad (18)$$

2. Achieved availability (AchA):

$$AchA = \frac{100 \times MTBM}{MTBM + MCMT + MPMT} \qquad (19)$$

3. Operational availability (OpA):

$$OpA = \frac{100 \times MTBM}{MTBM + MDT} \qquad (20)$$

Where MTBF = Mean Time Between Failures

MTTR = Mean Time to Repair

MTBM = Mean Time Between Maintenance

MCMT = Mean Corrective Maintenance Time

MPMT = Mean Preventive Maintenance Time

MDT = Mean Downtime due to Spares, Maintenance (corrective and preventive), and other delays resulting from maintenance actions

However, Sherbrooke asserts that IA is a "measure of hardware reliability and maintainability and has nothing to do with spares" and "while AchA is a slight improvement over IA, it is a similar measure that relates to hardware considerations and excludes spares delays" (Sherbrooke, 1992:36-37). He states that an aircraft is available when it is not down due to maintenance or supply of items and OpA is the measure that considers both situations. We will compute OpA in two parts:

4. Maintenance AA (MAA):

$$MAA = \frac{100 \times MTBM}{MTBM + MCMT + MPMT} \qquad (21)$$

5. Supply AA (SAA):

$$SAA = \frac{100 \times MTBM}{MTBM + MSD} \qquad (22)$$

Where MSD = Mean Supply Delay

MCMT + MCMT + MSD = MDT

Sherbrooke divides the computation of AA in MAA and SAA since their product is a good approximation for OpA when both values are high. On the one hand, MAA does not depend on stockage policy and it is easy to compute after maintenance manning, test equipment, and preventive maintenance policy have been defined. On the other hand, SAA is independent of maintenance policy but it is a function of the stockage policy. We will refer SAA as AA, define it as "the expected percentage of aircraft fleet that is not down for any given spare", and we compute it as (Sherbrooke, 1992:38):

$$AA = 100 \times \prod_{i=1}^{I} [1 - \frac{EBO_i(S_i)}{NZ_i}]^{Z_i} \qquad (23)$$

Where Zi = The number of occurrences on an aircraft of the LRUi

N = The number of aircraft

$EBO_i(S_i) \leq NZ_i$

If every LRUi has Zi occurrences in an aircraft and if there are N aircraft in the fleet considered, we will have NZi possibilities of having a hole in one aircraft and the probability of having a hole will be $EBO_i(S_i)/NZ_i$.

Sherbrooke proves that maximization of AA is approximately the same than minimizing the total BO for the system, the problem that was explained above when we maximize the ΔBFB for every LRUi in equation (17).

Summary

The chapter included a presentation of the most important concepts under both methodologies ABC and TOC, their interrelationship and the scope of ABC in providing cost information of UVC for products and the used and unused capacity of resources that could be used by the TOC approach in the purpose of determining the constraint of a system. The chapter also described a comparison of TOC and ABC methodologies with respect to costing procedures. The chapter continues describing the fundamental trade off of every organization and how managers should evaluate the decision making process in terms of the BFB of the system. At the end of the chapter the AA model was introduced, since the purpose of military logistics systems can be measured by this metric. With the three methodologies, ABC measuring consumption of resources, the AA model used to measure the purpose of military logistic systems, and TOC recognizing the existence of CCR, managers can improve the decision making process in defining the mix of RIs in a Depot environment.

III. Methodology

Introduction

Chapter 2 provided the theoretical concepts of ABC, TOC and the AA model and how they can be used to improve the management's decision making process. This chapter describes the development of a simple but complete model showing the method that can be used to relate those approaches in the decision making about a mix of RIs at Depot level. The chapter is divided in three sections. Section 1 describes a simplified ABC model for AFMC's Depot level that considers the most important primary and secondary activities to determine the unitary variable costs for every RI, the consumption of the resources in the system and the CCR. Section 2 explains how the model was exercised in order to cover the relevant range of possible system's resources work load situations and also how the response for the model was collected. Section 3 describes how the different responses from the system will be analyzed to determine its similarities and differences and try to determine relationships that explain the different in responses.

Section 1 – The Model

Description of the Environment.

The first purpose of the research was to establish a valid ABC model for the AFMC. Since the two basic purposes of the AFMC, AIs and RIs, are performed in Depots, the focus of this ABC model is centered on Depots.

Figure 8 shows a schematic ABC model for AFMC's Depot level.

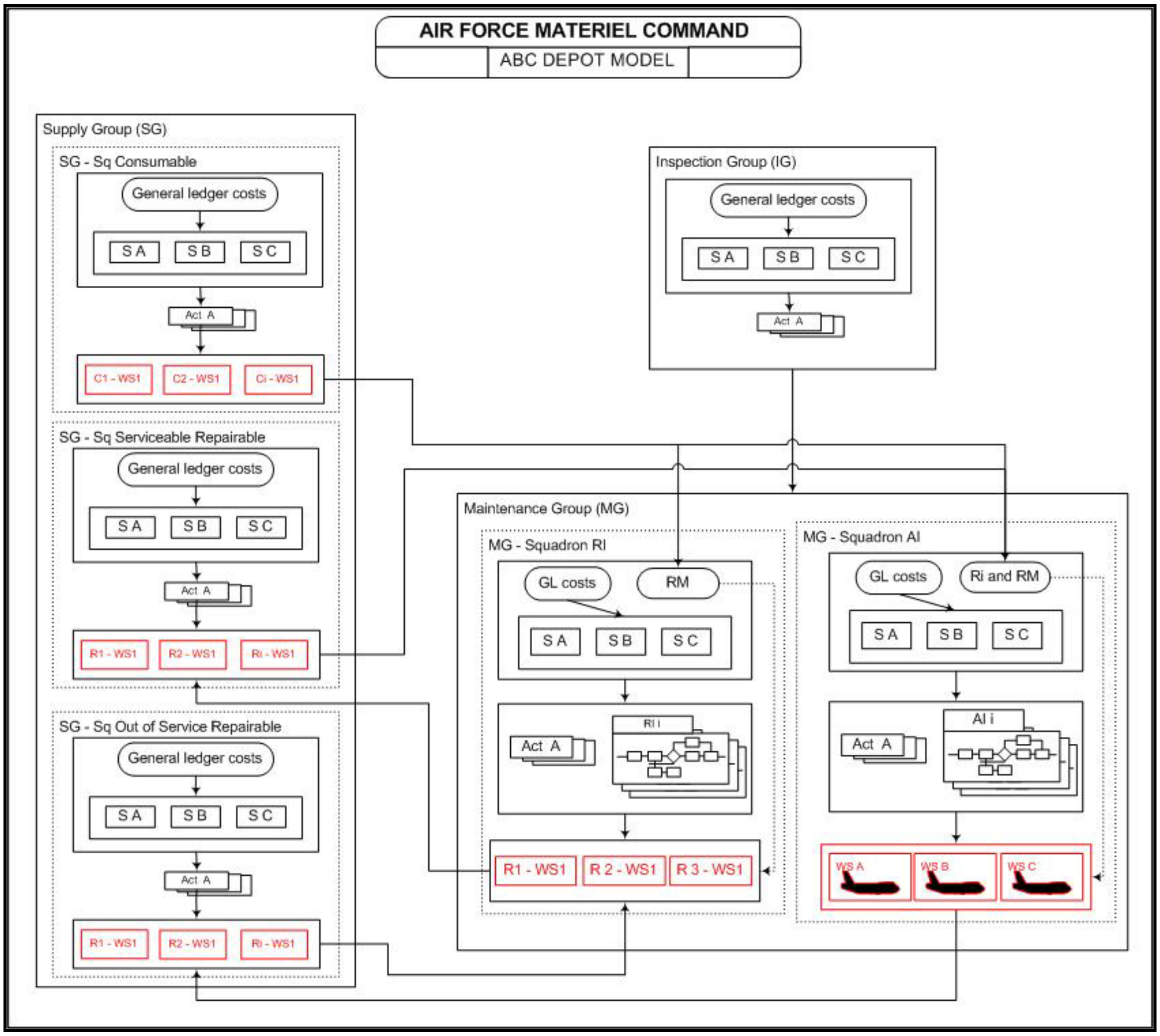


Figure 8. Schematic ABC Model for AFMC's D Level.

The model considers resources from the three main areas or sub-organizations at Depot level:

1. The maintenance group (MG) where AIs and RIs are performed. Primary and secondary activities within different squadrons are considered in the model.

2. The supply group (SG) where support activities such as receiving, handling, transporting, and requiring consumable for RIs are performed. Three main squadrons are differentiated within the SG:

   - Non serviceable (NS) repairable items squadron where repairable inventory out of service received from AIs or OL is stock waiting to be repaired in the MG.

- Consumable squadron where consumable items are stocked waiting to be used by AIs and RIs.

- Serviceable (S) repairable squadron where serviceable on hand repairable items inventory received from the MG is stocked waiting for being provided to OL or AIs at Depot level.

3. The inspection group (IG) develops quality control activities. These support activities are performed when non-serviceable items arrive from OL or MG and after the MG completes inspection before sending serviceable RIs to be stocked at the serviceable repairable squadron.

As mentioned above, two primary functions are performed at Depot level. On the one hand, a number of RIs are foreseen to be to be repaired in the Depot according to forecasted demand from OL and AIs in the time frame considered. Having the aggregate demand of RIs for the period and considering that resources are scarce and needs multiple (constrained environment), managers should schedule the maintenance plan, prioritizing the maintenance activities to maximize the BFB of the system. After RITs are repaired, they are stocked at the SG building stock level (SL) for every RIT. Therefore, managers deal with a constrained environment in terms of the budget assigned to pay labor and consumable resources used in the period and they have to allocate those resources to repair a mix of repairable items that will maximize the AA per unit of resource consumption in the period.

Managers will use the logic of the AAM both to evaluate the reduction in EBOs per resource consumed under ABC and TOC approaches to obtain the AA for the system.

On the other hand, when a Depot performs AIs, aircraft are delivered to the OL with a number of flying hours (FHs) available to the next inspection. Every AI provides AA to the OL in terms of the number of FHs available until next inspection. The procedure for evaluating the impact of every type of inspection on AA at OL thus appears to be different than the method used to evaluate the impact on AA at OL for repairable items, the AAM. This rationale justifies the fact that both AIs and RIs should be treated separately when managers want to measure their impact on AA for the whole system.

This research focuses at a first stage on RIs and the objective of prioritizing the mix of RITs to be repaired to maximize the AA of the system at minimum system's TC. The problem of defining priorities for AIs when the environment is constrained should be independently treated from the RIs environment and should be developed in future research.

The ABC Model.

For the definition of the ABC model, primary activities are those performed directly on the items to be repaired. Support-related activities, also called indirect, are those performed to support primary activities (Cokins, 2001:51). They are expenses associated to the organizational level. In the model these activities are basically planning, scheduling and requiring consumables used for performing RIs. The model considers only support activities from the Depot level. Supporting activities from higher levels such as the AFMC headquarters are not considered in the model.

Resources.

Labor (L) and RM are the main resources for building the ABC model. Neither special equipment for specific RIs nor depreciation costs of facilities and general equipment are considered in the model since the rationale developed in Chapter 2, Depreciation of Assets.

Table A-1 in Appendix A shows the areas at Depot level (IG, MG, and SG), specialties and categories of labor resources assigned to the Depot. Categories within specialties represent different level of skills associated with labor as follows:

1. In the IG:

    - QR – Labor that performs inspection tasks at reception of NSRIs. A primary visual inspection, primary diagnosis of possible failure and work to be done is defined by this specialty. These resources are used to performed non-destructive inspections on RIs as needed.

    - QEN – Engineering labor required for specific diagnosis, special procedures, or modifications on RIs.

2. In the MG:

   - MPR – Staff labor that perform planning and scheduling activities for RIs according to demands from OL and AIs at Depot level.

   - MR – Labor that performs primary activities to repair RIs.

   - MS – Labor that performs support activities as required by RIs such as electricity and electronics, paint and others.

3. In the SG:

   - SP – Labor managing requirements and purchasing RMs used in planned RIs.

   - SR – Labor associated with tasks of managing S and NS repairable items inventories at SG.

   - SC – Labor associated with tasks of managing inventories of RMs stocked for being used in RIs.

   - SRC – Labor related with activities of receiving, handling, moving and delivering repairable and RM items to MG for performing RIs.

   - RM – RMs used in every RI.

In Table A-1 it is also defined:

1. The time frame in weeks, the number days per week and hours per days that labor is available to perform the scheduled RI maintenance plan.

2. The number of resources by specialty and category available in every group and squadron.

3. Reasonable wage values for every specialty and category. These amounts entail the total amount of money spent by the D including social and fringe benefits for the labor.

4. The total (maximum) of hours available and expenses incurred for every specialty and category in the time frame considered, the OEs of the system.

5. Five categories of RMs with average prices ranging from fifteen dollars to three hundred and twenty five dollars, and the number of these items in stock in the SC.

The capacity of labor available and therefore its related expenses by specialty and category is represented by a step function that depends on the number of resources available. Figure 9 shows a typical step function of labor availability or costs.

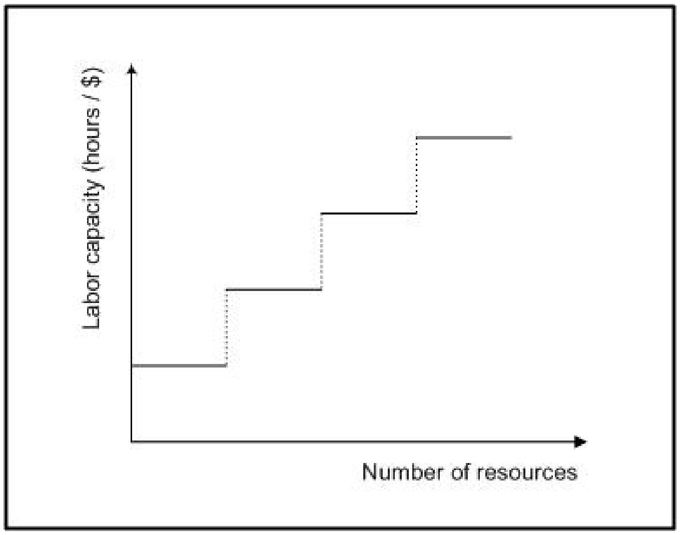


Figure 9. Availability Hour Step Function for Labor.

Activities.

Table A-2 in Appendix A shows the activities selected for building the ABC's Depot model. The criterion used was to select relevant activities, in terms of resources consumption, performed by group and squadron every time a RI is repaired. Those activities that were estimated as consuming less than five percent of the resources available in the system were not deemed relevant and therefore not considered in the model.

ADs.

Table A-2 also shows the ADs for every activity. None of the ADs were considered TADs but DADs since every RI consumes different amount of resources in every activity every time it is performed. Moreover, since different resources' skill levels were assigned to perform activities and the model differentiates between them, all ADs were deemed IADs since it is possible to distinguish between specialties and categories of resources that represent different expenses performing tasks for the organization.

<u>RDs.</u>

RDs trace expenditures or resources' hour availability classified by specialties and categories to activities. Since resources are always scarce, a hundred percent of them should be assigned by managers to perform RIs' activities. RDs represent the decision making of assigning resources to perform activities, the management's primary function. The same procedure is considered for resources from QG (except QEN) and planning from MG.

On the other hand, QEN's resources, support labor from MG and labor from SG are not assigned 100% to RIs' activities. They do not only perform activities for RIs since they are also used in performing others activities in the D (e.g. for AIs). Therefore, the RDs for these resources have been estimated within reasonable values and have been assigned only in percentages to be consumed by RI's activities. RDs are shown in Table A-3 in Appendix A.

The rationale of the assignment process is that managers always assign people to perform activities. This procedure allows determining the capacity in hours for every activity in the time frame.

However, since management recognizes that labor assigned to activities is not committed 100% of this time to actually perform activities, the model allows setting up a percent of idle time for labor. Reasonable values for idle time range from ten to twenty five percent. Therefore, resources' hour availability is reduced in a percentage (idle time) to compute practical capacity (PC). The values for PC are shown in Table A-1 and A-3.

<u>Activity's Drivers Rates (ADR).</u>

Table A-3 calculates ADRs for every specialty and category of resources performing activities. Every ADR is calculated as the quotient between the activity expenditure in the time frame, the cost of resources assigned to activities through RDs, and the PC of the activity. It is important to notice that the greater the idle time allowed by managers the greater the ADRs since PCs are reduced and expenses (resources' expenditures) are deemed constant in the period. The rationale for this calculation relies on the fact that labor are paid their total capacity in the time frame, however, only their PC is actually used to perform RIs. ADRs represent the Depot's expenses incurred in every category of labor every time a unit of AD is used for a RI. The ADR is measured in dollars per hours and they are calculated for every category of resource within every activity (disaggregate) since every resource's category represents different expenses for the organization. ADRs are constant values in the period.

ABC-Unit Variable Costs (UVC) for Every RI.

The number of units of AD used by specialty and category in every RI is defined in Table A-3. The AD usage is multiplied by the ADR to obtain the ABC-calculated UVC by resource's specialty and category for every RI. Summing up UVCs across resources' categories according to ABC principles, the model calculates the ABC-UVC for every RI. Figure 10 shows the schematic procedure.

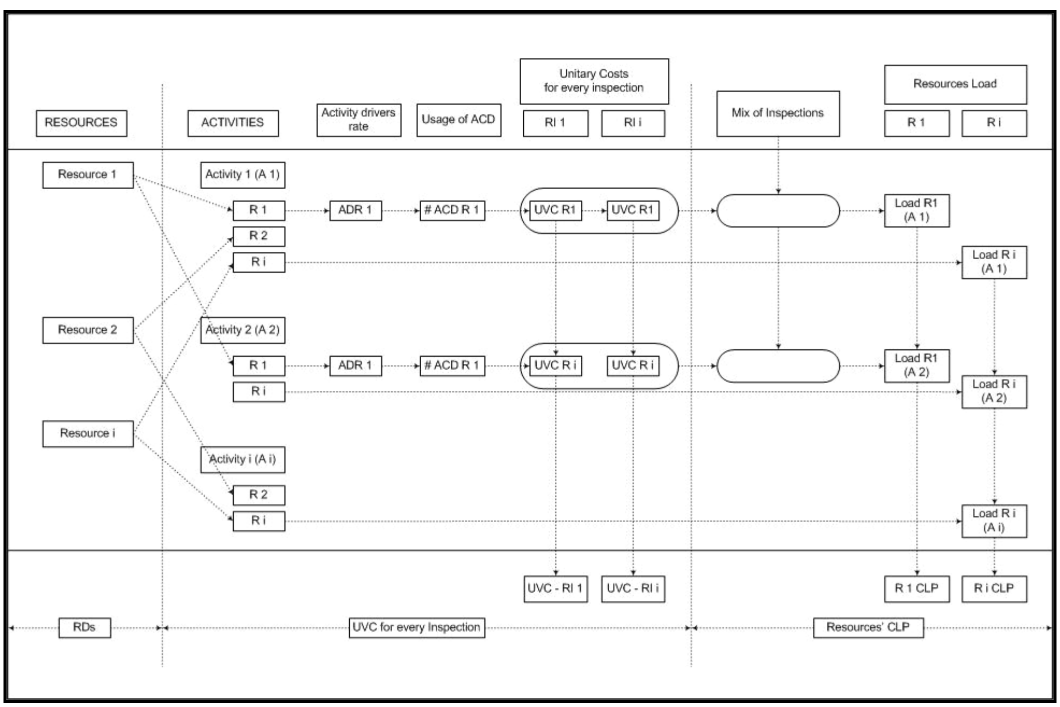


Figure 10. Schematic ABC Model Explanation.

Resource Capacity Load Profiles (CLP).

Since every RI loads resources in a particular way, the mix of RIs to be repaired in the period will determine the total resources' load in the time frame analyzed, their CLP. Multiplying the AD usage of every category in every RI by the number of RIs to be processed in the period, the mix of RIs, the model calculates the CLP by specialty and category. Summing up the loads of every resource across activities where it is used, the model calculates every resource's CLP in the time frame. The schematic procedure is shown in Figure 10 and the actual values in Table A-4 in Appendix A.

Table A-5 in Appendix A shows an auxiliary table used to build the model. It allows entering the RDs, the number of units of ADs used for every resource by every RI. This procedure allows us obtaining the unitary resource's CLP and to enter the number of classes of RMs used by every RI.

Verification and Validation of the Model.

The ABC model is consistent with the conceptual principles under ABC theory. The model performs what was intended since it reliably represents the actual allocation of costs by resources in performing activities every time a RIT is processed:

1. The most important resources, labor and RMs, representing actual organizational expenses have been considered in the ABC model. General facility and special equipment depreciation costs have been deemed irrelevant as actual expenses for the organization.

2. RDs, the percentages of resources assigned to activities, have been defined based on personal experience and the work distribution commonly seen for most of the maintenance personnel's specialties considered in the model.

3. ADRs are automatically calculated in the model. However, they have been increased purposely by defining a percentage of idle time for all resources, which makes sense according to expertise opinions and personal experience.

4. The model considers the most important activities that intervene in RIs. It is can lose some fidelity in the calculation of UVC for every inspection but at this point we rely on the ABC mantra "it is better to be approximately right that accurately wrong" when estimating cost of products and services.

5. The objects or output for the AFMC at Depot level are clearly defined as AIs and RIs. The ABC model only considers RIs, leaving for future research the treatment for AIs.

The results obtained from the ABC model allows us to assure also its validity since it provides accurately information for the basic purposes for which it was built, as follows:

1. An allocation into UVC for every RI.
2. The used and unused capacity for every resource involved in the system. Managers will approximately know the expected load for every resource according to the forecasted demand for the period.
3. A reference for the repair time to consider for every RI.

Finally, the model allow managers to vary several relevant factors such as time frame, resources' wages, idle time, and weekly labor hours to experiment with the model as if were the real system.

The AAM.

The second part of the model consists of developing the procedure from SSIM's rationale to help managers in the decision making process of defining priorities for the RIs under ABC and TOC approaches to determine which one provides the best system's AA curve.

The AA curves under ABC and TOC approaches are built using the information from the ABC model as follows:

1. Average annual demand (AAD) for every RI is calculated based on the forecasted demand used as product of RIs mix to position the system in different resources' work load situations. The forecasted demand for the time frame considered in the ABC model is modified by a factor so that it can represent the AAD for the Depot.
2. The average repair time (RT) for every RI is estimated according to the number of total labor's hours for every RI corrected by a coefficient that allows the researcher to introduce changes in the variable.

3. The ABC-UVC for every RI is directly used to evaluate the marginal analysis under the ABC approach.

4. The number of hours of the CCR, detected through the ABC model, used by every item is used to calculate the marginal approach under what it is called the TOC 1 approach.

5. The OE for the period used to calculate the UVC allocated to every RI in proportion to the usage of the CCR according to Swartz as discussed in Chapter 2 is used to evaluate the marginal approach under what is called the TOC 2 approach.

<u>The Marginal Analysis Procedure.</u>

Using the data from the ABC model, the marginal analysis to evaluate the reduction in EBOs for producing one more RIT is developed under both ABC and TOC's rationales in order to establish the system's AA curves.

The SSIM uses the discrete Poisson probability distribution to determine the steady-state probability distribution of the number of repairable units in repair (DI) to develop the marginal analysis procedure for establishing priorities for RIs. A typical Poisson probability distribution for the number of units DI is shown in Figure 11.

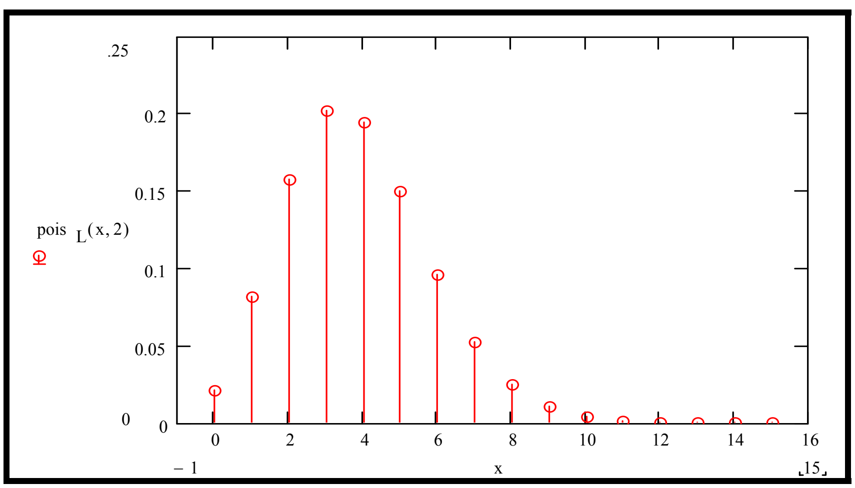


Figure 11. Discrete Poisson Distribution.

Every time a unit is repair at Depot its serviceable stock increases in one unit. The EBOs for every item in the system are calculated as the probability that the number of items DI is greater than the number of serviceable items in stock as was stated in formula 16 Chapter 2 where Pr is a Poisson distribution for the number of items DI.

The Repairable List and the System's AA Curve.

The final priorities for the RIs in the mix under every approach ABC, TOC 1, and TOC 2 are determined as follows:

1. The marginal analysis under the ABC approach, shown in Table A-6 in Appendix A, uses the ABC-UVC for every RI to determine the Repairing List (RL) to be incorporated in the Depot maintenance plan. The AA of the system shown in Table A-7 in Appendix A is computed as the products of individuals AA for every RI.

2. The mix of RIs under the TOC approach is developed under two different procedures:

   - Table A-8 in Appendix A shows the marginal analysis under the TOC 1 approach that is calculated based on the usage of the CCR by every RI. The CCR is the first resource that reaches 95 % utilization of PC in the time frame and it is obtained from the ABC model. The AA curves are also computed as the products of individuals AA for every RI.

   - Table A-9 in Appendix A shows the marginal analysis under the TOC 2 approach calculated based on the allocation of OE into every RI according to their use of the CCR. The AA curves are also computed as the products of individuals AA for every RI

Verification and Validation of the AAM Built.

The researcher positioned the model in a particular and limiting situation in order to evaluate if it properly responded to the rationale under the AAM. For this purpose the RT for all the RITs were significantly reduced so that the number of items DI at Depot is reduced significantly. This means that every time an item is requested for being repaired at Depot, it is quickly processed and put in serviceable stock at shelves. What is expected is that the repairing list copies almost exactly the forecasted demand for the period.

Table A-10 in Appendix A shows the results obtained in exercising the model. The values obtained for the mix of RITs to be repair in a range for AA between .67 to .99

copy proportionally and almost exactly the forecasted demand for the period with little differences.

Section 2 – Experimental Design – Data Collection

Data collection is developed in two stages. First the researcher establishes the parameters to position the model under different work load situations. In a second stage the model is exercised; the experimental design (ED) layout and the collection of the system's responses are explained.

The model provides data to know the resources' work load, their costs, the system's work load, and the CCR of the system. On the other hand, the model provides data to develop the system's AA curve through the marginal approach procedure so that managers can determine RIs priorities (repairing list) for the Depot maintenance plan.

Setting the Model.

Before exercising the model and collecting response data, we will define some parameters in order to position the system is four starting work load situations coincident with the forecasted requirements for RIs in the period.

Resources' Work Load Situations.

The work load situations for every resource are defined as follows:

1. A resource loaded between 95% and 100% percent of its PC is considered a constraint (C).
2. A resource loaded between 75% and 94% of its PC is considered as "HIGH" loaded. Two situations can be differentiated in a resource loaded as high:
   - HIGH 1 a resource loaded between 75% and 84% of its PC.
   - HIGH 2 a resource loaded between 85% and 94% of its PC.
3. A resource loaded between 50% and 74% of its PC is considered as "MEDIUM" loaded.

4. A resource loaded less than 50% of its PC is considered "LOW" loaded. However, for the purpose of the research we will consider three possible levels under "LOW" load:

   - LOW 1 a resource loaded between 1% and 15% of its PC.
   - LOW 2 a resource loaded between 16% and 30% of its PC.
   - LOW 3 a resource loaded between 31% and 49% of its PC.

Figure 12 shows graphically the situations explained.

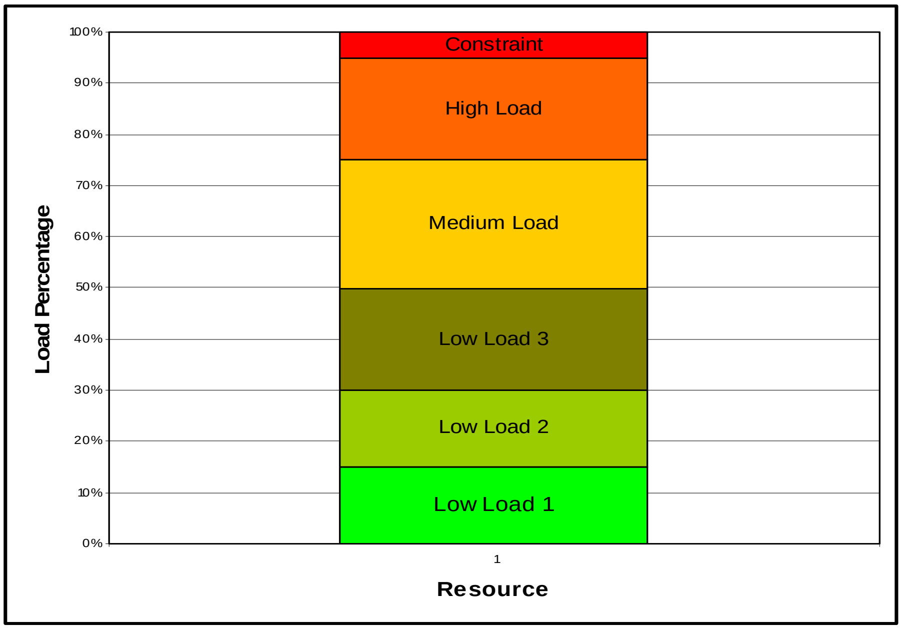


Figure 12. Resources' Load Profile Scheme.

<u>RIs Selected.</u>

There have been selected five classes of RIs. Every one represents a particular resources' work load for the system. The resources' work loads for every RI were chosen to cover a relevant range of resources' work load so that the researcher selecting particular RIs' mixes can exercise the system covering the vast range of work load situations that can be presented in reality. Table A-5 describe as an auxiliary table for building the model in Section 1 "Resources' Capacity Load Profile" shows the resources' work load for every RI.

The work loads produced by each RI over the system are:

1. RI 1 consumes a total of 59 hours of system's labor resources. Although the hours of work consumed by RI 1 on every system's resource is different, the average percentage of resources' PC consumed for every 10 units of RI 1 produced is constant (3.61 %) and considered low for the purpose of the research. Since this percentage of load is constant, the variance of load over resources is equal to cero as can be seen in Table 4. RI 1 represents a low and balanced system's resources consumption.

2. RI 2 consumes a total of 122 hours of system's labor resources. This item represents a balanced percentage of resources' PC consumption over the system as for RIT 1. However, the intensity of load in resources consumption caused by RI 2 over system' resources (7.21 %) is higher than for the case of RI 1. This value is considered medium for the purpose of the research. RI 2 represents a high and balanced load over the system.

3. RI 5 represents a high intensity load over the system's resources. RI 5 loads resources' system in a percentage of 9.01 % of their PCs. RI 5 also represents a balanced load situation for the system but at high level of intensity.

4. RI 3 consumes 49.5 hours of system's labor resources. Its average percentage of resources' consumption (3.08 %) is similar to RI 1. However RI 3 loads the system's resources unevenly. Its variance of percentage of resources' consumption is 0.07 % instead of cero. RI 3 represents a low and unbalanced load for the system.

5. RI 4 consumes the same amount of total system resources' hours (128.8 hours) than RI 2. Its average percentage of resources' consumption (7.71 %) is almost equal to that of RI 2. However RI 3 loads the system's resources unevenly. Its variance of percentage of resources' consumption is 0.42 % instead of cero. RI 4 represents a high and unbalanced load for the system.

System's Work Load Situations.

Since resources are always scarce and needs multiple the system will always have a constraint. For this purpose, the work load for the resource MR 3, the highest skilled resource used in primary activities, has been purposely increased so that this resource will always be the system's constraint. The work load consumption for this resource has been excluded in the calculation of percentage and variance resources' consumption for every item in Table A-4.

Different mixes of RIs forecasted will positioned the system at different work load situations. If the mix of RIs includes a large percentage of balanced RIs (RI 1, RI 2 and RI 5) the system will be in a balanced situation for resource consumption. According to the number of items considered, the system will be in high or low load. On the other hand a large percentage of unbalanced RIs in the mix (RI 3 and RI 4) will situate the system in an unbalanced situation. The system is always considered as having only one constraint. The alternatives for the intensity and balance of system load are the following:

1. Intensity Load (IL):
    - Low (L) load: The average percentage of resources' PC consumption is located between 30 and 65 percent.
    - High (H) load: The average percentage of resources' PC consumption is located between 70 and 80 percent.
2. Homogeneity Load (HL):
    - Balanced (B) load: The percentage of resources between a 10 percent range from the mean percentage resources' consumption is greater than 80 percent.
    - Unbalanced (U) load: The percentage of resources between a 20 percent range from the mean percentage resources' consumption is less than 30 percent.

Therefore, the system can be positioned in four work load situations according to the combinations among levels of intensity and homogeneity of load as follows:

1. High load intensity and balanced load (HB)
2. High load intensity and unbalanced load (HU).
3. Low load intensity and balanced load (LB)
4. Low load intensity and unbalanced load (LU)

Through trail and error the model was exercised and brought to the four work load situations explained above. The resulting forecasted RITs mixes were the following:

1. For LB: RI 1 = 50, RI 2 = 20, RI 3 = 5, RI 4 = 2, and RI 5 = 20.

2. For LU: RI 1 = 20, RI 2 = 8, RI 3 = 25, RI 4 = 20, and RI 5 = 10.

3. For HB: RI 1 = 70, RI 2 = 25, RI 3 = 5, RI 4 = 5, and RI 5 = 35.

4. For HU: RI 1 = 40, RI 2 = 15, RI 3 = 8, RI 4 = 20, and RI 5 = 30.

Figure 13 shows the system under low and balanced workload and provides graphically the following information:

1. The work load for every of the labor resources involved in the system as a percentage of its PC.

2. The mean system's of resources work load and the 10 and 20 percent ranges from the mean value (red lines). The mean value pinpoints the intensity load situation for the system and the percentages of resources within and outside the mean ranges mentioned above determine the homogeneouosity in the load for the system.

3. The system's constraint MR3 chosen purposely.

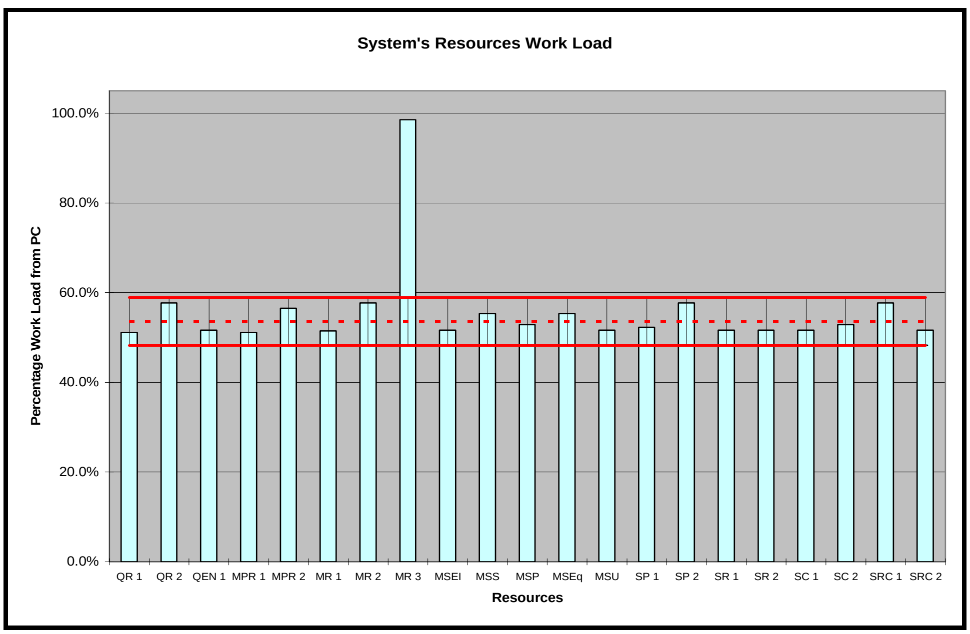


Figure 13. LB System's Resources Work Load.

Figures B-1, B-2, and B-3 in Appendix B shows the same information for the system under load unbalanced, high balanced, and high unbalanced workloads.

Other System's Parameters.

Table A-11 in Appendix A displays a summary of the most relevant information for the whole system in three sections. Section 1 shows the following information:

1. Time frame considered (in weeks), idle time allowed by managers for all resources involved in the system, and the value of OE for the system. OE are captured from Table A-1 "System's Resources".
2. The number of resources in every work load situation according to Figure 12.
3. The work load situation of the system.

In Section 2 is shown the forecasted demand used as the mix of RIs for the period, the total number of resources' hours consumption, also in percentages, and its associated costs by labor group for every RI, and the total UVC for every RI.

Section 3 shows a complete set of resources' information:

1. Number of resources by group and specialty in the Depot.
2. AD rates associated to PC and MC for every resource.
3. Practical, used and unused capacities in hours, percentages and costs associated for every resource. This information allows detecting the system's CCR.
4. The work load of every resource according to Figure 11, the information if the resource is positioned within the range of 10 or 20 percent from the mean of the resources' load, and the total amount of resources between those ranges for the whole system.
5. The total costs of used and unused PC and MC for every resource.
6. OEs, RMs and total costs spent in the system for processing the RIs mix chosen.

Exercising the Model.

Experimental Design Layout – Data Arrangement.

There has been detected that the model's response is sensitive to changes in the following factors or IVs:

1. Approach used (ABC, TOC 1, or TOC 2).
2. IL.
3. HL.
4. Number of aircraft (NAirc) in the site.
5. Number of RITs (NRITs) per aircraft.
6. RT for each RIT.
7. Relationship RM/UVC (RM%) for each RIT.

All these factors with the exception of "approach" can take continuous values. The experimental design will consist in two steps.

Data arrangement for determining main factors. In the first step the data will be arranged to determine which the main factors that influence the system's response are. The fact that each individual factor can be treated at different levels persuades the researcher in developing a full factorial Experimental Design (ED). Instead, it is decided to perform a "fractional" factorial ED (Neter and others, 1996:1264). For this purpose a Base Situation (BS) composed by reasonable medium values for every factor is defined based on expertise opinion and personal experience and from this based situation every factor is varied independently one at a time determining a reduced number of treatment known as fractional ED. Table 1 shows a scheme of the 9 possible treatments for the model under a LB workload.

Each combination is considered a treatment for the model. The system will also be exercised under the same configuration but for work load situations LU, HB, and HU. The total amount of treatments to exercise the model will be 36. Within every treatment the model will provide 3 different responses (paired data) AA, AA/TUVC and AA/System's Total Costs (STC) as functions of the number of RIs in the mix (NRIM). The number of data points in every set of data pair will coincide with the feasible number of items possible to be repaired in the period that is determine by the D's labor resources availability.

Table 1. Experimental Design Layout

Load Intensity	Load Homogeneousity	Approach	No Aircraft	No RITs	Repair Time	RM/UVC (%)
L	**B**	**ABC**	**16**	**3**	**4**	**50%**
L	**B**	**TOC 1**	**16**	**3**	**4**	**50%**
L	**B**	**TOC 2**	**16**	**3**	**4**	**50%**
L	B	ABC	**24**	3	4	50%
L	B	TOC 1	**24**	3	4	50%
L	B	TOC 2	**24**	3	4	50%
L	B	ABC	**8**	3	4	50%
L	B	TOC 1	**8**	3	4	50%
L	B	TOC 2	**8**	3	4	50%
L	B	ABC	16	**4**	4	50%
L	B	TOC 1	16	**4**	4	50%
L	B	TOC 2	16	**4**	4	50%
L	B	ABC	16	**2**	4	50%
L	B	TOC 1	16	**2**	4	50%
L	B	TOC 2	16	**2**	4	50%
L	B	ABC	16	3	**8**	50%
L	B	TOC 1	16	3	**8**	50%
L	B	TOC 2	16	3	**8**	50%
L	B	ABC	16	3	**2**	50%
L	B	TOC 1	16	3	**2**	50%
L	B	TOC 2	16	3	**2**	50%
L	B	ABC	16	3	4	**25%**
L	B	TOC 1	16	3	4	**25%**
L	B	TOC 2	16	3	4	**25%**
L	B	ABC	16	3	4	**75%**
L	B	TOC 1	16	3	4	**75%**
L	B	TOC 2	16	3	4	**75%**

Data arrangement for determining differences between approaches. After defining the main factors that influence system's responses, the number of treatment for the model will be reduced. Within each of the reduced treatments every set of data pair AA – NRIM under ABC, TOC 1, and TOC 2 approaches will be arranged separately in order to determine the approach that maximizes the system's responses.

System's Response Data Collection.

There are two groups of system's responses the researcher wants to collect:

1. AA obtained under ABC, TOC 1, and TOC 2 approaches as a function of the NRIM selected.

2. The rates AA/TUVC (ABC approach) and AA/STC (TOC rationale) in the period. These measures, referred as BFB in Chapter 2, are the most representative for managers since they are measuring the rate at which the system is reaching its purpose per unit of dollar spent.

The data for developing the AA curves and the rates AA/TUVC and AA/STC as a function of the NRIM will be collected for each treatment in the ED (Table 1) according to the procedure shown in Table A-7 that calculates the system's AA as the product of individual AAs based on every item's SL reached after repairing an additional unit. Table A-7 shows values of AA, TUVC and STC.

TUVC are computed under the ABC approaches that claims all costs as variable in the time frame. On the other hand, STC under the rationale of TOC are OE, considered fixed costs in the RR, plus RM costs deemed the only UVC in the period in accordance with the NRIM.

Visual comparisons will include in separate graphs the responses AA and AA/TUVC (ABC approach) on the one hand, and on the other hand AA and AA/STC (TOC rationale).

Section 3 – Experimental Design – Data Treatment

Main Factor Determination.

For the purpose of determining the main factors that influence the response of the system, the researcher will use the metric AA. Within each treatment the system's responses is composed by a set of pair data AA-number of RIs in the mix depicting a logistic curve.

Instead of performing an analysis of variance in a factorial experimental design for comparison of means values, visual examination from the responses suggests using a first order regression model to predict the system's response AA. Regression techniques are specifically designed for experimental data in which the levels of the predictor variables are fixed by the investigator (Kachigan, 1991:160).

Variable Definition for the Regression Model.

The dependent variable (DV) that represents the system's response is AA. The IVs for the model are as follows:

1. NRITs in the mix. IV "Step".
2. NAirc in the site.
3. NRITs per aircraft.
4. RT for each RIT.
5. Relationship RM/UVC (RM%) for each RIT.
6. Approaches. This variable can take the values ABC, TOC 1 and TOC 2.
7. IL. This variable can take the levels H and L.
8. HL. This variable can take the values B and U.

Fitting the model.

Every quantitative IV will have one variable associated in the regression model while each qualitative variable with "c" classes or levels will have "c-1" indicator variables, each taking the values 0 and 1 (Neter and others, 1996:456). Therefore, the regression model proposed will have 5 variable associated to the independent variables and 4 "indicator variables" variables associated to the qualitative IVs.

The first-order regression model proposed without interactions is:

$$Y_i = \beta_0 \times X_{i0} + \beta_1 \times X_{i1} + \beta_2 \times X_{i2} + ...\beta_9 \times X_{i9} + \varepsilon_i \qquad (24)$$

Where Y_i = AA data points obtained for every approach (DV or response).

$\beta_0, \beta_1, \beta_2, ...\beta_9$ = the coefficients for the regression model.

X_{i0} = 1.

$X_{i1}...X_{i5}$ = the quantitative IVs in the regression model.

$X_{i6}...X_{i9}$ = The indicators variables for the regression model.

ε_i = The error for every data point of the regression line.

In order to test significant differences between levels of qualitative variables and quantitative variables, the researcher will test whether or not some of the the β_i coefficients are equal to cero. For this purpose it is used the following F test statistic (Neter and others, 1996:268):

$$F^* = \frac{SSE(R) - SSE(F)}{df_R - df_F} - \frac{SSE(F)}{df_F} \qquad (25)$$

Where F^* = F test statistics.

SSE = Error sum of squares.

R = Reduced model.

F = Full model.

df = Degree of freedom.

Optimal Approach Selection.

The procedure to be used will consist on a comparison of the AA and AA/STC responses for a reduced number of treatments defined after dismissing those factors that do not contribute significantly to explain the variation in responses.

The comparison will be conducted performing the Friedman's Test for a Randomized Block Experiment using as the block variable the NRITs in the mix and as treatment effects the approaches ABC, TOC 1, and TOC 2. The Friedman's test statistic measures the discrepancy between the expected value (I+1)/2 of each rank average and the rank averages for each of the treatments $\bar{r}_{i.}$'s. (Devore, 2000:673):

$$F_r = (\frac{12 \times J}{I \times J \times (I+1)})^2 \times \sum R_{i.}^2 - 3 \times J \times (I+1) \qquad (26)$$

Where F_r = Friedman's test statistics.

I = The number of treatments (ABC, TOC 1, and TOC 2).

J = The number of blocks. In this case the NRITs.

The statistics shown in equation 26 determines if significant differences exists between the approaches considered. However, comparisons between two particular treatments (ranks of each approach) are made comparing their rank sums and the second term of equation 27.

$$\left|R_i - R_j\right| \leq z \times \sqrt{\frac{k \times n \times (n+1)}{6}} \qquad (27)$$

Where R_{i-j} = Rank sums of responses for each treatment.

z = The quantile point of a normal curve that corresponds to a right-tail probability of $\alpha / n \times (n-1)$.

n = Number of treatments (ABC, TOC 1, and TOC 2).

K = Number of blocks. In this case the NRITs.

All pair of differences of columns sums that are larger than the right-hand side of equation 27 are deemed significant different pairs (Gibbons, 1976:313).

Summary

The chapter has described the methodology to develop an integrative model to connect the ABC, TOC and AAM rationales to determine the mix of RIs at Depot level under the approaches ABC, TOC 1, and TOC 2 in order to maximize the performance of the system. The model also provides most of the relevant information of the system so that managers can control the usage of the resources, determine the system's CCR and also plan the requirements of resources in advance according to the forecasted demand of RIs for the period.

The chapter also described the factors that impact the performance of the system and the treatments to exercise the model according to a fractional ED to determine in the next chapter in a first stage which are the main factors impacting the system's response and in a second stage if differences in system's performances are detected under the different approaches ABC, TOC 1 and TOC 2.

IV. Results and Analysis

Introduction

The chapter is divided into 3 sections. In the first section the researcher determines the main factors that affect the responses AA and AA/STC of the system. A linear regression model is fitted in the purpose of determining which factors impact the responses significantly. In section 2 system's responses for a reduced set of treatments are compared under ABC , TOC 1 and TOC 2 approaches for the purpose of determining significant differences in responses across approaches and pinpointing which approach gives managers the highest values for the performance metrics selected. Section 3 provides a visual analysis of the impact caused by the main factors on the metrics AA, AA/TUVC, and AA/STC.

Section 1 – Main Factors Determination

In Chapter 3 8 possible factors were defined to exercise the model. The system's responses AA, AA/STC, and AA/TUVC from the factor combinations defined in the fractional factorial ED (36 treatments) in Chapter 3 Section 2 "Exercising the Model" are shown in Appendix B.

The linear regression model estimates the responses of the system with respect to the metrics AA and AA/STC. The purpose of this section is to determine the main factors that are statistically significant in estimating the performance of the system.

Aircraft Availability.

Full Model.

In this regression all factors are considered without interactions to determine which of them contribute significantly to explain the system's response. Figure 14 shows the set up for the regression model for the metric AA in the software JMP 5.

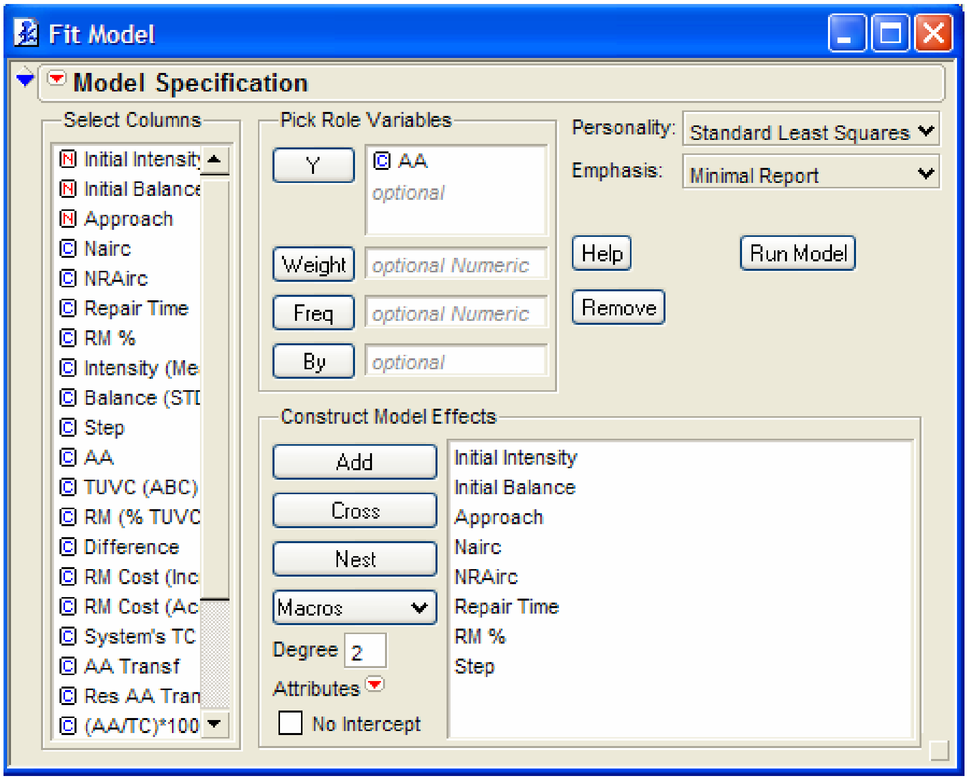


Figure 14. Setup of the Regression Model (AA - Full Model).

Table 2 shows the summary of fit and the analysis of variance for AA. The number of observations (data points for AA) are 7404 and the Adjusted R^2 = .8771, which means that the model proposed is explaining 87.7% of the variance in the response of the system. The p value for the test statistics (Prob > F = 0.0000) suggests that the model has an acceptable statistical significance.

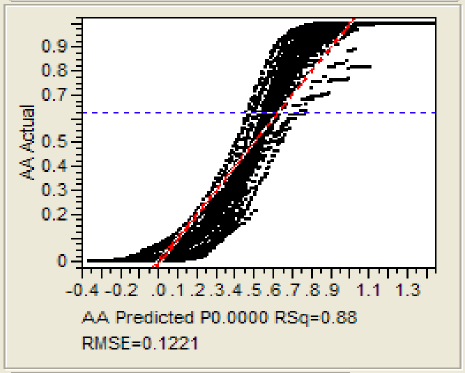
The parameters estimates in Table 3 show the relative influence of every parameter in explaining AA. It also shows that the parameters NRAirc and RM% are not statistically significant, at level of significance $\alpha = .01$.

Table 2. Summary of Fit for AA (Full Model).

Response AA

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.877105
RSquare Adj	0.876955
Root Mean Square Error	0.122134
Mean of Response	0.626449
Observations (or Sum Wgts)	7404

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	9	787.16840	87.4632	5863.459
Error	7394	110.29369	0.0149	Prob > F
C. Total	7403	897.46209		0.0000

Table 3. Parameters Estimates for AA (Full Model).

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.398541	0.013398	29.75	<.0001
Initial Intensity[H]	-0.102991	0.001419	-72.56	0.0000
Initial Balance[B]	-0.036137	0.001428	-25.31	<.0001
Approach[ABC]	0.004881	0.002001	2.44	0.0147
Approach[TOC 1]	-0.007717	0.001993	-3.87	0.0001
Nairc	0.0127197	0.000378	33.68	<.0001
NRAirc	0.0044224	0.003021	1.46	0.1433
Repair Time	-0.105704	0.000958	-110.4	0.0000
RM %	-0.001283	0.012086	-0.11	0.9155
Step	0.013188	0.000071	185.43	0.0000

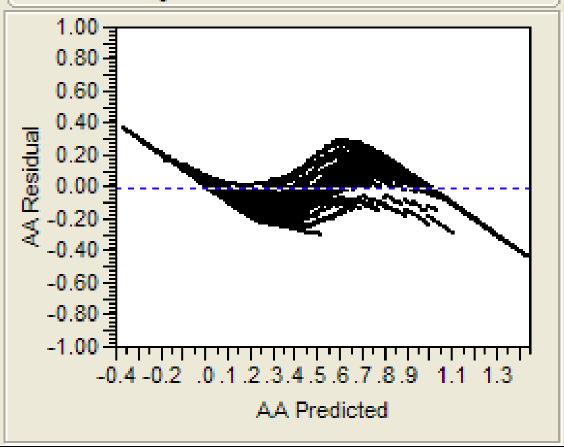
The effect tests in Table 4 confirm the factors that contribute significantly to explain the variance in responses. The residual plot shows a violation of the linear assumption and equivariance in the regression model. However, the values of the residuals are small in comparison with possible values for AA. Although the linear regression is relatively robust to departures from normality and homoscedasticity, a non parametric test will be required for strong conclusions regarding the selection of the best approach. On the other hand, the regression model is suitable for the initial purpose of determining which factors show the greatest explanatory power with respect to the outcome variables.

Table 4. Effects Tests and Residuals Plots for AA (Full Model).

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Initial Intensity	1	1	78.52854	5264.49	0.0000
Initial Balance	1	1	9.55452	640.5275	<.0001
Approach	2	2	0.23009	7.7127	0.0005
Nairc	1	1	16.91940	1134.263	<.0001
NRAirc	1	1	0.03196	2.1424	0.1433
Repair Time	1	1	181.77244	12185.88	0.0000
RM %	1	1	0.00017	0.0113	0.9155
Step	1	1	512.91628	34385.49	0.0000

Residual by Predicted Plot



Reduced Model.

The predictors NRAirc and RM% will be dismissed since they are not statistically significant in explaining the responses of the system. The fit of a "reduced model" with factors statistically significant and interaction is shown in Figure 15.

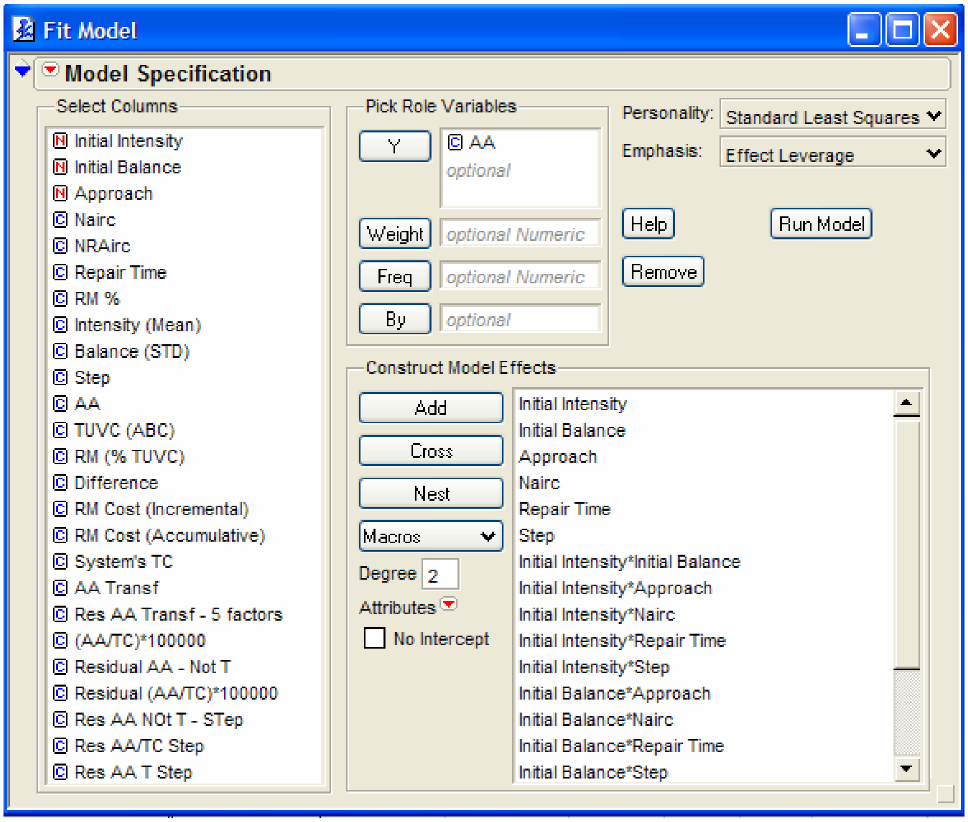


Figure 15. Setup of the Regression Model (AA - Reduced Model).

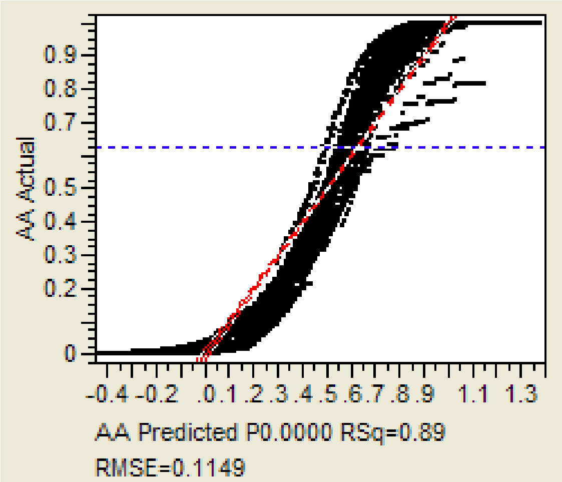
The results after fitting the reduced model for AA are shown in Tables 5, 6, and 7. Table 5 shows the summary of fit and the analysis of variance for AA. This model exhibits the same failures to the assumptions of the statistical test of the previous model. The number of observations (data points for AA) are 7404 and the Adjusted R^2 = .891 which means that the proposed model is explaining 89.10 % of the variance in the response of the system, more variance than in the case of the full model since fewer degrees of freedom are lost using fewer factors.

Table 5. Summary of Fit for AA (Reduced Model).

Response AA

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.891466
RSquare Adj	0.891083
Root Mean Square Error	0.114908
Mean of Response	0.626449
Observations (or Sum Wgts)	7404

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	26	800.05669	30.7714	2330.473
Error	7377	97.40540	0.0132	Prob > F
C. Total	7403	897.46209		0.0000

The parameters estimates in Table 6 show the relative influence of every parameter in explaining AA. The important parameters appear to be RT, IL, HL, NAirc, and Approach.

Table 6. Parameters Estimates for AA (Reduced Model).

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.4110821	0.007364	55.82	0.0000
Initial Intensity[H]	-0.103333	0.001338	-77.20	0.0000
Initial Balance[B]	-0.036218	0.001345	-26.94	<.0001
Approach[ABC]	0.0048397	0.001888	2.56	0.0104
Approach[TOC 1]	-0.007826	0.00188	-4.16	<.0001
Nairc	0.0126217	0.000356	35.43	<.0001
Repair Time	-0.105514	0.000904	-116.7	0.0000
Step	0.0132249	0.000068	193.91	0.0000
Initial Intensity[H]*Initial Balance[B]	0.0039782	0.001343	2.96	0.0031
Initial Intensity[H]*Approach[ABC]	0.0020807	0.001883	1.11	0.2692
Initial Intensity[H]*Approach[TOC 1]	0.003435	0.001876	1.83	0.0671
Initial Intensity[H]*(Nairc-16)	0.0020327	0.000355	5.72	<.0001
Initial Intensity[H]*(Repair Time-4.23231)	-0.016192	0.000901	-17.97	<.0001
Initial Intensity[H]*(Step-34.9481)	0.000775	0.000067	11.58	<.0001
Initial Balance[B]*Approach[ABC]	0.0012591	0.001895	0.66	0.5065
Initial Balance[B]*Approach[TOC 1]	0.0046296	0.001887	2.45	0.0142
Initial Balance[B]*(Nairc-16)	0.0006643	0.000358	1.86	0.0633
Initial Balance[B]*(Repair Time-4.23231)	-0.003784	0.000909	-4.16	<.0001
Initial Balance[B]*(Step-34.9481)	-0.000146	0.000068	-2.15	0.0318
Approach[ABC]*(Nairc-16)	-0.000504	0.000501	-1.01	0.3142
Approach[TOC 1]*(Nairc-16)	-0.000166	0.000499	-0.33	0.7392
Approach[ABC]*(Repair Time-4.23231)	0.0012275	0.001269	0.97	0.3336
Approach[TOC 1]*(Repair Time-4.23231)	0.0000876	0.001263	0.07	0.9447
Approach[ABC]*(Step-34.9481)	0.0000996	0.000094	1.06	0.2891
Approach[TOC 1]*(Step-34.9481)	-0.000039	0.000093	-0.42	0.6718
(Nairc-16)*(Step-34.9481)	-0.000365	0.000018	-20.32	<.0001
(Repair Time-4.23231)*(Step-34.9481)	-0.000117	0.000044	-2.64	0.0084

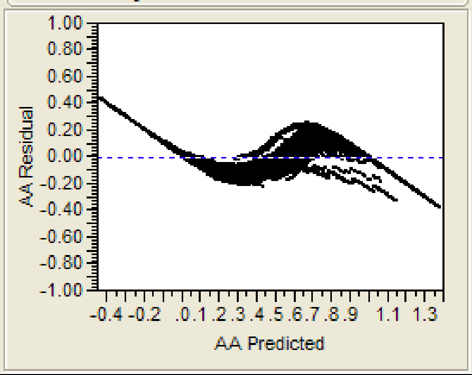
The effects tests shown in Table 7 confirm that all included the parameters (given the violation of the assumptions) are statistically significant at level of significance $\alpha = .01$. The residual plot shows a violation of the assumptions in the regression model but the same considerations made for the residual plot under the full model apply. The regression model is suitable for the limited purpose of determining the factors that are statistically significant.

