MODELING AND ANALYZING A HEALTH CARE SUPPLY CHAIN SYSTEM

A thesis submitted for the degree of Doctor of Philosophy

By

Ahmed Hamad Al-Thumairi

School of Engineering and Design
Brunel University
April 2006

Abstract

MODELING AND ANALYZING A HEALTH CARE SUPPLY CHAIN SYSTEM

By: Ahmed H. Al Thumairi, ME

Chairperson of the Supervisory Committee:
Dr Ozbayrak M.
Professor Balachandran W.
School of Engineering and Design

A Thesis presented on Improving and Redefining the Supply Chain in Healthcare, defining existing problems with current Supply Chain applications, and reviewing current applications and trends in the Supply Chain culture within the Manufacturing Industries and Healthcare Industries. Research of successful applications of new, and improvements to existing supply chain methodologies are presented. The concept of a future Supply Chain Management System, extending the boundaries of conventional Healthcare Supply Chain to include both conventional customer (Healthcare Materiel and Capital Assets Requestors and Distributors) and the non-conventional (the Healthcare Beneficiary), is presented in detail. Final discussions and conclusions of this concept are offered as a review of this concept for the reader of this manuscript.

Acknowledgments

The author wishes to express sincere appreciation to Dr Ozbayrak M. and Professor Balachandran W. for their assistance and guidance in the preparation of this manuscript.

Contents

Chapter 1: **Introduction** 1

Chapter 2: **SUPPLY CHAIN SYSTEM** 6

2.1 Introduction. 6

2.1.1 What is a Supply Chain? 6

2.2 The Objective of a Supply Chain 7

2.3 Supply Chain in the Manufacturer Process and its Drivers 8

2.3.1 Cycle View of Supply Chain Processes. . . 8

2.3.1.1 Customer Order Cycle 9

2.3.1.2 Replenishment Cycle 9

2.3.1.3 Manufacturing Cycle 9

2.3.1.4 Procurement Cycle 9

2.3.2 Push/Pull View of Supply Chain Processes.10

2.3.3. Supply chain Drivers 10

2.3.3.1 Inventory 11

2.3.3.2 Transportation 11

2.3.3.3 Facilities 11

2.3.3.4 Information 12

2.4 Supply Chain in the Healthcare. 12

2.4.1 Hospital 12

2.4.2 Materials Management in the Hospital (Logistic) 14

2.4.2.1 Originating Department 16

2.4.2.2 Purchasing Department 16

2.4.2.2.1 Group Purchasing 17

2.4.2.2.2 Prime Vendors 19

2.4.2.2.3 Buying on Consignment 20

2.4.2.2.4 Stockless Purchasing. 21

2.4.2.3 Receiving Department 23

2.4.2.4 Inventory Control 24

2.4.2.5 Distribution 25

2.4.2.5.1 Requisition 25
2.4.2.5.2 PAR Level Systems 26
2.4.2.5.3 Point of Use Replenishment 27
2.4.2.5.4 Exchange Carts 27

Chapter 3: LITERATURE REVIEW 29

3.1 Introduction 29
3.2 Supply Chain Management 29
3.2.1 Supply Chain Management in the Service Industry and the relationship, manufacture 31
3.2.1.1 Relationship with the customers. . 34
3.2.1.2 New Technology adaptation in S.C. 35
3.2.1.3 Forecasting in the supply chain. . 35
3.2.1.4 Outsourcing in the supply chain. . 36
3.2.2 The Integration of Supply Chain Management 37
3.2.2.1 Information Flows 37
3.2.2.2 Physical Logistics 38
3.2.2.3 Partnerships, Alliances and Cooperation 39
3.3 The Supply Chain in Health Care 40
3.3.1 Current View of the Medical Supply Management Materials 40
3.3.1.1 Just In Time (JIT) 41
3.3.1.2 Why Has the Healthcare Industry Not Implemented Just-In-Time? 42
3.3.1.3 Stockless Distribution 44
3.3.1.4 EDI to Improve Supply Chain 45
3.3.1.5 Integrated delivery system 47
3.4 Supply Chain Model 48
3.4.1 Deterministic Models 50
3.4.2 Stochastic Models 51
3.4.3 Simulation Models 52
3.4.4 Information Technology Driven Models. 54
3.5 Performance in the Healthcare Supply Chain. 54

3.5.1 Supply Chain Flexibility 55
3.5.2 Supply Chain Integration 56
3.5.3 Customer Responsiveness 57
3.5.4 Supplier Performance 57
3.5.5 Partnership Quality. 58
3.6 Cost Management in Health Care Supply Chain. 59
3.6.1 Traditional Cost Accounting 61
3.6.2 The ABC Model 61
3.6.2.1 Resource and Activity Drivers . . . 62
3.6.2.2 Benefits of ABC 62
3.7 Conclusion 66

Chapter 4: Modeling and Analyzing a Health Care Supply Chain System 67

4.1 Introduction 67
4.2 Aim. 67
4.3 Objectives of the research 69
4.4 Outline of the Problem and the Research Needs 70
4.5 The Methodology of the research 73
4.6 Supportive Research Tool 76
4.6.1 Simulation in the Health Care 77
4.6.2 Solution as an Integrated Health Care Supply Chain Model 79
4.7 Research Contribution to Health Care Supply Chain 80

Chapter 5: Simulation Modeling of Supply Chain in Health Care 82

5.1 Introduction 82
5.2 Why Healthcare Simulation Modeling 82
5.3 Conceptual supply chain model in healthcare. 84
5.4 Chemistry Laboratory 90
5.4.1 Definitions of S.C. terms in the Lab. 90
5.4.2 Responsibilities 91

5.4.3 Inventory Policies Adopted 92
5.4.4 Supplies Requisition Mechanisms. . . . 93
5.5 The Simulation of the Healthcare S.C. model. 99

5.5.1 Simulation Modeling Assumption 99
5.5.1.1 General Assumption 99
5.5.1.2 Patient Arrivals. 100
5.5.1.3 Lab 100
5.5.1.4 Logistics 101
5.5.1.5 Suppliers 101
5.5.2 Data Collection 101
5.5.3 Arena Simulation Environment. 102
5.5.4 Structure of Simulation Model 103
5.5.4.1 First Element: Patient Arrival, Test Requests. 107
5.5.4.2 Second Element: The Chemistry Lab. . 110
5.5.4.3 Third Element: The Logistics . . . 113
5.5.4.4 Fourth Element: The Suppliers . . . 115

Chapter 6: Analysis of Healthcare Supply Chain. 116

6.1 Introduction. 116
6.2 Reference Model 117
6.3 Scenarios of the supply chain. 118
6.4 The Framework for the Analysis 119
6.5 Performance Measures of Reference Model. . . 120
6.5.1 Primary Performance Measures. 120
6.5.1.1 Lead Time for Orders for R. M. . . . 121
6.5.1.2 Material Flow Time for R. M. 123
6.5.1.3 Throughput. for R. M. 126
6.5.1.4 Inventory Status. for R. M. 127
6.5.1.5 W I P. for R. M. 129
6.5.1.6 Cost of Test for R. M. 130
6.5.2 Secondary Performance Measures 131
6.5.2.1 Equipment Utilization for R.M. 131

6.5.2.2 Staff Utilization for R. M. 132
6.5.2.3 Material Order Size for R. M. . . 133
6.5.2.4 Queue Size for R. M. 134

6.6 Scenario Based Analysis 135
6.6.1 Scenario One: Low Customer. 136
6.6.1.1 Primary Performance Measures 136
6.6.1.1.1 Lead Time. 136
6.6.1.1.2 Material Flow Time 137
6.6.1.1.3 Throughput. 140
6.6.1.1.4 Inventory Status. 141
6.6.1.1.5 W I P. 143
6.6.1.1.6 Cost of Test. 144
6.6.1.2 Secondary Performance Measures 146
6.6.1.2.1 Equipment Utilization 146
6.6.1.2.2 Staff Utilization. 147
6.6.1.2.3 Material Order Size 148
6.6.1.2.4 Queue Size 149
6.6.1.3 Conclusion. 150

6.6.2 Scenario Two: Unreliable Supplier . . . 151
6.6.2.1 Primary Performance Measures 151
6.6.2.1.1 Lead Time. 151
6.6.2.1.2 Material Flow time. 152
6.6.2.1.3 Throughput. 155
6.6.2.1.4 Inventory Status. 157
6.6.2.1.5 W I P 158
6.6.2.1.6 Cost of Test. 159
6.6.2.2 Secondary Performance Measures. 161
6.6.2.2.1 Equipment Utilization. 161
6.6.2.2.2 Staff Utilization. 162
6.6.2.2.3. Material Order Size 164
6.6.2.2.4. Queue Size 164
6.6.2.3 Conclusion. 165

6.6.3 Scenario Three: Imax. 166
6.6.3.1 Primary Performance Measures 166
6.6.3.1.1 Lead Time. 166
6.6.3.1.2 Material Flow Time 167
6.6.3.1.3 Throughput 171
6.6.3.1.4 Inventory Status. 171
6.6.3.1.5 W I P 173
6.6.3.1.6 Cost of Test. 174
6.6.3.2. Secondary Performance Measures 176
6.6.3.2.1 Equipment Utilization. 176
6.6.3.2.2 Staff Utilization. 177
6.6.3.2.3. Material Order Size 178
6.6.3.2.4. Queue Size 179
6.6.3.3 Conclusion. 180

Chapter 7: Discussion of the Results 181

7.1 Introduction. 181
7.2 Modeling of Health Care Supply Chain. 181
7.2.1 Software. 185
7.3 Comparative Assessment of Scenarios 186
7.3.1 Comparisons of Scenarios 187
7.4 Final Overview. 190

Chapter 8: Conclusions. 194
8.1 Contribution of this study to the Healthcare Research. 194
8.2 Future work 197

References: 199

Appendix A. 210
Appendix B. 219
Appendix C. 232

INDEX OF TABLES AND FIGURES

Table & Figure No.	DESCRIPTION	
Figure 2.1	Supply Chain Stages	7
Figure 5.1	General Modeling Structure	89
Figure 5.2	Supplies Requisition Routine	96
Figure 5.3	Relationship between Logistics, Vendor and Chemistry Lab	97
Figure 5.4	Present Supply Chain in the Laboratory Services.	98
Figure 5.5	Flowchart on the Path of Test & Needed Components	105
Figure 5.6	First Hierarchical Level of the Model	106
Table 5.1	All Tests with the Percentage of Arrival	109
Table 6.1	Lead Time for Each Test	123
Table 6.2	Reagent Table	125
Table 6.3	Calibrator Table	125
Table 6.4	Controller Table	125
Table 6.5	Throughput of each Test	126
Table 6.6	Lab Storage Table	128
Table 6.7	WIP	129
Table 6.8	Cost of each Test	130
Table 6.9	Equipment Utilization	132
Table 6.10	Staff Utilization	133
Table 6.11	Material Order Size	134
Table 6.12	Queue Size	134

Table and Graphs for the first three Scenarios

The rest of scenarios can be seen in Appendix C page 232

Table and Graph for all Scenarios

Table and Graph Description	Scenario/Page No.		
	1	2	3
Lead Time	137	152	166
Calibrator	140	155	170
Controller	139	154	169
Reagent	138	153	168
Throughput	142	155	171
Storage	142	157	172
WIP	143	159	173
Cost of Tests	144	160	174
Material Order Size	149	164	179
Queue Size	149	164	179
Equipment Utilization	146	161	176
Staff Utilization	147	163	177

CHAPTER ONE

INTRODUCTION

In today's global marketplace, individual firms no longer compete as independent entities with unique brand names, but rather as integral parts of supply chain links. As such, the ultimate success of a firm will depend on its managerial ability to integrate and coordinate the intricate network of business relationships among supply chain members (Drucker 1998; Lambert & Cooper, 2000). A supply chain is referred to as an *integrated system* which synchronizes a series of inter-related business processes in order to: (1) acquire raw materials and parts; (2) transform these raw materials and parts into finished products; (3) add value to these products; (4) distribute and promote these products to either retailers or customers; (5) facilitate information exchange among various business entities (e.g. suppliers, manufacturers, distributors, third-party Logistics providers, and retailers). Its main objective is to enhance the operational efficiency, profitability and competitive position of a firm and its supply chain partners. Also, supply chain management is defined as `the integration of key business processes from end-users through original suppliers that provide products, services, and information and added value for customers and other stakeholders' (Cooper, 2000). A supply chain is characterized by a forward flow of goods and a backward flow of information.

By reviewed the available literature it became obvious that there is lack of published research work in the field of health care supply chain in comparison to literature published about manufacturing industry. It becomes worst if we go deep to the chemistry Lab papers, which is rarely available. But with what has been reviewed in the research it can be concluded the need to have a supply chain model can provide health care provider with a baseline roadmap for effective change at all levels of the organization. It can provide also an insight into functions and practices needed in this time as well as the following benefits:

1. Learn from the experience of others how to best organize the health care firms.
2. Achieve significant saving in cost and improve the process of handling supply chain
3. Minimize the impact on staff time and resources during reengineering project.
4. Provide better monitoring and assessment.
5. Allows for accurate requirements analysis.
6. A mean of evaluating the impact of process changes prior to implementation.
7. A concrete benchmarking example to build better health care process.
8. Provide an automated health care business process.
9. Provide a framework for identifying points and outcome metrics.
10. Provide a foundation for continues improvement of the supply chain process.
11. It gives the measuring tools for quality and efficiency process.

There is a strong research need in the health care supply chain to create a streamline environment, which guarantees the availability of the needed supplies at the right time, the right place, and the right cost. The nature of the product in the health care system is very different than the product managed in the manufacturing supply chain system. The supply chain (in terms of liability) is the highest cost and risk segment of the health care delivery process. Improving the supply chain yields readily apparent benefits in the lower costs and improving health care delivery. The product of health care supply chain is human health and life and an error or a mistake generated by the health care system may be very costly which impossible to recover. Therefore, the model that will be created must guarantee that, created system improves the quality and availability of HC supply.

An integrated supply chain model is developed, in the Healthcare environment, in particular focusing on the Chemistry Laboratory. This research focuses on relative performance modeling through cost, and system performance modeling. It is not only giving particular benefit to reduce the cost or to improve the quality or to have an, overall, improved system, but a continuous monitoring mechanism is developed, to measure all of these parameters for adjustment, as required. Also, to know the effect of any change, like manpower or selling cost, of a material, to the entire system. The developed model can be beneficial for other Healthcare services, as well.

The Two Major Components of the Model

- Cost Modeling

  Measuring the cost involved in healthcare supply chain.

- Performance modeling

  To create an efficient Healthcare supply chain system based on certain criteria to measure the system effectiveness: these performance measures are envisioned as:

  - Lead time
  - Material flow time
  - Throughput
  - Inventory status
  - Work in process
  - Cost of each test
  - Material order size
  - Queue size
  - Equipment utilization
  - Staff utilization

The brief summary of the contents of this thesis is provided below chapter by chapter review:

Chapter 2 - This chapter presents Supply Chain and Health care the working mechanics of Supply Chain in HealthCare.

Chapter 3 - This chapter presents a comprehensive Literature review in supply chain, costing and health care system in general and related technologies. The chapter provides a systematic review of the research published in recent years to build a solid background for this research and to give an opportunity to the readers to compare the available published research and this research so that the contribution of this research work is made more visible.

Chapter 4 - This chapter explains the research aims and objectives as well as the contribution of this research to the knowledge in health care supply chain operations and analysis. This chapter further explains the methodology used and its benefits in this research.

Chapter 5 - This chapter presents the simulation model created for the modeling, operation and analysis of the health care system in a supply chain environment. This chapter also presents the modeling environment, parameters, data used, performance metric used as well as the limits of this study.

Chapter 6 - This chapter presents the results found through the modeling of health care supply chain. Different aspects of the supply chain problems are modeled through number of scenarios to create a better understanding for the true nature of the problems encountered in this area. A comprehensive analysis is provided for each of the scenario-based model using the two sets of performance metrics. This provides a better understanding of the complicated problems in health care supply chain and creates a more solid platform for the possible solutions.

Chapter 7 - This chapter presents further comments made on the modeling and analysis presented in the previous chapter. It provides further insight into the understanding the true nature of the problems experienced in health care supply chain and the major contribution made through this study.

Chapter 8 - This is the chapter that presents the conclusions drawn from the comprehensive modeling and analysis of the health care supply chain. This chapter further presents the possible research extensions based on the findings of this research work.

CHAPTER TWO

SUPPLY CHAIN SYSTEM

2.1 Introduction

This chapter presents the supply chain system within the context of manufacturing and healthcare so that readers who are familiar with manufacturing would be able to understand the healthcare supply chain better and could compare the similarities and differences. Further, the components of supply chain system, their functionalities and integration with other elements of supply chain are also presented to give background information to the readers to understand the model created and presented better in following chapters.

2.1.1 What is a Supply Chain?

A supply chain consists of all stages involved, directly or indirectly in fulfilling a customer request (Chopra & Meindl, 2001). The supply chain not only includes the manufacturer and suppliers, but also transporters, warehouses, retailers, and customers themselves. With each organization, such as a manufacturer, the supply chain includes all functions involved in filling a customer request. These functions include, but are not limited to, new product development, marketing, operations, distribution, and finance and customer service.

A supply chain is the constant flow of information and product between different stages. Each stage of the supply chain performs different processes and interacts with other stages of the supply chain. Supply chain activities begin with a customer order and end when a satisfied customer has paid for his or her purchase. The term supply chain conjures up images of product, or supply, moving from suppliers to manufacturers to distributors to retailers to customers along a chain. It is important to visualize information, funds and product flows along both directions of this chain. The term may also imply that only one player is involved at each stage (Chopra & Meindl.2001). In reality, manufacturer may receive material from several suppliers and then supply several distributors. Therefore, most supply chains are actually networks.

A typical supply chain may involve a variety of stages. These supply chain stages are shown in Figure 2.1 and include the following:

Customers

Retailers

Wholesalers/distributors

Manufacturers

Component/raw material suppliers

Each stage in Figure 2.1 needs to be present in a supply chain. The appropriate design of the supply chain will depend on both the customer's needs and the roles of the stages involved in filling those needs.

Figure: 2.1 Supply Chain Stages

2.2 The Objectives of a Supply Chain

The objective of every supply chain is to maximize the overall value generated. The value a supply chain generates is the difference between what the final product is worth to the customer and the effort the supply chain expends in filling the customer's request.

For most commercial supply chains, value will be strongly correlated with supply chain profitability, the difference between the revenue generated from the customer and the overall cost across the supply chain.

2.3 Supply Chain in the manufacturing process and its drivers

A supply chain is a sequence of processes and flow that take place within and between different supply chain stages and combine to fill a customer need for a product. There are two different ways to view the processes performed in a supply chain, cycle view and push/pull process. (Chopra & Meindl, 2001)

2.3.1 Cycle View of Supply Chain Processes

The processes in a supply chain are divided into a series of cycles, each performed at the interface between two successive stages of a supply chain. A cycle view of the supply chain is very useful when considering operational decisions, because it clearly specifies the roles and responsibilities of each member of the supply chain. The cycle view provides clarity, for example, when setting up information systems to support supply chain operations, as process ownership and objectives are clearly defined. In the following sections, descriptions of the various supply chain cycles.

Given the five stages of a supply chain shown in figure 2.1, all supply chain processes can be broken down into the following four process cycles.

2.3.1.1 Customer Order Cycle

The customer order cycle occurs at the customer/retailer interface and includes all processes directly involved in receiving and filling the customer order.

2.3.1.2 Replenishment Cycle

The replenishment cycle occurs at the retailer/distributor interface and includes all processes involved in replenishing retailer inventory. It is initiated when a retailer places an order to replenish inventories to meet future demand.

2.3.1.3 Manufacturing Cycle

The manufacturing cycle typically occurs at the distributor/manufacturer interface and includes all processes involved in replenishing distributor inventory.

The manufacturing cycle is triggered by customer orders, replenishment orders from a retailer or distributor, or by the forecast of customer demand and current product availability in the manufacturer's finished product warehouse.

2.3.1.4 Procurement Cycle

The procurement cycle occurs at the manufacturer/supplier interface and includes all processes necessary to ensure that materials are available for manufacturing to occur according to schedule. During the procurement cycle, the manufacturer orders components from suppliers that replenish the component inventories.

The relationship is quite similar to that between a distributor and manufacturer, with one significant difference: Whereas retailer/distributor orders are triggered by uncertain customer demand, component orders can be determined precisely once the manufacturer has decided what the production schedule will be. Component orders are dependent on the production schedule.

2.3.2 Push/Pull View of Supply Chain Processes

All processes in a supply chain fall into one of two categories, depending on the timing of their execution relative to customer demand. In pull processes, execution is initiated in response to a customer order. Push processes are those that are executed in anticipation of customer orders. At the time of execution of a push process, demand is not known with certainty. Pull processes may also be referred to as reactive processes because they react to customer demand. Push processes may also be referred to as speculative processes because they respond to speculated (or forecast) rather than actual demand. (Chopra & Meindl, 2001)

A push/pull view of the supply chain is very useful when considering strategic decisions relating to supply chain design. This view forces a more global consideration of supply chain processes as they relate to a customer order. Such a view may, for instance, result in responsibility for certain processes being passed on to a different stage of the supply chain if making this transfer allows a push process to become a pull process.

2.3.3 The Supply Chain drivers

To study supply chain performance in terms of responsiveness and efficiency, we must examine the four drivers of supply chain performance: inventory, transportation, facilities, and information. These drivers not only determine the supply chain's performance in terms of responsiveness and efficiency, they also determine whether strategic fit is achieved across the supply chain. The following sub-sections provide a brief of each driver:

2.3.3.1 Inventory

Inventory exists in the supply chain because of a mismatch between supply and demand. The mismatch is also intentional at a retail store, where inventory is held in anticipation of future demand. An important role that inventory plays in the supply chain is to increase the amount of demand that can be satisfied by having the product ready and available when the customer wants it.

2.3.3.2 Transportation

Transportation moves the product between different stages in a supply chain. Like the other supply chain drivers, transportation has a large impact on both responsiveness and efficiency.

Faster transportation, whether in the form of different modes of transportation or different amounts being transported, allows a supply chain to be more responsive but reduce its efficiency. The type of transportation a copy uses also effects the inventory and facility locations in the supply chain.

2.3.3.3 Facilities

Facilities are the places in the supply chain network where supplies are stored, assembled, or fabricated. The two major types of facilities are production sites and storage sites. Whatever the function of the facility, decisions regarding location, capacity, and flexibility of facilities have a significant impact on the supply chain's performance.

2.3.3.4 Information

Information could be overlooked as a major supply chain driver because it does not have a physical presence. Information, however, deeply affects every part of the supply chain in many ways. Consider the following:

1. Information serves as the connection between the supply Chain's various stages, allowing them to coordinate their actions and bring about many of the benefits of maximizing total supply chain profitability.

2. Information is also crucial to the daily operations of each stage in a supply chain. For instance, a production scheduling system uses information on demand to create a schedule that allows a factory to produce the right products in an efficient manner. A warehouse management system uses information to give the warehouse's inventory visibility. The company can then use this information to determine whether new orders can be filled.

2.4 Supply Chain in the Healthcare

Healthcare environment is very broad and it consists of hospital as a main center, clinic, companies, equipment and supply companies, insurance regulatory body, Ministry of Health. It is mainly representing patient as customer, hospital as a provider, supplier as support service. The following subsection provide more detail about the hospital as representing healthcare, also Material management department which responsible and controlling all supplies needed by the patient. (Mckone-sweet, 2005)

2.4.1 Hospital

Patient care is the primary function of the hospital whether in-patient or outpatient. To understand how the managerial decisions take place, it is important to know the organization structure of the hospital as well as the type of management, which will help to understand the obstacles of improving the supply chain in healthcare (refer to 4.4). The hospital organization is consisting of five major functions: 1) Medical, 2) Finance and business, 3) Management, 4) Ancillary services and 5) Support service.

Hospital is mainly a bureaucratic organization and use bureaucratic principles. A principle of bureaucratic organization that supplies effectively to hospitals is the grouping of individual positions and clusters of positions into a hierarchy or pyramid. Communication among these position governed by certain rules, hospital rules are the guidelines of official boundaries for actions within the hospital.

The major sources of power in the hospital are the board, the CEO or management, and the hospital's medical staff. These relationships may be regarded as a kind of three-legged stool or a tripartite hospital governance concept. Just as the activities of the medical staff impact significantly on the management and governance of the institution, so do the board's actions impinge on the doctors. The main organizational units that enable the medical staff to relate formally to the board are the medical staff's executive committee and the board's joint conference committee.

However, the more dynamic links between the board and the medical staff are in the informal day-to-day dealing between the two groups, both in the hospital setting and socially outside the institution.

The tripartite relationship is now challenged by the increasing pressure to provide high-quality, low-cost services that require a greater cohesiveness between the physician and administrative staffs. More common goals and motivators must be sought as the industry moves toward the probability of fewer payees, bundled (hospital and physician) reimbursement, and capitation.

Hospital in this time, is trying to join each other under one umbrella, to overcome the increasing cost especially management, personnel and purchasing. It is also the ability to provide a wide spectrum of care and increased access to capital market.

2.4.2 Materials Management in the Hospital (Logistic)

Material management (logistic) can be defined as: "the management and control of goods, services, and equipment from acquisition to disposition." (Ferrier, 1984)

The essence of this definition is that there should be centralization of the purchasing, receiving, inventory, and distribution functions within the hospital.

It is commonly estimated that 30-35% of a hospital's budget is related to materials and equipment, including managing and storing them. (Dacosta-Clavo, 2002)

Prior to 1970, the management of materials was often performed in a haphazard fashion, which was one of the contributing factors to the escalation of the cost of hospital care. In the 1970s, as these costs reached increasingly unacceptable levels, the concept of centralized materials management (which collects all sub inventories in the hospital and centralize it in one department called Material Management) began to gain favor. As a result, methods of controlling expenses like group purchasing, that had been used for many years in other industries began to be routinely applied in the health care industry. (Croom et al, 2000).

During the 1980s, greater emphasis was placed on group purchasing programs (refer to 2.4.2.2.1), centralized management of total inventories, and increased reliance on vendors to provide additional services such as consignment buying, (refer to 2.4.2.2.4) and "just-in-time" shipments (refer to 3.3.1.1). In fact, this shift to the practice of using the vendor to actually provide hospital support services has continued into the 1990s to such an extent that some people have difficulty defining the rightful place of a materials manager in the hospital.

As the national debate over health care cost control intensifies, so does the need to find ways to reduce the total cost of acquiring and managing materials and services.

Regardless of how the job of materials manager is structured, the need to successfully perform the function of reducing cost will continue to be critical. While one would think that by now every hospital would have an effective materials management department, this is not the case. Therefore, it is still worthwhile for administrators to take a serious and critical look at how this function is being performed in their organizations.

The two most critical elements in a materials management program are (1) a corporate strategy for ensuring that materials—goods, services, and equipment—are purchased at the lowest total cost and (2) a related strategy to ensure that the inventories and their associated carrying costs are aggressively monitored and controlled(Eastaugh, 2001).

Material or Supply Management in the hospital is very complex, it is a network of each department, and one relies on each other. The following sections will represent all elements that participate in supply chain in the hospital, sharing these functions, the path of supply information, and the problems and challenges.

2.4.2.1 Originating Department

The actual decision to acquire supplies and equipment almost always takes place in individual departments throughout the hospital. However, the materials manager can assist the head of the originating department in a number of ways, such as helping forecast needs for the coming year, providing information on sources of supply and prevailing market conditions, conducting negotiations with vendors, and designating effective systems for storing and maintaining materials until they are consumed (Eastaugh, 2001).

Also, it is noticeable that the originating department does not exercise sufficient care in accepting and documenting the delivery. A second problem is the vendor may overstock the department in order to increase sales. These kind of change needs to be addressed and to find a proper solution.

2.4.2.2 Purchasing Department

There are different techniques to deal with procurement of the supply:

The primary contribution of the purchasing department is to lower the price of goods and services acquired by the hospital. The two main tools to be used in accomplishing this objective are competitive bidding and direct negotiation (Bruss, 2005).

The three purposes of the purchasing department are to:

1. Assist all departments in obtaining products and services of appropriate quality from reputable and

reliable vendors at the lowest total cost to the organization.

2. Ensure that appropriate and ethical business practices are applied throughout the organization.

3. Serve as a source of information for the rest of the hospital concerning available products, sources of supply, current and anticipated market conditions, and application of effective purchasing techniques.

The following sub sections show different methods the purchasing department trying to adopt for reducing cost.

2.4.2.2.1 Group Purchasing

Group Purchasing; start with number of small hospital suffering from increasing price of items comparing with larger hospital. These hospitals assign an office to coordinate and facilitate the contractual obligations with the supplier on the agreeable items and large quantity. Each hospital will have the vote of the selected item. If the vote goes to unwanted brand by one of the member, he can not to join the group of that particular purchase. The membership money is used to run the group purchase office.

Larger purchase generally results in lower prices. As a result, groups of buyers can, by pooling their buying power, gain even lower prices than any of the individuals acting alone (Ayers, 1999).

However, there are costs involved in belonging to a purchasing group. These include the direct cost of membership, usually expressed as an annual fee, and a certain loss of control in product selection. The members of the group must meet periodically to evaluate vendor proposals, products, and performance and to monitor well the group itself is performing. There are also costs associated with participating in these meetings.

The question of whether a hospital should either join or maintain its membership in a group is an economic one. Will membership result in lower total costs to the hospital? If so, membership is worthwhile. However, before committing to a particular group, some additional issues should be considered. The following are considerations to be studied involving the group itself:

- How well do group goals and objectives correlate with those of the institution?

- Is the group program well focused and mature or does the group still has to get its program fully organized?

- What are the administrative costs of the group? How efficiently does the group operate?

- How skilled is the group at negotiation? Is the group going to negotiate major contracts on the hospital's behalf; is the institution satisfied that the group can do that job well?

- How does the group handle product evaluation and standardization? Since product standardization is an essential element of group purchasing, is the hospital sure it can participate effectively in that process?

- How does the group track record overall compare with other groups—or with what the hospital can do on its own?

As for the vendors who hold agreements with the group, are the products, quality, and service they offer generally acceptable to the hospital? As for the other hospitals in the group:

Are they larger or smaller than the hospital? Generally, smaller hospitals benefit most from being in groups with larger ones.

- What is the level of commitment of the member hospitals? More committed groups generally produce lower prices.

- How well managed are the other hospitals in the group? Are they institutions with which the hospital will be comfortable working closely?

- Has though been given to the competitive position of the hospital vis-à-vis others in the group?

Other hospitals, including members, should be asked about the group. So, too, with other hospitals that might have belonged to the group but do not. Why not and hospitals that once belonged to the group but left—Why did they?

Almost every hospital now belongs to at least one purchasing group and many belong to more than one group. This presents a dilemma in that a group's effectiveness depends in part on its ability to deliver agreed upon blocks of purchases to its vendors. If members participate in more than one group, and each group provides contracts for the same items, which group's contract will the members utilize? The answer for the hospital is usually to use the contract that provides the lowest price, or that provides a preferred brand at a satisfactory price.

2.4.2.2.2 Prime Vendors

Another approach to obtaining lower prices and better service is to establish a relationship with a single vendor to which major portions of the hospital's purchases are directed (Ayers, 2000). In return, the vendor is expected to provide:

- Lower prices
- Extended price protection
- Minimal back orders
- Lower in-hospital inventory levels
- Simplified paperwork in purchasing, receiving, and paying for items
- Other special services

Potential disadvantages of using a prime vendor include the following:

- Economic competition may be reduced over a period of time
- Inconsistent quality may exist across the vendor's complete line of products
- The hospital may become overly dependent on the vendor, and a change in vendors may be disruptive to hospital routines
- Prices may "creep" upward if inadequate controls are placed on the relationship

Overall, a prime vendor relationship can provide significant economic and operational advantages to the hospital if it is well thought out effectively negotiated, designed with adequate controls to protect the hospital, and carefully monitored. If any of these elements is missing, it can have a negative effect on the hospital.

2.4.2.2.3 Buying on Consignment

Buying on consignment, the hospital takes physical possession of items, but does not pay for them until they are actually consumed. Obviously, this method provides a cash flow advantage to the hospital. It also should cause the vendor to work more aggressively with the hospital to reduce inventory levels, because higher inventories mean more supplies for which payment has not yet been received (Bruss, 2005).

As in any special arrangement, however, there are potential disadvantages, including the following:

- Proper inventory control practices are necessary to avoid payment for lost or damaged goods.
- Prices may raise more than a normal amount to cover the vendor's additional costs.
- The vendor may place too little stock in inventory.
- The vendor may place too much stock in order to obtain free warehouse space.
- If the vendor "buys out" existing supplies, it becomes difficult to terminate the relationship because a major one-time expense will be required to re-establish the hospital's inventory.

Consignment buying has traditionally been applied most often to expensive, specialized items that show relatively slow usage but to which the hospital must have immediate access. Examples include orthopedic hardware, intraocular lenses, and special types of sutures. However, a number of companies are now providing consignment programs for broad categories of medical/surgical supplies.

2.4.2.2.4 Stockless Purchasing

In this technique certain categories of supplies are removed from the hospital's inventory and are carried only in the vendor's warehouse. Hospital departments send requisitions for supplies directly to the vendor, instead of the hospital storeroom. The vendor then prepares the orders for shipment directly to the individual departments (Rivard-Royer et al, 2002).

The hospital's purchasing staffs do not review orders, nor do the receiving department staffs check them in. As the items sent directly to the end user, but consolidated invoices are reviewed by the accounts payable department only to verify that they are generally reasonable in size. The risk, of course, is that payment will be made for items that were not received. The control on these purchases must reside in the individual ordering departments, as they both check on their orders when they are received and reconcile charges against their departmental budgets at the end of the month.

The advantages to the hospital in this system involve improved cash flow because of reduced inventories, and operating savings because of the simplified paperwork and reduced workload in purchasing, receiving, and, to some extent accounts payable departments. Another advantage to the hospital is the ability to make use of the large-volume buying power of the vendor.

For example, items that might be important, but of low volume to the hospital, would normally have a relatively high price. The vendors, because they buy for multiple accounts, can usually achieve a lower price. Part of this price reduction should be passed on to the hospital as a benefit of the program.

One disadvantage is that both the vendor and the individual ordering departments must be reliable in maintaining the accuracy of shipments and receipts. No emergency stock is maintained in a central on-site inventory, which makes accurate forecasting and ordering by the individual departments even more important.

This can be somewhat mitigated by building a small reserve in the basic supply level of the ordering department. This should be done carefully, however, in order not to diminish the inventory reduction savings. As in consignment buying, the removal of supplies from the hospital's inventory has the effect of tying the hospital closely to the particular vendor. As a result, it would be difficult to terminate the relationship.

This technique can afford the hospital significant savings. However, it is vital that the vendor be carefully selected and that performance, in terms of prices, order fill rate, and stock picking/billing accuracy, be closely monitored. In addition, the hospital should identify a list and bind the vendors to never being out of stock on these items. Finally, the hospital should always maintain final authority over product selection. This should never be relinquished to the vendor.

2.4.2.3 Receiving Department

The primary contribution of the receiving department is to ensure that the correct items, in proper condition, are officially received into the organization (Jarrett, 1998). The challenge to the receiving supervisor is to make sure that when goods bypass the receiving dock and to directly to the originating department, they are properly inspected and recorded into the inventory and payment records of the hospital.

This department's contribution to the hospital's bottom line rests largely on two key functions: 1) invoice matching, and 2) adjusting the timing of payments to vendors. It is essential that the vendor's invoice be accurately matched to the documents and accurately there is a high risk of paying for goods not actually received.

In general, payments should be held for as long as possible up to the point that a discount will be lost. Excessive delays in making payments damage a hospital's business reputation and weaken its future negotiating power. However, excessive speed in making payments results in unnecessarily giving away the use of the hospital's money.

In order to successfully maintain an effective schedule of correct payments, there must be a smooth flow of communication between the purchasing, receiving, and accounts payable departments.

2.4.2.4 Inventory Control

The goal of inventory control is to hold the least possible number of supplies in the hospital, while not running out of critical items. Inventory in hospitals has usually been considered to be only that material stored in the official storeroom and carried as an asset in the accounting records (Lancioni, 2000).

It is more appropriate, however, to also classify as inventory those supplies stored in the various operating departments of the hospital, even though they have been charged out as an expense to the departmental accounts. These are so called unofficial inventories can be worth up to three times the value of the official inventory. Obviously, they provide a significant opportunity for total cost reduction.

Most areas do not use a perpetual inventory system; that is, one that keeps constant track as supplies are added to and deducted from storage. It is harder to calculate the inventory of these areas, because in addition to finding and listing each item, it is necessary to look up the most recent price of the items.

There is a significant cost reduction potential in all inventories in the hospital whether official or unofficial.

2.4.2.5 Distribution

The selection and design of systems for distributing materials throughout the hospital and for replenishing stocks of supplies in user departments are key variables in the ability to manage inventory levels effectively. There are four basic options for distributing material: (1) requisitions, (2) PAR-level systems, (3) point-of-use replenishment systems, and (4) exchange carts (Power, 2005).

Any of these can be enhanced through the application of computer software programs, which can more accurately and more quickly handle the large volume and data generated by the multitude of daily transactions. However, computerization does not change the basic systems themselves.

2.4.2.5.1 Requisitions

This is the most traditional system and generally the least effective. Control of the process of deciding when and how much to order is retained by the personnel of individual departments.

It is common either to find highly paid, clinically trained employees spending time performing this function or for this function to be delegated to lower-paid employees. In either case, it is often a low priority and does not receive adequate attention. As a result, the quality of the ordering process is inconsistent and random, which can lead to both unnecessarily high inventory levels and at other times, unacceptably low levels. This system also has the effect of inflating the inventory in the central storeroom, as the storeroom supervisor builds an extra cushion to protect against random requests for large orders. A final result of this system is that it generates a large number of extra requisitions and telephone requests for additional supplies. These are time consuming and expensive for both the ordering department and the central storeroom.