Table 7. Effects Tests and Residuals Plots for AA (Reduced Model).

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Initial Intensity	1	1	78.69826	5960.214	0.0000
Initial Balance	1	1	9.57954	725.5069	<.0001
Approach	2	2	0.23428	8.8716	0.0001
Nairc	1	1	16.57859	1255.58	<.0001
Repair Time	1	1	179.91421	13625.81	0.0000
Step	1	1	496.49759	37602.26	0.0000
Initial Intensity*Initial Balance	1	1	0.11578	8.7682	0.0031
Initial Intensity*Approach	2	2	0.11183	4.2347	0.0145
Initial Intensity*Nairc	1	1	0.43196	32.7148	<.0001
Initial Intensity*Repair Time	1	1	4.26390	322.9267	<.0001
Initial Intensity*Step	1	1	1.76982	134.0376	<.0001
Initial Balance*Approach	2	2	0.13816	5.2319	0.0054
Initial Balance*Nairc	1	1	0.04555	3.4494	0.0633
Initial Balance*Repair Time	1	1	0.22890	17.3356	<.0001
Initial Balance*Step	1	1	0.06088	4.6109	0.0318
Approach*Nairc	2	2	0.02486	0.9412	0.3902
Approach*Repair Time	2	2	0.01707	0.6466	0.5239
Approach*Step	2	2	0.01487	0.5631	0.5695
Nairc*Step	1	1	5.45172	412.8864	<.0001
Repair Time*Step	1	1	0.09185	6.9560	0.0084

Residual by Predicted Plot



AA / STC.

<u>Full Model.</u>

This regression fits a linear model considering all factors without interactions to estimate the system's response AA/STC as previously accomplished for AA alone. Figure 16 shows the set up for the regression model in the software JMP 5.

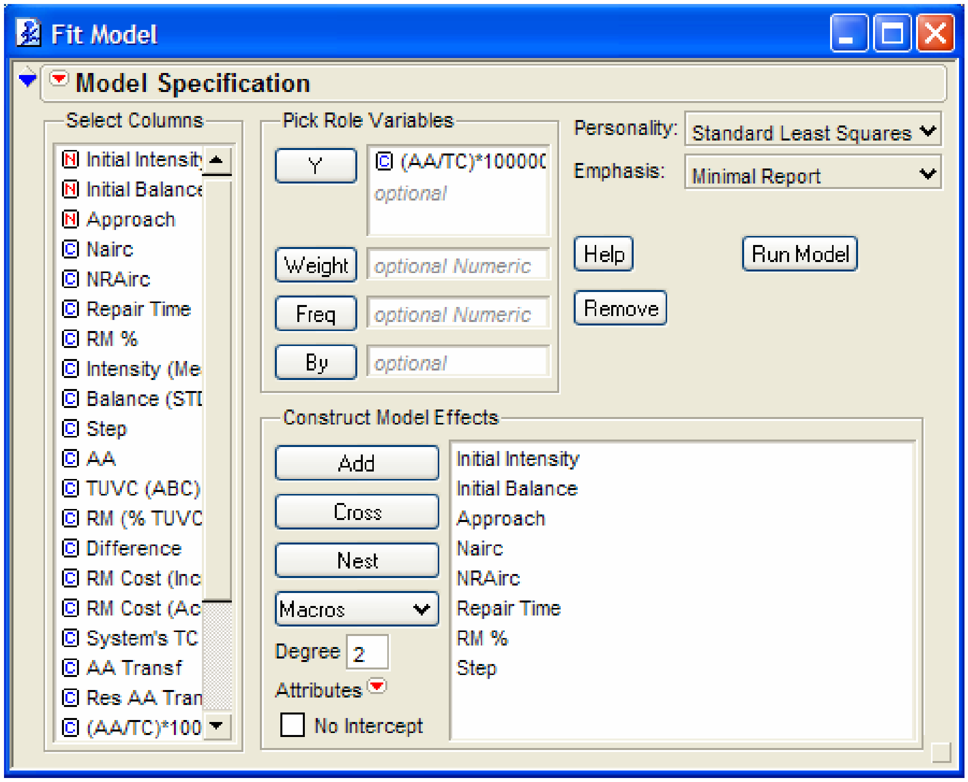


Figure 16. Setup of the Regression Model (AA/STC - Full Model).

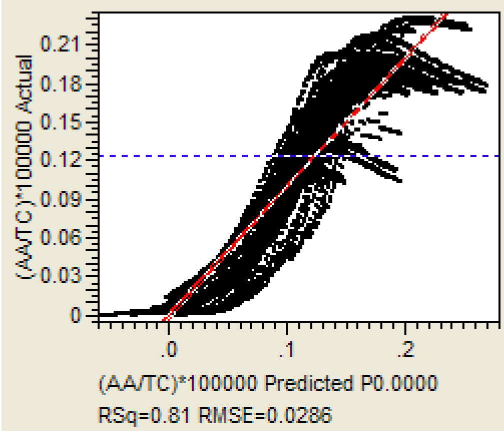
Table 8 shows the summary of fit and the analysis of variance for AA. The number of observations (data points for AA) are 7404 and the Adjusted R^2 = .813 which means that the model proposed is explaining 81.30 % of the variance in the response of the system. The p value for the test statistics (Prob > F = 0.0000) suggests that the model may have an acceptable statistical significance (given the failure to satisfy the assumptions of the statistical test used).

The parameter estimates in Table 9 show the approximate influence of each parameter in explaining AA/STC and also that the parameter NRAirc is the only one not statistically significant. The factor RM% now is statistically significant since the metric itself includes STC in the influence of this factor.

Table 8. Summary of Fit for AA/STC (Full Model).

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.813256
RSquare Adj	0.813028
Root Mean Square Error	0.028597
Mean of Response	0.12417
Observations (or Sum Wgts)	7404

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	9	26.332469	2.92583	3577.802
Error	7394	6.046613	0.00082	Prob > F
C. Total	7403	32.379083		0.0000

Table 9. Parameters Estimates for AA/STC (Full Model).

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.1559081	0.003137	49.70	0.0000
Initial Intensity[H]	-0.022254	0.000332	-66.96	0.0000
Initial Balance[B]	-0.007599	0.000334	-22.73	<.0001
Approach[ABC]	0.0011265	0.000469	2.40	0.0162
Approach[TOC 1]	-0.001345	0.000467	-2.88	0.0040
Nairc	0.0028614	0.000088	32.36	<.0001
NRAirc	0.001045	0.000707	1.48	0.1397
Repair Time	-0.021874	0.000224	-97.56	0.0000
RM %	-0.119765	0.00283	-42.32	0.0000
Step	0.0020649	0.000017	124.00	0.0000

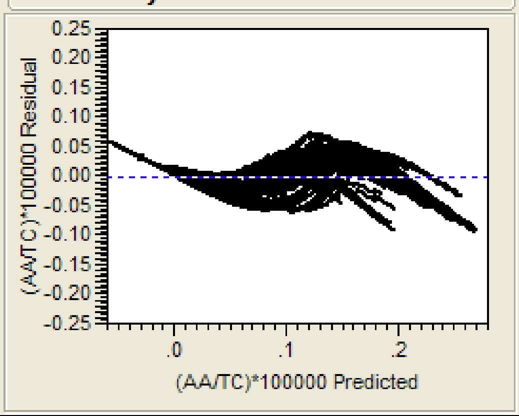
The effects tests in Table 10 confirm the factors that contribute significantly to explain the variance in responses. The residual plot shows a violation of the linear assumption and equivariance in the regression model. However, the values of the residuals are small in comparison to the possible values for AA/STC. Although the linear regression is relatively robust to departures from normality and homoscedasticity, a non parametric test will be required for strong conclusions regarding the selection of the best approach. On the other hand, the regression model is suitable for the initial purpose of determining which factors show the greatest explanatory power with respect to the outcome variables.

Table 10. Effects Tests and Residuals Plots for AA/STC (Full Model).

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Initial Intensity	1	1	3.666286	4483.256	0.0000
Initial Balance	1	1	0.422527	516.6802	<.0001
Approach	2	2	0.007899	4.8296	0.0080
Nairc	1	1	0.856208	1047	<.0001
NRAirc	1	1	0.001784	2.1819	0.1397
Repair Time	1	1	7.783890	9518.4	0.0000
RM %	1	1	1.464848	1791.265	0.0000
Step	1	1	12.573871	15375.75	0.0000

Residual by Predicted Plot



Reduced Model.

The predictor NRAirc is dismissed since it is not statistically significant in explaining the responses of the system. The set up for a "reduced model" with factors statistically significant and interaction is shown in Figure 17.

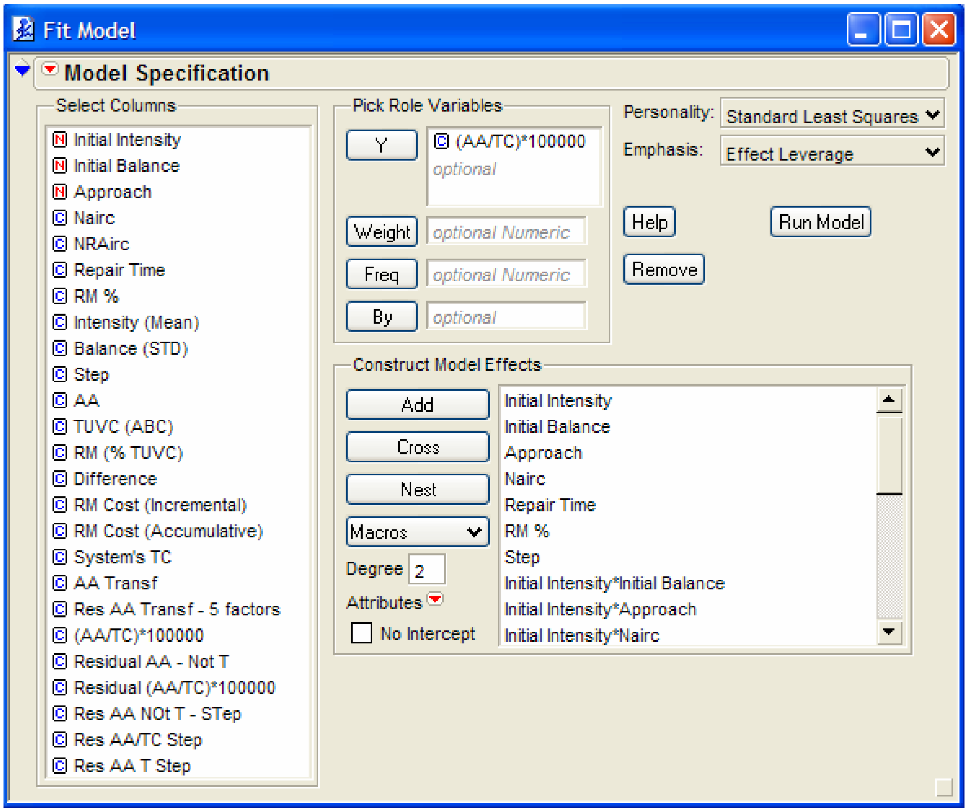


Figure 17. Setup of the Regression Model (AA/STC - Reduced Model).

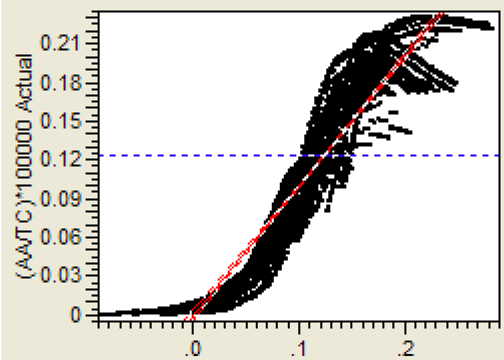
The results after fitting the reduced model for AA/STC are shown in Tables 11, 12, and 13. Table 11 shows the summary of fit and the analysis of variance for AA/STC. The number of observations (data points for AA) are 7404 and the Adjusted R^2 = .8549 which means that the model proposed is explaining 85.49 % of the variance in the response of the system. The p value for the test statistics (Prob > F = 0.0000) suggests that the reduced model has an acceptable statistical significance (given the violations of the statistical test used).

Table 11. Summary of Fit for AA/STC (Reduced Model).

Response (AA/TC)*100000

Whole Model

Actual by Predicted Plot



(AA/TC)*100000 Predicted P0.0000
RSq=0.86 RMSE=0.0252

Summary of Fit

RSquare	0.855559
RSquare Adj	0.854932
Root Mean Square Error	0.025189
Mean of Response	0.12417
Observations (or Sum Wgts)	7404

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	32	27.702225	0.865695	1364.385
Error	7371	4.676857	0.000634	Prob > F
C. Total	7403	32.379083		0.0000

The parameter estimates in Table 12 show the relative influence of every parameter in explaining AA/STC. The important parameters are now RM%, IL, RT, HL, NAirc, and Approach.

The effects tests shown in Table 13 suggest that all the parameters are statistically significant. The residual plot shows a violation of the linear assumption in the regression model but the same considerations made for the residual plot under the full model apply. The regression model is suitable for the limited purpose of determining the factors that are significant.

Table 12. Parameters Estimates for AA/STC (Reduced Model).

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.1600813	0.002041	78.42	0.0000
Initial Intensity[H]	-0.022353	0.000293	-76.18	0.0000
Initial Balance[B]	-0.007627	0.000295	-25.88	<.0001
Approach[ABC]	0.0010935	0.000414	2.64	0.0082
Approach[TOC 1]	-0.001421	0.000412	-3.45	0.0006
Nairc	0.0028349	0.000078	36.31	<.0001
Repair Time	-0.021884	0.000198	-110.4	0.0000
RM %	-0.121121	0.002499	-48.47	0.0000
Step	0.0020694	0.000015	138.42	0.0000
Initial Intensity[H]*Initial Balance[B]	0.0011544	0.000295	3.92	<.0001
Initial Intensity[H]*Approach[ABC]	0.0002851	0.000413	0.69	0.4898
Initial Intensity[H]*Approach[TOC 1]	0.0005537	0.000411	1.35	0.1782
Initial Intensity[H]*(Nairc-16)	0.0003644	0.000078	4.68	<.0001
Initial Intensity[H]*(Repair Time-4.23231)	-0.002776	0.000198	-14.05	<.0001
Initial Intensity[H]*(RM %-0.5)	0.0126395	0.002493	5.07	<.0001
Initial Intensity[H]*(Step-34.9481)	0.0002341	0.000015	15.95	<.0001
Initial Balance[B]*Approach[ABC]	0.0002243	0.000415	0.54	0.5893
Initial Balance[B]*Approach[TOC 1]	0.0009244	0.000414	2.23	0.0255
Initial Balance[B]*(Nairc-16)	0.0001493	0.000078	1.90	0.0570
Initial Balance[B]*(Repair Time-4.23231)	-0.000774	0.000199	-3.89	0.0001
Initial Balance[B]*(RM %-0.5)	0.0069482	0.002509	2.77	0.0056
Initial Balance[B]*(Step-34.9481)	-0.000019	0.000015	-1.31	0.1901
Approach[ABC]*(Nairc-16)	-0.000083	0.00011	-0.76	0.4493
Approach[TOC 1]*(Nairc-16)	-0.000006	0.000109	-0.05	0.9573
Approach[ABC]*(Repair Time-4.23231)	0.0001766	0.000278	0.63	0.5257
Approach[TOC 1]*(Repair Time-4.23231)	-0.000054	0.000277	-0.20	0.8448
Approach[ABC]*(RM %-0.5)	0.0000553	0.003515	0.02	0.9874
Approach[TOC 1]*(RM %-0.5)	0.0026158	0.003501	0.75	0.4551
Approach[ABC]*(Step-34.9481)	0.0000105	0.000021	0.51	0.6107
Approach[TOC 1]*(Step-34.9481)	-0.000015	0.00002	-0.75	0.4553
(Nairc-16)*(Step-34.9481)	-0.000091	0.000004	-23.13	<.0001
(Repair Time-4.23231)*(Step-34.9481)	0.0000759	0.00001	7.79	<.0001
(RM %-0.5)*(Step-34.9481)	-0.003977	0.000126	-31.58	<.0001

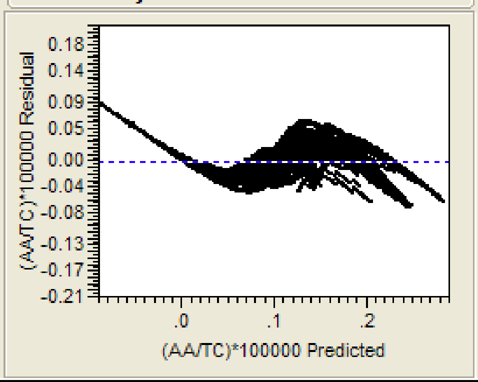
Under the metric AA the factors not significant were NRAirc and RM%, and under the metric AA/STC only NRAirc was not significant. However, at this point our primary metric is AA, and the following analysis consider IL, HL, NAirc and RT as main factors.

Table 13. Effects Tests and Residual Plots for AA/STC (Reduced Model).

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Initial Intensity	1	1	3.682627	5804.034	0.0000
Initial Balance	1	1	0.424820	669.5413	<.0001
Approach	2	2	0.008345	6.5761	0.0014
Nairc	1	1	0.836341	1318.122	<.0001
Repair Time	1	1	7.739483	12197.88	0.0000
RM %	1	1	1.490917	2349.773	0.0000
Step	1	1	12.157441	19160.84	0.0000
Initial Intensity*Initial Balance	1	1	0.009749	15.3650	<.0001
Initial Intensity*Approach	2	2	0.002625	2.0682	0.1265
Initial Intensity*Nairc	1	1	0.013886	21.8848	<.0001
Initial Intensity*Repair Time	1	1	0.125306	197.4895	<.0001
Initial Intensity*RM %	1	1	0.016310	25.7058	<.0001
Initial Intensity*Step	1	1	0.161486	254.5121	<.0001
Initial Balance*Approach	2	2	0.005330	4.2003	0.0150
Initial Balance*Nairc	1	1	0.002300	3.6246	0.0570
Initial Balance*Repair Time	1	1	0.009590	15.1147	0.0001
Initial Balance*RM %	1	1	0.004866	7.6687	0.0056
Initial Balance*Step	1	1	0.001089	1.7168	0.1901
Approach*Nairc	2	2	0.000507	0.3998	0.6705
Approach*Repair Time	2	2	0.000264	0.2084	0.8119
Approach*RM %	2	2	0.000470	0.3707	0.6903
Approach*Step	2	2	0.000379	0.2990	0.7416
Nairc*Step	1	1	0.339499	535.0696	<.0001
Repair Time*Step	1	1	0.038466	60.6248	<.0001
RM %*Step	1	1	0.632737	997.2302	<.0001

Residual by Predicted Plot



Section 2 – Optimal Approach Selection

The purpose of this section is to determine if there are significant differences in system's responses AA and AA/STC when decisions are made under different approaches ABC, TOC 1, and TOC 2. In addition, we are interested in how the model responds under different circumstances that are defined according to the level of the main factors determined in Section 1. Moreover, the purpose of the section is also to determine the best approach for decision making and to define which special circumstances influence the causes for differences in responses due to decision made under different approaches.

We dismiss the factors RM% and RIAirc according to Section 1. The possible treatments for the system under intensity of load “L” and homogeneity of Load “B” are 5 and they are summarized in Table 14. The total number of treatments will ascend to 20 when all possible combinations (4) of intensity and homogeneity of load are considered.

Table 14. Treatments for Comparison of Approaches.

Treatment No	Load Intensity	Load Homogeneity	No Aircraft	Repair Time
1	L	B	16	4
2	L	B	**24**	4
3	L	B	**8**	4
4	L	B	16	**8**
5	L	B	16	**2**

Under each treatment the responses AA and AA/STC will be compared among approaches ABC, TOC 1, and TOC 2 to determine if significant differences exist in responses due to the approach used to decide the mix of RIs in the Depot.

The statistical test used, called the Friedman’s Test, ranks the values for AA and AA/STC across a block variable, in this case the number of RIs in the mix (NRIM), and sum all ranks of the responses to give a final rank value for every approach. Approaches are compared according to their final rank values. The results obtained for every approach and differences of sum ranks among approaches are shown in Table 15 for the metric AA/STC.

Table 15. Comparison of Approaches under Metric AA/STC.

T	IL	HL	Nairc	RT	ABC	TOC 1	TOC 2	ABC - TOC1	ABC - TOC2	TOC1 - TOC2	z value
1	H	B	8	4	**153.5**	122.5	126	**31**	27.5	3.5	27.71
2	H	B	16	2	**164.5**	146.5	91	18	**73.5**	**55.5**	27.71
3	H	B	16	4	153.5	**167.5**	93	14	**60.5**	**74.5**	28.12
4	H	B	16	8	118.5	122.5	**161**	4	**42.5**	**38.5**	27.71
5	H	B	24	4	**162.5**	122.5	117	**40**	**45.5**	5.5	27.71
6	H	U	8	4	**147**	104	115	**43**	**32**	11	26.44
7	H	U	16	2	**155**	128.5	82.5	26.5	**72.5**	**46**	26.44
8	H	U	16	4	115.5	111.5	**187**	4	**71.5**	**75.5**	28.12
9	H	U	16	8	100.5	104.5	**161**	4	**60.5**	**56.5**	26.44
10	H	U	24	4	**150**	103	113	**47**	**37**	10	26.44
11	**L**	B	8	4	**168.5**	136.5	109	**32**	**59.5**	27.5	28.12
12	**L**	B	16	2	**168**	161	85	7	**83**	**76**	28.12
13	**L**	B	16	4	**166.5**	139.5	108	27	**58.5**	**31.5**	28.12
14	**L**	B	16	8	**163**	116	135	**47**	28	19	28.12
15	**L**	B	24	4	**165.5**	140.5	108	25	**57.5**	**32.5**	28.12
16	**L**	U	8	4	**146.5**	113	118.5	**33.5**	**28**	5.5	26.87
17	**L**	U	16	2	**156**	136.5	85.5	19.5	**70.5**	**51**	26.87
18	**L**	U	16	4	**146.5**	117	114.5	**29.5**	**32**	2.5	26.87
19	**L**	**U**	**16**	**8**	**135**	83.5	**159.5**	**51.5**	24.5	**76**	26.87
20	**L**	U	24	4	**143.5**	122	112.5	21.5	**31**	9.5	26.87
					75%	5%	20%	**85%**	**80%**		
								45%	**70%**		

Across all treatments ABC is the approach that gives the best AA/STC 75% of the times, TOC 1 gives the best metric 5% of the times, and TOC 2 is the approach that gives the best AA/STC 20% of the times.

Responses under ABC are also 85% of the times greater than responses under TOC 1 and 45% of the times significantly greater than TOC 1. Moreover, responses under ABC are 80% of the times greater than responses under TOC 2 and 70 % of the times significantly greater than them.

The approach ABC is consistently optimal, getting the first position for IL = L except for the case of RT = 8 weeks in which the TOC 2 approach turns out to obtain the best response as shown in Table 15.

The results obtained evaluating the metric AA are shown in Table 16.

Table 16. Comparison of Approaches under Metric AA.

T	IL	HL	Nairc	RT	ABC	TOC 1	TOC 2	ABC - TOC1	ABC - TOC2	TOC1 - TOC2	z value
1	H	B	8	4	**151.5**	122.5	128	**29**	23.5	5.5	27.71
2	H	B	16	2	**173.5**	132.5	96	**41**	**77.5**	**36.5**	27.71
3	H	B	16	4	**155.5**	153.5	105	2	**50.5**	**48.5**	28.12
4	H	B	16	8	116.5	121.5	**164**	5	**47.5**	**42.5**	27.71
5	H	B	24	4	**157.5**	116.5	128	**41**	**29.5**	11.5	27.71
6	H	U	8	4	**146**	105	115	**41**	**31**	10	26.44
7	H	U	16	2	**159**	117.5	89.5	**41.5**	**69.5**	**28**	26.44
8	H	U	16	4	120.5	101.5	**192**	19	**71.5**	**90.5**	28.12
9	H	U	16	8	99.5	104.5	**162**	5	**62.5**	**57.5**	26.44
10	H	U	24	4	**153**	98	115	**55**	**38**	17	26.42
11	**L**	B	8	4	**170.5**	131.5	112	**39**	**58.5**	19.5	28.12
12	**L**	B	16	2	**177**	148	89	**29**	**88**	**59**	28.12
13	**L**	B	16	4	**169.5**	131.5	113	**38**	**56.5**	18.5	28.12
14	**L**	B	16	8	**157**	112	145	**45**	12	**33**	28.12
15	**L**	B	24	4	**169.5**	131.5	113	**38**	**56.5**	18.5	28.12
16	**L**	U	8	4	**154.5**	99	124.5	**55.5**	**30**	25.5	26.87
17	**L**	U	16	2	**162**	124.5	91.5	**37.5**	**70.5**	**33**	26.87
18	**L**	U	16	4	**154.5**	99	124.5	**55.5**	**30**	25.5	26.87
19	**L**	**U**	**16**	**8**	**132**	78.5	**167.5**	**53.5**	**35.5**	**89**	26.87
20	**L**	U	24	4	**154.5**	99	124.5	**55.5**	**30**	25.5	26.87
					80%	**0%**	**20%**	**90%**	**90%**		
								80%	**80%**		

Across all treatments ABC is the approach that gives the best AA 80% of the times. TOC 1 and TOC 2 give the best response 0% and 20% of the times respectively. Responses under ABC are 90% of the times significantly greater than responses under TOC 1 and 80% significantly greater than those responses. Moreover, responses under ABC are 90% of the times greater than responses under TOC 2 and 80 % of the times significantly greater than them.

The approach ABC, as in the case of the metric AA/STC, is consistently optimal for IL = L except of RT = 8 weeks in which the TOC 2 approach turns out to obtain the best performance as shown in Table 16.

Table 17 shows the precedence of the approaches obtained from the ranking procedure of each approach across all treatments evaluated under the metric AA/STC. As relevant information we emphasize that ABC scores in first position 75 % of the times, TOC 1 scores in first position only 5% of the times and TOC 2 in third position 55 % of the times.

Table 17. Precedence of Approaches Across Treatments – Metric AA/STC.

Metric AA/STC			
Approach	Order		
	First	Second	Third
ABC	**75%**	15%	**10%**
TOC 1	**5%**	60%	**35%**
TOC 2	20%	25%	**55%**

Table 18 shows the precedence of the approaches obtained from the ranking procedure of each approach across all treatments evaluated under the metric AA. As relevant information we emphasizes that ABC scores in first position 80 % of the time, TOC 1 scores in first position only 0% of the time and in third position 50 % of the time.

Table 18. Precedence of Approaches Across Treatments – Metric AA.

Metric AA			
Approach	Order		
	First	Second	Third
ABC	**80%**	10%	10%
TOC 1	**0%**	50%	**50%**
TOC 2	20%	40%	40%

Section 3 – Visual Comparison of Responses

Visual comparisons of the responses will be developed analyzing the following metrics:

1. AA of the system.

2. AA / TUVC as if all the costs of resources were variable in the period, the rationale under the ABC approach.

3. AA / STC of the system. This approach uses the logic under the TOC approach where STC is the sum of OEs, considered fixed in the period, and the RM costs, the only variable costs.

A base situation including only the main factors determined in Section 1 is defined and the comparison will be developed varying one factor at the time from this base situation.

The BS defined is IL = H, HL = B, NAirc = 8 and RT = 4 weeks since it is considered likely for the Depot to operate under these particular conditions.

Metric Analysis.

Visual inspection of the shapes of the curves in Appendix B shows that the metric AA/STC consistently shows a maximum point that suggests an Optimal Operational Point (OOP) for the Depot. At the OOP the Depot will reach its maximum performance in terms of AA/STC, which is measuring the bang for the buck of the whole system.

On the other hand, the shapes of the curves AA/TUVC do not suggest any particular point of operation. Most of the curves show that the metric decreases insofar the number of RIs in the mix increases. Sometimes the metric shows a local optimum in a particular range but at low values for the number of RIs the metric depicts higher values which lead the researcher to consider this metric as a misleading one and to dismiss in the following analysis the consideration of this metric.

The Effect of Number of Aircraft (NAirc)

<u>AA.</u>

Increasing the NAirc in the site the system reaches higher levels of AA at the same number of RIs in the mix. In this analysis the annual aggregate demand is deemed constant and not varying according to the amount of aircraft in the site.

The AA curves under ABC and TOC 1 approaches appear to be the same. The TOC 2 approach is optimal at lower levels of NRIM but it turns out to be sub-optimal for higher values. Moreover, the TOC 2 approach appears to increase its sub-optimality when the NAirc decreases obtaining lower values of AA at particular NRIM repaired.

AA/STC.

This metric reaches a maximum point that suggests an OOP for the Depot that coincides with high values for AA. For values of AA = 97 % the NRIM is 56 and 65 from NAirc = 24, and 8. Figures 18 and 19 show the effects.

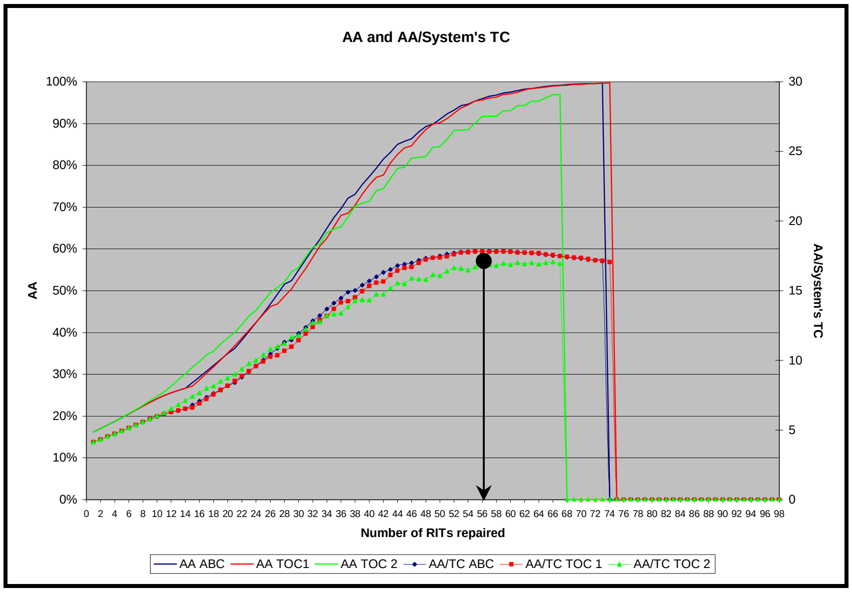


Figure 18 – System Response for NAirc = 24 (High).

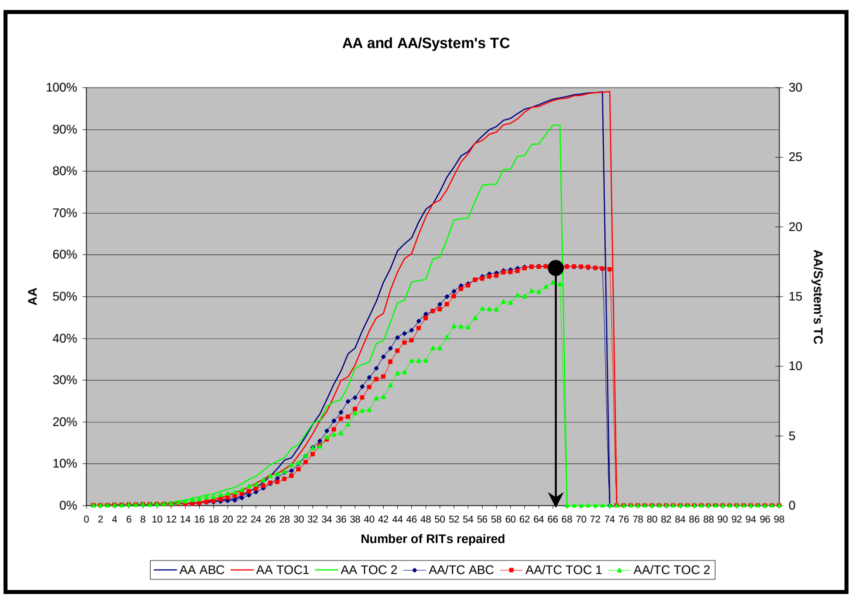


Figure 19 – System Response for NAirc = 8 (Low).

Depot operations at levels of NRIM higher than the suggested OOP should be carefully evaluated by managers since the rate of ROI is decreasing and significant investments in RM will not cause significant improvements in system's AA.

The Effect of Repair Inspections Times (RT).

AA.

This is the factor that visually most influences the response of the system. For low values of RT the system obtains high levels of AA at relatively low values for the NRIM. For RT = 2 at NRITs = 33, the Depot can expect AA values above 95%. On the other hand, for RT = 8 the system reaches its resource constraint for values of AA lower than 60%.

The approach TOC 1 appears to optimize the use of the resource constraint since under this approach the constraint is reached at NRIM = 82 instead of NRIM = 79 under ABC and 68 under TOC 2. Moreover the difference of NRIM at maximum capacity between TOC 1 and ABC increases from 1 to 3 when RT increases from 2 to 8 weeks in average.

AA/STC.

The metric is suggesting an OOP for RT = 2 at NRIM = 33. For RT = 8, the system reaches its constraint while the metric is increasing its values which suggests operating the Depot at its maximum capacity.

For RT = 2 the Depot could operate at low values of NRIM reaching values of AA greater than 95%, which allow managers to plan reallocating resources in advance. Moreover, higher values for RT bring the TOC 2 approach to a very sub-optimal situation in comparison ABC and TOC 1. TOC 2 gets its constraint at NRIM = 68 with an expected AA of less than 25%. Figures 20 and 21 show the effects.

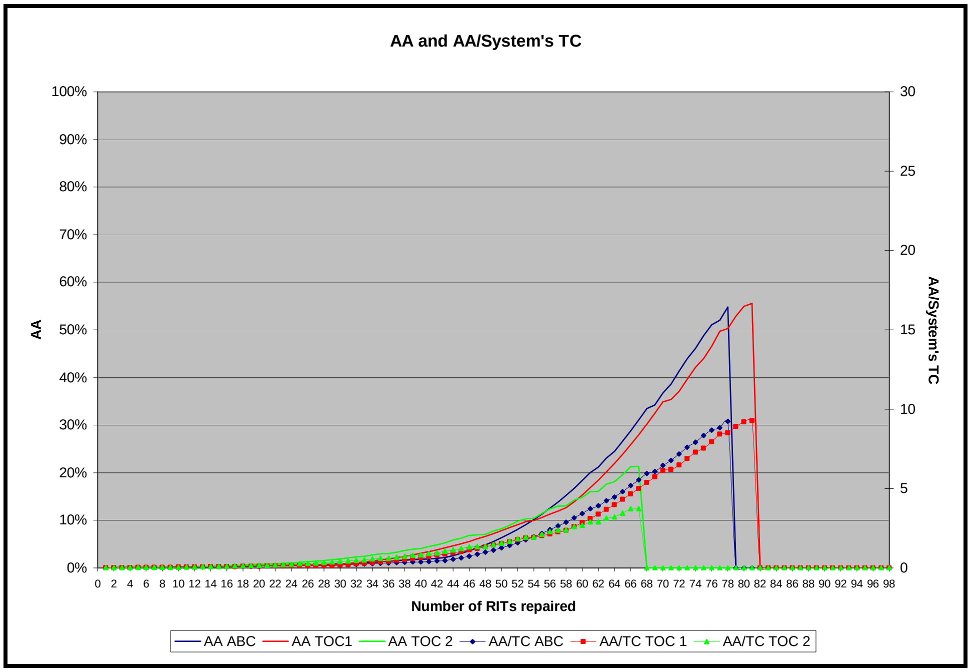


Figure 20 – System Response for RT = 8 (High).

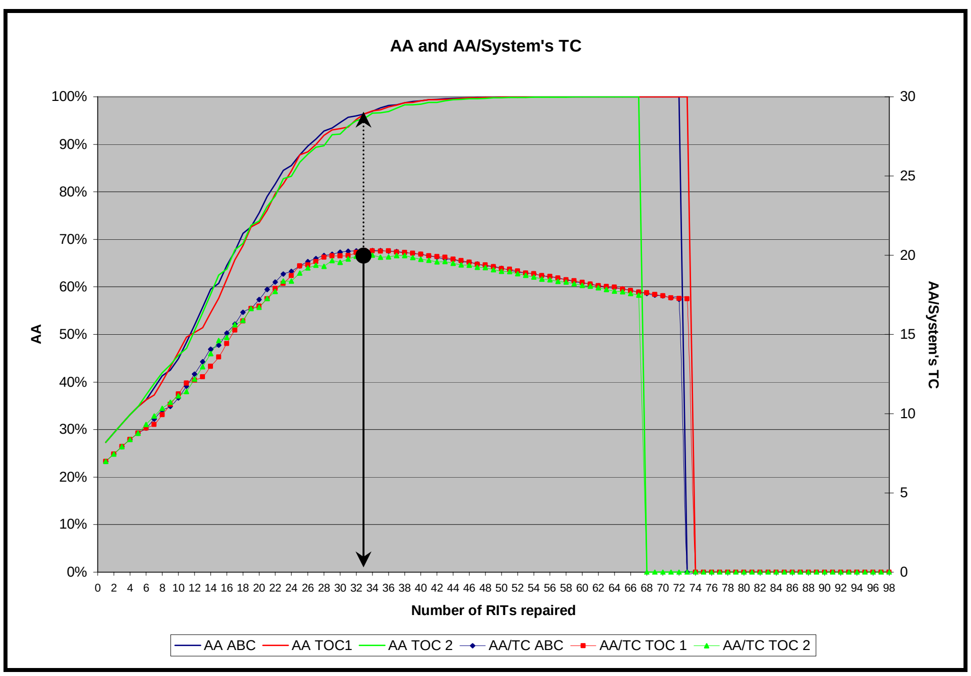


Figure 21 – System Response for RT = 2 (Low).

The Effect of IL.

__*AA.*__

When it is expected the system working at low levels of demand (IL = L) in the period, it reaches high levels of AA at relative low values for NRIM. Figure 23 shows that at NRIM = 42 under all approaches the expected AA for the system is approximately 97%. On the other hand, for high levels of demand forecasted (IL = H) at NRIM = 46, managers should expect AA levels of approximately 80%. Under IL = H values of AA > 95 % requires NRIM = 60 as shown in Figure 22. The approach TOC 2 turns out to be less optimal when the system is load at IL = H at high values for NRIM.

__*AA/STC.*__

The metric is always suggesting OOP for the Depot. On the one hand at intensity "L" the OOP is located at NRITs = 42 and expected AA = 97%. On the other hand for intensity "H" the OOP is located at NRITs = 60 and expected AA = 97%. Figures 22 and 23 show the effects.

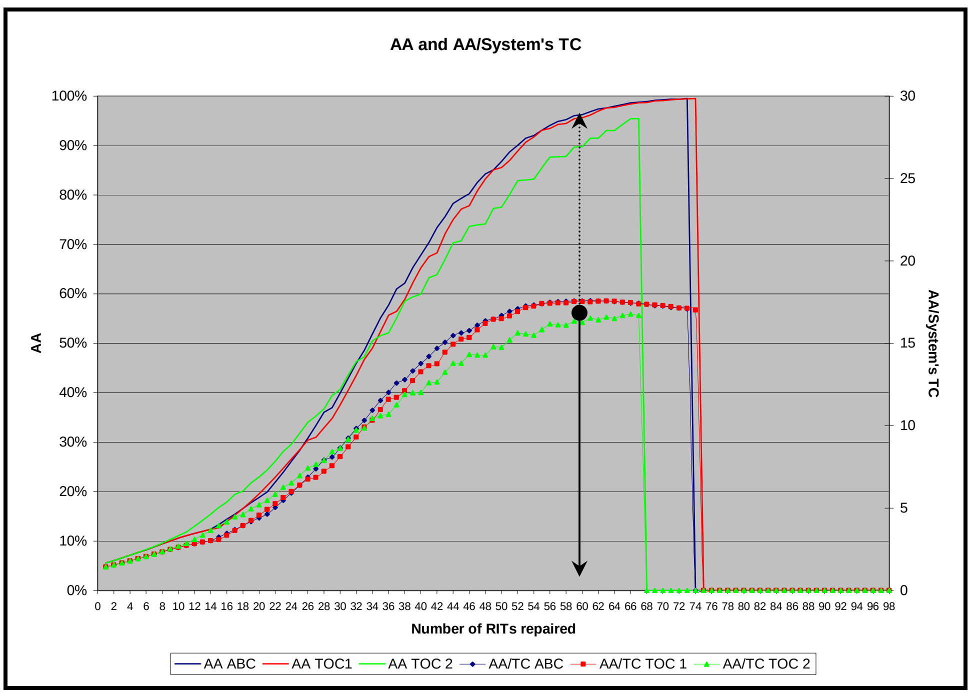


Figure 22– System Response for IL = High.

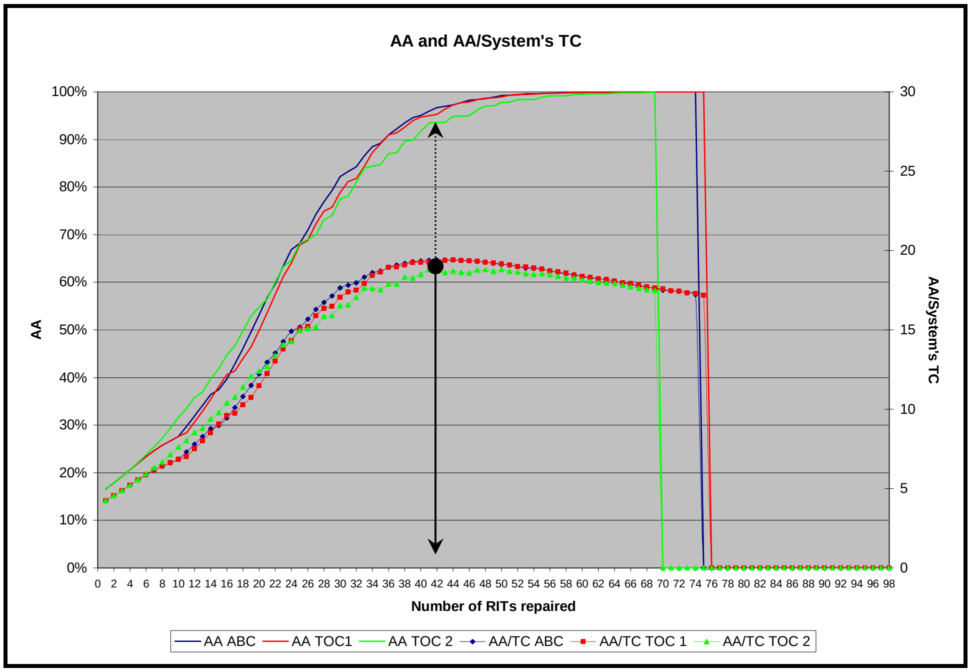


Figure 23 – System Response for IL = Low.

The Effect of HL.

AA.

When the system is unbalanced load it reaches its constraint at lower levels of NRIM than for the case in which the system is balanced loaded. Under the approaches ABC and TOC 1, those that provides better values of expected AA at high NRIM, the system's constraint is reached for HL = B at NRITM = 75 items and for HL = U at NRIM = 66 as shown in Figures 24 and 25. However, the values of AA obtained at the system's constraint turn out to be not significant different since both are approximately 99%.

AA/STC.

This metric is consistently suggesting a Depot OOP. For HL = B the OOP is located at NRIM = 60 and for HL = U at NRIM = 56. The values for AA in both cases are greater than 95 % as it is shown in Figures 24 and 25.

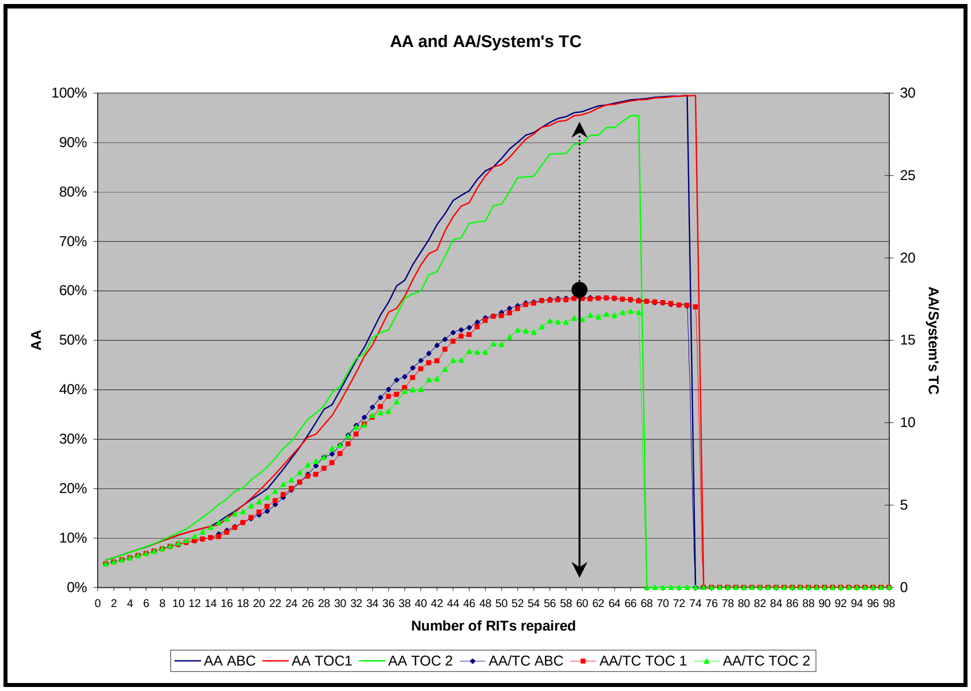


Figure 24 – System Response for HL = Balanced.

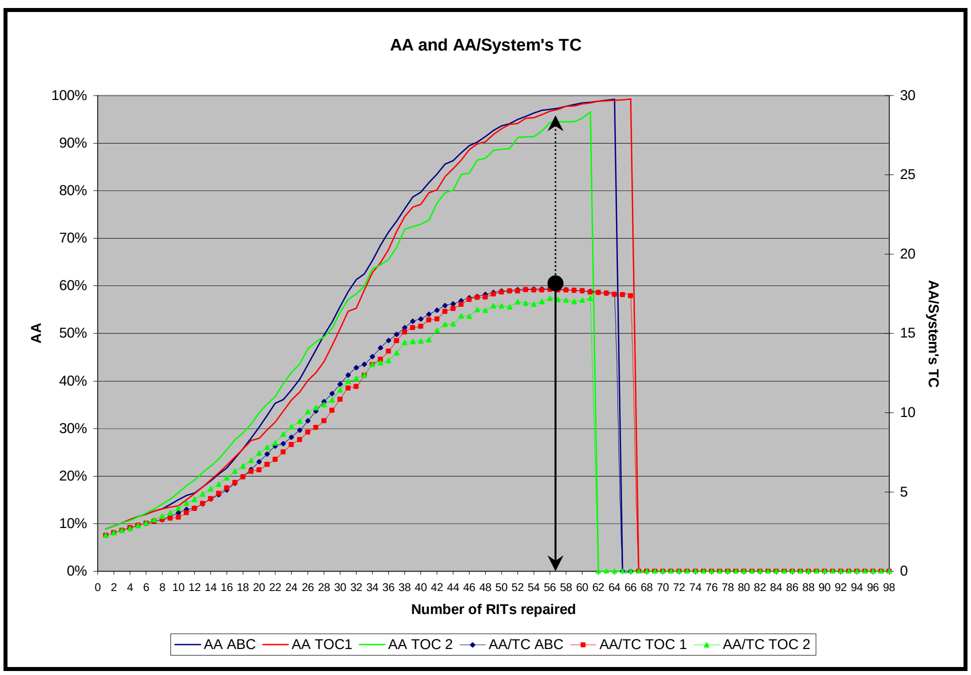


Figure 25 – System Response for HL = Unbalanced.

Summary

The results obtained in Section 1 determined the main factors affecting the metrics AA and AA/STC used to measure the whole performance of the system. The non parametric test for comparison of responses developed under Section 2 gave clear evidence that the Traditional Management Account approach should be used to determine the NRIM to develop the maintenance RIs plan for the future period. Visual comparisons of the shapes of the responses under different levels for the main factors gave enough information to determine the relative impact of main factors on the metrics AA and AA/STC that will allow making conclusions in Chapter 5.

V. Discussion, Conclusions and Recommendations

Introduction

Chapter 4 describes the results obtained in exercising the model under different treatments and gives enough information for making conclusions. This chapter is divided in 3 Sections. In Section 1, conclusions of this research and recommendations for managers are presented. Section 2 describes the managerial implications and the findings of the research. Section 3 opens a vast amount of complementary studies that as future researches could enhance the scope and the implications of the research.

Section 1 - Conclusions and Recommendations

Main Factors Impacting AFMC's Metrics.

According to Chapter 4 the main factors impacting the AFMC's performance are IL, HL, RT, NAIrc, and the type of approach used for the deciding the mix of RITs for developing the AFMC Depot maintenance RIs plan. The impact of approaches in system's responses was separately analyzed thru a rank test procedure. The following discussion will determine the final conclusions for every particular factor.

HL.

The statistical analysis determined that this factor is significant for explaining the performance metrics of the AFMC. The visual analysis has shown that changes in HL (B, U) suggest light differences in the OOP suggested for the Depot (B - NRIM = 62, U – NRITM = 56 for AA = 97%).

The most common situation is to operate the Depot at HL = U since it will be repairing a wide range of RITs that would increase the variance of load posed on the system. Therefore, this research considers this factor NOT RELEVANT.

IL.

This factor has been deemed statistically significant estimating the responses for the system. The visual analysis has also shown that for reaching AA values of 97 % the NRIM for IL = L is less (NRIM = 42) than for IL = H (NRIM = 60).

However, operating the Depot at IL = L is will not be a common situation since managers will allow such a situation and they will reallocate resource in advance so that the Depot operates in an IL = H environment, which leads the researcher to consider this factor as NOT RELEVANT from a practical perspective.

NAirc.

Both statistical and visual analysis has deemed this factor as impacting significantly the system's responses. Higher values of NAirc in the site allows expecting AA values of 97 % for lower values of NRIM (NRITM = 56 for NAirc =24 and NRITM = 66 for NAirc = 8).

This result leads the researcher to assert that from a logistic standpoint the expected AA at a particular site of operation will increase insofar the NAirc increases. This rationale supports advising the centralization of operations for a particular WS as much as possible. However, on the one hand this advice could be easily refuted from an operational perspective and on the other hand this factor is not manageable by the AFMC diminishing its logistic relevance.

Therefore, based on these considerations and in the nature of the ED model the research does not make a particular conclusion but suggests further research in the area with the purpose of determining the operational impact of centralizing operations.

RT.

This factor was deemed statistically significant and also the visual effects have been on system's response are paramount. Under an average RT = 2 weeks the expected AA in the system at the OOP suggested by the metric AA/STD is 97% at NRIM = 32 leaving a vast amount of unused capacity that could be avoided if it is planned in advance as it is shown in Figure 26.

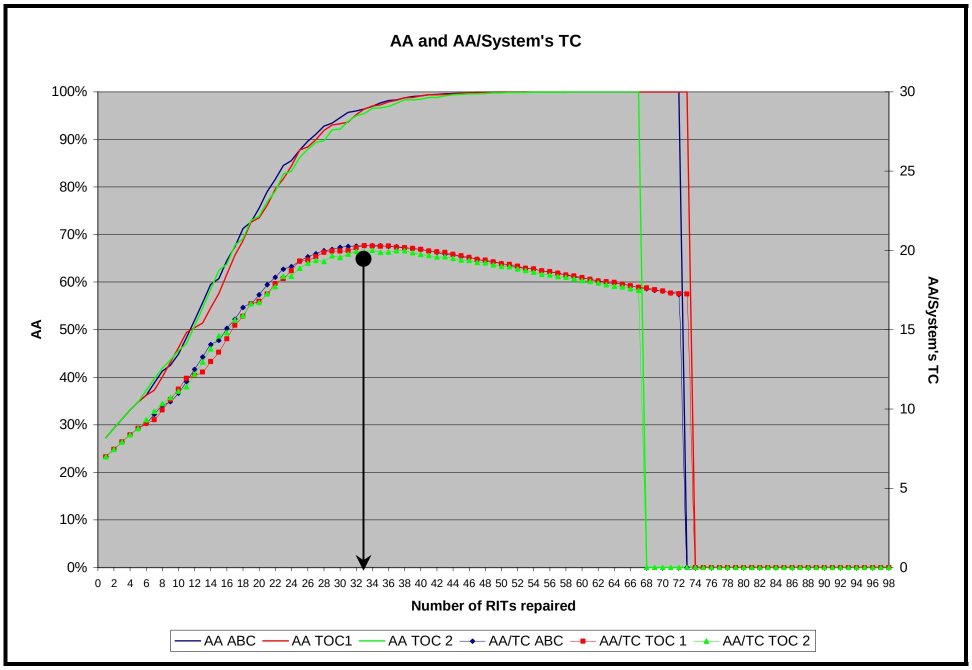


Figure 26. System Response Under IL = H, HL = B and **<u>RT = 2 weeks</u>**.

On the other hand, the responses of the system under an average RT = 8 weeks are dramatically affected as can be seen in Figure 27.

The system reaches its constraint at NRIM = 82 for the TOC 1 and NRIMs = 79 for ABC with values of expected AA less than 60% as can be seen in Figure 27.

The results lead to assert that RT is the most important factor to be controlled at Depot level in the AFMC. It also allows to advise intensify controlling RIs at Depot level with the purpose of reducing average Depot RIs' RTs.

Moreover, the conclusion is also supported by the fact that RIs are one of the two main functions performed by the AFMC at Depot level and therefore definitely under the command and control of the AFMC' headquarters management.

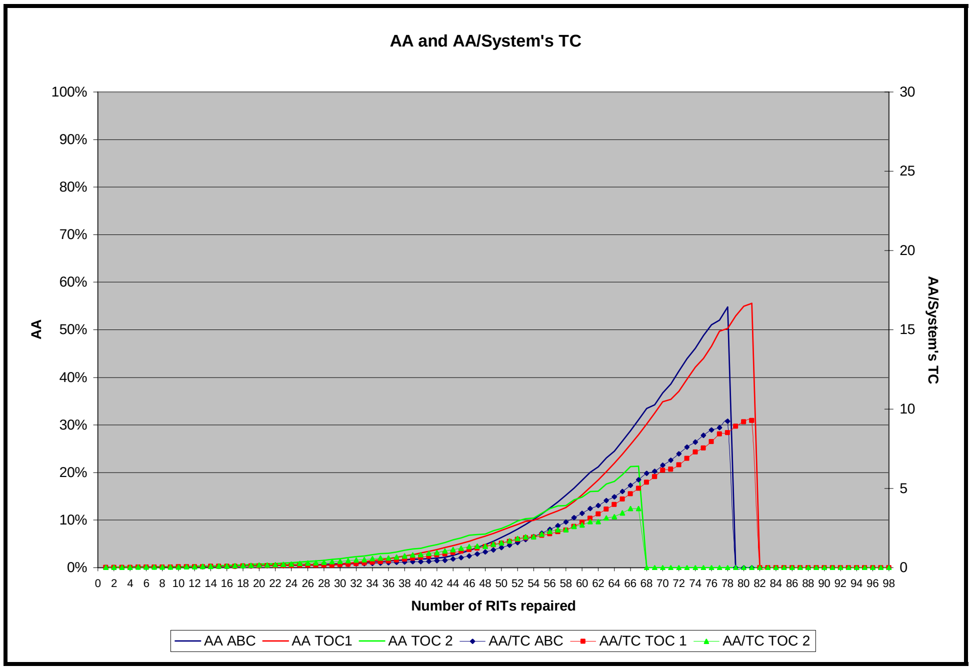


Figure 27. System Response Under IL = H, HL = B and **RT = 8 weeks.**

Optimal Approach to Define the Maintenance RIs Plan at D Level.

The results of the rank tests performed in Chapter 4 in the purpose of determining the approach that gives the best system's responses in terms of the metrics AA/STC and AA shows clear evidence that managers should employ the rationale under the traditional management approach, identified in this research with ABC, in order to define the NRIM to be incorporated in the AFMC Depot Maintenance RIs plan for a future time frame.

This conclusion is based on the fact that on the one hand the metric AA/STC for decisions made under the rationale of ABC surpasses responses under TOC 1 85% of the times (45% significantly different) and responses under TOC 2 80% of the times (70% significantly different) and on the other hand, the metric AA for decisions made under the rationale of ABC surpasses both responses under TOC 1 and TOC 2 90% of the times, 80% of the times with significant differences.

Findings - Metrics and The Optimal Operational Point (OOP) for Depot level.

Comparison of the curves that represent the metrics AA and AA/STC as a function of the NRIM shows that the only metric that gives managers relevant information for decision making is the metric AA/STC. This metric is based on the rationale under the TOC methodology that considers the cost of operating the Depot (OEs) as fixed in the time frame leaving only RMs costs as variable costs.

On the other hand, the metric AA/TUVC that uses the rationale under ABC, traditional approach, in which all costs are considered variable, does not suggest any particular point for operating the Depot.

In all treatments analyzed, the metric AA/STC increases insofar NRIM increases up to a maximum point that gives expected AA values always greater than 92% except for the cases in which the average RT is set at high values of 8 weeks, which causes the system reaching its CCR before the AA/STC reaches its maximum.

The maximum point of the curve AA/STC is the point at which the system operates at maximum bang for the buck or AA per dollar spent and therefore it is an optimal point of operation (OOP). This rationale allows the research to suggest using the metric AA/STC as the performance measure to be used for defining the OOP for the AFMC at Depot level and also for the purpose of dimensioning Depot operations.

The capacity for operating the Depot should be enough to allow the Depot to operate at the level of NRIM suggests by the OOP. A Depot planned to operate at another level of NRIM will operate in an inefficient condition. Operating at lower levels than the OOP will leave idle capacity in the Depot. Operating at higher levels than the OOP will lead to pay overtime first and eventually hire more labor that will turn out to be a permanent increment in OEs. Managers should consider outsourcing options for Depot operations above the OOP.

Answer to IQs.

IQ 1: Which are the factors that most impact the AFMC Depot metrics AA and AA/STC achieved by selecting the optimal mix of RIs for the maintenance RIs plan under both methodologies ABC and TOC?

The main factors affecting the metrics AA and AA/STC are RT and NAirc in the site. However, RT is considered the most important factor for this research since it is strictly under the AFMC's control.

IQ 2: Which is the amount of effect of each factor in the metrics AA and AA/STC under ABC and TOC approaches?

The approximate or estimated precedence in the factors for the metric AA is: RT, IL, HL, NAirc, and Approach. The precedence in the factors for the metric AA/STC is: RM%, IL, RT, HL, NAirc, and Approach.

IQ 3: Are there significant differences between decisions made under the traditional approach (ABC) and the TOC approach in defining the optimal mix for the AFMC Depot maintenance RIs plan?

Yes, there are. The non parametric test performed to select the best approach to define the mix of RIs to include in the Depot maintenance RIs plan shows:

1. There are significant differences in responses between mix decisions made under ABC and TOC 1, 45% of the time for the metric AA/STC and 80% of the time for the metric AA.
2. There are significant differences in responses between mix decisions made under ABC and TOC 2, 70% of the time for the metric AA/STC and 80% of the time for the metric AA.

IQ 4: Which is the approach that defines the mix for the AFMC D's maintenance RIs plan that maximize the metrics AA and AA/STC?

The traditional approach, identified in this research as the ABC method, is the approach that gave the best performance for the system in terms of AA and AA/SCT.

System's responses based on decisions made under ABC surpassed responses under TOC 1 85% of the time for the metric AA/STC and 80% of the time for the metric AA. On the other hand responses under ABC surpassed responses under TOC 2 80% of the time for the metric AA/STC and 90% of the time for the metric AA.