The only advantages to this system are that it is simple; easy to understand, if not to do well; and requires minimal capital investment.

2.4.2.5.2 PAR-Level Systems

In this system a person from the central storeroom visits each ordering department on a scheduled basis, counts the supplies, writes an order, obtains supplies, returns them to the department, and brings the supplies up to a standard or PAR-level. A variation of this system, utilizing computer support, analyzes data about past consumption and calculates a predicted order, and the storeroom employee delivers this order to the unit. Additional supplies that may be required are delivered on a later trip.

In either case, this is a relatively Labor-intensive system. In addition, it provides somewhat weaker control over the productivity of the employees who deliver the orders.

One of the advantages of this type is that it more effectively links the disbursement of supplies to actual usage. It also places performance of the distribution function in the hands of employees who are lower paid than clinical employees and for whom the function is a high priority. Finally, it requires a relatively low capital investment.

2.4.2.5.3 Point of Use Replenishment

Whenever a supply item is taken for use, it triggers a request for replenishment. This is usually supported by automatic computer generation of an order. However, it can be done by hand, through the total number of transactions makes this cumbersome and prone to errors of omission (Appold, 2002).

Replenishment orders can be filled from the hospital's central inventory or directly from vendor's warehouse. In either case, the orders for single units of an item can be held for a period of time and consolidated into a reasonable size order to make more efficient use of delivery system.

2.4.2.5.4 Exchange Carts

In this case, all or most of the supplies for a department care placed on a movable cart. The standard quantities can be adjusted dynamically through the application of a computer software program if desired (Langabeer, 2005). A second identical cart is also prepared. On a scheduled basis, the first cart, which has been depleted, is taken from the user department, and the second cart, filled, is exchanged with it.

The primary advantage of this system lies in having greater control over the productivity and performance quality of the employees who fill the carts. By replenishing all carts in a central area, the storeroom supervisor is better able to monitor performance. In addition, compared to the PAR-level system, travel time is reduced by replacing multiple trips between the ordering department and the storeroom with a single trip for delivering the cart.

However, this advantage does not exist when comparing exchange carts with a computerized point-of-use replenishment system. In the latter case, orders are sent and consolidated by computer into a single order for delivery. The trend will continue to be more toward the installation of point-of-use systems, whenever possible.

However, the capital cost of the point-of-use installation will be a deterrent for some organizations. The disadvantages are that a large capital investment in carts is required, and space is needed for holding carts in both the user department and the storeroom.

CHAPTER 3

LITERATURE REVIEW OF HEALTHCARE SUPPLY CHAIN

3.1 Introduction

The aim of this literature review is to provide a review of supply chain management within the health care sector. The review covers the problems encountered. A discussion of related research work in this area and the factors influencing the performance of the health care supply chain system would be studied.

First, the general concept of supply chain in manufacturing and healthcare is presented.

A cross-section of different models of supply chain systems and an evaluation of each with the emphasis on suitable model for health care supply chain is reviewed.

The last section will present the health care supply chain performance measures and the existing methods of calculating supply chain cost.

3.2 Supply Chain Management - general overview

The main objective of studying supply chain is to eliminate waste and improve the flow of materials. This is what most authors agreed on. This is yield to cost reduction, quality and efficiency improvement.

Since the supply chain term has been used in the manufacture setting until now, it passes through different improvement stages, and has been attractive to other industry like healthcare.

For many years, researchers and practitioners have primarily investigated the various processes of the supply chain individually, whether supply chain management term or other term such as network sources, supply pipeline management, value chain management and value stream management have become subject of increasing interest in recent years, to academics, consultants and business management (Croom et al, 2000).

Langabeer (2005) pointed out the need of adapting the manufacturer system to healthcare. He suggest that the hospitals create an evolutionary path for supply chain technologies to increase vendor collaboration, implementing better business practices, optimize pricing, and improve the prediction of required order quantities.

As the supply chain represents one of the largest opportunities for cost savings and value creation in the healthcare enterprise, extended studies are needed to assist hospitals to understand and implement any changes.

The estimation of purchased materials and services account form between 50% and 80% of the total product manufacturing cost and it is further estimated that the suppliers product for 30% of the quality problem and 80% of the product lead-time. On the other hand, it is estimated 35% to 40% of the total budget of any hospital goes directly to the suppliers used in the healthcare setting (Dacosta-Clavo, 2002).

The term supply chain management is a new concept illustrated in 1958 by Jay Forrester. This concept has been crystallized recently to be defined as "as the integration of key business processes from end users through original suppliers that provide products, services and information and add value from customers and other stakeholders" (Cooper et al, 1997).

A supply chain is characterized by forward flow of goods and a backward flow of information.

A value chain is concerned with several theorized objectives:

- o Optimizing the overall activities of firms working together to create bundles of goods and services
- o Managing and coordinating the whole chain from raw material suppliers to end customers, rather than focusing on maximizing the interests of one player
- o Developing highly competitive chains and positive outcomes for all firms involved
- o Establishing a portfolio approach to working with suppliers and customers; that is, deciding which players to work with most closely and establishing the processes and information technology (IT) infrastructure to support the relationships (Gordon, 2000)

3.2.1 Supply Chain Management in the Service Industry and the relationship with the manufacturing

The service industry is becoming increasingly dominant in our world, and employment numbers are shifting from manufacturing towards services. The problem is the separation between the service industry and manufacturing is not always as black and white as many experts thought (Cooper et al, 1997). Sometimes there is a gray area, a mixed industry that blends both the manufacturing and service sectors. An effective supply chain is needed to link these sectors.

As defined before, supply chain can be narrow and broad depending on the definer. But the definition by Ayers (2000) can be covering all supply chain aspect;

Supply Chain: "*Life cycle processes supporting physical, information, financial and knowledge flows for moving products and services from suppliers to end-users*".

The following is a breaking of the definition further:

- *Life cycle* refers to both the market life cycle and the usage life cycle. These aren't the same for both durable goods and services.

- *Physical, information and financial* flows are frequently cited dimensions of the supply chain. The traditional viewpoint of supply chains as only physical distribution is too limiting.

- *Services* also have supply chains. Production planning for the product development department, which produces designs, not products, can benefit from the same techniques used by product manufacturers.

- The term *product* describes the basic product or service the *extended product* includes the basic product or service, the supply chain that delivers it, plus other features and factors that go along with the product or service.

Supply chain management has received attention since the early 1980s, yet conceptually the management of supply chains is not particularly well-understood, and many authors have highlighted the necessity of clear definitional constructs and conceptual frameworks on supply chain management (Saunders, 1995, 1998; New, 1995; Cooper et al, 1997, Babar and Prasad, 1998). Saunders (1995) warns that pursuit of a universal definition may "lead to unnecessary frustration and conflict", and also highlights the fragmented nature of the field of supply chain management, drawing as it does on various antecedents including industrial economics, systems dynamics, marketing, purchasing and inter-organizational behavior. The scientific development of a coherent supply chain management discipline requires that advancements be made in the development of the theoretical models to inform our understanding of supply chain phenomena.

The development of supply chain over the years has been slow. Companies developed individual parts of their supply chains beginning first with the transportation component and moving on to include warehousing, finished goods inventory, materials handling, packaging, customer service, purchasing, and finally, raw materials inventory. The goals of supply chain systems are multi-dimensional and include cost minimization, increased levels of service, improved communication among supply chain companies, and increased flexibility in terms of delivery and response time.

Today, much of the reluctance to interface with other firms in supply chains is breaking down. The change in attitude is due to variety of factors including just-in-time (JIT) programs, electronic data interchange, and point-of-sale data sharing programs. Each factor made traditional Logistics managers realize that there is more to gain by working with other supply chain firms than there is to lose.

For example, one of the greatest barriers to JIT was the fear that sharing production information with vendors would hurt a company by revealing its production-planning schedule to the competition. The fear was groundless, because what mattered most was keeping inventories low and reducing the resulting administrative costs of carrying inventory at manufacturing, plant, and dealer locations. Such influencing factors are explained as follows:

1. Electronic data interchange (EDI) had same effect on the fears of the data sharing in the supply chain. Here, firms were actually linking up their companies with computer-to-computer ordering and data exchange. The fear was greatest among small companies. Implementation of EDI required an investment in companies and software, on the parts of both the vendor and the buyer. Standardization was also a requirement that made the switch to EDI a lot slower than with JIT (more detail can be seen in 3.3.1.4).

2. Point-of-sale information programs were a major influence in altering among Logistics managers the thinking that data exchange in the supply chain can be beneficial to all parties involved.

3. The growth of the Internet has presented supply chains with many significant opportunities for cost reduction and service improvements.

Supply chain management was perceived mainly as a manufacturing terms although it is applied to any service sector using materials, it is in fact very attractive to healthcare industry as the cost is extremely high without proper mechanism to control it.

The following sub-sections highlight some of the solutions offered in the literature and indicate the relationships among the manufacturing industry, the service sector and customers.

3.2.1.1 Relationships with customer

The most important contributor to success in the service industry is building strong relationships with customers. Companies can benefit in numerous ways from loyal customers, including increased revenues, predictable sales and profits, low customer turnover, generation of new business and costs that can be amortized over a longer (Gwinner et al, 1998). However, for the relationship to be successful and long term, the customer must also benefit.

3.2.1.2 New technology adaptation in supply chain

Changes in technology have extreme effects on how a firm manages its supply chain. Specifically, electronic commerce (EC) is extending value within the SCM process. Businesses use EC to integrate their internal functions with the applications of shippers, suppliers, and customers (Scarborough and Spatarella, 1998). Electronic commerce allows shipment status messages to be received instantaneously and provides vendor-managed and continuous replenishment inventory programs (DeCovny, 1998). This new technology decreases inventory risks and maximizes the sale of product with short life cycles by reducing the time it takes to reach the broadest possible market (Scarborough & Spatarella, 1998). EC also promotes competitive advantages by having a more accessible order-entry process, decreased paper handling, and less re-keying of information (DeCovny, 1998).

3.2.1.3 Forecasting in supply chain

A company can effectively use customer date to synchronize its supply chain operations with consumer needs. This can be done through customer-supplied forecasts, which many people deem a necessary part of managing a supply chain. Robert Altabet, who is vice president of business management in the Duracell North Atlantic Group, states that, "the latest emphasis of forecasting has been in the areas of scheduling and Logistics, renamed "Supply Chain Management" (Altabet, 1998). Another article says, "Forecast horizons could impact a host of functional areas in the supply chain" (Saran, 1998).

An accurate sales forecast can have numerous advantageous results in the process of SCM. Effective forecasts provide vendors with more accurate data, improve efficiencies in product distribution, reduce supply chain inventories, and enhance customer service (Kiely, 1998, 1999). In general, forecasting helps businesses serve their customers more efficiently, without the constant fear of excess inventory. However, if SCM uses an erroneous forecast, the result will be felt throughout the entire system.

3.2.1.4 Outsourcing in supply chain

Manufacturing and service industries are grappling with the decision of whether to make or buy the parts used to manufacture their products. To answer this question, a company must weigh the cost factors. Experts believe that companies are heading toward greater specialization and outsourcing for the materials needed to make their product (Laios and Moschuris, 1999). Product complexity and commercial uncertainty is linked to how much technology is involved and the degree of risk for the business (Laios and Moschuris, 1999). In the service industry satisfying the customer is the highest priority. Businesses must link the decision to make or buy based on which option provides optimal customer satisfaction and the most cost-effective methodology. This is why procurement is being recognized as an important tool for improving a service corporation's bottom line (Anderson & Katz, 1998). Generally, the end product and ultimately the customer will benefit from outsourcing in the service industry. This importance is being pushed on the outsourcer to ensure that materials will arrive on time and in good condition. Service firms must consider quality, reliability, transportation costs, the costs of acquiring and managing, and the value of the final product to the customer.

In the healthcare outsourcing the distribution of non-critical items is always a viable alternative. (Nicholson et al, 2004).

3.2.2 The integration of supply chain management

As improvement of supply chain management the integration of supply chain have been introduced. Power, (2005) stated "implementation of technologies and methodologies for the management of supply chains is likely to be accompanied by significant intra and inter-organizational change"

The purpose of supply chain management is described by (Kaufman, 1997) as to bring to "remove communication barriers and eliminate redundancies" through coordinating, monitoring and controlling processes. The integration of supply chains has been described by Clancy as:

"attempting to elevate the linkages within each component of the chain, (to facilitate) better decision making and to get all the pieces of the chain to interact in a more efficient way and thus create supply chain visibility and identify bottlenecks" (Clancy, 1998).

The main drivers of integration are listed by (Handfield and Nichols, 1998) as:

3.2.2.1. Information flows

Effective application of information technology to the integration of supply chain activities has the effect of reducing levels of complexity. Senge (1990) defines two types of complexity, detail and dynamic. Detail complexity exists when there are many variables, like demand, needing to be managed. Dynamic complexity exists where cause and effect are separated, and difficult to associate, in both time and space.

There are a large number of software applications developed to allow better flow of information throughout the supply chain including order management systems to automate the order fulfillment process, demand planning system for managing and monitoring forecasts (Huson and Owens, 2000). These systems have suffered from the fact that they are not linked together within the organization they are considered as a short-term solution. Christopher (2000) states, "The use of information technology to share data between buyers and suppliers is, in fact, creating a virtual supply chain. Virtual supply chains are information-based rather than inventory-based".

3.2.2.2 Physical logistics

The importance of the management of physical inventory is being amplified by the following factors; decreasing product life-cycles; decreasing levels of standardization of products and demands for customization; customers demanding shorter delivery lead times; increased levels of competition due to globalization and lowering of tariff barriers; and increasing levels of dynamism (rate of change), complexity (number of changes) and uncertainty (what will change) in global markets (Stalk and Hout, 1990; Pine, 1993; Handfield and Nichols, 1999). Levels of inventory in supply chains are directly linked to cycle times, and cycle times in physical Logistics are largely a function of distance, uncertainty and complexity (Bowersox and Calantone, 1998). From the point-of-view of the movement of physical goods, an integrated supply chain offers the opportunity for firms to compete on the basis of speed and flexibility, while at the same time holding minimum levels of inventory in the chain.

3.2.2.3 Partnerships, alliances and cooperation

Handfield and Nichols (1999) also emphasize the importance of relationships for the effective management of supply chains. They state that the technological and physical transfer elements are understood, and that the issue of relationships is more difficult, less well understood and therefore more fundamentally important.

For Lambert and Cooper (2000) the key to these relationships is the level of management and integration required, with highly strategic inputs requiring the highest levels of management and integration by the focal company. They also make a valid point about the importance of monitoring the relationships suppliers and customers have with competitors.

A key component of this infrastructure will be based on robust and durable collaborative arrangements with trading partners. The most effective of these networks will be those that are able to get the mix of information requirements, physical Logistics and collaboration right, providing shared benefits to a majority of partner organizations.

The requirement for integration of supply chains is inherently strategic, and a potential source of competitive advantage for multiple trading partners. The nature of the integration model is an implementation issue that needs to be addressed with a view to customer needs and other variables such as industry and market characteristics (Damien Power, 2005).

3.3 The supply chain in health care

Historically, the healthcare industry has viewed itself as being operationally different from other businesses. Unpredictably, patient mix leads to uncertainty of supply consumption. This is one of the factors most researchers have concentrated on supply chain process improvements.

Despite well-documented evidence of significant competitive advantage and cost reduction resulting from supply chain management (SCM) practices, the healthcare industry has been extremely slow to embrace these practices. (McKone-Sweet et al, 2005)

However, in the past few years supply chain situation has started to change since healthcare financial resources are increasingly limited, researchers focused to study on the method for operational improvement in order to maintain the care services required by healthcare benefactors and to reduce costs. Hence, different studies about resource utilization strategies in healthcare organization (Giokas, 2001).

3.3.1 Current view of the medical supply management

Healthcare has been learning the supply chain practices from manufacturing supply chain, such managing inventory, demand, quality planning and control, also trying to adapt these practices in health care. However, most of these practices have been developed in industry over the year according to the need of manufacturing sector. These practices need to be changed or modified to suite the health care environment to get the best out of them. The supply chain practices in health care, therefore, show strong similarities with manufacturing practices. This is mainly because of the similarities in the problems encountered in both sectors. The health care industry lagged in bringing effective solutions to its problems in recent years. Therefore, learning from manufacturing supply chain would contribute to the faster solutions to the sector problems and this learning should be encouraged in health care.

The following sections review the methods and technologies that the researchers and healthcare practitioners try to implement, as it is successful in the manufacture industry. One of these technologies is the (Just In Time) which is proven to be very effective in bringing solutions to many manufacturing problems yielding a substantial savings in the manufacturing industry.

3.3.1.1 Just In Time (JIT)

A JIT delivery system can help to reduce the non value-added activities such as procurement, receiving and inventory management. Although these activities are done routinely, they do not add any positive value to the services provided by the healthcare organization. So the required items would be delivered to the needing departments in the hospital directly at the time they are required. The objective of JIT is to minimize inventory (medical supplies) to levels that satisfy customer demand and eliminate all the waste, which is defined to be non-value adding activities (Papadopoulou and Ozbayrak, 2005). One of the most important issues in JIT is to choose the suppliers very carefully so the organization can expect a fast (and high quality) delivery of supplies when they are needed. JIT purchasing requires that suppliers deliver materials just in time. Thus, supplier linkages are vital (Hansen & Mowen, 1997). In a JIT environment, the number of suppliers is relatively limited and the purchase contracts are long-term. With a long-term contract, the supplier's uncertainty is reduced, and the mutual confidence between supplier and purchaser can be built more easily (Monden, 1998).

Management of medical supplies is one of the most important managerial aspects of the healthcare industry. Inventory management in most industries has improved (Baker et al, 1996), and the level of inventory has been reduced by implementing methods, such JIT. Nevertheless, some healthcare organizations still hesitate to reduce the level of inventory because the costs of lack of inventory (such as loss of lives) are much higher than the costs of keeping additional inventory. However, current trends and market pressure on the healthcare are making healthcare providers seeks ways to reduce operating costs. Reducing the cost of carrying medical inventory is such an item.

The majority of current supply chain research has been focused on refinement to existing JIT systems used in the manufacturing industry. With specific regard to the health care industry there has been very little research directed toward implementation of the JIT concept. Most research in the health care industry has been directed toward process and information system improvements. Rather than being contradictory, current health care Logistical research has been to focus on specific supply chain processes.

3.3.1.2 Why Has The Healthcare Industry Not Implemented Just-In-Time?

Healthcare industry, by nature, provides a very vital and critical service to the public. Its main activity is to provide solutions to human health and well-being. Traditionally human health and life cannot be measured by cost and there is no equivalent unit of measurement of saving a human life. This type of cultural concept in health has prevented the sector to consider more cost effective approaches to the problems they have been experiencing. Therefore, the sector has long neglected the effective solution technologies such as JIT in their every day problems. Another major problem in healthcare is the high level unpredictability in determining the level of medical supplies. The sector, by nature, is highly unpredictable and most of the time, a well-working technology in manufacturing industry, not necessarily is enough to work well in healthcare sector. Therefore, the practitioners in the sector approached to these technologies with reservations with fear of not getting enough benefit out of them, which prevented them from adapting JIT technology in healthcare sector. Third reason could be the lack of a proper information system to be used between the hospital and the suppliers to track all the item trafficking. The fourth reason is the fear of not having enough medical items once the hospital needs them, because one of the main goals of JIT is to have zero inventories.

However, since the resources such as capital and assets are becoming more and more limited in the industry the health care providers have to find effective solutions to its problems.

With introduction of managed care, public pressure to reduce escalating cost, and increased competition for a shrinking inpatient market, healthcare leaders now have the incentive to evaluate their supply chain management practices and consider implementing JIT. (Jarrett, 1998)

The manufacturing industry shares many similar business processes with the health care industry, especially in the areas of supply distribution, inventory control, and product production. While the health care industry has been trying to manage its escalating operational cost and heal its sickly supply chain with many new supply-chain management strategies, it has been reluctant to make the comparison between itself and the manufacturing industry and take advantage to the savings associated with adaptation of manufacturing's (JIT) system.

Therefore, JIT technology, since it has already been proven that it is very effective in manufacturing industry, has began becoming one of the most effective tool to provide solutions to healthcare problems.

3.3.1.3 Stockless Distribution

Stockless distribution refers to product delivered in the lowest unit or measure either to the dock or directly to the using department in the hospital.

In the early 1990s the two terms quickly became buzz words, used interchangeable by hospital administrators and materials managers to describe a canned approached for taking costs out of the supply system. Meanwhile, the rest of the hospital staff lived by "Just in Case", the traditional belief that it was necessary to see, touch and feel lots of inventory, (Rivard-Royer et al., 2002).

In the early days of stockless, few materials managers looked at the total cost when evaluating stockless distribution as a means of improving the bottom line. Instead, they pointed to the quick benefits, such as FTE reductions that followed cutbacks in inventory. A decade later, there is better understanding of the components of total costs in an organization such as a hospital. Benchmarks help determine costs and point to what the most sense for a particular organization.

Hospital and distributors have learned to design contracts that align incentives between the parties, promoting mutual benefits and savings.

As a result of this better understanding of costs and benefits, hospitals have begun to look at stockless distribution as just one of a variety of options to help remove costs from the supply chain.

Stockless distribution is not the answer for everyone. For example, it wouldn't be advisable for a small rural hospital, 300 miles from the nearest distributor warehouse, with only a rudimentary computer system, or none at all. For another hospital, perhaps in an urban location, with a well-organized standardization program and high Labor costs, even stockless distribution might not go far enough. This hospital may want outsource the entire materials management function. (Eastaugh, 2001)

As for hospitals that have already gone stockless or JIT, it may be time to rethink the decision. Stockless is now just one piece of a much larger distribution pie. If it once provided 100% of the solution to a particular hospital, it may now account for only 15% or less of the total picture.

Not only is stockless losing its status as the ultimate distribution option, but also distribution itself is not as powerful a cost driver as materials managers once thought.

Product utilization reviews, activity based costing, risk sharing with vendors, procedure based delivery, outsourcing, and electronic data interchange are just a few of the more recent cost saving strategies for hospitals. (Refer to 2.4.2.4 for saving by inventory control)

3.3.1.4 EDI to Improve Supply Chain

Electronic data interchange (EDI) is rapidly growing technology, even though it has been widely available since the beginning of the 1980s (Lim and Palvia, 2001). Among many benefits of EDI are: faster processing speed, greater accuracy, reduced costs, competitive advantage, improved operations, security, tracking and control, intra and inter company communications, and customer service (Craig 1989; Gourley 1998; Hansen and Hill 1989; Male 1999; Richardson 1988).

In 1996, manufacturers, distributors, and providers in the healthcare industry in USA conducted a study of ways to make the healthcare supply chain process more efficient. The study, Efficient Healthcare Consumer Response (EHCR), improving the Efficiency of the Healthcare Supply Chain,

The EHCR study found that achieving targeted savings would require widespread adoption of EDI throughout the healthcare industry. The EHCR study identified $11 billion in annual supply chain costs that could be eliminated by increasing efficiencies at manufacturing, distribution, and provider organizations.

The study identified four areas where efficiencies could be realized to the benefit of all participants in the healthcare supply chain: distribution, transportation, order management, and inventory management. A potential 41% savings identified for distributors and the 33% savings identified for manufacturers. According to the study, healthcare financial managers are responsible for the areas that have the potential to yield the greatest savings for providers.

Efficiencies in order management-defined as the processing of price catalog updates, purchase orders, shipping notices, invoices, and related payments-offer providers the greatest potential savings.

The study recommends that about 90% of all order-management-related document exchanges be completed electronically in order for providers to reap the projected savings. (Jarrett, 1998)

3.3.1.5 Integrated delivery system

Today's integrated delivery systems (IDSs) require efficient supply chain processes to speed products delivery to users at the lowest possible cost. Most excess costs within the supply chain are a result of inefficient and redundant processes involved in the transport and delivery of supplies from suppliers to healthcare providers. By integrating and assuming control of these supple chain processes, improving supply chain management practices, and organizing and implementing a disciplined redesign plans, IDSs can achieve substantial savings and better focus their organization on their core patient care mission.

Many integrated delivery systems have reached the size, geographic coverage, and scale of operations at which the traditional model of decentralized support services creates inefficiencies and excess costs. To manage these services more efficiently, IDSs have sought ways to centralize management of core operational functions; create production centers for food preparation, laundry, and other scale sensitive services; and implement standard policies and procedures system-wide.

To achieve and maintain the level of service efficiencies that will help ensure their long-term success, IDSs increasingly will need to focus on integrating the entire supply chain. The supply chain is the chain of activities, information, and flow of funds that extends from manufacturers to the customers, or patient. Traditionally, marketing, distribution, planning, manufacturing, and purchasing have been independent processes within the supply chain, and the objectives of these processes within the supply chain, and the objectives of these processes have often conflicted.

Effective supply chain management integrates these disparate processes to bring finished goods to customers faster and less expensive. (Brennan, 1998)

3.4 Supply Chain Models

Considerable improvements have been made in supply chain management in many industries, but there has been limited success in making system wide SCM improvements in the healthcare industry. Yet, there is significant evidence that this industry is in need of broader changes.

Research by McKone-Sweet, et al, (2005) found that hospital spending accounted for 47% of the overall 7.2% increase in healthcare costs during 2000.

Everand (2001) attributed the lack of progress in SCM to the fact that each link in the healthcare supply chain operated solely in its own best interests. Although most healthcare professionals generally agree that change is necessary, fear of making the first move limits progress.

Considering a broad spectrum of the supply chain concept, there may be various classification schemes to categorize supply chain models. To minimize confusion, (Min and Zhou, 2002) developed a taxonomy based on classical textbook guidelines to indicate the mathematical models: as deterministic and stochastic (Bradley et al, 1983). As noted by Budnick et al, (1988), Silver (1981) and Zipkin (2000), some supply chain models based on inventory theory and simulation contain both deterministic and stochastic elements and consequently should be treated as hybrids. Therefore, they added a hybrid model to the category. Another category called `IT-driven models' was added to the taxonomy to reflect the current advances in IT for improving supply chain efficiency. These categories are somewhat different from the taxonomy developed by (Beamon, 1998) who did not report the evolution of IT-driven models. To elaborate, they (Min, and Zhou, 2002) classified supply chain models into four major categories: (1) deterministic (non-probabilistic); (2) stochastic (probabilistic); (3) hybrid; (4) IT-driven. Deterministic models assume that all the model parameters are known and fixed with certainty, whereas stochastic models take into account the uncertain and random parameters. While Beamon (1998), classified this to: 1) deterministic analytical models, in which the variables are known and specified, 2) stochastic analytical models, where at least one of the variables is unknown, and is assumed to follow a particular probability distribution, 3) economic models and 4) simulation model. It is important to have simulation be an individual as it reflects the dynamic of process of supply chain.

Deterministic models are showing as single objective and multiple objective models. This category was developed to reflect the increasing need to harmonize conflicting objectives of different supply chain partners. Stochastic models are sub-classified into optimal control theoretic and dynamic programming models. Hybrid models have elements of both deterministic and stochastic models. These models include inventory-theoretic and simulation models that are capable of dealing with both certainty and uncertainty involving model parameters.

Shapiro (2001) observed that IT development was the major driving force for supply chain innovations and the subsequent re-engineering of the business process. Considering the proliferation of IT applications for supply chain modeling, we decided to add the category of IT-driven models to the taxonomy. IT-driven models aim to integrate and coordinate various phases of supply chain planning on real-time basis using application software so that they can enhance visibility throughout the supply chain.

Modeling practitioners developed supply chain model for the better understanding of functional relationships between the organizations. The following sub-section presents the supply chain models in more detail.

3.4.1 Deterministic Models

One of the earliest efforts to create an integrated supply chain model dates back to (Glover et al, 1979). They developed a computer-based production, distribution, and inventory (PDI) planning system that integrated three supply chain segments comprised of supply, storage/location, and customer demand planning. The core of the PDI system was a network model and diagram that increased the decision maker's insights into supply chain connectivity. The model, however, was confined to a single-period and single-objective problem.

Cohen and Lee (1989) developed a mixed-integer; non-linear, value-added chain model that coordinated the supply chain process comprised of sourcing, centralized production planning, and inter-plant transshipment. The model incorporated capacity, demand, and production constraints, but failed to capture risk factors inherent in a global setting.

(Arntzen et al, 1995) presented a mixed-integer programming model, called global supply chain model (GSCM), which evaluated global supply chain alternatives involving multiple products and multiple stages (echelons). More specifically, GSCM took into account the inter-dependence of production, inventory and delivery processes to minimize activity days and costs associated with production, inventory, material handling, and transportation.

In an effort to integrate inventory, transportation and location functions of a supply chain, (Nozick and Turnquist, 2001) proposed an approximate inventory cost function and then embedded it into a fixed-charge facility location model. The fixed-charge facility location model was designed to consider a trade-off between demand coverage and cost associated with the location of automobile. Although the model deals with multiple objective (service-cost trade-off) issues, it is confined to a single period, single echelon problem with no capacity constraint.

3.4.2 Stochastic Models

In an increasingly competitive environment, there are many uncertain or random elements in the supply chain such as customer demands, lead times, and production fluctuation. The stochastic models take into account these uncertain and random elements. One of the pioneering works dealing with the stochastic nature of the integrated supply chain is credited to Midler (1969), who developed a dynamic programming model based on optimal control theory for selecting an optimal combination of transportation modes, commodity flows, and re-routing of carriers from customers to suppliers over a multi-period planning horizon.

(Tapiero and Soliman, 1972) utilized optimal control theory to solve multi-commodity transportation, multi-regional production and inventory planning problems over time with uncertain demand. Despite its merit, the model combining linear and parametric programs created severe computational difficulty.

(Lee and Billington, 1993) attempted to integrate the material flows of marketing, manufacturing, and distribution processes by developing a stochastic program. Their model was designed to determine the material ordering policy, the customer service level for each product, and postponement strategies. Similarly, Lee and Swaminathan presented stochastic models to formulate postponement (delayed product differentiation) strategies. In particular, (Swaminathan and Tayur, 1999) solved a so-called *vanilla box* problem where the inventories of semi-finished products were stored in vanilla boxes and then were assembled into final products after a customer actually ordered them further into the supply chain. Their model considered random customer orders.

In the meantime, several attempts have been made to quantify the effects of imbalance between supply and demand in the supply chain. These attempts include (Fisher, Hammond, Obermeyer, and Raman, 1997) who developed a stochastic program that aimed to minimize underproduction and overproduction costs as a result of imbalance between supply and uncertain demand in the supply chain. Similarly, (Lee et al, 1997) investigated the bullwhip effect that might arise when order variances distorted customer demand and consequently created imbalance between supply and demand in the supply chain. (Metters, 1997) followed up on (Lee et al, 1997) by developing a dynamic programming model that aimed to minimize the expected costs of production, inventory holding, and excess demand penalty, subject to production obeying capacity constraints.

3.4.3 Simulation Models

Simulation has traditionally been used in manufacturing modeling very widely. Parallel to the developments in computer technology and software engineering, simulation became more reachable to many people to use in modeling and analysis of systems, in particular manufacturing systems. The use of simulation in health care is certainly not new. Many simulation applications in health care industry have appeared in recent years (Jun et al 1999; Issenbery et al, 1999; Weinstein et al, 2003; Lake 2005; Scalese and Issenberg 2005; Murray et al, 2005).

Simulation modeling is preferred because it has the ability to model the systems in more detail than any of the modeling tools can. Further, it can introduce certain level of stochastic to reflect the true nature of randomness. However, it has some drawbacks as well. One of the major drawbacks is that it needs some substantial time to collect the data set to use and build the model. It needs a certain level of expertise in probability, statistics and computing. Another shortcoming of the model is severe computational complexity that may prohibit its application to a real-world problem. (Singh and Vrat, 1984) developed a more practical model that was designed to determine the optimal location of repair part stocking points and the allocation of repair part inventory to that location.

Petrovic (1998) developed a fuzzy generative supply chain model to determine target order-up-to levels of inventories along a supply chain under uncertain demand and external supply of raw material. The results of the fuzzy model were then used as input data for an evaluative simulation model that aimed to calculate replenishment quantities during a finite planning horizon. The simulation model also provides the user with the assessment of supply chain performance (e.g. end-product delivery performance). These fuzzy and simulation models, however, were confined to a single product problem with no capacity constraint. (Petrovic, 2001) extended these models by incorporating the element of uncertain lead times during the replenishment process into the fuzzy model framework. Both of these simulation studies are useful for understanding supply chain dynamics under uncertainty, but are still limited to periodic review inventory systems.

The details as well as further explanation of the simulation and simulation modeling can be found in Section 5.2 and Section 6.2 for the reference model.

3.4.4 Information Technology Driven Models

One of the most critical drivers of supply chain success is the enhanced visibility through an information sharing mechanism linking supply chain partners. Considering the significant role of IT in supply chain success, IT driven models are high demand. Although IT-driven modeling efforts are still in their infancy, they are used widely in supply chain models (Ayers, 2000).

3.5 Performance measures in the Health Care Supply Chain

The following literature review will be the basis for selecting the performance metrics of the proposed healthcare supply chain model in Sections 4.2. Smith and Swinehart (2005) pointed that the healthcare is looking for a measure to determine the organization success. Efficiency, effectiveness and cooperation are important to achieve, but first it needs to be measured. An important component in supply chain design and analysis is the establishment of appropriate performance measures (Beamon, 1998). Different researchers have attempted to assess SCM performance in different ways, but most performance measures up to now are more oriented towards economic performance than to other aspects of performance such as customer satisfaction (Harland, 1996). Garwood (1999) cautions that old yardsticks for SCM performance such as purchase price variance, direct Labor efficiency, equipment utilization, and production development budget are no longer adequate, and a new set of metrics to motivate and reward the right behavior is needed. Combining different set of performance measurement to focus on the healthcare supply chain is crucial for successful measurement, which can be seen in Section 4.2 which is the aim of the research. Lack of measurement slows acceptance and implementation of major changes in the supply chain (Owen and Richmond, 1995). It is becoming more important to achieve fully integrated supply chain than individual performance measure (Gunasekarn et al, 2001).

A number of researchers have suggested different measures of SCM performance. For example, Stevens (1990) suggest that an organization measure the performance of supply chain in terms of inventory level, service level, throughput efficiency, supplier performance, and cost. Narasimhan and Jayaram (1998) use the customer responsiveness and manufacturing performance as the measure for SCM performance. Spekman et al, (1998) use cost reduction and customer satisfaction as the SCM measures. Hewitt (1999) recommends customer satisfaction, return on trading assets and flexibility as the measurements for a supply chain performance. Beamon (1998) identifies several qualitative SCM performance measures; customer satisfaction, flexibility, information and material flow integration, effective risk management, and supplier performance. It can be seen that each of above researchers, more or less, has addressed some dimensions of SCM performance measures, but not all. Among all measures, customer responsiveness/satisfaction receives the most recognition. Synthesizing above findings, five major dimensions of SCM performance are studied and discussed below.

3.5.1 Supply Chain Flexibility

In general, flexibility reflects an organization's ability to effectively adapt or respond to change. Flexibility describes the organization's ability to meet the needs of the market without excessive cost, time, organizational disruption, or loss of performance (Aggarwal, 1997). Vickery et al, (1999) suggest the flexibility should be viewed from the perspective of the entire value-adding system and examined from an integrative, customer-oriented perspective. They define flexibility as encompassing those flexibilities that directly impact an organization's customers (i.e. flexibilities that add value in the customer's eyes) and all the shared responsibility of two or more functions along the supply chain, whether internal (e.g., marketing, manufacturing) or external (e.g., suppliers, channel members) to the organization.

3.5.2 Supply Chain Integration

Supply Chain Integration is defined as the extent which all activities within an organization, and the activities of its suppliers, customers, and other supply chain members, are integrated together (Wood, 1997; Narasimhan and Jayaram, 1998). As shown in Section 4.6.2 and 4.7, There are two interrelated forms of integration along the supply chain: the first type of integration involves coordinating and integrating the forward physical flow of deliveries between suppliers, manufacturers, and customers; and the other prevalent type of integration involves the backward coordination of information technologies and the flow of data from customers, to manufacturers, to suppliers (Frohlich & Westbrook, 2001).

A highly integrated supply chain is a real representation of superior SCM performance. Organizations that operate in isolation are placing themselves at competitive disadvantage (Wood, 1997). Not only must organizations collaborate internally across business functions, but also they must establish external strategic linkages with other organizations. One true indicator of supply chain integration is that there is no distinction, and certainly no disconnection, between a myriad of transaction processing applications within an organization, and the organization's ability to optimize and utilize decision support capabilities to improve integration of suppliers and customers and to better serve customer needs.

3.5.3 Customer Responsiveness

Customer Responsiveness is defined as the speed of an organization's response to the customer requests (Narasimham & Jayaram, 1998; Beamon, 1998). The performance of SCM must ultimately be measured by its responsiveness to customers (Lee and Billington, 1992). As mentioned by Owens and Richmond (1995), while SCM strategy varies from organization to organization, its overall objectives are clear: to become increasing responsive to customer needs, to drive costs out of the system, and to turn savings into additional value for the customers. BY measuring the performance of activities critical to ensuring satisfaction of customers, managers can target their efforts more effectively and can assess the results of their actions more objectively.

3.5.4 Supplier Performance

Supplier Performance is defined as suppliers' consistency in delivering materials, components, or products to an organization on time and in good condition (Beamon, 1998). In the literature, supplier performance is considered one of the determining factors for the organization's operational success (Shin et al, 2000; Vonderembse and Tracey, 1999) and a very important dimension of SCM performance (Stevens, 1990; Beamon, 1998; Gunasekaran et al, 2001). Poor vendor quality and delivery performance result in higher levels of inventory and order backlog (Shin et al, 2000).