IQ 5: Under which circumstances decisions made under ABC and TOC approaches differs?

The traditional approach turns out to be consistently optimal when the system works under LOW intensity of load according to the analysis in Chapter 4 that showed the ABC approach obtaining consistently the best system's response under IL = L except for the case in which RT = 8 weeks.

Section 2 - Managerial Implications

Resources' Utilization and Reallocation.

The ABC model clearly shows the expected rate of utilization for the resources committed in the period according to the level of activity forecasted. This method allows managers foreseeing areas where resources are scarce and others where they are in excess and therefore to reallocate or restrain labor resources to meet the forecasted demand.

Extension of the AAM rationale.

In the AAM the costs of the spares bought or repaired from outside the organization can be thought as UVC (prices) paid for the AFMC to external providers, method known as outsourcing. In this case the constrained resource for the organization is its budget.

However, when resources are available in the organization, it makes sense to perform the work inbound instead of outsourcing it. In this case the constrained resource changes from budget to practical capacity of labor resources in the Depot. No savings at all will be obtained for outsourcing RIs unless management decide to reduce or lay off inbound labor (OEs) that would be employed if the reparable items were restored inbound. Otherwise the total amount paid would not only be the price paid to contractors but also the OEs of the now idle labor in the Depot.

Comparison Between ABC and TOC Methodologies.

The results of the research have shown that mix decisions under ABC and TOC methodologies causes statistical significant differences in system's responses and that the traditional approach (ABC) should be used in mix decisions making to optimize the whole performance of the system.

However, it was found that the metric AA/STC is the most suitable to evaluate the performance of the AFMC at the Depot level. This metric supports the considerations under TOC in costs treatments since it considers STC as OEs, fixed in the period, plus RMs costs as UVC according to the mix of RIs to produce.

Both method ABC and TOC are complementary in the research. While the traditional approach should be used for mix RIs decisions, TOC considerations about cost treatments should be employed in system's performance analysis.

Additionally, ABC allows managers to determine used and unused PC of resources pinpointing the CCR of the system that is the basic information needed by TOC methodology to develop its rationale.

Outsourcing Implications.

Depot operations at NRIM greater than the number suggested by the OOP will cause increases in OEs (labor hired) that will turn out to be fixed for the future when the Depot may need to reduce its level of operation.

This rationale suggests planning inbound restorations at level of NRIM equal or less than the number suggested by the OOP. In case of NRIM greater than the OOP outsourcing options should be considered by managers in the purpose of maximizing the performance of the AFMC at Depot level.

Information Provided by the ABC Model.

An ABC model contemplating all workshops that intervene in processing RIs for a WS would provide managers helpful information for support cost-based decision making. A summary of the information provided by the ABC model is the following:

1. UVCs for each RIs used for cost-based decision making.
2. The CCR of the system used by the TOC 1 methodology in this research.
3. OEs and the CCR used by the TOC 2 methodology in this research.

The ABC model would also allow managers to study the system as a constraint environment including the restrictions in RMs availability and carcasses restrictions at the Depot.

Transference prices among sub-organizations should be calculated according to the use of internal resources in processing the RITs. An ABC model provides a suitable tool to determine transference prices.

Section 3 - Suggestions for Future Research

Suggestions for future research are based on extensions that can be done on the proposed model so that managers can completely describe the effects of all possible factors affecting both metrics of interest AA/STC and AA. Therefore, suggestions are described under each of the particular methods used in this research.

Under AAM.

<u>Aircraft Inspections.</u>

The rationale of the AAM used in the research considers SAA as a substitute for measuring the AA of the WS. However, this measure does not contemplate the impact of performing AIs by the AFMC in the purpose of providing AA to the OL for a WS. Therefore, managers are interested in measuring the expected AA developed by the AFMC in performing both main functions AIs and RIs.

In considering the impact of AIs on a WS' AA the logic under the rationale of the AAM based on calculations of EBO for the system is not more valid. Another rationale should be developed in order to measure the effect of AIs in AA for a particular WS.

Every time an AI is finished at Depot level an aircraft is delivered to OL. The availability of the WS from the standpoint of the AFMC can be measured under two basic perspectives:

1. Flying hours (FHs) provided until next inspection (hours to next inspection).
2. Incremental percentage of aircraft FMC at OL that supposes all aircraft delivered to the OL are FMC.

Transportation Times and SRUs.

The model uses the rationale of the SSIM where re-supply times are deemed equal to cero since aircraft are operating at the site where the RITs are processed. Two extensions can be considered in the model to measure the impact of other factors in system's responses:

1. ***Multi-echelon environment***. Since a multi-echelon environment is analyzed in the Metric formulation for the AAM, ordering and transportation times can be incorporated to the rationale. Under this approach RTs at bases and at Depots can be differentiated.
2. ***Shop Repairable Units (SRUs).*** In the Varimetric formulation for the AAM, a multi-indenture environment is considered. This would allow managers measuring the impact on system's AA due to resources' assignment to SRU inspections at Depot level. This extension of the model would correct one of the limitations for the current research that was limited to consider only FIIs.

It is convenient to emphasize that the more the RITs considered in the model for a WS the less the system's AA that should be expected by managers since the effects among all repairable items on the WS' AA are independent.

Under ABC.

<u>Secondary Activities.</u>

The ABC model can be enhanced to take into consideration other secondary or support activities at higher level such as headquarters activities. The basic effect expected from this consideration would be:

1. Increments in UVC for each RIT under ABC rationale.
2. Increments of OEs under the TOC approach.

These changes in UVC and OE could change the performance of the system measured in terms of AA/STC and AA. The purpose of this extension should be to detect changes in the conclusions of this research.

<u>Inventory Costs.</u>

RMs are deemed variable costs under both ABC and TOC methodology. Since the model considers a particular time frame to evaluate the OOP for the Depot, holding costs as the opportunity costs due to investment in RMs should be evaluated in the period.

RMs were not deemed as a source of system' constraint. This assumption supposed that enough stock of RMs were always available to process RIs. However, in reality higher SL of RMs will increase holding costs for the period and therefore OEs for the system. Therefore, SLs of RMs should be treated in the model as sources of constraints. trade offs between RMs' SLs and holding costs should be addressed in order to evaluate OEs and also the impact of holding costs on UVC for the RIs under ABC method.

At this point, the item approach should be used to determine the safety stock for every RM involved in every inspection according to mean and variance of demands from RIs and LTs from external sources and also considering a particular service level (95 %).

After defining SLs for RMs, managers would be able to assess the effect of limiting funding for purchasing RMs in the period, which was not deemed a limitation in the current research.

Another possible extension is to treat holding costs for carcasses in the model. Carcasses were assumed infinite in the research. Considering holding costs for carcasses will cause to determine trade offs between the SLs and OEs, almost the same consideration made for RMs.

Including RMs and carcasses holding costs will increase OEs for the whole system in the time frame considered and could alter decisions under TOC approaches or the suggested OOP for the Depot.

Transportation Costs.

The Metric case under the AAM allows managers to make consideration of supply and transportation times. The transportation function may be performed inbound the organization and the ABC model can be extended to consider transportation activities that will influence not only UVC for every RIs but OEs. On the other hand, transportation activities can be outsourced in which case transportation costs will turn out to be variable costs and they should be treated as the costs of RMs every time a RIT is processed and sent from Depot to the OL.

Under Project Management - Critical Chain.

One of the assumptions for the research was that all activities considered in the model were sequentially performed and that it was not resource contention. This assumption can be considered true for activities developed across squadrons. However, activities or RIs within a particular squadron or workshop could be performed in parallel, which could cause resource dependency or contention (Newbold, 1998: 82).

An extension of the model should consider in a first stage developing all actual single-project scheduling for RIs using Microsoft Project or another software. Therefore, Critical Chain (CC) methodology could be used to minimize project duration times and solve resources contention.

The metrics used to evaluate the Depot performance in the current research have been very sensitive to changes in RTs. Using CC will help managers in reducing RTs for

RIs and also determining tasks that most influence the response of the system. Managers could obtain information on how changes in times projected for the activities of each RIs will influence the expected performance of the system and the OOP at Depot level. Therefore, the convenience of hiring resource labor to solve resource contention could be analyzed in terms of AA and the OOP for the whole system.

In a second stage, single-project scheduling for AIs should be considered and managers could intend developing a model to determine the OOP for the Depot considering all the main functions performed at Depot level, AIs and RIs.

Completion of the Rationale Over the AFMC's SC.

In first place the model should be enhanced to include the effect of AIs in the performance of the whole AFMC at Depot level. This will allow considering the maintenance part of operational availability.

The Varimetric formulation of the AAM considers SRUs (SIIs). The ABC model should be extended to consider the RIs of all RITs (FII, SII and other levels) that contribute to determine the expected SAA (AA) for a particular WS.

Moreover, in the purpose of including all possible items influencing the values of expected WS' AA, consumables items acting as FII and all RIs (FII and also SIIs) outsourced but under the management of the AFMC should be considered.

Final extensions should be done to incorporate transportation costs and holding costs since all these costs are under the control of the AFMC.

Summary

The conclusions and recommendations of this research and the answer to the IQs posed in Chapter 1 have been described in this chapter. The importance of the control of the RT for RIs performed at Depot level is the most clear and important recommendation from this research. The emphasis of this recommendation relies also on the fact that controlling RT for RIs is under strict control of AFMC management and reduction in RIs' RT could turn out to be in dramatically improvements of the AFMC's performance.

Section 2 addressed managerial implications of the results of this research and the findings that were not explicitly searched at the beginning of the work. It is emphasized the fact that the research found a way to determine an OOP at AFMC Depot level. The determination of an OOP for Depots will contribute in the management' effort to plan resources according to desire levels of performance for the organization.

Finally, Section 3 describes new areas of research that will contribute not only to complete and validate the conclusions of this research but to continue the management's efforts in the purpose of optimizing the AFMC' performance.

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Table A-1. Resources Assigned to RIs Activities at D

Time Frame considered (weeks)	13										
Days per week	5										
Hours per day	8										
Areas	RESOURCES										
	Code	Specialty	Category	Number of resources	Weekly hours	Unitary Monthly Payment	**Maximum Capacity (MC) of resources (Hours)**	**Practical Capacity (PC) of resources (Hours)**	**Total Costs (TC) ($)**	**Rate (TC / PC)**	**Rate (TC / MC)**
CEO / Staff											
Facility Suport Depot Group											
Quality Control Squadron											
Aircraft Quality Control	L 1	**QR**	**1**	2	40.0	$5,000.00	**1,040.00**	**832.00**	**$30,000.00**	**36.06**	**28.85**
	L 2	**QR**	**2**	2	40.0	$6,000.00	**1,040.00**	**832.00**	**$36,000.00**	**43.27**	**34.62**
		Total		**4**							
Engineering	L 4	**QEN**	**1**	1	40.0	$6,000.00	**520.00**	**416.00**	**$18,000.00**	**43.27**	**34.62**
		Subtotal	**4**	**1**			**Subtotal**		**$84,000.00**	**22%**	
Maintenance Group											
Chief and Staff											
Planning repairable inspections	L 5	**MPR 1**	**1**	2	40.0	$4,000.00	**1,040.00**	**832.00**	**$24,000.00**	**28.85**	**23.08**
	L 6	**MPR 2**	**2**	1	40.0	$5,000.00	**520.00**	**416.00**	**$15,000.00**	**36.06**	**28.85**
		Subtotal	**3**	**3**							
Equipment and Facilities											
Rapairable Inspection Squadron											
Chief and Staff											
Section Repairables 1											
	L 7	**MR 1**	**1**	5	40.0	$2,500.00	**2,600.00**	**2,080.00**	**$37,500.00**	**18.03**	**14.42**
	L 8	**MR 2**	**2**	3	40.0	$3,000.00	**1,560.00**	**1,248.00**	**$27,000.00**	**21.63**	**17.31**
	L 9	**MR 3**	**3**	1	40.0	$4,000.00	**520.00**	**416.00**	**$12,000.00**	**28.85**	**23.08**
		Subtotal	**6**	**9**							
Equipment and Facilities											
Support Maintenance Squadron											
Chief and Staff											
Section Electronics & Instrumental	L 10	**MSEI**	**1**	2	40.0	$3,000.00	**1,040.00**	**832.00**	**$18,000.00**	**21.63**	**17.31**
Section Structure	L 11	**MSS**	**1**	2	40.0	$3,000.00	**1,040.00**	**832.00**	**$18,000.00**	**21.63**	**17.31**
Section Paint	L 12	**MSP**	**1**	2	40.0	$3,000.00	**1,040.00**	**832.00**	**$18,000.00**	**21.63**	**17.31**
Section Equipment support	L 13	**MSEq**	**1**	2	40.0	$3,000.00	**1,040.00**	**832.00**	**$18,000.00**	**21.63**	**17.31**
Section Upholstery	L 14	**MSU**	**1**	2	40.0	$3,000.00	**1,040.00**	**832.00**	**$18,000.00**	**21.63**	**17.31**
		Subtotal	**5**				**Subtotal**		**$205,500.00**	**53%**	
Suply Group											
Chief and Staff											
Planning supply support	L 15	**SP 1**	**1**	2	40.0	$3,000.00	**1,040.00**	**832.00**	**$18,000.00**	**21.63**	**17.31**
	L 16	**SP 2**	**2**	1	40.0	$3,500.00	**520.00**	**416.00**	**$10,500.00**	**25.24**	**20.19**
		Total		**3**							
Supply Repairable Squadron											
Chief and Staff											
Sections	L 17	**SR 1**	**1**	2	40.0	$2,500.00	**1,040.00**	**832.00**	**$15,000.00**	**18.03**	**14.42**
	L 18	**SR 2**	**2**	1	40.0	$3,000.00	**520.00**	**416.00**	**$9,000.00**	**21.63**	**17.31**
		Total		**3**	40.0						
Consumable Support Squadron											
Chief and Staff											
Sections	L 19	**SC 1**	**1**	2	40.0	$2,500.00	**1,040.00**	**832.00**	**$15,000.00**	**18.03**	**14.42**
	L 20	**SC 2**	**2**	1	40.0	$3,000.00	**520.00**	**416.00**	**$9,000.00**	**21.63**	**17.31**
		Total		**3**			**Subtotal**		**$76,500.00**	**20%**	
				Number in stock		**Unitary cost**			**Total cost in stock**		
Consumable 1	RM 1	**RM 1**	**0 - 30 $**	30		$15.00			**$450.00**		
Consumable 2	RM 2	**RM 2**	**31 - 70 $**	30		$50.00			**$1,500.00**		
Consumable 3	RM 3	**RM 3**	**71 - 150 $**	30		$110.00			**$3,300.00**		
Consumable 4	RM 4	**RM 4**	**151 - 250 $**	30		$200.00			**$6,000.00**		
Consumable 5	RM 5	**RM 5**	**251 - 400 $**	30		$325.00			**$9,750.00**		
							Subtotal		**$21,000.00**	**5%**	
Supply Support Section											
Chief and Staff											
Reception and Expedition	L 21	**SRC 1**		2	40.0	$2,500.00	**1,040.00**	**832.00**	**$15,000.00**	**18.03**	**14.42**
Handling and Moving materials	L 22	**SRC 2**		1	40.0	$3,000.00	**520.00**	**416.00**	**$9,000.00**	**21.63**	**17.31**
		Total		**3**			**Subtotal**		**$24,000.00**	**6%**	
							OPERATIONAL EXPENSES (OE)		**$390,000.00**		

Table A-2. Activities Considered in the ABC Model

Area	No of Activity	Activity Description	Level of Activity	Activity costs Driver (ACD)	Type of ACD
CEO / Staff					
Quality Control Squadron					
Repairable Quality Control	**A 1**	Repairable inspection on reception	Unit Level	Hours of repairable inspection	Duration (Intensity)
	A 2	Repairable inspection prior to delivery	Unit Level	Hours of repairable inspection	Duration (Intensity)
Engineering	**A 3**	Non destructive inspection	Unit Level	Hours of engineering	Duration (Intensity)
	A 4	Repairable modifications / enginnering	Unit Level	Hours of engineering	Duration (Intensity)
Maintenance Group					
Chief and Staff					
Planning repairable inspections	**A 5**	Planning, scheduling and maintaining scheduling for repairables	Unit Level	Hours spent scheduling and controlling Ris	Duration (Intensity)
	A 6	Requiring and controlling materials for repairable inspections	Batch Level	Hours requiring Consumables for every Ris	Duration (Intensity)
Aircraft Maintenance Squadron					
Chief and Staff					
Rapairable Inspection Squadron					
Chief and Staff					
Section Repairables 1					
		Inspection Rep 1/2/3/4/5 - WS1			
	DAR 1	Activity 1 - Testing repairable failure - Labor skill 4	Unit Level	Hours testing failures - Level Skill 5	Intensity
	DAR 2	Activity 2 - Taking apart repairable - Labor Skill 4	Unit Level	Hours taking apart repairables - Labor Skill 7	Intensity
	DAR 3	Activity 3 - Check material availability - Labor skill 6	Unit Level	Hours spent checking and picking consumable items fro Ris	Duration (Intensity)
	DAR 4	Activity 4 - Set up equipment - Labor skill 6	Unit Level	Hours consumed in set ups - Level Skill 6	Intensity
	DAR 5	Activity 5 - Replace and install materials - Labor skill 5 and 7	Unit Level	Hours taking apart repairables - Labor Skill 8	Intensity
Support Maintenance Squadron					
Chief and Staff					
Section Electronics & Instrumental	**A 7**	Electronic support to inspections	Unit Level	Hours of electronic support to inspection	Duration (Intensity)
Section Structure	**A 8**	Structure support to inspections	Unit Level	Hours of structure support to inspection	Duration (Intensity)
Section Paint	**A 9**	Paint support to inspections	Unit Level	Hours of paint support to inspection	Duration (Intensity)
Section Equipment support	**A 10**	Maintaining technical equipments and general support	Unit Level	Hours of technical equipment support to inspection	Duration (Intensity)
Section Upholstery	**A 11**	Upholstery support to inspections	Unit Level	Hours of upholstery support to inspection	Duration (Intensity)
Suply Group					
Chief and Staff					
Planning supply support					
	A 12	Receiving and processing material orders for repairable inspections	Unit Level	Hours used in planning and ordering materials by type of inspection	Duration (Intensity)
	A 13	Ordering materials non available at Depot	Unit Level	Hours spent ordering materials by RIs	Duration (Intensity)
	A 14	Scheduling material delivery required for inspections	Unit Level	Hours of scheduling delivery for inspection	Duration (Intensity)
Supply Repairable Squadron					
Chief and Staff					
Section Repairable in service	**A 15**	Handling, storing and preparing repairables for delivering to OL	Unit Level	Hours spent preparing and handling repairable for the inspection	Duration (Intensity)
Consumable Support Squadron					
Chief and Staff					
Section Consumables 1	**A 16**	Handling, storing and preparing consumables for delivering to Ris	Unit Level	Hours spent preparing and handling consumables for the inspection	Duration (Intensity)
Supply Support Section					
Chief and Staff					
Reception and Expedition	**A 17**	Reception of non serviceable RI from OL or AIs	Unit Level	Hours spent receiving materials	Duration (Intensity)
	A 18	No serviceable RITs' inspection in the reception	Unit Level	Hours spent inspecting Ris in the reception	Duration (Intensity)
	A 19	Moving No Serviceable (NS) RITs to NS RITs' sections in SG	Unit Level	Hours spent moving and storaging RITs in SG (Carcasses)	Duration (Intensity)
Handling and Moving materials	**A 20**	Preparing RITs (carcasses) for shipment to RIs in MG	Unit Level	Hours spent reparing materials for shipping to Ris	Duration (Intensity)
	A 21	Shipment or transporting Rs to MG for RIs	Unit Level	Hours spent tranporting materials from and to inspections	Duration (Intensity)

Table A-3. ABC Model – Internal Calculations

Area	No of Activity	Activity Description	Type of resource	Percentage Assigned (Resource Drivers)	Activity Capacity		Activity Cost in the Time Frame ($)	Practical capacity of Act in units of CD	AD rates ($)	Inspection R 1			Inspection R 2			Inspection R 3			Inspection R 4			Inspection R 5		
					Value	Units				Unitary AD (Hs or #)	Unitary Cost	Mix Costs	Unitary AD (Hs or #)	Unitary Cost	Mix Costs	Unitary AD (Hs or #)	Unitary Cost	Mix Costs	Unitary AD (Hs or #)	Unitary Cost	Mix Costs	Unitary AD (Hs or #)	Unitary Cost	Mix Costs
CEO / Staff		Percentage of usage resource	**80%**					**Mix of repairable items**		50	0	0	20	0	0	5	0	0	2	0	0	20	0	0
Quality Control Squadron																								
Quality Control Squadron																								
Repairable Quality Control	**A 1**	Repairable inspection on reception	QR 1	0.25	260.00	HS	$7,500.00	208.00	36.06	3.00	$108.17	$5,408.65	6.00	$216.35	$4,326.92	0.50	$18.03	$90.14	1.25	$45.07	$90.14	7.50	$270.43	$5,408.65
			QR 2	0.25	260.00	HS	$9,000.00	208.00	43.27	1.00	$43.27	$2,163.46	2.00	$86.54	$1,730.77	2.00	$86.54	$432.69	5.00	$216.35	$432.69	2.50	$108.17	$2,163.46
				TC =	**260.00**					**4.00**			**8.00**			**2.50**			**6.25**			**10.00**		
	A 2	Repairable inspection prior to delivery	QR 2	50%	520.00	HS	$18,000.00	416.00	43.27	1.00	$43.27	$2,163.46	2.00	$86.54	$1,730.77	2.00	$86.54	$432.69	5.00	$216.35	$432.69	2.50	$108.17	$2,163.46
	A 3	Non destructive inspection	QR 2	25%	260.00	HS	$9,000.00	208.00	43.27	1.00	$43.27	$2,163.46	2.00	$86.54	$1,730.77	2.00	$86.54	$432.69	5.00	$216.35	$432.69	2.50	$108.17	$2,163.46
Engineering																								
	A 4	Repairable modifications / enginnering	QEN	10%	52.00	HS	$1,800.00	41.60	43.27	1.00	$43.27	$2,163.46	2.00	$86.54	$1,730.77	0.50	$21.63	$108.17	1.25	$54.09	$108.17	2.50	$108.17	$2,163.46
									Sub-total	**7.00**	**281.25**	**14,062.50**	**14.00**	**562.50**	**11,250.00**	**7.00**	**299.28**	**1,496.39**	**17.50**	**748.20**	**1,496.39**	**17.50**	**703.13**	**14,062.50**
Maintenance Group																								
Chief and Staff																								
Planning repairable inspections	**A 5**	Planning, scheduling and maintaining scheduling for repairables	MPR 1	100%	1,040.00	HS	$24,000.00	832.00	28.85	3.00	$86.54	$4,326.92	6.00	$173.08	$3,461.54	0.50	$14.42	$72.12	1.25	$36.06	$72.12	7.50	$216.35	$4,326.92
			MPR 2	75%	390.00	HS	$11,250.00	312.00	36.06	0.50	$18.03	$901.44	1.00	$36.06	$721.15	2.00	$72.12	$360.58	5.00	$180.29	$360.58	1.25	$45.07	$901.44
			MR 3	15%	78.00	HS	$1,800.00	62.40	28.85	0.25	$7.21	$360.58	1.00	$28.85	$576.92	0.50	$14.42	$72.12	2.50	$72.12	$144.23	0.75	$21.63	$432.69
			QEN	20%	104.00	HS	$3,600.00	83.20	43.27	0.50	$21.63	$1,081.73	1.00	$43.27	$865.38	0.00	$0.00	$0.00	0.00	$0.00	$0.00	1.25	$54.09	$1,081.73
				TC	**1,508.00**		**$37,050.00**			**4.25**			**9.00**			**3.00**			**8.75**			**10.75**		
	A 6	Requiring and controlling materials for repairable inspections	MPR 2	25%	130.00	Hs	$3,750.00	104.00	36.06	1.00	$36.06	$1,802.88	2.00	$72.12	$1,442.31	0.50	$18.03	$90.14	1.25	$45.07	$90.14	2.50	$90.14	$1,802.88
			MR 3	15%	78.00	HS	$1,800.00	62.40	28.85	0.25	$7.21	$360.58	1.00	$28.85	$576.92	0.50	$14.42	$72.12	2.50	$72.12	$144.23	0.75	$21.63	$432.69
				TC	**1,638.00**		**$40,800.00**			**1.25**			**3.00**			**1.00**			**3.75**			**3.25**		
									Sub-total	**5.50**	**176.68**	**8,834.13**	**12.00**	**382.21**	**7,644.23**	**4.00**	**133.41**	**667.07**	**12.50**	**405.65**	**811.30**	**14.00**	**448.92**	**8,978.37**
Rapairable Inspection Squadron																								
		Inspection Rep 1/2/3 - WS1																						
	DAR 1	Activity 1 - Testing repairable failure - Labor skill MR 2,3	MR 2	25%	390.00	HS	$6,750.00	312.00	21.63	1.50	$32.45	$1,622.60	3.00	$64.90	$1,298.08	3.00	$64.90	$324.52	7.50	$162.26	$324.52	3.75	$81.13	$1,622.60
			MR 3	35%	182.00	HS	$4,200.00	145.60	28.85	0.75	$21.63	$1,081.73	3.00	$86.54	$1,730.77	0.50	$14.42	$72.12	2.50	$72.12	$144.23	2.25	$64.90	$1,298.08
	DAR 2	Activity 2 - Taking apart repairable - Labor Skill MR 2	MR 2	15%	234.00	HS	$4,050.00	187.20	21.63	1.50	$32.45	$1,622.60	3.00	$64.90	$1,298.08	3.00	$64.90	$324.52	7.50	$162.26	$324.52	3.75	$81.13	$1,622.60
	DAR 3	Activity 3 - Check material availability - Labor skill MR 1	MR 1	50%	1,300.00	HS	$18,750.00	1,040.00	18.03	2.50	$45.07	$2,253.61	5.00	$90.14	$1,802.88	0.50	$9.01	$45.07	1.25	$22.54	$45.07	6.25	$112.68	$2,253.61
	DAR 4	Activity 4 - Set up equipment - Labor skill MR 1	MR 1	25%	650.00	HS	$9,375.00	520.00	18.03	2.50	$45.07	$2,253.61	5.00	$90.14	$1,802.88	0.50	$9.01	$45.07	1.25	$22.54	$45.07	6.25	$112.68	$2,253.61
	DAR 5	Activity 5 - Replace and install materials - Labor skill MR 1,2,3	MR 1	25%	650.00	HS	$9,375.00	520.00	18.03	2.50	$45.07	$2,253.61	5.00	$90.14	$1,802.88	1.00	$18.03	$90.14	2.50	$45.07	$90.14	6.25	$112.68	$2,253.61
			MR 2	60%	936.00	HS	$16,200.00	748.80	21.63	1.50	$32.45	$1,622.60	3.00	$64.90	$1,298.08	3.00	$64.90	$324.52	7.50	$162.26	$324.52	3.75	$81.13	$1,622.60
			MR 3	35%	182.00	HS	$4,200.00	145.60	28.85	0.75	$21.63	$1,081.73	3.00	$86.54	$1,730.77	0.50	$14.42	$72.12	2.50	$72.12	$144.23	2.25	$64.90	$1,298.08
				TC	**2,236.00**		**$34,950.00**			**13.50**	**$275.84**	**$13,792.07**	**30.00**	**$638.22**	**$12,764.42**	**12.00**	**$259.62**	**$1,298.08**	**32.50**	**$721.15**	**$1,442.31**	**34.50**	**$711.24**	**$14,224.76**
Support Maintenance Squadron																								
Section Electronics & Instrumental	**A 7**	Electricity and electronic supporting inspection	MSEI	40%	416.00	HS	$7,200.00	332.80	21.63	3.00	$64.90	$3,245.19	6.00	$129.81	$2,596.15	1.00	$21.63	$108.17	2.50	$54.09	$108.17	7.50	$162.26	$3,245.19
Section Structure	**A 8**	Structure support to inspections	MSS	40%	416.00	HS	$7,200.00	332.80	21.63	3.00	$64.90	$3,245.19	6.00	$129.81	$2,596.15	4.00	$86.54	$432.69	10.00	$216.35	$432.69	7.50	$162.26	$3,245.19
Section Paint	**A 9**	Paint support to inspections	MSP	40%	416.00	HS	$7,200.00	332.80	21.63	3.00	$64.90	$3,245.19	6.00	$129.81	$2,596.15	2.00	$43.27	$216.35	5.00	$108.17	$216.35	7.50	$162.26	$3,245.19
Section Equipment support	**A 10**	Maintaining technical equipments and general support	MSEq	40%	416.00	HS	$7,200.00	332.80	21.63	3.00	$64.90	$3,245.19	6.00	$129.81	$2,596.15	4.00	$86.54	$432.69	10.00	$216.35	$432.69	7.50	$162.26	$3,245.19
Section Upholstery	**A 11**	Upholstery support to inspections	MSU	40%	416.00	HS	$7,200.00	332.80	21.63	3.00	$64.90	$3,245.19	6.00	$129.81	$2,596.15	1.00	$21.63	$108.17	2.50	$54.09	$108.17	7.50	$162.26	$3,245.19
				TC	**1,248.00**		**$21,600.00**			**15.00**	**324.52**	**16,225.96**	**30.00**	**649.04**	**12,980.77**	**12.00**	**259.62**	**1,298.08**	**30.00**	**649.04**	**1,298.08**	**37.50**	**811.30**	**16,225.96**
									Sub-total	**28.50**	**600.36**	**30,018.03**	**60.00**	**1,287.26**	**25,745.19**	**24.00**	**519.23**	**2,596.15**	**62.50**	**1,370.19**	**2,740.38**	**72.00**	**1,522.54**	**30,450.72**
Suply Group																								
Chief and Staff																								
Planning supply support																								
	A 12	Receiving and processing material orders for repairable inspections	SP 1	20%	208.00	HS	$3,600.00	166.40	21.63	1.00	$21.63	$1,081.73	2.00	$43.27	$865.38	0.50	$10.82	$54.09	1.25	$27.04	$54.09	2.50	$54.09	$1,081.73
			SP 2	10%	52.00	HS	$1,050.00	41.60	25.24	0.00	$0.00	$0.00	0.00	$0.00	$0.00	1.00	$25.24	$126.20	2.50	$63.10	$126.20	0.00	$0.00	$0.00
				TC	**208.00**		**$4,650.00**			**1.00**			**2.00**			**1.50**			**3.75**			**2.50**		
	A 13	Ordering materials non available at Depot	SP 1	10%	104.00	Hs	$1,800.00	83.20	21.63	0.00	$0.00	$0.00	0.00	$0.00	$0.00	0.00	$0.00	$0.00	0.00	$0.00	$0.00	0.00	$0.00	$0.00
			SP 2	30%	156.00	Hs	$3,150.00	124.80	25.24	1.50	$37.86	$1,893.03	3.00	$75.72	$1,514.42	2.00	$50.48	$252.40	5.00	$126.20	$252.40	3.75	$94.65	$1,893.03
				TC	**364.00**		**$4,950.00**			**1.50**			**3.00**			**2.00**			**5.00**			**3.75**		
	A 14	Scheduling material delivery required for inspections	SP 1	20%	208.00	HS	$3,600.00	166.40	21.63	2.00	$43.27	$2,163.46	4.00	$86.54	$1,730.77	1.00	$21.63	$108.17	2.50	$54.09	$108.17	5.00	$108.17	$2,163.46
			SP 2	10%	52.00	HS	$1,050.00	41.60	25.24	0.00	$0.00	$0.00	0.00	$0.00	$0.00	0.00	$0.00	$0.00	0.00	$0.00	$0.00	0.00	$0.00	$0.00
				TC	**728.00**		**$4,650.00**			**2.00**			**4.00**			**1.00**			**2.50**			**5.00**		
Supply Repairable Squadron																								
Section Repairable in service	**A 15**	Receiving, handling and storing repairable from inspections	SR 1	50%	520.00	HS	$7,500.00	416.00	18.03	3.00	$54.09	$2,704.33	6.00	$108.17	$2,163.46	1.00	$18.03	$90.14	2.50	$45.07	$90.14	7.50	$135.22	$2,704.33
			SR 2	50%	260.00	HS	$4,500.00	208.00	21.63	1.50	$32.45	$1,622.60	3.00	$64.90	$1,298.08	0.50	$10.82	$54.09	1.25	$27.04	$54.09	3.75	$81.13	$1,622.60
				TC	**1,248.00**		**$12,000.00**			**4.50**			**9.00**			**1.50**			**3.75**			**11.25**		
Consumable Support Squadron																								
Section Consumables 1	**A 16**	Handling, preparing and moving consumable for inspections	SC 1	50%	1,040.00	HS	$15,000.00	832.00	18.03	3.00	$54.09	$2,704.33	6.00	$108.17	$2,163.46	1.00	$18.03	$90.14	2.50	$45.07	$90.14	7.50	$135.22	$2,704.33
			SC 2	50%	520.00	HS	$9,000.00	416.00	21.63	1.50	$32.45	$1,622.60	3.00	$64.90	$1,298.08	1.00	$21.63	$108.17	2.50	$54.09	$108.17	3.75	$81.13	$1,622.60
				TC	**0.00**		**$0.00**			**4.50**			**9.00**			**2.00**			**5.00**			**11.25**		
Reception and Expedition	**A 17**	Reception of non serviceable RI from OL or Ais	SRC 1	8%	83.20	HS	$1,200.00	66.56	18.03	1.00	$18.03	$901.44	2.00	$36.06	$721.15	2.00	$36.06	$180.29	5.00	$90.14	$180.29	2.50	$45.07	$901.44
Handling and Moving materials			SRC 2	15%	78.00	HS	$1,350.00	62.40	21.63	0.00	$0.00	$0.00	0.00	$0.00	$0.00	0.00	$0.00	$0.00	0.00	$0.00	$0.00	0.00	$0.00	$0.00
				TC	**83.20**		**$2,550.00**			**1.00**			**2.00**			**2.00**			**5.00**			**2.50**		
	A 18	No serviceable R inspection in the reception	SRC 1	8%	83.20	HS	$1,200.00	66.56	18.03	0.00	$0.00	$0.00	0.00	$0.00	$0.00	1.00	$18.03	$90.14	2.50	$45.07	$90.14	0.00	$0.00	$0.00
			SRC 2	15%	78.00	HS	$1,350.00	62.40	21.63	1.00	$21.63	$1,081.73	2.00	$43.27	$865.38	0.00	$0.00	$0.00	0.00	$0.00	$0.00	2.50	$54.09	$1,081.73
				TC	**166.40**		**$2,550.00**			**1.00**			**2.00**			**1.00**			**2.50**			**2.50**		
	A 19	Moving No Serviceable (NS) R to NS sections in SG	SRC 1	12%	124.80	HS	$1,800.00	99.84	18.03	1.00	$18.03	$901.44	2.00	$36.06	$721.15	1.00	$18.03	$90.14	2.50	$45.07	$90.14	2.50	$45.07	$901.44
			SRC 2	5%	26.00	HS	$450.00	20.80	21.63	0.00	$0.00	$0.00	0.00	$0.00	$0.00	0.00	$0.00	$0.00	0.00	$0.00	$0.00	0.00	$0.00	$0.00
				TC	**291.20**		**$2,250.00**			**1.00**			**2.00**			**1.00**			**2.50**			**2.50**		
	A 20	Preparing Rs for shipment to RI in MG	SRC 1	7%	72.80	HS	$1,050.00	58.24	18.03	0.00	$0.00	$0.00	0.00	$0.00	$0.00	1.00	$18.03	$90.14	2.50	$45.07	$90.14	0.00	$0.00	$0.00
			SRC 2	10%	52.00	HS	$900.00	41.60	21.63	0.50	$10.82	$540.87	1.00	$21.63	$432.69	0.50	$10.82	$54.09	1.25	$27.04	$54.09	1.25	$27.04	$540.87
				TC	**364.00**		**$1,950.00**			**0.50**			**1.00**			**1.50**			**3.75**			**1.25**		
	A 21	Shipment or transporting Rs to MG for RIs	SRC 1	15%	156.00	HS	$2,250.00	124.80	18.03	1.00	$18.03	$901.44	2.00	$36.06	$721.15	1.00	$18.03	$90.14	2.50	$45.07	$90.14	2.50	$45.07	$901.44
			SRC 2	5%	26.00	HS	$450.00	20.80	21.63	0.00	$0.00	$0.00	0.00	$0.00	$0.00	0.00	$0.00	$0.00	0.00	$0.00	$0.00	0.00	$0.00	$0.00
				TC	**520.00**		**$2,700.00**			**1.00**			**2.00**			**1.00**			**2.50**			**2.50**		
									Sub-total	**18.00**	**362.38**	**18,118.99**	**36.00**	**724.76**	**14,495.19**	**14.50**	**295.67**	**1,478.37**	**36.25**	**739.18**	**1,478.37**	**45.00**	**905.95**	**18,118.99**
								LABOR			1,420.67			2,956.73			1,247.60			3,263.22			3,580.53	
Raw materials invested																								
Consumable 1		**Consumable 1**							15.00	3.00	$45.00	$2,250.00	4.00	$60.00	$1,200.00	3.00	$45.00	$225.00	4.00	$60.00	$120.00	3.00	$45.00	$900.00
Consumable 2		**Consumable 2**							50.00	2.00	$100.00	$5,000.00	3.00	$150.00	$3,000.00	2.00	$100.00	$500.00	3.00	$150.00	$300.00	3.00	$150.00	$3,000.00
Consumable 3		**Consumable 3**							110.00	1.00	$110.00	$5,500.00	2.00	$220.00	$4,400.00	1.00	$110.00	$550.00	2.00	$220.00	$440.00	2.00	$220.00	$4,400.00
Consumable 4		**Consumable 4**							200.00	0.00	$0.00	$0.00	1.00	$200.00	$4,000.00	0.00	$0.00	$0.00	1.00	$200.00	$400.00	1.00	$200.00	$4,000.00
Consumable 5		**Consumable 5**							325.00	0.00	$0.00	$0.00	1.00	$325.00	$6,500.00	0.00	$0.00	$0.00	1.00	$325.00	$650.00	0.00	$0.00	$0.00
										6.00	**$255.00**	**$12,750.00**	11.00	**$955.00**	**$19,100.00**	6.00	**$255.00**	**$1,275.00**	11.00	**$955.00**	**$1,910.00**	9.00	**$615.00**	**$12,300.00**
									Sub-total															
Facility Suport Group																								
									TOTAL COST		**$1,675.67**	**$83,784**		**$3,911.73**	**$78,235**		**$1,502.60**	**$7,513**		**$4,218.22**	**$8,436**		**$4,195.53**	**$83,911**

Resources' Load Profile (Hours)

Area	No of Activity	Activity Description	Type of resource	Quality			Planificacion		Primary Repairable Inspection			Maintenance Support					Supply Support							
CEO / Staff		Percentage of usage resource	**80%**	QR 1	QR 2	QEN	MPR 1	MPR 2	MR 1	MR 2	MR 3	MSEI	MSS	MSP	MSEq	MSU	SP 1	SP 2	SR 1	SR 2	SC 1	SC 2	SRC 1	SRC 2
Quality Control Squadron																								
Quality Control Squadron																								
Repairable Quality Control	A 1	Repairable inspection on reception	QR 1	425.00																				
			QR 2		160.00																			
	A 2	Repairable inspection prior to delivery	QR 2		160.00																			
	A 3	Non destructive inspection	QR 2		160.00																			
Engineering																								
	A 4	Repairable modifications / enginnering	QEN			145.00																		
Maintenance Group																								
Chief and Staff																								
Planning repairable inspections	A 5	Planning, scheduling and maintaining scheduling for repairables	MPR 1				425.00																	
			MPR 2					90.00																
			MR 3								55.00													
			QEN			70.00																		
	A 6	Requiring and controlling materials for repairable inspections	MPR 2					145.00																
			MR 3								55.00													
Rapairable Inspection Squadron																								
		Inspection Rep 1/2/3 - WS1																						
	DAR 1	Activity 1 - Testing repairable failure - Labor skill MR 2,3	MR 2							240.00														
			MR 3								150.00													
	DAR 2	Activity 2 - Taking apart repairable - Labor Skill MR 2	MR 2							240.00														
	DAR 3	Activity 3 - Check material availability - Labor skill MR 1	MR 1						355.00															
	DAR 4	Activity 4 - Set up equipment - Labor skill MR 1	MR 1						355.00															
	DAR 5	Activity 5 - Replace and install materials - Labor skill MR 1,2,3	MR 1						360.00															
			MR 2							240.00														
			MR 3								150.00													
Support Maintenance Squadron																								
Section Electronics & Instrumental	A 7	Electricity and electronic supporting inspection	MSEI									430.00												
Section Structure	A 8	Structure support to inspections	MSS										460.00											
Section Paint	A 9	Paint support to inspections	MSP											440.00										
Section Equipment support	A 10	Maintaining technical equipments and general support	MSEq												460.00									
Section Upholstery	A 11	Upholstery support to inspections	MSU													430.00								
Suply Group																								
Chief and Staff																								
Planning supply support																								
	A 12	Receiving and processing material orders for repairable inspections	SP 1														145.00							
			SP 2															10.00						
	A 13	Ordering materials non available at Depot	SP 1														0.00							
			SP 2															230.00						
	A 14	Scheduling material delivery required for inspections	SP 1														290.00							
			SP 2															0.00						
Supply Repairable Squadron																								
Section Repairable in service	A 15	Receiving, handling and storing repairable from inspections	SR 1																430.00					
			SR 2																	215.00				
Consumable Support Squadron																								
Section Consumables 1	A 16	Handling, preparing and moving consumable for inspections	SC 1																		430.00			
			SC 2																			220.00		
Reception and Expedition	A 17	Reception of non serviceable RI from OL or Ais	SRC 1																				160.00	
Handling and Moving materials			SRC 2																					0.00
	A 18	No serviceable R inspection in the reception	SRC 1																				10.00	
			SRC 2																					140.00
	A 19	Moving No Serviceable (NS) R to NS sections in SG	SRC 1																				150.00	
			SRC 2																					0.00
	A 20	Preparing Rs for shipment to RI in MG	SRC 1																				10.00	
			SRC 2																					75.00
	A 21	Shipment or transporting Rs to MG for RIs	SRC 1																				150.00	
			SRC 2																					0.00
Raw materials invested																								
Consumable 1		**Consumable 1**																						
Consumable 2		**Consumable 2**																						
Consumable 3		**Consumable 3**																						
Consumable 4		**Consumable 4**																						
Consumable 5		**Consumable 5**																						
Facility Suport Group																								
				QR 1	QR 2	QEN	MPR 1	MPR 2	MR 1	MR 2	MR 3	MSEI	MSS	MSP	MSEq	MSU	SP 1	SP 2	SR 1	SR 2	SC 1	SC 2	SRC 1	SRC 2
				425.0	480.0	215.0	425.0	235.0	1,070.0	720.0	410.0	430.0	460.0	440.0	460.0	430.0	435.0	240.0	430.0	215.0	430.0	220.0	480.0	215.0

Table A-4. Resources' Capacity Load Profile

Table A-5. Auxiliary Table

Resources				Activity	Percentage Assigned (Resource Drivers)	Total	PC (Hours)	Repairable Inspection 1			Repairable Inspection 2			Repairable Inspection 3			Repairable Inspection 4			Repairable Inspection 5		
								Unitary AD (Hs or #)	Total	%	Unitary AD (Hs or #)	Total	%	Unitary AD (Hs or #)	Total	%	Unitary AD (Hs or #)	Total	%	Unitary AD (Hs or #)	Total	%
LABOR	QG		QR 1	A 1	25%	25%	832	3.0	3.0	3.61%	6.0	6.0	7.21%	0.5	0.5	0.60%	1.3	1.3	1.50%	7.5	7.5	9.01%
			QR 2	A 1	25%	100%	832	1.0	3.0	3.61%	2.0	6.0	7.21%	2.0	6.0	7.21%	5.0	15.0	18.03%	2.5	7.5	9.01%
				A 2	50%			1.0			2.0			2.0			5.0			2.5		
				A 3	25%			1.0			2.0			2.0			5.0			2.5		
			QEN	A 4	10%	30%	416	1.0	1.5	3.61%	2.0	3.0	7.21%	0.5	0.5	1.20%	1.3	1.3	3.00%	2.5	3.8	9.01%
				A 5	20%			0.5			1.0			0.0			0.0			1.3		
	Subtotal for QG								7.5			15.0			7.0			17.5			18.8	
	MG	Planning	MPR 1	A 5	100%	100%	832	3.0	3.0	3.61%	6.0	6.0	7.21%	0.5	0.5	0.60%	1.3	1.3	1.50%	7.5	7.5	9.01%
			MPR 2	A 5	75%	100%	416	0.5	1.5	3.61%	1.0	3.0	7.21%	2.0	2.5	6.01%	5.0	6.3	15.02%	1.3	3.8	9.01%
				A 6	25%			1.0			2.0			0.5			1.3			2.5		
				Sub for Planning					4.500			9.000			3.000			7.500			11.250	
		Primary	MR 1	DAR 3	50%	100%	2080	2.5	7.5	3.61%	5.0	15.0	7.21%	0.5	2.0	0.96%	1.3	5.0	2.40%	6.3	18.8	9.01%
				DAR 4	25%			2.5			5.0			0.5			1.3			6.3		
				DAR 5	25%			2.5			5.0			1.0			2.5			6.3		
			MR 2	DAR 1	25%	100%	1248	1.5	4.5	3.61%	3.0	9.0	7.21%	3.0	9.0	7.21%	7.5	22.5	18.03%	3.8	11.3	9.01%
				DAR 2	15%			1.5			3.0			3.0			7.5			3.8		
				DAR 5	60%			1.5			3.0			3.0			7.5			3.8		
			MR 3	A 5	15%	100%	416	0.25	2.0	4.81%	1.00	8.0	19.23%	0.50	2.0	4.81%	2.50	10.0	24.04%	0.75	6.0	14.42%
				A 6	15%			0.25			1.00			0.50			2.50			0.75		
				DAR 1	35%			0.75			3.00			0.50			2.50			2.25		
				DAR 5	35%			0.75			3.00			0.50			2.50			2.25		
				Sub for Primary					14.0			32.0			13.0			37.5		0.0	36.0	
		Support	MSEI	A 7	40%	40%	832	3.0	3.0	3.61%	6.0	6.0	7.21%	1.0	1.0	1.20%	2.5	2.5	3.00%	7.5	7.5	9.01%
			MSS	A 8	40%	40%	832	3.0	3.0	3.61%	6.0	6.0	7.21%	4.0	4.0	4.81%	10.0	10.0	12.02%	7.5	7.5	9.01%
			MSP	A 9	40%	40%	832	3.0	3.0	3.61%	6.0	6.0	7.21%	2.0	2.0	2.40%	5.0	5.0	6.01%	7.5	7.5	9.01%
			MSEq	A 10	40%	40%	832	3.0	3.0	3.61%	6.0	6.0	7.21%	4.0	4.0	4.81%	10.0	10.0	12.02%	7.5	7.5	9.01%
			MSU	A 11	40%	40%	832	3.0	3.0	3.61%	6.0	6.0	7.21%	1.0	1.0	1.20%	2.5	2.5	3.00%	7.5	7.5	9.01%
				Sub for Support					15.0			30.0			12.0			30.0		0.0	37.5	
	Subtotal for MG								33.5			71.0			28.0			75.0		0.0	84.8	
	SG		SP 1	A 12	20%	50%	832	1.0	3.0	3.61%	2.0	6.0	7.21%	0.5	1.5	1.80%	1.3	3.8	4.51%	2.5	7.5	9.01%
				A 13	10%			0.0			0.0			0.0			0.0			0.0		
				A 14	20%			2.0			4.0			1.0			2.5			5.0		
			SP 2	A 12	10%	50%	416	0.0	1.5	3.61%	0.0	3.0	7.21%	1.0	3.0	7.21%	2.5	7.5	18.03%	0.0	3.8	9.01%
				A 13	30%			1.5			3.0			2.0			5.0			3.8		
				A 14	10%			0.0			0.0			0.0			0.0			0.0		
			SR 1	A 15	50%	50%	832	3.0	3.0	3.61%	6.0	6.0	7.21%	1.0	1.0	1.20%	2.5	2.5	3.00%	7.5	7.5	9.01%
			SR 2	A 15	50%	50%	416	1.5	1.5	3.61%	3.0	3.0	7.21%	0.5	0.5	1.20%	1.3	1.3	3.00%	3.8	3.8	9.01%
			SC 1	A 16	50%	50%	832	3.0	3.0	3.61%	6.0	6.0	7.21%	1.0	1.0	1.20%	2.5	2.5	3.00%	7.5	7.5	9.01%
			SC 2	A 16	50%	50%	416	1.5	1.5	3.61%	3.0	3.0	7.21%	1.0	1.0	2.40%	2.5	2.5	6.01%	3.8	3.8	9.01%
			SRC 1	A 17	8%	50%	832	1.0	3.0	3.61%	2.0	6.0	7.21%	2.0	6.0	7.21%	5.0	15.0	18.03%	2.5	7.5	9.01%
				A 18	8%			0.0			0.0			1.0			2.5			0.0		
				A 19	12%			1.0			2.0			1.0			2.5			2.5		
				A 20	7%			0.0			0.0			1.0			2.5			0.0		
				A 21	15%			1.0			2.0			1.0			2.5			2.5		
			SRC 2	A 17	15%	50%	416	0.0	1.5	3.61%	0.0	3.0	7.21%	0.0	0.5	1.20%	0.0	1.3	3.00%	0.0	3.8	9.01%
				A 18	15%			1.0			2.0			0.0			0.0			2.5		
				A 19	5%			0.0			0.0			0.0			0.0			0.0		
				A 20	10%			0.5			1.0			0.5			1.3			1.3		
				A 21	5%			0.0			0.0			0.0			0.0			0.0		
	Subtotal for SG								18.0			36.0			14.5			36.3			45.0	
	Mean								2.81	3.61%		5.81	7.21%		2.36	3.08%		6.13	7.71%		7.07	9.01%
	Variance								1.81	0.00%		7.36	0.00%		5.20	0.07%		33.27	0.42%		11.17	0.00%
	GRAND TOTAL							59.0	59.0		122.0	122.0		49.5	49.5		128.8	128.8		148.5	148.5	
RAW MATERIALS			RM 1					3			4			3			4			3		
			RM 2					2			3			2			3			3		
			RM 3					1			2			1			2			2		
			RM 4					0			1			0			1			1		
			RM 5					0			1			0			1			0		

Table A-6. Marginal Analysis Under ABC Approach

Item	R 1				R 2				R 3				R 4				R 5			
UVC	**$2,844**		**Factor**	**1,000,000**	**$5,917**				**$2,497**				**$6,529**				**$7,166**			
Avg Annual Dem	**200**				**80**				**20**				**8**				**80**			
Avg Repair Time	**0.04538**				**0.09385**				**0.03808**				**0.09904**				**0.11423**			
X	Poisson	S	EBO	**BCR**	Poisson	S	EBO	**BCR**	Poisson	S	EBO	**BCR**	Poisson	S	EBO	**BCR**	Poisson	S	EBO	**BCR**
0	0.000	0	9.0769230769		0.001	0	7.5076923077		0.467	0	0.7615384615		0.453	0	0.7923076923		0.000	0	9.1384615385	
1	0.001	1	8.0770373496	**351.63004**	0.004	1	6.5082411539	**168.90522**	0.356	1	0.2284859549	**213.46896**	0.359	1	0.2451063610	**83.80677**	0.001	1	8.1385689910	**139.53328**
2	0.005	2	7.0781888666	**351.26528**	0.015	2	5.5129105685	**168.20885**	0.135	2	0.0510319240	**71.06416**	0.142	2	0.0566608979	**28.86142**	0.004	2	7.1396583942	**139.39625**
3	0.014	3	6.0840478768	**349.60979**	0.039	3	4.5330479627	**165.59479**	0.034	3	0.0089788511	**16.84079**	0.038	3	0.0103379519	**7.09460**	0.014	3	6.1452345565	**138.77013**
4	0.032	4	5.1041500719	**344.60089**	0.073	4	3.5918949678	**159.05295**	0.007	4	0.0012967907	**3.07640**	0.007	4	0.0015499270	**1.34593**	0.031	4	5.1644780777	**136.86288**
5	0.059	5	4.1565733402	**333.23453**	0.109	5	2.7233969347	**146.77441**	0.001	5	0.0001584423	**0.45587**	0.001	5	0.0001967038	**0.20725**	0.057	5	4.2149462570	**132.50553**
6	0.089	6	3.2676717876	**312.60021**	0.137	6	1.9639931211	**128.33770**	0.000	6	0.0000167515	**0.05674**	0.000	6	0.0000216108	**0.02682**	0.087	6	3.3224835038	**124.54164**
7	0.115	7	2.4675352495	**281.38420**	0.146	7	1.3410969463	**105.26819**	0.000	7	0.0000015596	**0.00608**	0.000	7	0.0000020913	**0.00299**	0.113	7	2.5169413304	**112.41202**
8	0.131	8	1.7825005985	**240.90629**	0.137	8	0.8646089643	**80.52550**	0.000	8	0.0000001296	**0.00057**	0.000	8	0.0000001807	**0.00029**	0.130	8	1.8248734963	**96.57687**
9	0.132	9	1.2280623192	**194.97944**	0.115	9	0.5255194402	**57.30544**	0.000	9	0.0000000097	**0.00005**	0.000	9	0.0000000141	**0.00003**	0.132	9	1.2624282728	**78.48826**
10	0.120	10	0.8053366201	**148.66004**	0.086	10	0.3010460656	**37.93555**	0.000	10	0.0000000007	**0.00000**	0.000	10	0.0000000010	**0.00000**	0.120	10	0.8315998539	**60.12136**
11	0.099	11	0.5021654167	**106.61629**	0.059	11	0.1626229694	**23.39322**	0.000	11	0.0000000000	**0.00000**	0.000	11	0.0000000001	**0.00000**	0.100	11	0.5210489458	**43.33684**
12	0.075	12	0.2976475735	**71.92284**	0.037	12	0.0829306926	**13.46783**	0.000	12	0.0000000000	**0.00000**	0.000	12	0.0000000000	**0.00000**	0.076	12	0.3104208927	**29.39278**
13	0.052	13	0.1677521437	**45.68036**	0.021	13	0.0399828258	**7.25810**	0.000	13	0.0000000000	**0.00000**	0.000	13	0.0000000000	**0.00000**	0.053	13	0.1758879369	**18.77384**
14	0.034	14	0.0899599375	**27.35720**	0.011	14	0.0182553994	**3.67189**	0.000	14	0.0000000000	**0.00000**	0.000	14	0.0000000000	**0.00000**	0.035	14	0.0948466827	**11.30917**
15	0.020	15	0.0459489422	**15.47736**	0.006	15	0.0079077257	**1.74874**	0.000	15	0.0000000000	**0.00000**	0.000	15	0.0000000000	**0.00000**	0.021	15	0.0487219897	**6.43662**
16	0.012	16	0.0223799104	**8.28853**	0.003	16	0.0032557640	**0.78617**	0.000	16	0.0000000000	**0.00000**	0.000	16	0.0000000000	**0.00000**	0.012	16	0.0238695401	**3.46812**
17	0.006	17	0.0104077618	**4.21025**	0.001	17	0.0012764057	**0.33451**	0.000	17	0.0000000000	**0.00000**	0.000	17	0.0000000000	**0.00000**	0.007	17	0.0111668142	**1.77264**
18	0.003	18	0.0046276141	**2.03271**	0.000	18	0.0004773464	**0.13504**	0.000	18	0.0000000000	**0.00000**	0.000	18	0.0000000000	**0.00000**	0.003	18	0.0049952520	**0.86123**
19	0.001	19	0.0019699285	**0.93463**	0.000	19	0.0001705828	**0.05184**	0.000	19	0.0000000000	**0.00000**	0.000	19	0.0000000000	**0.00000**	0.002	19	0.0021395113	**0.39851**
20	0.001	20	0.0008039453	**0.41004**	0.000	20	0.0000583458	**0.01897**	0.000	20	0.0000000000	**0.00000**	0.000	20	0.0000000000	**0.00000**	0.001	20	0.0008785869	**0.17596**
21	0.000	21	0.0003149656	**0.17196**	0.000	21	0.0000191310	**0.00663**	0.000	21	0.0000000000	**0.00000**	0.000	21	0.0000000000	**0.00000**	0.000	21	0.0003463707	**0.07427**
22	0.000	22	0.0001186101	**0.06905**	0.000	22	0.0000060224	**0.00222**	0.000	22	0.0000000000	**0.00000**	0.000	22	0.0000000000	**0.00000**	0.000	22	0.0001312628	**0.03002**
23	0.000	23	0.0000429877	**0.02659**	0.000	23	0.0000018227	**0.00071**	0.000	23	0.0000000000	**0.00000**	0.000	23	0.0000000000	**0.00000**	0.000	23	0.0000478768	**0.01164**
24	0.000	24	0.0000150124	**0.00984**	0.000	24	0.0000005311	**0.00022**	0.000	24	0.0000000000	**0.00000**	0.000	24	0.0000000000	**0.00000**	0.000	24	0.0000168271	**0.00433**
25	0.000	25	0.0000050575	**0.00350**	0.000	25	0.0000001492	**0.00006**	0.000	25	0.0000000000	**0.00000**	0.000	25	0.0000000000	**0.00000**	0.000	25	0.0000057054	**0.00155**
26	0.000	26	0.0000016455	**0.00120**	0.000	26	0.0000000404	**0.00002**	0.000	26	0.0000000000	**0.00000**	0.000	26	0.0000000000	**0.00000**	0.000	26	0.0000018683	**0.00054**
27	0.000	27	0.0000005175	**0.00040**	0.000	27	0.0000000106	**0.00001**	0.000	27	0.0000000000	**0.00000**	0.000	27	0.0000000000	**0.00000**	0.000	27	0.0000005914	**0.00018**
28	0.000	28	0.0000001575	**0.00013**	0.000	28	0.0000000027	**0.00000**	0.000	28	0.0000000000	**0.00000**	0.000	28	0.0000000000	**0.00000**	0.000	28	0.0000001812	**0.00006**
29	0.000	29	0.0000000464	**0.00004**	0.000	29	0.0000000007	**0.00000**	0.000	29	0.0000000000	**0.00000**	0.000	29	0.0000000000	**0.00000**	0.000	29	0.0000000538	**0.00002**
30	0.000	30	0.0000000133	**0.00001**	0.000	30	0.0000000002	**0.00000**	0.000	30	0.0000000000	**0.00000**	0.000	30	0.0000000000	**0.00000**	0.000	30	0.0000000155	**0.00001**
31	0.000	31	0.0000000037	**0.00000**	0.000	31	0.0000000000	**0.00000**	0.000	31	0.0000000000	**0.00000**	0.000	31	0.0000000000	**0.00000**	0.000	31	0.0000000043	**0.00000**
32	0.000	32	0.0000000010	**0.00000**	0.000	32	0.0000000000	**0.00000**	0.000	32	0.0000000000	**0.00000**	0.000	32	0.0000000000	**0.00000**	0.000	32	0.0000000012	**0.00000**
33	0.000	33	0.0000000003	**0.00000**	0.000	33	0.0000000000	**0.00000**	0.000	33	0.0000000000	**0.00000**	0.000	33	0.0000000000	**0.00000**	0.000	33	0.0000000003	**0.00000**
34	0.000	34	0.0000000001	**0.00000**	0.000	34	0.0000000000	**0.00000**	0.000	34	0.0000000000	**0.00000**	0.000	34	0.0000000000	**0.00000**	0.000	34	0.0000000001	**0.00000**
35	0.000	35	0.0000000000	**0.00000**	0.000	35	0.0000000000	**0.00000**	0.000	35	0.0000000000	**0.00000**	0.000	35	0.0000000000	**0.00000**	0.000	35	0.0000000000	**0.00000**
36	0.000	36	0.0000000000	**0.00000**	0.000	36	0.0000000000	**0.00000**	0.000	36	0.0000000000	**0.00000**	0.000	36	0.0000000000	**0.00000**	0.000	36	0.0000000000	**0.00000**
37	0.000	37	0.0000000000	**0.00000**	0.000	37	0.0000000000	**0.00000**	0.000	37	0.0000000000	**0.00000**	0.000	37	0.0000000000	**0.00000**	0.000	37	0.0000000000	**0.00000**
38	0.000	38	0.0000000000	**0.00000**	0.000	38	0.0000000000	**0.00000**	0.000	38	0.0000000000	**0.00000**	0.000	38	0.0000000000	**0.00000**	0.000	38	0.0000000000	**0.00000**
39	0.000	39	0.0000000000	**0.00000**	0.000	39	0.0000000000	**0.00000**	0.000	39	0.0000000000	**0.00000**	0.000	39	0.0000000000	**0.00000**	0.000	39	0.0000000000	**0.00000**
40	0.000	40	0.0000000000	**0.00000**	0.000	40	0.0000000000	**0.00000**	0.000	40	0.0000000000	**0.00000**	0.000	40	0.0000000000	**0.00000**	0.000	40	0.0000000000	**0.00000**
41	0.000	41	0.0000000000	**0.00000**	0.000	41	0.0000000000	**0.00000**	0.000	41	0.0000000000	**0.00000**	0.000	41	0.0000000000	**0.00000**	0.000	41	0.0000000000	**0.00000**
42	0.000	42	0.0000000000	**0.00000**	0.000	42	0.0000000000	**0.00000**	0.000	42	0.0000000000	**0.00000**	0.000	42	0.0000000000	**0.00000**	0.000	42	0.0000000000	**0.00000**
43	0.000	43	0.0000000000	**0.00000**	0.000	43	0.0000000000	**0.00000**	0.000	43	0.0000000000	**0.00000**	0.000	43	0.0000000000	**0.00000**	0.000	43	0.0000000000	**0.00000**
44	0.000	44	0.0000000000	**0.00000**	0.000	44	0.0000000000	**0.00000**	0.000	44	0.0000000000	**0.00000**	0.000	44	0.0000000000	**0.00000**	0.000	44	0.0000000000	**0.00000**
45	0.000	45	0.0000000000	**0.00000**	0.000	45	0.0000000000	**0.00000**	0.000	45	0.0000000000	**0.00000**	0.000	45	0.0000000000	**0.00000**	0.000	45	0.0000000000	**0.00000**
46	0.000	46	0.0000000000	**0.00000**	0.000	46	0.0000000000	**0.00000**	0.000	46	0.0000000000	**0.00000**	0.000	46	0.0000000000	**0.00000**	0.000	46	0.0000000000	**0.00000**
47	0.000	47	0.0000000000	**0.00000**	0.000	47	0.0000000000	**0.00000**	0.000	47	0.0000000000	**0.00000**	0.000	47	0.0000000000	**0.00000**	0.000	47	0.0000000000	**0.00000**
48	0.000	48	0.0000000000	**0.00000**	0.000	48	0.0000000000	**0.00000**	0.000	48	0.0000000000	**0.00000**	0.000	48	0.0000000000	**0.00000**	0.000	48	0.0000000000	**0.00000**
49	0.000	49	0.0000000000	**0.00000**	0.000	49	0.0000000000	**0.00000**	0.000	49	0.0000000000	**0.00000**	0.000	49	0.0000000000	**0.00000**	0.000	49	0.0000000000	**0.00000**
50	0.000	50	0.0000000000	**0.00000**	0.000	50	0.0000000000	**0.00000**	0.000	50	0.0000000000	**0.00000**	0.000	50	0.0000000000	**0.00000**	0.000	50	0.0000000000	**0.00000**
51	0.000	51	0.0000000000	**0.00000**	0.000	51	0.0000000000	**0.00000**	0.000	51	0.0000000000	**0.00000**	0.000	51	0.0000000000	**0.00000**	0.000	51	0.0000000000	**0.00000**
52	0.000	52	0.0000000000	**0.00000**	0.000	52	0.0000000000	**0.00000**	0.000	52	0.0000000000	**0.00000**	0.000	52	0.0000000000	**0.00000**	0.000	52	0.0000000000	**0.00000**
53	0.000	53	0.0000000000	**0.00000**	0.000	53	0.0000000000	**0.00000**	0.000	53	0.0000000000	**0.00000**	0.000	53	0.0000000000	**0.00000**	0.000	53	0.0000000000	**0.00000**
54	0.000	54	0.0000000000	**0.00000**	0.000	54	0.0000000000	**0.00000**	0.000	54	0.0000000000	**0.00000**	0.000	54	0.0000000000	**0.00000**	0.000	54	0.0000000000	**0.00000**
55	0.000	55	0.0000000000	**0.00000**	0.000	55	0.0000000000	**0.00000**	0.000	55	0.0000000000	**0.00000**	0.000	55	0.0000000000	**0.00000**	0.000	55	0.0000000000	**0.00000**
56	0.000	56	0.0000000000	**0.00000**	0.000	56	0.0000000000	**0.00000**	0.000	56	0.0000000000	**0.00000**	0.000	56	0.0000000000	**0.00000**	0.000	56	0.0000000000	**0.00000**
57	0.000	57	0.0000000000	**0.00000**	0.000	57	0.0000000000	**0.00000**	0.000	57	0.0000000000	**0.00000**	0.000	57	0.0000000000	**0.00000**	0.000	57	0.0000000000	**0.00000**
58	0.000	58	0.0000000000	**0.00000**	0.000	58	0.0000000000	**0.00000**	0.000	58	0.0000000000	**0.00000**	0.000	58	0.0000000000	**0.00000**	0.000	58	0.0000000000	**0.00000**
59	0.000	59	0.0000000000	**0.00000**	0.000	59	0.0000000000	**0.00000**	0.000	59	0.0000000000	**0.00000**	0.000	59	0.0000000000	**0.00000**	0.000	59	0.0000000000	**0.00000**
60	0.000	60	0.0000000000	**0.00000**	0.000	60	0.0000000000	**0.00000**	0.000	60	0.0000000000	**0.00000**	0.000	60	0.0000000000	**0.00000**	0.000	60	0.0000000000	**0.00000**
61	0.000	61	0.0000000000	**0.00000**	0.000	61	0.0000000000	**0.00000**	0.000	61	0.0000000000	**0.00000**	0.000	61	0.0000000000	**0.00000**	0.000	61	0.0000000000	**0.00000**
62	0.000	62	0.0000000000	**0.00000**	0.000	62	0.0000000000	**0.00000**	0.000	62	0.0000000000	**0.00000**	0.000	62	0.0000000000	**0.00000**	0.000	62	0.0000000000	**0.00000**
63	0.000	63	0.0000000000	**0.00000**	0.000	63	0.0000000000	**0.00000**	0.000	63	0.0000000000	**0.00000**	0.000	63	0.0000000000	**0.00000**	0.000	63	0.0000000000	**0.00000**
64	0.000	64	0.0000000000	**0.00000**	0.000	64	0.0000000000	**0.00000**	0.000	64	0.0000000000	**0.00000**	0.000	64	0.0000000000	**0.00000**	0.000	64	0.0000000000	**0.00000**
65	0.000	65	0.0000000000	**0.00000**	0.000	65	0.0000000000	**0.00000**	0.000	65	0.0000000000	**0.00000**	0.000	65	0.0000000000	**0.00000**	0.000	65	0.0000000000	**0.00000**
66	0.000	66	0.0000000000	**0.00000**	0.000	66	0.0000000000	**0.00000**	0.000	66	0.0000000000	**0.00000**	0.000	66	0.0000000000	**0.00000**	0.000	66	0.0000000000	**0.00000**
67	0.000	67	0.0000000000	**0.00000**	0.000	67	0.0000000000	**0.00000**	0.000	67	0.0000000000	**0.00000**	0.000	67	0.0000000000	**0.00000**	0.000	67	0.0000000000	**0.00000**
68	0.000	68	0.0000000000	**0.00000**	0.000	68	0.0000000000	**0.00000**	0.000	68	0.0000000000	**0.00000**	0.000	68	0.0000000000	**0.00000**	0.000	68	0.0000000000	**0.00000**
69	0.000	69	0.0000000000	**0.00000**	0.000	69	0.0000000000	**0.00000**	0.000	69	0.0000000000	**0.00000**	0.000	69	0.0000000000	**0.00000**	0.000	69	0.0000000000	**0.00000**
70	0.000	70	0.0000000000	**0.00000**	0.000	70	0.0000000000	**0.00000**	0.000	70	0.0000000000	**0.00000**	0.000	70	0.0000000000	**0.00000**	0.000	70	0.0000000000	**0.00000**
71	0.000	71	0.0000000000	**0.00000**	0.000	71	0.0000000000	**0.00000**	0.000	71	0.0000000000	**0.00000**	0.000	71	0.0000000000	**0.00000**	0.000	71	0.0000000000	**0.00000**
72	0.000	72	0.0000000000	**0.00000**	0.000	72	0.0000000000	**0.00000**	0.000	72	0.0000000000	**0.00000**	0.000	72	0.0000000000	**0.00000**	0.000	72	0.0000000000	**0.00000**
73	0.000	73	0.0000000000	**0.00000**	0.000	73	0.0000000000	**0.00000**	0.000	73	0.0000000000	**0.00000**	0.000	73	0.0000000000	**0.00000**	0.000	73	0.0000000000	**0.00000**
74	0.000	74	0.0000000000	**0.00000**	0.000	74	0.0000000000	**0.00000**	0.000	74	0.0000000000	**0.00000**	0.000	74	0.0000000000	**0.00000**	0.000	74	0.0000000000	**0.00000**
75	0.000	75	0.0000000000	**0.00000**	0.000	75	0.0000000000	**0.00000**	0.000	75	0.0000000000	**0.00000**	0.000	75	0.0000000000	**0.00000**	0.000	75	0.0000000000	**0.00000**
76	0.000	76	0.0000000000	**0.00000**	0.000	76	0.0000000000	**0.00000**	0.000	76	0.0000000000	**0.00000**	0.000	76	0.0000000000	**0.00000**	0.000	76	0.0000000000	**0.00000**
77	0.000	77	0.0000000000	**0.00000**	0.000	77	0.0000000000	**0.00000**	0.000	77	0.0000000000	**0.00000**	0.000	77	0.0000000000	**0.00000**	0.000	77	0.0000000000	**0.00000**
78	0.000	78	0.0000000000	**0.00000**	0.000	78	0.0000000000	**0.00000**	0.000	78	0.0000000000	**0.00000**	0.000	78	0.0000000000	**0.00000**	0.000	78	0.0000000000	**0.00000**
79	0.000	79	0.0000000000	**0.00000**	0.000	79	0.0000000000	**0.00000**	0.000	79	0.0000000000	**0.00000**	0.000	79	0.0000000000	**0.00000**	0.000	79	0.0000000000	**0.00000**
80	0.000	80	0.0000000000	**0.00000**	0.000	80	0.0000000000	**0.00000**	0.000	80	0.0000000000	**0.00000**	0.000	80	0.0000000000	**0.00000**	0.000	80	0.0000000000	**0.00000**

Table A-7. Repairing List Under ABC Approach

RI		R 1				R 2				R 3				R 4				R 5				AA ABC	TOTAL UVC (ABC)	TOTAL FIXED COSTS	TOTAL RM COSTS	TOTAL SYSTEM COSTS
UVC (ABC)		$2,843.57				$5,917.23				$2,497.10				$6,529.32				$7,165.98								
RM		$1,422.90				$2,960.50				$1,249.50				$3,266.10				$3,585.45								
Step	RI	#	# Tot	EBO	AA	#	# Tot	EBO	AA	#	# Tot	EBO	AA	#	# Tot	EBO	AA	#	# Tot	EBO	AA					
1	R 1	1	1	8.07703735	0.5753665	0	0	7.50769231	0.6003353	0	0	0.76153846	0.953155	0	0	0.79230769	0.9512937	0	0	9.13846154	0.5306843	0.166208	$2,844	$390,000	$1,423	$391,423
2	R 1	1	2	7.07818887	0.619642	0	0	7.50769231	0.6003353	0	0	0.76153846	0.953155	0	0	0.79230769	0.9512937	0	0	9.13846154	0.5306843	0.178998	$5,687	$390,000	$2,846	$392,846
3	R 1	1	3	6.08404788	0.6659081	0	0	7.50769231	0.6003353	0	0	0.76153846	0.953155	0	0	0.79230769	0.9512937	0	0	9.13846154	0.5306843	0.192363	$8,531	$390,000	$4,269	$394,269
4	R 1	1	4	5.10415007	0.7137106	0	0	7.50769231	0.6003353	0	0	0.76153846	0.953155	0	0	0.79230769	0.9512937	0	0	9.13846154	0.5306843	0.206172	$11,374	$390,000	$5,692	$395,692
5	R 1	1	5	4.15657334	0.762061	0	0	7.50769231	0.6003353	0	0	0.76153846	0.953155	0	0	0.79230769	0.9512937	0	0	9.13846154	0.5306843	0.220140	$14,218	$390,000	$7,115	$397,115
6	R 1	1	6	3.26767179	0.8093582	0	0	7.50769231	0.6003353	0	0	0.76153846	0.953155	0	0	0.79230769	0.9512937	0	0	9.13846154	0.5306843	0.233802	$17,061	$390,000	$8,537	$398,537
7	R 1	1	7	2.46753525	0.8535712	0	0	7.50769231	0.6003353	0	0	0.76153846	0.953155	0	0	0.79230769	0.9512937	0	0	9.13846154	0.5306843	0.246574	$19,905	$390,000	$9,960	$399,960
8	R 1	1	8	1.78250060	0.8926796	0	0	7.50769231	0.6003353	0	0	0.76153846	0.953155	0	0	0.79230769	0.9512937	0	0	9.13846154	0.5306843	0.257872	$22,749	$390,000	$11,383	$401,383
9	R 3	0	8	1.78250060	0.8926796	0	0	7.50769231	0.6003353	1	1	0.22848595	0.9857875	0	0	0.79230769	0.9512937	0	0	9.13846154	0.5306843	0.266700	$25,246	$390,000	$12,633	$402,633
10	R 1	1	9	1.22806232	0.9251931	0	0	7.50769231	0.6003353	0	1	0.22848595	0.9857875	0	0	0.79230769	0.9512937	0	0	9.13846154	0.5306843	0.276414	$28,089	$390,000	$14,056	$404,056
11	R 2	0	9	1.22806232	0.9251931	1	1	6.50824115	0.6458949	0	1	0.22848595	0.9857875	0	0	0.79230769	0.9512937	0	0	9.13846154	0.5306843	0.297391	$34,006	$390,000	$17,016	$407,016
12	R 2	0	9	1.22806232	0.9251931	1	2	5.51291057	0.6935012	0	1	0.22848595	0.9857875	0	0	0.79230769	0.9512937	0	0	9.13846154	0.5306843	0.319311	$39,924	$390,000	$19,977	$409,977
13	R 2	0	9	1.22806232	0.9251931	1	3	4.53304796	0.7425981	0	1	0.22848595	0.9857875	0	0	0.79230769	0.9512937	0	0	9.13846154	0.5306843	0.341917	$45,841	$390,000	$22,937	$412,937
14	R 2	0	9	1.22806232	0.9251931	1	4	3.59189497	0.7918866	0	1	0.22848595	0.9857875	0	0	0.79230769	0.9512937	0	0	9.13846154	0.5306843	0.364611	$51,758	$390,000	$25,898	$415,898
15	R 1	1	10	0.80533662	0.9505062	0	4	3.59189497	0.7918866	0	1	0.22848595	0.9857875	0	0	0.79230769	0.9512937	0	0	9.13846154	0.5306843	0.374587	$54,602	$390,000	$27,321	$417,321
16	R 2	0	10	0.80533662	0.9505062	1	5	2.72339693	0.8392625	0	1	0.22848595	0.9857875	0	0	0.79230769	0.9512937	0	0	9.13846154	0.5306843	0.396997	$60,519	$390,000	$30,281	$420,281
17	R 5	0	10	0.80533662	0.9505062	0	5	2.72339693	0.8392625	0	1	0.22848595	0.9857875	0	0	0.79230769	0.9512937	1	1	8.13856899	0.5727102	0.428436	$67,685	$390,000	$33,866	$423,866
18	R 5	0	10	0.80533662	0.9505062	0	5	2.72339693	0.8392625	0	1	0.22848595	0.9857875	0	0	0.79230769	0.9512937	1	2	7.13965839	0.6168538	0.461459	$74,851	$390,000	$37,452	$427,452
19	R 5	0	10	0.80533662	0.9505062	0	5	2.72339693	0.8392625	0	1	0.22848595	0.9857875	0	0	0.79230769	0.9512937	1	3	6.14523456	0.6629962	0.495977	$82,017	$390,000	$41,037	$431,037
20	R 5	0	10	0.80533662	0.9505062	0	5	2.72339693	0.8392625	0	1	0.22848595	0.9857875	0	0	0.79230769	0.9512937	1	4	5.16447808	0.7107035	0.531666	$89,183	$390,000	$44,623	$434,623
21	R 5	0	10	0.80533662	0.9505062	0	5	2.72339693	0.8392625	0	1	0.22848595	0.9857875	0	0	0.79230769	0.9512937	1	5	4.21494626	0.7590213	0.567812	$96,349	$390,000	$48,208	$438,208
22	R 2	0	10	0.80533662	0.9505062	1	6	1.96399312	0.8822044	0	1	0.22848595	0.9857875	0	0	0.79230769	0.9512937	0	5	4.21494626	0.7590213	0.596865	$102,266	$390,000	$51,169	$441,169
23	R 5	0	10	0.80533662	0.9505062	0	6	1.96399312	0.8822044	0	1	0.22848595	0.9857875	0	0	0.79230769	0.9512937	1	6	3.32248350	0.8063867	0.634111	$109,432	$390,000	$54,754	$444,754
24	R 5	0	10	0.80533662	0.9505062	0	6	1.96399312	0.8822044	0	1	0.22848595	0.9857875	0	0	0.79230769	0.9512937	1	7	2.51694133	0.8507957	0.669033	$116,598	$390,000	$58,340	$448,340
25	R 1	1	11	0.50216542	0.9689419	0	6	1.96399312	0.8822044	0	1	0.22848595	0.9857875	0	0	0.79230769	0.9512937	0	7	2.51694133	0.8507957	0.682009	$119,442	$390,000	$59,763	$449,763
26	R 2	0	11	0.50216542	0.9689419	1	7	1.34109695	0.9185015	0	1	0.22848595	0.9857875	0	0	0.79230769	0.9512937	0	7	2.51694133	0.8507957	0.710069	$125,359	$390,000	$62,723	$452,723
27	R 5	0	11	0.50216542	0.9689419	0	7	1.34109695	0.9185015	0	1	0.22848595	0.9857875	0	0	0.79230769	0.9512937	1	8	1.82487350	0.8902266	0.742978	$132,525	$390,000	$66,309	$456,309
28	R 4	0	11	0.50216542	0.9689419	0	7	1.34109695	0.9185015	0	1	0.22848595	0.9857875	1	1	0.24510636	0.9847589	0	8	1.82487350	0.8902266	0.769115	$139,054	$390,000	$69,575	$459,575
29	R 2	0	11	0.50216542	0.9689419	1	8	0.86460896	0.9469295	0	1	0.22848595	0.9857875	0	1	0.24510636	0.9847589	0	8	1.82487350	0.8902266	0.792920	$144,971	$390,000	$72,535	$462,535
30	R 5	0	11	0.50216542	0.9689419	0	8	0.86460896	0.9469295	0	1	0.22848595	0.9857875	0	1	0.24510636	0.9847589	1	9	1.26242827	0.9231552	0.822249	$152,137	$390,000	$76,121	$466,121
31	R 1	1	12	0.29764757	0.9815121	0	8	0.86460896	0.9469295	0	1	0.22848595	0.9857875	0	1	0.24510636	0.9847589	0	9	1.26242827	0.9231552	0.832916	$154,981	$390,000	$77,543	$467,543
32	R 3	0	12	0.29764757	0.9815121	0	8	0.86460896	0.9469295	1	2	0.05103192	0.9968139	0	1	0.24510636	0.9847589	0	9	1.26242827	0.9231552	0.842233	$157,478	$390,000	$78,793	$468,793
33	R 5	0	12	0.29764757	0.9815121	0	8	0.86460896	0.9469295	0	2	0.05103192	0.9968139	0	1	0.24510636	0.9847589	1	10	0.83159985	0.9489203	0.865739	$164,644	$390,000	$82,378	$472,378
34	R 2	0	12	0.29764757	0.9815121	1	9	0.52551944	0.9675133	0	2	0.05103192	0.9968139	0	1	0.24510636	0.9847589	0	10	0.83159985	0.9489203	0.884558	$170,561	$390,000	$85,339	$475,339
35	R 1	1	13	0.16775214	0.9895521	0	9	0.52551944	0.9675133	0	2	0.05103192	0.9968139	0	1	0.24510636	0.9847589	0	10	0.83159985	0.9489203	0.891804	$173,405	$390,000	$86,762	$476,762
36	R 5	0	13	0.16775214	0.9895521	0	9	0.52551944	0.9675133	0	2	0.05103192	0.9968139	0	1	0.24510636	0.9847589	1	11	0.52104895	0.9677867	0.909535	$180,571	$390,000	$90,347	$480,347
37	R 2	0	13	0.16775214	0.9895521	1	10	0.30104607	0.9813024	0	2	0.05103192	0.9968139	0	1	0.24510636	0.9847589	0	11	0.52104895	0.9677867	0.922497	$186,488	$390,000	$93,308	$483,308
38	R 5	0	13	0.16775214	0.9895521	0	10	0.30104607	0.9813024	0	2	0.05103192	0.9968139	0	1	0.24510636	0.9847589	1	12	0.31042089	0.9807239	0.934829	$193,654	$390,000	$96,893	$486,893
39	R 4	0	13	0.16775214	0.9895521	0	10	0.30104607	0.9813024	0	2	0.05103192	0.9968139	1	2	0.05666090	0.9964629	0	12	0.31042089	0.9807239	0.945940	$200,183	$390,000	$100,159	$490,159
40	R 1	1	14	0.08995994	0.994388	0	10	0.30104607	0.9813024	0	2	0.05103192	0.9968139	0	2	0.05666090	0.9964629	0	12	0.31042089	0.9807239	0.950563	$203,027	$390,000	$101,582	$491,582
41	R 2	0	14	0.08995994	0.994388	1	11	0.16262297	0.9898705	0	2	0.05103192	0.9968139	0	2	0.05666090	0.9964629	0	12	0.31042089	0.9807239	0.958862	$208,944	$390,000	$104,543	$494,543
42	R 5	0	14	0.08995994	0.994388	0	11	0.16262297	0.9898705	0	2	0.05103192	0.9968139	0	2	0.05666090	0.9964629	1	13	0.17588794	0.9890472	0.967000	$216,110	$390,000	$108,128	$498,128
43	R 3	0	14	0.08995994	0.994388	0	11	0.16262297	0.9898705	1	3	0.00897885	0.9994389	0	2	0.05666090	0.9964629	0	13	0.17588794	0.9890472	0.969547	$218,607	$390,000	$109,378	$499,378
44	R 1	1	15	0.04594894	0.9971309	0	11	0.16262297	0.9898705	0	3	0.00897885	0.9994389	0	2	0.05666090	0.9964629	0	13	0.17588794	0.9890472	0.972221	$221,451	$390,000	$110,801	$500,801
45	R 2	0	15	0.04594894	0.9971309	1	12	0.08293069	0.9948258	0	3	0.00897885	0.9994389	0	2	0.05666090	0.9964629	0	13	0.17588794	0.9890472	0.977088	$227,368	$390,000	$113,761	$503,761
46	R 5	0	15	0.04594894	0.9971309	0	12	0.08293069	0.9948258	0	3	0.00897885	0.9994389	0	2	0.05666090	0.9964629	1	14	0.09484668	0.9940838	0.982064	$234,534	$390,000	$117,347	$507,347
47	R 1	1	16	0.02237991	0.9986019	0	12	0.08293069	0.9948258	0	3	0.00897885	0.9994389	0	2	0.05666090	0.9964629	0	14	0.09484668	0.9940838	0.983512	$237,378	$390,000	$118,769	$508,769
48	R 2	0	16	0.02237991	0.9986019	1	13	0.03998283	0.9975032	0	3	0.00897885	0.9994389	0	2	0.05666090	0.9964629	0	14	0.09484668	0.9940838	0.986159	$243,295	$390,000	$121,730	$511,730
49	R 4	0	16	0.02237991	0.9986019	0	13	0.03998283	0.9975032	0	3	0.00897885	0.9994389	1	3	0.01033795	0.999354	0	14	0.09484668	0.9940838	0.989020	$249,824	$390,000	$124,996	$514,996
50	R 5	0	16	0.02237991	0.9986019	0	13	0.03998283	0.9975032	0	3	0.00897885	0.9994389	0	3	0.01033795	0.999354	1	15	0.04872199	0.996958	0.991880	$256,990	$390,000	$128,581	$518,581
51	R 1	1	17	0.01040776	0.9993497	0	13	0.03998283	0.9975032	0	3	0.00897885	0.9994389	0	3	0.01033795	0.999354	0	15	0.04872199	0.996958	0.992623	$259,834	$390,000	$130,004	$520,004
52	R 2	0	17	0.01040776	0.9993497	1	14	0.01825540	0.9988595	0	3	0.00897885	0.9994389	0	3	0.01033795	0.999354	0	15	0.04872199	0.996958	0.993972	$265,751	$390,000	$132,965	$522,965
53	R 5	0	17	0.01040776	0.9993497	0	14	0.01825540	0.9988595	0	3	0.00897885	0.9994389	0	3	0.01033795	0.999354	1	16	0.02386954	0.9985089	0.995519	$272,917	$390,000	$136,550	$526,550
54	R 3	0	17	0.01040776	0.9993497	0	14	0.01825540	0.9988595	1	4	0.00129679	0.999919	0	3	0.01033795	0.999354	0	16	0.02386954	0.9985089	0.995997	$275,414	$390,000	$137,800	$527,800
55	R 1	1	18	0.00462761	0.9997108	0	14	0.01825540	0.9988595	0	4	0.00129679	0.999919	0	3	0.01033795	0.999354	0	16	0.02386954	0.9985089	0.996357	$278,258	$390,000	$139,223	$529,223
56	R 5	0	18	0.00462761	0.9997108	0	14	0.01825540	0.9988595	0	4	0.00129679	0.999919	0	3	0.01033795	0.999354	1	17	0.01116681	0.9993022	0.997148	$285,424	$390,000	$142,808	$532,808
57	R 2	0	18	0.00462761	0.9997108	1	15	0.00790773	0.9995058	0	4	0.00129679	0.999919	0	3	0.01033795	0.999354	0	17	0.01116681	0.9993022	0.997794	$291,341	$390,000	$145,769	$535,769
58	R 4	0	18	0.00462761	0.9997108	0	15	0.00790773	0.9995058	0	4	0.00129679	0.999919	1	4	0.00154993	0.9999031	0	17	0.01116681	0.9993022	0.998342	$297,870	$390,000	$149,035	$539,035
59	R 1	1	19	0.00196993	0.9998769	0	15	0.00790773	0.9995058	0	4	0.00129679	0.999919	0	4	0.00154993	0.9999031	0	17	0.01116681	0.9993022	0.998508	$300,714	$390,000	$150,458	$540,458
60	R 5	0	19	0.00196993	0.9998769	0	15	0.00790773	0.9995058	0	4	0.00129679	0.999919	0	4	0.00154993	0.9999031	1	18	0.00499525	0.9996878	0.998893	$307,880	$390,000	$154,043	$544,043
61	R 2	0	19	0.00196993	0.9998769	1	16	0.00325576	0.9997965	0	4	0.00129679	0.999919	0	4	0.00154993	0.9999031	0	18	0.00499525	0.9996878	0.999184	$313,797	$390,000	$157,004	$547,004
62	R 3	0	19	0.00196993	0.9998769	0	16	0.00325576	0.9997965	1	5	0.00015844	0.9999901	0	4	0.00154993	0.9999031	0	18	0.00499525	0.9996878	0.999255	$316,294	$390,000	$158,253	$548,253
63	R 1	1	20	0.00080395	0.9999498	0	16	0.00325576	0.9997965	0	5	0.00015844	0.9999901	0	4	0.00154993	0.9999031	0	18	0.00499525	0.9996878	0.999327	$319,138	$390,000	$159,676	$549,676
64	R 5	0	20	0.00080395	0.9999498	0	16	0.00325576	0.9997965	0	5	0.00015844	0.9999901	0	4	0.00154993	0.9999031	1	19	0.00213951	0.9998663	0.999506	$326,304	$390,000	$163,261	$553,261
65	R 2	0	20	0.00080395	0.9999498	1	17	0.00127641	0.9999202	0	5	0.00015844	0.9999901	0	4	0.00154993	0.9999031	0	19	0.00213951	0.9998663	0.999630	$332,221	$390,000	$166,222	$556,222
66	R 4	0	20	0.00080395	0.9999498	0	17	0.00127641	0.9999202	0	5	0.00015844	0.9999901	1	5	0.00019670	0.9999877	0	19	0.00213951	0.9998663	0.999714	$338,750	$390,000	$169,488	$559,488
67	R 5	0	20	0.00080395	0.9999498	0	17	0.00127641	0.9999202	0	5	0.00015844	0.9999901	0	5	0.00019670	0.9999877	1	20	0.00087859	0.9999451	0.999793	$345,916	$390,000	$173,074	$563,074
68	R 1	1	21	0.00031497	0.9999803	0	17	0.00127641	0.9999202	0	5	0.00015844	0.9999901	0	5	0.00019670	0.9999877	0	20	0.00087859	0.9999451	0.999823	$348,760	$390,000	$174,496	$564,496
69	R 2	0	21	0.00031497	0.9999803	1	18	0.00047735	0.9999702	0	5	0.00015844	0.9999901	0	5	0.00019670	0.9999877	0	20	0.00087859	0.9999451	0.999873	$354,677	$390,000	$177,457	$567,457
70	R 5	0	21	0.00031497	0.9999803	0	18	0.00047735	0.9999702	0	5	0.00015844	0.9999901	0	5	0.00019670	0.9999877	1	21	0.00034637	0.9999784	0.999907	$361,843	$390,000	$181,042	$571,042
71	R 1	1	22	0.00011861	0.9999926	0	18	0.00047735	0.9999702	0	5	0.00015844	0.9999901	0	5	0.00019670	0.9999877	0	21	0.00034637	0.9999784	0.999919	$364,686	$390,000	$182,465	$572,465
72	R 3	0	22	0.00011861	0.9999926	0	18	0.00047735	0.9999702	1	6	0.00001675	0.999999	0	5	0.00019670	0.9999877	0	21	0.00034637	0.9999784	0.999928	$367,184	$390,000	$183,715	$573,715
73	R 2	0	22	0.00011861	0.9999926	1	19	0.00017058	0.9999893	0	6	0.00001675	0.999999	0	5	0.00019670	0.9999877	0	21	0.00034637	0.9999784	0.999947	$373,101	$390,000	$186,675	$576,675
74	R 5	0	22	0.00011861	0.9999926	0	19	0.00017058	0.9999893	0	6	0.00001675	0.999999	0	5	0.00019670	0.9999877	1	22	0.00013126	0.9999918	0.999960	$380,267	$390,000	$190,261	$580,261
75	R 4	0	22	0.00011861	0.9999926	0	19	0.00017058	0.9999893	0	6	0.00001675	0.999999	1	6	0.00002161	0.9999986	0	22	0.00013126	0.9999918	0.000000	$0	$0	$0	$0
76	R 1	1	23	0.00004299	0.9999973	0	19	0.00017058	0.9999893	0	6	0.00001675	0.999999	0	6	0.00002161	0.9999986	0	22	0.00013126	0.9999918	0.000000	$0	$0	$0	$0
77	R 2	0	23	0.00004299	0.9999973	1	20	0.00005835	0.9999964	0	6	0.00001675	0.999999	0	6	0.00002161	0.9999986	0	22	0.00013126	0.9999918	0.000000	$0	$0	$0	$0
78	R 5	0	23	0.00004299	0.9999973	0	20	0.00005835	0.9999964	0	6	0.00001675	0.999999	0	6	0.00002161	0.9999986	1	23	0.00004788	0.999997	0.000000	$0	$0	$0	$0
79	R 1	1	24	0.00001501	0.9999991	0	20	0.00005835	0.9999964	0	6	0.00001675	0.999999	0	6	0.00002161	0.9999986	0	23	0.00004788	0.999997	0.000000	$0	$0	$0	$0
80	R 2	0	24	0.00001501	0.9999991	1	21	0.00001913	0.9999988	0	6	0.00001675	0.999999	0	6	0.00002161	0.9999986	0	23	0.00004788	0.999997	0.000000	$0	$0	$0	$0
81	R 3	0	24	0.00001501	0.9999991	0	21	0.00001913	0.9999988	1	7	0.00000156	0.9999999	0	6	0.00002161	0.9999986	0	23	0.00004788	0.999997	0.000000	$0	$0	$0	$0
82	R 5	0	24	0.00001501	0.9999991	0	21	0.00001913	0.9999988	0	7	0.00000156	0.9999999	0	6	0.00002161	0.9999986	1	24	0.00001683	0.9999989	0.000000	$0	$0	$0	$0
83	R 1	1	25	0.00000506	0.9999997	0	21	0.00001913	0.9999988	0	7	0.00000156	0.9999999	0	6	0.00002161	0.9999986	0	24	0.00001683	0.9999989	0.000000	$0	$0	$0	$0
84	R 4	0	25	0.00000506	0.9999997	0	21	0.00001913	0.9999988	0	7	0.00000156	0.9999999	1	7	0.00000209	0.9999999	0	24	0.00001683	0.9999989	0.000000	$0	$0	$0	$0

Table A-8. Marginal Analysis Under TOC 1 Approach

Item	R 1				R 2				R 3				R 4				R 5			
Constraint Usage	2.00		Factor	1,000	8.00				2.00				10.00				6.00			
Avg Annual Demand	200				80				20				8				80			
Avg Repair Time	0.04538				0.0938				0.03808				0.0990				0.1142			
X	Poisson	S	EBO	**BCR**	Poisson	S	EBO	**BCR**	Poisson	S	EBO	**BCR**	Poisson	S	EBO	**BCR**	Poisson	S	EBO	**BCR**
0	0.000	0	9.0769230769		0.001	0	7.5076923077		0.467	0	0.7615384615		0.453	0	0.7923076923		0.000	0	9.1384615385	
1	0.001	1	8.0770373496	**499.94286**	0.004	1	6.5082411539	**124.93139**	0.356	1	0.2284859549	**266.52625**	0.359	1	0.2451063610	**54.72013**	0.001	1	8.1385689910	**166.64876**
2	0.005	2	7.0781888666	**499.42424**	0.015	2	5.5129105685	**124.41632**	0.135	2	0.0510319240	**88.72702**	0.142	2	0.0566608979	**18.84455**	0.004	2	7.1396583942	**166.48510**
3	0.014	3	6.0840478768	**497.07049**	0.039	3	4.5330479627	**122.48283**	0.034	3	0.0089788511	**21.02654**	0.038	3	0.0103379519	**4.63229**	0.014	3	6.1452345565	**165.73731**
4	0.032	4	5.1041500719	**489.94890**	0.073	4	3.5918949678	**117.64412**	0.007	4	0.0012967907	**3.84103**	0.007	4	0.0015499270	**0.87880**	0.031	4	5.1644780777	**163.45941**
5	0.059	5	4.1565733402	**473.78837**	0.109	5	2.7233969347	**108.56225**	0.001	5	0.0001584423	**0.56917**	0.001	5	0.0001967038	**0.13532**	0.057	5	4.2149462570	**158.25530**
6	0.089	6	3.2676717876	**444.45078**	0.137	6	1.9639931211	**94.92548**	0.000	6	0.0000167515	**0.07085**	0.000	6	0.0000216108	**0.01751**	0.087	6	3.3224835038	**148.74379**
7	0.115	7	2.4675352495	**400.06827**	0.146	7	1.3410969463	**77.86202**	0.000	7	0.0000015596	**0.00760**	0.000	7	0.0000020913	**0.00195**	0.113	7	2.5169413304	**134.25703**
8	0.131	8	1.7825005985	**342.51733**	0.137	8	0.8646089643	**59.56100**	0.000	8	0.0000001296	**0.00071**	0.000	8	0.0000001807	**0.00019**	0.130	8	1.8248734963	**115.34464**
9	0.132	9	1.2280623192	**277.21914**	0.115	9	0.5255194402	**42.38619**	0.000	9	0.0000000097	**0.00006**	0.000	9	0.0000000141	**0.00002**	0.132	9	1.2624282728	**93.74087**
10	0.120	10	0.8053366201	**211.36285**	0.086	10	0.3010460656	**28.05917**	0.000	10	0.0000000007	**0.00000**	0.000	10	0.0000000010	**0.00000**	0.120	10	0.8315998539	**71.80474**
11	0.099	11	0.5021654167	**151.58560**	0.059	11	0.1626229694	**17.30289**	0.000	11	0.0000000000	**0.00000**	0.000	11	0.0000000001	**0.00000**	0.100	11	0.5210489458	**51.75848**
12	0.075	12	0.2976475735	**102.25892**	0.037	12	0.0829306926	**9.96153**	0.000	12	0.0000000000	**0.00000**	0.000	12	0.0000000000	**0.00000**	0.076	12	0.3104208927	**35.10468**
13	0.052	13	0.1677521437	**64.94771**	0.021	13	0.0399828258	**5.36848**	0.000	13	0.0000000000	**0.00000**	0.000	13	0.0000000000	**0.00000**	0.053	13	0.1758879369	**22.42216**
14	0.034	14	0.0899599375	**38.89610**	0.011	14	0.0182553994	**2.71593**	0.000	14	0.0000000000	**0.00000**	0.000	14	0.0000000000	**0.00000**	0.035	14	0.0948466827	**13.50688**
15	0.020	15	0.0459489422	**22.00550**	0.006	15	0.0079077257	**1.29346**	0.000	15	0.0000000000	**0.00000**	0.000	15	0.0000000000	**0.00000**	0.021	15	0.0487219897	**7.68745**
16	0.012	16	0.0223799104	**11.78452**	0.003	16	0.0032557640	**0.58150**	0.000	16	0.0000000000	**0.00000**	0.000	16	0.0000000000	**0.00000**	0.012	16	0.0238695401	**4.14207**
17	0.006	17	0.0104077618	**5.98607**	0.001	17	0.0012764057	**0.24742**	0.000	17	0.0000000000	**0.00000**	0.000	17	0.0000000000	**0.00000**	0.007	17	0.0111668142	**2.11712**
18	0.003	18	0.0046276141	**2.89007**	0.000	18	0.0004773464	**0.09988**	0.000	18	0.0000000000	**0.00000**	0.000	18	0.0000000000	**0.00000**	0.003	18	0.0049952520	**1.02859**
19	0.001	19	0.0019699285	**1.32884**	0.000	19	0.0001705828	**0.03835**	0.000	19	0.0000000000	**0.00000**	0.000	19	0.0000000000	**0.00000**	0.002	19	0.0021395113	**0.47596**
20	0.001	20	0.0008039453	**0.58299**	0.000	20	0.0000583458	**0.01403**	0.000	20	0.0000000000	**0.00000**	0.000	20	0.0000000000	**0.00000**	0.001	20	0.0008785869	**0.21015**
21	0.000	21	0.0003149656	**0.24449**	0.000	21	0.0000191310	**0.00490**	0.000	21	0.0000000000	**0.00000**	0.000	21	0.0000000000	**0.00000**	0.000	21	0.0003463707	**0.08870**
22	0.000	22	0.0001186101	**0.09818**	0.000	22	0.0000060224	**0.00164**	0.000	22	0.0000000000	**0.00000**	0.000	22	0.0000000000	**0.00000**	0.000	22	0.0001312628	**0.03585**
23	0.000	23	0.0000429877	**0.03781**	0.000	23	0.0000018227	**0.00052**	0.000	23	0.0000000000	**0.00000**	0.000	23	0.0000000000	**0.00000**	0.000	23	0.0000478768	**0.01390**
24	0.000	24	0.0000150124	**0.01399**	0.000	24	0.0000005311	**0.00016**	0.000	24	0.0000000000	**0.00000**	0.000	24	0.0000000000	**0.00000**	0.000	24	0.0000168271	**0.00517**
25	0.000	25	0.0000050575	**0.00498**	0.000	25	0.0000001492	**0.00005**	0.000	25	0.0000000000	**0.00000**	0.000	25	0.0000000000	**0.00000**	0.000	25	0.0000057054	**0.00185**
26	0.000	26	0.0000016455	**0.00171**	0.000	26	0.0000000404	**0.00001**	0.000	26	0.0000000000	**0.00000**	0.000	26	0.0000000000	**0.00000**	0.000	26	0.0000018683	**0.00064**
27	0.000	27	0.0000005175	**0.00056**	0.000	27	0.0000000106	**0.00000**	0.000	27	0.0000000000	**0.00000**	0.000	27	0.0000000000	**0.00000**	0.000	27	0.0000005914	**0.00021**
28	0.000	28	0.0000001575	**0.00018**	0.000	28	0.0000000027	**0.00000**	0.000	28	0.0000000000	**0.00000**	0.000	28	0.0000000000	**0.00000**	0.000	28	0.0000001812	**0.00007**
29	0.000	29	0.0000000464	**0.00006**	0.000	29	0.0000000007	**0.00000**	0.000	29	0.0000000000	**0.00000**	0.000	29	0.0000000000	**0.00000**	0.000	29	0.0000000538	**0.00002**
30	0.000	30	0.0000000133	**0.00002**	0.000	30	0.0000000002	**0.00000**	0.000	30	0.0000000000	**0.00000**	0.000	30	0.0000000000	**0.00000**	0.000	30	0.0000000155	**0.00001**
31	0.000	31	0.0000000037	**0.00000**	0.000	31	0.0000000000	**0.00000**	0.000	31	0.0000000000	**0.00000**	0.000	31	0.0000000000	**0.00000**	0.000	31	0.0000000043	**0.00000**
32	0.000	32	0.0000000010	**0.00000**	0.000	32	0.0000000000	**0.00000**	0.000	32	0.0000000000	**0.00000**	0.000	32	0.0000000000	**0.00000**	0.000	32	0.0000000012	**0.00000**
33	0.000	33	0.0000000003	**0.00000**	0.000	33	0.0000000000	**0.00000**	0.000	33	0.0000000000	**0.00000**	0.000	33	0.0000000000	**0.00000**	0.000	33	0.0000000003	**0.00000**
34	0.000	34	0.0000000001	**0.00000**	0.000	34	0.0000000000	**0.00000**	0.000	34	0.0000000000	**0.00000**	0.000	34	0.0000000000	**0.00000**	0.000	34	0.0000000001	**0.00000**
35	0.000	35	0.0000000000	**0.00000**	0.000	35	0.0000000000	**0.00000**	0.000	35	0.0000000000	**0.00000**	0.000	35	0.0000000000	**0.00000**	0.000	35	0.0000000000	**0.00000**
36	0.000	36	0.0000000000	**0.00000**	0.000	36	0.0000000000	**0.00000**	0.000	36	0.0000000000	**0.00000**	0.000	36	0.0000000000	**0.00000**	0.000	36	0.0000000000	**0.00000**
37	0.000	37	0.0000000000	**0.00000**	0.000	37	0.0000000000	**0.00000**	0.000	37	0.0000000000	**0.00000**	0.000	37	0.0000000000	**0.00000**	0.000	37	0.0000000000	**0.00000**
38	0.000	38	0.0000000000	**0.00000**	0.000	38	0.0000000000	**0.00000**	0.000	38	0.0000000000	**0.00000**	0.000	38	0.0000000000	**0.00000**	0.000	38	0.0000000000	**0.00000**
39	0.000	39	0.0000000000	**0.00000**	0.000	39	0.0000000000	**0.00000**	0.000	39	0.0000000000	**0.00000**	0.000	39	0.0000000000	**0.00000**	0.000	39	0.0000000000	**0.00000**
40	0.000	40	0.0000000000	**0.00000**	0.000	40	0.0000000000	**0.00000**	0.000	40	0.0000000000	**0.00000**	0.000	40	0.0000000000	**0.00000**	0.000	40	0.0000000000	**0.00000**
41	0.000	41	0.0000000000	**0.00000**	0.000	41	0.0000000000	**0.00000**	0.000	41	0.0000000000	**0.00000**	0.000	41	0.0000000000	**0.00000**	0.000	41	0.0000000000	**0.00000**
42	0.000	42	0.0000000000	**0.00000**	0.000	42	0.0000000000	**0.00000**	0.000	42	0.0000000000	**0.00000**	0.000	42	0.0000000000	**0.00000**	0.000	42	0.0000000000	**0.00000**
43	0.000	43	0.0000000000	**0.00000**	0.000	43	0.0000000000	**0.00000**	0.000	43	0.0000000000	**0.00000**	0.000	43	0.0000000000	**0.00000**	0.000	43	0.0000000000	**0.00000**
44	0.000	44	0.0000000000	**0.00000**	0.000	44	0.0000000000	**0.00000**	0.000	44	0.0000000000	**0.00000**	0.000	44	0.0000000000	**0.00000**	0.000	44	0.0000000000	**0.00000**
45	0.000	45	0.0000000000	**0.00000**	0.000	45	0.0000000000	**0.00000**	0.000	45	0.0000000000	**0.00000**	0.000	45	0.0000000000	**0.00000**	0.000	45	0.0000000000	**0.00000**
46	0.000	46	0.0000000000	**0.00000**	0.000	46	0.0000000000	**0.00000**	0.000	46	0.0000000000	**0.00000**	0.000	46	0.0000000000	**0.00000**	0.000	46	0.0000000000	**0.00000**
47	0.000	47	0.0000000000	**0.00000**	0.000	47	0.0000000000	**0.00000**	0.000	47	0.0000000000	**0.00000**	0.000	47	0.0000000000	**0.00000**	0.000	47	0.0000000000	**0.00000**
48	0.000	48	0.0000000000	**0.00000**	0.000	48	0.0000000000	**0.00000**	0.000	48	0.0000000000	**0.00000**	0.000	48	0.0000000000	**0.00000**	0.000	48	0.0000000000	**0.00000**
49	0.000	49	0.0000000000	**0.00000**	0.000	49	0.0000000000	**0.00000**	0.000	49	0.0000000000	**0.00000**	0.000	49	0.0000000000	**0.00000**	0.000	49	0.0000000000	**0.00000**
50	0.000	50	0.0000000000	**0.00000**	0.000	50	0.0000000000	**0.00000**	0.000	50	0.0000000000	**0.00000**	0.000	50	0.0000000000	**0.00000**	0.000	50	0.0000000000	**0.00000**

Table A-9. Marginal Analysis Under TOC 2 Approach

Item	R 1				R 2				R 3				R 4				R 5			
RM Costs	**1422.9**		**Factor**	**10,000**	**2960.5**				**1249.5**				**3266.1**				**3585.45**			
Constraint usage	**2.0**				**8.0**				**2.0**				**10.0**				**6.0**			
PC of Constraint	**416**				**416**				**416**				**416**				**416**			
UVC	**1,432**				**3,054**				**1,343**				**4,438**				**3,656**			
Avg Annual Demand	**200**				**80**				**20**				**8**				**80**			
Avg Repair Time	**0.0192**				**0.0769**				**0.0192**				**0.0769**				**0.0577**			
X	Poisson	S	EBO	**BCR**	Poisson	S	EBO	**BCR**	Poisson	S	EBO	**BCR**	Poisson	S	EBO	**BCR**	Poisson	S	EBO	**BCR**
0	0.021	0	3.8461538462		0.002	0	6.1538461538		0.681	0	0.3846153846		0.540	0	0.6153846154		0.010	0	4.6153846154	
1	0.082	1	2.8675155853	**6.83275**	0.013	1	5.1559714457	**3.26717**	0.262	1	0.0653277829	**2.37698**	0.333	1	0.1558176119	**1.03553**	0.046	1	3.6252829910	**2.70833**
2	0.158	2	1.9710378598	**6.25912**	0.040	2	4.1711754565	**3.22435**	0.050	2	0.0078526422	**0.42788**	0.102	2	0.0288247600	**0.28615**	0.105	2	2.6808661771	**2.58336**
3	0.203	3	1.2325611637	**5.15597**	0.083	3	3.2266216794	**3.09259**	0.006	3	0.0007260515	**0.05305**	0.021	3	0.0041624164	**0.05557**	0.162	3	1.8418758490	**2.29498**
4	0.195	4	0.6966498898	**3.74168**	0.127	4	2.3646160300	**2.82232**	0.001	4	0.0000544033	**0.00500**	0.003	4	0.0004909463	**0.00827**	0.187	4	1.1650801143	**1.85131**
5	0.150	5	0.3555130605	**2.38178**	0.156	5	1.6296074998	**2.40651**	0.000	5	0.0000034225	**0.00038**	0.000	5	0.0000488413	**0.00100**	0.173	5	0.6754319875	**1.33939**
6	0.096	6	0.1642027270	**1.33571**	0.160	6	1.0509031165	**1.89475**	0.000	6	0.0000001854	**0.00002**	0.000	6	0.0000041966	**0.00010**	0.133	6	0.3585354987	**0.86684**
7	0.053	7	0.0689350190	**0.66515**	0.141	7	0.6325106787	**1.36987**	0.000	7	0.0000000088	**0.00000**	0.000	7	0.0000003171	**0.00001**	0.088	7	0.1745248853	**0.50334**
8	0.025	8	0.0264379844	**0.29671**	0.108	8	0.3550518193	**0.90844**	0.000	8	0.0000000004	**0.00000**	0.000	8	0.0000000214	**0.00000**	0.051	8	0.0781313326	**0.26368**
9	0.011	9	0.0093114658	**0.11958**	0.074	9	0.1860034049	**0.55349**	0.000	9	0.0000000000	**0.00000**	0.000	9	0.0000000013	**0.00000**	0.026	9	0.0322860841	**0.12541**
10	0.004	10	0.0030270480	**0.04388**	0.046	10	0.0910817904	**0.31079**	0.000	10	0.0000000000	**0.00000**	0.000	10	0.0000000001	**0.00000**	0.012	10	0.0123630430	**0.05450**
11	0.001	11	0.0009126691	**0.01476**	0.026	11	0.0417766683	**0.16143**	0.000	11	0.0000000000	**0.00000**	0.000	11	0.0000000000	**0.00000**	0.005	11	0.0044040975	**0.02177**
12	0.000	12	0.0002563457	**0.00458**	0.013	12	0.0179912621	**0.07788**	0.000	12	0.0000000000	**0.00000**	0.000	12	0.0000000000	**0.00000**	0.002	12	0.0014650524	**0.00804**
13	0.000	13	0.0000673477	**0.00132**	0.006	13	0.0072928898	**0.03503**	0.000	13	0.0000000000	**0.00000**	0.000	13	0.0000000000	**0.00000**	0.001	13	0.0004567381	**0.00276**
14	0.000	14	0.0000166118	**0.00035**	0.003	14	0.0027895630	**0.01474**	0.000	14	0.0000000000	**0.00000**	0.000	14	0.0000000000	**0.00000**	0.000	14	0.0001338904	**0.00088**
15	0.000	15	0.0000038599	**0.00009**	0.001	15	0.0010093332	**0.00583**	0.000	15	0.0000000000	**0.00000**	0.000	15	0.0000000000	**0.00000**	0.000	15	0.0000370207	**0.00026**
16	0.000	16	0.0000008475	**0.00002**	0.000	16	0.0003462714	**0.00217**	0.000	16	0.0000000000	**0.00000**	0.000	16	0.0000000000	**0.00000**	0.000	16	0.0000096826	**0.00007**
17	0.000	17	0.0000001763	**0.00000**	0.000	17	0.0001128896	**0.00076**	0.000	17	0.0000000000	**0.00000**	0.000	17	0.0000000000	**0.00000**	0.000	17	0.0000024018	**0.00002**
18	0.000	18	0.0000000349	**0.00000**	0.000	18	0.0000350481	**0.00025**	0.000	18	0.0000000000	**0.00000**	0.000	18	0.0000000000	**0.00000**	0.000	18	0.0000005664	**0.00001**
19	0.000	19	0.0000000066	**0.00000**	0.000	19	0.0000103827	**0.00008**	0.000	19	0.0000000000	**0.00000**	0.000	19	0.0000000000	**0.00000**	0.000	19	0.0000001273	**0.00000**
20	0.000	20	0.0000000012	**0.00000**	0.000	20	0.0000029404	**0.00002**	0.000	20	0.0000000000	**0.00000**	0.000	20	0.0000000000	**0.00000**	0.000	20	0.0000000273	**0.00000**
21	0.000	21	0.0000000002	**0.00000**	0.000	21	0.0000007974	**0.00001**	0.000	21	0.0000000000	**0.00000**	0.000	21	0.0000000000	**0.00000**	0.000	21	0.0000000056	**0.00000**
22	0.000	22	0.0000000000	**0.00000**	0.000	22	0.0000002074	**0.00000**	0.000	22	0.0000000000	**0.00000**	0.000	22	0.0000000000	**0.00000**	0.000	22	0.0000000011	**0.00000**
23	0.000	23	0.0000000000	**0.00000**	0.000	23	0.0000000518	**0.00000**	0.000	23	0.0000000000	**0.00000**	0.000	23	0.0000000000	**0.00000**	0.000	23	0.0000000002	**0.00000**
24	0.000	24	0.0000000000	**0.00000**	0.000	24	0.0000000125	**0.00000**	0.000	24	0.0000000000	**0.00000**	0.000	24	0.0000000000	**0.00000**	0.000	24	0.0000000000	**0.00000**
25	0.000	25	0.0000000000	**0.00000**	0.000	25	0.0000000029	**0.00000**	0.000	25	0.0000000000	**0.00000**	0.000	25	0.0000000000	**0.00000**	0.000	25	0.0000000000	**0.00000**
26	0.000	26	0.0000000000	**0.00000**	0.000	26	0.0000000006	**0.00000**	0.000	26	0.0000000000	**0.00000**	0.000	26	0.0000000000	**0.00000**	0.000	26	0.0000000000	**0.00000**
27	0.000	27	0.0000000000	**0.00000**	0.000	27	0.0000000001	**0.00000**	0.000	27	0.0000000000	**0.00000**	0.000	27	0.0000000000	**0.00000**	0.000	27	0.0000000000	**0.00000**
28	0.000	28	0.0000000000	**0.00000**	0.000	28	0.0000000000	**0.00000**	0.000	28	0.0000000000	**0.00000**	0.000	28	0.0000000000	**0.00000**	0.000	28	0.0000000000	**0.00000**
29	0.000	29	0.0000000000	**0.00000**	0.000	29	0.0000000000	**0.00000**	0.000	29	0.0000000000	**0.00000**	0.000	29	0.0000000000	**0.00000**	0.000	29	0.0000000000	**0.00000**
30	0.000	30	0.0000000000	**0.00000**	0.000	30	0.0000000000	**0.00000**	0.000	30	0.0000000000	**0.00000**	0.000	30	0.0000000000	**0.00000**	0.000	30	0.0000000000	**0.00000**
31	0.000	31	0.0000000000	**0.00000**	0.000	31	0.0000000000	**0.00000**	0.000	31	0.0000000000	**0.00000**	0.000	31	0.0000000000	**0.00000**	0.000	31	0.0000000000	**0.00000**
32	0.000	32	0.0000000000	**0.00000**	0.000	32	0.0000000000	**0.00000**	0.000	32	0.0000000000	**0.00000**	0.000	32	0.0000000000	**0.00000**	0.000	32	0.0000000000	**0.00000**
33	0.000	33	0.0000000000	**0.00000**	0.000	33	0.0000000000	**0.00000**	0.000	33	0.0000000000	**0.00000**	0.000	33	0.0000000000	**0.00000**	0.000	33	0.0000000000	**0.00000**
34	0.000	34	0.0000000000	**0.00000**	0.000	34	0.0000000000	**0.00000**	0.000	34	0.0000000000	**0.00000**	0.000	34	0.0000000000	**0.00000**	0.000	34	0.0000000000	**0.00000**
35	0.000	35	0.0000000000	**0.00000**	0.000	35	0.0000000000	**0.00000**	0.000	35	0.0000000000	**0.00000**	0.000	35	0.0000000000	**0.00000**	0.000	35	0.0000000000	**0.00000**
36	0.000	36	0.0000000000	**0.00000**	0.000	36	0.0000000000	**0.00000**	0.000	36	0.0000000000	**0.00000**	0.000	36	0.0000000000	**0.00000**	0.000	36	0.0000000000	**0.00000**
37	0.000	37	0.0000000000	**0.00000**	0.000	37	0.0000000000	**0.00000**	0.000	37	0.0000000000	**0.00000**	0.000	37	0.0000000000	**0.00000**	0.000	37	0.0000000000	**0.00000**
38	0.000	38	0.0000000000	**0.00000**	0.000	38	0.0000000000	**0.00000**	0.000	38	0.0000000000	**0.00000**	0.000	38	0.0000000000	**0.00000**	0.000	38	0.0000000000	**0.00000**
39	0.000	39	0.0000000000	**0.00000**	0.000	39	0.0000000000	**0.00000**	0.000	39	0.0000000000	**0.00000**	0.000	39	0.0000000000	**0.00000**	0.000	39	0.0000000000	**0.00000**
40	0.000	40	0.0000000000	**0.00000**	0.000	40	0.0000000000	**0.00000**	0.000	40	0.0000000000	**0.00000**	0.000	40	0.0000000000	**0.00000**	0.000	40	0.0000000000	**0.00000**

Table A-10. Verification and Validation of the AAM Built

RI		R 1				R 2				R 3				R 4				R 5				AA ABC	TOTAL COSTS (ABC)
UVC		**$1,675.67**				**$3,911.73**				**$1,502.60**				**$4,218.22**				**$4,195.53**					
Step	RI	#	# Tot	EBO	AA	#	# Tot	EBO	AA	#	# Tot	EBO	AA	#	# Tot	EBO	AA	#	# Tot	EBO	AA		
1	R 1	1	1	1.13533528	0.8580831	0	0	0.80000000	0.9	0	0	0.12000000	0.985	0	0	0.08000000	0.99	0	0	0.80000000	0.9	0.677775	$1,675.67
2	R 1	1	2	0.54134113	0.9323324	0	0	0.80000000	0.9	0	0	0.12000000	0.985	0	0	0.08000000	0.99	0	0	0.80000000	0.9	0.736423	$3,351.35
3	R 1	1	3	0.21801755	0.9727478	0	0	0.80000000	0.9	0	0	0.12000000	0.985	0	0	0.08000000	0.99	0	0	0.80000000	0.9	0.768346	$5,027.02
4	R 2	0	3	0.21801755	0.9727478	1	1	0.24932896	0.9688339	0	0	0.12000000	0.985	0	0	0.08000000	0.99	0	0	0.80000000	0.9	0.827110	$8,938.75
5	R 5	0	3	0.21801755	0.9727478	0	1	0.24932896	0.9688339	0	0	0.12000000	0.985	0	0	0.08000000	0.99	1	1	0.24932896	0.968833879	0.890370	$13,134.28
6	R 1	1	4	0.07514101	0.9906074	0	1	0.24932896	0.9688339	0	0	0.12000000	0.985	0	0	0.08000000	0.99	0	1	0.24932896	0.968833879	0.906717	$14,809.95
7	R 3	0	4	0.07514101	0.9906074	0	1	0.24932896	0.9688339	1	1	0.00692044	0.9991349	0	0	0.08000000	0.99	0	1	0.24932896	0.968833879	0.919728	$16,312.55
8	R 2	0	4	0.07514101	0.9906074	1	2	0.05812110	0.9927349	0	1	0.00692044	0.9991349	0	0	0.08000000	0.99	0	1	0.24932896	0.968833879	0.942418	$20,224.28
9	R 5	0	4	0.07514101	0.9906074	0	2	0.05812110	0.9927349	0	1	0.00692044	0.9991349	0	0	0.08000000	0.99	1	2	0.05812110	0.992734863	0.965667	$24,419.81
10	R 1	1	**5**	0.02248799	0.997189	0	**2**	0.05812110	0.9927349	0	**1**	0.00692044	0.9991349	0	**0**	0.08000000	0.99	0	**2**	0.05812110	0.992734863	**0.972083**	$26,095.48
11	R 4	0	5	0.02248799	0.997189	0	2	0.05812110	0.9927349	0	1	0.00692044	0.9991349	1	1	0.00311635	0.9996105	0	2	0.05812110	0.992734863	0.981520	$30,313.70
12	R 2	0	5	0.02248799	0.997189	1	3	0.01069850	0.9986627	0	1	0.00692044	0.9991349	0	1	0.00311635	0.9996105	0	2	0.05812110	0.992734863	0.987380	$34,225.43
13	R 5	0	5	0.02248799	0.997189	0	3	0.01069850	0.9986627	0	1	0.00692044	0.9991349	0	1	0.00311635	0.9996105	1	3	0.01069850	0.998662687	0.993276	$38,420.96
14	R 1	1	6	0.00592438	0.9992595	0	3	0.01069850	0.9986627	0	1	0.00692044	0.9991349	0	1	0.00311635	0.9996105	0	3	0.01069850	0.998662687	0.995339	$40,096.63
15	R 3	0	6	0.00592438	0.9992595	0	3	0.01069850	0.9986627	1	2	0.00027133	0.9999661	0	1	0.00311635	0.9996105	0	3	0.01069850	0.998662687	0.996167	$41,599.23
16	R 1	1	7	0.00139058	0.9998262	0	3	0.01069850	0.9986627	0	2	0.00027133	0.9999661	0	1	0.00311635	0.9996105	0	3	0.01069850	0.998662687	0.996732	$43,274.90
17	R 2	0	7	0.00139058	0.9998262	1	4	0.00161865	0.9997977	0	2	0.00027133	0.9999661	0	1	0.00311635	0.9996105	0	3	0.01069850	0.998662687	0.997864	$47,186.63
18	R 5	0	7	0.00139058	0.9998262	0	4	0.00161865	0.9997977	0	2	0.00027133	0.9999661	0	1	0.00311635	0.9996105	1	4	0.00161865	0.999797669	0.998998	$51,382.16
19	R 4	0	7	0.00139058	0.9998262	0	4	0.00161865	0.9997977	0	2	0.00027133	0.9999661	1	2	0.00008200	0.9999897	0	4	0.00161865	0.999797669	0.999377	$55,600.38
20	R 1	1	8	0.00029386	0.9999633	0	4	0.00161865	0.9997977	0	2	0.00027133	0.9999661	0	2	0.00008200	0.9999897	0	4	0.00161865	0.999797669	0.999515	$57,276.06
21	R 2	0	8	0.00029386	0.9999633	1	5	0.00020734	0.9999741	0	2	0.00027133	0.9999661	0	2	0.00008200	0.9999897	0	4	0.00161865	0.999797669	0.999691	$61,187.79
22	R 5	0	8	0.00029386	0.9999633	0	5	0.00020734	0.9999741	0	2	0.00027133	0.9999661	0	2	0.00008200	0.9999897	1	5	0.00020734	0.999974083	0.999867	$65,383.32
23	R 3	0	8	0.00029386	0.9999633	0	5	0.00020734	0.9999741	1	3	0.00000804	0.999999	0	2	0.00008200	0.9999897	0	5	0.00020734	0.999974083	0.999900	$66,885.91
24	R 1	1	9	0.00005641	0.9999929	0	5	0.00020734	0.9999741	0	3	0.00000804	0.999999	0	2	0.00008200	0.9999897	0	5	0.00020734	0.999974083	0.999930	$68,561.59
25	R 2	0	9	0.00005641	0.9999929	1	6	0.00002299	0.9999971	0	3	0.00000804	0.999999	0	2	0.00008200	0.9999897	0	5	0.00020734	0.999974083	0.999953	$72,473.32
26	R 5	0	9	0.00005641	0.9999929	0	6	0.00002299	0.9999971	0	3	0.00000804	0.999999	0	2	0.00008200	0.9999897	1	6	0.00002299	0.999997126	0.999976	$76,668.85
27	R 1	1	**10**	0.00000991	0.9999988	0	**6**	0.00002299	0.9999971	0	**3**	0.00000804	0.999999	0	**2**	0.00008200	0.9999897	0	**6**	0.00002299	0.999997126	**0.999982**	$78,344.52
28	R 4	0	10	0.00000991	0.9999988	0	6	0.00002299	0.9999971	0	3	0.00000804	0.999999	1	3	0.00000163	0.9999998	0	6	0.00002299	0.999997126	0.999992	$82,562.74
29	R 2	0	10	0.00000991	0.9999988	1	7	0.00000225	0.9999997	0	3	0.00000804	0.999999	0	3	0.00000163	0.9999998	0	6	0.00002299	0.999997126	0.999994	$86,474.47
30	R 3	0	10	0.00000991	0.9999988	0	7	0.00000225	0.9999997	1	4	0.00000019	1	0	3	0.00000163	0.9999998	0	6	0.00002299	0.999997126	0.999995	$87,977.07
31	R 1	1	11	0.00000161	0.9999998	0	7	0.00000225	0.9999997	0	4	0.00000019	1	0	3	0.00000163	0.9999998	0	6	0.00002299	0.999997126	0.999996	$89,652.74
32	R 5	0	11	0.00000161	0.9999998	0	7	0.00000225	0.9999997	0	4	0.00000019	1	0	3	0.00000163	0.9999998	1	7	0.00000225	0.999999719	0.999999	$93,848.27
33	R 1	1	12	0.00000024	1	0	7	0.00000225	0.9999997	0	4	0.00000019	1	0	3	0.00000163	0.9999998	0	7	0.00000225	0.999999719	0.999999	$95,523.94
34	R 2	0	12	0.00000024	1	1	8	0.00000020	1	0	4	0.00000019	1	0	3	0.00000163	0.9999998	0	7	0.00000225	0.999999719	0.999999	$99,435.67
35	R 5	0	12	0.00000024	1	0	8	0.00000020	1	0	4	0.00000019	1	0	3	0.00000163	0.9999998	1	8	0.00000020	0.999999976	1.000000	$103,631.20