3.5.5 Partnership Quality

Partnership Quality is defined as how well the outcome of a partnership matches the participants' expectation (Lee and Kim, 1999). One big problem in SCM measurement system is that it usually consists of hard, objective measures which are in direct conflict with the shared destiny principles of partnership and long-term relationships underlying SCM (Harland, 1996). Marketing-based and service -based views have emphasized the importance of customers' perception in measuring relationship (Christopher, 1992). These issues are of far greater importance in measuring long-term relationship performance. From the standpoint of service-based view, partnership quality is considered as a soft measure for SCM performance, which represents the result of a partner comparing with the expectations with against the perception of supply chain performance. Previous research in channel relationship has indicated that satisfaction of a channel member is instrumental in increased morale, cooperation between channel members, few terminations of relationships, and reduced litigation (Ganesan, 1994).

With the escalating cost of providing healthcare, politicians and hospital operators are searching continuously for innovative ways to contain costs without sacrificing quality of services. The increasing cost of providing health care is due to changing disease patterns, which in turn lead to advances in medical knowledge and technology, and to a greater use of medical technology. Hospitals have become aware of the acute need to cap rising operating costs and to meet or even exceed a higher level of expected patient quality (Butler, 1995).

In order to achieve the goal of "providing healthcare efficiently and cost-effectively", one of the requisites of achieving medical excellence, numerous studies and investigations have been done on diagnostic and therapeutic techniques, advanced technology implementations and cost sharing. However, there is little or no research on the measurement of the results of the goals to be achieved, in this case the performance measurement of the system.

Alt (1997) points out that the increase in healthcare costs and inefficiencies are due to inadequate and tedious purchasing procedures. The health care cost escalation has been based on the explicit assumptions that medical supply purchasing information systems are inadequate, and that the delivery of the healthcare has been inefficient.

Inefficiencies in the healthcare supply chain could be significantly improved through the application of supply chain best practices from other industries. Prior to the changes, there was an urgent need to assess assumptions that medical supply purchasing information systems are inadequate, and that the delivery of health care has been inefficient.

3.6 Cost Management of Health Care Supply Chain

Cost Management in the healthcare setting does not enter into decision-making and action of the matter concern medical aspect (Cleveley, 2000). So the evolution of health care created a climate in which cost was subordinate to medical treatment. Current reimbursement constraints have increased the need for providers to be cost conscious, but they have discovered that current accounting practices do not provide the appropriate information to determine the cost of service or make decisions.

One of the greatest challenges facing health care providers is cost determination. Health care providers do not know what it costs to provide services. In addition, standard accounting systems are of little help and can provide misleading information.

Literature survey of cost management in health care supply chain is not as in the manufacturers it is relatively new concept.

Traditional costing systems break costs into direct and indirect expenses. Activity-based costing (ABC) however, defines costs in terms of organizations' processes or activities and determines costs associated with significant activities or events. For example, using ABC, a healthcare organization is able to better understand costs associated with patient assessment or the provision of diagnostic tests, as well as factors influencing cost (eg, Labor). Thus, ABC can help healthcare organizations achieve their strategic objectives.

Traditional costing systems have several shortcomings. In the manufacturing industry, for example, costs are based on production measures relative to volume, such as the number of cars produced.

Overhead traditionally is allocated proportionally among all work centers in the form of indirect cost. These costs are allocated to final products by using direct Labor hours or machine hours as their bases for allocation.

This system is relatively successful, except when overhead is allocated using an appropriate base. For example, allocating the overhead for electrical expense at a soft drink bottling plant using direct Labor hours rather than machine hours as the allocation base is inappropriate. Clearly, expensing electrical power as a function of Labor output is inappropriate.

ABC more accurately distributes indirect costs by choosing the most appropriate cost base for allocation.

Furthermore, it allows for more than one base to serve as a factor influencing cost.

3.6.1 Traditional Cost Accounting

Most organizations have three distinct costs: 1) direct; 2) indirect; and 3) overhead. Direct costs are expenditures for resources that can be tracked to specific products or customers (Lindahl, 1997). These are costs, such as Labor or supplies that are consumed in creating a product or service. They have a clear cause and effect relationship with output and the costs associated with acquiring these resources rise and fall with output. Managers can see where the resource was used, how many units were employed and their cost. There is a little ambiguity as to why these expenditures are incurred and who should pay for them.

Traditional cost accounting relies on cost allocation to distribute support costs originating outside revenue producing departments back to user departments and subsequently to outputs and/or customers.

This is where cost accounting and real-world production begin to part ways. Production relies on cause and effect relationships to create products and services. Accounting often relies on easily available measures to allocate production costs to output and customers.

3.6.2 The ABC Model

ABC starts with the identification of resources consumed by the production process. These are function specific aggregates (i.e., how much is spent for resources used in the production process). The next step is to identify to cost driver. Cost drivers are the things that cause work to be undertaken. A cost driver is an event that results in activities being performed and causes the expenditures of resources (Cagwin and Bouwman, 2002). In this example, the primary cost driver is ER visits and they determine a large percentage of costs incurred. ABC attempts to trace how the arrival of patients in the ER creates demands on resources used for direct care (i.e., Labor and supplies) support services (i.e., maintenance, materials management, utilities, housekeeping) and overhead (i.e., A&G, finance, marketing).

According to Brimson, "activities represent the orchestration of technology, people, raw materials, and skills that go into the delivery of health care. Furthermore, they describe what an enterprise does, the way time is used, and the final outcome of the process.

Activity mapping, which involves mapping activities in an illustrated sequence; activity analysis, which involves defining and assigning a time value to activities, and bill of activities, which involves generating a cost for each main activity.

3.6.2.1 Resource and Activity Drivers

ABC relies on resource and activity drivers to trace expenses to their source (e.g., why were resources purchased, how were they used in the production process, and what did they produce or who benefited from their expenditure). Resource drivers specify the cost to produce an activity and activity drivers specify the amount of work required to produce an output. A prime benefit of ABC methodology is the explicit recognition of work activities (Canby, 1995).

3.6.2.2 Benefits of ABC

As stated by Cooper and Kaplan (1991), they report that ABC is not just a way of accurately calculating products costs, but is an extremely useful management guide which can help in decision making and directly lead to higher profits. According to Cooper and Kaplan, ABC can give management a clear idea of how products, brands, customers, regions and distribution channels can make profits and consume resources.

This can be achieved by the willingness of managers to separate expenses incurred to produce individual units of a specific product from the expenses required to produce different products, irrespective of how many units are bought or sold (Cooper and Kaplan, 1991) Once this is done managers must be willing to act, and explore ways of reducing the amount of resources required for various activities, then either reduce spending on those resources or increase output, only then can higher profitability be achieved (Cooper and Kaplan, 1991).

Chan (1993) discusses the issue of how ABC can guide managers to effective cost reduction by focusing on non-value added activities. Chan then elaborates that cost can be reached by Ramsey is that he was able to theoretically illustrate how ABC could be successfully applied in a health care environment.
Carr (1993) was able to illustrate how ABC allows management to efficiently manage staffing and obtain a more accurate cost assessment for services provided. Braintree Rehabilitation center was used as an example to show how ABC could be both developed and implemented on a center, which provides nursing services. Skill levels of the nurses were divided into three categories and the relating pay scales were chosen to range from low to high. Routine and special nursing events were monitored, and a database was built up which would illustrate the distribution of nursing care against type of activity and patient diagnosis. Results of the study found that as the patient's health progressed, the lower skilled nurses usually took over from the higher skilled nurses. Therefore, ABC was able to recognize this and

consequently such information allowed management to manage staffing more efficiently.

Lawson's (1994) study used ABC on a health care organization working in five geographical locations, and found regional variations in the overheads consumed, in some cases this variation was up to 30% in some localities. Therefore Lawson reached the conclusion that TCA methods can create problems and can give distorted information when used in the health care industry, just as it does when it used in the manufacturing industry.

Caltrider et al, (1995) recount how ABC was used in a junior hospital in America, as an important part of their continuous quality improvement (CQI) approach. Hospital reviews highlighted that the orthopaedic outpatients clinic was a high cost area, and consequently an ABC review (combined with the CQI) method, was able to reduce costs by up to 20% on some forms of patient treatments. Shields (1995) concur with these results as he also reports that using ABC alongside other quality initiatives (amongst other factors) will aid in successful ABC implementation.

Speeding and Sun (1997) assert that ABC can be inserted into simulation tools, and describes how such simulation models can be developed. This is done by observing the Actual processing times of activities in a system and then characterizing their variation by statistical distribution. Representation of the manufacturing system using a simulation program acts as a visual tool and this technique is commonly used by the management of such organizations, when exploring tactical moves or decision-making. Therefore, Speeding and Sun (1997) provides mathematical equations, which allow the implementation of the ABC model on to a simulation program.

Cagwin and Bouwman (2002) investigate the association between improved financial statuses with the adoption of ABC. Cagwin and Bouwman employed the use of the confirmatory factor analysis and structural equation model to investigate the relationship, and the results yielded a positive link between the use of ABC and improved financial performance, thus illustrating the success of ABC. Furthermore, Cagwin and Bouwman (2002) were able to identify factors under which such financial improvement could be achieved, these factors include using ABC simultaneously with other strategic business initiatives (such as Just in Time), implementation in complex and diverse firms and when ABC is sued in firms where costs are relatively vital. Such a study gives positive encouragement to the healthcare industry, as ABC can lead to improved financial status. Moreover, Cagwin and Bouwman findings are supported by previous studies, which also illustrate that ABCs potential benefits are somewhat limited by environmental factors.

Gordon and Silvester (1999) studied the event of the stock market reaction to the installation of ABC and the results yielded a lack of any noteworthy reaction. Therefore this appears to suggest that ABC may have different effects, which are specific to the firm, and the benefits of ABC are dependant upon the way the company is structured and functions (Gordon and Silvester, 1999). Devine et al, (2000) also concurs with these studies, as they claim that in order for ABC to be successfully implement in a health care setting, management must be fully committed via resources and training.

Greasley (2000) uses a variety of tools, namely Business Process Simulation (BPS) in association with ABC. By using a case study of a police custody case, in order to redesign processes, Greasley was able to show that ABC can be sued to show where costs are being generated.

Ozbayrak et al, (2004) focuses on ABC estimation in an advanced manufacturing system, and they assert that while it is extremely valuable to possess high automation levels, high product quality and flexibility, if this is now backed up with an accurate and realistic costing method, then companies run a high risk of becoming uncompetitive. Ozbayrak et al, (2004) provides a simulation model that uses ABC to estimate manufacturing and product costs, within an advanced manufacturing industry. While, Ozbayrak et al's paper was specifically for the manufacturing industry, it is needless to say that there are many similarities between the manufacturing and healthcare industry (such as an increase in the level of automation), and therefore it is highly possible that this paper may have some relevance in applying ABC on the healthcare industry.

3.7 Conclusions

It may be concluded that the literature review given in this chapter reveals that the available research in health care supply chain mainly focuses on isolated operational problems in any health care unit ignoring the connection of this care unit with wider systems such as supply chain and makes some over-optimistic assumptions which hinder the validity of the model built to analyze the problem. The extensive literature review provided has proven that there is a considerable lack of proper research in health care supply chain and this thesis aims to fill this gap by providing a comprehensive supply chain modeling in health care to analyze a number of problems encountered in health care industry to improve the system performance.

CHAPTER 4

Modeling and Analyzing a Health Care Supply Chain System

4.1 Introduction

This chapter presents the aim, objectives, motivation and framework of this PhD study. It also presents the research need and the main contributions of this study to the health care supply chain research.

4.2 Aim

The aim of this study is to develop a healthcare supply chain model to be used as a guide in improving the efficiency while reducing the escalated cost.

For this reason, a comprehensive health care supply chain model has been built using simulation-modeling technique.

The model concentrates on modeling the relative performance of the healthcare supply chain, in particular focuses on system performance modeling as been recommended from the literature review as discussed in the section 3.4,also based on the author experience which found the following measuring metrics represent the healthcare supply chain performance: lead time, throughout, WIP, cost of test, waiting time (Queuing), material order size, flow time, inventory level, and equipment, staff utilization, the motivation for the selection of these performance metrics is to observe the system performance within the organization as individual and interacting activities, so that a better picture could be obtained in understanding the system behavior. The classification of the performance metrics is based on the level of explanation about the system behavior they could provide. The first set of metrics is used to measure the direct relationships of activities such as throughput, lead time, flow time and WIP with the factors such as supply level and quality, inventory level, and demand pattern that affect the quality and dimension of aforementioned activities. The second set of metrics are used to measure the secondary activities such as staff and equipment utilization, queue size and supply order size with the general supply chain factors that influence the overall system performance. These metrics are needed to get a better picture about the system behavior as well as to understand the interactions between the different elements of the processes. These performance metrics are chosen for the ability to measure the system's performance in different dimensions. These metrics give the opportunity to the modelers and analysts to measure the different aspects of system's performance so that they can understand whether the system performs and functions as expected or not. Further, they give the opportunity to the analysts to interfere to the system in case of diverting from the expected performance levels or when any malfunction arises.

Also it calculates the cost of each test including all related resources as part of the simulation model using the ABC method, (see Sections 3.6.2 for further discussion).

The model created has particularly concentrated on a key health-care unit and sample-testing Lab in a very large local hospital. The model deals with supply chain elements and gives detailed analysis of the events take place in this unit considering the supply chain boundaries.

A number of real-life scenarios have been modeled using the reference simulation model, which assumes that all the elements in supply chain work properly and no malfunction would happen during the operation of the system, to capture all the activities take place in a chain focusing on the Lab to explore the health care system better to create a stream-line Supply Chain System in Health Care industry. (See Section 6.2 for further discussion on Reference Model)

4.3 Objectives of the research

The following objectives are envisioned in the context of this research work:

- Building an integrated health care supply chain model composing; the system performance and health care cost.
- Utilizing this simulation model to capture the relationship among all supply chain parties: Logistic, Chemistry Lab, Patient, and the Supplier.
- Building a performance-modeling tool using simulation to measure the healthcare supply chain performance.
- Utilizing the structure of the developed model to be used in different department in the hospital

This research is examining why Healthcare Supply Chains lag behind the manufacturing supply chain system and tries to identify the areas and amount of savings available, estimate the impact of supply chain management "best practices", identify: efficiency improvements, cost reduction and reductions in medical error through a relative performance modeling. The integrated model which connecting all elements of healthcare supply chain system with fowrwrd of information and backword of information as will be covered in the section 5.3.

4.4 Outline of the Problem and the Research Needs

One of the major causes of inefficiency in the health care system is that isolated or localized expertise. In the past several years this situation has started changing. Since health care financial resources are increasingly limited, manager's focus on methods for operational improvements in order to maintain the care services required by the population and to reduce the costs. Hence, different studies about resource utilization strategies in health care organization (Li et al, 2002; Pasin et al, 2002; Van Merode et al, 2002; Jun et al, 1999) or total quality management (TQM) implementation techniques (Eisenberg et al, 2001) have been developed. According to 1998 OECD reports on health care expenditures for several countries, the UK spends 6.7 percent of her GDP on health care and with the recent government decision related to National Health Service (NHS), this expenditure will increase further (Department of Health Report 2002). Despite this scale of high expenditures, the UK health care system has been suffering from many malfunctions, including shortage of nurses and specialist doctors, long waiting lists and times, low quality of treatments, and most importantly high cost of health care delivery.

There are several reports that highlight the magnitude of the problems NHS facing in the key areas of safety, effectiveness, and responsiveness to patients, timeliness, efficiency, and equity (Department of Health Report 2002). Escalating health care costs have prompted hospitals and in particular the NHS to get serious about major cost producing problems such as inefficient hospital operations management, inventory control and cost recovery, but, unless the effecting factors become integrated, costs will continue to spiral out of control.

Even the short view of the problems listed above can prove that the health care system has been suffering from serious malfunctions and a close examination can reveal that the most of these problems originate from poor management of the supply-demand balance across the health care supply chain system.

Therefore, this research intend to examine why Healthcare Supply Chain lag behind those utilized within the private sector, and manufacturing supply chain system and tries to identify the areas and amount of savings available, estimate the impact of supply chain management "best practices", identify: efficiency improvements, cost reduction and reductions in medical error through a relative performance modeling.

It is illogical to assume that old processes will meet future challenges. Instead, healthcare managers must look to other industries for proven approaches to become more cost-effective and efficient in the delivery of health services. Application of activity based cost modeling and Business Process Reengineering (BPR) has enabled American manufacturing to regain its worldwide leadership position, and can enable similar improvements within applied healthcare. (Wisnosky, 2000)

The problem facing today's Healthcare leaders has become: "How can we provide care to the same number of patients at a greatly reduced cost without harming quality"? Revenues per patient visit are declining at a faster rate that the rate of cost reduction. In order to remain viable, any money of lost revenue must be matched by money in reduced variable expense.

Since the end result of the supply chain is customer service (patient care), all aspects, both human and mechanistic, support the goal of quality, cost effective care.

Since the healthcare supply chain system is too complicated with too many sections, departments, input, output and parameters, it is beyond any study to model the entire healthcare supply chain. Therefore, a chemistry Lab, which contains many health care supply chain activities and has a key position in supply chain, is considered in this study to develop a model and understand activities happen in the supply chain system.

Consequently, the Chemistry Laboratory has been chosen as an example of other departments in the Hospital, as it has all variable components like equipment, manpower, supply. The Lab outcome is the test's results, which can be considered as a manufacture's product. Finally the Lab has the capability of integrated with other section like, logistics, clinical and technical departments.

By reviewing the literature listed above it is obvious that there is a lack of research in healthcare supply chain in comparison to the research carried out in manufacturing supply chain. It becomes worst if we go further to the chemistry Lab centered research, which is rarely available in the literature. As a result, from the reviewed literature it can be concluded that there is a strong need to have a model that can help the health care providers with a baseline roadmap for effective change at all levels of the organization to improve the system performance and reduce the cost. It can provide also an insight into functions and practices needed for supply chain as well as the following benefits:

- Learn from the experience of others how to best organize the health care firm.
- Achieve significant saving in cost and time start and complete heath care process improvement project.
- Minimize the impact on staff time and resources during reengineering project.

- Provide better monitoring and assessment.
- Allows for accurate requirements analysis.
- A mean of evaluating the impact of process changes prior to implementation.
- A concrete benchmarking example to build better health care process.
- Provide an automated health care business process.
- Provide a framework for identifying measuring points and outcome metrics.
- Provide a foundation for continues improvement of the supply chain process.

Therefore, since the availability of resources is limited this model must also improve resource utilization, efficiency of resource utilization and related cost.

4.5 The Methodology of the Research

The following are the methodology used in this research

1- Understand the supply chain management in manufacture and adapt it to the healthcare and defined the need

Healthcare is suffering of the un-efficient mechanism of controlling the supplies. The needs to learn from the experience of manufacture how to best organize and optimize the supplies. By understanding the manufacturing process, it can be adapted to be used in the healthcare setting.

2- Literature review

An extended literature review was conducted covering supply chain management in the healthcare and in the manufacture, emphasizing to the performance and the best way of modeling the system. The aim is to identify any related research been Carried out and to examine why healthcare supply chain lag behind the manufacture supply chain.

3- Define supply chain in the healthcare

The nature of the product in the healthcare is different than in the manufacture. It is affecting the human life, so assuring the availability in the right time, right place, and in the right cost is very essential. So, it is very important to identify all the element or players who participate of delivering this service to the patient.

4- Select the Chemistry Lab as an example of healthcare supply chain

Healthcare supply chain system is too complicated with many section, department, input, output and different parameters; it is beyond any study to model the entire healthcare supply chain. Therefore, a Chemistry Lab, which contains many healthcare supply chain activities and has a key position in supply chain, is considered in this study to develop a model to understand activities happen in the healthcare supply chain system. The Chemistry Lab of King Fisal hospital has been chosen to be the case study.

5- Create performance measures

A set of performance measures have been identified based on the literature review and been selected based on the wide rang of capturing the performance activates of all supply chain elements.

6- Define the novel approach of an integrated supply chain in healthcare; performance and cost

The research contributes the available literature in two ways. One is the contribution to the modeling and analysis of health-care problems within the supply chain context by providing a modeling platform. The second is to treat the problems encountered in health-care supply chain in an integrated manner by considering both relative performance and the cost issues together

7- Conceptual model

A conceptual model is developed to describe the general functional relationship among all components of the healthcare supply chain system.

The structure for modeling and performance evaluation for this type of supply chain through conceptualization is done in a hierarchical way, in order to define a detail level of the functions (Or activities) in each element.

8- Select simulation technique

Healthcare systems are usually too complex to be dealt with from an analytical point-of-view, especially when processes have characteristics like high variety and low quantity need, unexpected events, lack of planning, high cost, etc. In such scenarios, simulation comes up as a powerful tool for performance analysis and optimization.

9- Range of scenarios

In the effort to cover all possible circumstances that may effect the functionality of the reference model, fifteen different scenarios were designed and clustered into three major groups; the Test Demand Fluctuation which is affected by patient arrival pattern, Resource Reliability which is related to staff and equipment availability, and Inventory/Outsourcing of Supplies, as this involves the suppliers as well as hospital logistics department.

10- Results and analysis

Finally, analysis of the results found through the simulation experimentation is presented, which is based on the case study of Chemistry Lab of King Fisal Hospital in Saudi Arabia.

4.6 Supportive Research Tool

The tool to help building the model will be the Simulation. The reason is its ability to deal with very complicated models of correspondingly complicated systems. The healthcare modeling process is not a straightforward work. It takes a lengthy procedure to put all the components together and define the parameter interactions with each other to formulate what we can expect from the Healthcare modeling. So Simulation Model would be the best choice to model such complicated environment. Further, it is suitable for the dynamic model like health care, which frequently changes with the time; like number of surgical cases or the needed medication to reflect the ongoing activities. It also generates very detailed output in comparison to the mathematical modeling or other modeling tools such as artificial intelligence-based models or algorithmic models.

Another reason for simulation's increasing popularity is the obvious improvement in performance/price ratios of computer hardware, making it ever more cost effective to do what was prohibitively expensive computing just decade ago. Finally, advances in simulation software power, flexibility, and ease of use have moved the approach from the realm of tedious and error-prone low-level programming to the arena of quick and valid decision making tool.

4.6.1 Simulation in the Health Care

Over the past four decades, simulation has proven to be a significant tool in the modeling and analysis of a wide variety of health care delivery systems. Over 41 years ago, Fetter and Thompson (1965) as well as Robinson, Wing, and Davis (1968) applied simulation to patient scheduling and other hospital operational problems. These simulation modeling efforts have increasingly continued to apply in different parts of the healthcare systems and a few examples among many more are Jun et al, 1999; Weinstein et al, 2003; Issenberg et al, 1999; Wong 2004; McLaughlin et al, 2002; Bond and Spillane 2002; Murray et al, 2005.

Several characteristics of simulation make this technology uniquely applicable in the health care arena and especially for this research. The importance of the simulation can be viewed from the following points, which provide the basis of selecting simulation as a tool for this research:

1. Computer simulation models conform both to system structure and to available system data (Pritsker 1989).

   Simulation models emphasize the direct representation of the structure and logic of a system as opposed to abstracting the system into a strictly mathematical form.
   The availability of system descriptions and data influence the choice of simulation model parameters as well as which system objects and which of their attributes can be included in the model.

2. Simulation supports experimentation with systems at relatively low cost and at little risk.

Alternatives can be assessed without the fear that negative consequences will damage day-to-day operations, as would be the case if experiments were conducted directly on existing, operating systems.

3. Variation matters.

Variation has to do with the reality that no system does the same activity in exactly the same way or in the same amount of time always. If every aspect of every operation always worked exactly on the average, system design and improvement would be much easier tasks.

Variation may be represented by the second central moment of a statistical distribution, the variance. For example, the times between arrivals to a drop-in outpatient clinic near its opening time could be exponentially distributed with mean 5 minutes and, therefore, variance 25 minutes. Variation may also arise from decision rules that change-processing procedures based on what a system is currently doing or because of the characteristics of the patient receiving care. For instance, the examination time for a patient needing two sutures removed could be 5 minutes and for a patient receiving an annual physical could be 30 minutes.

4. Simulation experiment results conform to unique system requirements for information.

Using simulation, the analyst is free to define and compute any performance measure of interest, including those unique to a particular system.

Transient or time varying behaviors can be observed by examining individual observations of these quantities. Thus, simulation is uniquely able to generate information that leads to a thorough understanding of system design and operation.

5. Simulation is an extremely useful tool for modeling uncertainty.

   It is a major characteristic of illness (for example), which makes emulation so attractive for modeling health care system. It is also easy to contain probabilistic (random) components.

6. Modeling large scale and complex system.

   It is a suitable method for this kind of system. Determining in the health care how to allocate and schedule all resources can rarely be performed with the aid of a simple formula.

4.6.2 Solution as an Integrated Health Care Supply Chain Model

An integrated supply chain model is developed in the healthcare environment, in particular focusing on the Chemistry Laboratory. It focuses on relative performance modeling through cost and system performance modeling. It is not only giving particular benefit to reduce the cost or to improve the quality or to have an overall improved system, but a continuous monitoring mechanism is developed to measure all of these parameters for adjustment as required. Also, it provides a basis to know the effect of any change, like manpower or selling cost of a material, on the entire system. The developed model can be beneficial for other Healthcare services as well.

4.7 Research Contribution to Health Care Supply Chain

This research contributes the available literature in two ways. One is the contribution to the modeling and analysis of health-care problems within the supply chain context by providing a modeling platform. The second is to treat the problems encountered in health-care supply chain in an integrated manner by considering both relative performance and the cost issues together as described in section 5.5.

Integrated is referred to the connectivity of all elements so the variation in one of the element will effect the others instead of studying each element only individually.

In order to explain the complicated relationships between the system parameters such as test demands, consumable inventories, procurement, suppliers, time and cost, it is needed to have a properly built, integrated model, which must capture all the detail relationships, dynamics and the performance in a more understandable way, to identify the problems, and provide correct solutions. For this reason, there is a strong need to build a proper supply chain model in health-care system. This research seeks to fill this gap and answers the research questions posed by researchers and practitioners related to the performance of the healthcare supply chain system. Therefore, this research makes a considerable contribution to healthcare supply chain research by providing an integrated and detailed model as a basis to do all the needed analysis, (See Section 3.5.2 for the baseline discussion).

Another contribution of this research is in the cost calculation method used in healthcare systems. The cost calculation is always exaggerated considerably in health-care business and most of the time it works against the interest of the patients. This research uses an activity-based cost calculation method to calculate the cost in health-care, which identifies the cost sources as well as level of cost towards forming the overall cost.

Therefore, it is easy under this scheme to identify where all these cost items come from and what their levels are, which gives a considerable advantage to the analyst to tackle the problem and eliminate or minimize the unnecessary factors that contribute the cost.

This research has consolidated the cost calculation to the performance modeling so that it enables to measure the system performance along with cost which provides a strong basis to the analyst and managers to make better decisions in health-care industry considering all the relevant parameters.

CHAPTER 5

SIMULATION MODELING OF SUPPLY CHAIN IN HEALTH CARE

5.1 Introduction

This chapter presents a detailed description of the simulation model created to improve the efficiency of health care supply chain, in particular the chemistry Lab. Therefore, it is started with the detailed description of the chemistry Lab, its inputs, outputs, working mechanics, and the modeling with simulation.

Then the entire simulation model built is presented with a step-by-step approach to give the readers an insight into how and why the simulation model was created, its components, connections and functionalities. Finally, some sample output is presented to complete the modeling circle.

5.2 Why Healthcare Simulation Modeling

As simulation has been proven to be efficient in the healthcare setting, which was presented in section (4.6.1) in more detail, this section points out the reason of selecting simulation modeling for supply chain in healthcare?

Healthcare systems are usually too complex to be dealt with from an analytical point-of-view, especially when processes have characteristics like high variety and low quantity need, unexpected events, lack of planning, high cost, etc. In such scenarios, simulation comes up as a powerful tool for performance analysis and optimization.

The healthcare supply chain in this dissertation is following these simulation steps, which can be summarized as:

- Conceptual problem formulation and analysis;
- Data and information collection;
- Model building;
- Verification and validation;
- Experiment design;
- Experiment execution and results analysis;
- Refinement of experiment design;
- Final results analysis; and
- Process documentation.

As we learn from the manufacturing system and process, simulation has been used at several different applications. Objective varies, but based on past works, simulation is usually related to the following which make it most suitable approach for healthcare supply chain model:

- Inventory reduction - setting appropriate levels according to the production planning;
- Performance improvement;
- Making sure that new processes are tested and approved before their actual implementations;
- Reaching the optimal use of resources (machines, production lines, personnel, etc.);
- Obtaining better Logistics results within the supply chain;
- Use of a model to foresee the future behavior, that is, the effects produced by changes in the system or by new operations methods (Pedgen et al, 1990);

- Study of capacity usage, inventory levels, control logic, integration, sequencing/scheduling, bottlenecks, search for better layouts (Lobao & Porto, 1996).

Most of simulation tools are designed as interactive tools to be sued by a human planner not as real time decision-making tools, which are directly linked to control system to dispatch tasks. Simulation tools aid human planner to make a right decision by providing information. However, human planner should be able to interpret and modify the plan in order to achieve better supply chain performances.

Benefits of supply chain simulation are as follows:

- It helps to understand the overall supply chain processes and characteristics by Graphics/animation.
- Able to forecast; using probability distribution, user can model unexpected events in certain areas and understand the impact of these events on the supply chain.
- It could dramatically minimize the risk of changes in planning process: By what-if simulation, user can test various alternatives before changing plan.

5.3 Conceptual supply chain model in health care

A conceptual model is described as the general functional relationship among components of a system (Felix, 2003).

As defined by Ching (2001), the traditional Logistics chain is composed by six layers: suppliers' suppliers (sources), suppliers, processors (manufacturers), distributors (or wholesalers), retailers and consumers. The Healthcare SC structure mainly for chemistry Lab considered in this research has four elements based on the literature recommendations and the author expertness in the healthcare supply chain setting. (as reviewed in 3.5.2): Suppliers, Logistics Department, Chemistry Lab, and Patients. There are two main objectives in the development of a conceptual model in this thesis: 1) to create a platform for the analysis and study the performance of SC network and 2) to create a mechanism to calculate the cost of activities happen in a supply chain.

The goal of the conceptual model is to define all the involving elements, their functionalities, their interactions with the other system elements and generate a platform to create a software-based model, such as simulation or mathematical models.

The expected benefits from these modeling efforts are to have a way to reduce lead times, forecasting errors, inventory levels and cost and increase in service levels.

Figure 5.1 illustrates the structure of the proposed conceptual model of the SCM-HC of a chemistry lab. It is a hierarchical way structure in order to define a detail level of the functions (Or activities) in each element. This is to aid in having an accurate performance measure during the software simulation modeling presented in chapter 6.

There are four hierarchical levels in the structure of the conceptual model as shown in figure 5.1, these are:

Level 1: Represent the main element of the SCM-HC of the chemistry lab as defined above. The integration of this level is achieved in two ways. First, the information flows from patient to the rest of the supply chain. The Second is the flow of material from the supplier to the rest of the supply chain. The mechanism to organize such the flow of information and the order of the supply is presented in section 5.5.4 and figure 5.1.

Level 2: The second hierarchical level represents each element of SCM-HC which performs as intermediate modeling of each. Each element has its own structure (details of it will be in the level 3). It indicates the workflow among all sub-models and the requirements of each. It represents more detail than the first hierarchy.

Level 3: Detailed modeling of specific functions (intra-company) is designed at this level. A sub-model of each element has been structured. For patient arrival there is tests ordered represented as a demand and test's result represented as receiving detail explanation in section 5.5.4.1 The second element is the lab which is considered is the heart of the model consist of two areas, the first is performing the tests which have different structure of each test. The other area is storage of the components witch it has its own structure; this can be seen in section 5.5.4.2. Third element is Logistic which is responsible of ordering the supplies needed to perform the needed tests, also to receive them in the arrival component sub-module, the third sub-model is the storage of the components which considered as the main storage area. Section 5.5.4.3 has more detail. The fourth element is the suppliers, which has the structure of all suppliers in terms of providing the needed supplies as requested by the logistic of the hospital. The structure and explanation of this sub-model can be seen in figure 5.2 and section 5.4.4.4.

Level 4: This level represents the order and storage mechanism of the components for two of the supply chain elements, the Lab and the Logistic. It provides the information of all supplies (components) utilized by the lab.

In order to understand the proposed conceptual model the following paragraphs present a typical walk through scenario in a chemistry lab and it interactions with the supply chain. It is considered the Lab test results as tangible products that are performed (manufacture) in the Chemistry Lab. The patient is the consumer who request particular Lab test. In order to perform the test, supplies have to be available within the reach of lab; otherwise, no results could be given to the patient who is the primary client. So, the summary of the order flow is described below following the conceptual model's hierarchical steps.

Patient arrival, each patient has a demand pattern and there are different demand behaviors based on number of needed tests. Patient arrives to the Lab are assumed to follow an exponentially distributed inter-arrival pattern, which is believed to reflect the actual pattern.

Once the Lab receives the specimen, first the lab will make sure the availability of needed components to perform the test are all available, and the test is performed in its own sequence. The specimen is held at the beginning of the test in case of any needed component is missing, until the component arrives to the Lab storage.

Logistics on the other hand, will check if required quantity is available in their inventory, it will send the needed items immediately to the Lab. Otherwise, the Logistics sends whatever available and issue an order of the out of stock component by Procurement section to a particular supplier.

Supplier receives order for a component or item from the Hospital Logistics. If the supplier has enough inventories of required items it immediately dispatches ordered component to the Hospital. If the supplier does not have the quantity needed in stock (warehouse), a request of required component or item to manufacturers will take place. Once the components are ready, then they will be delivered to the Hospital.

Therefore, the proposed conceptual model structure follows the principle of pull system.

SC performance measures are mainly related to meeting demand (service levels), both at each stage and at the whole supply chain level.

The inventory control policy adopted, at this time, simply follows the following routine: when an inventory level is below the safety level, an order for the material to be purchased is placed. The optimum order size (quantity) and the safety inventory levels are calculated by the inventory policy adopted and ordered following the number of orders and order times.

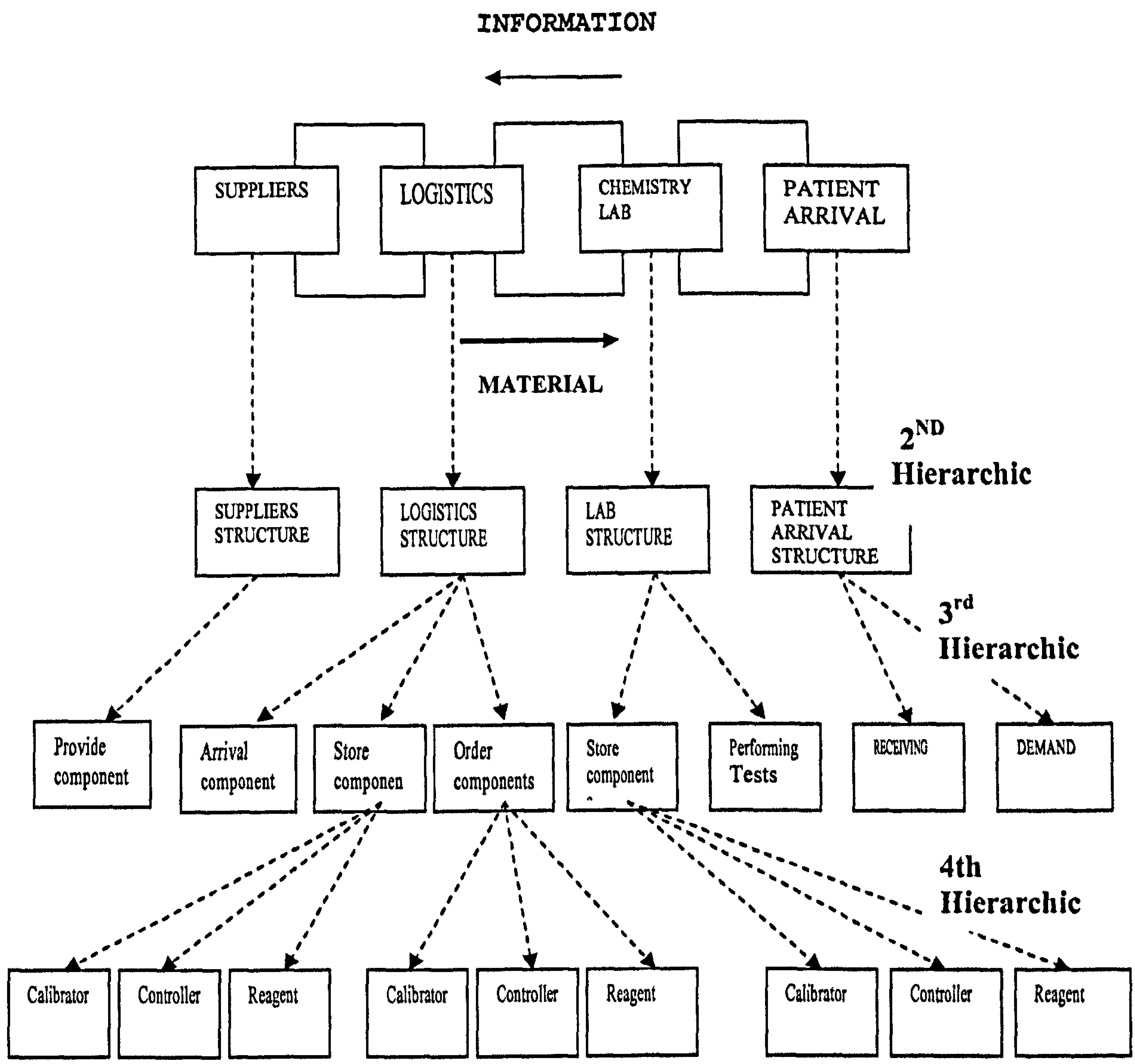


Figure 5.1 General Modeling Structure

5.4 Chemistry Laboratory

The following sub-section present the terminology used with the operation of the lab, the responsibilities of the staff working at the lab, the inventory policy adopted, and supplies requisition mechanism.

5.4.1 Definitions of supply chain terms in the Lab

Chemistry Laboratory is one of the most dynamic environments in health care. To better understand some terms used in communication with the other party in the Supply Chain the following section of the different used in the model:

1. Special Purchase Request (SPR): The mechanism by which items are stored by the warehouse may be obtained.
2. Signatory Authority Levels: Authorization levels are based on the total value of special purchase request (SPR).
3. Non-Stock Items: Items and supplies that do not meet the criteria for stock items. Purchase of these items shall be through the special purchase request (SPR).
4. Stock Items: Shall mean products for which a continuous need has been demonstrated and is approved for inclusion in the Materials Managements stock items catalogue set by the Product Evaluation & Standardization Committee and kept in the warehouse for immediate issue and use.
5. Supplies: Shall mean items, excluding equipment, which are required to perform Laboratory testing, i.e., testing reagents and calibrators, controllers and other consumables.

Appendix A shows all variables been used in the model with definitions.

5.4.2 Responsibilities

The four elements of supply chain representing the whole model (refer to 5.4.4), each element is a part of a department and has responsibilities to be distributed among the staff as follows:

1. Laboratory, which the primary function is to, performed the assigned test.

Section Heads and Supervisors (or designees) are responsible for maintaining an adequate inventory of required supplies to provide uninterrupted testing services at all times.

Laboratory Administration is responsible for rapid authorization of SPR's and to assist with the expediting process when the section has been unsuccessful.

Laboratory Supply Staff are responsible for the receipt and delivery of all supplies and interaction with the Materials Management and Purchasing Departments to troubleshoot delivery problems in a timely manner.

2. Logistics which is the function is to provide the needed supply equipment which it is underneath; Purchasing, Receiving and Inventory Controller.

The Purchasing Department is responsible for negotiating, awarding, and generating Purchase Order (PO).

- Buyer, buy the needed supply
- Material Controller, maintain the inventory
- General Section, transferring the items section separately.

5.4.3 Inventory Policies Adopted

All Laboratory sections (i.e. Section Head and Supervisor) are responsible for developing an effective inventory system to ensure an adequate quantity of supplies is available to provide uninterrupted service at all times. The system utilized shall include the following elements:

- A list of all required supplies
- Minimum and maximum supply levels to be maintained. Consideration is to be given to the order processing and expected delivery times when defining the minimum and maximum levels
- A requirement for periodic physical inventory to ensure accuracy of calculated inventory levels
- A method for obtaining the necessary stock items
- A process for initiating SPR's for non-stock items
- A system to track, monitor and follow-up the status of SPR orders and PO's

Supply inventory should be rotated to prevent any unnecessary outdating of supplies.

The inventory control policy: when an inventory level gets lower safety inventory level an order for the material (component) purchase (or manufacturing) is placed. The optimum order size (quantity) and the safety inventory levels are given by the decision-maker. At The Chemistry Lab, two types of orders exist: purchase Orders for the purchasing of components from Logistics and suppliers, and Test Order (production orders), to perform the test (different TEST types are considered, and each TEST is made of different combination of components).

Regarding the patient request, each patient has demand patterns. The information been gathered for one year, according to actual data.

A supplier receives orders for a component from the Logistics. If it has enough inventories, it immediately dispatches the ordered components to them. If the supplier does not have the quantity needed in stock (warehouse), it will then manufacturer the component and then delivers it to the hospital. In this case, the supply chain service level and cycle time will be deteriorated.

If the Chemistry Lab has enough component the test will be performed and send to the patient file, so the order will be closed. On the contrary, the order remains open until the Lab performs the test and sends it to the patient.

When the Lab does not have enough inventory of the needed component to meet the needed demand the Lab will dispatch appropriate orders to Logistics, which they will check their inventory whether the items available to be send directly to the Lab or not, than an order initiated to a proper supplier to provide the components. As soon as the Chemistry Lab receives all of the needed components from the Logistics, a signal is sent to initiate production. The test then will be performed and sent to the file.

Therefore, the proposed simulation structure follows the principle of pull production, however. SC performance measured are mainly related to meeting demand (service levels), how quickly this is done (cycle times), and inventory levels, both for at a stage and at the whole supply chain.

5.4.4 Supplies Requisition Mechanisms

Any supply needed the equipment to be used in the Chemistry Laboratory should go through a certain path as shown in the Figure 5.2.

Once the request takes place by the originated section in the Laboratory, it will go to Logistics with identification code whether the items needed is a stock or non-stock items.

If it is a stock item, it will be ordered internally

- Supplies are obtained from the warehouse and delivered to the Lab sections by the Laboratory supply staff with a copy of the list of items requested/delivered.
- Section staff must check the items received against the list to confirm accuracy of the delivery.

If it is non-stock items if requires a special purchase request (SPR) (external requisition).

- Determine if the required item is currently in the Purchasing database. If not the item must be standardized by completing a request for Standardization form. The Standardization form must be signed by the Supervisor and initialed by the Section Head.
- Submit the completed Standardization form to Laboratory Supply staff for processing.
- Enter the order in the Oracle system and include information, i.e. item code, quantity, required delivery dates (if it is to be a standing order), etc.
- Forward the order for the required approval signatures.
- Periodically check the status of the SPR and expedite if necessary using Expedite Form.
- Prior to signing for receipt of supplies from the Receiving Section of Materials Management, the user must check the goods received against the attached copy of the Purchase Order to verify the accuracy of the order and whether the items are received in full or partial delivery. Any discrepancy should be reported immediately

to the Receiving Section of Materials Management prior to signing for receipt. Fig 5.3 gives a general relationship between purchasing, receiving, vendors, and the chemistry Lab.

- Any request, revision, adjustment or cancellation, in an existing SPR or PO, must be in the form of a speed letter or memo. Justification for the change must be included. The speed letter or memo must be signed by the Supervisor, initialed by the Section Head, and transmitted to the Laboratory Administrator (or designee) for signature. The completed speed letter, or memo, is returned to the originating section for forwarding to the applicable department for necessary action.

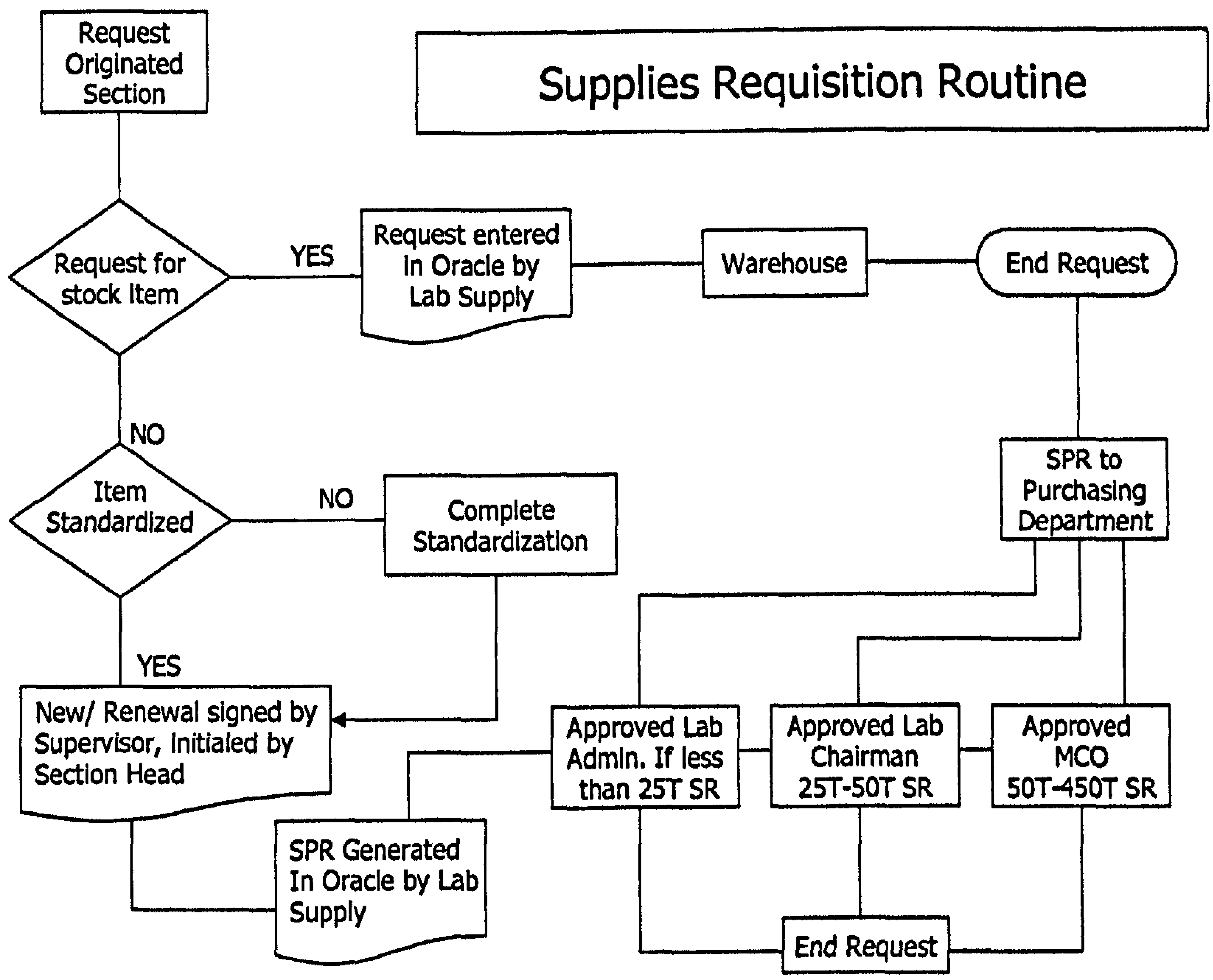


Figure 5.2

Bird's Eye View on the present relationship between Logistics (Receiving and Purchasing), Vendors and Laboratory

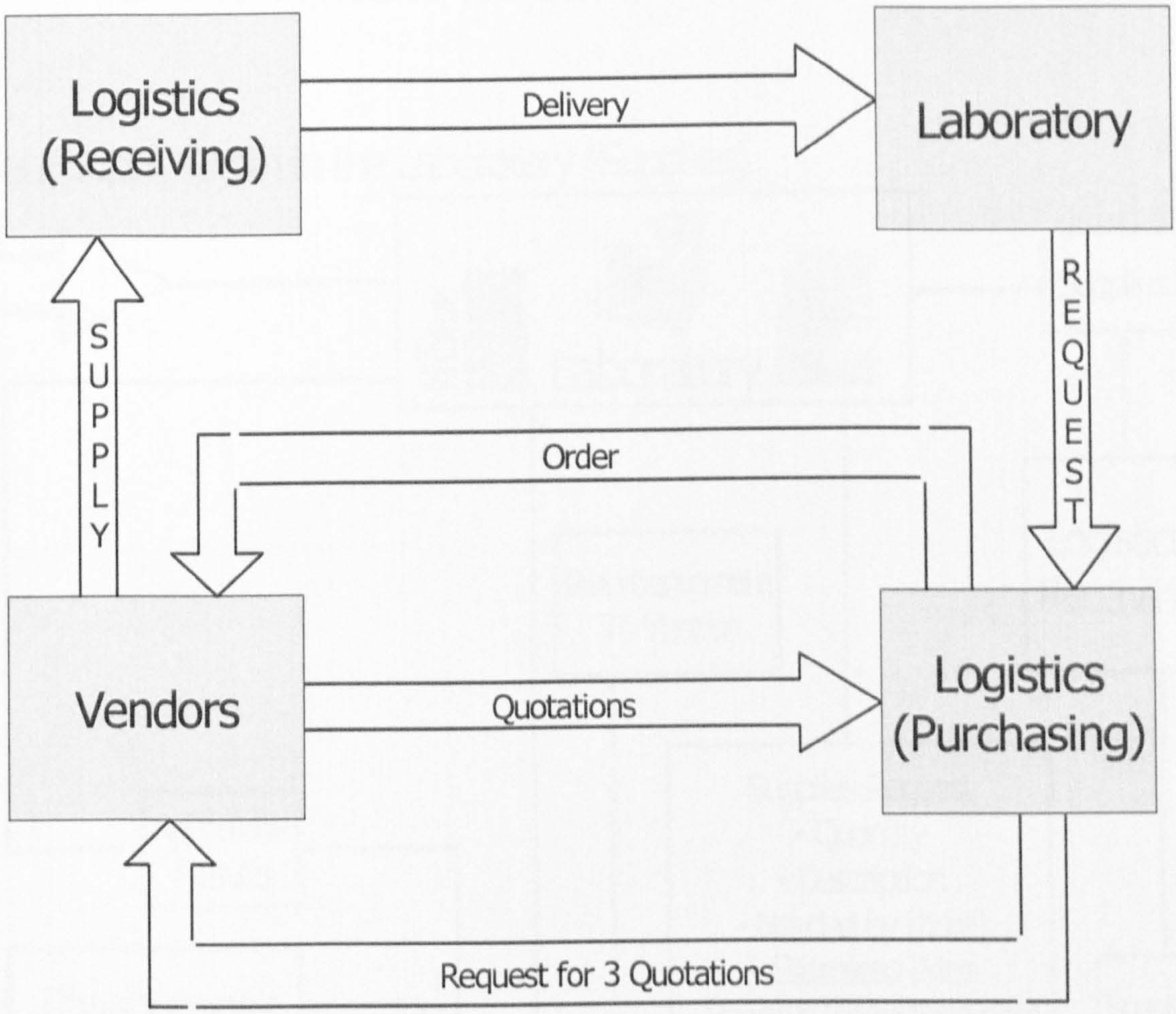


Figure 5.3
Bird's eye view on the present relationship among Logistics (Receiving, Purchasing and Inventory), suppliers and chemistry Laboratory

By focusing into the chemistry Laboratory supply or stand in Figure 5.4 it indicates relationship among all parties concerning the equipment and supply which is consists beside the Lab finance and they will pay to the supplier (vendors) according to the purchase ordered by Logistics and accepting from the end-user which in this case is the Laboratory. It also indicates the needed information between Logistics and Laboratory.

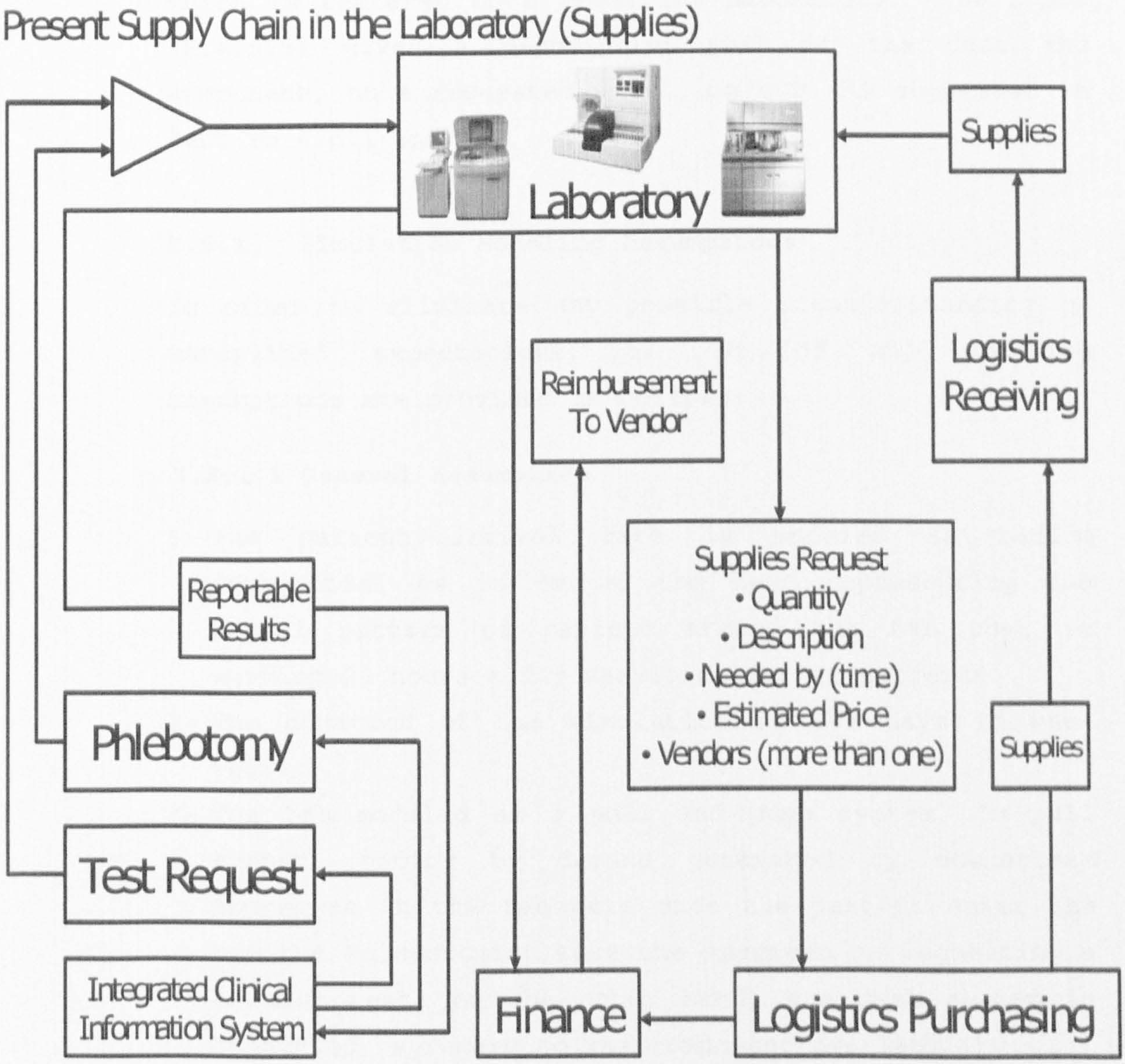


Figure 5.4

The relationship among all parties concerning equipment and supplies

5.5 The Simulation of the Healthcare Supply Chain Model

The following is the detailed description of the simulation model built for the health-care. Supply chain, which is centered on a chemistry Laboratory. Flow chart (Fig.5.5) gives a description path of the test and component, once requested until log out. As suggested in section 4.6.1 and 5.2.

5.5.1 Simulation Modeling Assumptions

In order to eliminate any possible misunderstanding or unrealized expectations, a list of all modeling assumptions are provided as follows:

5.5.1.1 General Assumption

1- The patient arrival rate is modeled as random exponential as it formed the best representing the actual pattern of patient around the Lab that is working 24 hours a day servicing out/in patients.
2- The duration of the simulation is 365 days in one-year?
3- The Lab modeled as a pull and push system. In pull system, entity by demand generated by downstream processes in the Lab case once the patient enter the Lab the Phlebotomist take the specimen as requesting a certain test, on the other hand, the push system is conducted is regard to the component availability.
4- Expenses data in the model are based on how the average for staffing, in order to ensure that the yearly salaries remain consistent regardless of the simulated time, the cash flow portion of the model user date converted into hourly averages instead of basing them by case. However, resources like equipment are identified by cases, as busy or ideal.

5.5.1.2 Patient Arrivals:

5- Inter arrival times are assumed Exponential with mean 1 arrival per minute.

6- Upon arrival of the order, test type decided before the patient arrives the reception.

5.5.1.3 Lab:

7- Each specimen is treated separately, one after the other.

8- Test type has its own line. Two tests of two types are not done in one process, although they may share some resources.

9- Unit of component is a quantity enough for one use only. That is one test for reagents, one control process or one calibrations process.

10- First component called reagent, one reagent process is performed every test

11- Second component called control, One control process is performed every 10 tests?

12- Third component called calibrator, One calibration process is performed every 20 tests?

13- It is assumed that a technologist does not wait a process if it takes more than 15 minutes long. Instead he puts the specimen (a process that takes 5% of the original process) and leaves it until it's ready. He then transfers it to the next process (a process that takes 5% of the original process).

14- It is assumed that inventory control in the Lab is a process that is run separately from analysis and in parallel with it. However, inventory and chemical analysis both interact and affect each other directly.

15- It is assumed that when order is issued, no other order is issued until receiving the old order or no response from the supplier.

5.5.1.4 Logistics

16- If the Lab orders a certain material that is not available in the Logistics, the Logistics sends whatever available and issues an order to the supplier. Otherwise, an order is issued if it is found that inventory is below safety level during a periodic check

17- The purchasing department decides which component to order from which supplier.

5.5.1.5 Suppliers

18- There are only 8 suppliers

19- A supplier is assigned 2 Reagents, 2 Controls, and 2 Calibrators

20 - A supplier can provide any quantity of any component it is assigned (except in the unreliable supplier's scenario)

21- The internal system of suppliers is not of interest to this model. So it is represented by the resulted delay.

5.5.2 Data Collection

Data collected over a period of one (1) year by Lab Technologist and Administrators interview of the clinical information system, these data mainly consisted of patient arrival time, specimen process, test results process, component process, from the need to be purchased. An interview with the staff manager provided the standard staff scheduling time and requirements. Data collection and the Lab based on 432523 specimens per year and all requirements from staff, suppliers, utilities, etc. This information was gathered form the Chemistry Laboratory of King Fisal Hospital, as it is the case study of the research.

5.5.3 Arena Simulation Environment

The simulation language, Arena, was used to model the Lab. Arena is a Windows-based platform that is popular and widely used to its tremendous flexibility and ease of use.

Arena has been used to model everything from manufacturing work cells to complex interactions in an emergency room.

Furthermore, Arena's Input and Output Analyzers provide excellent tools to fit input probability distributions based on actual data and analyze of the clinic provides a visual representation of the Lab, and analyze the results format. As discussed in 4.6.1.

One of the major contribution of using Arena is the capability of continues calculating the accumulated cost for each test as can be seen in the scenario based analysis section under the cost of test.

Arena is a development of the special-purpose simulation language SIMAN, which is a powerful, general-purpose simulation language written for modeling discrete, continuous or combined systems. The Arena simulation package is an extension of SIMAN in that it supports hierarchical modeling. Thus, Arena combines the ease of use found in high-level simulators with the flexibility of special-purpose simulation languages. Arena is also compatible with general-purpose procedural languages like Microsoft Visual Basic, FORTRAN and C.

Arena provides a wide range of modules that can be combined into a flowchart to build a variety of simulation models. Arena is arranged in the familiar Microsoft Windows format, with drop down menus, toolbars and icons. The system under study can be considered as containing physical elements such as machines, workers, transporters, storage and part flow. Each of these physical elements can be represented by a module icon, which can be selected, dragged and dropped onto the model window. When linked, these modules form the system model. In some cases the system will have logic flow, which is connected in a similar manner. Models are combined with an experimental component that specifies the experimental conditions such as initial conditions, length of run, and type of statistics to be gathered and part routes (Kelton et al, 2004).

As the simulation runs, Arena keeps track of the response of the system. Arena provides a reporting system that compiles simple output summary report and is capable of producing high-level table and graphs of user defined system data. Statistics can also be automatically reported in other file formats, including HTML, Word and Excel.

5.5.4 Structure of Simulation Model

For the modeling of the proposed structure in the simulation software ARENA, a set of global variables needs to be defined as exemplified at Appendix A.

The ARENA tool has been used to simulate the SCM-HC of the chemistry lab covering its main elements namely suppliers, Logistics, chemistry lab, patients arrival

This model covers four elements of the health-care chain system, namely suppliers, hospital Logistics department, chemistry department, patients.

The following is the step-by-step hierarchy of the supply chain-working mechanic, which is reflected in the simulation model built. The explanation will be provided for individual component of the model along with its functionality as well as its integration with the other elements of the simulation model. Figure 5.5.

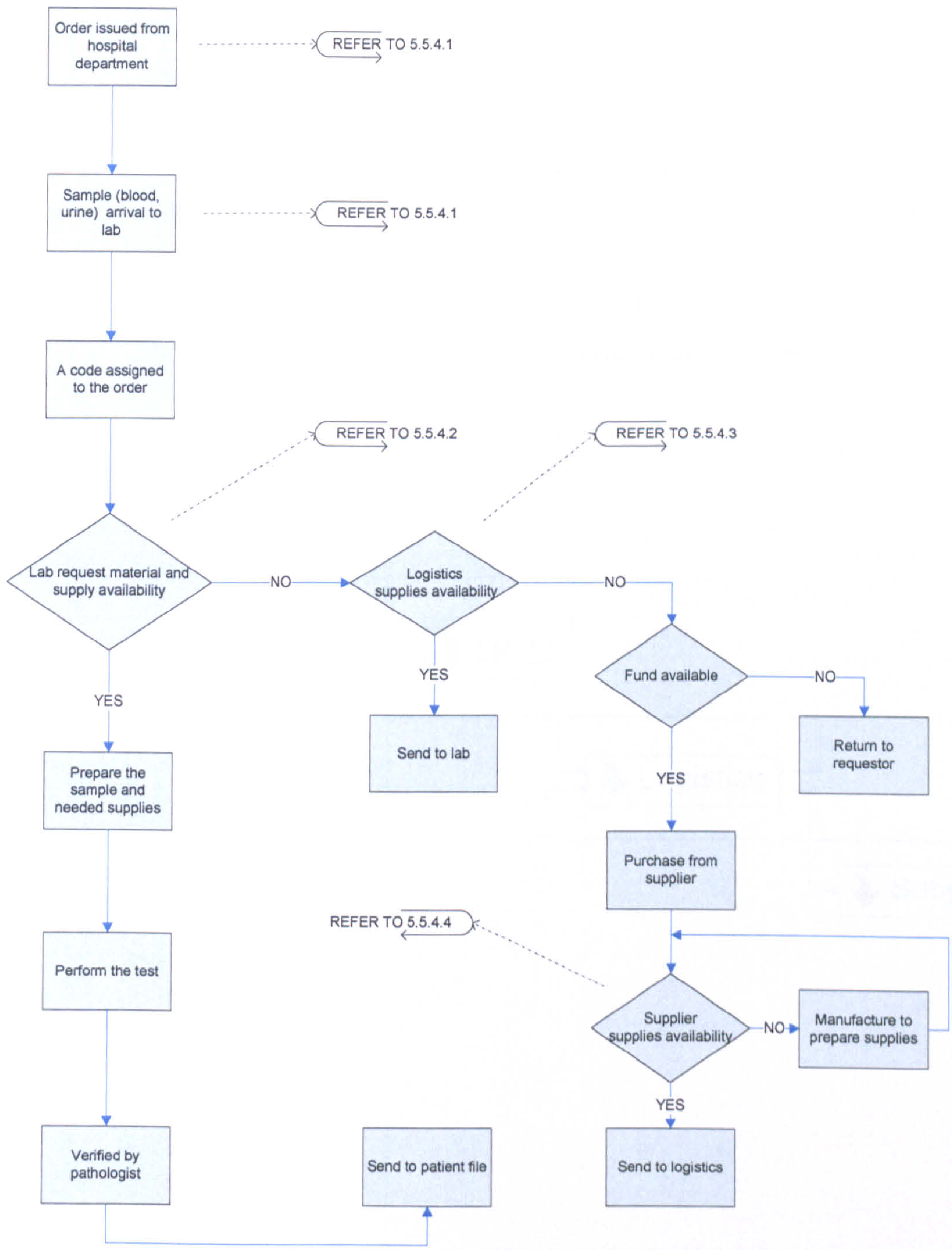


Figure 5.5; Flow chart representing the path of test and needed components.

To illustrate how the model works the following: Section including the figures, which been taken directly from the simulation program, it shows how its hierarchical from the simulation program, it shows how its hierarchical levels were implemented, through the use of sub-models, as well as the interlink and specific and managerial functions of Suppliers, Lab, Logistics and patient Figure 5.6 presents its model for the first hierarchical level.

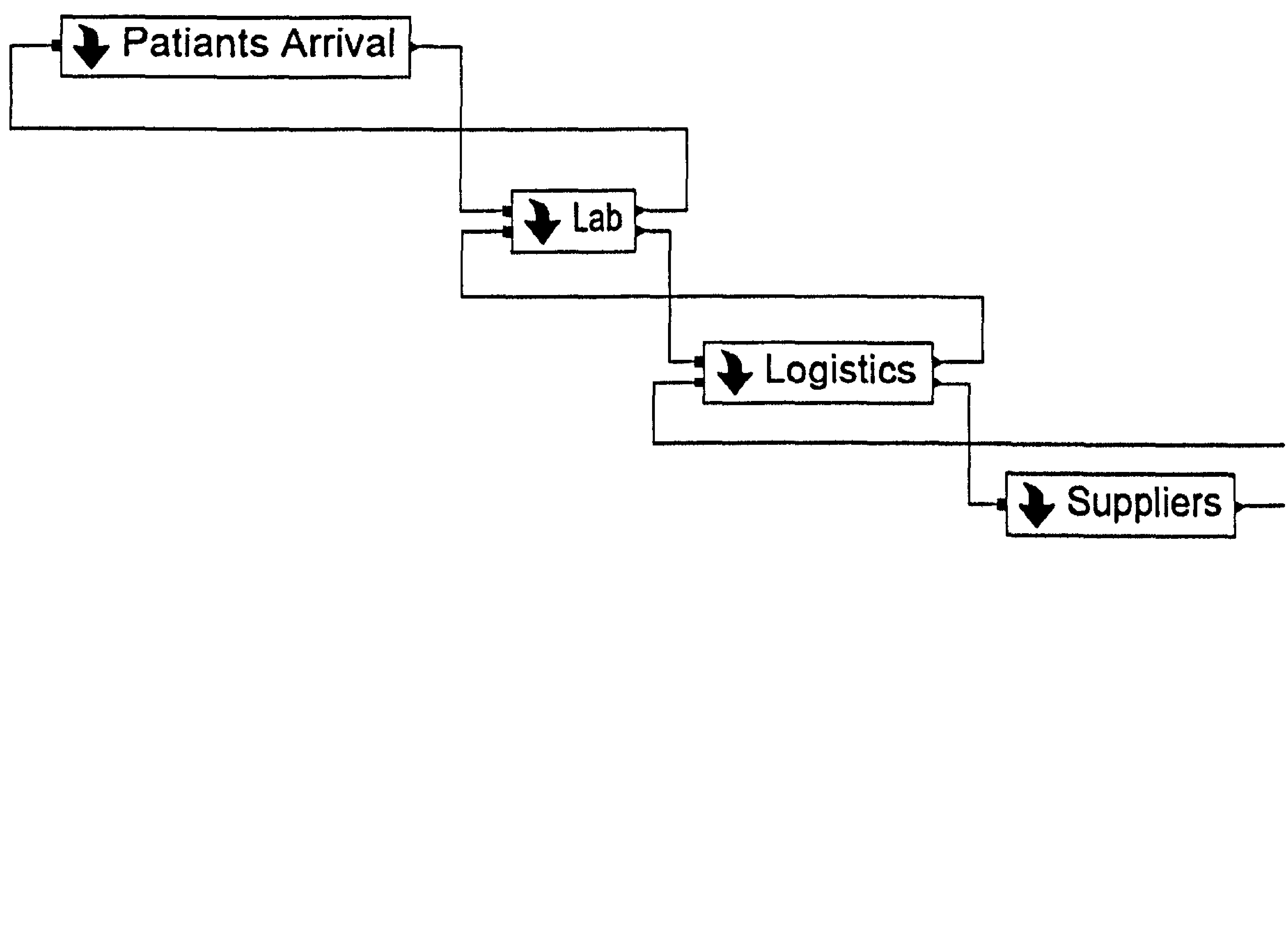


Figure 5.6 **First hierarchical level of the Model**

It shows all four blocks connected by lines with arrows, the right to left arrows, indicates order signals and left to right arrows components or test results delivery. On the entry points are represented by little squares on the left side of the rectangles, while, exit points are triangles on its right side for the sub-model rectangle. In the case of Lab, sub-model two pairs of entry-exit points exist, the upper pair regards orders from the patient and result of the requested test related to patient block while the bottom pair representing orders to Logistics for components then to be received to the Lab once available, as well as its order from Logistics to its supplier and getting the components from all supplier to the Hospital Logistics.

The following is the detail structure of healthcare supply chain model's element:

5.5.4.1 First element: Patient Arrival, Tests Request

The input of the module is the results of the tests; they are stores in the Hold block, "Keep in Record" to avoid losing cost data while, disposing entities, to be stored in the electronic patient record, called; Hospital Information System, Physician can have access to it at any time also, to compare it with the previous tests.

The output of this module is the start of the whole model; it represents arrival of the patient to the Lab which inter-arrival exponentially distributed with mean 1 arrival per minute.

Each patient is assigned a test types as requested by his physician, at the Reception, Phlebotomists take the blood and send it to the specific Lab section. The entity is assigned a new type; a specific test name. The distributions of tests based on the actual data have been gathered for one year.

Lab is capable of doing different tests, to meet the different departments' demands. More than 100 different types of tests are done in the Lab but 16 different types of tests are considered in this study.

The requests (orders) come to the Lab randomly following an exponential distribution with an average of 1 minute.

The tests are varies in term of arrival, it follows a certain percentage from the total number of test which is 432523 according to the Table 5.1. It is also represent the total number of each kind of test.

When a tests request arrives to the Lab, the request is assigned a unique order number or code until it is processed, reported and delivered to the requesting department, then the case is closed and archived.

Table 5.1 Represent all Tests with the percentage of arrival

And the number of tests

S/N	TEST	PERCENTAGE OF EACH TEST	NUMBER OF TESTS
1	Core C. Glucose	29.5	127594
2	Core C. Ketone	1.4	6055
3	Core C. Osmo	4.3	18598
4	Core C. Urine Protein	13.47	58260
5	RIA 1.25 Vitamin D	2.28	9861
6	RIA BHCG	0.3	1297
7	RIA Folate	3	12975
8	RIA Homocytine	0.6	2595
9	Special c. AAT	1	4325
10	Special c. G6PD	0.4	1730
11	Special c. HBAIC	21.5	92992
12	Special c. VMA	0.25	1081
13	TDM CARB	5	21626
14	TDM FK506	16	69203
15	TDM MTX	0.3	1297
16	TDM Opiates	0.7	3027

5.5.4.2 Second Element: The Chemistry Lab

Consist of two parts: (1) performing tests (2) storage of components

1) Performing Test

The input consists of two; one from reception, which is a specimen, comes from the patient module and the needed components from the Logistics Department. On the other hand, the output is the results of Lab test which to be kept in the patient records, also another output to Logistics as components orders.

The specimen arrives from reception then distributed to their test lines. When a specimen enters the particular test line, then this is giving the path of all tests, also, the storage control in the Lab; it is representing the second hierarchical level of its supply chain structure. The system in the beginning makes sure the needed component to perform the tests is available, then that test to be performed in its own sequence.

The specimens are held at the beginning of the test if any of the needed components is not available, till it arrives to the Lab storage. If all components are available one unit of reagent (Re) is removed from the Lab storage, and a counter is increased by one. It is known by a default to do control (Co) every 10 tests, and a calibration (Ca) every 20 tests.

After the test is done the results are reviewed and verified to be sent to its patients records. Some results need a Pathologist or senior to review them to make sure of correct results, and analyze the result comparing with the patient file and offer advice; they are indicated in the model by a certain percentages taken from the Hospital history. The 3rd hierarchical level (Figure 5.1) will be presented below showing all kind of tests has been performed.

The Chemistry Lab is a major Section in the Department of Pathology Laboratory Medicine. Its value is the measurement and analysis of blood and urine Chemistry. All tests description with Arena Graph can be seen in Appendix B.

a) Core Chemistry Section: It is measuring General Chemistry assays, Renal Profile, Hepatic Profile, Lipid Profile, Cardiac Profile, Osmolalities, and Urine Chemistry.

1- Glucose Assays 1/20: Checking for glucose level for diabetic and non-diabetic patient.

2- Ketone1/1: It is one of the glucose derivatives used for diabetic patient and newborn babies.

3- Osmo 1/1: It is used as an indicator for hypertension and measuring osmolality after dialysis.

4-Urine Protein 1/7: It is used as an indicator for kidney function.

b) Radio Immunoassay Section (RIA): It is testing Hormones, Tumour Markers, Radio-isotopic assays, Cardiac markers and Anemia markers.

1- BHCG1/14: Tumour marker and to determine pregnancy.

2- Folate 1/1 (Red Cell): Anemia marker.

3- 1.25 vitamin D ¼: bone development marker.

4- Homocystine 1/1: Cardiac risk marker.

c) Special Chemistry Section: It is measuring Special Proteins, HbA1C, Caffeine, Sweat chlorides, and Extensive menu of miscellaneous manual assays.

1- Alpha-1-antitrypsin: This assay is useful for work-up of individuals with suspected disorders such as familial chronic lung disease.

2- HBAIC: Useful in evaluating the long-term control of blood glucose concentrations in diabetic patients.

3- VMA (Vanillylmandelic Acid): Useful for screening fro vascular tumour.

4- G6PD: G6PD deficiency is the most inborn error or metabolism, effecting over 100 million people with varying degrees of hemolytic disease.

d) TDM Section: It is measuring Therapeutic Drug and Monitoring Drugs of Abuse.

1- Carbamazepine (Carb): 1/11: Anti-convulsant marker

2- FK506 1/1: Immuno-suppression for liver and kidney transplant.

3- Methotrexate (MTX) ½: Inhibit the development of neoplasms cells, which is related to cancer.

4- Opiates 1/7: Drugs of abuse for psychiatric patients.

2) Storage Control in the Lab

The Chemistry Lab stores small quantities of the 16 Reagents, 16 Control and 14 Calibrators. It is made to make the needed components instantaneously ready to use for the tests. The system in a periodically manner, check the level of inventory for each component, and issue an order to the Logistics of the needed components (that is to set the entity type, order size, and component type and set X ordered to 1), when the new shipments arrive, the Lab storage system store these components in Lab storage (that is to add the order size to x Lab storage and set x ordered to 0.