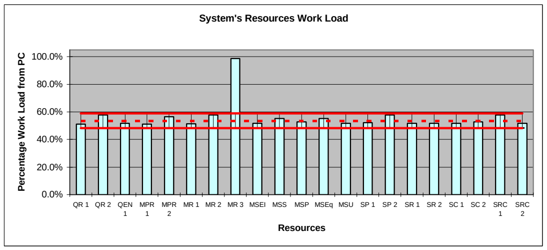
Table A-11. System Information

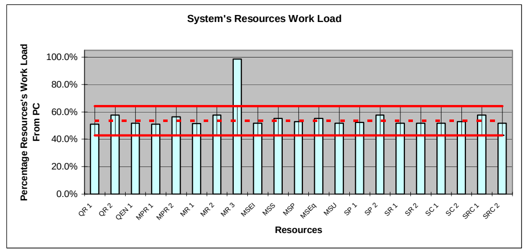
Section 1 - System Information

Time Frame (Weeks)		13
Percentage idle time for resources		20.00%
OEs from Resource sheet		$390,000
Range for the mean (High)	70%	95%
Range for the mean (Low)	30%	65%
Variance from the mean (Balanced)		10%
Variance from the mean (Unbalanced)		20%
Min % of resources in Variance (balanced)		80%
Max % of resources in Variance (Unbalanced)		30%

Sum percent load of not "C"	1071.27%
Average of percentage of not "C"	53.56%
Standard Deviationof not "C"	2.58%
Mean Between 75/95 = HIGH	NO
Mean Between 30/65 = LOW	YES
% of Res "NO C" in balanced range (10%)	100.00%
% Res "NO C" in Unbalanced range (20%)	100.00%
Is the system balanced ?	YES
Is the system unbalanced ?	NO

# resources with "Low" load	0
# resources with "Low 1" load	0
# resources with "Low 2" load	0
# resources with "Low 3" load	0
# resources with "MEDIUM" loa	20
# resources with "High" load	0
# resources with "High 1" load	0
# resources with "High 2" load	0
# of "CONSTRAINTS"	1
Total Resources	21





Repairable Inspection	R 1			R 2			R 3			R 4			R 5			Total Product Costs	%
Number of aircraft at site	8																
Quantity in the mix	50			20			5			2			20				
Repair Time at Depot	0.05673	Factor	2	0.08798	Factor	1.5	0.03570	Factor	1.5	0.09285	Factor	1.5	0.10709	Factor	1.5		
Number per aircraft	4			2			4			2			4				
Load Profile	Hours	UVC	%	Hours	UVC	%	Hours	UVC	%	Hours	UVC	%	Hours	UVC	%		
QG	7.0	$281	16.8%	14.0	$563	14.4%	7.0	$299	19.9%	17.5	$748	17.7%	17.5	$703	16.8%	$42,368	
MG - Planning	5.5	$177	10.5%	12.0	$382	9.8%	4.0	$133	8.9%	12.5	$406	9.6%	14.0	$449	10.7%	$26,935	
MG - Primary activities	**13.5**	$276	**16.5%**	**30.0**	$638	**16.3%**	**12.0**	$260	**17.3%**	**32.5**	$721	**17.1%**	**34.5**	$711	**17.0%**	$43,522	
MG - Support Activities	15.0	$325	19.4%	30.0	$649	16.6%	12.0	$260	17.3%	30.0	$649	15.4%	37.5	$811	19.3%	$48,029	
SG	18.0	$362	21.6%	36.0	$725	18.5%	14.5	$296	19.7%	36.3	$739	17.5%	45.0	$906	21.6%	$53,690	
Subtotal Labor		**$1,421**			**$2,957**			**$1,248**			**$3,263**			**$3,581**		$214,543	81.9%
RM ($)		**$255**	15.2%		**$955**	24.4%		**$255**	17.0%		**$955**	22.6%		**$615**	14.7%	$47,335	18.1%
Unitary Totals	59.00	**$1,676**		122.00	**$3,912**		49.50	**$1,503**		128.75	**$4,218**		148.50	**$4,196**		**$261,878**	

Section 3 - Resource Information

	Quality Group			MG - Planning		MG - Primary activities			MG - Support Activities					Supply Group							TOTALS	%
	QR 1	QR 2	QEN 1	MPR 1	MPR 2	MR 1	MR 2	MR 3	MSEI	MSS	MSP	MSEq	MSU	SP 1	SP 2	SR 1	SR 2	SC 1	SC 2	SRC 1	SRC 2		
Number of resources	2	2	1	2	1	5	3	1	2	2	2	2	2	2	1	2	1	2	1	2	1		
Practical Capacity (PC)	832	832	416	832	416	2,080	1,248	416	832	832	832	832	832	832	416	832	416	832	416	832	416		
AD rate (MC)	28.85	34.62	34.62	23.08	28.85	14.42	17.31	23.08	17.31	17.31	17.31	17.31	17.31	17.31	20.19	14.42	17.31	14.42	17.31	14.42	17.31		
AD rate (PC)	36.06	43.27	43.27	28.85	36.06	18.03	21.63	28.85	21.63	21.63	21.63	21.63	21.63	21.63	25.24	18.03	21.63	18.03	21.63	18.03	21.63		
Used Capacity	**425.00**	**480.00**	**215.00**	**425.00**	**235.00**	**1,070.00**	**720.00**	**410.00**	**430.00**	**460.00**	**440.00**	**460.00**	**430.00**	**435.00**	**240.00**	**430.00**	**215.00**	**430.00**	**220.00**	**480.00**	**215.00**		
Percentage used of PC	**51.1%**	**57.7%**	**51.7%**	**51.1%**	**56.5%**	**51.4%**	**57.7%**	**98.6%**	**51.7%**	**55.3%**	**52.9%**	**55.3%**	**51.7%**	**52.3%**	**57.7%**	**51.7%**	**51.7%**	**51.7%**	**52.9%**	**57.7%**	**51.7%**	1170%	
Used capacity cost (MC)	**$12,260**	**$16,615**	**$7,442**	**$9,808**	**$6,779**	**$15,433**	**$12,462**	**$9,462**	**$7,442**	**$7,962**	**$7,615**	**$7,962**	**$7,442**	**$7,529**	**$4,846**	**$6,202**	**$3,721**	**$6,202**	**$3,808**	**$6,923**	**$3,721**	**$171,635**	44.0%
Used capacity cost (PC)	**$15,325**	**$20,769**	**$9,303**	**$12,260**	**$8,474**	**$19,291**	**$15,577**	**$11,827**	**$9,303**	**$9,952**	**$9,519**	**$9,952**	**$9,303**	**$9,411**	**$6,058**	**$7,752**	**$4,651**	**$7,752**	**$4,760**	**$8,654**	**$4,651**	$214,543	
Unused Capacity (Related to MC)	615	560	305	615	285	1,530	840	110	610	580	600	580	610	605	280	610	305	610	300	560	305		
Unused capacity (related to PC)	407	352	201	407	181	1,010	528	6	402	372	392	372	402	397	176	402	201	402	196	352	201		
Percentage unused of PC	**48.9%**	**42.3%**	**48.3%**	**48.9%**	**43.5%**	**48.6%**	**42.3%**	**1.4%**	**48.3%**	**44.7%**	**47.1%**	**44.7%**	**48.3%**	**47.7%**	**42.3%**	**48.3%**	**48.3%**	**48.3%**	**47.1%**	**42.3%**	**48.3%**		
Unused Capacity Costs (MC)	**$17,740**	**$19,385**	**$10,558**	**$14,192**	**$8,221**	**$22,067**	**$14,538**	**$2,538**	**$10,558**	**$10,038**	**$10,385**	**$10,038**	**$10,558**	**$10,471**	**$5,654**	**$8,798**	**$5,279**	**$8,798**	**$5,192**	**$8,077**	**$5,279**	**$218,365**	56.0%
Resource situation	**Medium**	**Medium**	**Medium**	**Medium**	**Medium**	**Medium**	**Medium**	**C**	**Medium**	**Medium**	**Medium**	**Medium**	**Medium**	**Medium**	**Medium**	**Medium**	**Medium**	**Medium**	**Medium**	**Medium**	**Medium**		
Resource between 10 % of mean	YES	YES	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	**20**	
Resource between 20 % of mean	YES	YES	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	**20**	

OPERATIONAL EXPENSES	**$390,000**	89.2%
Raw Material Costs	**$47,335**	10.8%
TOTAL SYSTEM COSTS	**$437,335**	

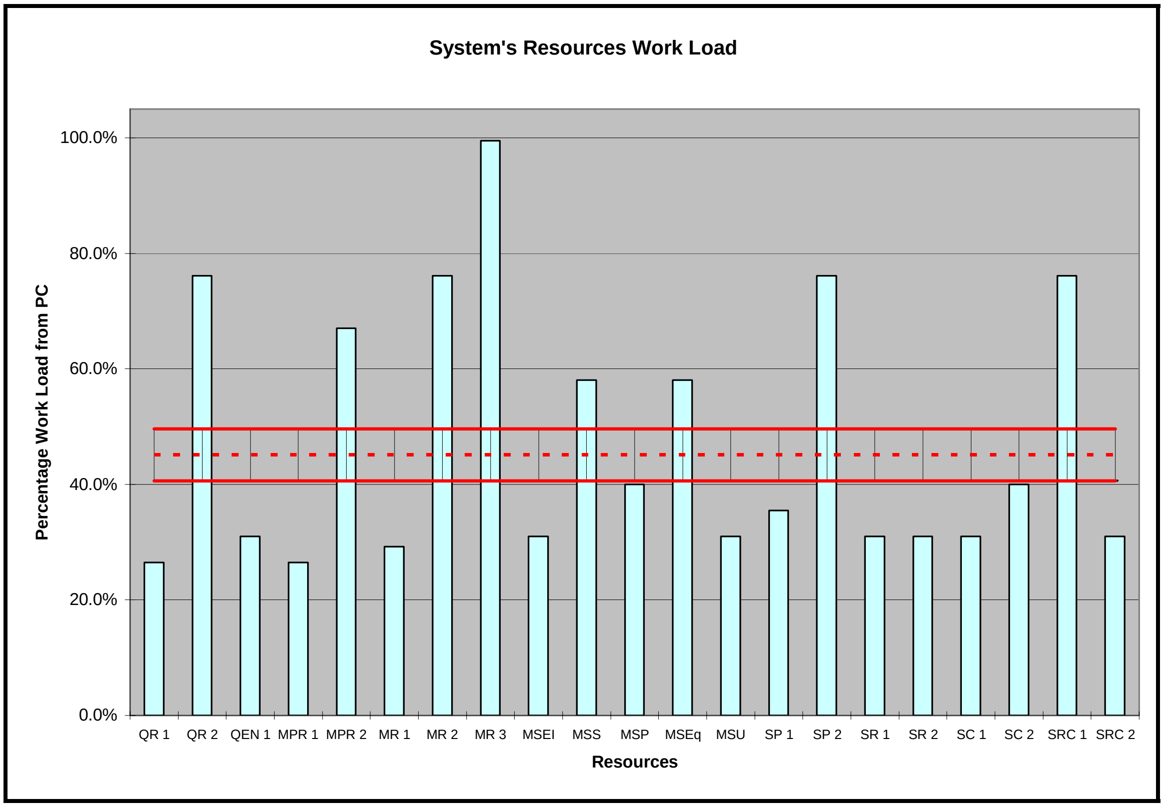


Figure B-1. LU System's Resources Work Load

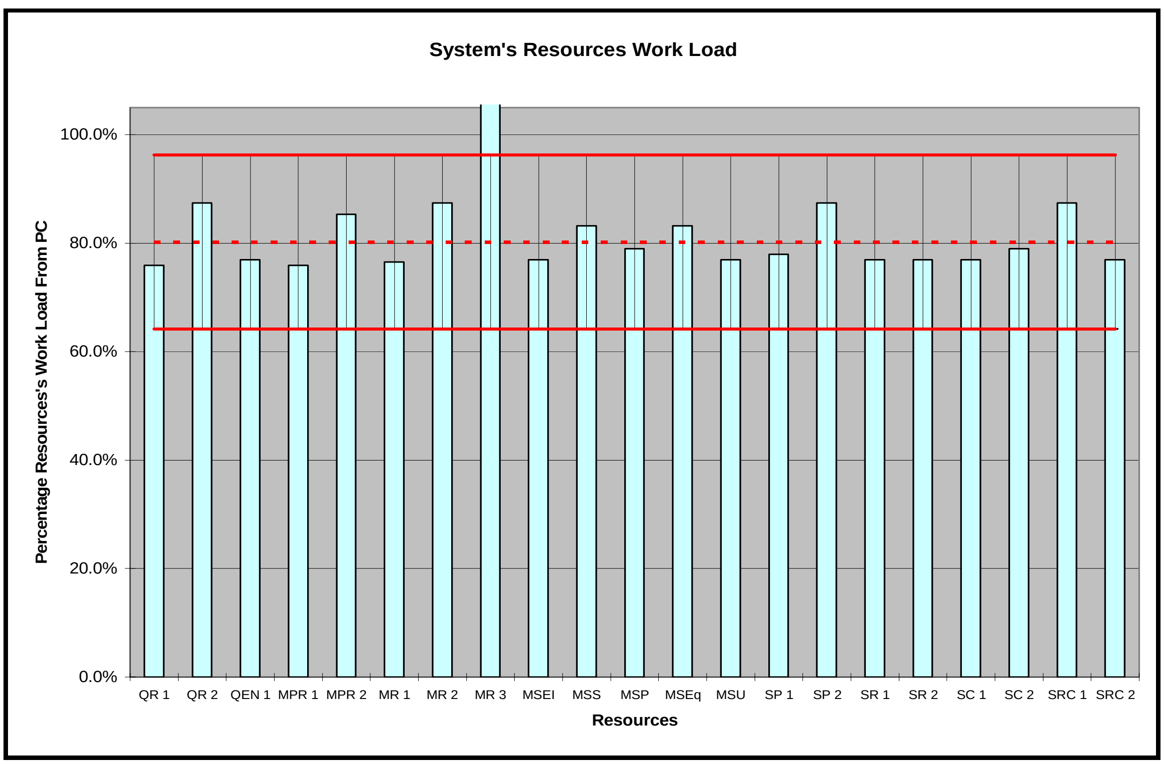


Figure B-2. HB System's Resources Work Load

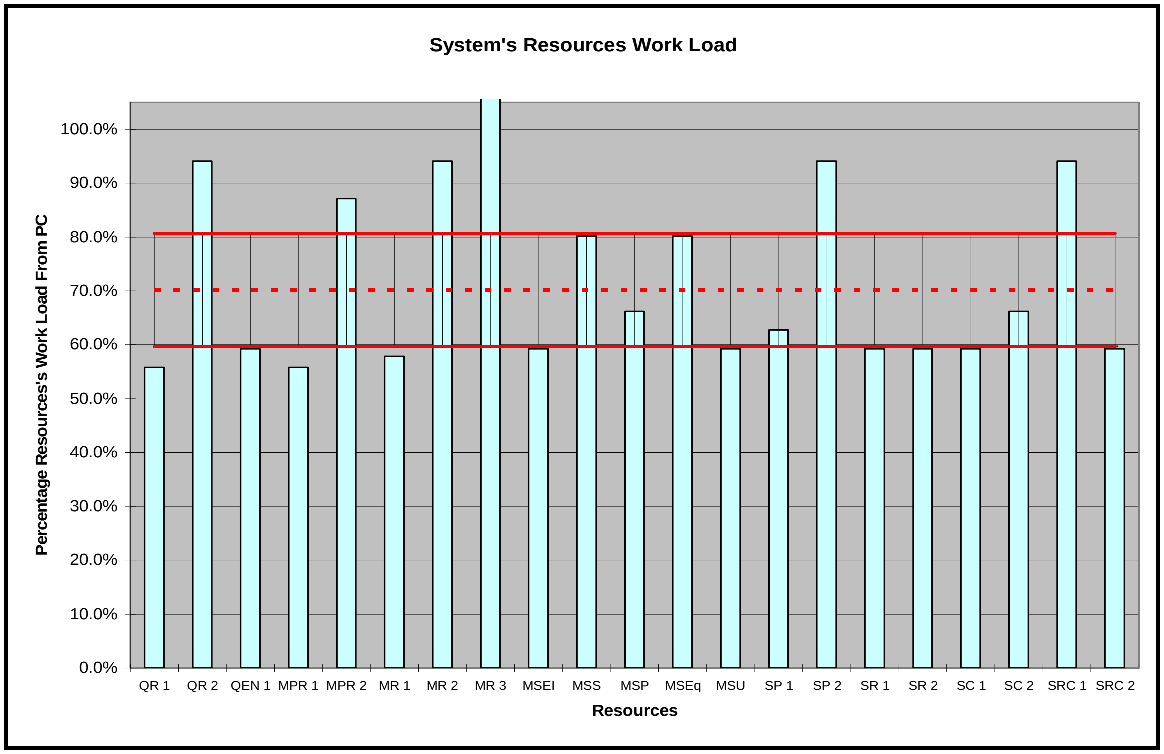


Figure B-3. HU System's Resources Work Load

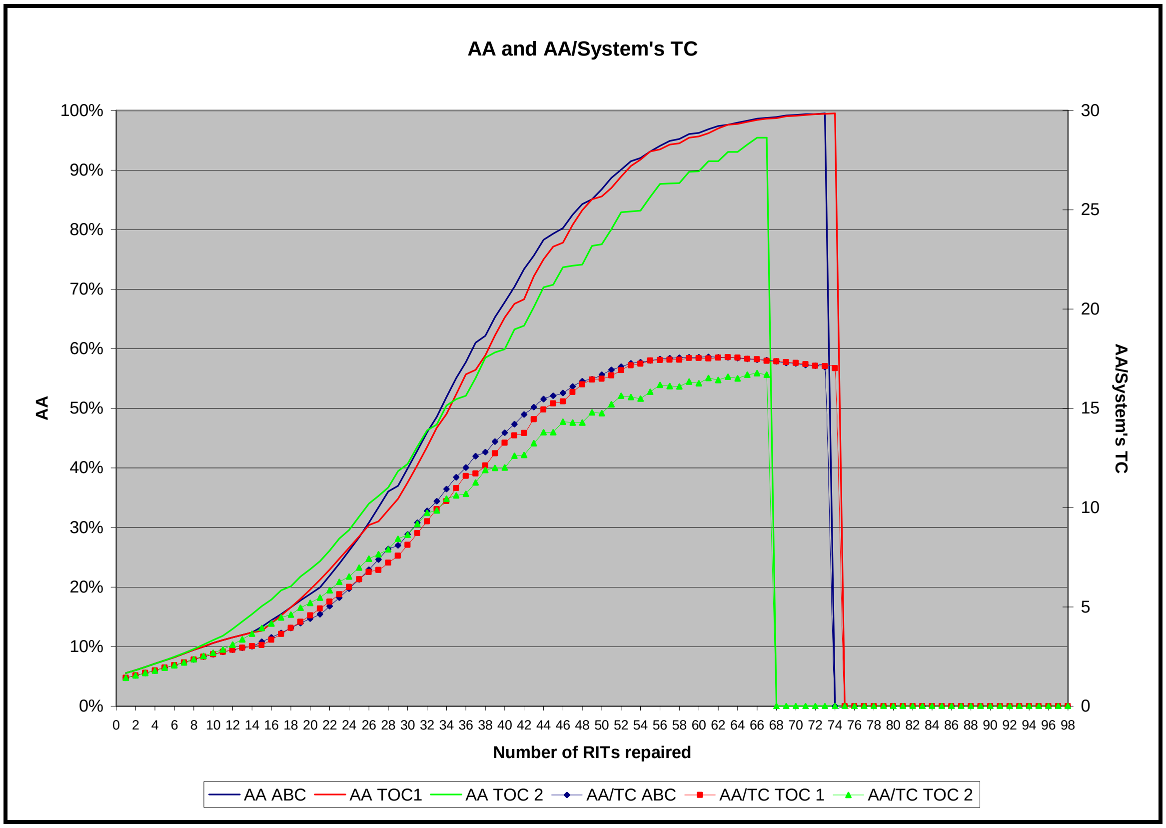


Figure C-1. – High Balance, NAirc = 16, NRAirc = 3, RT = 4, RM% = 50 %

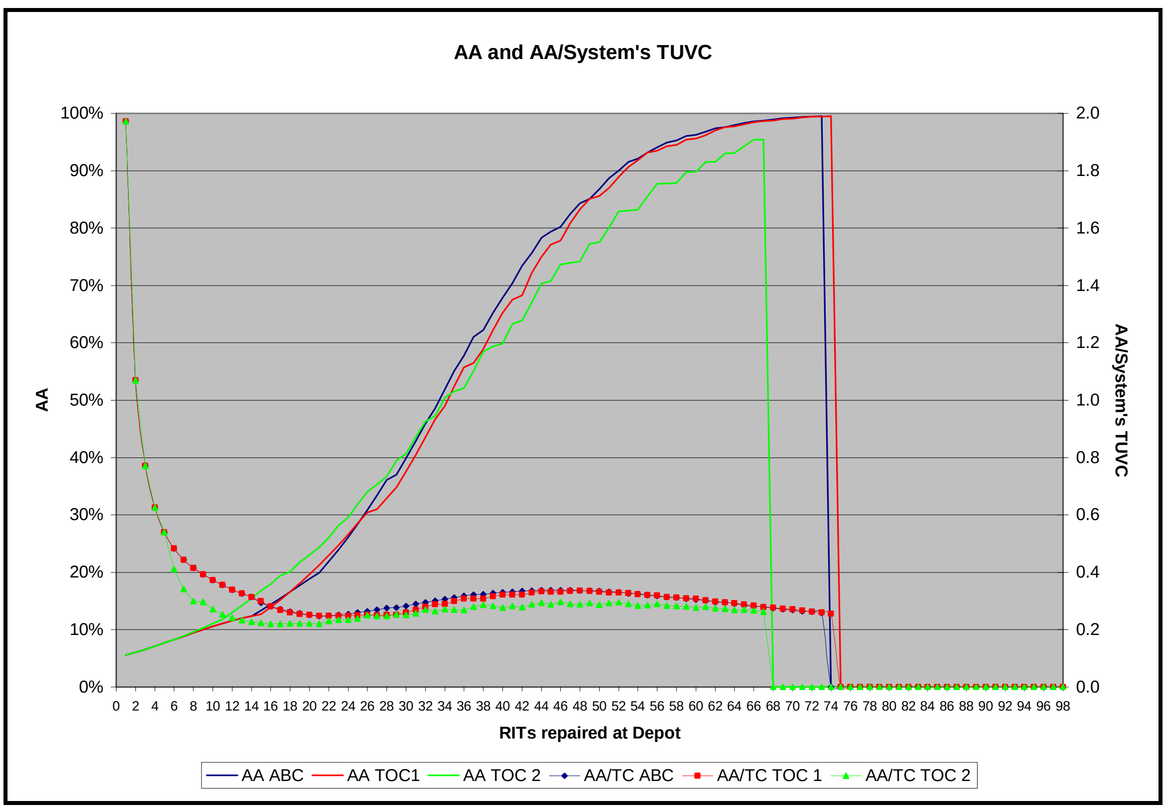


Figure C-2. – High Balance, NAirc =16, NRAirc = 3, RT = 4, RM% = 50 %

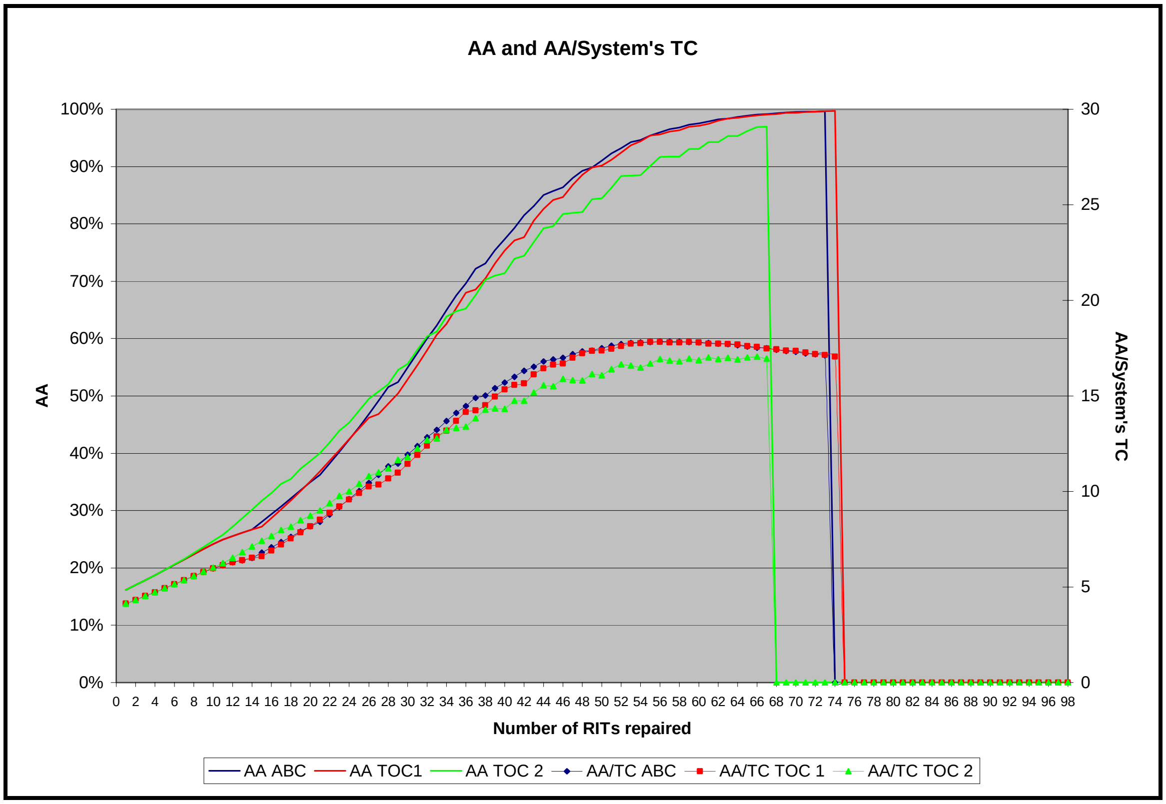


Figure C-3. – High Balance, NAirc = 24, NRAirc = 3, RT = 4, RM% = 50 %

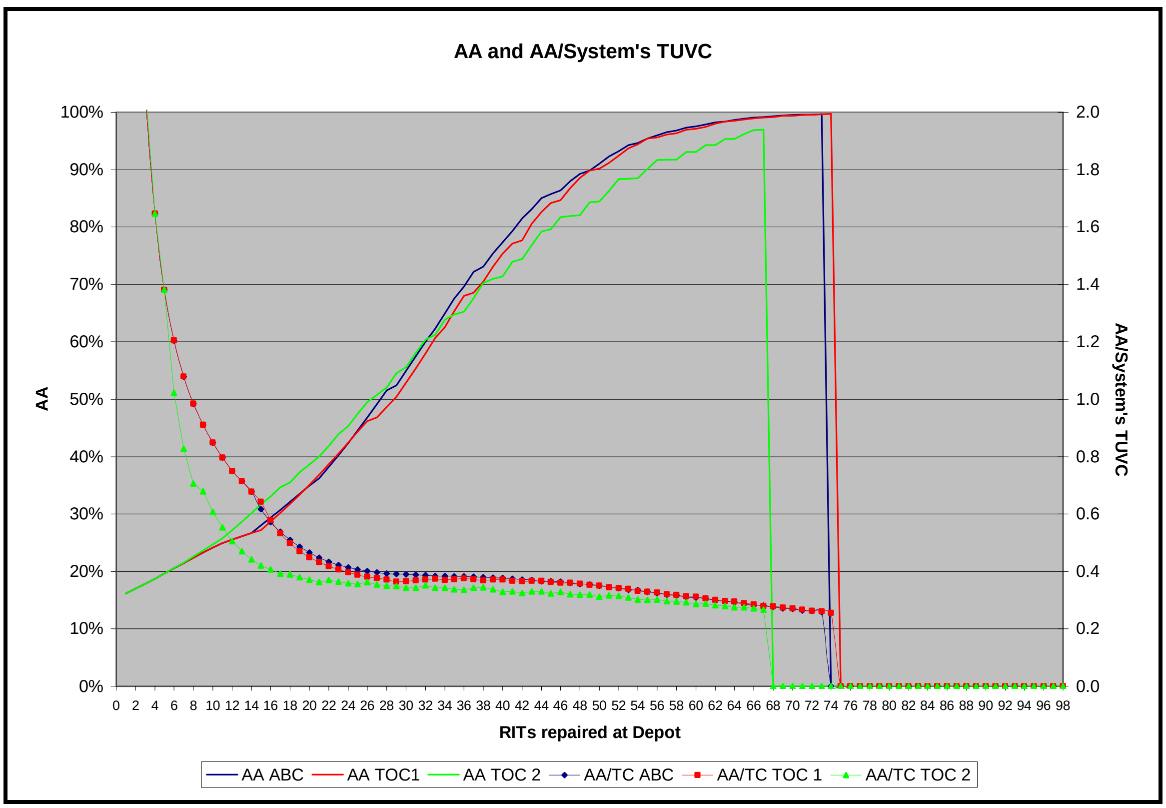


Figure C-4. – High Balance, NAirc = 24, NRAirc = 3, RT = 4, RM% = 50 %

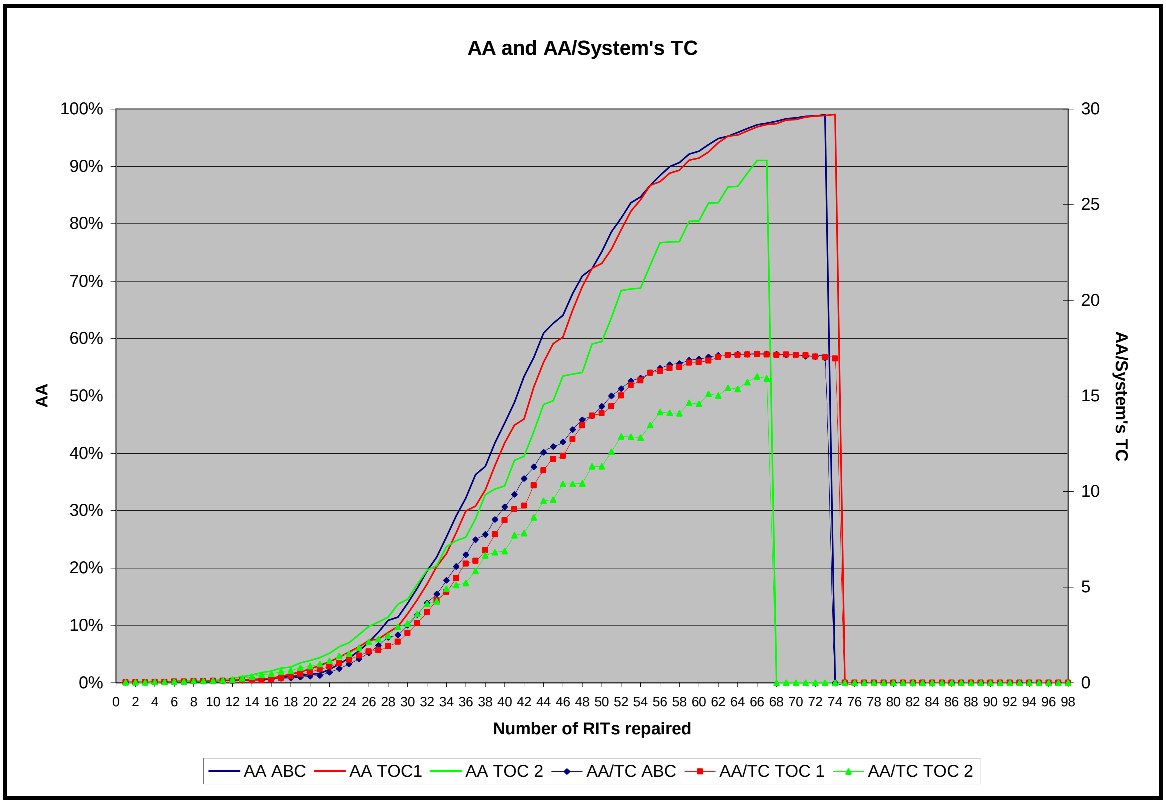


Figure C-5. – High Balance, NAirc = 8, NRAirc = 3, RT = 4, RM% = 50 %

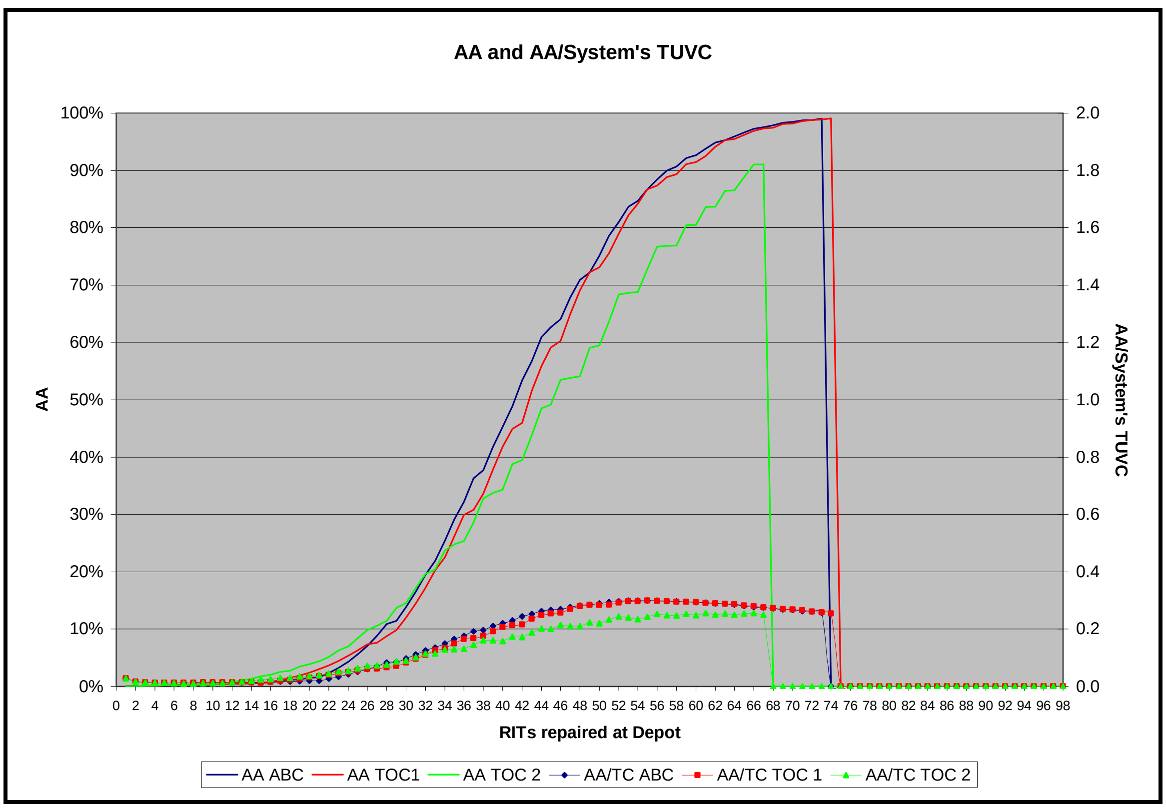


Figure C-6. – High Balance, NAirc = 8 NRAirc = 3, RT = 4, RM% = 50 %

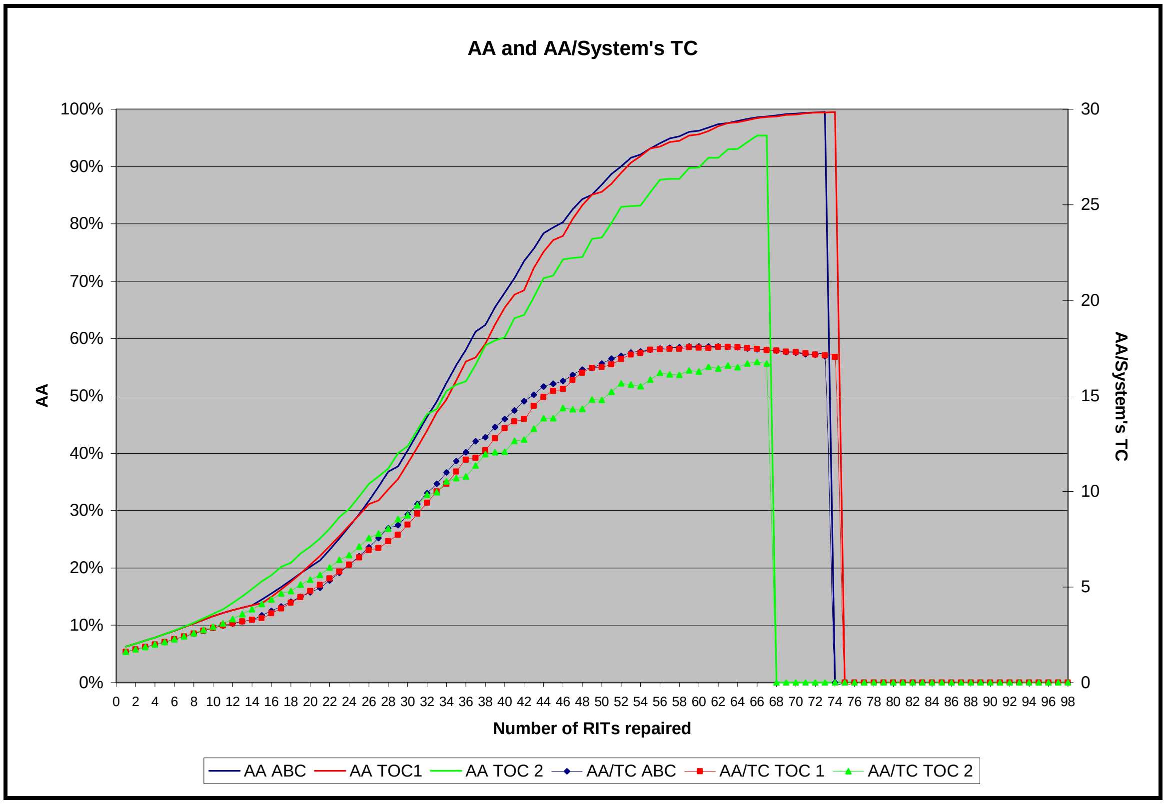


Figure C-7. – High Balance, NAirc = 16, NRAirc = 4, RT = 4, RM% = 50 %

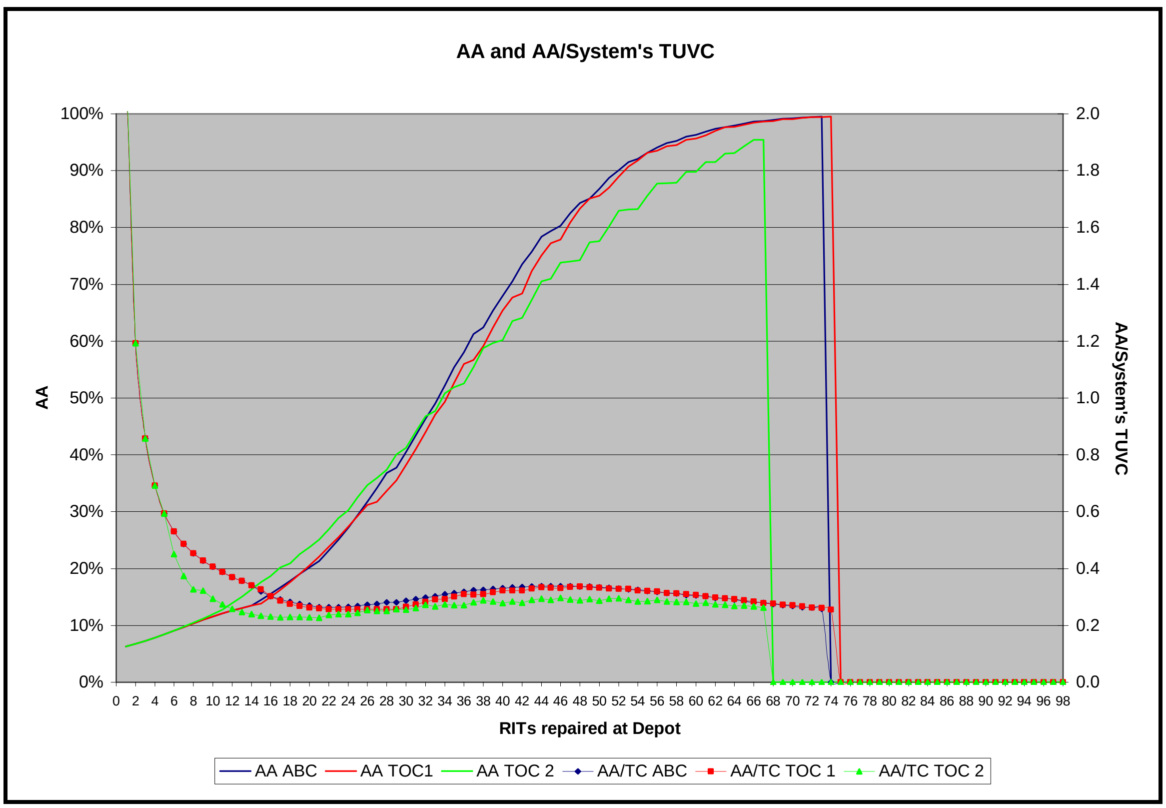


Figure C-8. – High Balance, NAirc = 16, NRAirc = 4, RT = 4, RM% = 50 %

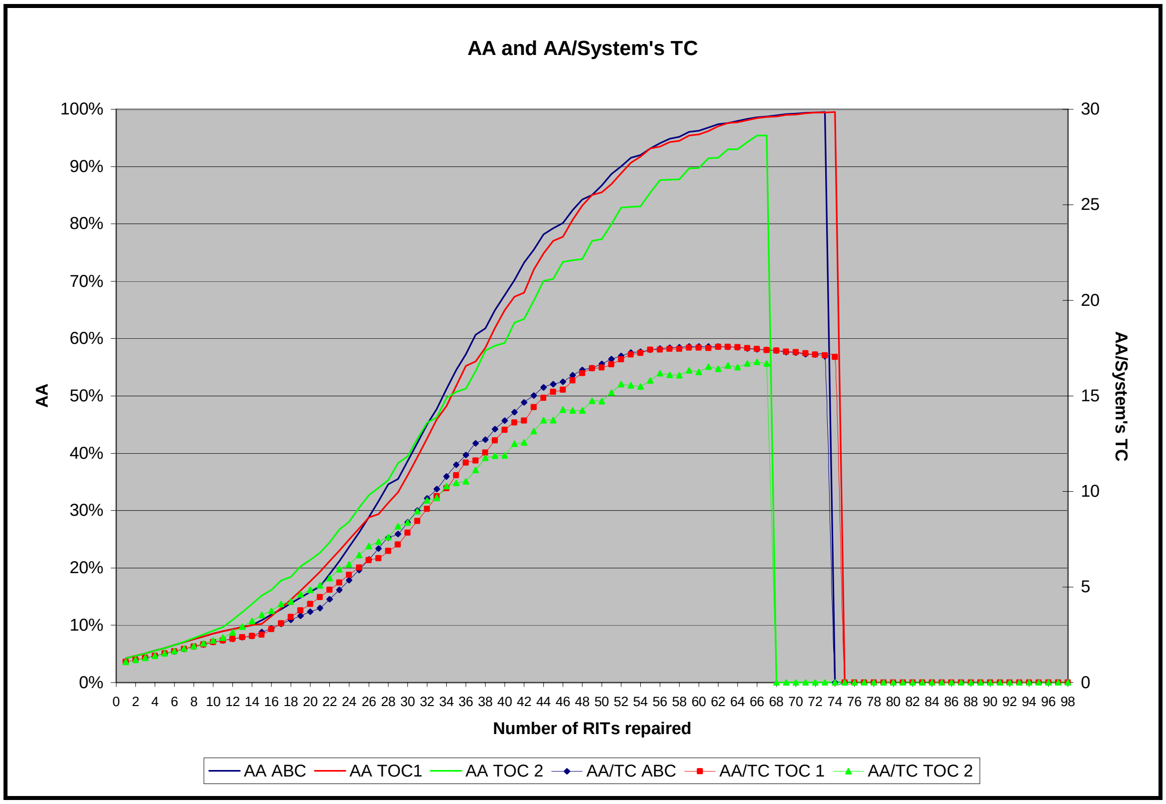


Figure C-9. – High Balance, NAirc = 16, NRAirc = 2, RT = 4, RM% = 50 %

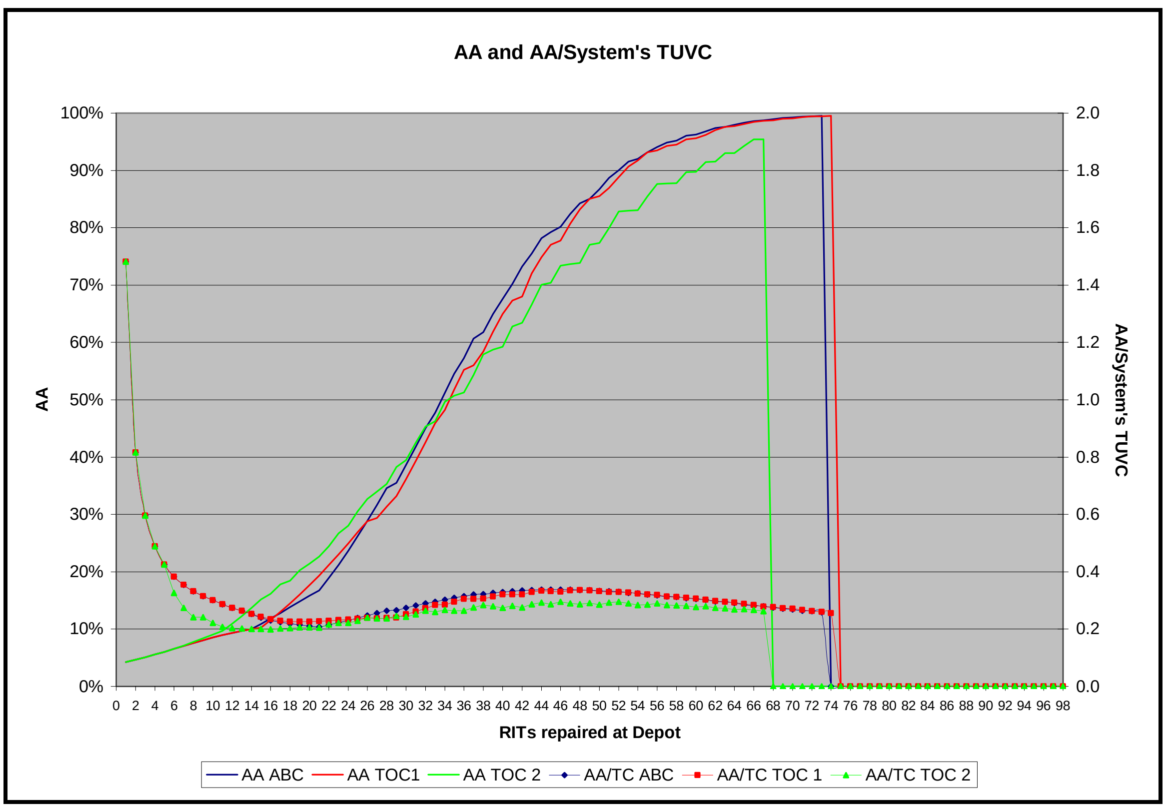


Figure C-10. – High Balance, NAirc = 16, NRAirc = 2, RT = 4, RM% = 50 %

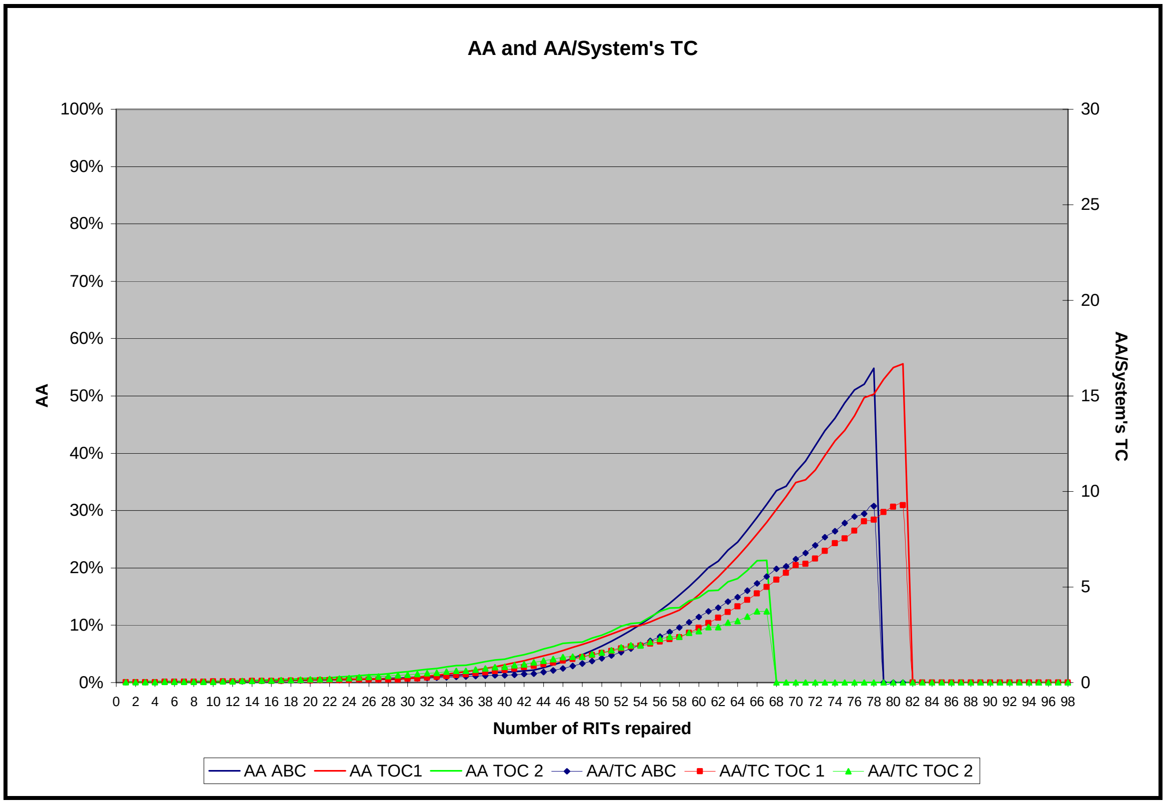


Figure C-11. – High Balance, NAirc = 16, NRAirc = 3, RT = 8, RM% = 50 %

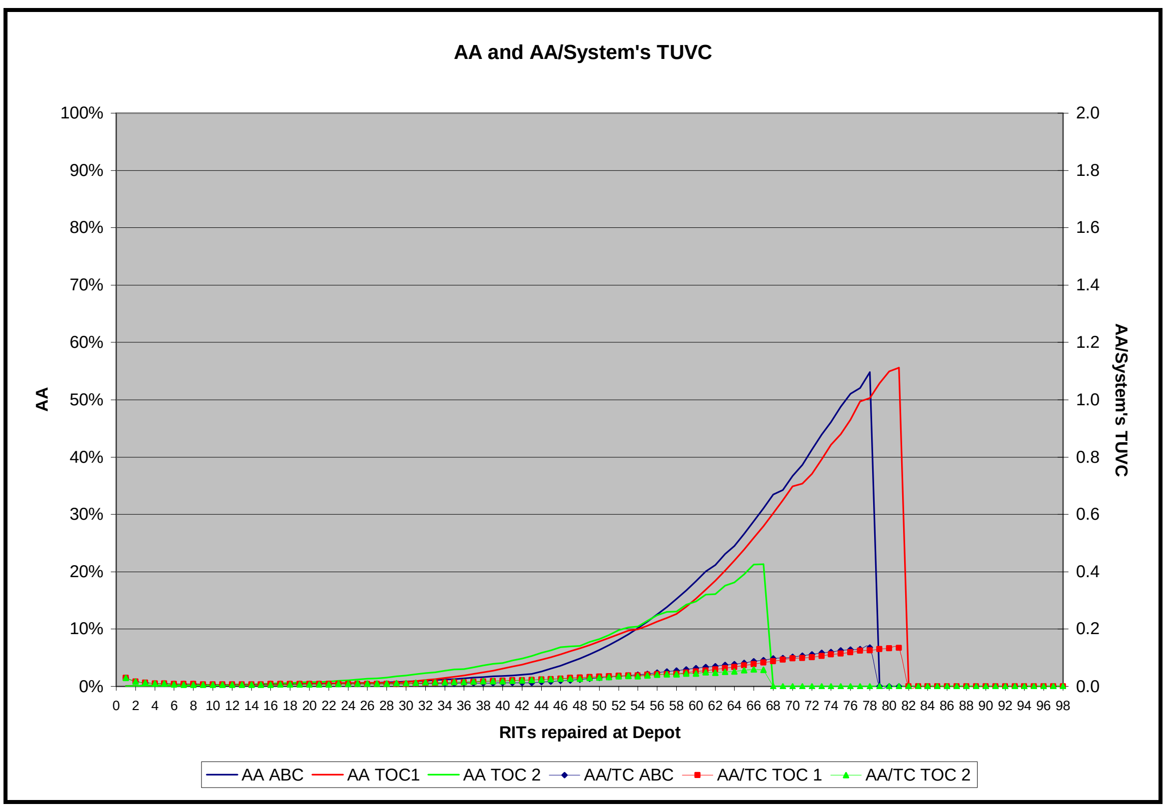


Figure C-12. – High Balance, NAirc = 16, NRAirc = 3, RT = 8, RM% = 50 %

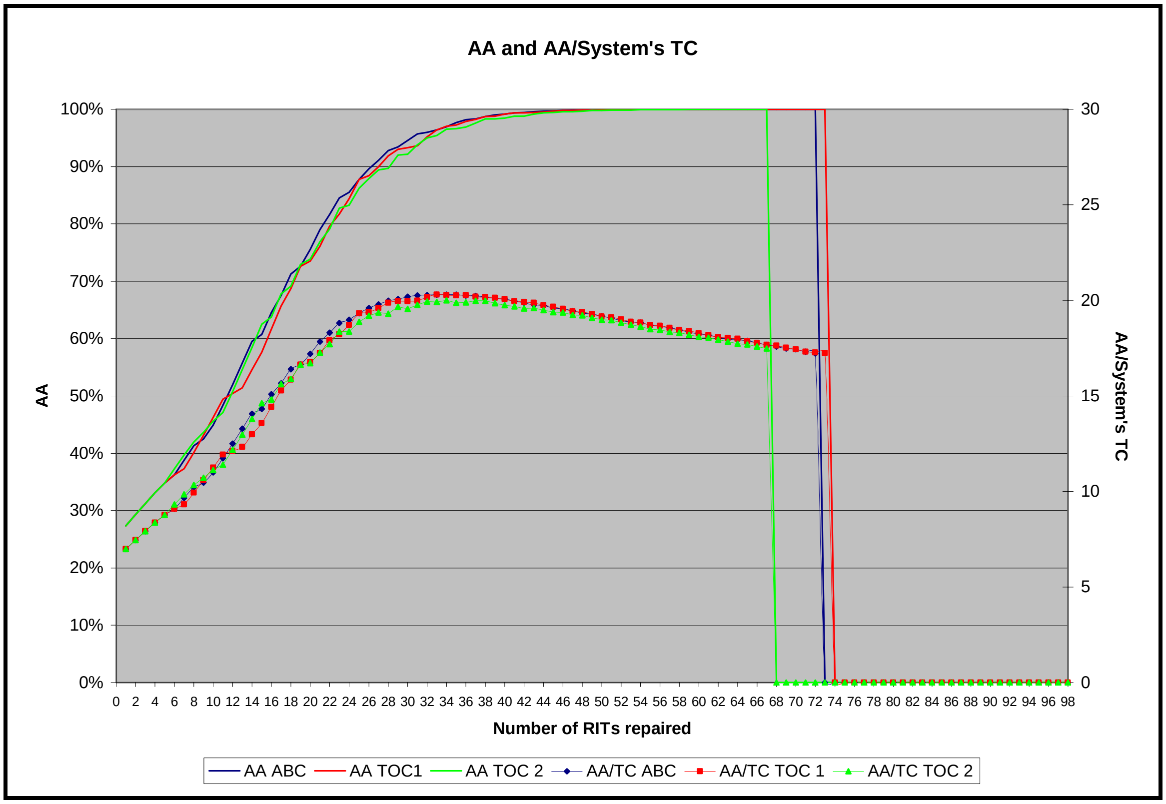


Figure C-13. – High Balance, NAirc = 16, NRAirc = 3, RT = 2, RM% = 50 %

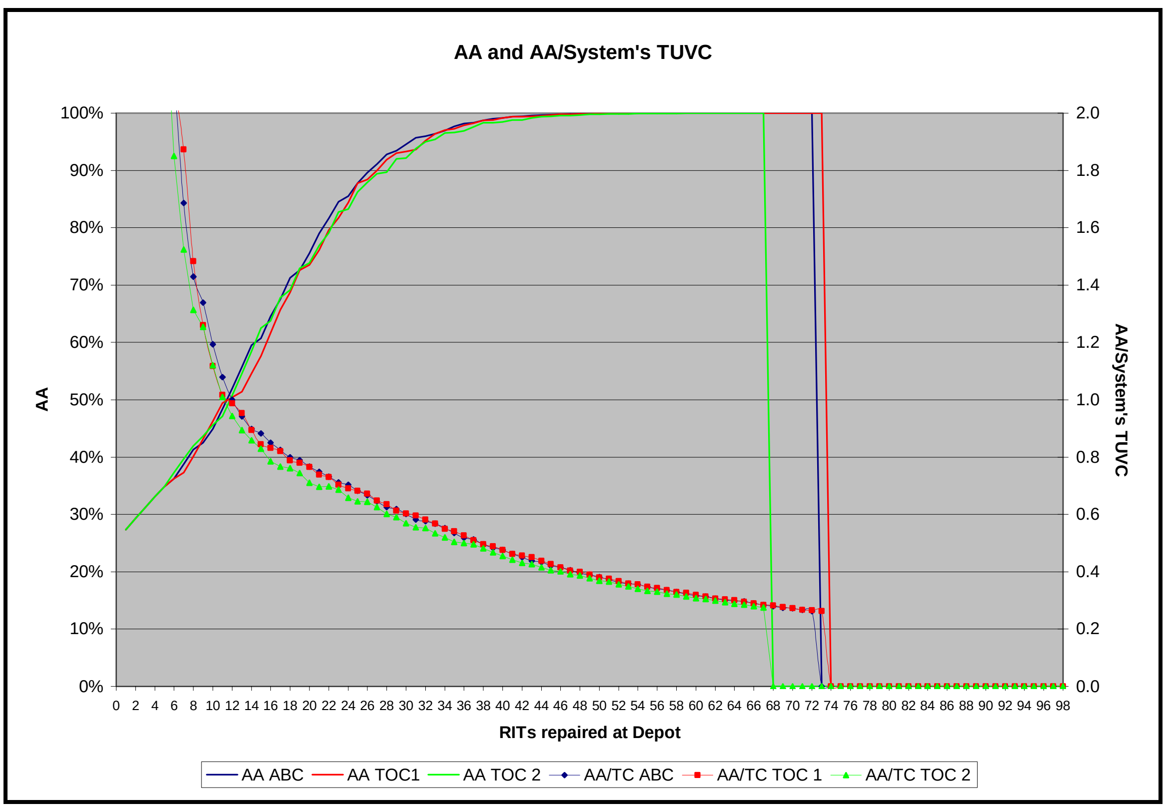


Figure C-14. – High Balance, NAirc = 16, NRAirc = 3, RT = 2, RM% = 50 %

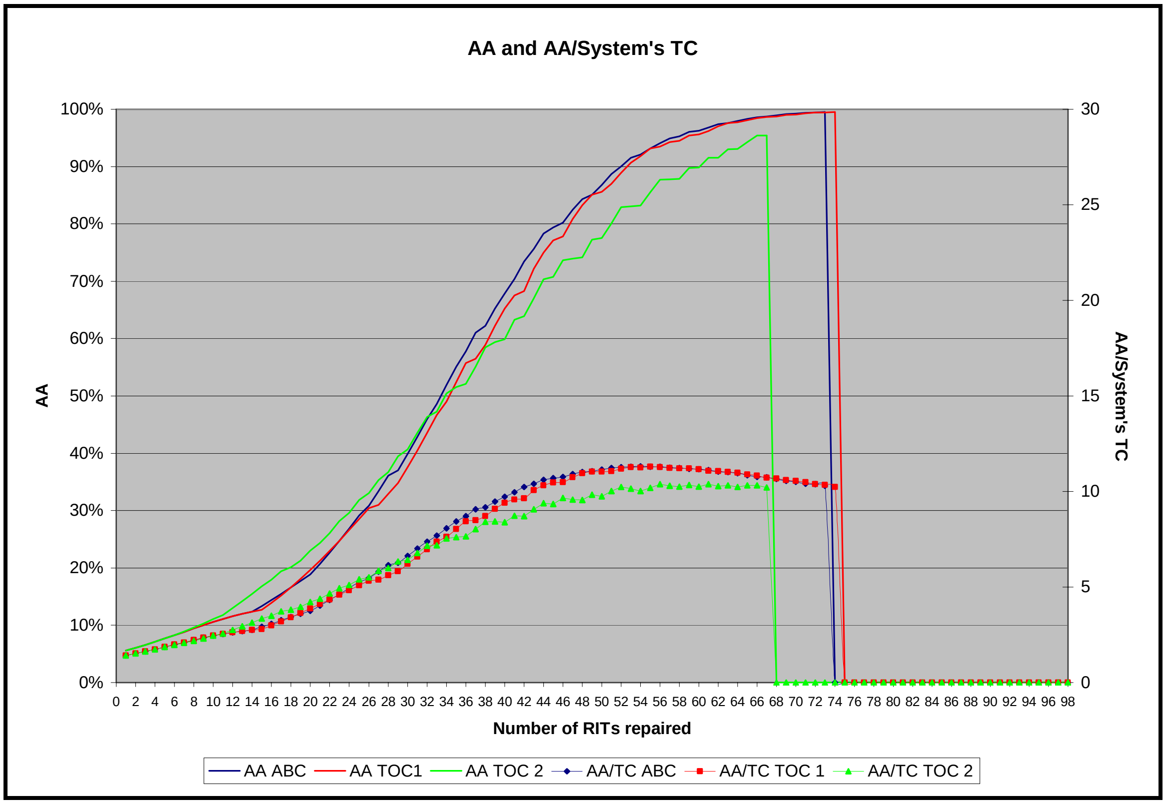


Figure C-15. – High Balance, NAirc = 16, NRAirc = 3, RT = 4, RM% = 75 %

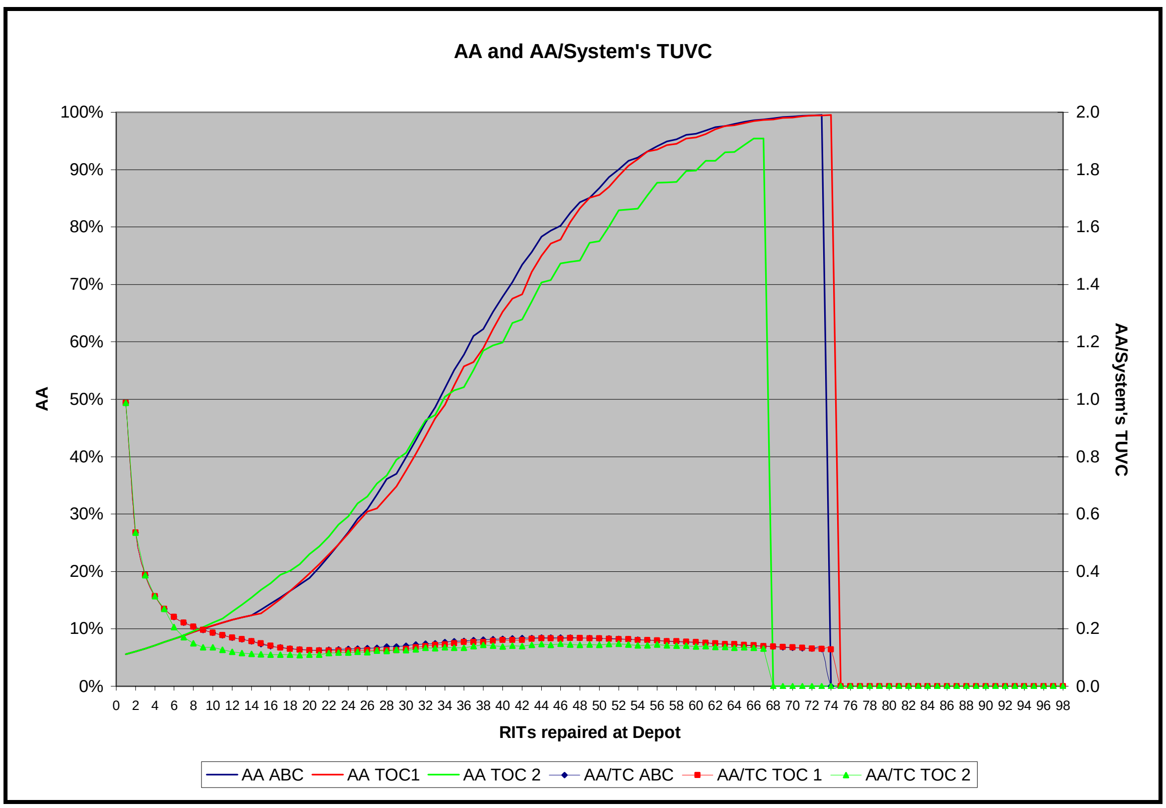


Figure C-16. – High Balance, NAirc = 16, NRAirc = 3, RT = 4, RM% = 75 %

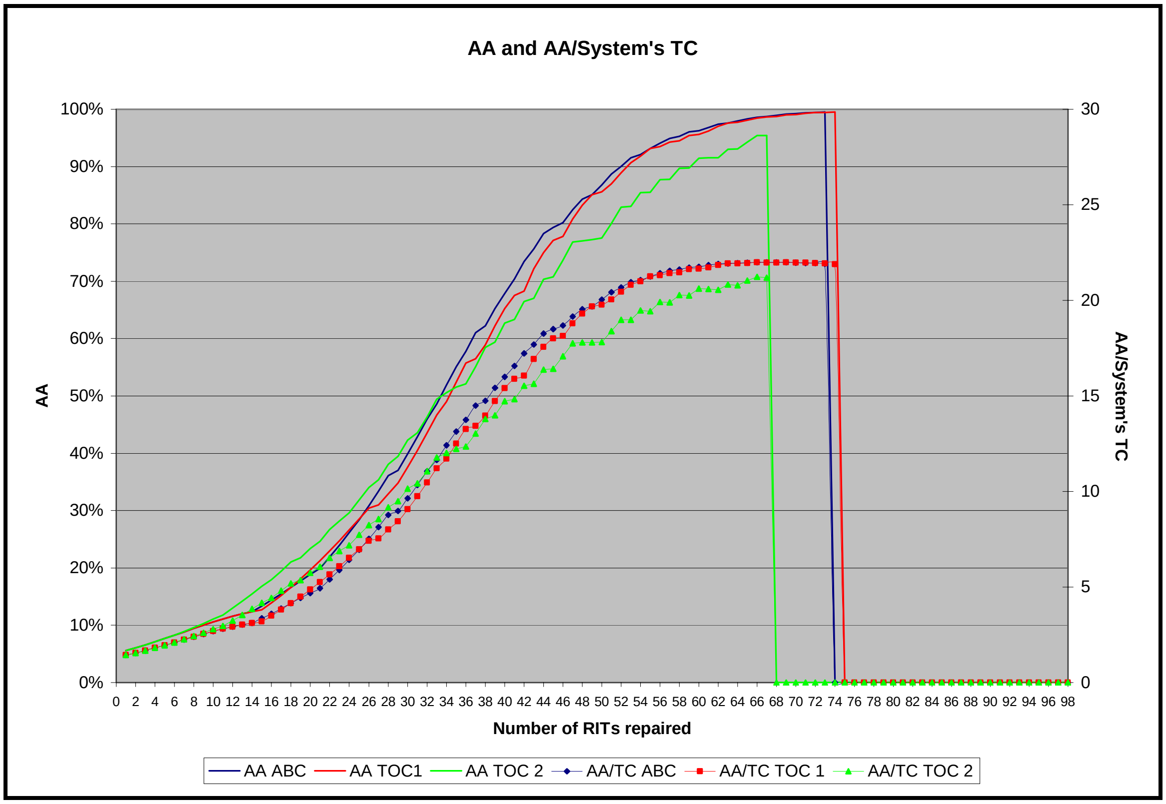


Figure C-17. – High Balance, NAirc = 16, NRAirc = 3, RT = 4, RM% = 25 %

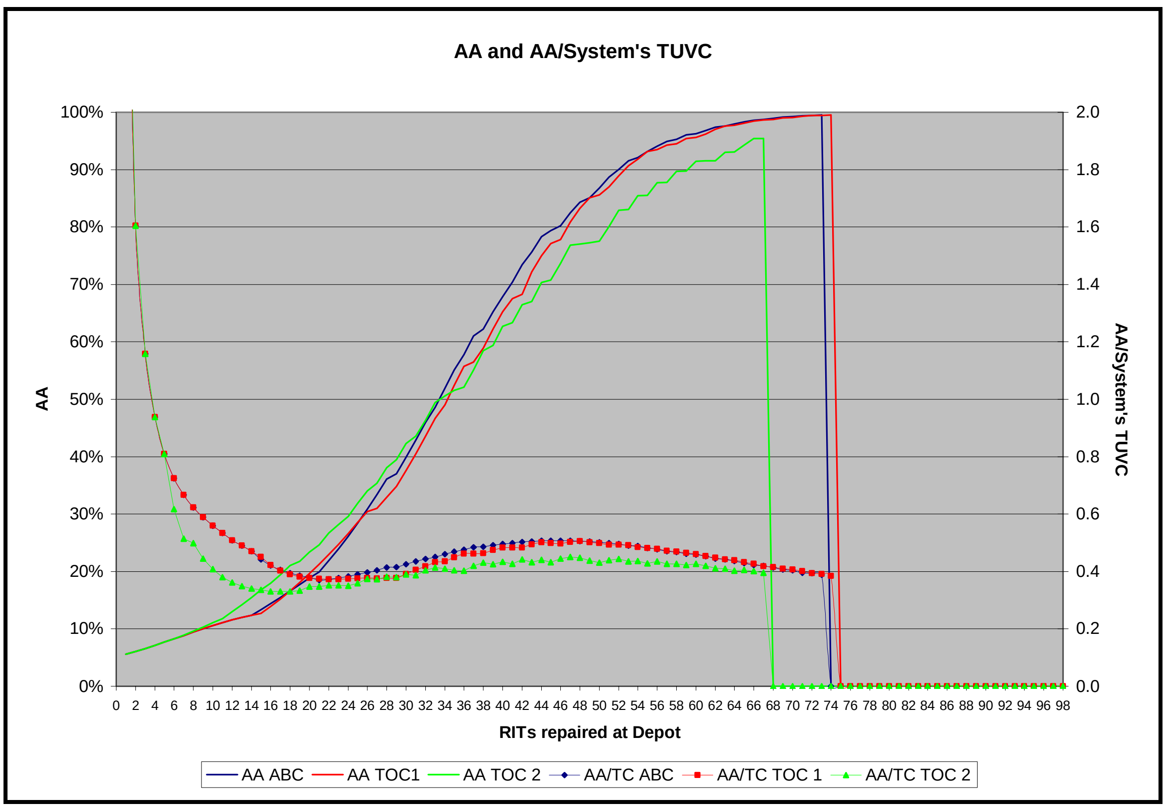


Figure C-18. – High Balance, NAirc = 16, NRAirc = 3, RT = 4, RM% = 25 %

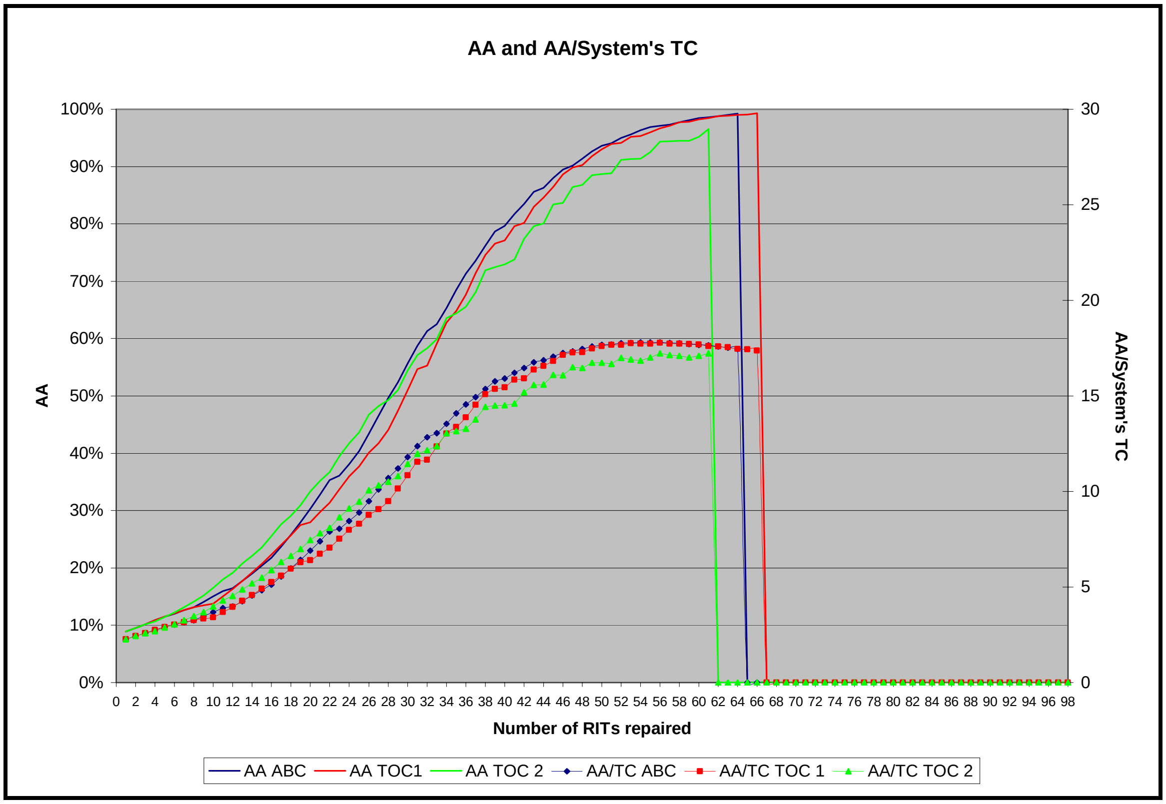


Figure C-19. – High Unbalanced, NAirc = 16, NRAirc = 3, RT = 4, RM% = 50 %

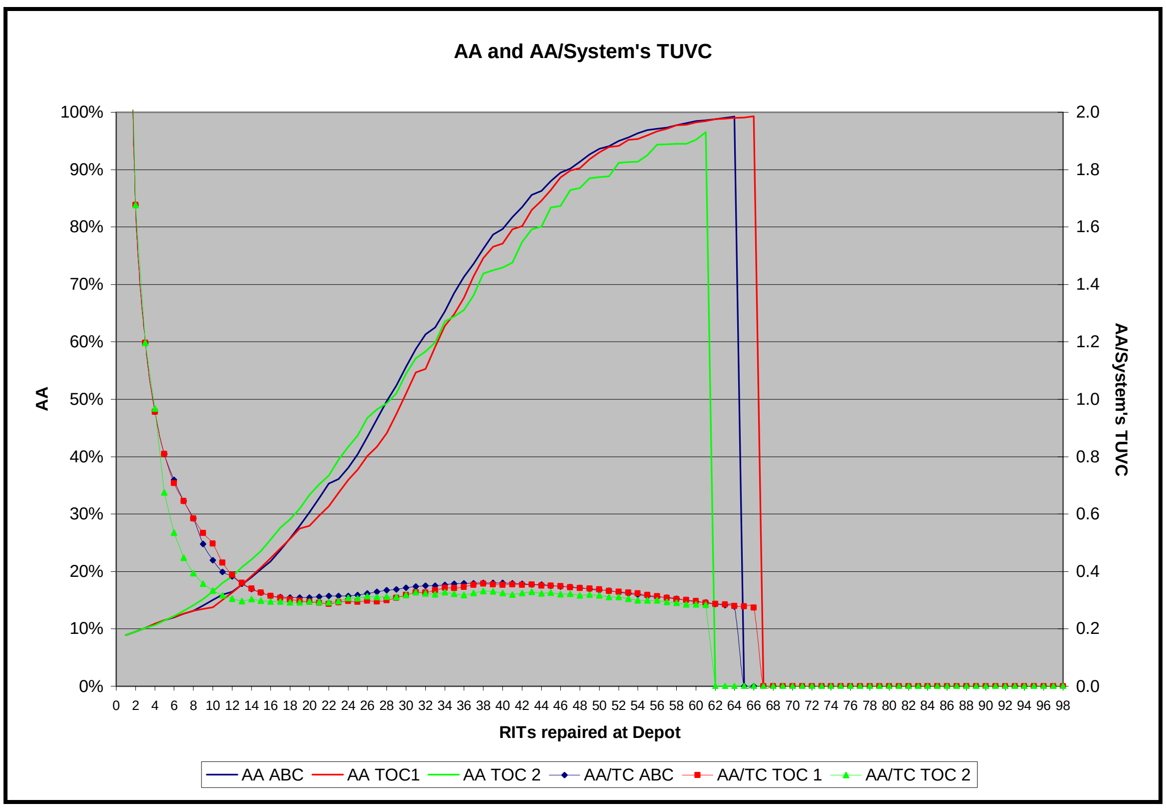


Figure C-20. – High Unbalanced, NAirc =16, NRAirc = 3, RT = 4, RM% = 50 %

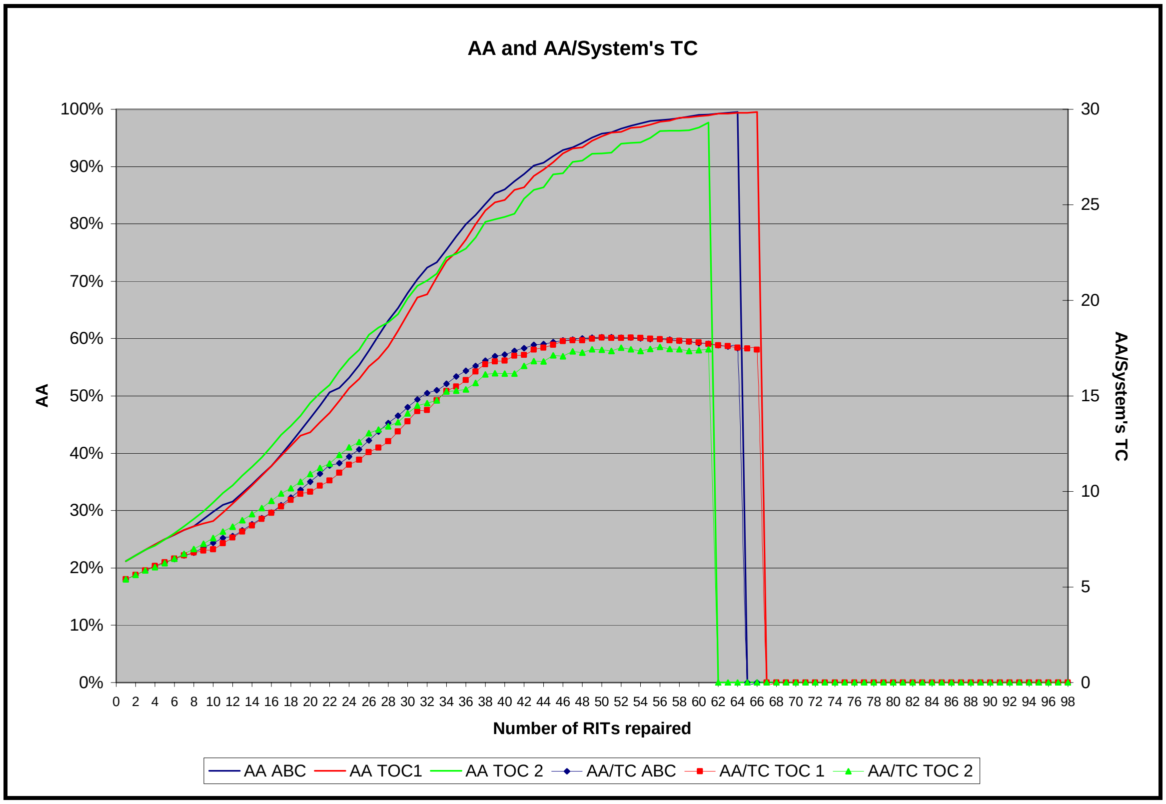


Figure C-21. – High Unbalanced, NAirc = 24, NRAirc = 3, RT = 4, RM% = 50 %

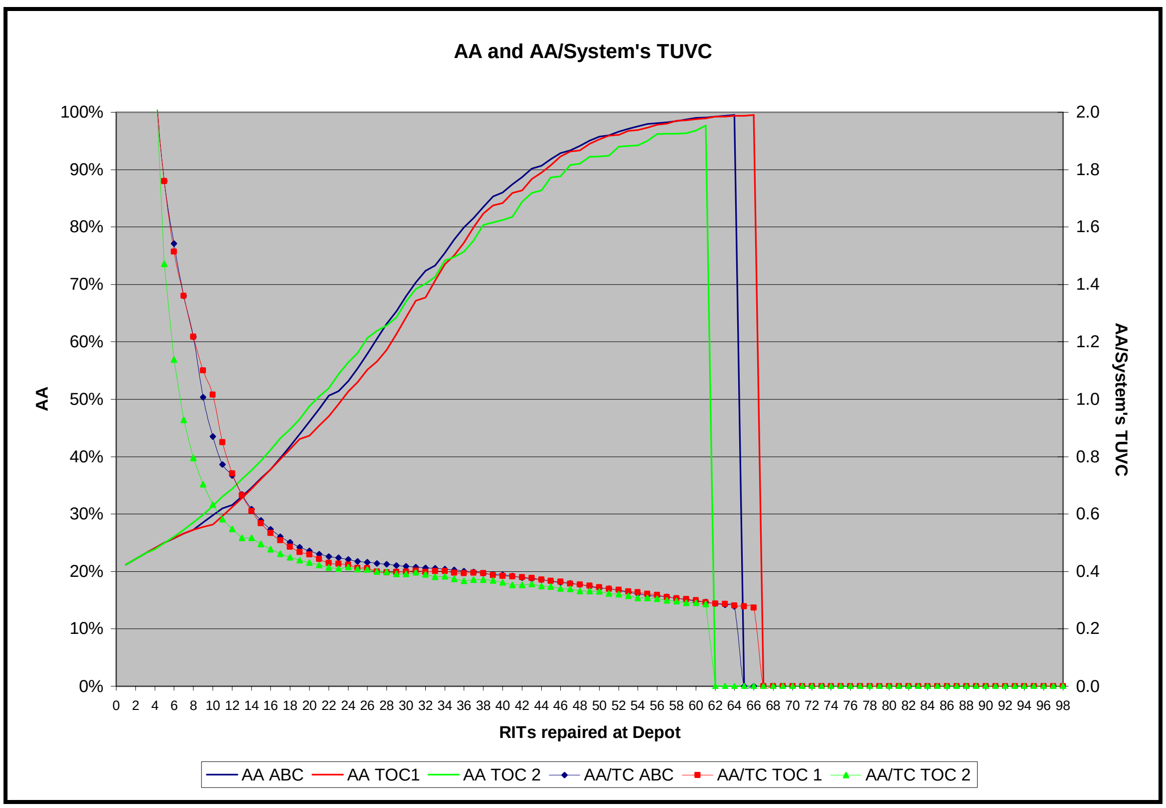


Figure C-22. – High Unbalanced, NAirc = 24, NRAirc = 3, RT = 4, RM% = 50 %

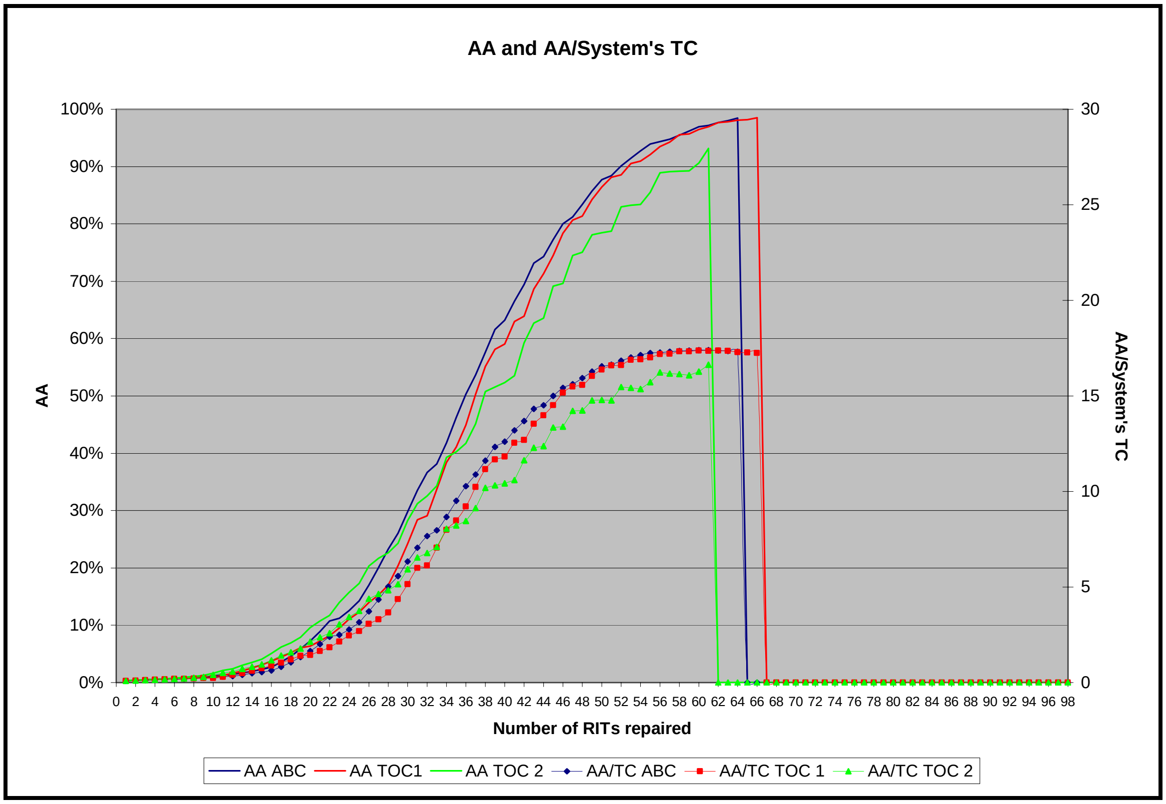


Figure C-23. – High Unbalanced, NAirc = 8, NRAirc = 3, RT = 4, RM% = 50 %

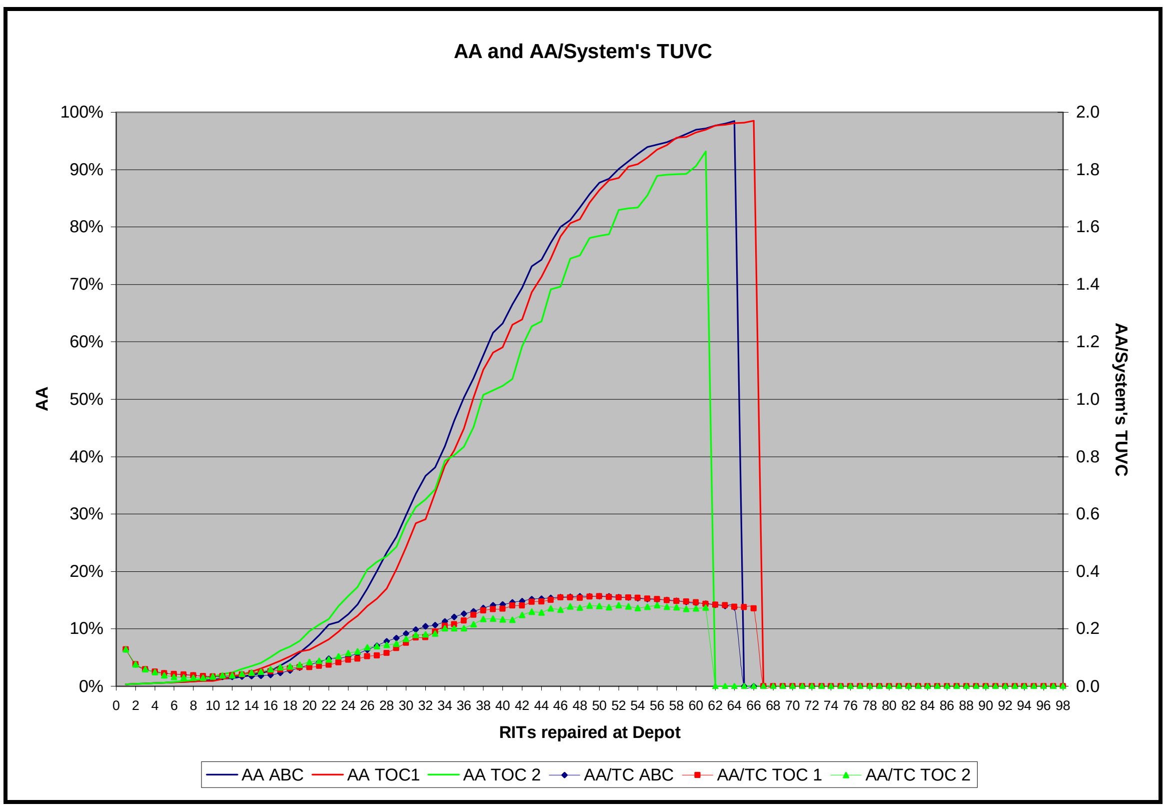


Figure C-24.– High Unbalanced, NAirc = 8 NRAirc = 3, RT = 4, RM% = 50 %

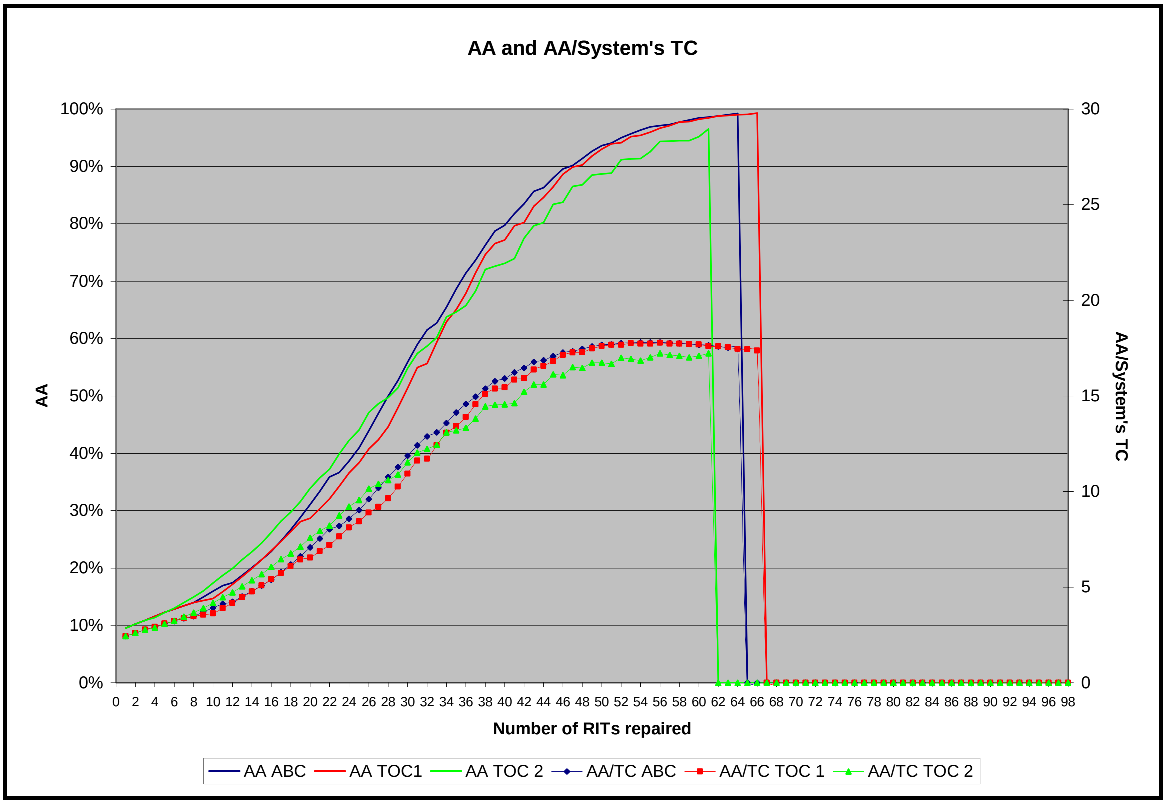


Figure C-25. – High Unbalanced, NAirc = 16, NRAirc = 4, RT = 4, RM% = 50 %

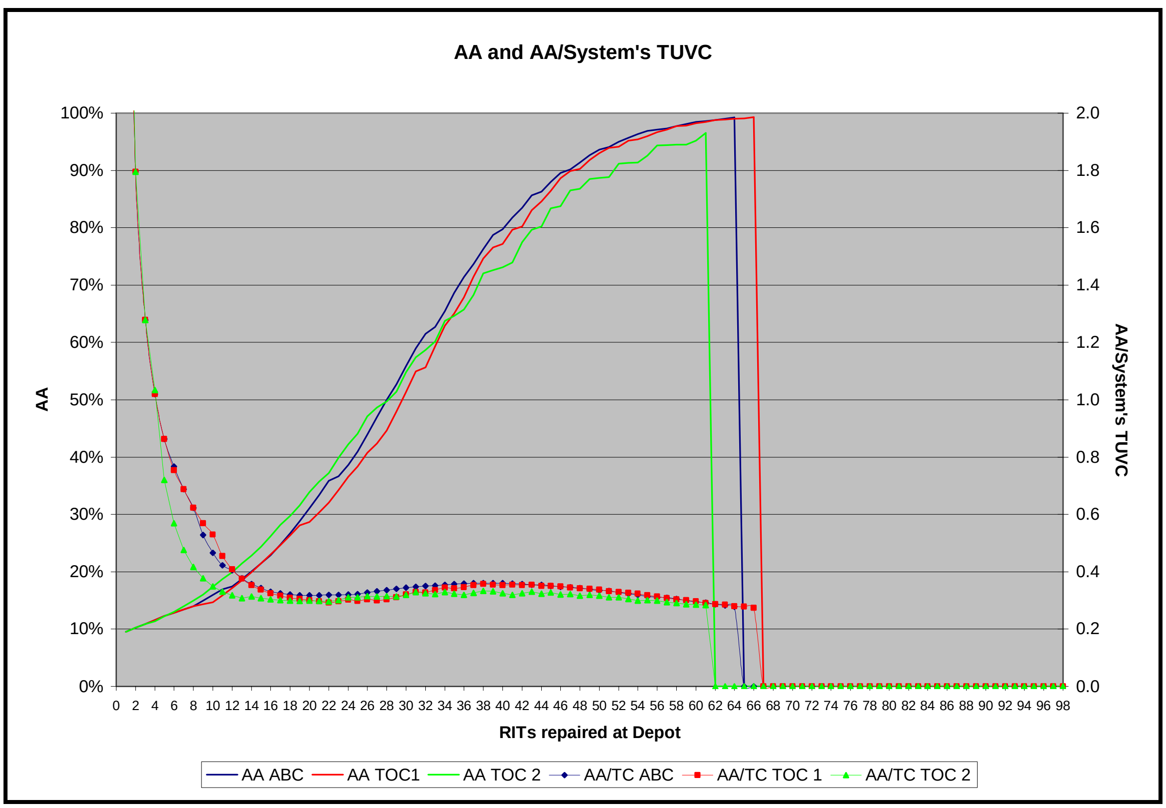


Figure C-26. – High Unbalanced, NAirc = 16, NRAirc = 4, RT = 4, RM% = 50 %

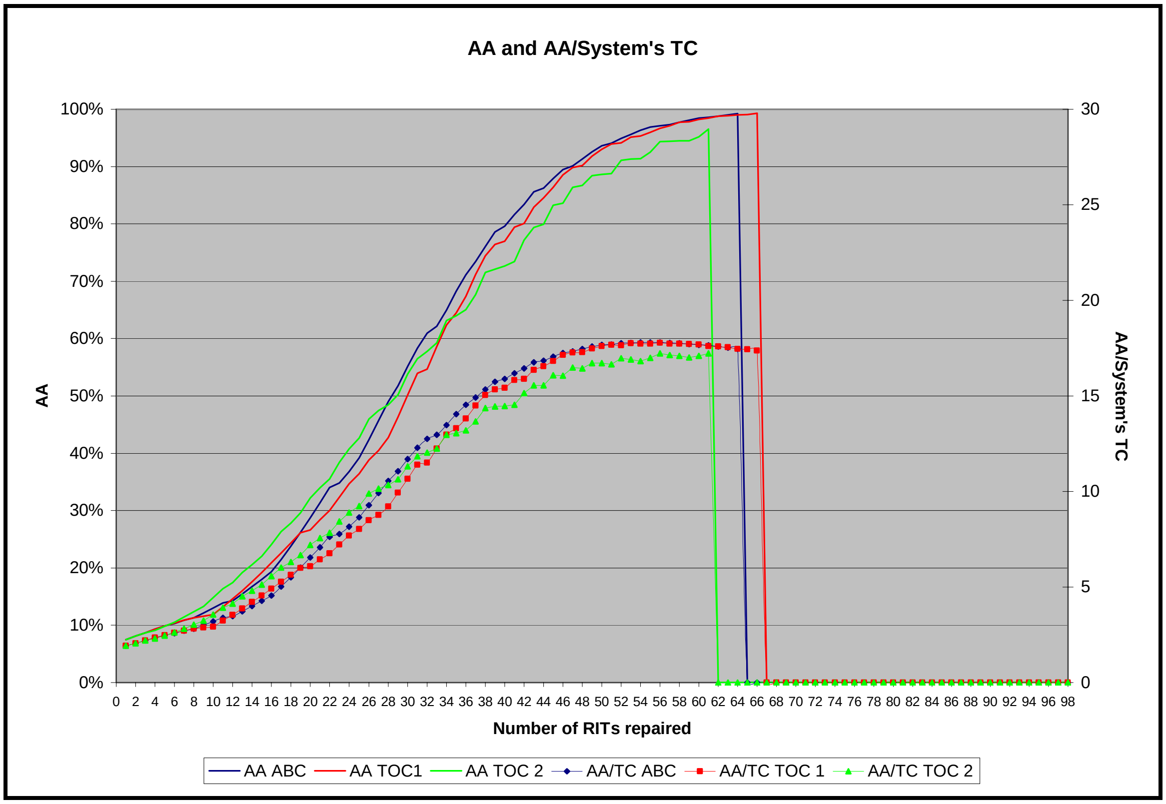


Figure C-27. – High Unbalanced, NAirc = 16, NRAirc = 2, RT = 4, RM% = 50 %

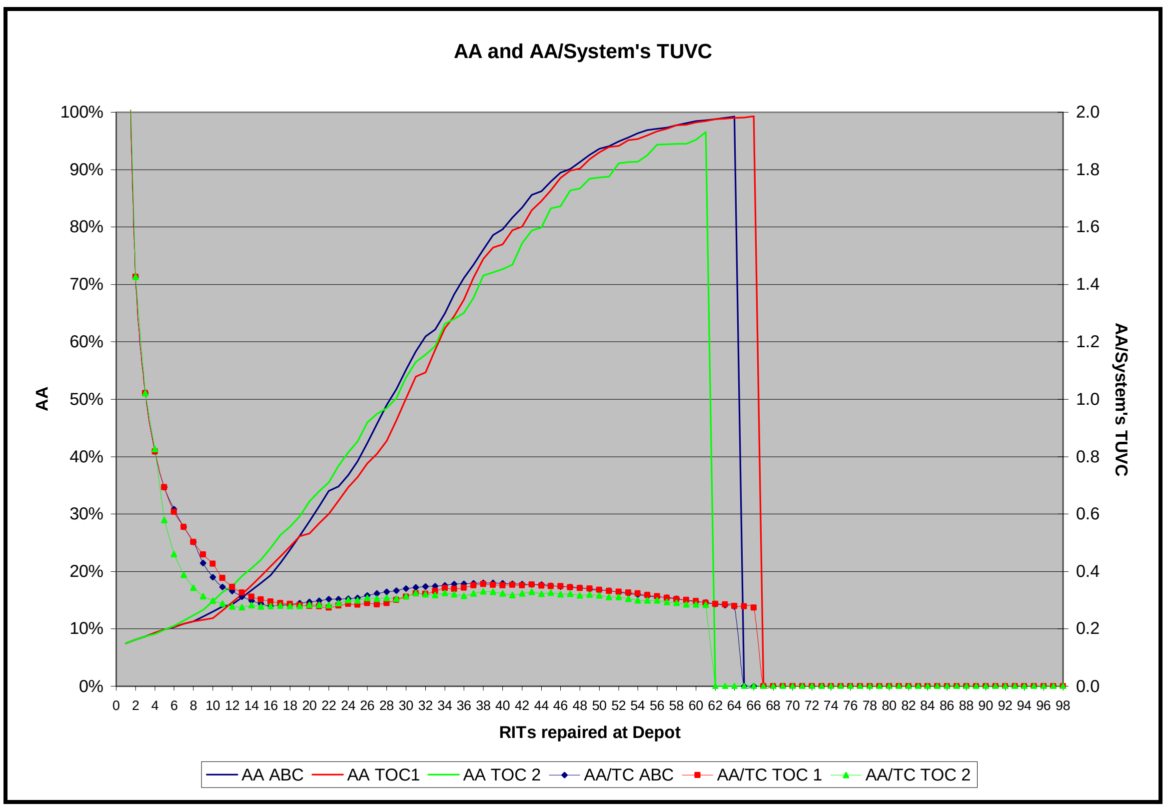


Figure C-28. – High Unbalanced, NAirc = 16, NRAirc = 2, RT = 4, RM% = 50 %

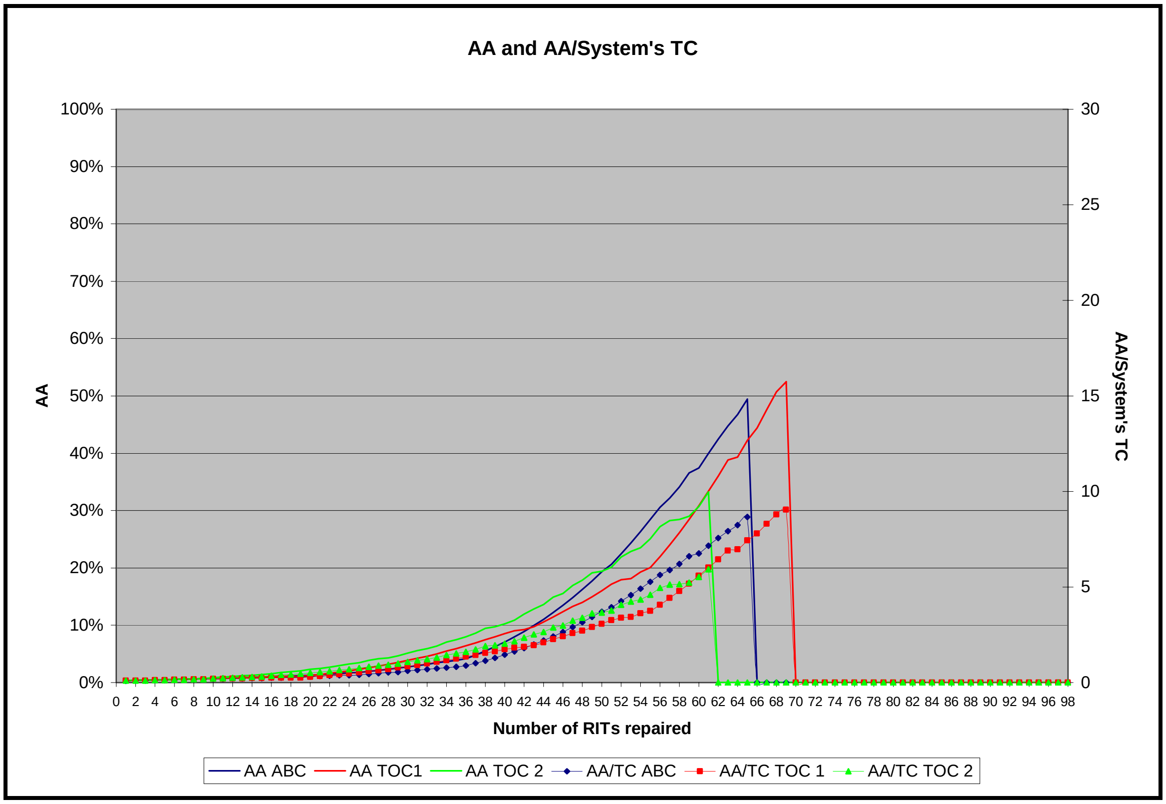


Figure C-29. – High Unbalanced, NAirc = 16, NRAirc = 3, RT = 8, RM% = 50 %

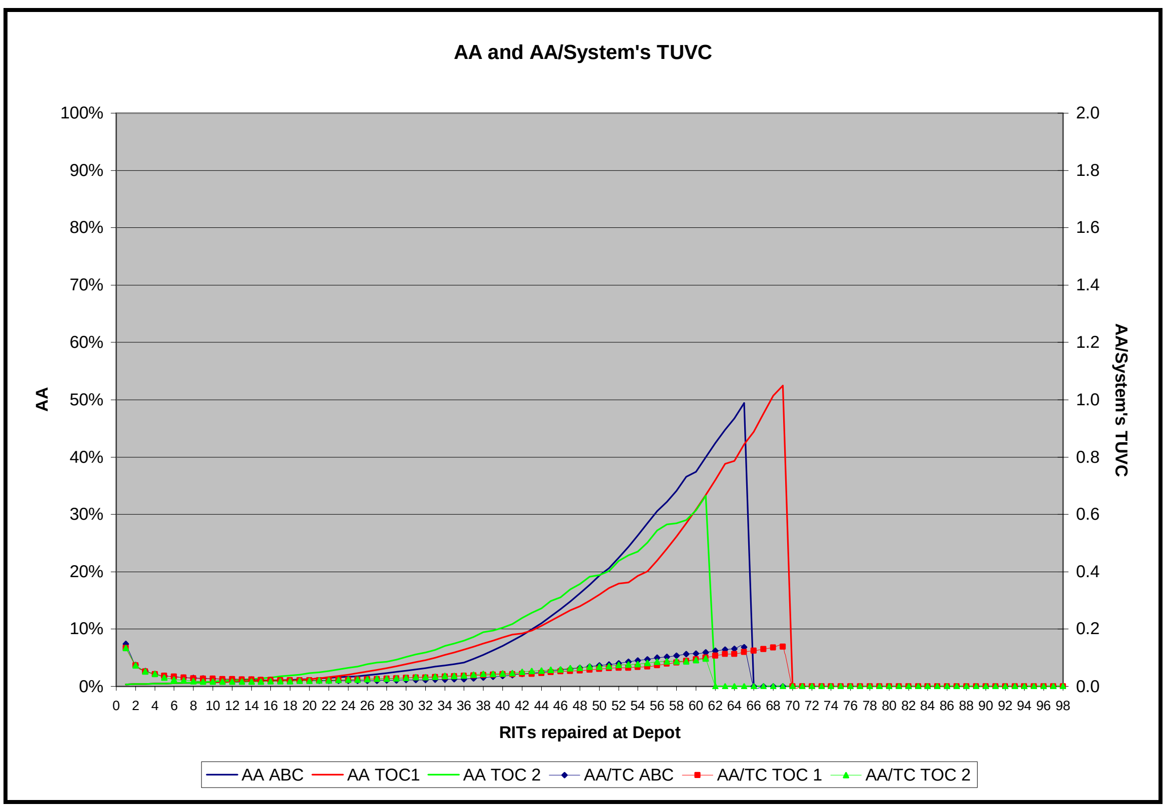


Figure C-30. – High Unbalanced, NAirc = 16, NRAirc = 3, RT = 8, RM% = 50 %

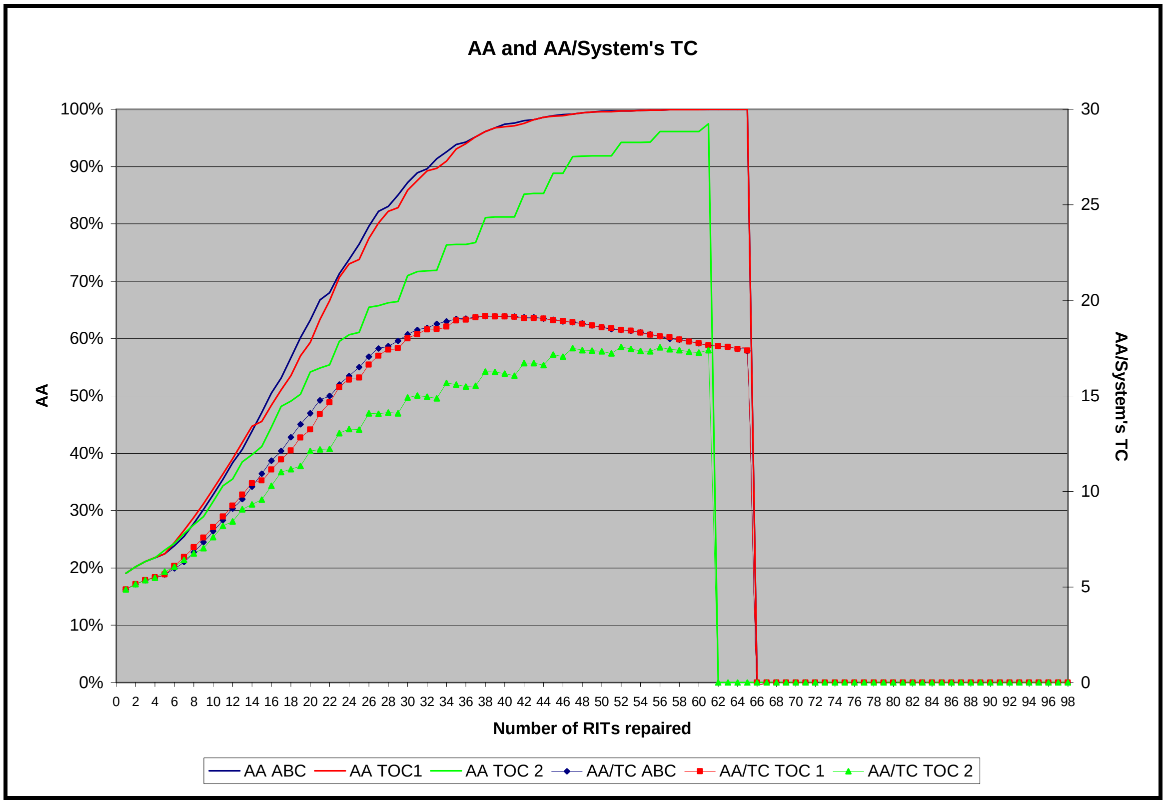


Figure C-31. – High Unbalanced, NAirc = 16, NRAirc = 3, RT = 2, RM% = 50 %

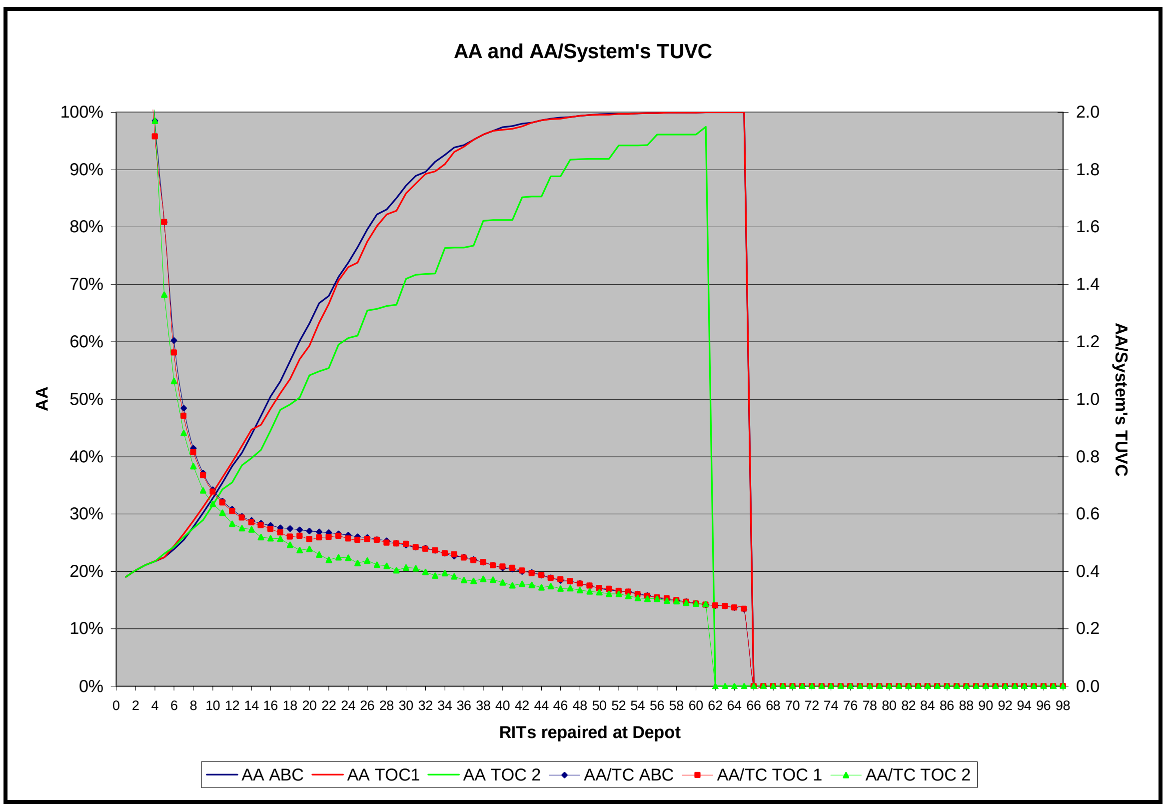


Figure C-32. – High Unbalanced, NAirc = 16, NRAirc = 3, RT = 2, RM% = 50 %

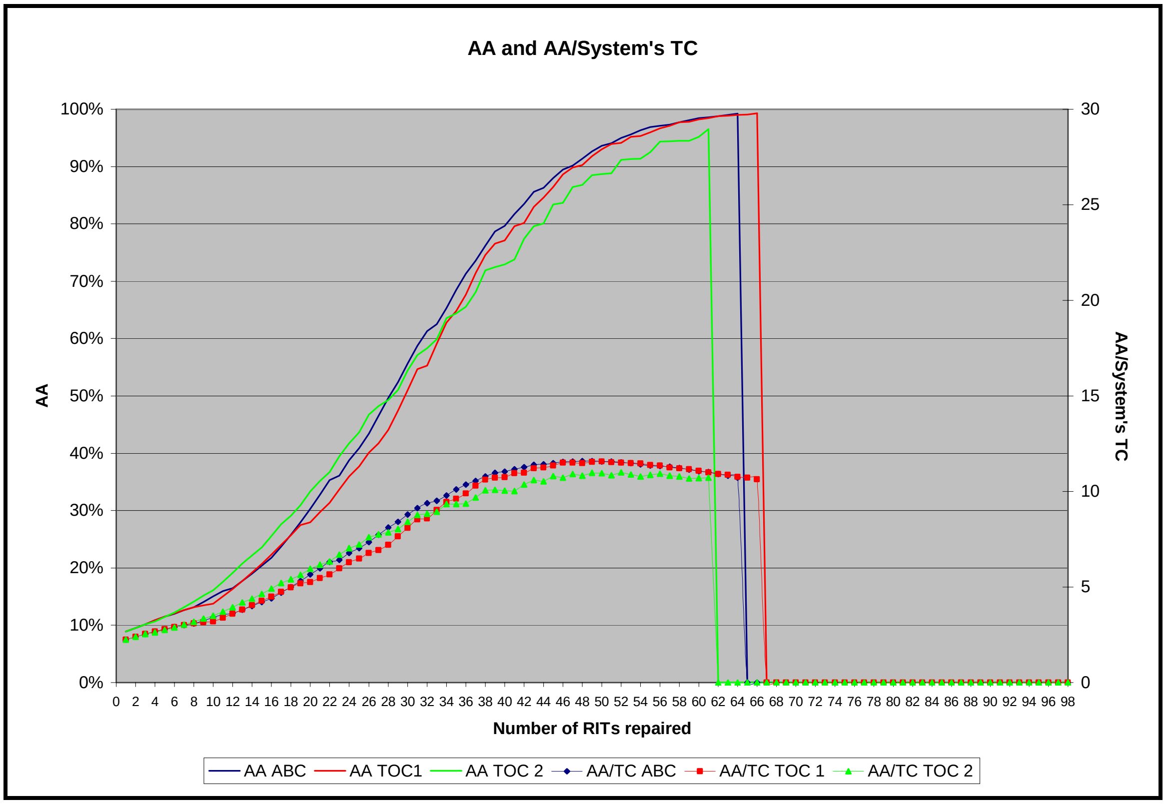