5.5.4.3 Third Element: The Logistics

The inputs of the Logistics modules are two: the first one, the orders from Lab storage system, the second are the component arriving from the suppliers.
There are two major inputs for the Logistics module, these are, x, and y.
The works in Logistics is consisting of two parts:

1. Order Processing
Once the order arrives from the Lab the system checks if required quantity is available in Logistics inventory, it is available, it will immediately send to the Lab. Otherwise, the Logistics send whatever available and issue an order of stock component (that is set entity type to component code, set order size and set Log ordered x variable to 1), to Purchasing Department to purchase the needed component. It is consist of two sub-models:

I- Component Availability

A) Reagent, Controller, and Calibrator control in Logistics

Identifying all reagents, differentiate which available to be sent to the Lab, out of stock reagent will make sure ordering to purchasing. If there is a quantity which less than the order for the Lab, it will be send to the Lab in the same time make a request to Purchasing Department.

B) Periodic Check

Logistics periodically check the inventory level of each component, and issues an order of Purchasing if the level is below safety level the order issued in the Logistics storage is assigned a type and send to the Purchasing Department.

II- Purchasing Department

Every request enters this department take the following processes:

If the component needed is standard (it have been order before which is approved to be used in the Hospital), it will go to renewal block. Otherwise, it is standardized and then sends to removal. From renewal it goes to generate an SPR, which stand for Special Purchase Request then to approve staff according to the approval authority, then to be check if there is enough fund for this order. If there is no fund, the request will be sent back to the SPR generator, but if the fund is available it will be decided from which supplier to order the component from, then finally, the order go to Procurement which will issues the purchase order and send it to corresponding supplier.

2. Component arrival and storing

When the Logistics receive a shipment from the supplier it will directly stored according to the type of the item, Reagent, Control, and Calibrations in log storage. The cost of the storage item is displayed, and the inventories of all components are displayed also.

5.5.4.4 Fourth Element: The Suppliers

This module has eight suppliers, which supply 46 different types of components to the Chemistry Lab through the Logistics Department.

When orders reach the suppliers block, it is decided to which supplier should be sent to, according to the user (Hospital) defined entity attribute call "My Supplier".

As there is no manufacture in Saudi Arabia for this component the supplier imports the items once is not available. Manufacturing time plus transporting the items to the supplier then to the requestors, which is the Hospital, take a long time, so it will delay the whole process

CHAPTER 6

ANALYSIS OF HEALTHCARE SUPPLY CHAIN

6.1 Introduction

The aim of this chapter is to analyze the results found through the simulation experimentation, which is based on the case study of Chemistry Lab of King Fisal Hospital in Saudi Arabia, concentrating on 16 different kinds of tests (Table 5.1) as explained in section 5.5.4.1. The experimentation was carried out through a number of designated scenarios, each targeting a specific problem within the healthcare supply chain, like shortage of supplies, unexpected breakdown of equipments, and instability of patient arrival rate. The scenarios are run for a one-year period to observe all the variations as well as developments within the system so that any potential problem related to run-time especially for short period runs would be eliminated.
The analysis is based on two sets of performance criteria. The first set of criteria, called Primary Performance Criteria (As defined in section 4.2 which is the aim of this research), consists of lead-time, throughput, WIP, inventory status, material flow time, and cost of test. The cost analysis of each test and for each scenario covers all resources participated in performing the tests. The second set of criteria, which is called Secondary Performance Criteria, consists of equipment utilization, staff utilization, queue size, and material order size.

The healthcare simulation model will be utilized in two ways. The first, as a reference model which is assumed to have an ideal environment, and the second, to be exposed to different set of scenarios to extract the result and compare them with reference model's results to analyze the output and come up with suitable recommendations to enhance the efficiency of healthcare supply chain.

6.2 Reference Model

Based on the conceptual model (section 5.3) a simulation model for the supply chain in the healthcare concentrating on the chemistry lab been created as a reference model which is the first stage of simulation based on ideal criteria's. All elements of healthcare supply chain are covered, starting from patient arrivals, Chemistry Lab, Logistic, and the suppliers, as stipulated in Figure 5.1. This is the so-called standard model, which assumes all the components of the healthcare supply chain system behave perfectly in Chemistry lab. It is assumed that there is no problem experienced in material or information flow.

This model is somewhat of an idealistic model and no short-term variations occur. For example, when an order is received by the Lab, it was assumed that all the requested materials, consumables equipment and staff are available. There may be a moderate level of queue at times that demand is high, in case of any missing material or shortage of consumables.

Then inventory department keep enough stock so that the required material or consumable was supplied in a reasonable timeframe to perform the task. It is assumed that there was no equipment breakdown, staff or inventory shortages, so that all the functions were performed normally within a reasonable period.

The performance of this base model is measured using primary and secondary performance metrics and is used as a reference to compare all the scenarios based model's output to measure the effects of different variations on the supply chain behavior.

6.3 Scenarios of the supply chain

The scenarios that have been simulated are designed to capture the dynamics of supply chain activities centered on a Chemical Lab within a large local hospital. In the effort to cover all possible circumstances that may affect the functionality of the reference model, fifteen different scenarios were designed and clustered into three major groups which are representing the most important factors affecting the efficiency of the supply chain, according to the literature recommendation and the healthcare supply chain experience of the author. Each group has different scenarios to cover all possible future problems and demand and to see how the Chemistry Lab will react accordingly. The first group is the Test Demand Fluctuation which is affected by patient arrival pattern, Resource Reliability is the second which is related to staff and equipment availability, and the third is the Inventory/Outsourcing of Supplies, as this involves the suppliers as well as hospital logistics department.
The clustered scenarios listed as below:

Group A: Test Demand Fluctuation

- Low customers
- High customers
- High demand
- Some tests are lower
- Some tests are higher
- Longer lead time

- Special line for emergency cases

Group B: Resource Reliability

- Unreliable equipment
- Unreliable supplier
- Shortage of staff
- Repair is longer

Group C: Inventory/Outsourcing of Supplies

- Continuous review
- Imax policy
- Batches policy in purchasing
- No funding

6.4 The Framework for the Analysis

The analysis of the simulation data has two dimensions. The first dimension is scenario-based and the findings from the scenarios are compared with the Reference Model findings and are presented in the following section. The second dimension is the comparisons of scenarios findings with alternative scenarios based on primary and secondary performance criteria. The aim of these comparisons is to analyze the output generated by different scenarios and come up with suitable recommendations to enhance the efficiency of healthcare supply chain. As stated in Section 6.1 it will help identifying the weakness and bottleneck in each element of supply chain, which would negatively affect the overall system performance, measured through primary and secondary performance metrics. The results are extracted from each of the simulation runs and presented in a table format for each performance measure. An analysis has been conducted for all fifteen scenarios but three scenario's results are demonstrated in this chapter as they are most representing each group, while the remaining twelve scenario's results and analysis can be found in Appendix C.

6.5 Performance Measures of the Reference Model

The performance measures of the reference model as well the scenario based models are done through primary and secondary performance metrics. The analysis of reference model and scenario-based models will provide a real basis for the decision making needed in supply chain system. Further, it will give all the indications whether the supply chain is efficient or not. It also indicates the potential problem areas and possible solutions. The following sub-section present the simulations of the performance measuring metrics based on the Reference Model. The simulation's results are presented in tables that are going to be used to compare them to the results of the 15 scenarios presented in this chapter and in Appendix C.

6.5.1 Primary Performance Measures for the Reference Model

As stated previously the primary performance metrics are lead-time, material flow time, throughput, inventory status, WIP, and cost of test. The data in the following tables for the reference and the scenarios model are the result of the simulation model, extracted from Arena software and stipulated in a table format for easy analysis and comparison, the following analysis is based on the above performance metrics. Each of the following sub-sections will present first an explanation of the data in the table, secondly; shows how significant the data to the healthcare supply chain and the third will be the relationship with other performance metrics to come up with a unique conclusion, an example of Glucose test will be presented in each performance metric.

6.5.1.1 Lead Time for the Reference Model

The lead time is the time measured once the test order take place until is delivered to the customer, which in this case; once the Chemistry Lab receive the test order through performing the test until posting the result in the hospital information system. The model assigns a unique identity and a start time for each order, which is the start time for lead-time measure as illustrated in Table 6.1. The unit of measure is hour.

The Table 6.1 is consisting of three columns, the first which indicate all the tests. The second is the minimum value for each particular test, the third is indicating the average value for each one, and the last column shows the maximum value. The average lead-time values in the third column are the base number for the comparison. The minimum number of the average lead time is 41.8 hours and the maximum value is 109 hours. It can be easily realized that the variation from mean value is between 41.8 hours and 109 hours. This indicates that the lead-time follows a narrow/wider bond. This can be explained with the 16 different types of the tests. Although these 16 tests mostly sharing some of the same resources using different consumables and materials each takes a different time to accomplish according to the length of performing the test and availability supplies and other resources.

The longest time taken to do a required test is for Test # 16 (TDM Opiates). It is understood that because the test is performed manually without using the analyzer, the results take a longer time to complete. The information gathered from Table 6.1 will be used as basis to compare with other scenario.

The lead time providing a very useful information to analyze the healthcare supply chain system, it is a first step to know the existent of the problem in the supply chain or not, if there is a problem as along lead time the other performance metric like throughput, material flow time, or staff and equipment utilization can narrow the reason and identify the bottlenecks.

The Chemistry Lab is performing 432523 tests per year for the 16 test. Glucose as an example is the highest percentage with 127594 tests per year (according to Table 5.1). In average the test takes 102 hours to produce the result and to be appeared in the patient's file, it needs component to start with as in Table 6.2,3,4 in section 6.5.1.4. The time to perform the test is only one hour, this is the result of subtract the lead time in Table 6.1 and the queue size in Table 6.12 which indicate the waiting time for each test. This information lead to an average of waiting time 101 hour for the Glucose test, the reason for that can be unavailability of resources like equipment and staff or mishandling the supplies, resulting unavailability of needed components. By reviewing the sections 6.5.2.1 and 6.5.2.2 which are equipment and staff utilization, it appears the low utilization in both resources 12.33 % for staff and 2.3 for equipment. The resources as above are adequate to handle the entire load without delay, so the only reason of the long waiting time is the mishandling the supplies, on the other hand according to the section 6.5.1.3 the throughput for the Glucose tests is 29.1 test per hour this can be also examine with the different scenarios in section 6.6.

Table 6.1
LEAD TIME FOR EACH TEST (hour)

TEST	MIN	AVR	MAX
GLUCOSE	0.4	102	733
KETONE	0.24	57.5	248
OSMO	0.29	61	249
URINE	0.41	100	725
VITAMIN D	2.4	85.5	383
BHCG	0.47	74	369.5
FOLATE	1.5	73.7	380.3
HOMOCYSTINE	1.13	73	355
AAT	0.39	61.6	258
G6PD	0.42	64	268
HBAIC	0.52	73	399.8
VMA	0.64	61.5	266.4
CARB	0.48	69	280
FK506	0.46	41.8	175.2
MTX	0.37	69.9	219.3
OPIATES	0.23	109	899

6.5.1.2 Material Flow Time for the Reference Model

The Material flow time (MFT) is the time elapse in hour unit between the points at which material enters the supply chain to the point it utilized. For this model MFT is counting the time for the component once received by the Chemistry Lab from Logistic until utilized by performing the test. The Arena software is providing this data as an indication of the relationship between the Logistic and the Lab concerning the availability of the supplies and how fast can the Logistic provide it to the Lab. It is important information to understand the two elements of the healthcare supply chain.

The Tables 6.2, 6.3, and 6.4 below consist of all materials (components) needed to perform the 16 tests. They are categories as: Reagents, Controllers, and Calibrators, as explained in section (5.5.1.3). Each table has three columns, the first shows all the tests while the second indicates the material flow time, the third is providing the total inventory in the lab and logistic of each concern item. The two tests VMA and FK506 do not have calibrators because they are manually preformed.

The faster material flow time the good indication of delivering the needed items on time. This indicator provides how the relationship between the chemistry lab and the logistic, in particular forward the material's requests and backward the needed components. As an example; The MFT of Glucose is 62 for reagent and calibrator, while MFT for the controller is 11 hours, these values are proportional with availability of the supplies and will be compared with the fifteen scenarios to monitor the relationship between the logistic and Lab in scenario based analyses section.

Table 6.2

REAGENT TABLE

TEST	MFT (Hour)	INV.
GLUCOSE	62	5518
KETONE	104	772
OSMO	43	8045
URINE	62	1688
VITAMIN D	57	2817
BHCG	68	1081
FOLATE	55	54196
HOMOCYSTINE	81	804
AAT	29	14193
G6PD	26	31410
HBAIC	126	1074
VMA	60	1963
CARB	83	81096
FK506	32	36331
MTX	54	12447
OPIATES	13	353

Table 6.3

Calibrator Table

TEST	MFT (Hour)	INV.
GLUCOSE	62	2101
KETONE	58	286
OSMO	11	3028
URINE	14	613
VITAMIN D	14	1012
BHCG	56	377
FOLATE	55	20091
HOMOCYSTINE	10	254
AAT	68	4763
G6PD	239	16331
HBAIC	1	234
VMA	N/A	N/A
CARB	12	25469
FK506	N/A	N/A
MTX	16	4498
OPIATES	2	655

Table 6.4

CONTROLLER TABLE

TEST	MFT (Hour)	INV.
GLUCOSE	11	2203
KETONE	542	2433
OSMO	53	2559
URINE	13	571
VITAMIN D	12	941
BHCG	11	382
FOLATE	11	20107
HOMOCYSTINE	13	238
AAT	10	4637
G6PD	306	17221
HBAIC	197	316
VMA	13	392
CARB	12	21692
FK506	12	14687
MTX	11	4089
OPIATES	8	805

6.5.1.3 Throughput for the Reference Model

Throughput is the rate (test per hour) at which the result of the lab tests is filed in the patient's chart. So it is number of total tests been performed divided by material flow time. The result is presented in Table 6.5. As increasing of the throughput as an indication of high efficacy the chemistry lab is. The comparison will be between the same kinds of test with different scenario.

Table 6.5
THROUGHPUT OF EACH TEST (rate of test/hour)

TEST	THROUGHPUT
GLUCOSE	29.118036
KETONE	1.3828767
OSMO	4.1858447
URINE	5.3260273
VITAMIN D	2.2187214
BHCG	0.2979452
FOLATE	2.9504566
HOMOCYSTINE	0.5760273
AAT	0.9703196
G6PD	0.4077625
HBAIC	21.281735
VMA	0.2605022
CARB	4.9803652
FK506	1.6050228
MTX	0.0821917
OPIATES	0.7038812

Table 6.5 shows all the throughput of the tests according to the available starting inventory. It appears that glucose is the highest among all tests at 29 hours, while MTX is 0.08, indicating a low demand.

On the other hand, the throughput of all components as illustrated in Table 6.2,3,4 indicates a big variation, which needs to be studied with the scenarios.

As the lead time in section 6.5.1.1 provides information about the whole element of supply chain, and MFT gives the relationship between the Chemistry Lab and Logistic, the throughput is examining the efficiency of the Chemistry Lab

6.5.1.4 Inventory Status for the Reference Model

The cost of inventory is most of the times is hidden because the finance in the hospital are considering the value of the supply without taking into account the cost of inventory including staff and storage facility.

Table 6.6 represents the level of inventory in the Laboratory and in Logistics, as the quantity of components should be enough for all tests the Lab performed. The quantity of materials ordered is depended on the Chemistry lab forecast. The organization has to take the necessary steps to reduce the level of inventory to an optimum level to sustain as well as not to interrupt its activities. Further, the Hospital must be careful not to lose control of inventory, which could cause costs spiral out of control. This is why it is important to monitor the level of inventory for all the supplies not only to replenish the items once it's below the safety level but also to watch the expiry and damaged items. The available components for Glucose tests as an example (Table 6.6) are stored in two areas; in the Chemistry Lab and in the Logistic. The values for the components are to start with, the quantity in Logistic is more as the space in the lab can not accommodate high level of quantity. The table is also indicate unbalanced of quantities of components with the number of tests as can be seen in Carb's test, which contains 62020 of reagent while the test is less than Gulocose which has 4036 of the reagent. This indicates lack of proper forecasting.

Table 6.6

LAB STORAGE TABLE
(number of components)

REAGENT

TEST	VALUE
LABRE1	1482
LABRE2	195
LABRE3	1918
LABRE4	394
LABRE5	640
LABRE6	248
LABRE7	13663
LABRE8	284
LABRE9	3258
LABRE10	10988
LABRE11	242
LABRE12	442
LABRE13	19076
LABRE14	9125
LABRE15	2893
LABRE16	55

CALIBRATOR

TEST	VALUE
LABCA1	91
LABCA2	12
LABCA3	120
LABCA4	23
LABCA5	37
LABCA6	15
LABCA7	766
LABCA8	10
LABCA9	183
LABCA10	671
LABCA11	184
LABCA12	N/A
LABCA13	989
LABCA14	N/A
LABCA15	167
LABCA16	38

CONTROLLER

TEST	VALUE
LABCO1	142
LABCO2	142
LABCO3	183
LABCO4	39
LABCO5	64
LABCO6	24
LABCO7	1448
LABCO8	15
LABCO9	335
LABCO10	28
LABCO11	3
LABCO12	34
LABCO13	1680
LABCO14	875
LABCO15	267
LABCO16	39

LOG STORAGE TABLE
(number of components)

REAGENT

TEST	VALUE
LOGRE1	4036
LOGRE2	577
LOGRE3	6127
LOGRE4	1294
LOGRE5	2177
LOGRE6	833
LOGRE7	40534
LOGRE8	520
LOGRE9	10935
LOGRE10	20422
LOGRE11	832
LOGRE12	1521
LOGRE13	62020
LOGRE14	27206
LOGRE15	9608
LOGRE16	298

CALIBRATOR

TEST	VALUE
LOGCA1	2010
LOGCA2	274
LOGCA3	2908
LOGCA4	590
LOGCA5	975
LOGCA6	362
LOGCA7	19325
LOGCA8	244
LOGCA9	4580
LOGCA10	15660
LOGCA11	5o
LOGCA12	N/A
LOGCA13	24480
LOGCA14	N/A
LOGCA15	4331
LOGCA16	617

CONTROLLER

TEST	VALUE
LOGCO1	2061
LOGCO2	2291
LOGCO3	2376
LOGCO4	532
LOGCO5	877
LOGCO6	358
LOGCO7	18659
LOGCO8	223
LOGCO9	4302
LOGCO10	17193
LOGCO11	313
LOGCO12	358
LOGCO13	20012
LOGCO14	13812
LOGCO15	3822
LOGCO16	766

6.5.1.5 Work In Process (WIP) for the Reference Model

All Chemistry Lab tests that have been ordered but not completed yet will be presented in Table 6.7. WIP is defined in the manufacture setting as inventory after the first step in manufacturing and before the last (Conway et al, 1987), WIP should stay small because the components used to perform the test are utilized without any outcome of reported result, so the components can be considered as a waste. Other reason can be the high in-process inventories increase cycle times and decrease responsiveness to patients. The table shows WIP for each test. It indicates the variation in WIP level from 3398 of FK506 to the minimum of 8 for VMA. There are several different reasons why the WIP level is so high and varies. One of them is availability of component, but insufficient staff. There will be an analysis for each of WIP levels in the scenario section.

Table 6.7
WIP (number of unfinished tests)

TEST	WIP
GLUCOSE	1487
KETONE	39
OSMO	127
URINE	2208
VITAMIN D	94
BHCG	11
FOLATE	108
HOMOCYSTINE	21
AAT	29
G6PD	13
HBAIC	776
VMA	8
CARB	161
FK506	3398
MTX	499
OPIATES	38

6.5.1.6 Cost of Test for the Reference Model

According to the Lab process and the utilization of resources, the accumulated costs are represented in the Table 6.8. The table is consist of four column, the first is the list of all tests, the second the value of average cost of each test which will be used as the base number for the comparison with other scenarios in section 6.6 scenario based analyses, the third column is the minimum value, the last is the maximum value. The cost of each test in the table is representing the resources wither staff or equipment participating by certain time in performing the needed test. As example the cost of Glucose test is 1.9 Pound. It is accumulated of the time of Medical technology core chemistry staff and Roche Hitachi P modular auto analyzer equipment and the cost of the supplies (reagent, controller, and calibrator) and the cost of handling the supplies wither in purchasing or storage facility. The Table 6.8 indicates the highest cost in Vitamin D with the value of 6.7, while the lowest is MTX with a value of 1.4. The scenarios presented in the next section will present the causes the organization faces for this level of cost for each of the item used in the Lab. Whereas, changing level of demand, at the same time would be the determining factor for the variation of the cost.

Table 6.8

COST OF EACH TEST (in sterling Pound)

TEST	AVE	MIN	MAX
GLUCOSE	1.909	1.3069	2.9198
KETONE	1.7877	1.2774	2.6887
OSMO	2.0059	1.4676	2.9917
URINE	2.0554	1.5012	3.0116
VITAMIN D	6.7123	5.028	1442.09
BHCG	2.5506	1.9726	3.409

FOLATE	6.0894	4.8963	7.6853
HOMOCYSTINE	4.2361	3.487	5.3294
AAT	2.146	1.5995	3.0629
G6PD	1.9706	1.4252	2.9165
HBAIC	4.1247	3.0526	11.6439
VMA	3.2474	2.4026	4.1936
CARB	1.6824	1.1864	2.6089
FK506	1.8503	1.3458	2.7603
MTX	1.4458	0.9949	2.1895
OPIATES	2.5481	2.1464	3.3417

6.5.2 Secondary Performance Measures for the Reference Model

Under the secondary performance metrics, there are criteria to look at the different aspects of the Lab performance within the supply chain to understand the dynamics of the behavior further. These criteria will help us to understand the individual parameters' effects on the system performance and possible interactions between the parameters as well, which will eventually help to evaluate overall performance. The following is the detailed analysis of the healthcare supply chain centered again on the chemistry Lab using the secondary performance metrics.

The metrics are equipment utilization, staff utilization, queue size and material order size.

6.5.2.1 Equipment Utilization for the Reference Model

Most of the works in Health Care, especially in the Chemistry Lab are dependent on the equipment. Utilizing the equipment as intended provide cost reduction and more throughputs. Also any breakdown of the equipment will effect negatively on the lead-time.

Table 6.9 indicates the different utilization rate for each test. The capability of the equipment is by far higher than the load; the equipment can be used for other tests. The information from the Table 6.9 is mainly for the intended test; this data will be useful more once identifying the reason of the delay of supply chain and how the equipment usage and reliability will affect that. The results show that generally the lab equipment is under utilized, as can be seen from the data; as example, the Glucose test is using the analyzer with a percentage of 2.4%. The reason of the low utilization can be the fear of the manager of possibility of receiving high load in a short period of time, so they purchase bigger equipment for something may not need it.

Table 6.9
EQUIPMENT UTILIZATION (percentage %)

EQUIPMENT	UTILIZATION
ABBOTT TDXFLX	0.1
BIORAD VARIANT II	4.2
CORNING CHLORIDE 925 ANALYZER	3.6
DADE BEHRING BNII	0.1
DADE BEHRING DIMENSION RXL	0.4
DADE BEHRING VIVA TWIN	1.7
ROCHE HITACHI E MODULAR AUTO ANALYSER	1.94
ROCHE HITACHI P MODULAR AUTO ANALYSER (for: Glucose test)	2.4

6.5.2.2 Staff Utilization for the Reference Model

Staffs in the Lab are sharing the responsibility among them for each test groups (Core Chemistry, Special Chemistry, RIA, and TDM). To eliminate any delay or bottleneck of performing the Lab tests, the management must take the necessary steps to make sure that the staffs in Chemistry lab are fully utilized.

Table 6.10
STAFF UTILIZATION (percentage %)

STAFF	UTILIZATION
BUYER 01	1.13
MEDICAL TECHNOLOGIST CORE CHEMISTRY (Glucose, Ketone, Osmo, and Ur. Protein)	12.3
MEDICAL TECHNOLOGIST RIA (Vitamin D, BHCG, Folate, Homocytine)	23.5
MEDICAL TECHNOLOGIST SPECIAL CHEMISTRY (AAT, G6PD, HBAIC, VMA)	49.2
MEDICAL TECHNOLOGIST TDM (Carb, FK506, MTX, Opiates)	1.8
PHLEBOTOMIST	54.8

The results in Table 6.10 represent the percentage of the time utilized by the staff, as 100 will be the maximum, which utilizes the whole available time. It appears that the staff utilization level is very low, especially for the case of the buyer and medical technologist TDM. This does not mean that the staffs are not working, but the contributions of staffs are not related to the function of the Lab's normal activities particularly to the intended tests.

It indicates that the utilization of all staff is very poor. The level of variation is high and this issue needs serious review and commitment from the managerial level to understand what causes this low level of staff utilization.

6.5.2.3 Material Order Size for the Reference Model

Among other resources, the material order size (Table 6.11) provides us with information of the component used to perform the tests. As the outcome of the model has a high number, the expectation is to have higher ordering of all components as well. The variation of the value among the material depends on the frequency of use. This performance measure will confer how the relationship among the Lab, Logistic and the supplier. In particular, how the logistic react to the need of the Lab and issuing purchase orders accordingly.

Table 6.11
MATERIAL ORDER SIZE

NAME OF COMPONENT'S ORDER	NUMBER OF ORDERS
CONTROL	393
CALIBRATOR	182
REAGENT	532

6.5.2.4 Queue Size for the Reference Model

One of the important issues of Health Care providers is how to reduce the queue size. Queuing to see a physician is only part of long chain as the physician waiting for the lab or radiology result the other department like Chemistry Lab are waiting for there parts and supplies to complete there work. In the Table 6.12 providing the average value of waiting time by hours to complete the tests and save the result in the patient's file. The reasons of having queues for performing tests are different. One of them is the availability of components. The comparison of the result would identify the reasons of delay. The delay can reach up to 276 hours for the protein urine analysis, which is very high.

Table 6.12
QUEUE SIZE(hour)

TEST	AVER
GLUCOSE	101
KETONE	57
OSMO	60
URINE	276
VITAMIN D	82
BHCG	73
FOLATE	72
HOMOCYSTINE	71
AAT	61

G6PD	63
HBAIC	72
VMA	60
CARB	64
FK506	41
MTX	69
OPIATES	108

6.6 Scenario-Based Analysis

This section of the analysis focuses on the output selected through scenario-based experimentation. Each scenario targets a specific case in the supply chain. While keeping the rest of the parameters fixed one parameter is changed according to a possible variation in the operation of the supply chain. For example, depending on the season or extra-ordinary development such as outbreak of certain diseases, demand for certain tests for a certain time period. Since this is not usual operation of the system, the supply chain will react upon this new situation in a different way in comparison to normal situation of system operation.

Although this is dependent on occurrence of certain outside factors, this is not an unusual circumstance and may happen in any Healthcare Supply Chain frequently. The research question here is to understand whether this new case will affect the overall system performance adversely or not. In other words, how all these variations in demand would affect the rest of the parameters and different performance measures?

The primary and secondary performance metrics are again used to understand the behavior of the system. The following is the detailed analysis of this metrics and all measures are used against the Reference Model created and analyzed in the beginning of this chapter (from section 6.4 to 6.6)

6.6.1 Scenario one: Low Customer Arrival Rate

The patient arrival module has been changed to: exponential distribution with mean 10 arrivals per hour, which is comparably very low.
In some seasons, especially during holidays, low patients affect the hospital performance. The Chemistry Lab is fully staffed and has all the resources but a low number of tests are requested. How the Lab will handle this situation is the question to be answered with this scenario. The expectation of the output of this scenario is to have low inventory matching with decrease of the patient rate. This is an important issue for supply chain as the excessive material will raise the cost and reducing it in an unplanned way would affect the quality of care.

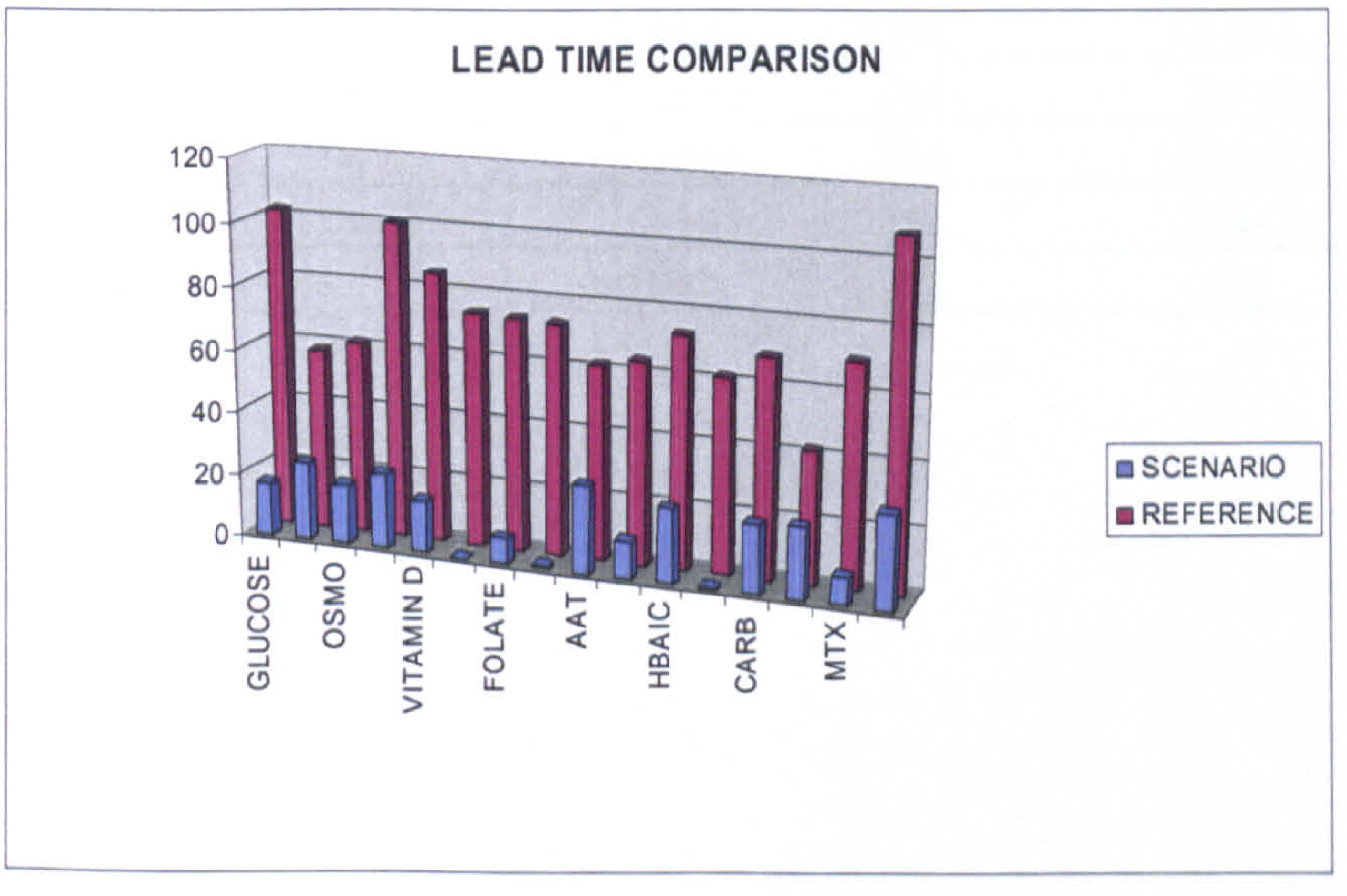
6.6.1.1 Primary Performance Measures
6.6.1.1.1 Lead Time

The lead time as shown in the Table and Graph 6.13 dropped in comparison to the reference model. This is a predicted decrease as the low rate of patient requesting fewer tests. The average lead time for Glucose for example has reduced by 82.6%. The data show a consistency, some are higher drop like RIA section which consists of BHCG, Vitamin D, Folate, and Homocystine. It is acceptable as RIA section has the low number of tests. Also the results indicate the availability of resources to do all tests without shortage of delivering the supplies.

Table and Graph 6.13

LEAD TIME COMPARISON TO REFERENCE MODEL (hour)

SCENARIO:				REFERENCE MODEL		
TEST	MIN	AVR	MAX	MIN	AVR	MAX
GLUCOSE	0.37	21	167	0.4	102	733
KETONE	0.24	20	148	0.24	57.5	248
OSMO	0.28	22	224	0.29	61	249
URINE	0.39	21	166	0.41	100	725
VITAMIN D	2.49	2.6	2.82	2.4	85.5	383
BHCG	0.21	1.1	83	0.47	74	369.5
FOLATE	1.6	1.6	172	1.5	73.7	380.3
HOMOCYSTINE	0.31	1.2	133	1.13	73	355
AAT	0.38	24	164	0.39	61.6	258
G6PD	0.414	20	149	0.42	64	268
HBAIC	0.516	24	169	0.52	73	399.8
VMA	0.633	24	145	0.64	61.5	266.4
CARB	0.469	22	168	0.48	69	280
FK506	0.459	20	192	0.46	41.8	175.2
MTX	0.379	26	166	0.37	69.9	219.3
OPIATES	0.229	18	158	0.23	109	899



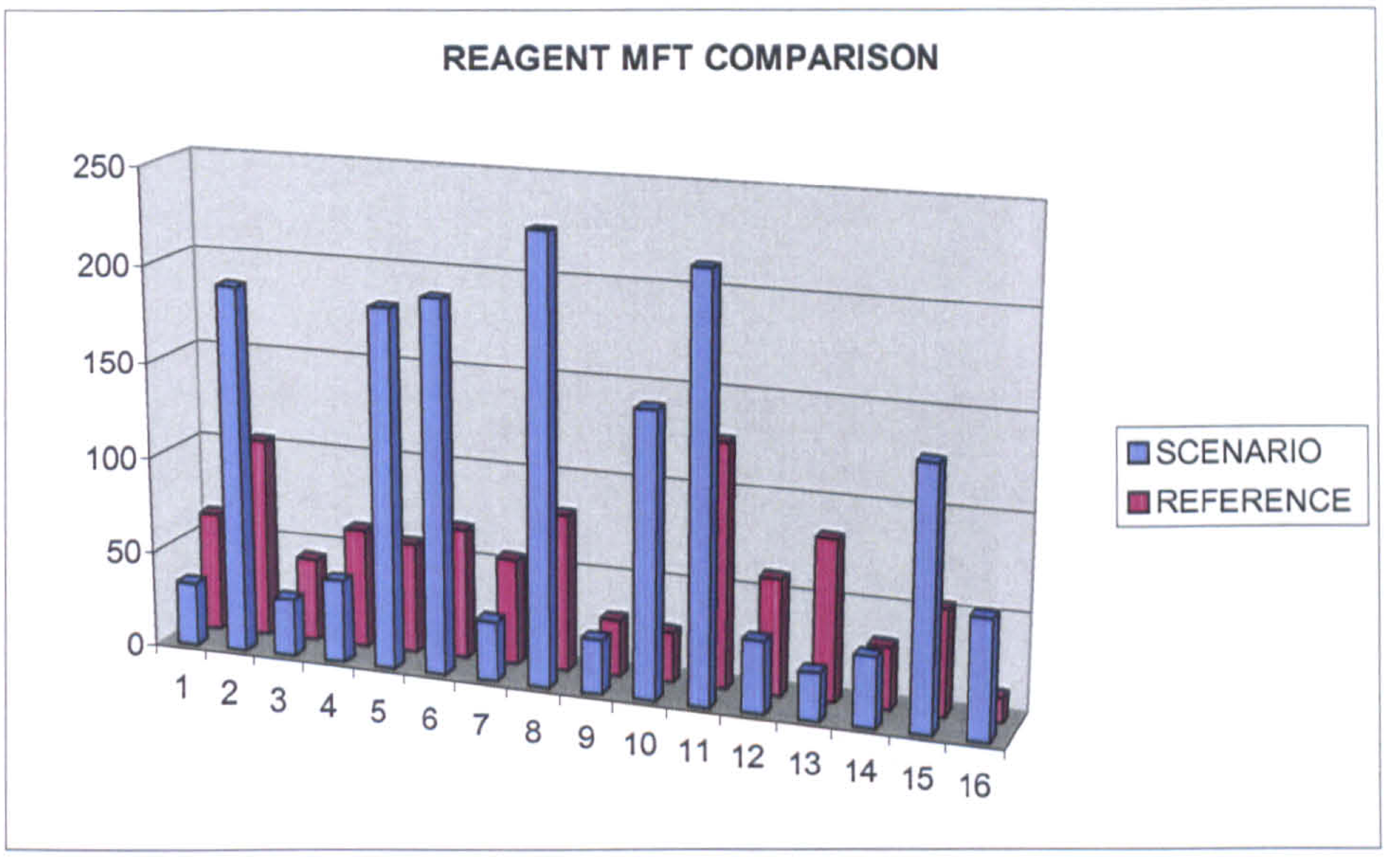
6.6.1.1.2 Material flow time

More than 70% of all tests are not affected by the low demand. This result is shown in Table and Graph 6.14 which consists of reagent, calibrator, and controller.

Accordingly, the level of inventory has dropped slightly as less material is ordered with less frequently because of the number of tests conducted. Seven tests like GLUCOSE and VMA indicate that they have less flow time and the other eight tests like KETONE and HBAIC have increased level of flow time.