Figure C-33. – High Unbalanced, NAirc = 16, NRAirc = 3, RT = 4, RM% = 75 %

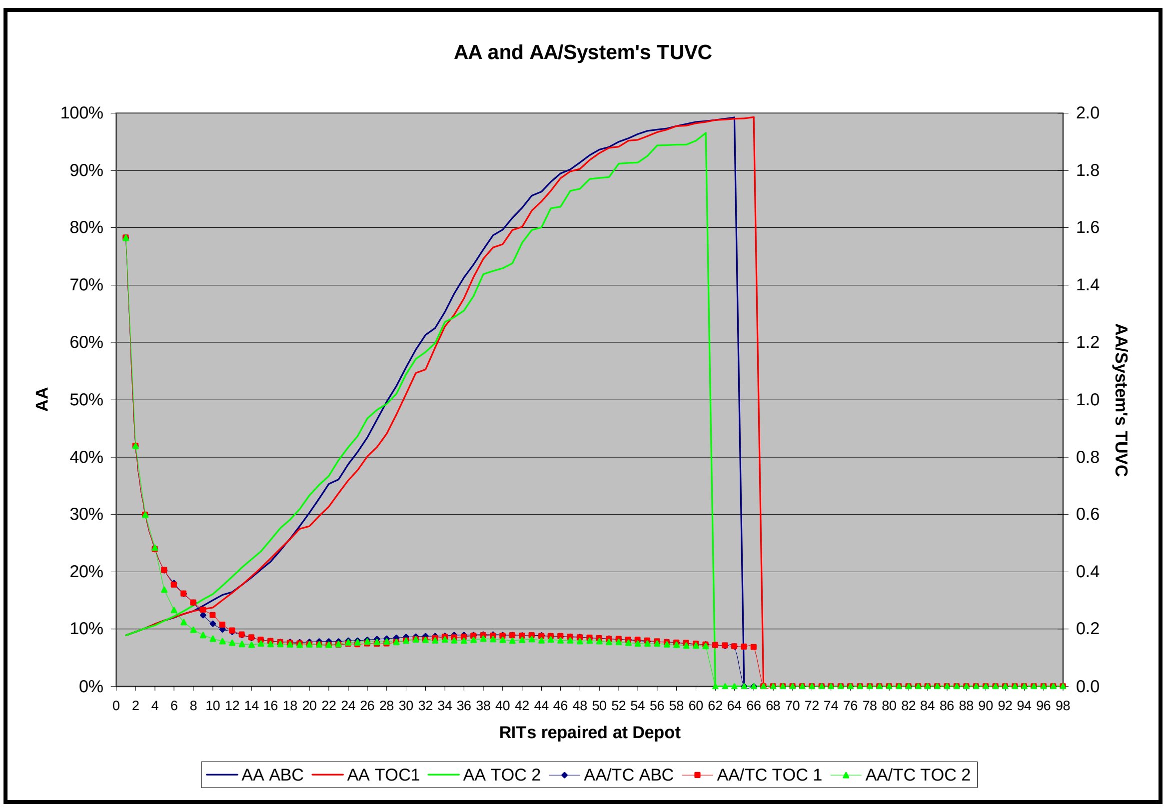


Figure C-34. – High Unbalanced, NAirc = 16, NRAirc = 3, RT = 4, RM% = 75 %

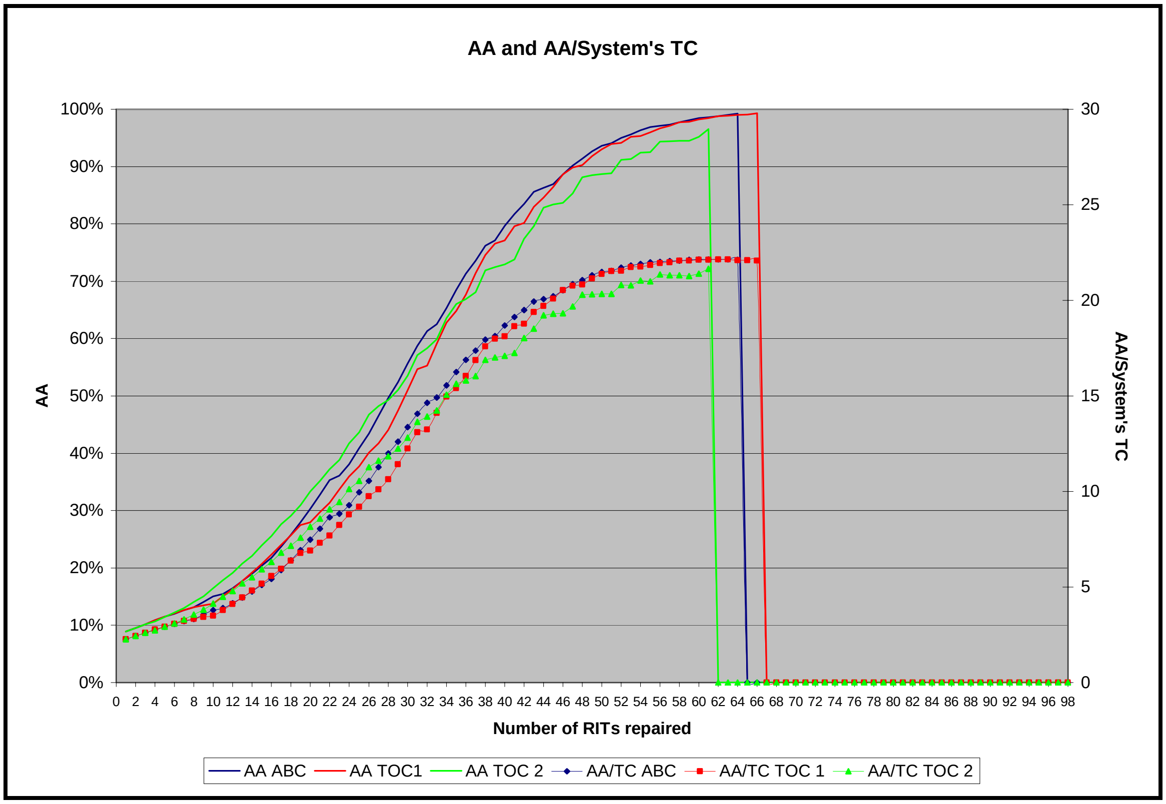


Figure C-35. – High Unbalanced, NAirc = 16, NRAirc = 3, RT = 4, RM% = 25 %

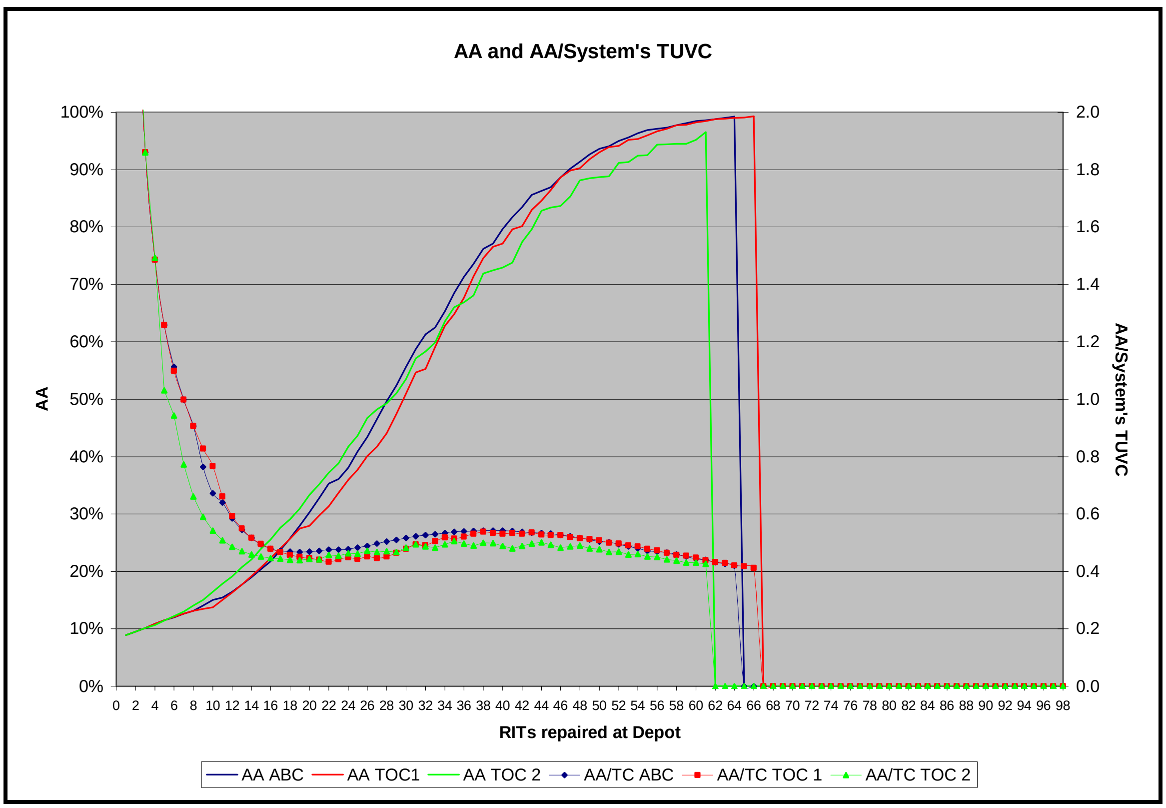


Figure C-36. – High Unbalanced, NAirc = 16, NRAirc = 3, RT = 4, RM% = 25 %

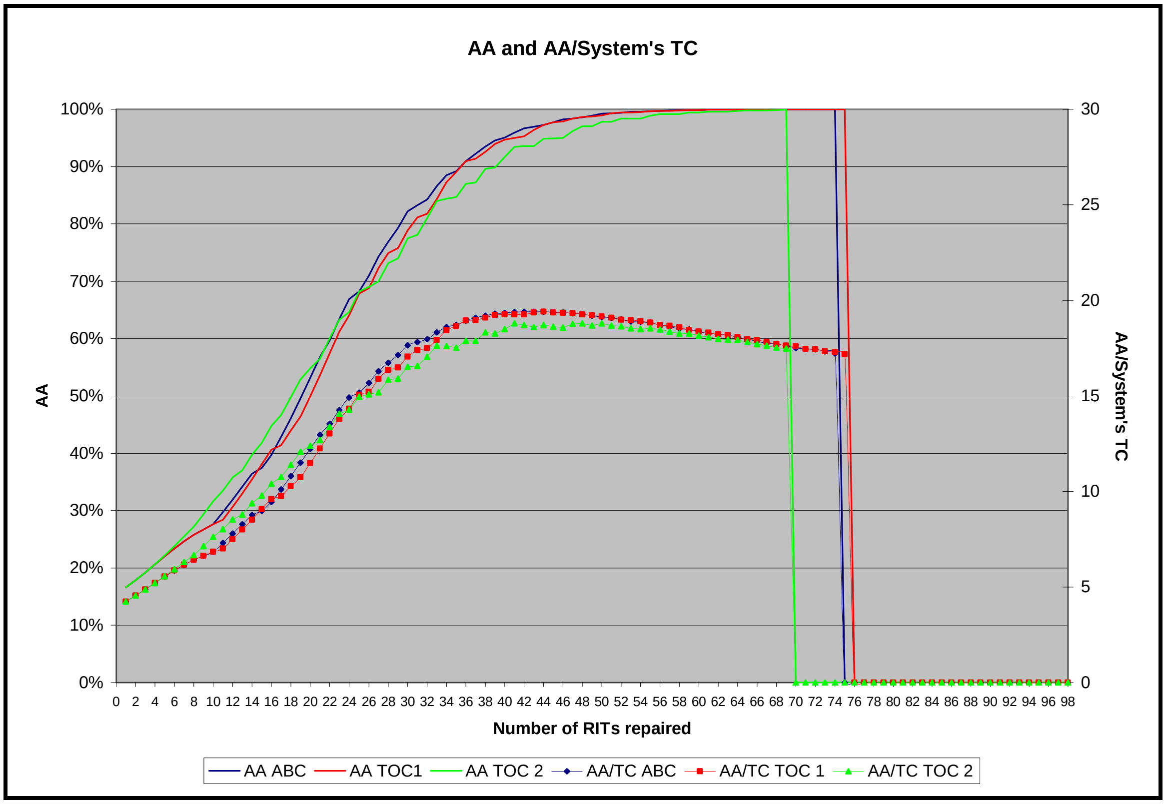


Figure C-37. – Low Balanced, NAirc = 16, NRAirc = 3, RT = 4, RM% = 50 %

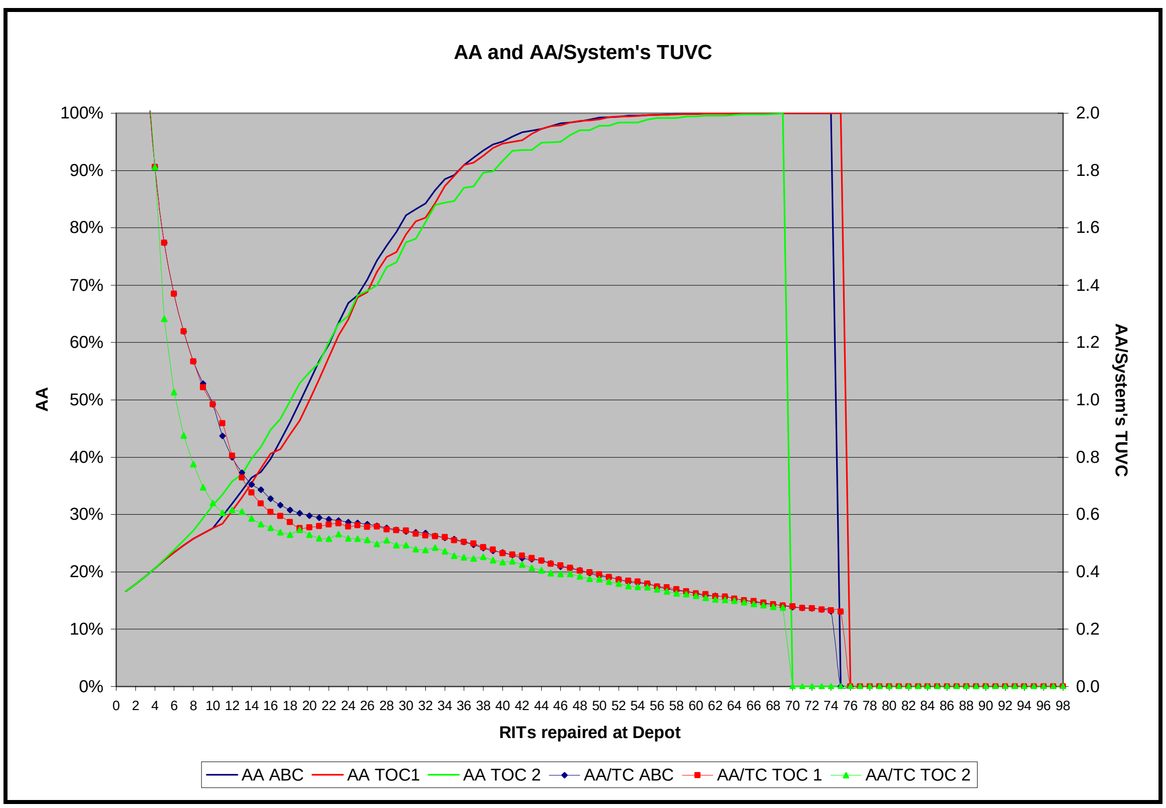


Figure C-38. – Low Balanced, NAirc =16, NRAirc = 3, RT = 4, RM% = 50 %

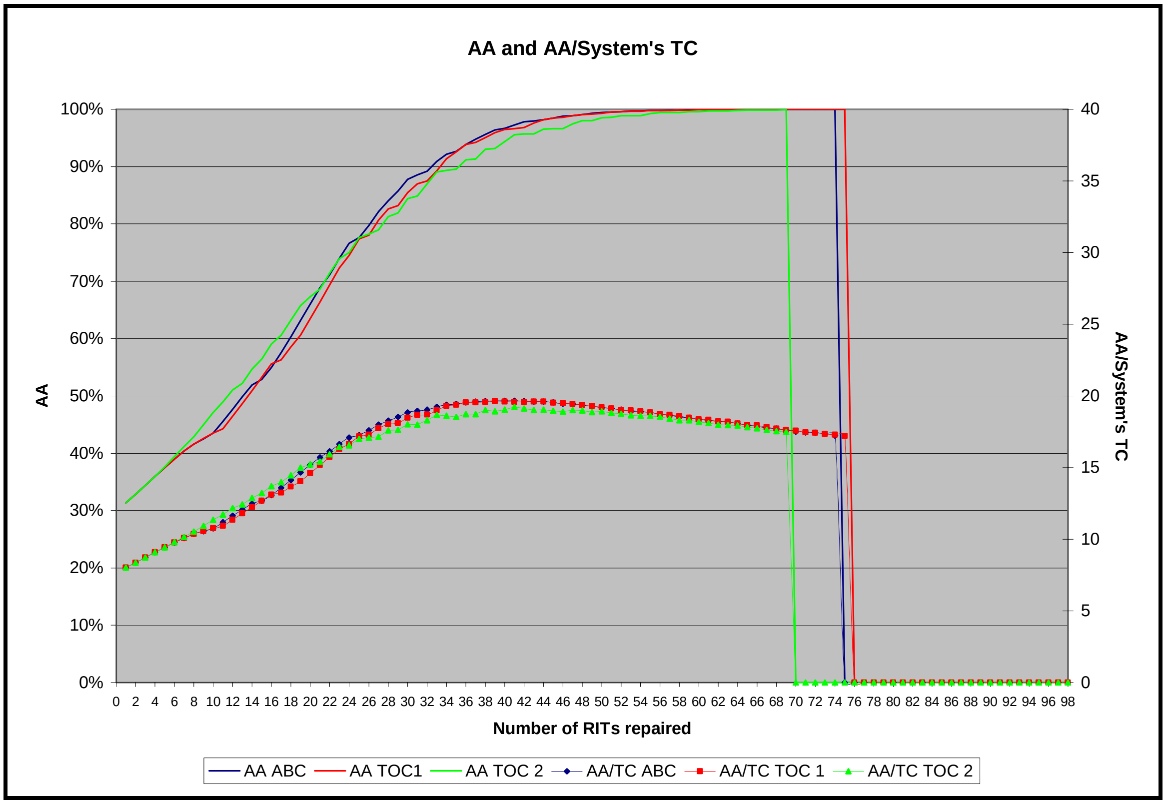


Figure C-39. – Low Balanced, NAirc = 24, NRAirc = 3, RT = 4, RM% = 50 %

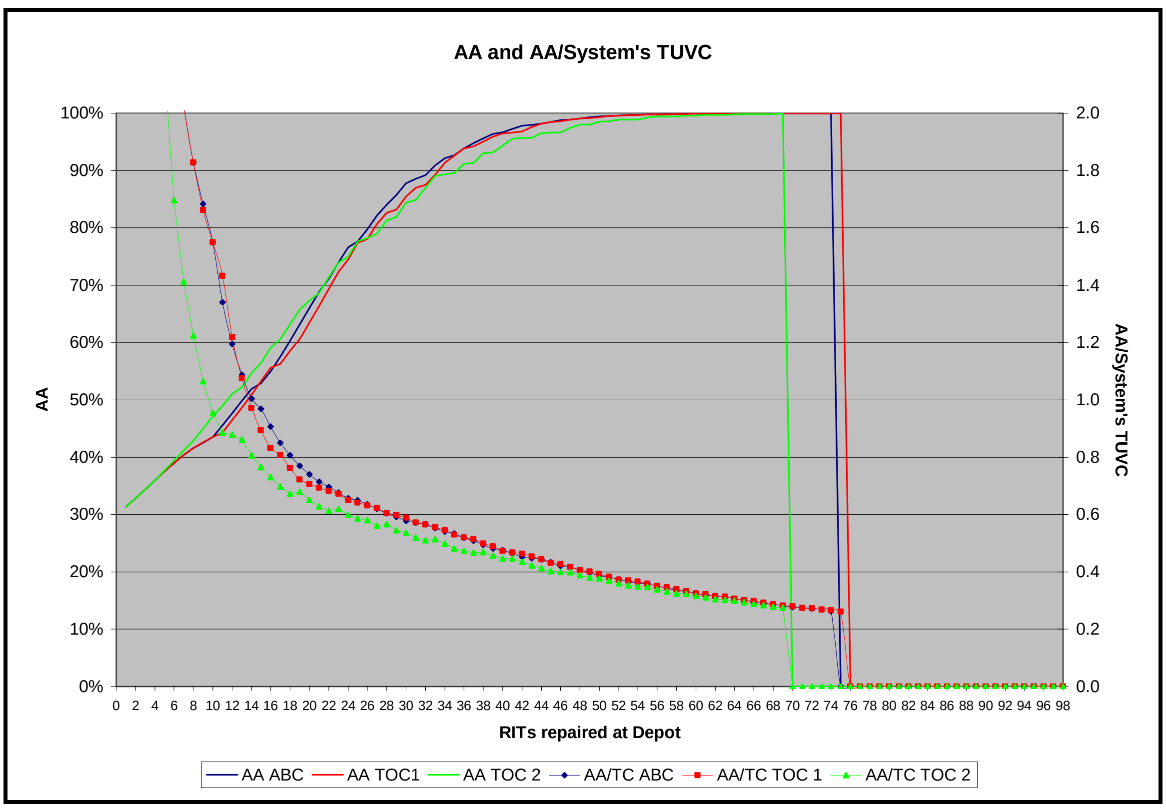


Figure C-40. – Low Balanced, NAirc = 24, NRAirc = 3, RT = 4, RM% = 50 %

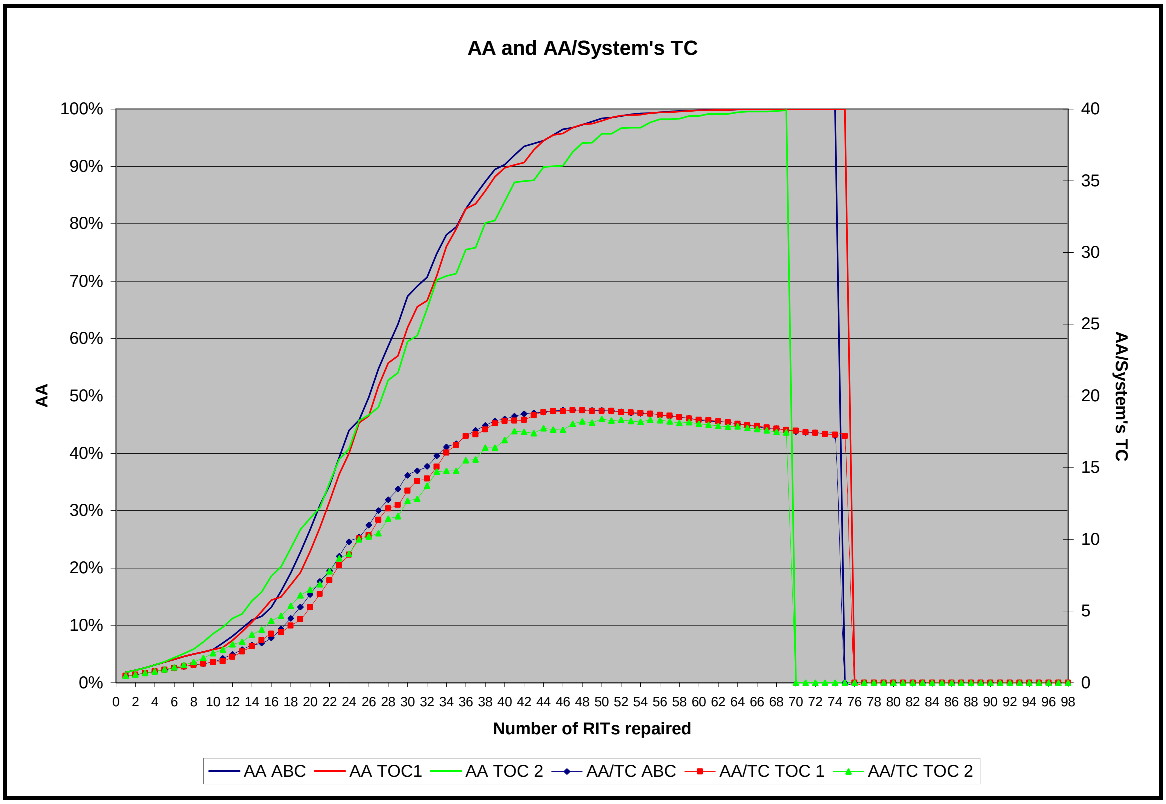


Figure C-41. – Low Balanced, NAirc = 8, NRAirc = 3, RT = 4, RM% = 50 %

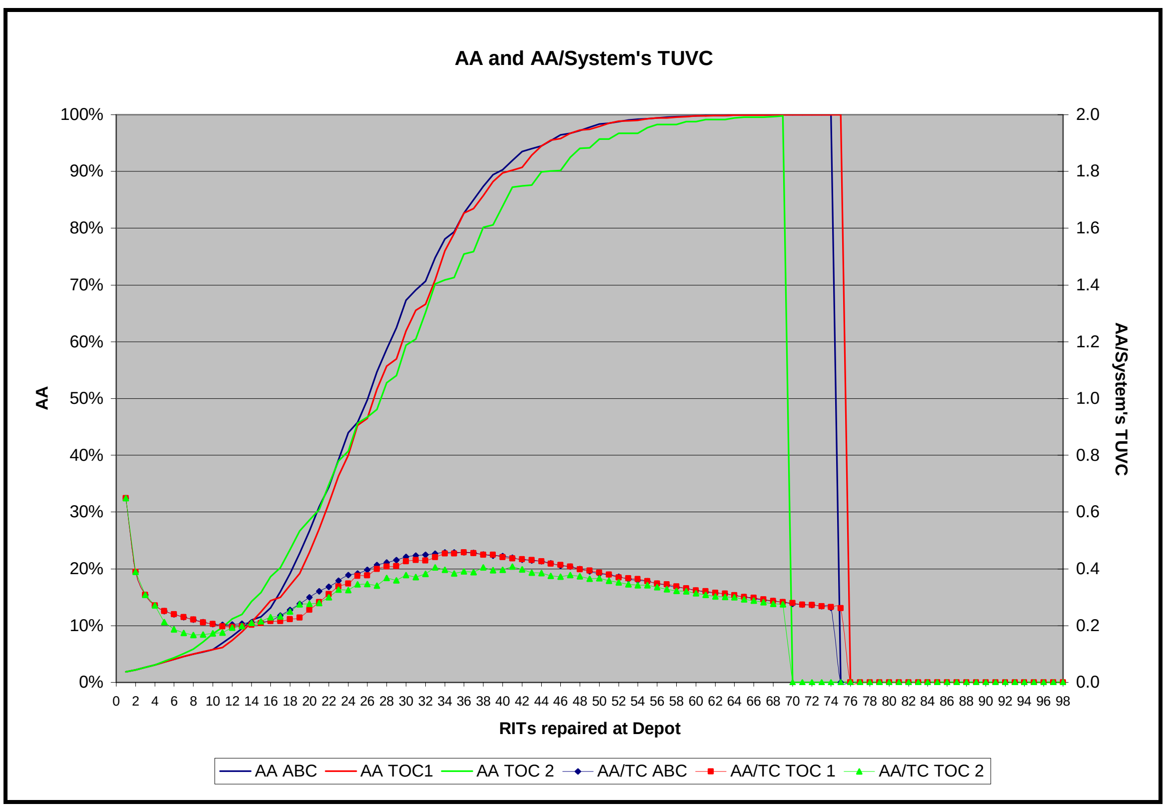


Figure C-42. – Low Balanced, NAirc = 8 NRAirc = 3, RT = 4, RM% = 50 %

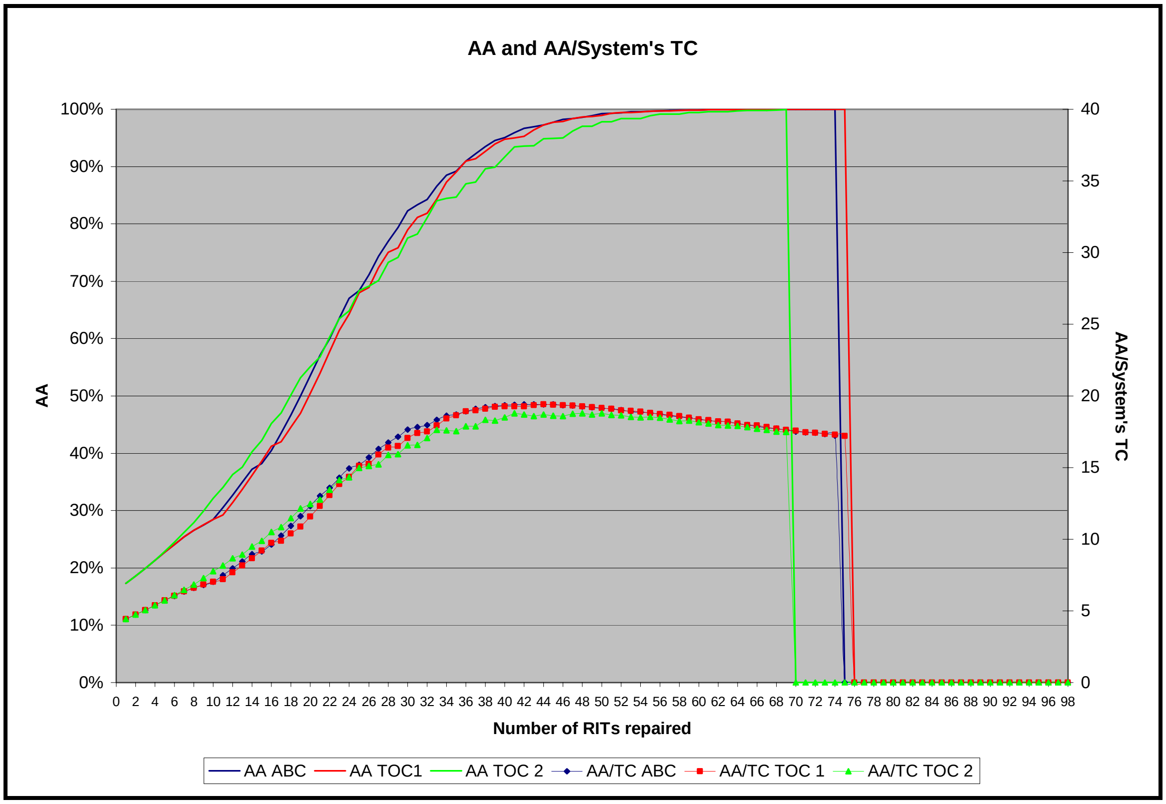


Figure C-43. – Low Balanced, NAirc = 16, NRAirc = 4, RT = 4, RM% = 50 %

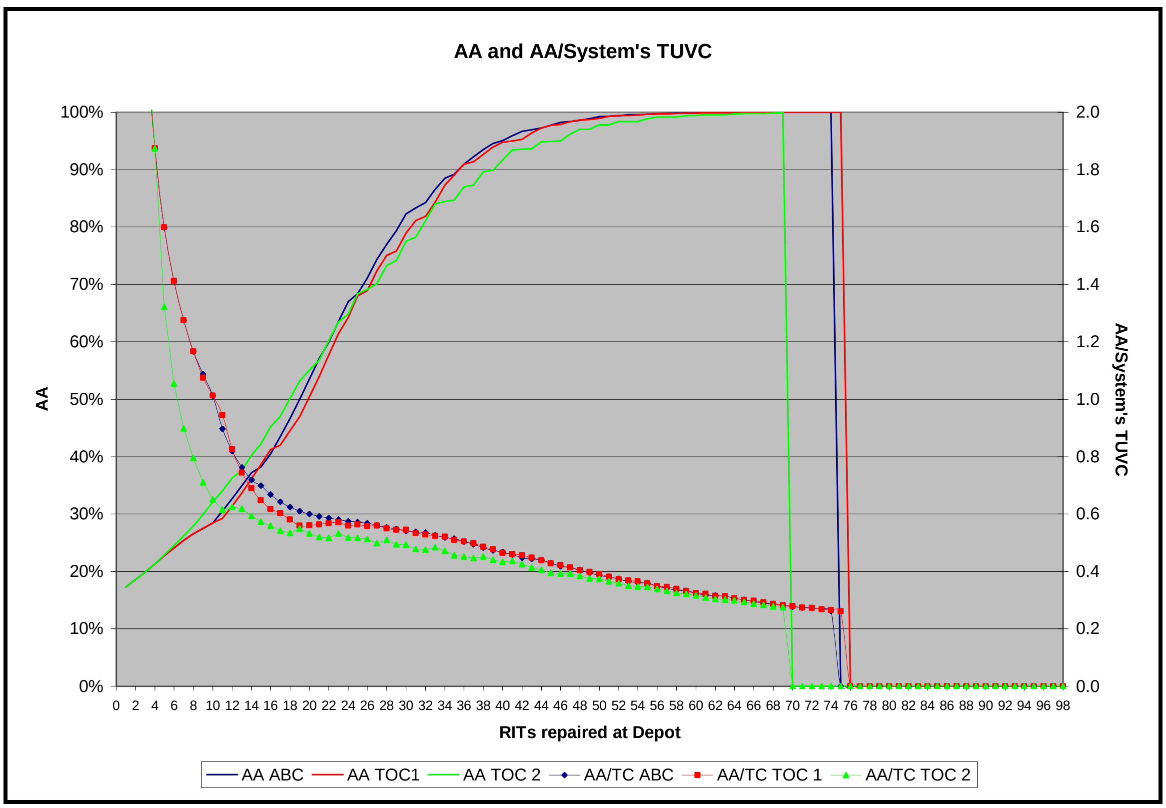


Figure C-44. – Low Balanced, NAirc = 16, NRAirc = 4, RT = 4, RM% = 50 %

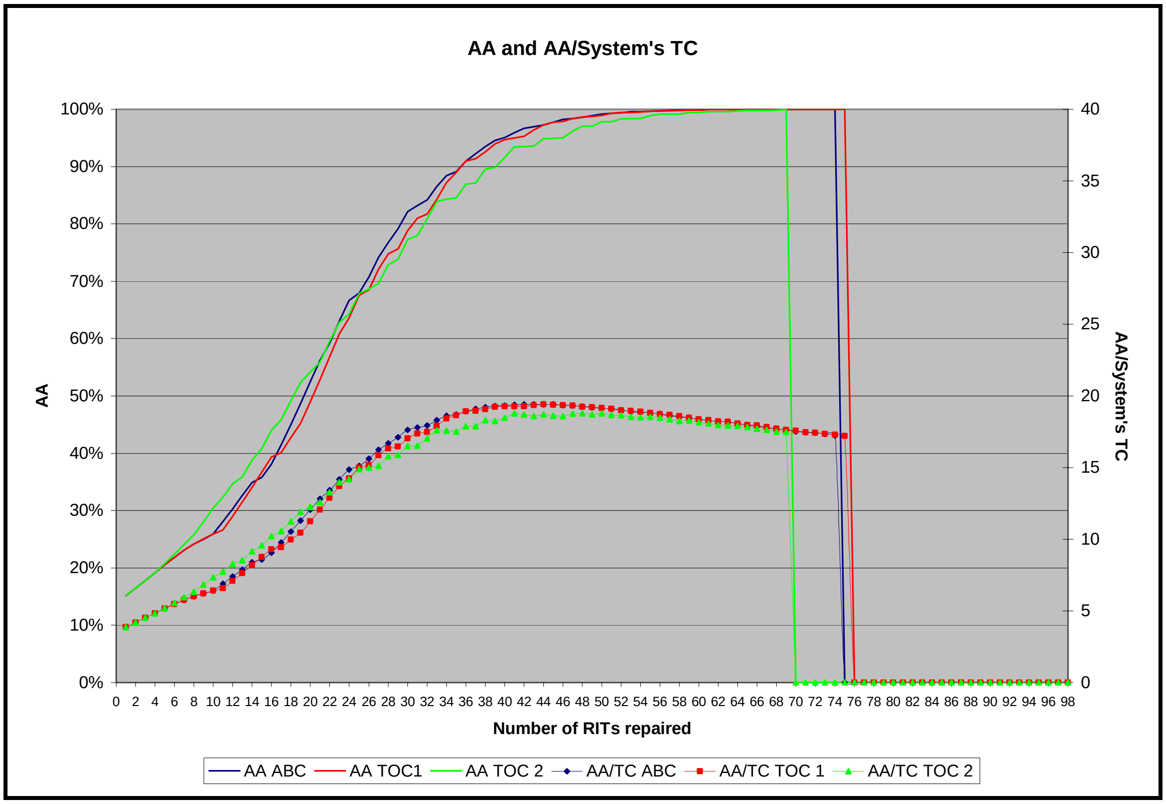


Figure C-45. – Low Balanced, NAirc = 16, NRAirc = 2, RT = 4, RM% = 50 %

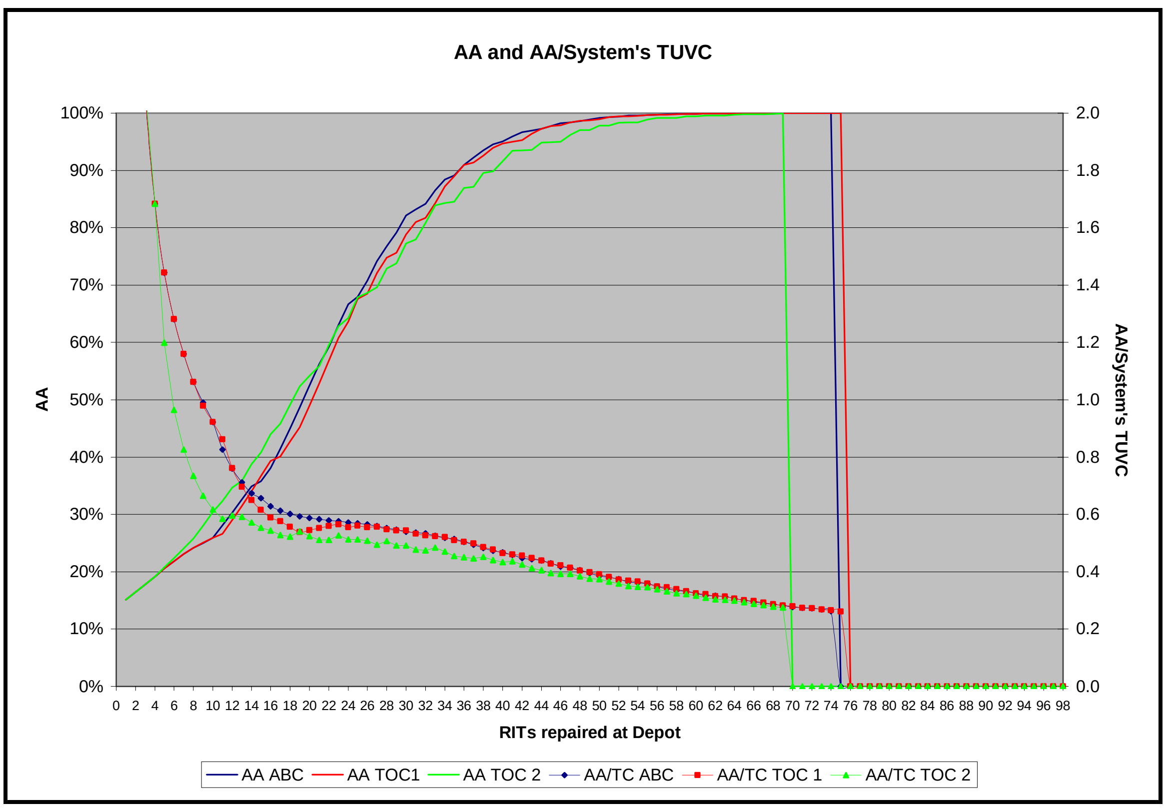


Figure C-46. – Low Balanced, NAirc = 16, NRAirc = 2, RT = 4, RM% = 50 %

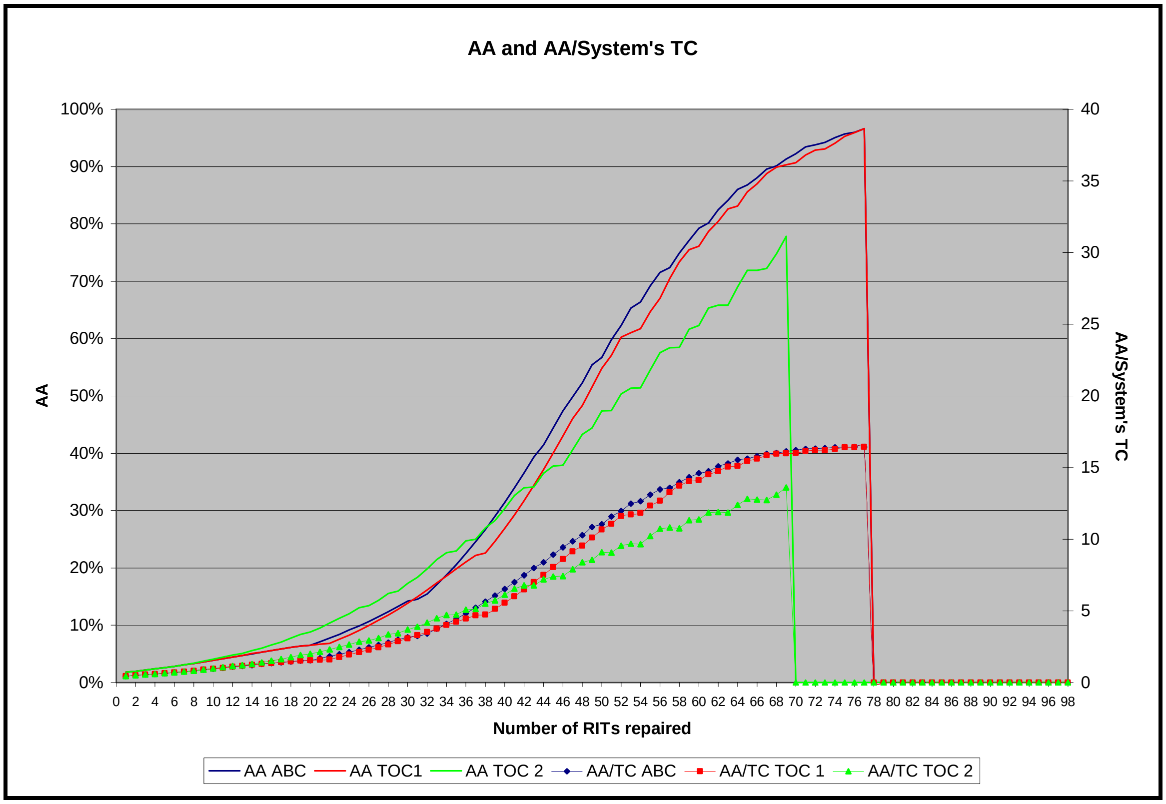


Figure C-47. – Low Balanced, NAirc = 16, NRAirc = 3, RT = 8, RM% = 50 %

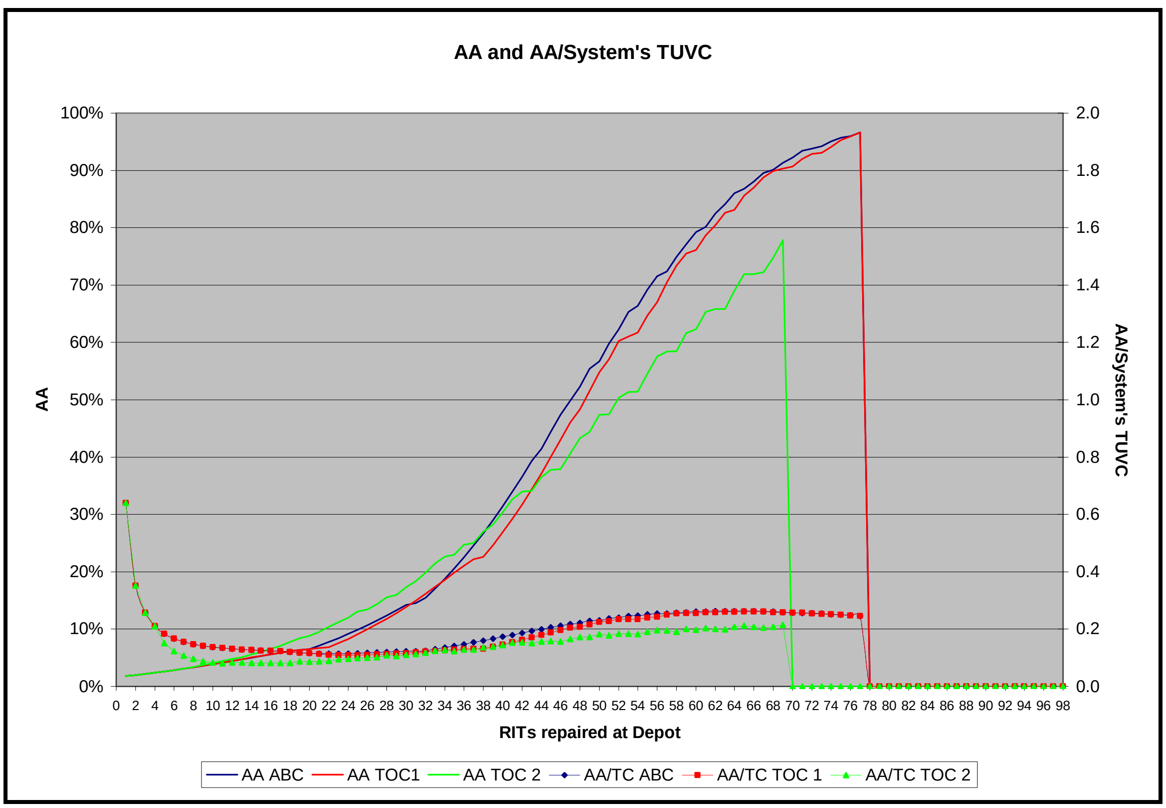


Figure C-48. – Low Balanced, NAirc = 16, NRAirc = 3, RT = 8, RM% = 50 %

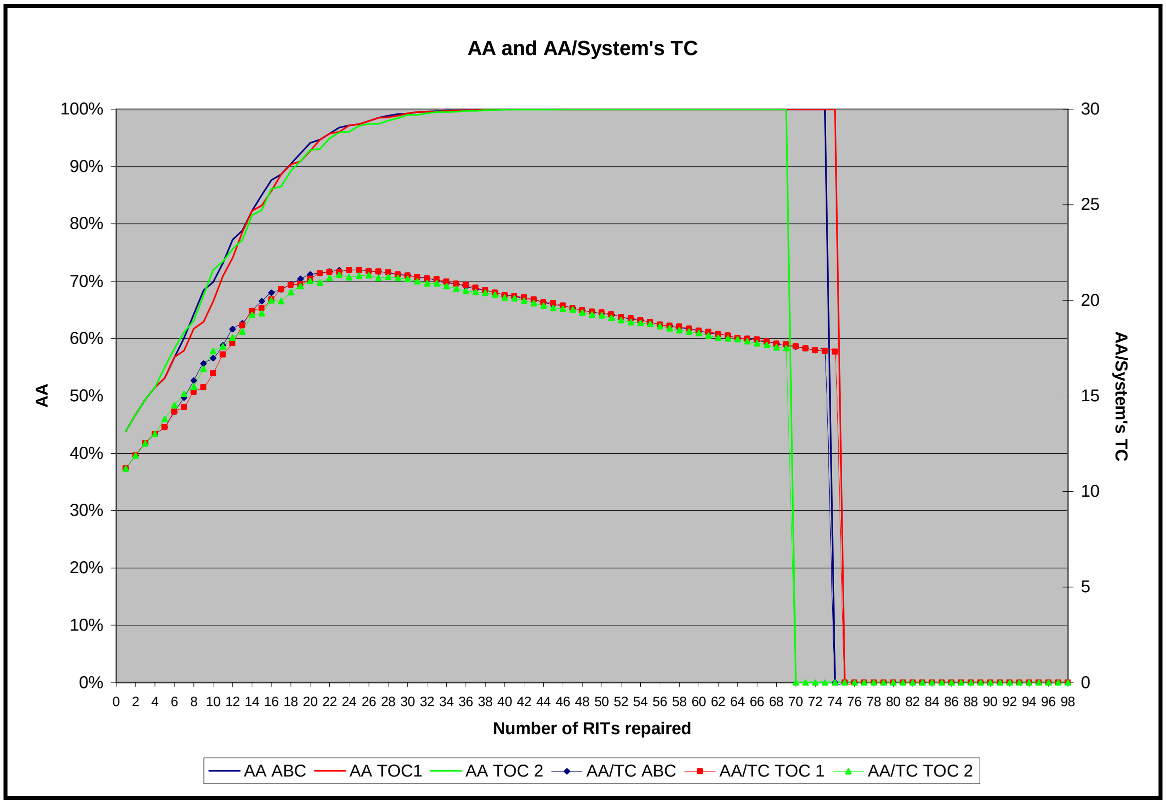


Figure C-49. – Low Balanced, NAirc = 16, NRAirc = 3, RT = 2, RM% = 50 %

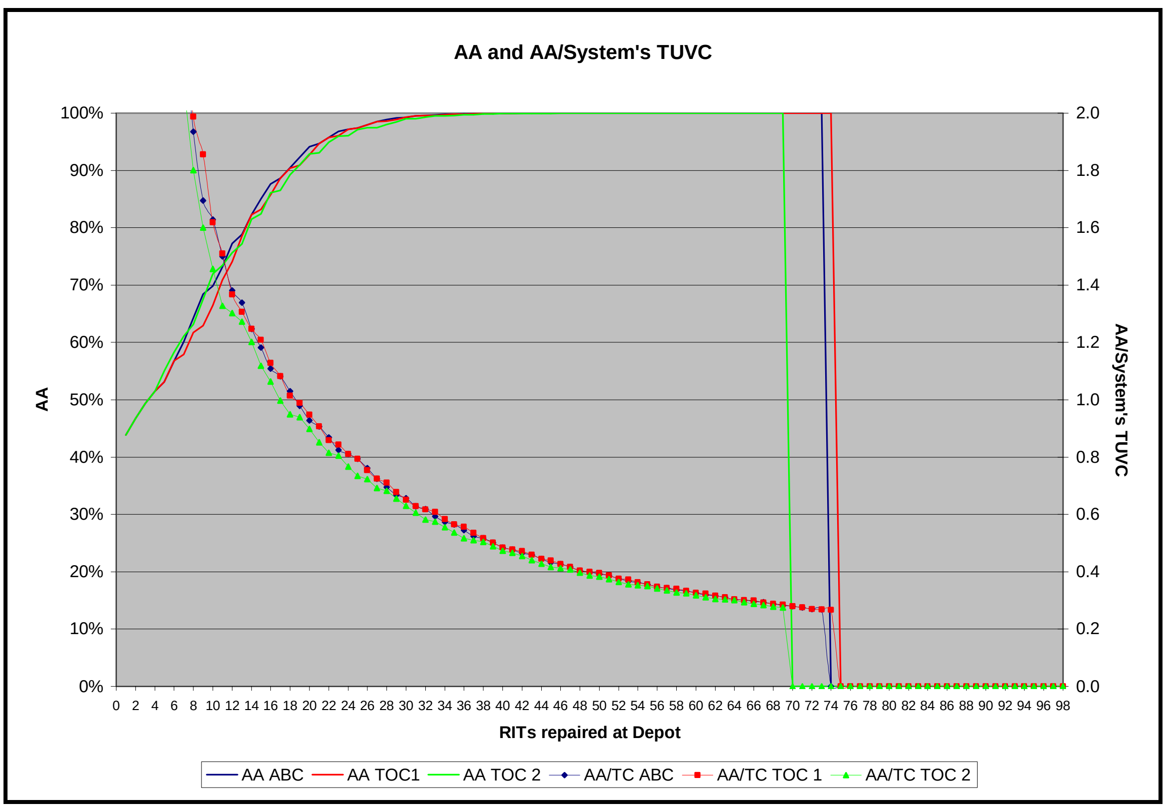


Figure C-50. – Low Balanced, NAirc = 16, NRAirc = 3, RT = 2, RM% = 50 %

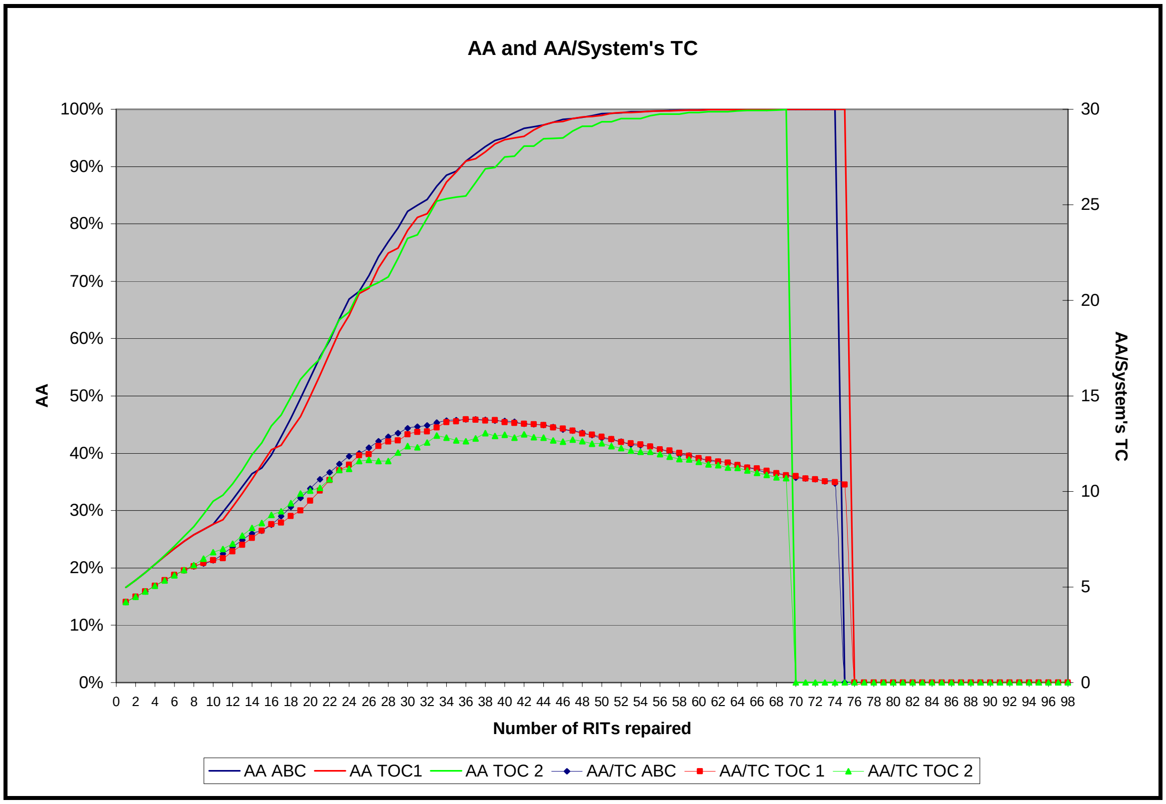


Figure C-51. – Low Balanced, NAirc = 16, NRAirc = 3, RT = 4, RM% = 75 %

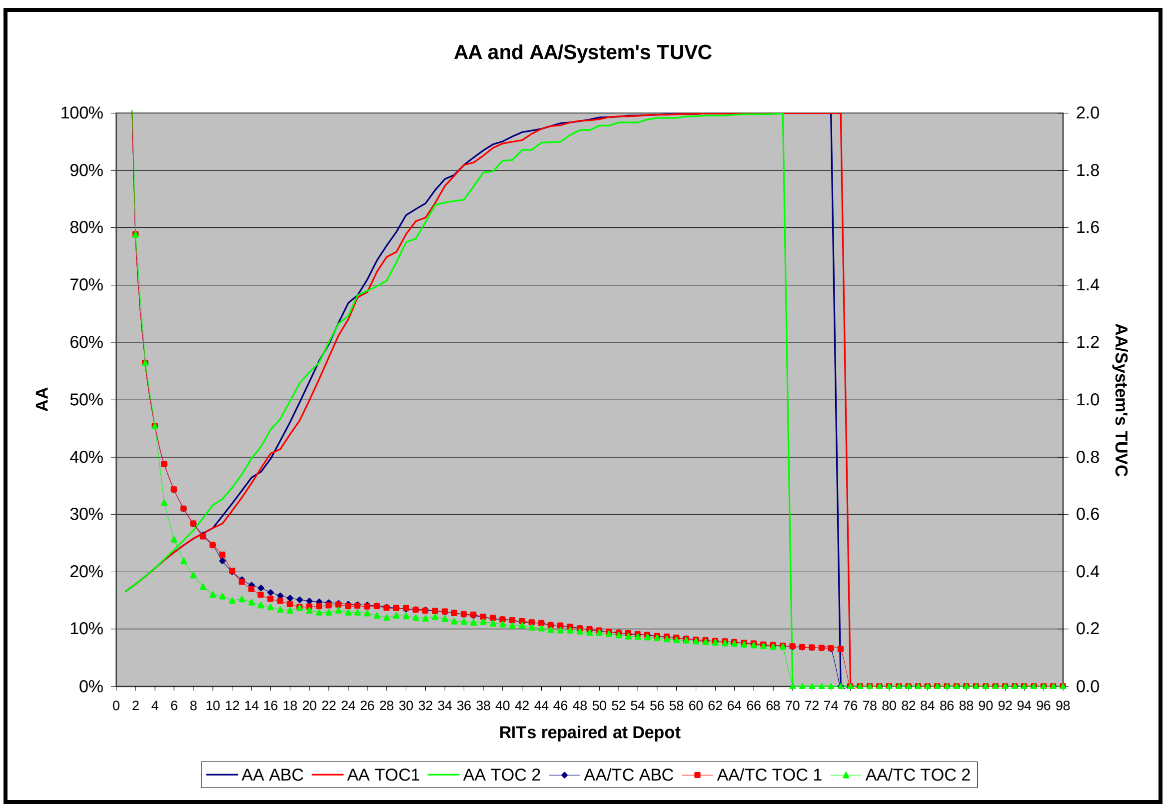


Figure C-52. – Low Balanced, NAirc = 16, NRAirc = 3, RT = 4, RM% = 75 %

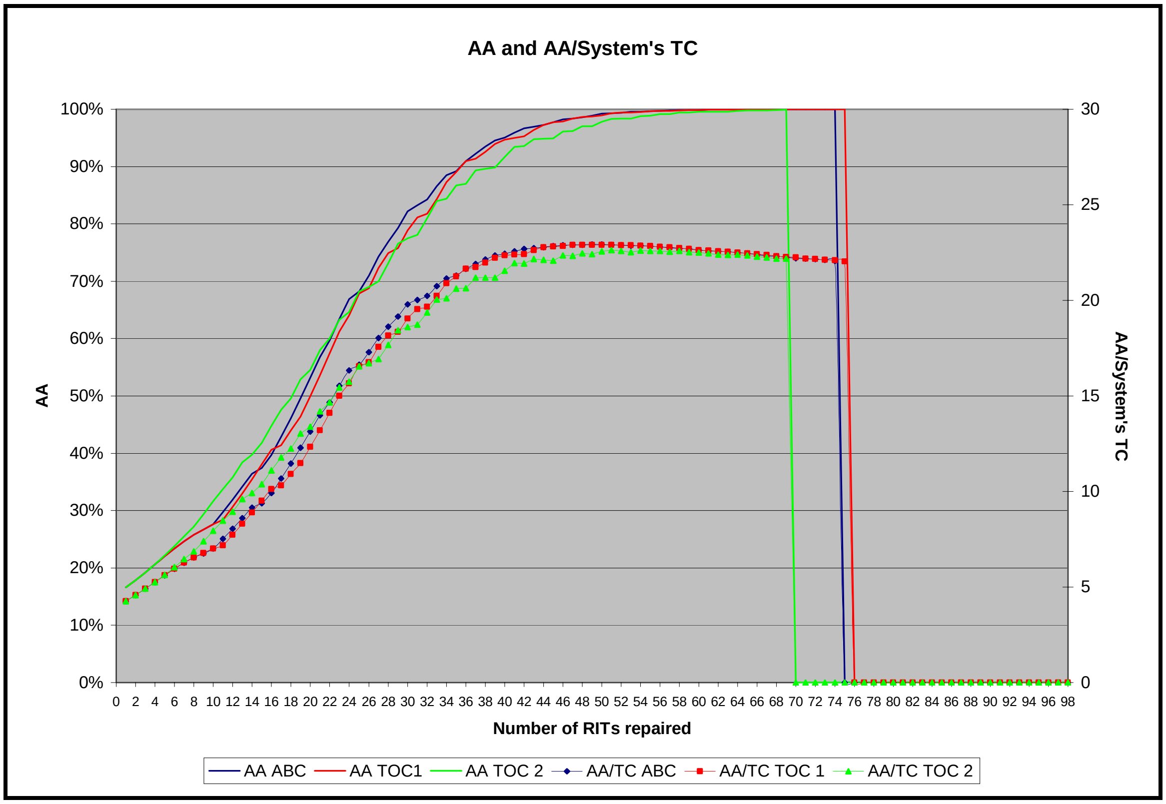


Figure C-53. – Low Balanced, NAirc = 16, NRAirc = 3, RT = 4, RM% = 25 %

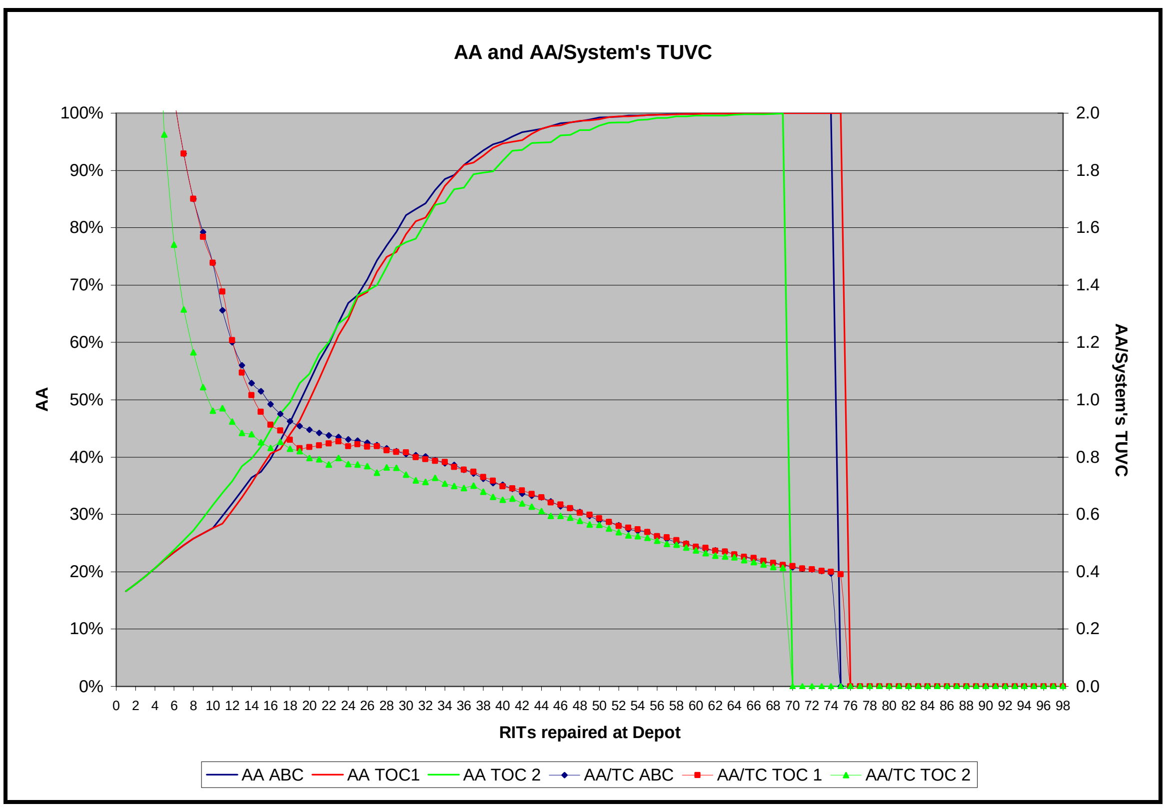


Figure C-54. – Low Balanced, NAirc = 16, NRAirc = 3, RT = 4, RM% = 25 %

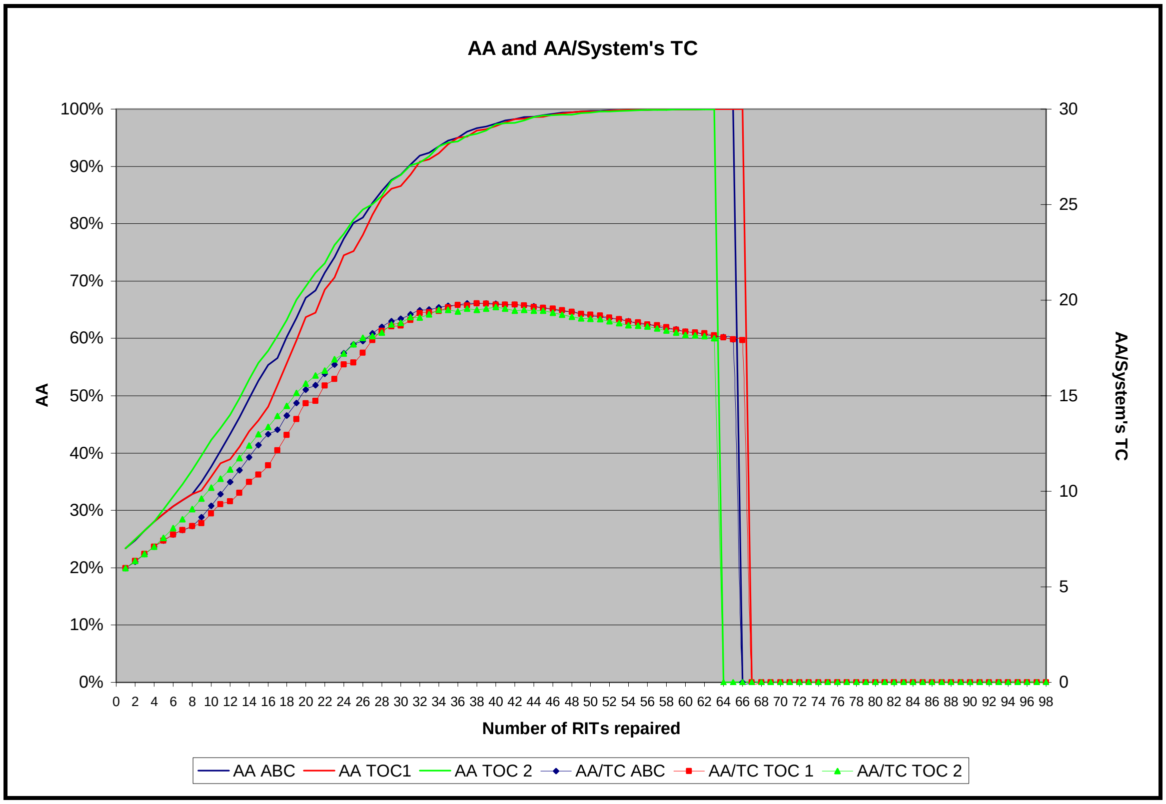


Figure C-55. – Low Unbalanced, NAirc = 16, NRAirc = 3, RT = 4, RM% = 50 %

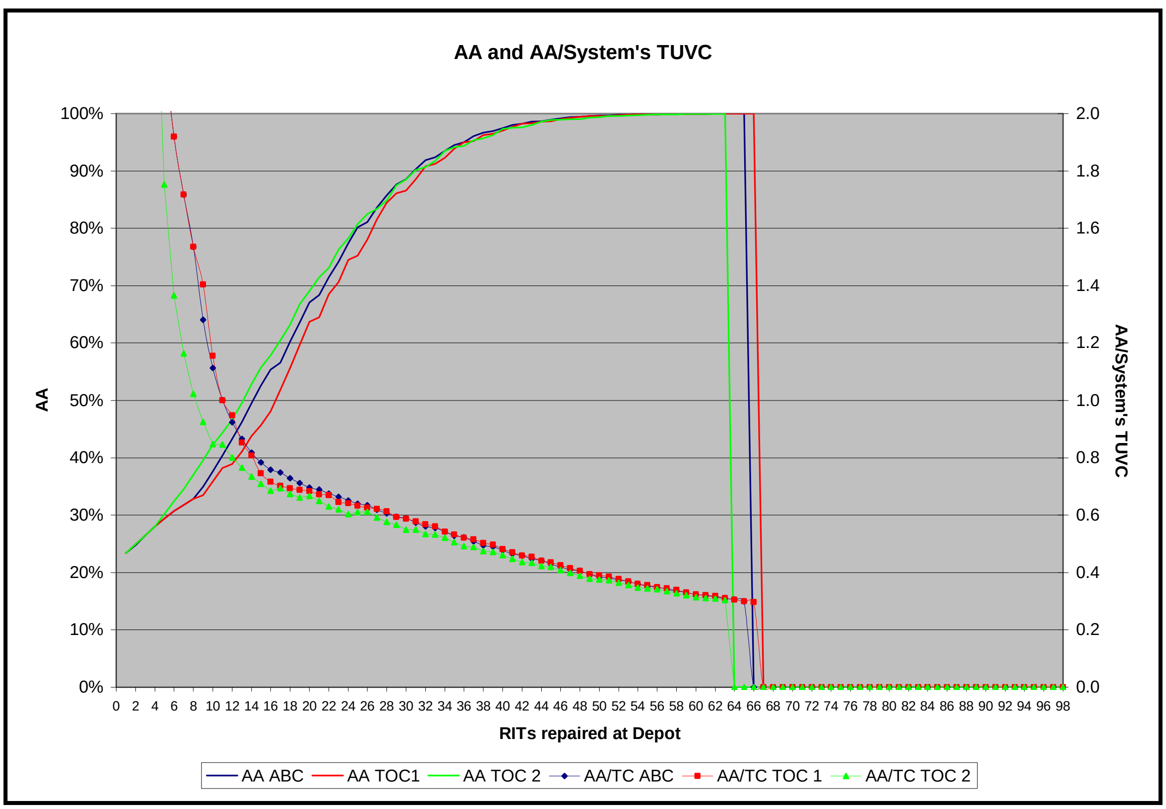


Figure C-56. – Low Unbalanced, NAirc =16, NRAirc = 3, RT = 4, RM% = 50 %

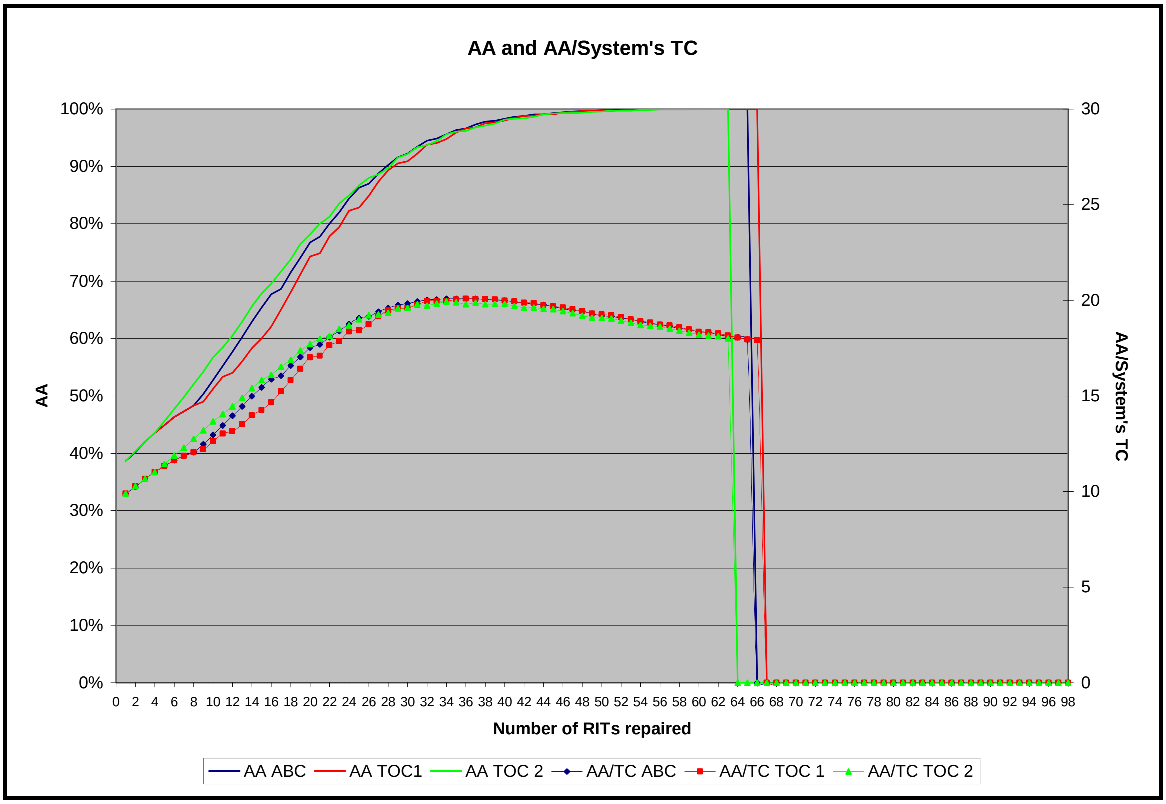


Figure C-57. – Low Unbalanced, NAirc = 24, NRAirc = 3, RT = 4, RM% = 50 %

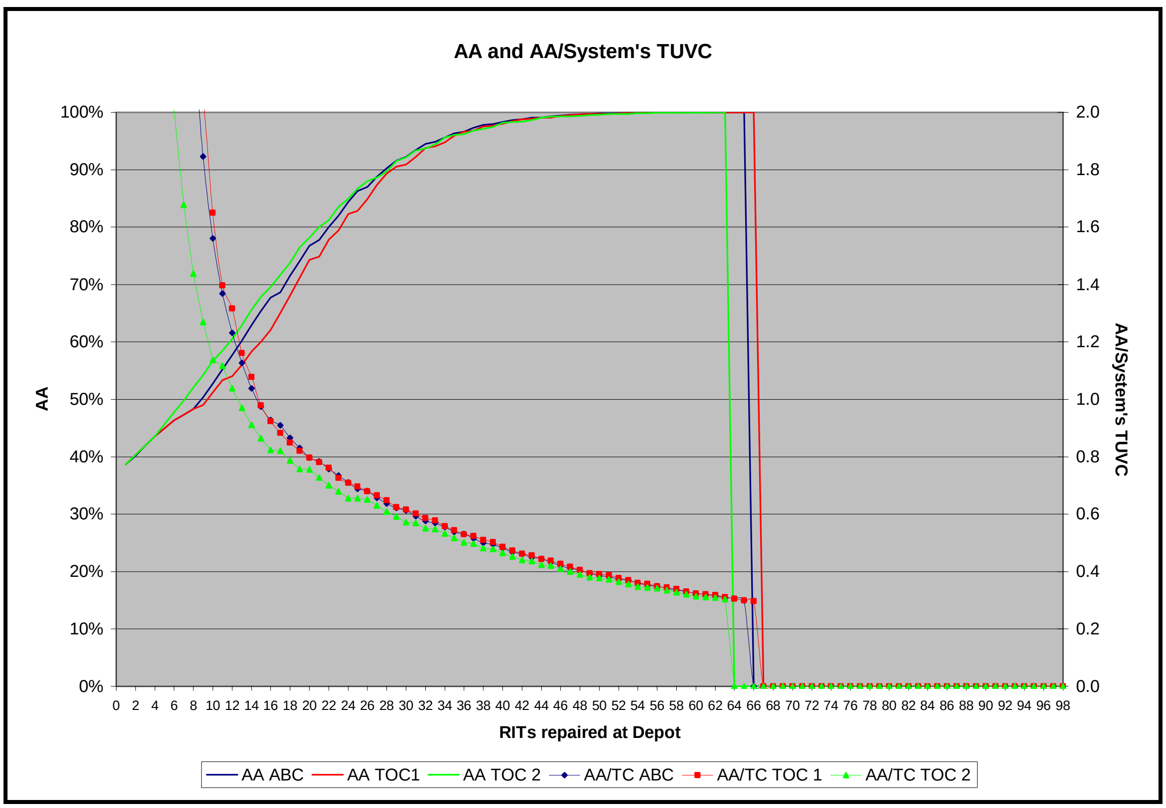


Figure C-58. – Low Unbalanced, NAirc = 24, NRAirc = 3, RT = 4, RM% = 50 %

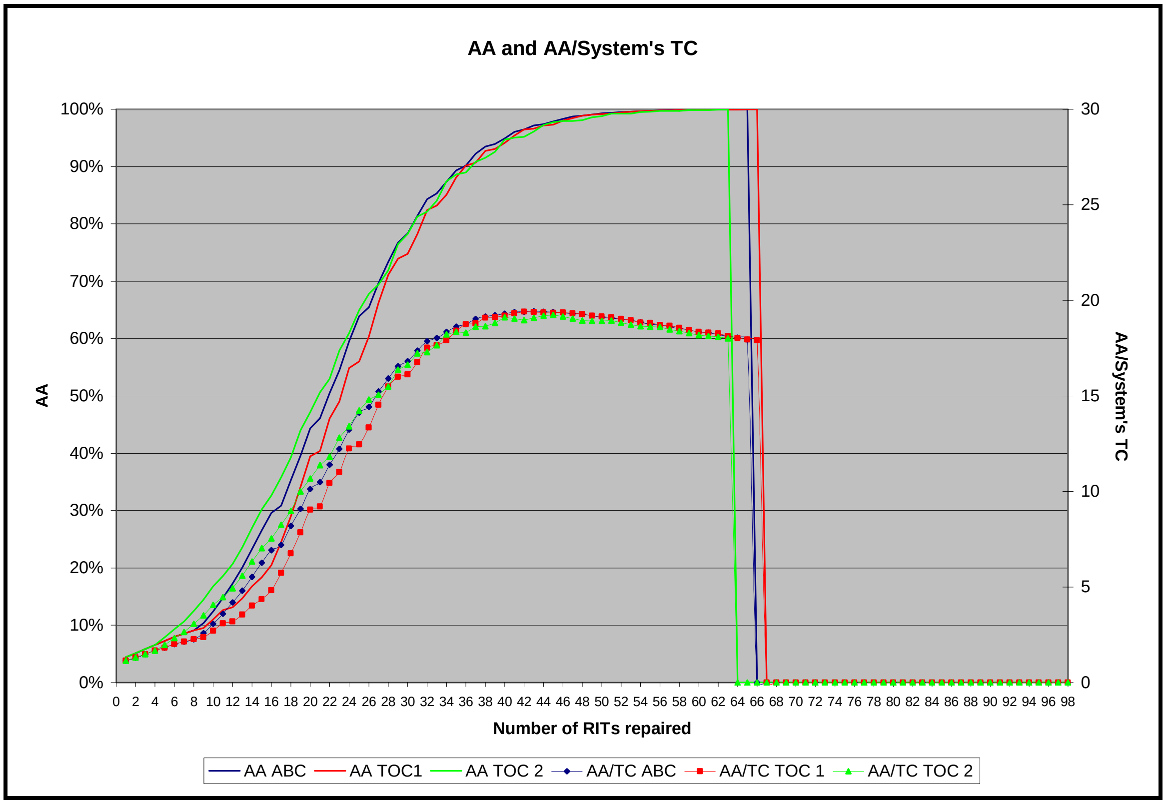


Figure C-59. – Low Unbalance, NAirc = 8, NRAirc = 3, RT = 4, RM% = 50 %

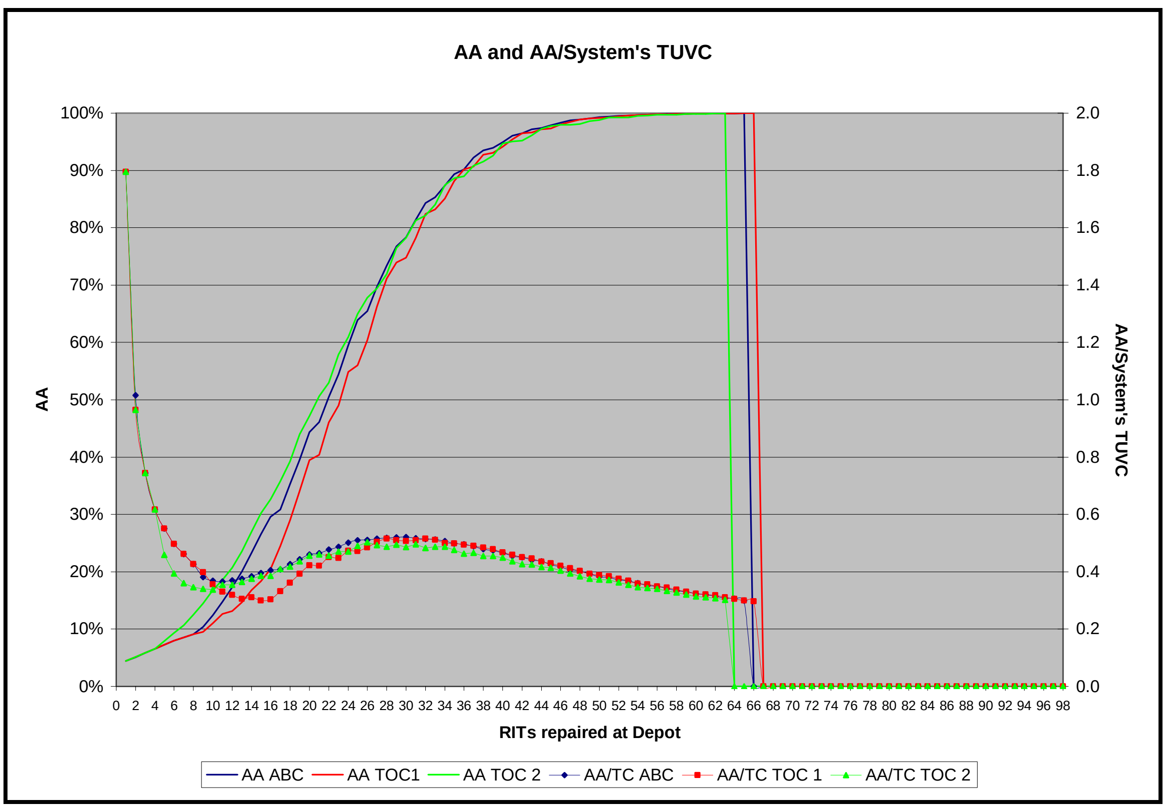


Figure C-60. – Low Unbalance, NAirc = 8 NRAirc = 3, RT = 4, RM% = 50 %

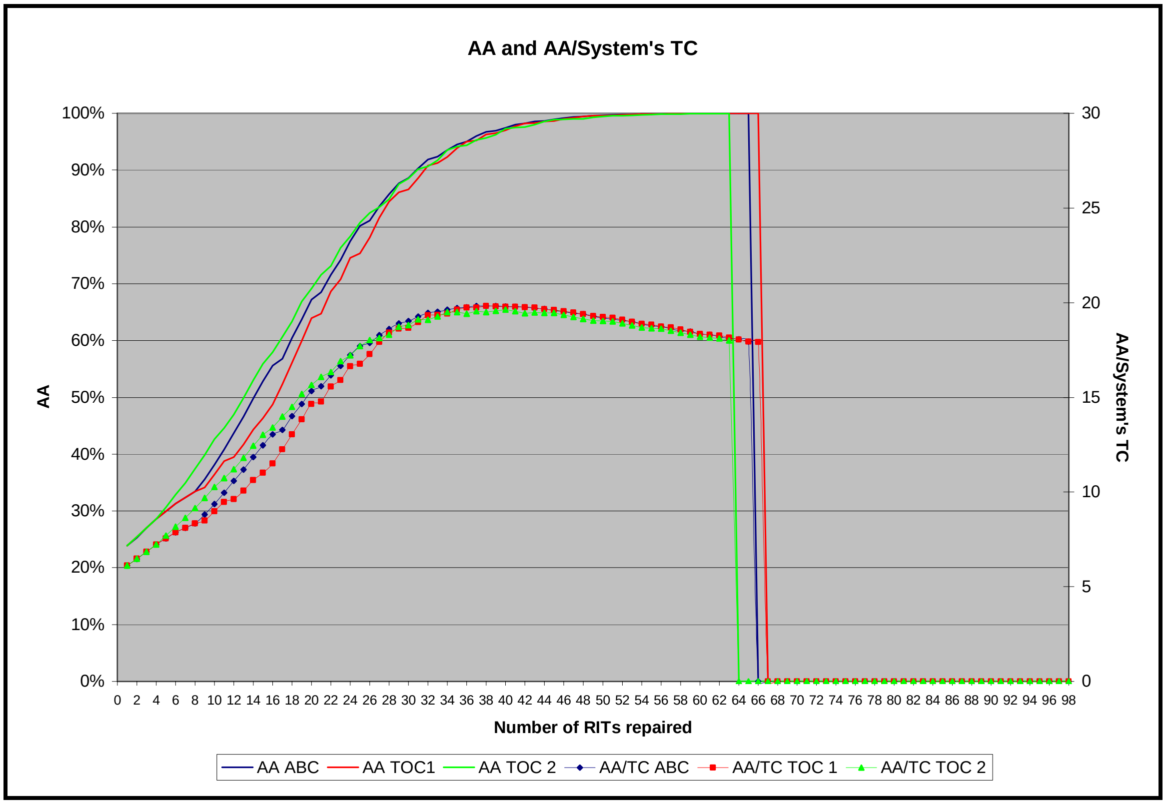


Figure C-61. – Low Unbalance, NAirc = 16, NRAirc = 4, RT = 4, RM% = 50 %

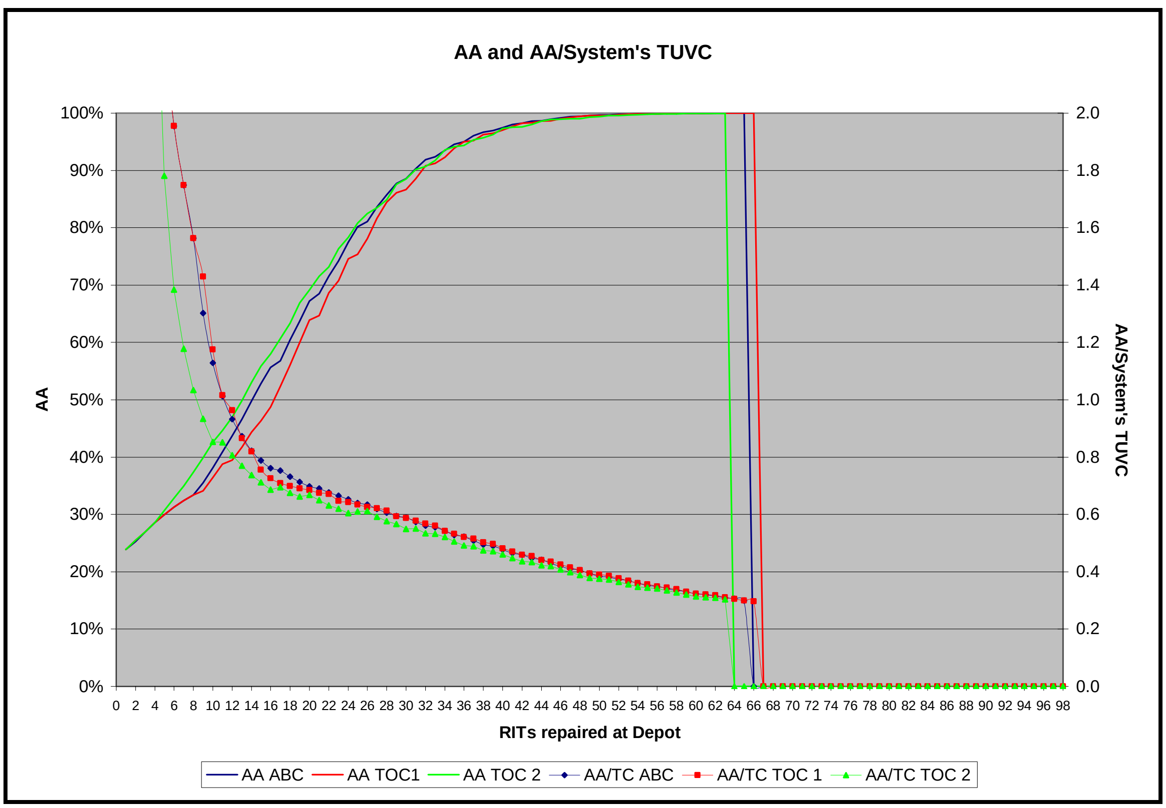


Figure C-62. – Low Unbalance, NAirc = 16, NRAirc = 4, RT = 4, RM% = 50 %

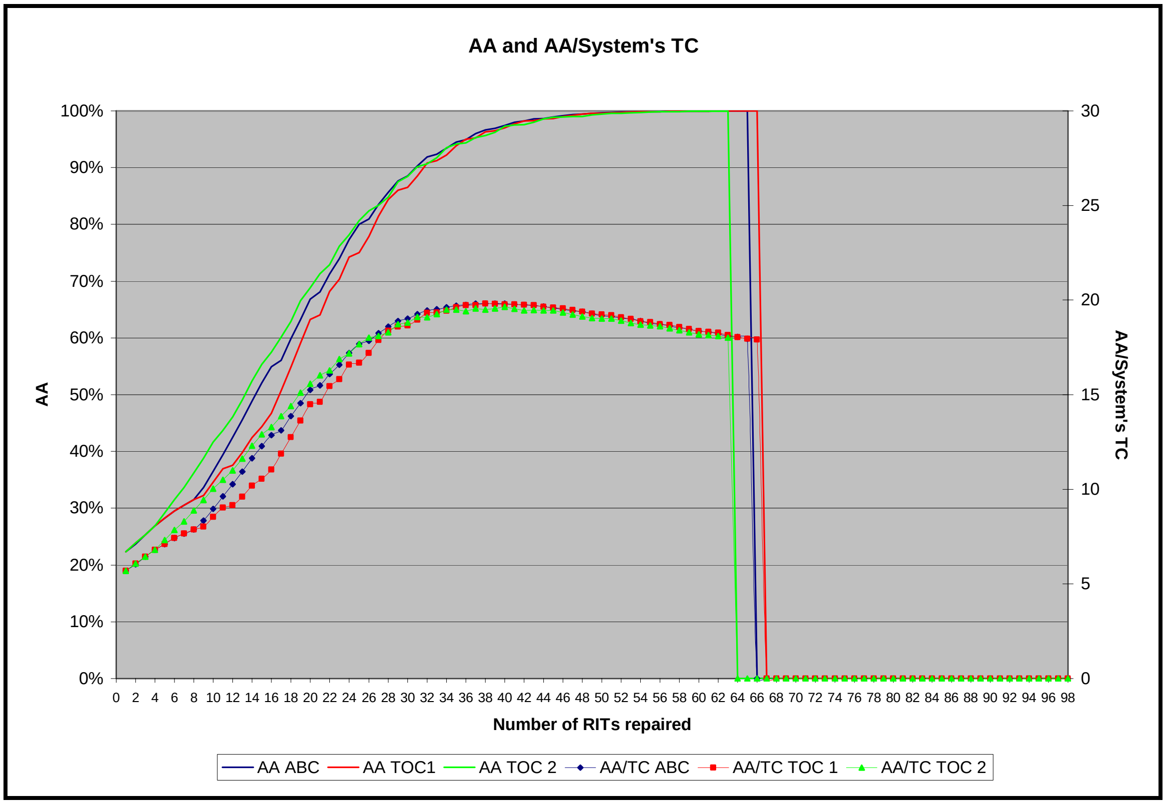


Figure C-63. – Low Unbalance, NAirc = 16, NRAirc = 2, RT = 4, RM% = 50 %

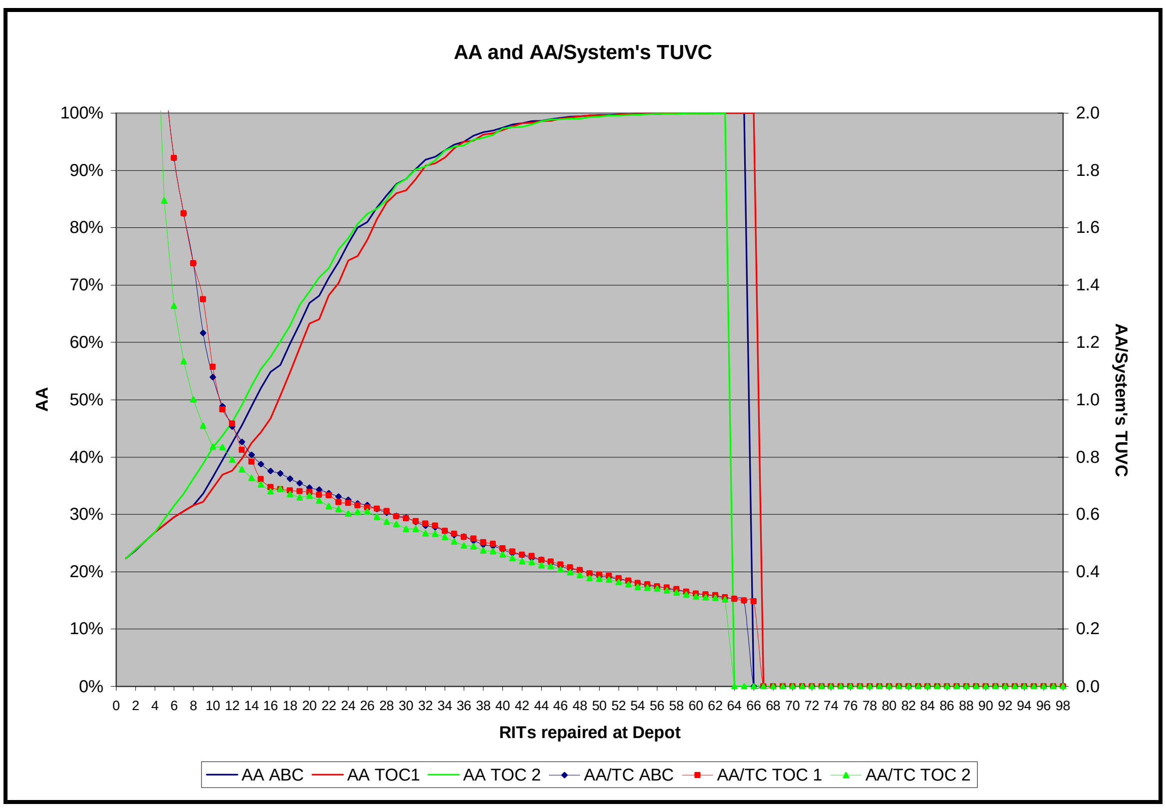


Figure C-64. – Low Unbalance, NAirc = 16, NRAirc = 2, RT = 4, RM% = 50 %

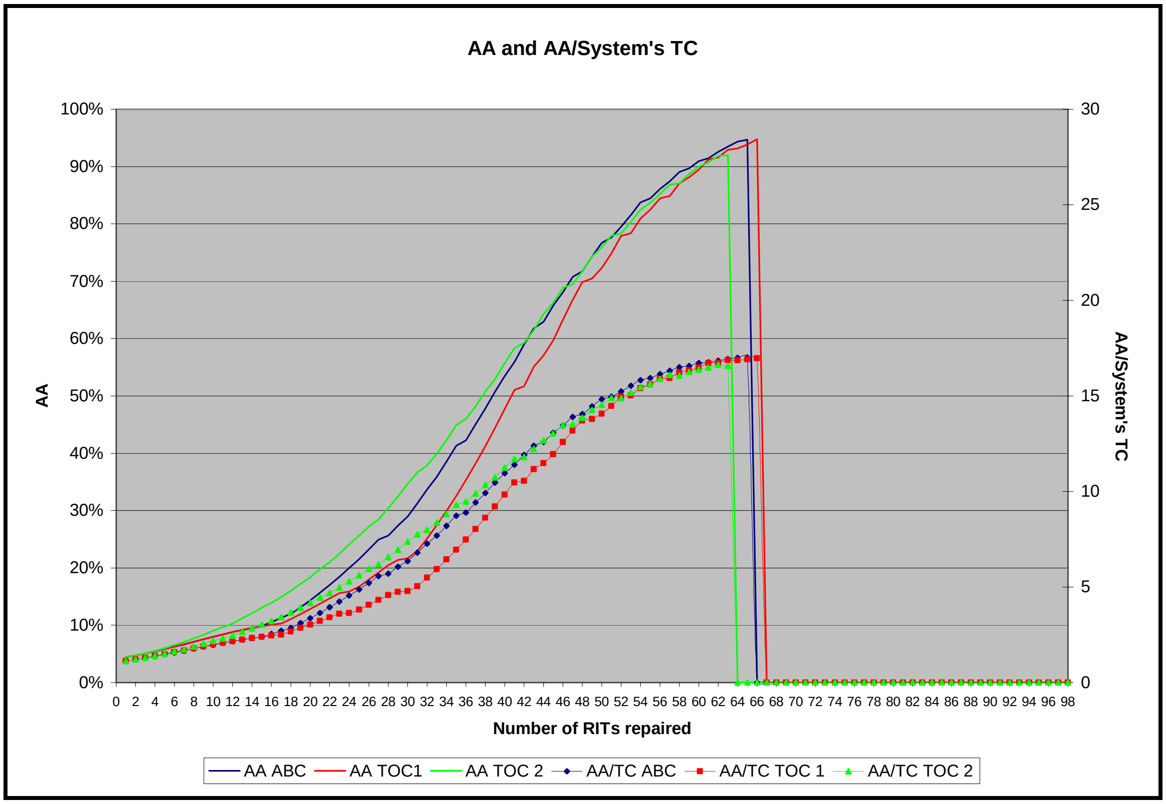


Figure C-65. – Low Unbalance, NAirc = 16, NRAirc = 3, RT = 8, RM% = 50 %

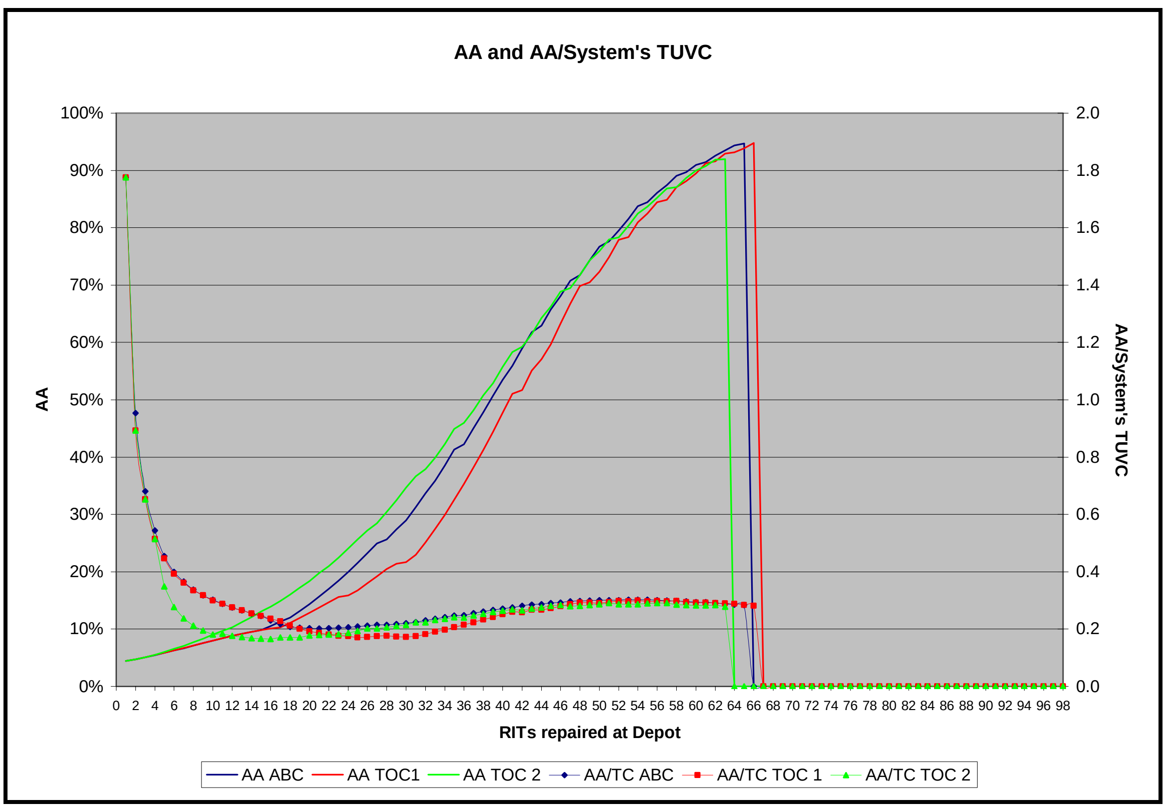


Figure C-66. – Low Unbalance, NAirc = 16, NRAirc = 3, RT = 8, RM% = 50 %

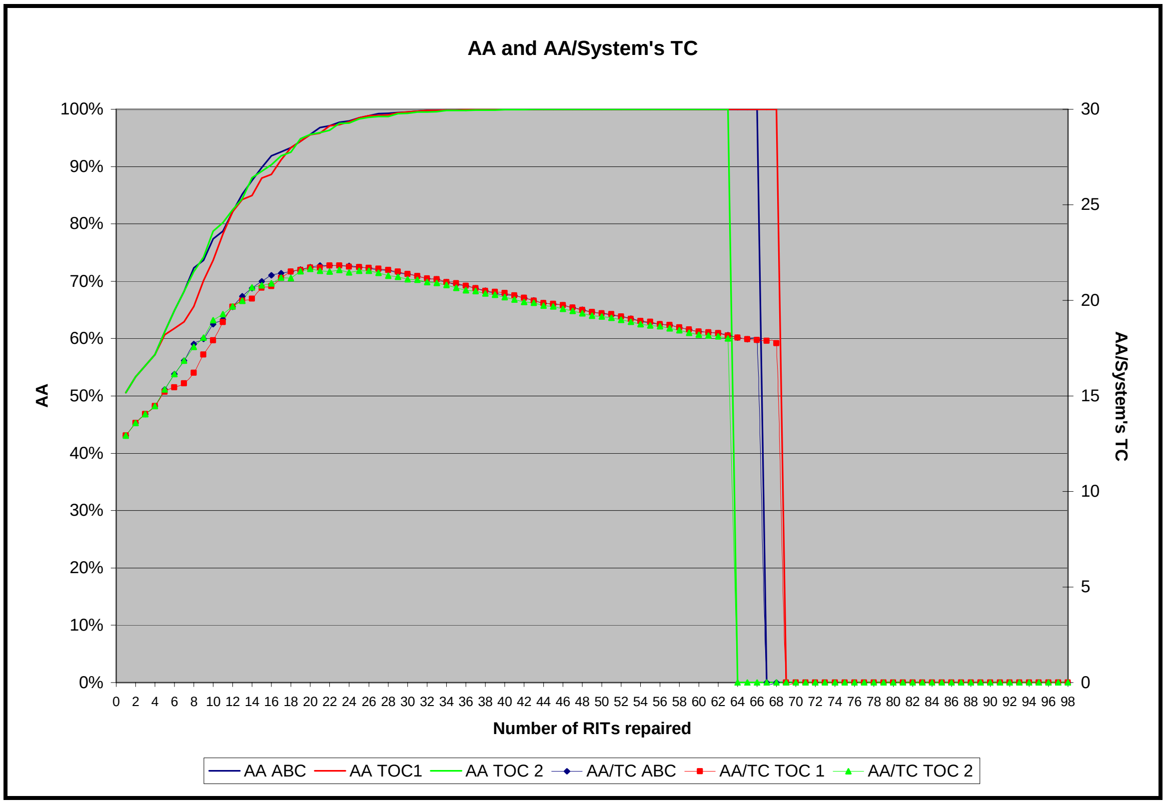


Figure C-67. – Low Unbalance, NAirc = 16, NRAirc = 3, RT = 2, RM% = 50 %