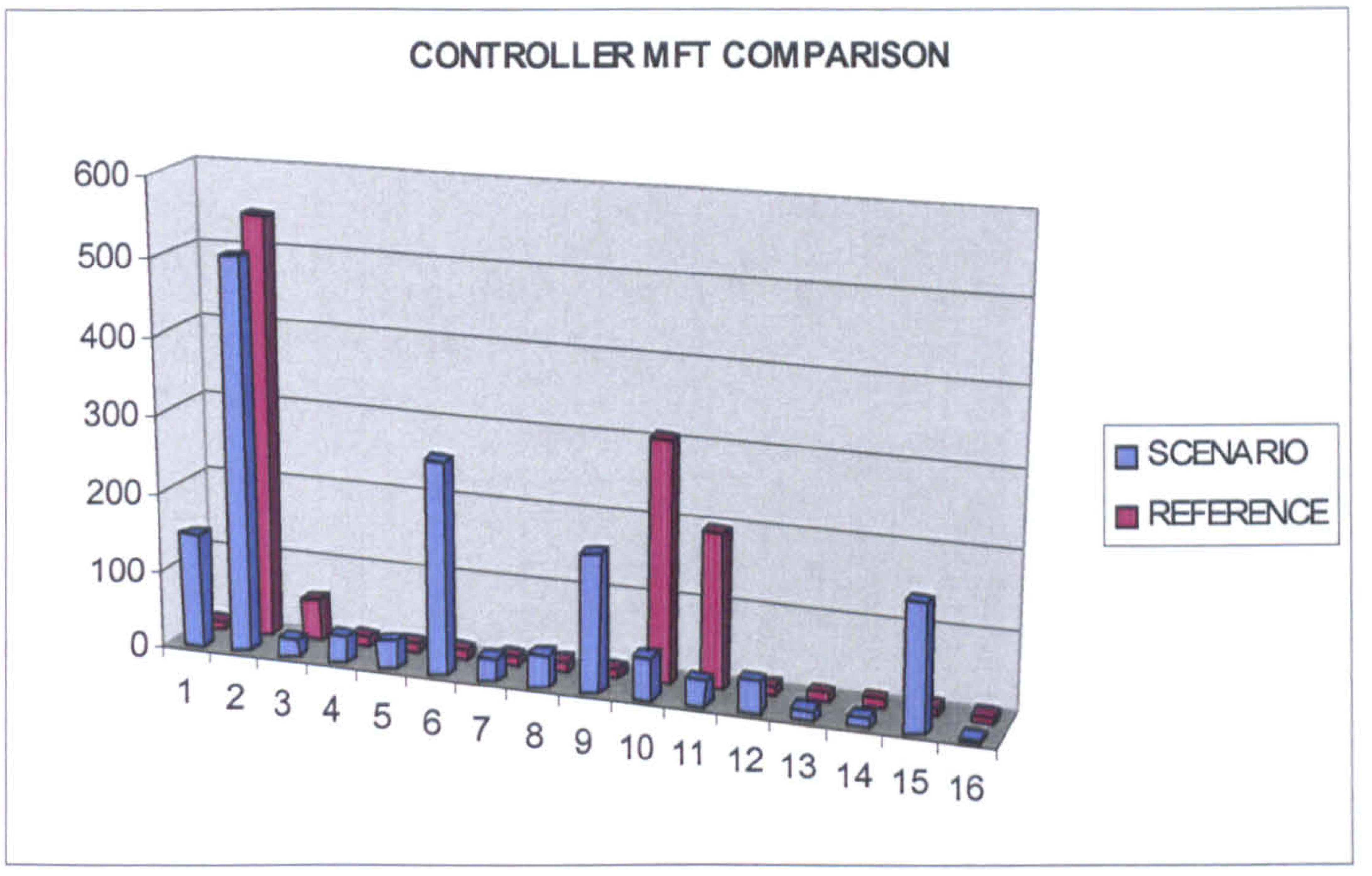
Table and Graph 6.14
REAGENT TABLE COMPARISON

SCENARIO			REFERENCE MODEL	
TEST	MFT(hour)	INV	MFT(hour)	INV
GLUCOSE	33	5974	62	5518
KETONE	191	842	104	772
OSMO	30	7874	43	8045
URINE	43	1673	62	1688
VITAMIN D	186	2463	57	2817
BHCG	193	1077	68	1081
FOLATE	31	55632	55	54196
HOMOCYSTINE	230	704	81	804
AAT	28	13061	29	14193
G6PD	147	34194	26	31410
HBAIC	218	818	126	1074
VMA	37	1914	60	1963
CARB	24	76567	83	81096
FK506	36	39602	32	36331
MTX	134	10554	54	12447
OPIATES	61	1863	13	353



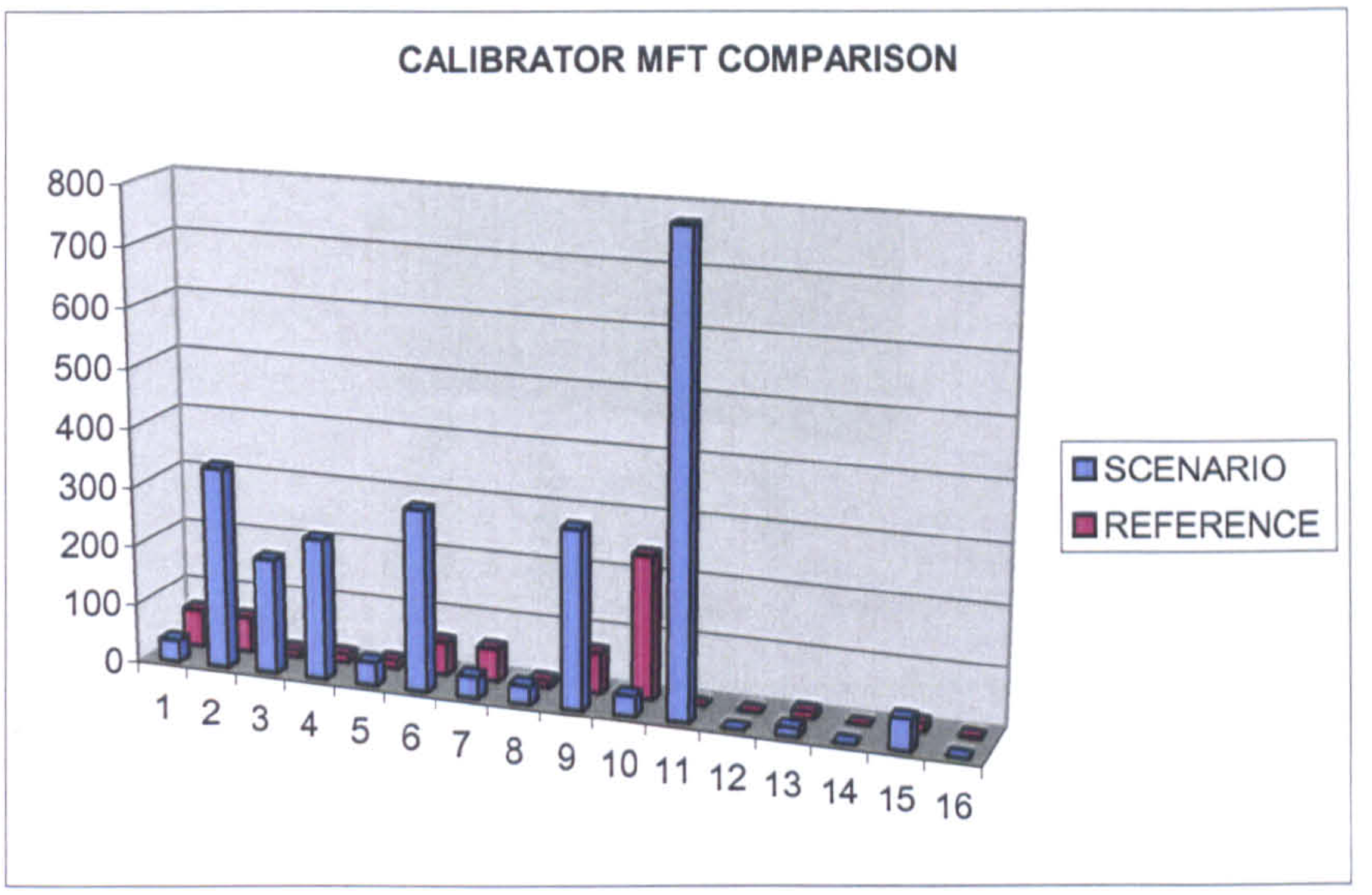
CONTROLLER COMPARISON TABLE

SCENARIO			REFERENCE	
TEST	MFT(hour)	INV	MFT(hour)	INV
GLUCOSE	146	2517	11	2203
KETONE	506	2192	542	2433
OSMO	23	3499	53	2559
URINE	35	709	13	571
VITAMIN D	36	1166	12	941
BHCG	271	429	11	382
FOLATE	31	24998	11	20107
HOMOCYSTINE	43	299	13	238
AAT	177	5340	10	4637
G6PD	55	18383	306	17221
HBAIC	34	366	197	316
VMA	41	603	13	392
CARB	13	28802	12	21692
FK506	13	13901	12	14687
MTX	161	4659	11	4089
OPIATES	3.6	1507	8	805



CALIBRATOR TABLE

SCENARIO			REFERENCE MODEL	
TEST	MFT(hour)	INV	MFT(hour)	INV
GLUCOSE	37	25817	62	2101
KETONE	339	319	58	286
OSMO	194	3130	11	3028
URINE	236	621	14	613
VITAMIN D	39	1125	14	1012
BHCG	305	425	56	377
FOLATE	36	24210	55	20091
HOMOCYSTINE	31	284	10	254
AAT	300	5401	68	4763
G6PD	35	18078	239	16331
HBAIC	789	511	0	234
VMA	N/A	N/A	N/A	N/A
CARB	14	28712	12	25469
FK506	N/A	N/A	N/A	N/A
MTX	53	5006	16	4498
OPIATES	0.45	953	2	655



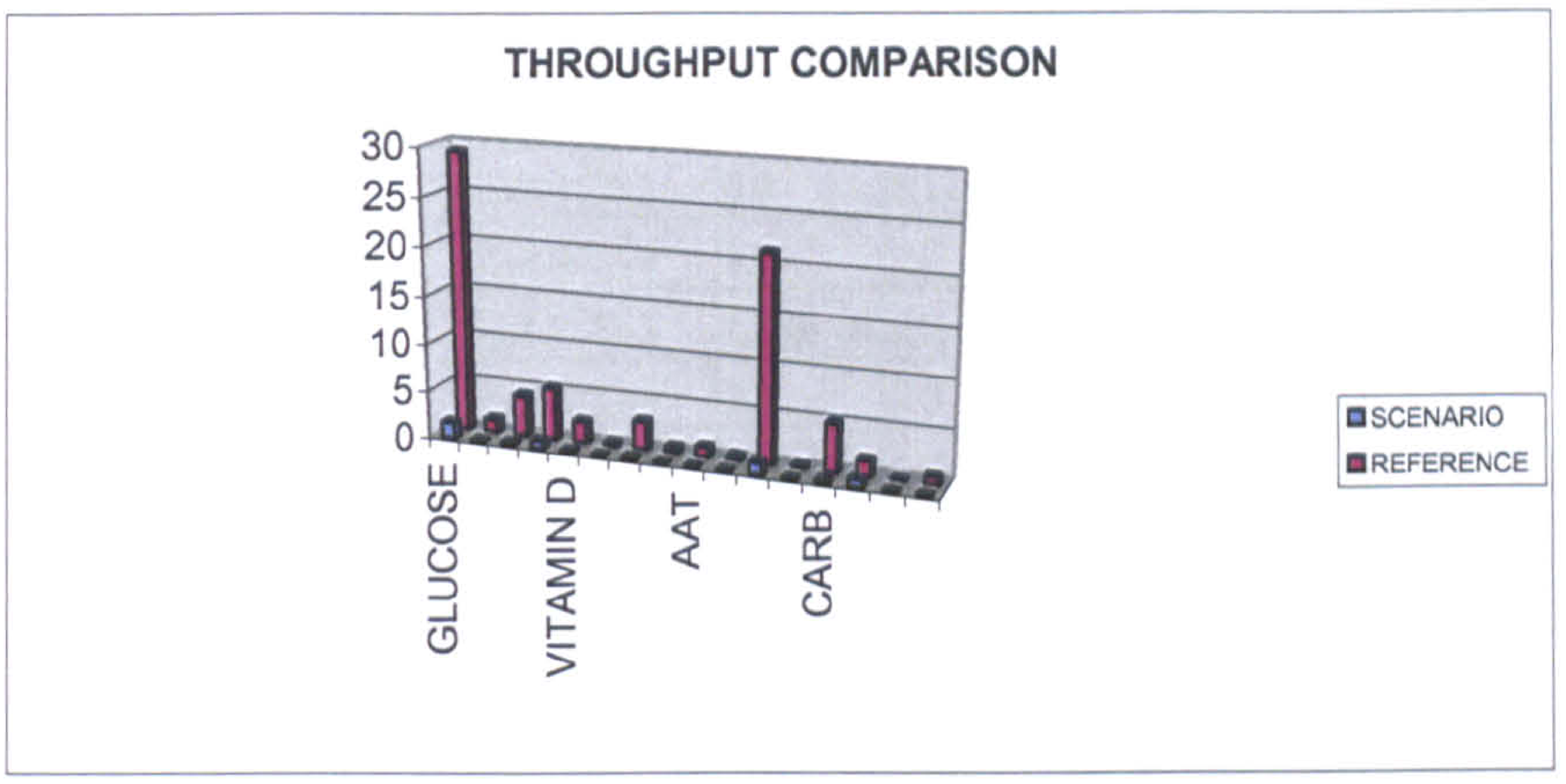
6.6.1.1.3 Throughput

Throughput of the test as indicated in the Table and Graph 6.15 was effected negatively by decreasing the demand. In fact, this result is a natural outcome of the low demand and the number of completed tests is now less parallel to the number of requested tests.

Table and Graph 6.15

THROUGHPUT COMPARISON(rate of test/hour)

SCENARIO		REFERENCE
TEST	THROUGHPUT	THROUGHPUT
GLUCOSE	1.7	29.118036
KETONE	0.0889	1.3828767
OSMO	0.251	4.1858447
URINE	0.8018	5.3260273
VITAMIN D	0.14	2.2187214
BHCG	0.0163	0.2979452
FOLATE	0.1807	2.9504566
HOMOCYSTINE	0.0347	0.5760273
AAT	0.0611	0.9703196
G6PD	0.0218	0.4077625
HBAIC	1.268	21.281735
VMA	0.0138	0.2605022
CARB	0.2913	4.9803652
FK506	0.8025	1.6050228
MTX	0.0194	0.0821917
OPIATES	0.04509	0.7038812



6.6.1.1.4 Inventory Status

Inventory status is a very important metric to indicate the performance of the supply chain. It indicates the responsiveness of the Chemistry Lab to any change. According to Table 6.16, there is a little change in the inventory of all components either in the Lab or Logistics in comparison to the Reference Model except test number 16 TDM Opate which has increased tremendously without any planned increase in usage. This unexpected increase in this specific material usage could be explained as a random nature of the simulation model. All the tests maintain the same inventory level with a little variation. This does not match with the decreasing level of the patient demand. As a result, there will be unused supplies which are subject to destruction, if the expire dates are passed, which is likely to happen in this case. A proper forecasting with reliable data is needed to prevent this situation from occurring, or to seek another alternative of managing the supplies as discussed in 2.4.2.2 and 3.3.1.

Table 6.16

STORAGE COMPARISON TABLE (number of components)

LAB STORAGE TABLE

REAGENT	CALIBRATOR	CONTROLLER

SCENARIO		REFERENCE
TEST	VALUE	VALUE
LABRE1	1497	1482
LABRE2	191	195
LABRE3	1974	1918
LABRE4	380	394
LABRE5	622	640
LABRE6	262	248
LABRE7	13961	13663
LABRE8	165	284
LABRE9	3283	3258
LABRE10	10480	10988
LABRE11	196	242
LABRE12	444	442
LABRE13	19201	19076
LABRE14	11139	9125
LABRE15	2763	2893
LABRE16	536	55

SCENARIO		REFERENCE
TEST	VALUE	VALUE
LABCA1	88	91
LABCA2	11	12
LABCA3	115	120
LABCA4	23	23
LABCA5	38	37
LABCA6	16	15
LABCA7	833	766
LABCA8	9	10
LABCA9	194	183
LABCA10	620	671
LABCA11	169	184
LABCA12	N/A	N/A
LABCA13	1071	989
LABCA14	N/A	N/A
LABCA15	167	167
LABCA16	72	38

SCENARIO		REFERENCE
TEST	VALUE	VALUE
LABCO1	150	142
LABCO2	143	142
LABCO3	197	183
LABCO4	38	39
LABCO5	61	64
LABCO6	26	24
LABCO7	1448	1448
LABCO8	17	15
LABCO9	328	335
LABCO10	297	28
LABCO11	20	3
LABCO12	44	34
LABCO13	1728	1680
LABCO14	699	875
LABCO15	283	267
LABCO16	54	39

LOG STORAGE TABLE

REAGENT

SCENARIO		REFERENCE
TEST	VALUE	VALUE
LOGRE1	4477	4036
LOGRE2	651	577
LOGRE3	5900	6127
LOGRE4	1293	1294
LOGRE5	1841	2177
LOGRE6	815	833
LOGRE7	41671	40533
LOGRE8	539	520
LOGRE9	9778	10935
LOGRE10	23714	20422
LOGRE11	622	832
LOGRE12	1470	1521
LOGRE13	57366	62020
LOGRE14	28463	27206
LOGRE15	7791	9608
LOGRE16	1327	298

CALIBRATOR

SCENARIO		REFERENCE
TEST	VALUE	VALUE
LOGCA1	2493	2010
LOGCA2	308	274
LOGCA3	3015	2908
LOGCA4	598	590
LOGCA5	1087	975
LOGCA6	409	362
LOGCA7	23377	19325
LOGCA8	275	244
LOGCA9	5207	4580
LOGCA10	17458	15660
LOGCA11	315	50
LOGCA12	N/A	N/A
LOGCA13	27641	24480
LOGCA14	N/A	N/A
LOGCA15	4839	4331
LOGCA16	881	617

CONTROLLER

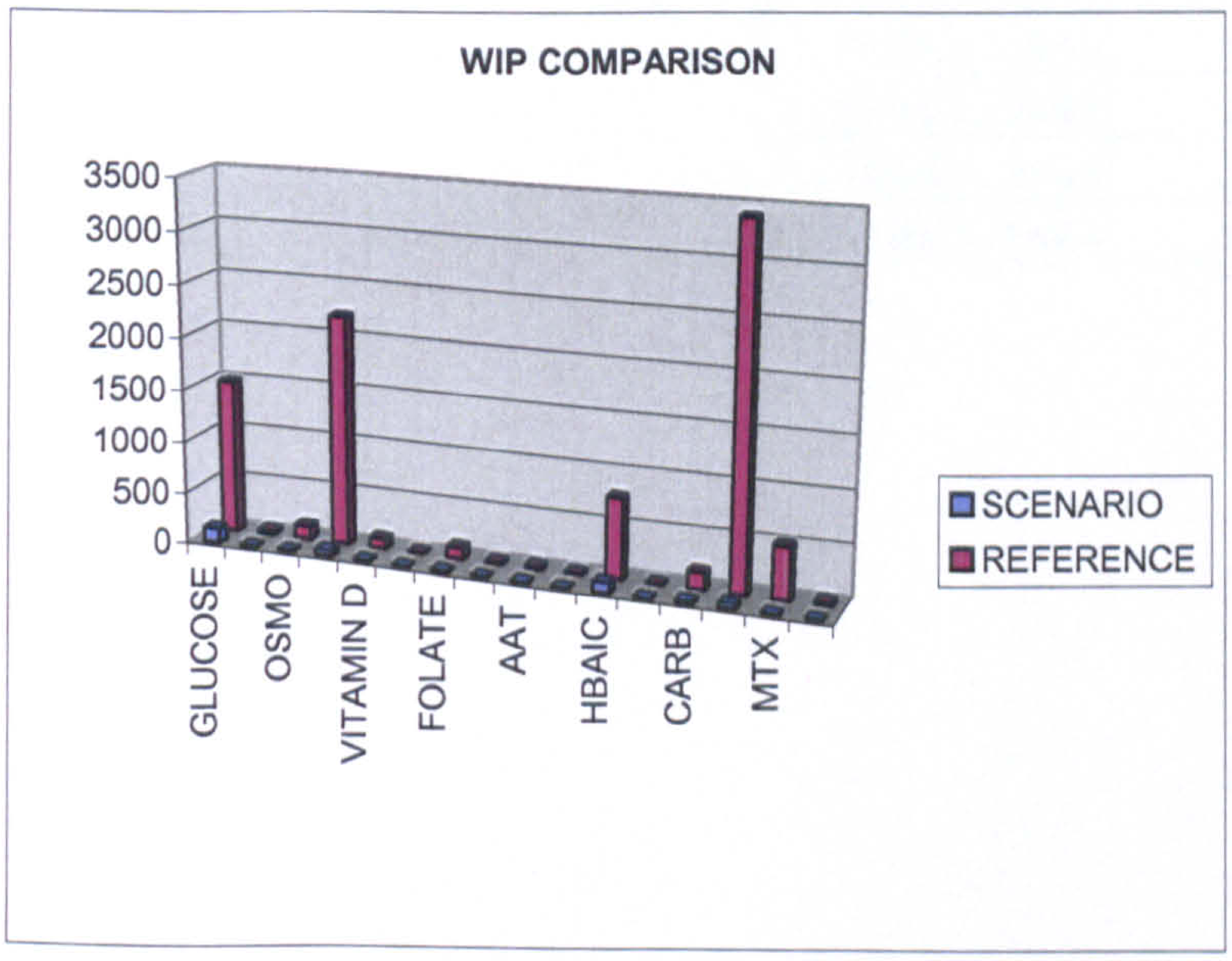
SCENARIO		REFERENCE
TEST	VALUE	VALUE
LOGCO1	2367	2061
LOGCO2	2049	2291
LOGCO3	3302	2376
LOGCO4	671	532
LOGCO5	1105	877
LOGCO6	403	358
LOGCO7	23550	18659
LOGCO8	282	223
LOGCO9	5012	4302
LOGCO10	18086	17193
LOGCO11	346	313
LOGCO12	559	35
LOGCO13	27074	20012
LOGCO14	13202	13812
LOGCO15	4376	3822
LOGCO16	1453	766

6.6.1.1.5 WIP

Table and Graph 6.17 indicates work in process, which are comparably very low. This again can be explained with a low demand rate. Since the Lab has no due date pressure and has more time to do the tests the work done is more quickly, reducing the WIP level considerably.

Table and Graph 6.17
WIP COMPARISON(number of unfinished tests)

TEST	SCENARIO	REFERENCE MODEL
GLUCOSE	142	1487
KETONE	7	39
OSMO	11	127
URINE	59	2208
VITAMIN D	8.9	94
BHCG	0.48	11
FOLATE	12	108
HOMOCYSTINE	4	21
AAT	5	29
G6PD	1	13
HBAIC	106	776
VMA	0.1	8
CARB	24	161
FK506	55	3398
MTX	3	499
OPIATES	3	38



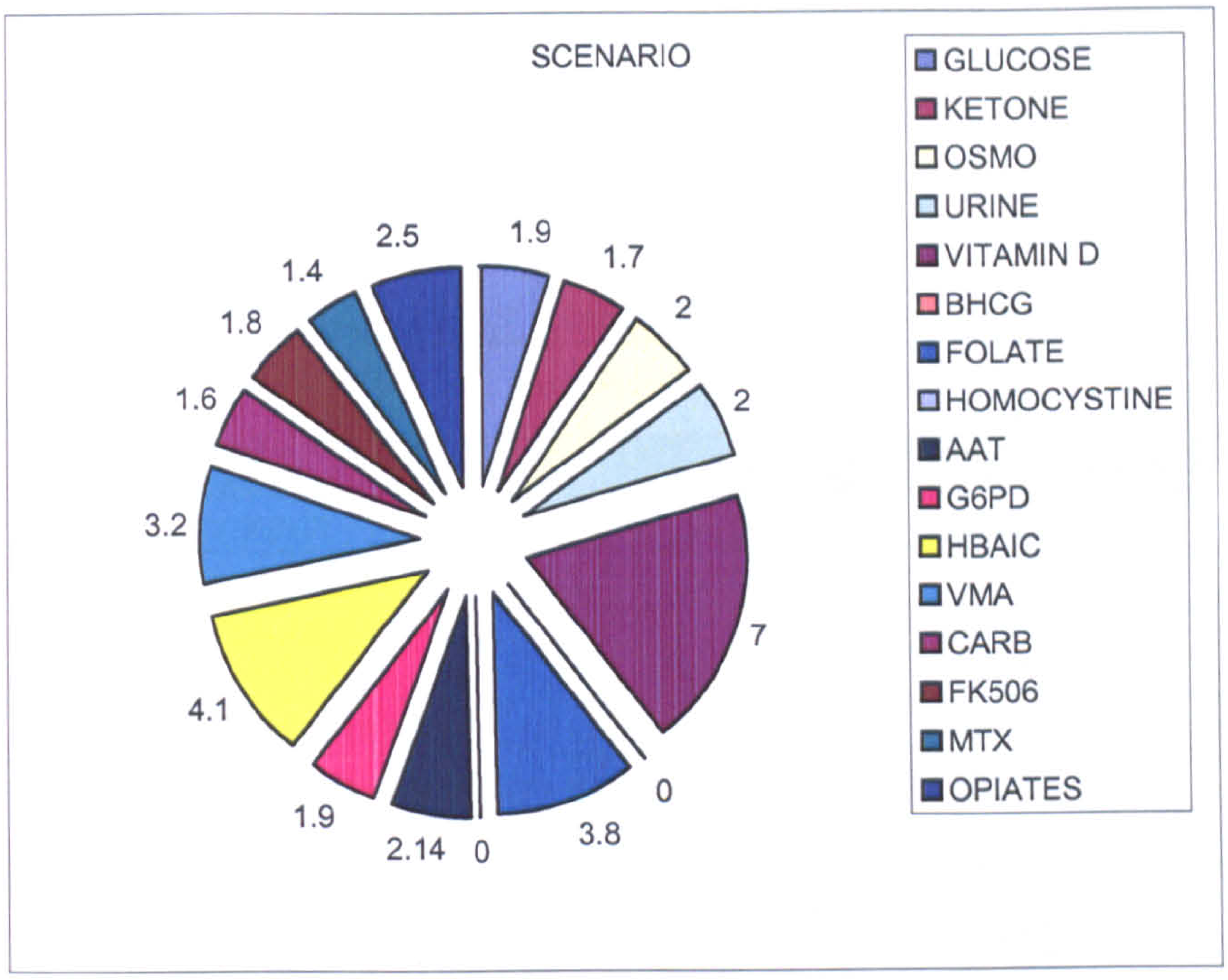
6.6.1.1.6 Cost of Test

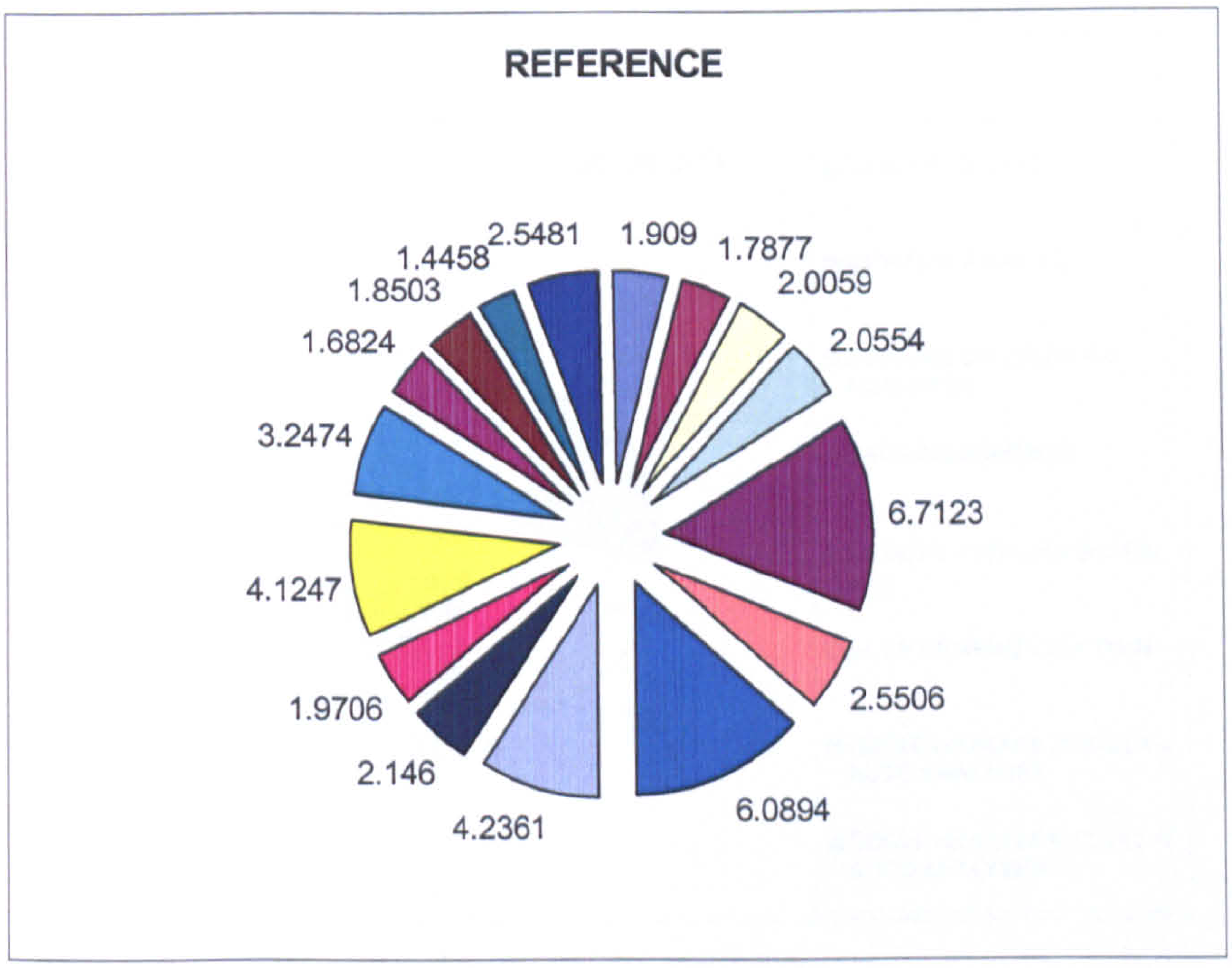
The cost of each test is not much different than the Reference Model Table and Graph 6.18 because the staff and resources are still included. The minor difference mainly comes from the reduced mean flow time for each test process. This means that the time spent for each test operation is less in comparison to the Reference Model and the direct Labor cost is slightly less than the normal level.

Table and Graph 6.18(in sterling Pound)

COST COMPARISON OF EACH TEST

SCENARIO				REFERENCE MODEL		
TEST	AVE	MIN	MAX	AVE	MIN	MAX
GLUCOSE	1.9	1.3	2.8	1.909	1.3069	2.9198
KETONE	1.7	1.3	2.5	1.7877	1.2774	2.6887
OSMO	2	1.4	2.9	2.0059	1.4676	2.9917
URINE	2	1.4	2.9	2.0554	1.5012	3.0116
VITAMIN D	7	6.6	7.2	6.7123	5.028	1442.09
BHCG	N/A	N/A	N/A	2.5506	1.9726	3.409
FOLATE	3.8	3.2	4.2	6.0894	4.8963	7.6853
HOMOCYSTINE	N/A	N/A	N/A	4.2361	3.487	5.3294
AAT	2.14	1.6	2.89	2.146	1.5995	3.0629
G6PD	1.9	1.4	2.68	1.9706	1.4252	2.9165
HBAIC	4.1	3.1	10.89	4.1247	3.0526	11.6439
VMA	3.2	2.5	4.2	3.2474	2.4026	4.1936
CARB	1.6	1.2	2.5	1.6824	1.1864	2.6089
FK506	1.8	1.3	2.7	1.8503	1.3458	2.7603
MTX	1.4	1.01	2.22	1.4458	0.9949	2.1895
OPIATES	2.5	2.1	3.1	2.5481	2.1464	3.3417





6.6.1.2 Secondary Performance Measures

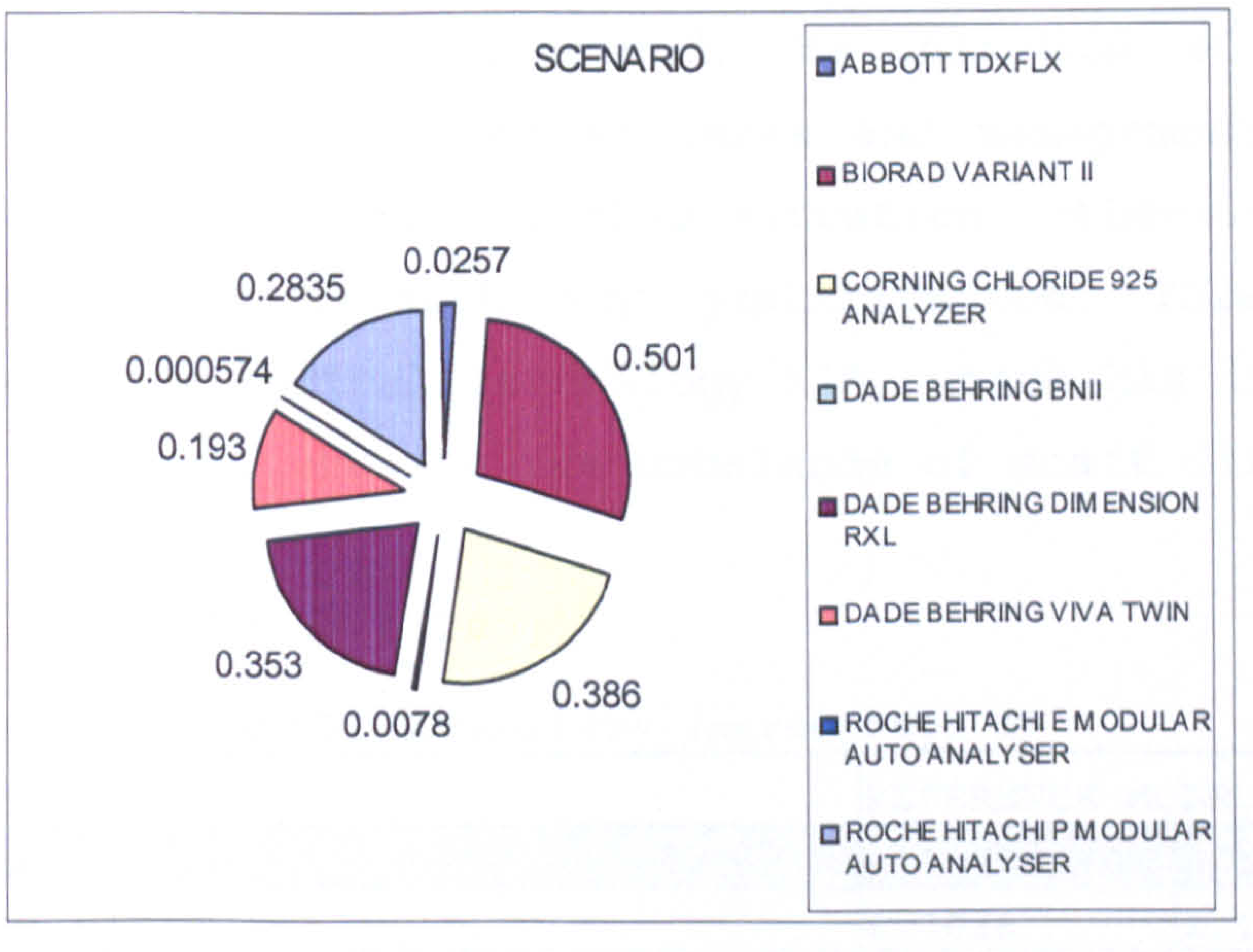
6.6.1.2.1 Equipment Utilization

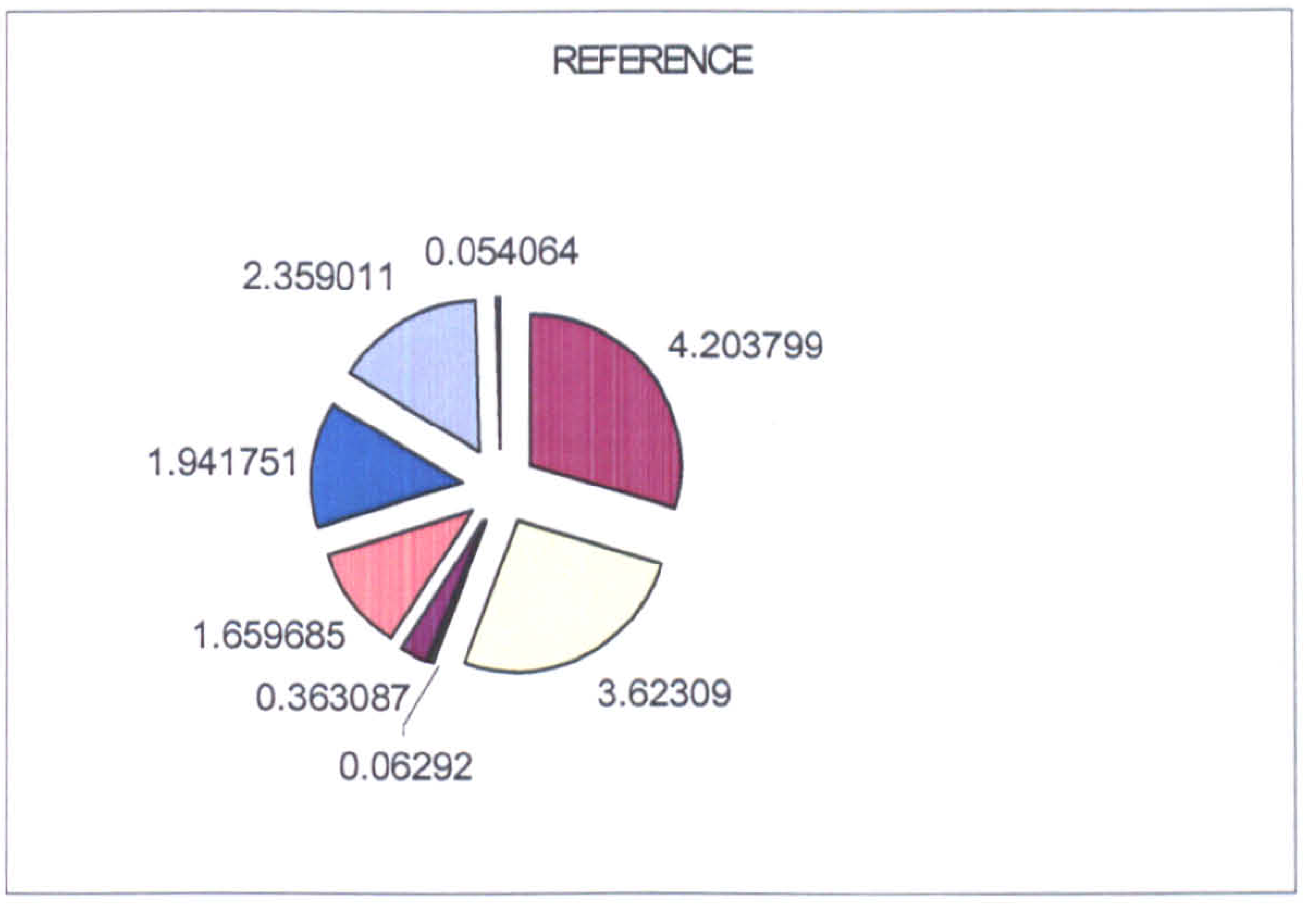
The utilization level has dropped matching the patient reduction. This is an expected result as reducing the demand. Maximum was the Biorad Vaviant II Analyzer (Table and Graph 6.19).

Table and Graph 6.19

EQUIPMENT UTILIZATION COMPARISON (percentage %)

SCENARIO		REFERENCE MODEL
EQUIPMENT	UTILIZATION	UTILIZATION
ABBOTT TDXFLX	0.03	0.1
BIORAD VARIANT II	0.5	4.2
CORNING CHLORIDE 925 ANALYZER	0.4	3.6
DADE BEHRING BNII	0.01	0.1
DADE BEHRING DIMENSION RXL	0.4	0.4
DADE BEHRING VIVA TWIN	0.2	1.7
ROCHE HITACHI E MODULAR AUTO ANALYSER	0.0006	1.94
ROCHE HITACHI P MODULAR AUTO ANALYSER	0.	2.4





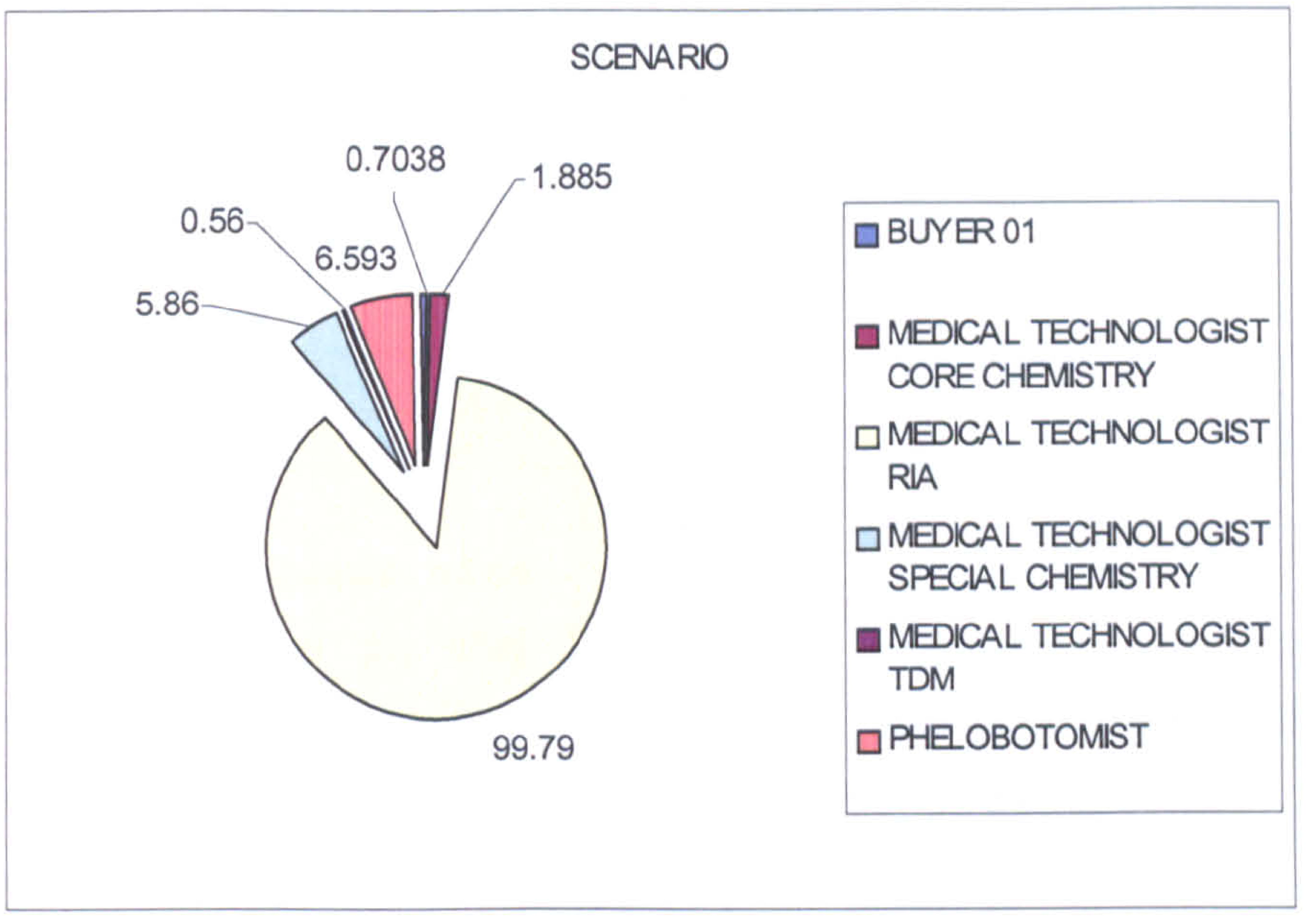
6.6.1.2.2 Staff Utilization

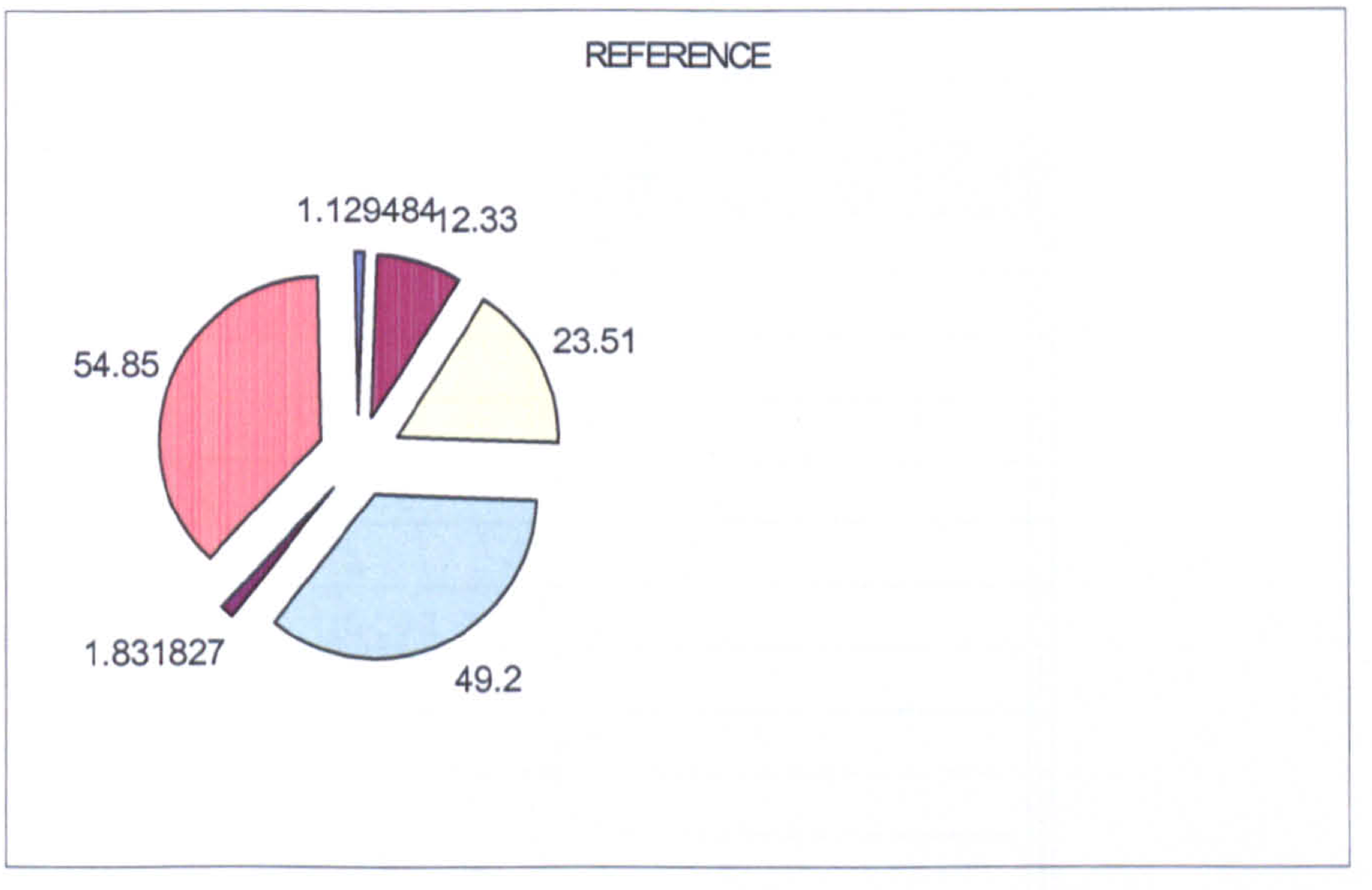
The staff utilization is lower than the reference model (Table and Graph 6.20). The staffs have now more unused time because of less demand. The unit cost of staff will now be higher than other cases and management must come up with a solution for this situation, otherwise the cost is inflated without any justification. This is valid except the Medical Technology RIA, which has increased to the maximum, showing the unbalance of staff distribution.

Table and Graph 6.20

STAFF UTILIZATION COMPARISON (percentage %)

SCENARIO		REFERENCE MODEL
STAFF	UTILIZATION	UTILIZATION
BUYER 01	0.7038	1.129484
MEDICAL TECHNOLOGIST CORE CHEMISTRY (Glucose, Ketone, Osmo, and Ur. Protein)	1.885	12.33
MEDICAL TECHNOLOGIST RIA (Vitamin D, BHCG, Folate, Homocytine)	99.79	23.51
MEDICAL TECHNOLOGIST SPECIAL CHEMISTRY (AAT, G6PD, HBAIC, VMA)	5.86	49.2
MEDICAL TECHNOLOGIST TDM (Carb, FK506, MTX, Opiates)	0.56	1.831827
PHLEBOTOMIST	6.593	54.85





6.6.1.2.3 Material Order Size

The material orders (Table 6.21) have been dropped by different percentage according to the components used. Matching the low demand with the low lot size and less frequent number of orders for the Chemistry Lab, it is expected that there should be a decrease in the inventory level as well; however, this is not reflected in the inventory level. This indicates a lack of proper communication between the Lab and Logistic in the ordering mechanism.

Table 6.21

MATERIAL ORDER SIZE COMPARISON

SCENARIO		REFERENCE MODEL
NAME OF ORDER	NUMBER OF ORDERS	NUMBER OF ORDERS
LAB CONTROL	129	393
LAB CALIBRATOR	65	182
REAGENT	70	532

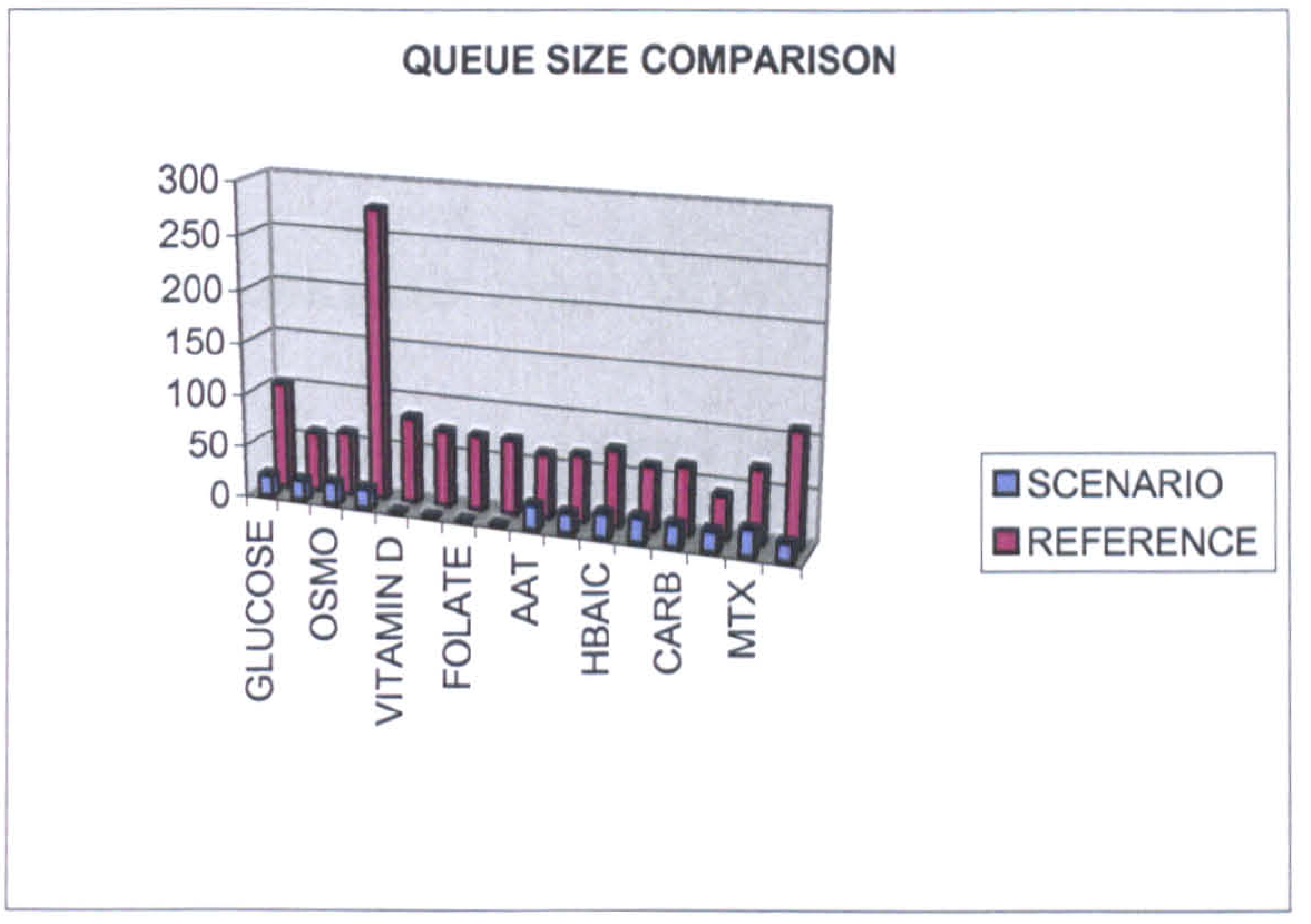
6.6.1.2.4 Queue size

As discussed in the lead time, similarly the queue size (Table and Graph 6.22) has been reduced tremendously for some test because of no due date pressure and less test requests.

Table and Graph 6.22

QUEUE SIZE COMPARISON (hour)

SCENARIO		REFERENCE MODEL
TEST	AVER	AVER
GLUCOSE	21	101
KETONE	20	57
OSMO	22	60
URINE	20	276
VITAMIN D	0.01	82
BHCG	1	73
FOLATE	0.01	72
HOMOCYSTINE	1.1	71
AAT	23	61
G6PD	19	63
HBAIC	23	72
VMA	23	60
CARB	21	64
FK506	19	41
MTX	25	69
OPIATES	17	108



6.6.1.3 Conclusion

From all the tables and graphs, the low flow of patients can affect positively to the level of waiting time, lead time, queue size, inventory status, material order size but negatively effect the utilization of equipment and staff. The summary of output of this scenario is as follows:

- Lead time is reduced tremendously
- Staff utilization has dropped matching with the low demand
- Throughput for the test became low
- Inventory for all component are the same with slight change in some materials. This does not match 100% with the low number of patients. This is an indication of poor forecasting.
- The cost is reduced in a small rate because of other factors like staff and resources are the same despite low demand.
- Number of orders reduced equivalent to the dropped of patient from the Chemistry Lab. But this does not affect the actual inventory level which remains the same as the reference model.

As a result; the management should look for alternative ways of handling the purchase and controlling the supply inventory. As discussed in section 2.4.2.2 and 3.3.1, Just In Time (JIT) may be the good choice.

6.6.2. Scenario two: Unreliable Suppliers

In this scenario, suppliers are considered as the source of problem in the supply chain. Improving the performance of the suppliers would enhance the flow of material throughout the chain. Problems in the suppliers' site will be directly and indirectly affect the patient who is the real beneficiary of the whole supply chain. Unreliable suppliers provide hospitals with needed medical items with an inconsistent pattern causing a lot of interruptions or other problems which affect the efficiency of the Chemistry Lab negatively. The aim of this scenario is to understand what kind of impact the unreliable supplier can have on the overall system performance and what measures need to be taken by the supply chain to overcome this problem. The output gathered for this scenario will be examined in the following sections.

6.6.2.1 Primary Performance Measures

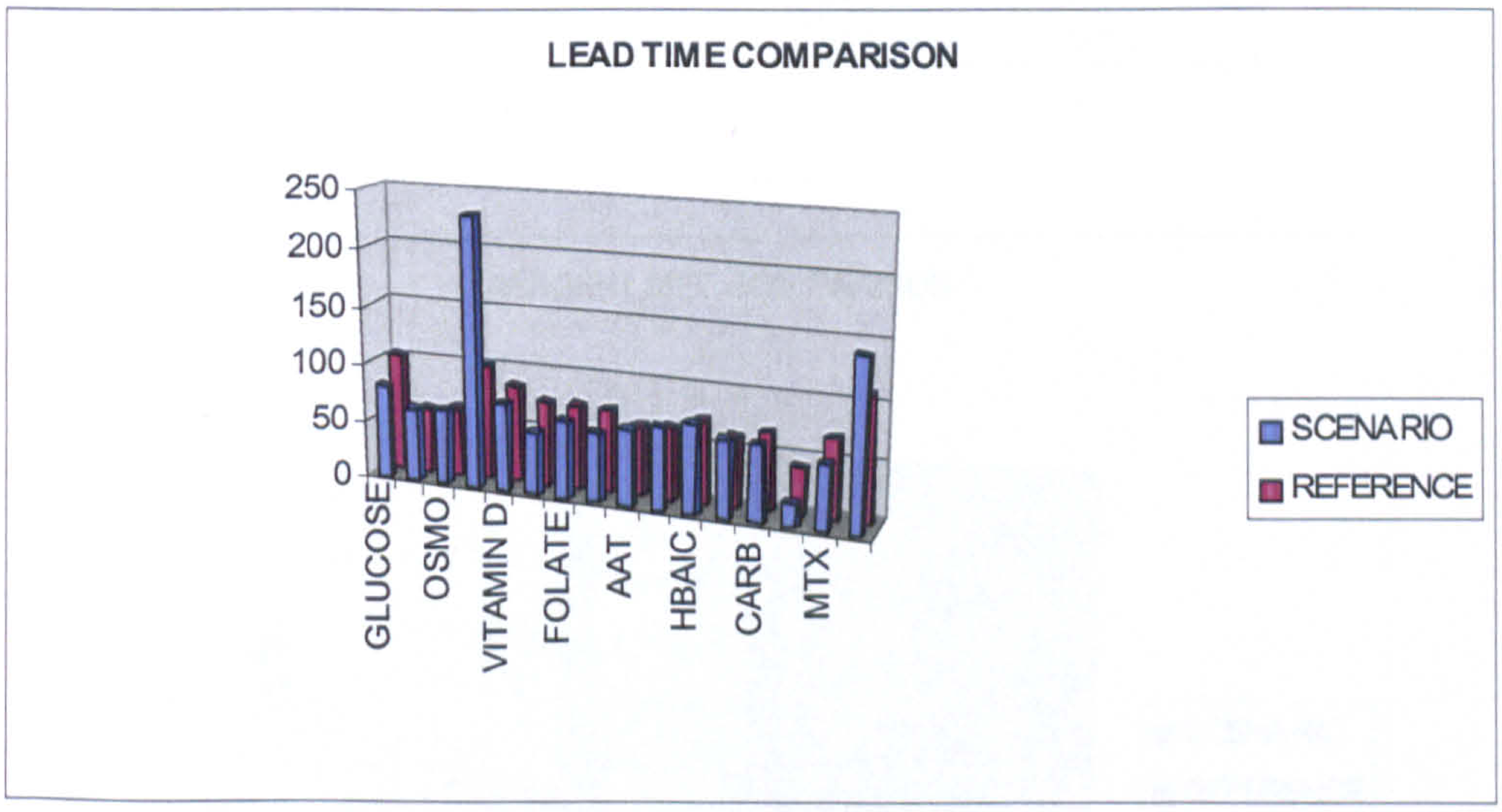
6.6.2.1.1 Lead Time

Eight different tests in Table and Graph 6.23 show the increased lead time while the other eight tests have dropped by 10 to 20 percent. The suppliers in this scenario show varying performance in responding to the hospital request for needed items. The delay from the supplier side has reflected as a longer lead time for the tests in the lab as they can be observed in the table.

Table and Graph 6.23

LEAD TIME COMPARISON TO REFERENCE MODEL(hour)

SCENARIO:				REFERENCE MODEL		
TEST	MIN	AVR	MAX	MIN	AVR	MAX
GLUCOSE	0.3844	81.7226	373.14	0.4	102	733
KETONE	0.2423	64.7832	288.99	0.24	57.5	248
OSMO	0.295	66.2047	293.27	0.29	61	249
URINE	0.4084	234.48	5128.98	0.41	100	725
VITAMIN D	2.4366	77.4657	314.31	2.4	85.5	383
BHCG	0.4829	55.9244	199.37	0.47	74	369.5
FOLATE	1.5183	68.8743	300.41	1.5	73.7	380.3
HOMOCYSTINE	1.142	61.0659	234.18	1.13	73	355
AAT	0.3868	67.2051	238.42	0.39	61.6	258
G6PD	0.4312	72.4026	317.55	0.42	64	268
HBAIC	0.5265	78.2133	455.64	0.52	73	399.8
VMA	0.6203	67.4101	224.45	0.64	61.5	266.4
CARB	0.4733	67.0685	207.93	0.48	69	280
FK506	0.4654	20.1582	94.7537	0.46	41.8	175.2
MTX	0.378	56.6607	190.22	0.37	69.9	219.3
OPIATES	0.236	147.74	712.42	0.23	109	899



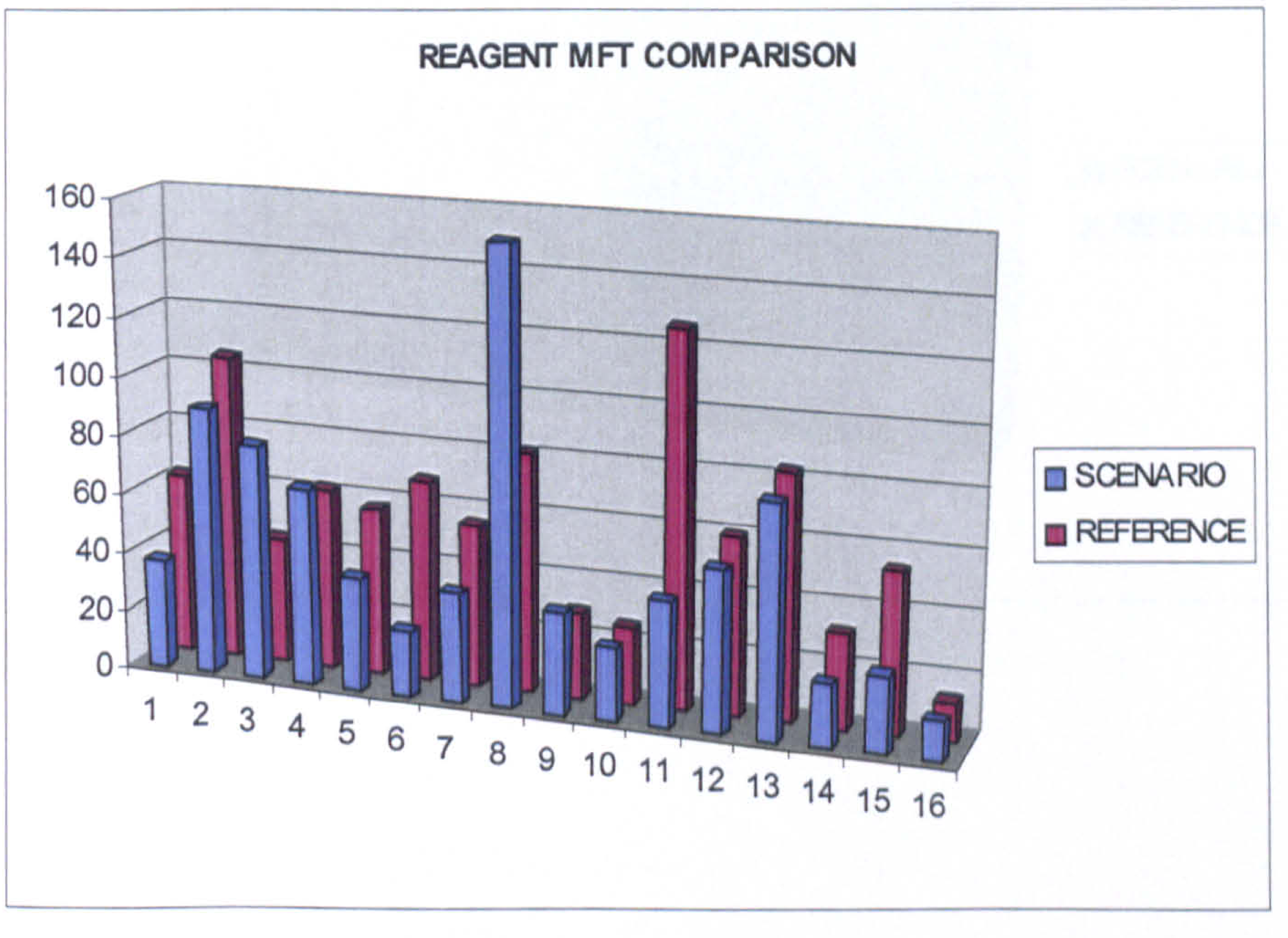
6.6.2.1.2 Material Flow time

The effect of the suppliers on the material flow is different from reagent to controller and calibrator. It mainly follows the demand and inventory level as illustrated in Table and Graph 6.24 which consist of reagent, calibrator, and controller. As we have each test need at least three components, these materials are purchased from different vendors. If one of the vendors refuses to deliver the test will not be performed.

Table and Graph 6.24

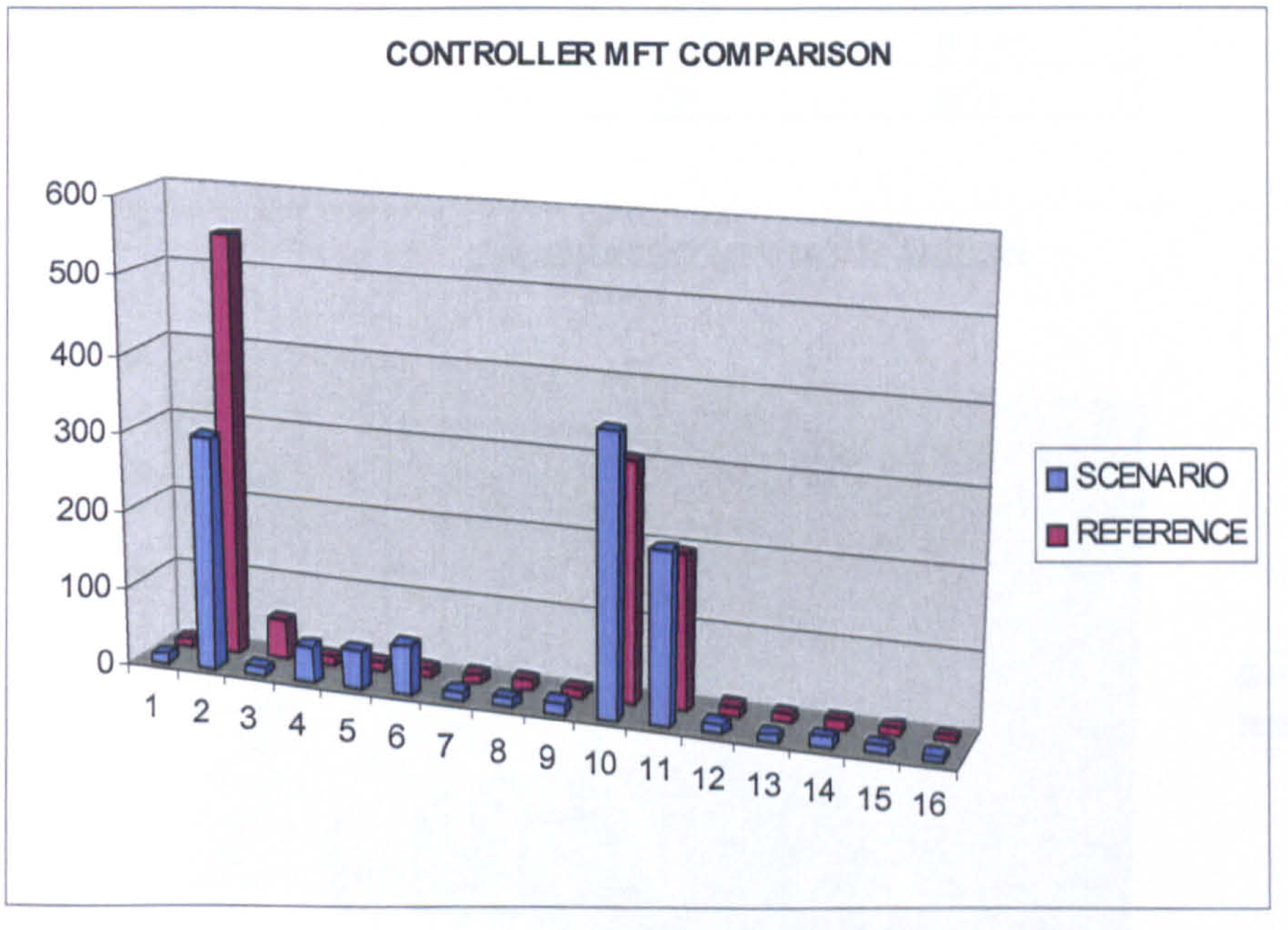
REAGENT TABLE COMPARISON

SCENARIO			REFERENCE MODEL	
TEST	MFT (hour)	INV	MFT(hour)	INV
1	36.96	5625	62	5518
2	90.7	893	104	772
3	79.65	7729	43	8045
4	66.69	2504	62	1688
5	38.4	3656	57	2817
6	22.32	1162	68	1081
7	36.84	55435	55	54196
8	152.78	775	81	804
9	34.167	23579	29	14193
10	24.3399	11830	26	31410
11	41.72	1765	126	1074
12	54.29	58367	60	1963
13	78.1	45459	83	81096
14	20.887	19346	32	36331
15	25.61	3104	54	12447
16	13	264	13	353



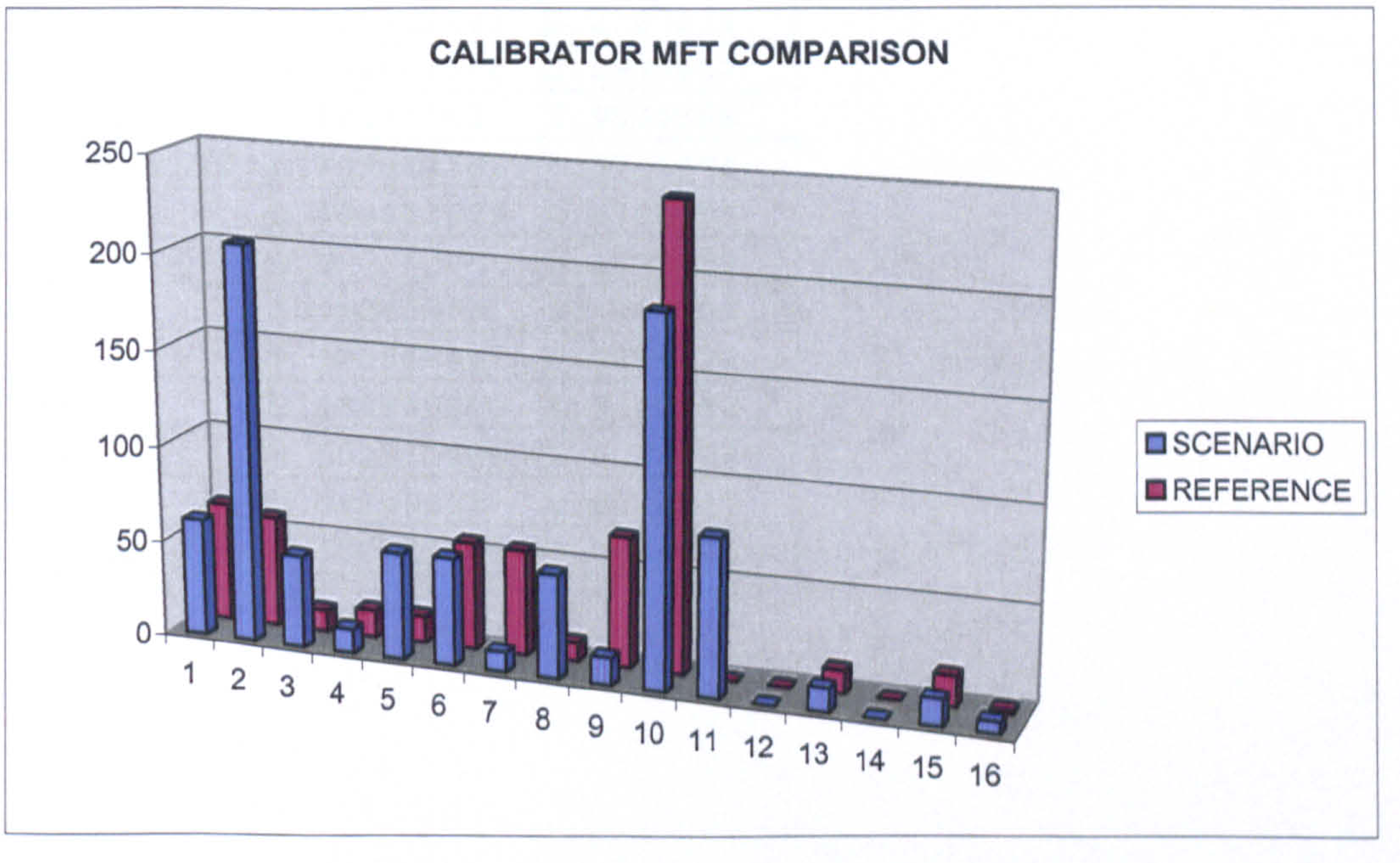
CONTROLLER COMPARISON TABLE

SCENARIO			REFERENCE	
TEST	MFT(hour)	INV	MFT(hour)	INV
1	12.38	2177	11	2203
2	299.87	1995	542	2433
3	10.256	2814	53	2559
4	47	500	13	571
5	48.76	863	12	941
6	63.168	337	11	382
7	12.855	20085	11	20107
8	12.922	240	13	238
9	14.854	4682	10	4637
10	358.31	16620	306	17221
11	219.8	315	197	316
12	13.6	294	13	392
13	7.99	24161	12	21692
14	13.9244	13392	12	14687
15	10.8	4097	11	4089
16	6.609	811	8	805



Calibrator comparison Table

SCENARIO			REFERENCE MODEL	
TEST	MFT(hour)	INV	MFT(hour)	INV
1	61.335	2096	62	2101
2	206.7	5	58	286
3	48.42	2768	11	3028
4	12.92	605	14	613
5	55.78	938	14	1012
6	56.15	377	56	377
7	10.414	21319	55	20091
8	54.12	231	10	254
9	14.29	5086	68	4763
10	190.12	16127	239	16331
11	81.9	523	0	234
12	N/A	N/A	N/A	N/A
13	12.42	25677	12	25469
14	N/A	N/A	N/A	N/A
15	13.714	4523	16	4498
16	6	544	2	655



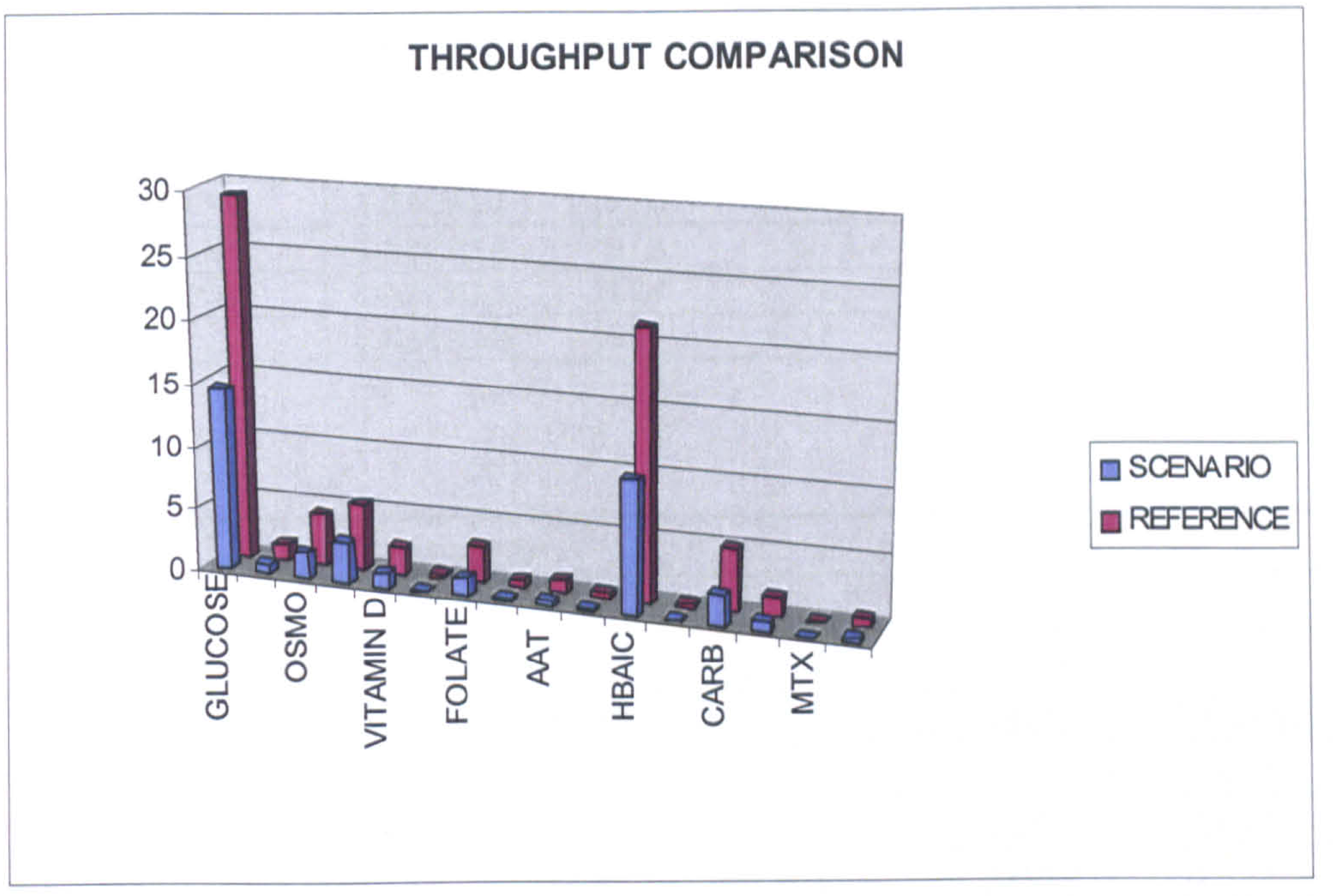
6.6.2.1.3 Throughput

Throughput of the test as indicated in the Table and Graph 6.25 was effected negatively by the supplier's poor commitment of delivering the items. Although the hospital tries to control the business within the premises, the effect of unreliable suppliers can have a huge role on the performance of delivering the services timely, as it is the case in this scenario. The throughput of the lab is affected negatively because of unreliable suppliers, so the different policies to purchase the needed items should be introduced such as prime vendors, as discussed in section 2.4.2.2.2.