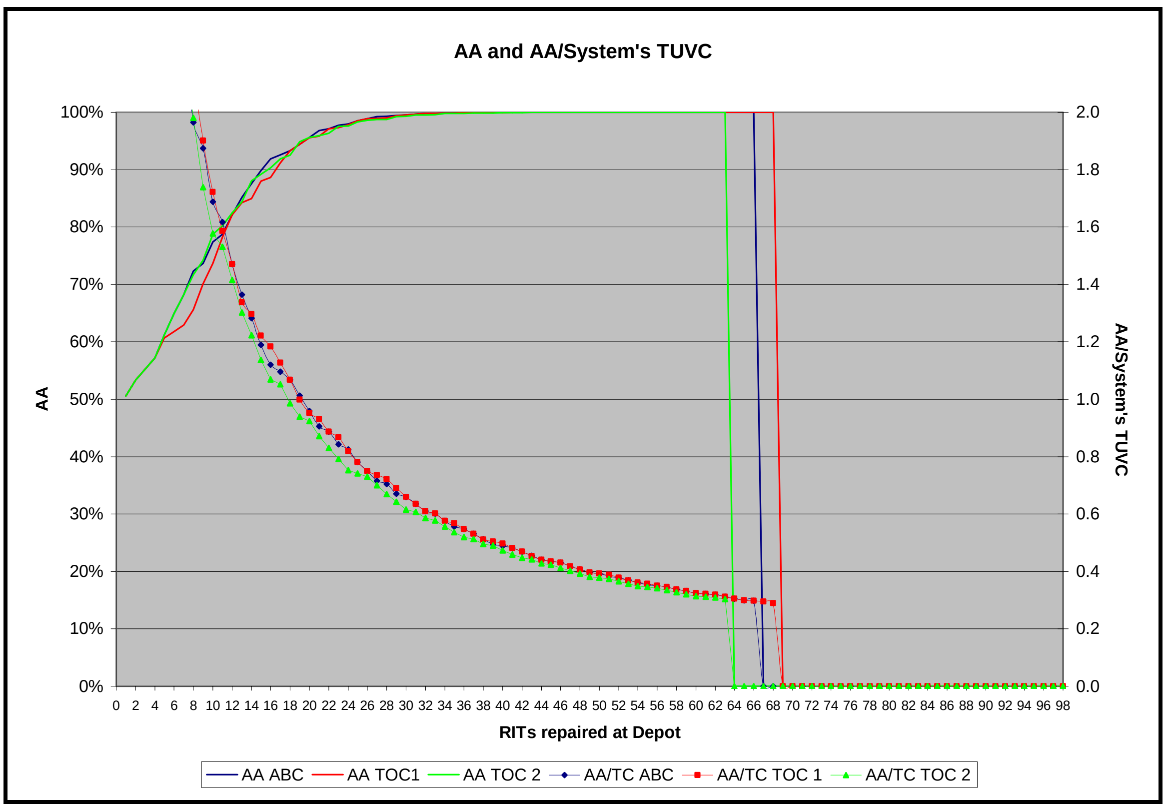


Figure C-68. – Low Unbalance, NAirc = 16, NRAirc = 3, RT = 2, RM% = 50 %

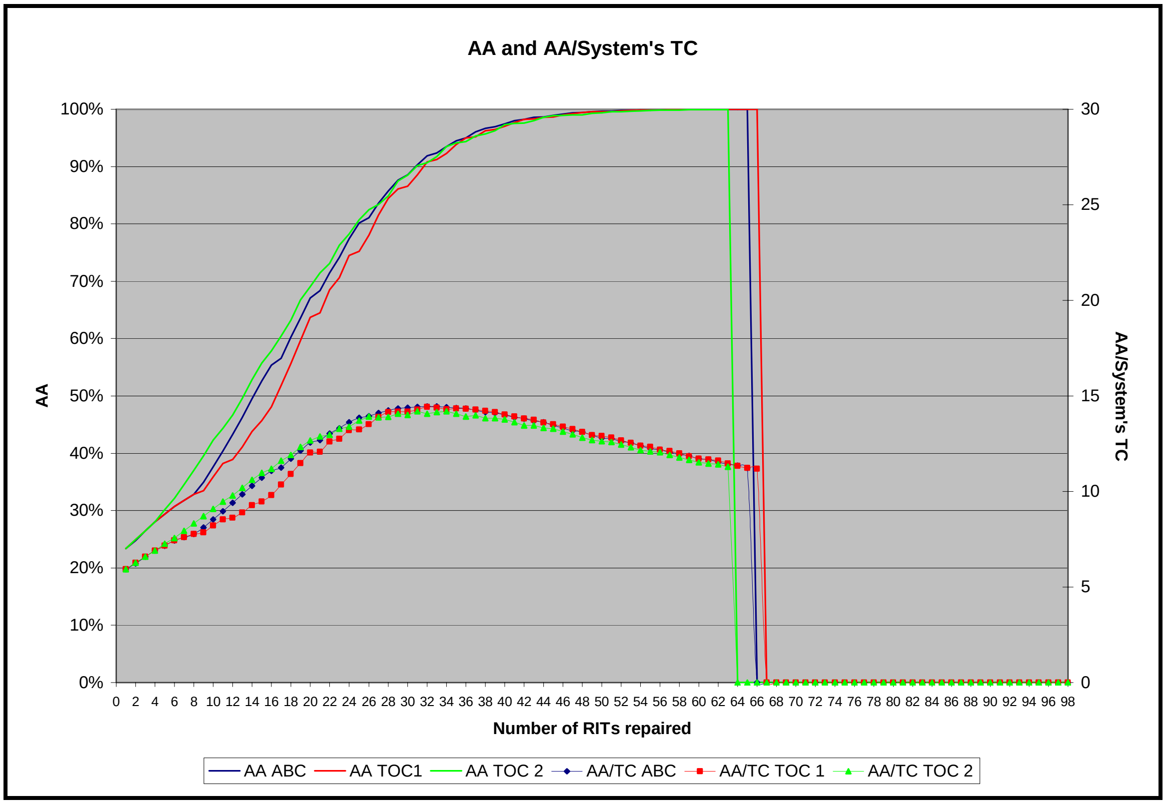


Figure C-69. – Low Unbalance, NAirc = 16, NRAirc = 3, RT = 4, RM% = 75 %

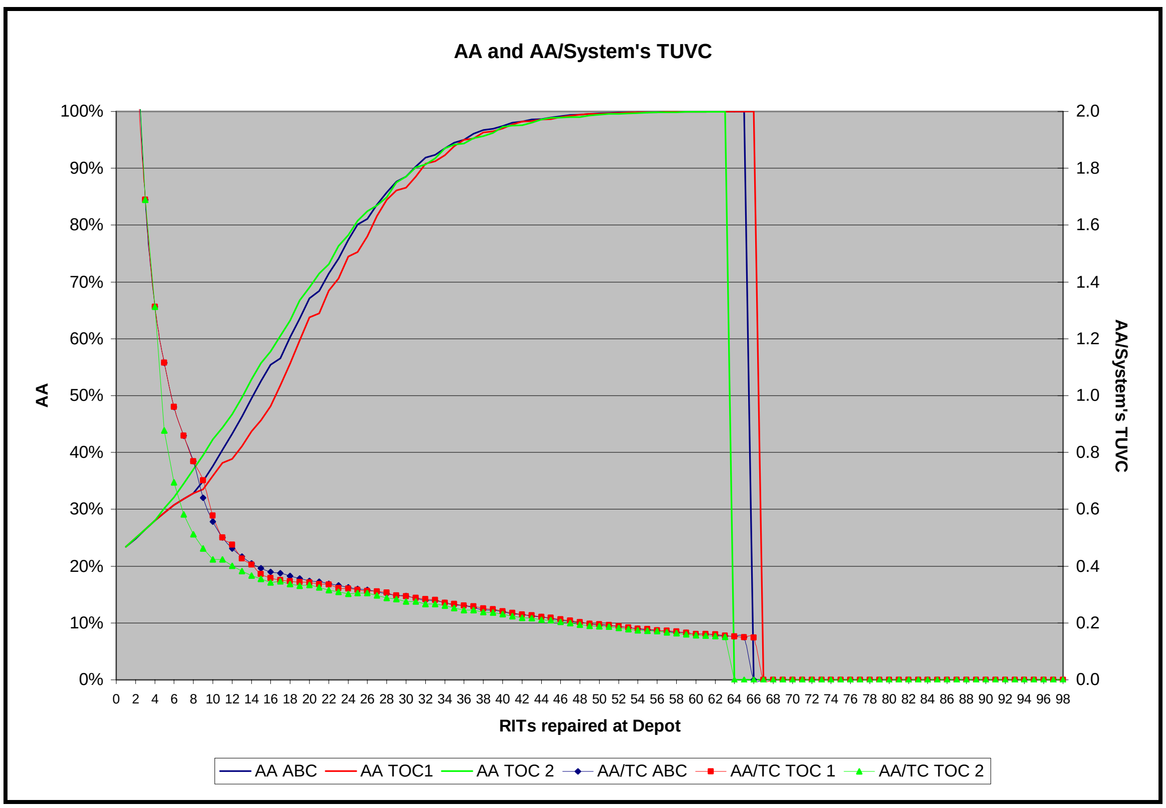


Figure C-70. – Low Unbalance, NAirc = 16, NRAirc = 3, RT = 4, RM% = 75 %

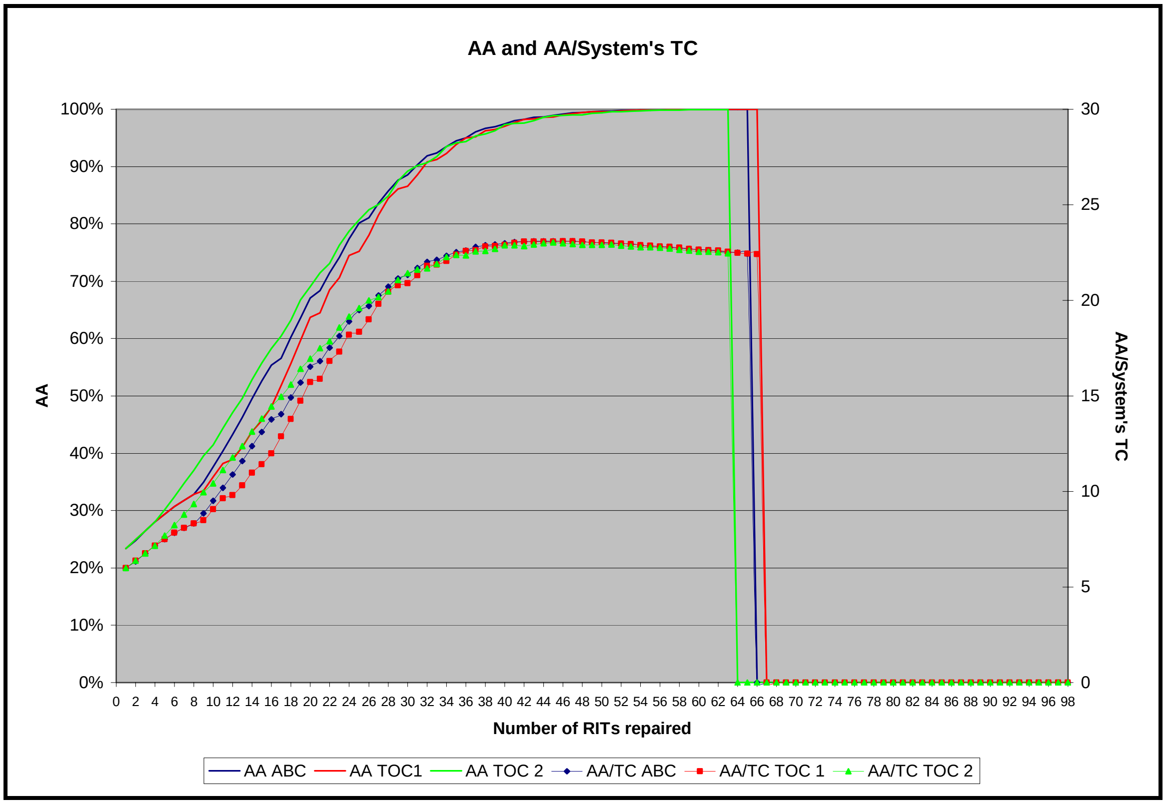


Figure C-71. – Low Unbalance, NAirc = 16, NRAirc = 3, RT = 4, RM% = 25 %

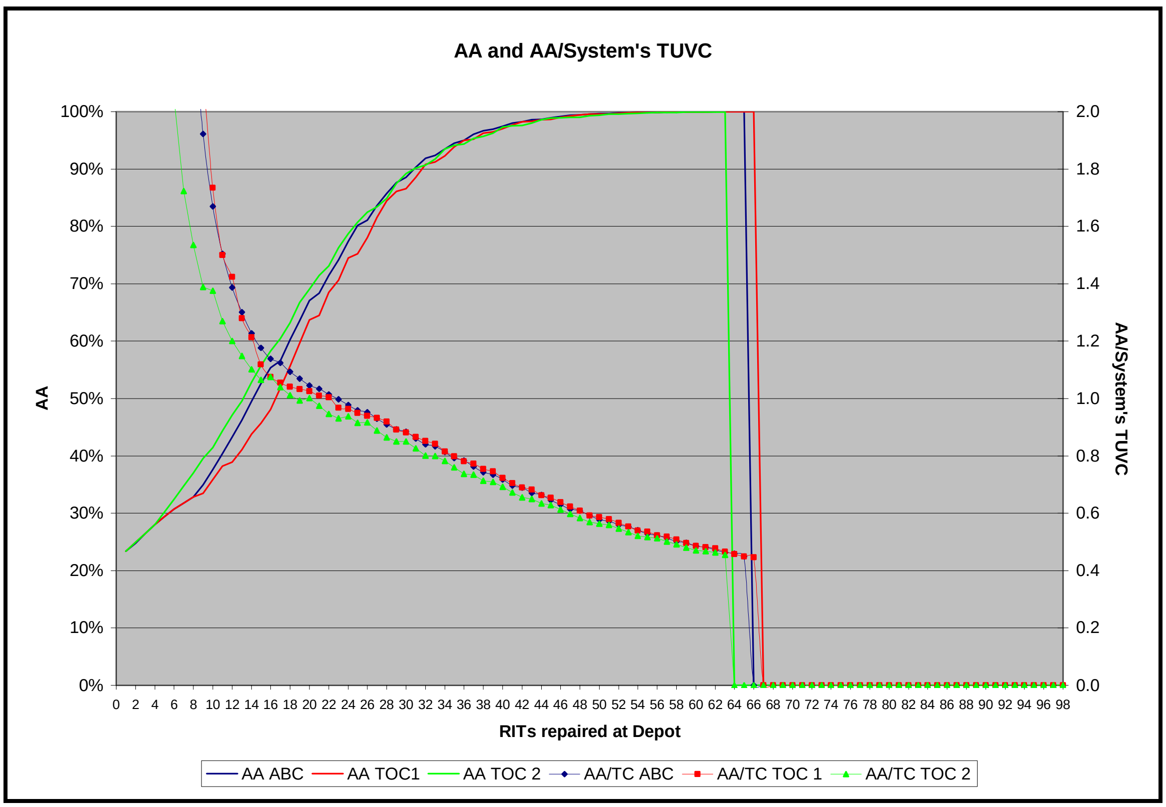


Figure C-72. – Low Unbalance, NAirc = 16, NRAirc = 3, RT = 4, RM% = 25 %

Vita

Lieutenant Colonel Gerardo Héctor ACOSTA VOEGELI graduated from Technical National High School in Buenos Aires, Argentina. He entered Military Education at the Argentine Air Force Academy in Córdoba, Argentina where he graduated as an Air Force Officer (Rank Alferez) with Honor Roll in December 1981.

He then went to undergraduate studies at the Air Force Aeronautical University in Córdoba, Argentina, where he graduated as Aeronautical and Mechanical Engineer with Honor Roll in December 1985. Afterwards he did both the Staff and Command and Superior Mayor Staff courses in the Superior Air War College in Argentina. He also entered a graduate course at the Salvador University in Buenos Aires, Argentina and achieved a Master in Business Management in 1999.

His first assignment was at the Materiel Command Supply Directorate as Chief of Procedures and Methods Division from March 1986 to December 1989. He was then assigned to the Maintenance Depot in Quilmes, Buenos Aires, Argentina first as Chief of General Maintenance of Instrumentals and Equipment Workshop and then as Chief of Aircraft Inspections Workshop from January 90 to December 1991.

Afterwards he was assigned to the 7th Air Brigade in Buenos Aires, from 1991 to 1995 where he served as Chief of Spare and Inspection Squadron and eventually Chief of Technical Squadron. Later he was assigned to the Materiel Command Supply General Directorate from 1997 to 2001 as Chief of Aviation Fuel and Products Division and afterwards as Chief of Material Division.

In September 2002, he entered the Graduate School of Engineering and Management, Air Force Institute of Technology. Upon graduation he will be assigned to the Air Force Materiel Command in Buenos Aires, Argentina.

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14. ABSTRACT

The Aircraft Availability Model (AAM) assists managers in the selection of an optimal list of items to repair in order to attain the best aircraft availability rate. The model considers procurement or repair costs for the components as if the costs were unit variable as a price, instead of a repair cost representing a mix of both fixed and variable cost.

This research used the AAM in conjunction with Activity Based-Costing (ABC) and The Theory of Constraints (TOC) methodologies to investigate the relationships between price, product mix, Aircraft Availability (AA) and total cost. This approach explicitly recognizes that the Air Force Material Command uses its own resources in repairing components, and that it is always operating in a constrained environment in which resources' practical capacities are exceeded by requirements that limit the attainable AA.

The results of this investigation shows that the choice of the optimal mix of reparable items is sensitive to the pricing method used as well as environmental factors like repair cycle time, fleet size, and the intensity and balanced of shop resource load. In addition, the research found that the performance of the repair center should be evaluated under the metric Aircraft Availability per System Total Cost, following the rationale under the TOC methodology that considers labor costs as operational expenses, fixed in the period, and only raw materials as variable costs.

15. SUBJECT TERMS
Product Mix, Product Costing, Aircraft Availability, Reparable Costing, Activity-Based Costing, Theory of Constraints.

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