Table and Graph 6.25

THROUGHPUT COMPARISON
(rate of test/hour)

SCENARIO		REFERENCE
TEST	THROUGHPUT	THROUGHPUT
GLUCOSE	14.63047945	29.118036
KETONE	0.698059361	1.3828767
OSMO	2.096803653	4.1858447
URINE	3.264383562	5.3260273
VITAMIN D	1.130251142	2.2187214
BHCG	0.068607306	0.2979452
FOLATE	1.48413242	2.9504566
HOMOCYSTINE	0.289840183	0.5760273
AAT	0.488013699	0.9703196
G6PD	0.2	0.4077625
HBAIC	10.5869863	21.281735
VMA	0.123858447	0.2605022
CARB	2.454908676	4.9803652
FK506	0.802511416	1.6050228
MTX	0.04109589	0.0821917
OPIATES	0.352283105	0.7038812



6.6.2.1.4 Inventory Status

According to Table 6.26, there is not much change in the inventory of all components whether in the Lab or Logistics in comparison to the Reference Model. The hospital gets use to the delays caused by suppliers, so they tend to store more items once the requested shipment is not delivered on time. This way of managing the important medical material does not only inflate the cost but also manipulates and risks the patient health.

Table 6.26

STORAGE COMPARISON (number of components)

LAB STORAGE TABLE

REAGENT

SCENARIO		REFERE
COMPON	VALUE	VALUE
LABRE1	1464	1482
LABRE2	165	195
LABRE3	1998	1918
LABRE4	435	394
LABRE5	583	640
LABRE6	251	248
LABRE7	13724	13663
LABRE8	275	284

CALIBRATOR

SCENARIO		REFER
COMPON	VALUE	VALUE
LABCA1	91	91
LABCA2	3	12
LABCA3	120	120
LABCA4	23	23
LABCA5	36	37
LABCA6	15	15
LABCA7	782	766
LABCA8	9	10

CONTROLLER

SCENARIO		REFER
COMPON	VALUE	VALUE
LABCO1	137	142
LABCO2	148	142
LABCO3	180	183
LABCO4	38	39
LABCO5	63	64
LABCO6	25	24
LABCO7	1,296	1448
LABCO8	17	15

LABRE9	3201	3258
LABRE10	10951	10988
LABRE11	242	242
LABRE12	440	442
LABRE13	19071	19076
LABRE14	9226	9125
LABRE15	2872	2893
LABRE16	38	55

LABCA9	184	183
LABCA10	673	671
LABCA11	184	184
LABCA12	N/A	N/A
LABCA13	976	989
LABCA14	N/A	N/A
LABCA15	169	167
LABCA16	42	38

LABCO9	304	335
LABCO10	28	28
LABCO11	3	3
LABCO12	28	34
LABCO13	1,818	1680
LABCO14	817	875
LABCO15	265	267
LABCO16	40	39

LOG STORAGE TABLE

REAGENT

SCENARIO		REFER
COMPON	VALUE	VALUE
LOGRE1	4161	4036
LOGRE2	727	577
LOGRE3	5730	6127
LOGRE4	2069	1294
LOGRE5	3072	2177
LOGRE6	910	833
LOGRE7	41710	40533
LOGRE8	499	520
LOGRE9	20378	10935
LOGRE10	879	20422
LOGRE11	1522	832
LOGRE12	57926	1521
LOGRE13	26388	62020
LOGRE14	10120	27206
LOGRE15	231	9608
LOGRE16	226	298

CALIBRATOR

SCENARIO		REFER
COMPON	VALUE	VALUE
LOGCA1	2004	2010
LOGCA2	2	274
LOGCA3	2648	2908
LOGCA4	581	590
LOGCA5	901	975
LOGCA6	362	362
LOGCA7	20536	19325
LOGCA8	221	244
LOGCA9	4901	4580
LOGCA10	15454	15660
LOGCA11	338	50
LOGCA12	N/A	N/A
LOGCA13	24701	24480
LOGCA14	N/A	N/A
LOGCA15	4354	4331
LOGCA16	501	617

CONTROLLER

SCENARIO		REFER
COMPON	VALUE	VALUE
LOGCO1	2040	2061
LOGCO2	1847	2291
LOGCO3	2633	2376
LOGCO4	461	532
LOGCO5	800	877
LOGCO6	31	358
LOGCO7	18788	18659
LOGCO8	223	223
LOGCO9	4378	4302
LOGCO10	16592	17193
LOGCO11	312	313
LOGCO12	266	358
LOGCO13	22343	20012
LOGCO14	12575	13812
LOGCO15	3832	3822
LOGCO16	771	766

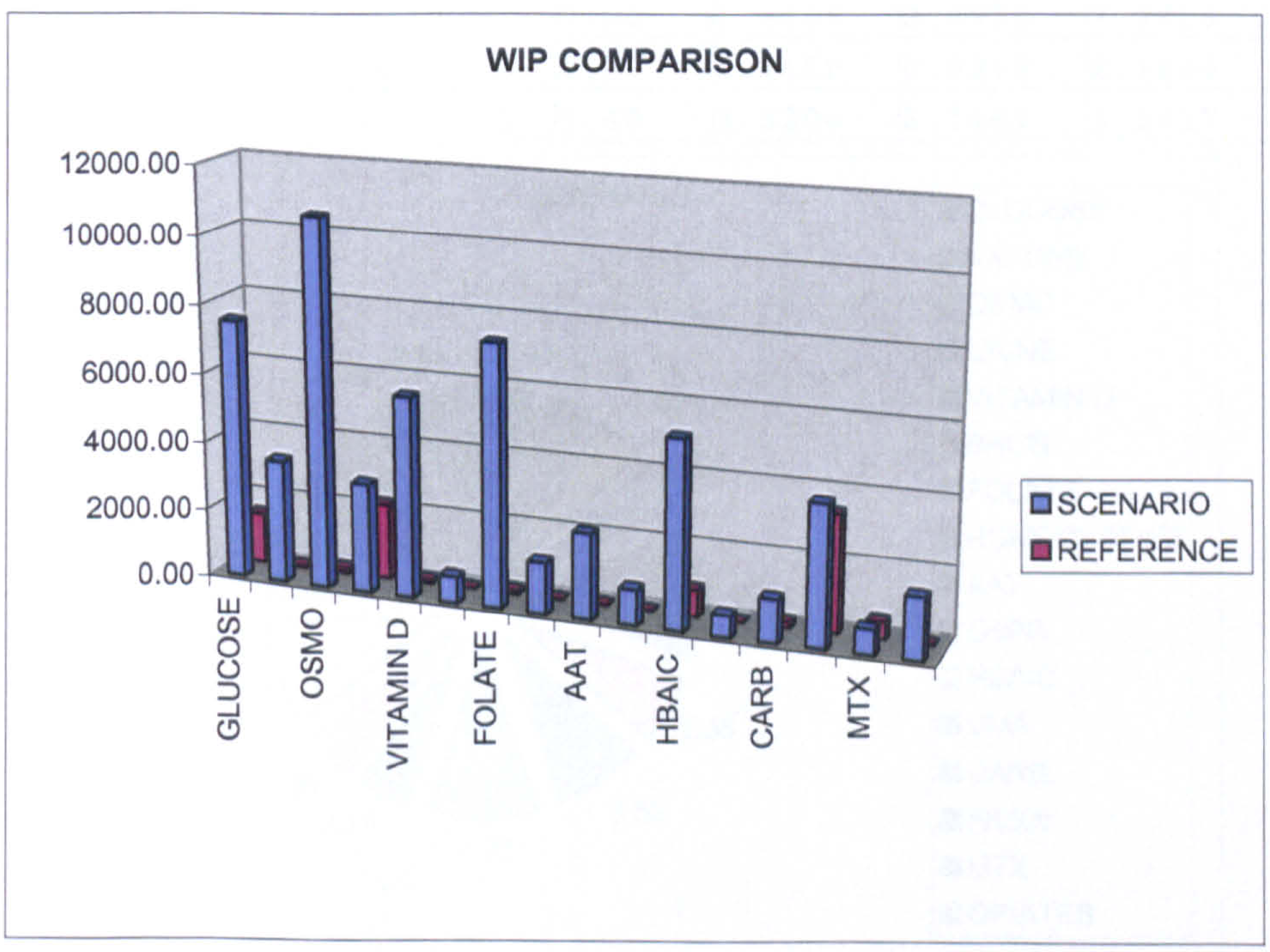
6.6.2.1.5 W I P

Table and Graph 6.27 indicates the level of work in process. The number of tests that are in progress has increased reflecting and correlated to the delay of the items that should be delivered on certain times. The effect of the supplier commitment to deliver on time is high causing high level of WIP. One of the possible ways of overcoming of this problem is to buy on consignment base as discussed in section (2.4.2.2.3). So, the inventory and accumulated cost can be shifted to the suppliers.

Table and Graph 6.27

WIP COMPARISON(number of unfinished tests)

SCENARIO		REFERENCE MODEL
TEST	AVERAGE	AVERAGE
GLUCOSE	7542	1487
KETONE	3576	39
OSMO	10741	127
URINE	3206	2208
VITAMIN D	5831	94
BHCG	766	11
FOLATE	7603	108
HOMOCYSTINE	1498	21
AAT	2509	29
G6PD	1045	13
HBAIC	5465	776
VMA	641	8
CARB	1261	161
FK506	4069	3398
MTX	733	499
OPIATES	1801	3

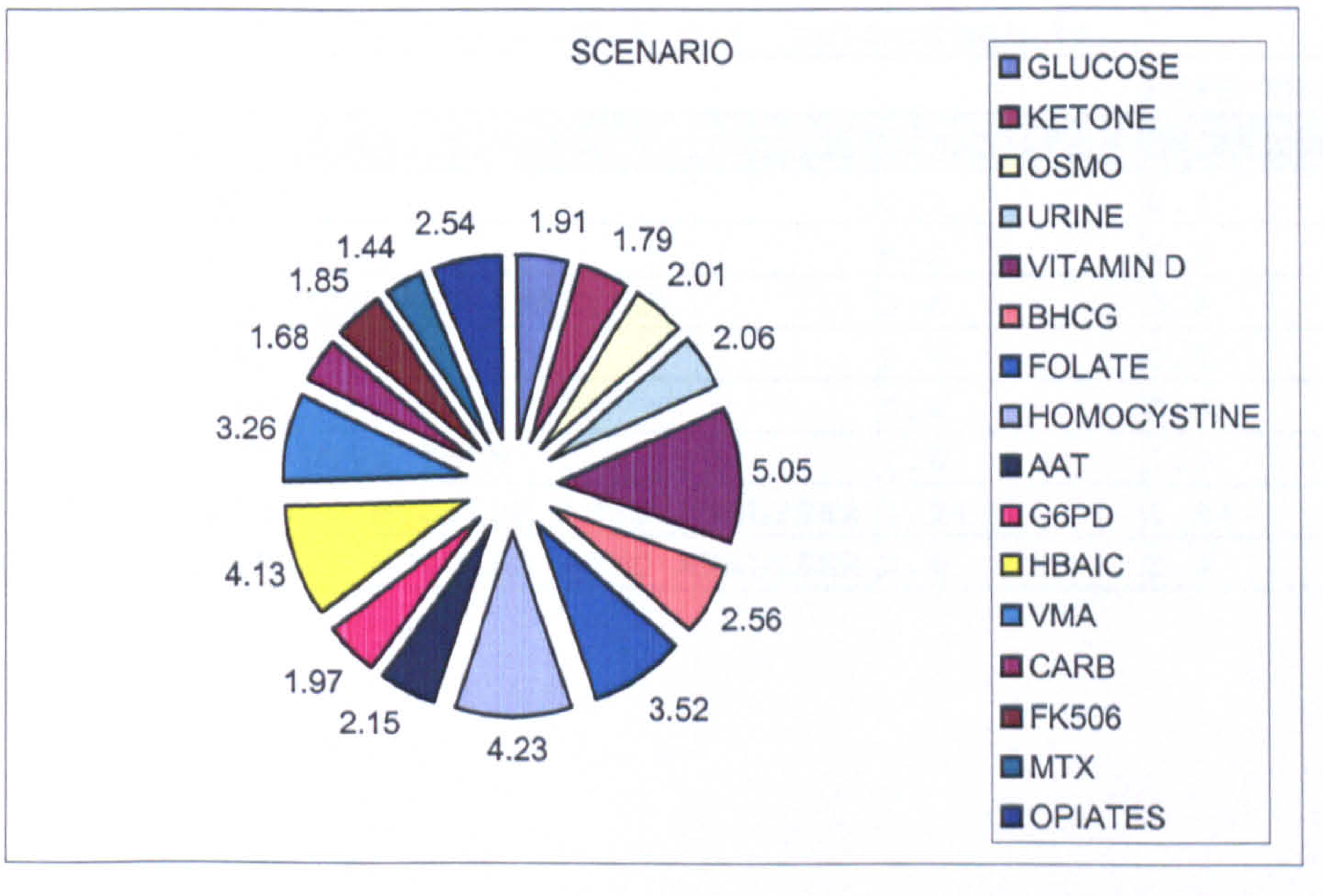


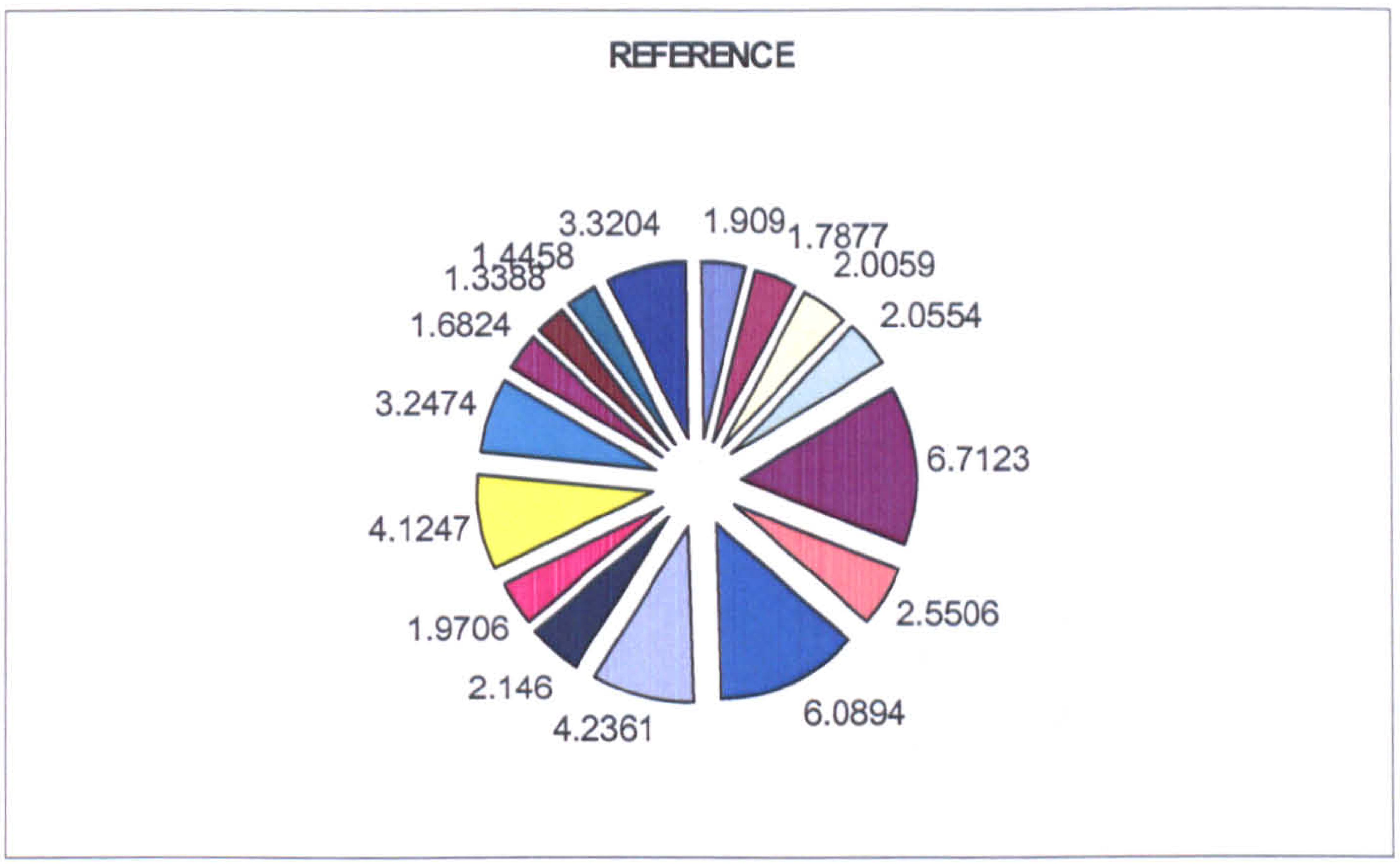
6.6.2.1.6 Cost of Test

The costs of each test are not much different than the Reference Model (Table and Graph 6.28) because of the staff and resources are still included as a part total value.

Table and Graph 6.28
COST COMPARISON OF EACH TEST(in sterling Pound)

SCENARIO				REFERENCE MODEL		
TEST	AVE	MIN	MAX	AVE	MIN	MAX
GLUCOSE	1.91	1.29	2.92	1.909	1.3069	2.9198
KETONE	1.79	1.31	2.76	1.7877	1.2774	2.6887
OSMO	2.01	1.44	2.91	2.0059	1.4676	2.9917
URINE	2.06	1.49	3.02	2.0554	1.5012	3.0116
VITAMIN D	5.05	4.34	6.12	6.7123	5.028	1442.09
BHCG	2.56	1.98	3.58	2.5506	1.9726	3.409
FOLATE	3.52	2.88	4.60	6.0894	4.8963	7.6853
HOMOCYSTINE	4.23	3.51	5.40	4.2361	3.487	5.3294
AAT	2.15	1.59	3.13	2.146	1.5995	3.0629
G6PD	1.97	1.42	2.87	1.9706	1.4252	2.9165
HBAIC	4.13	3.07	12.81	4.1247	3.0526	11.6439
VMA	3.26	2.45	4.38	3.2474	2.4026	4.1936
CARB	1.68	1.18	2.62	1.6824	1.1864	2.6089
FK506	1.85	1.35	0.00	1.3388	2.6976	2.7603
MTX	1.44	0.90	2.17	1.4458	0.9949	2.1895
OPIATES	2.54	2.17	3.40	3.3204	2.1464	3.3417





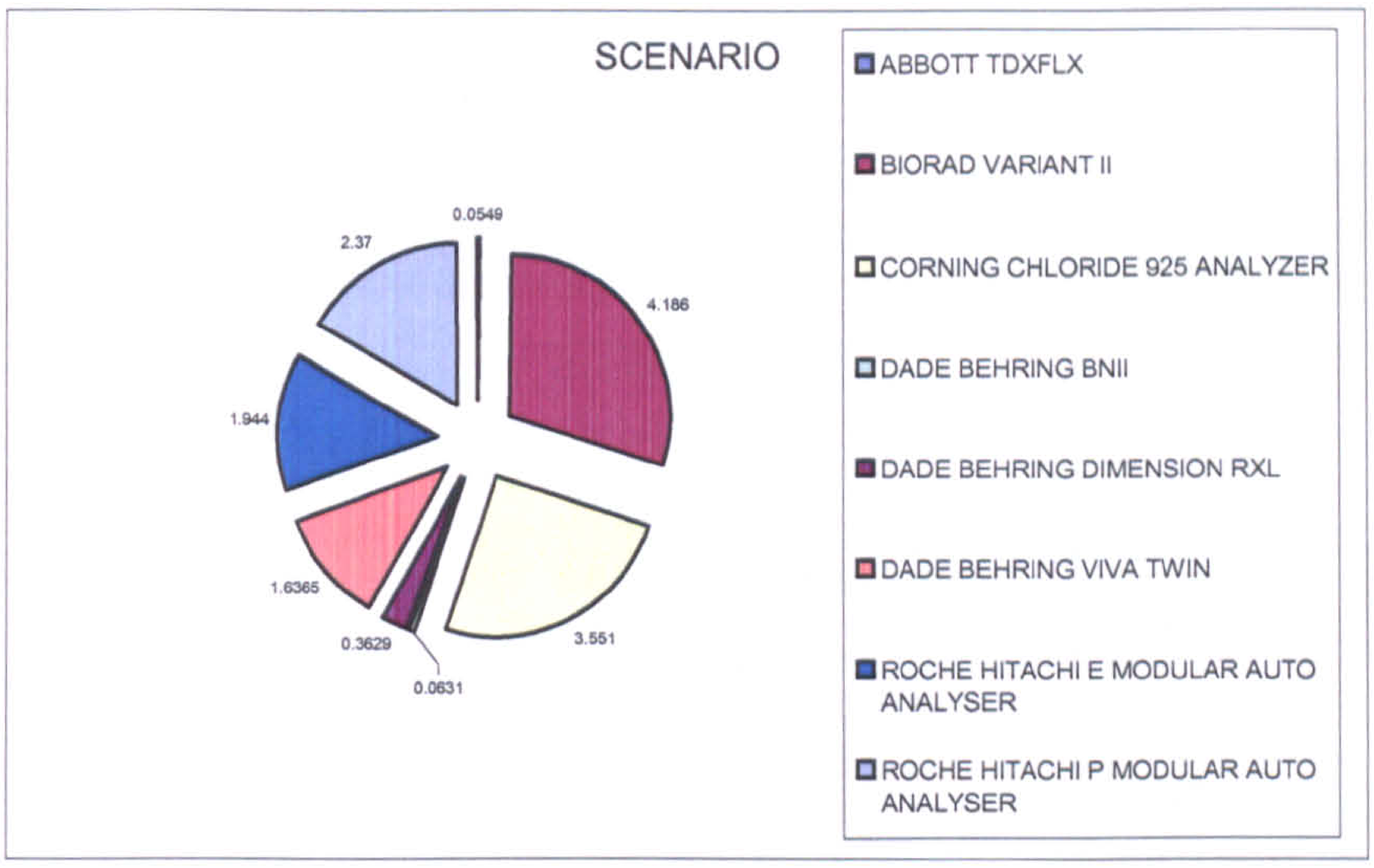
6.6.2.2 Secondary Performance Measures

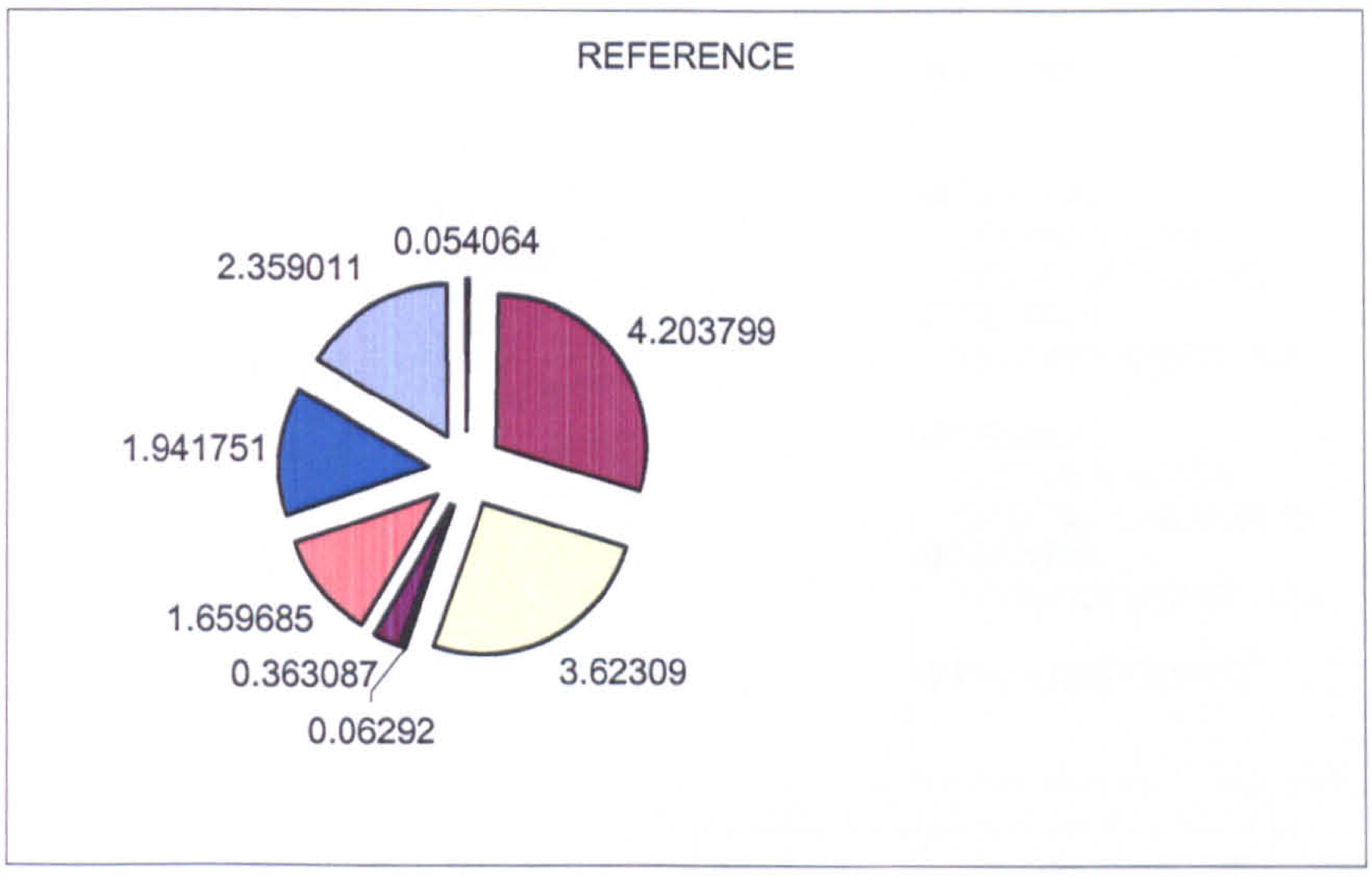
6.6.2.2.1 Equipment Utilization

The utilization is more or less the same as the Reference Model for all items, since the system is assumed to be working normal conditions except some occasional interruptions in material supply (Table and Graph 6.29).

Table and Graph 6.29
EQUIPMENT UTILIZATION COMPARISON (percentage %)

SCENARIO		REFERENCE
EQUIPMENT	UTILIZATION	UTILIZATION
ABBOTT TDXFLX	0.1	0.1
BIORAD VARIANT II	4.2	4.2
CORNING CHLORIDE 925 ANALYZER	3.6	3.6
DADE BEHRING BNII	0.1	0.1
DADE BEHRING DIMENSION RXL	0.4	0.4
DADE BEHRING VIVA TWIN	1.6	1.7
ROCHE HITACHI E MODULAR AUTO ANALYSER	1.94	1.94
ROCHE HITACHI P MODULAR AUTO ANALYSER	2.4	2.4





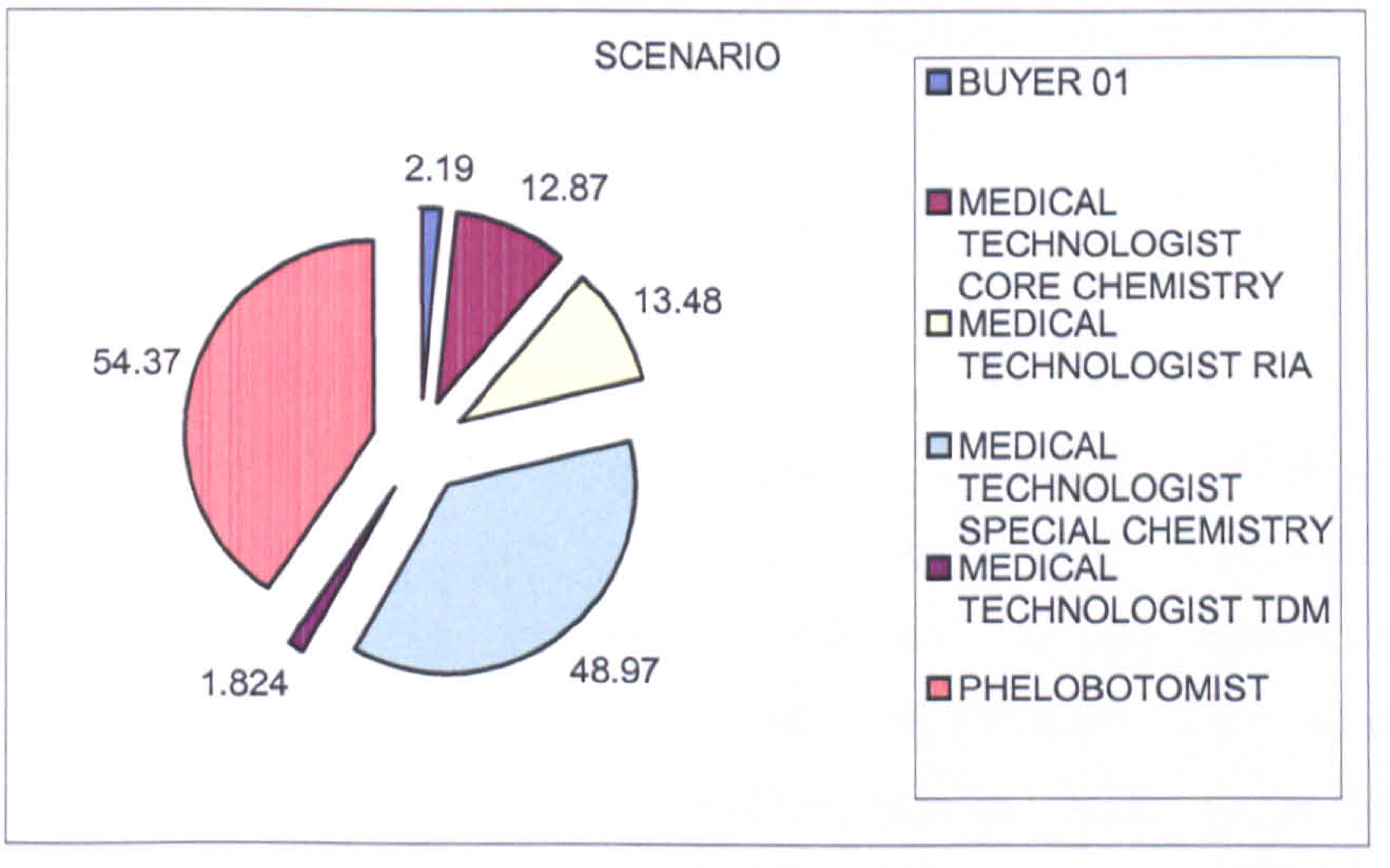
6.6.2.2.2 Staff Utilization

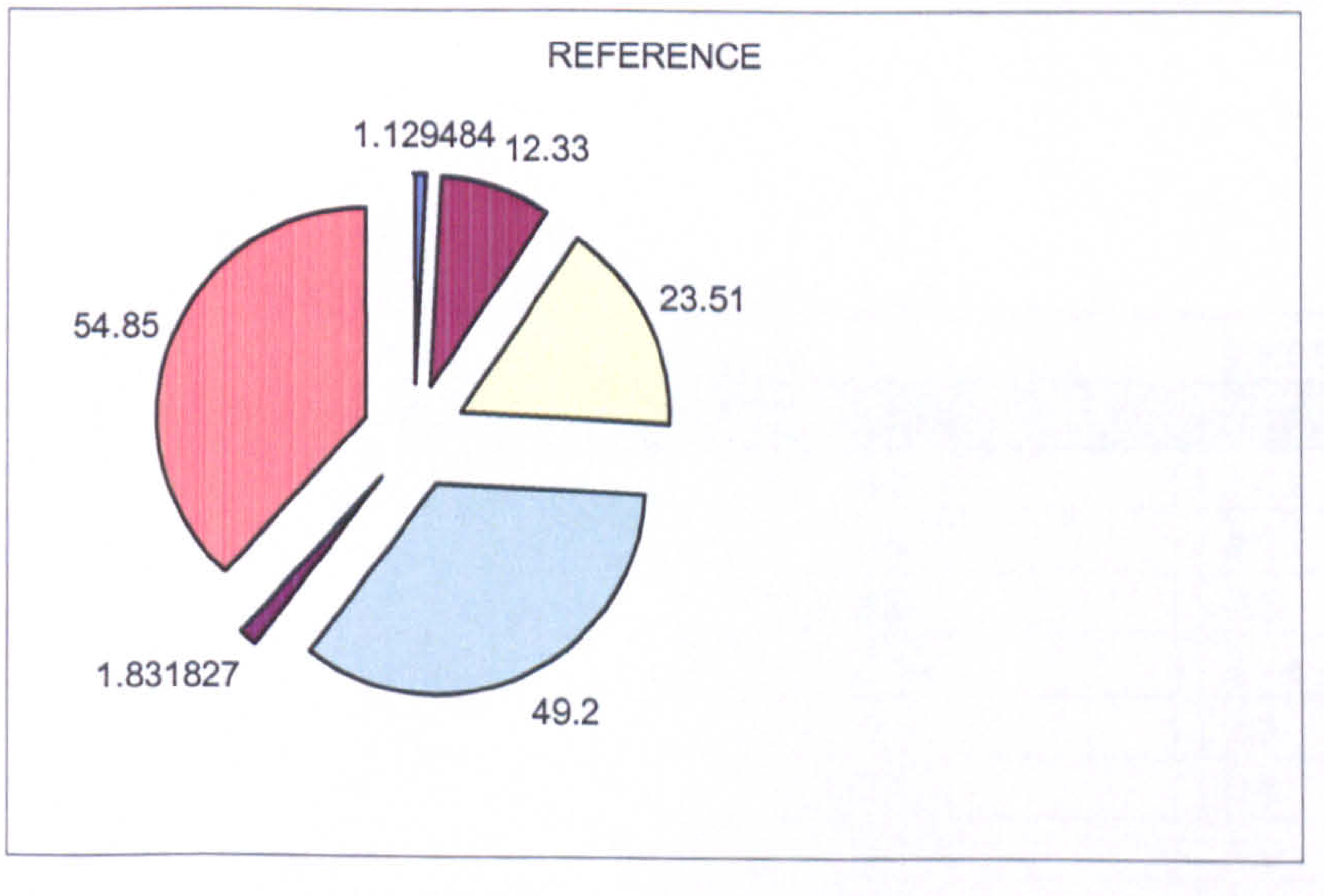
The utilization remained the same as the Reference Model with the exception of the buyer which was slightly increased reflecting the increase of the number of orders. Also the RIA Medical Technologist dropped by 50 percent, indicating of less number of requests for this particular group (Table and Graph 6.30).

Table and Graph 6.30

Staff Utilization (percentage %)

SCENARIO		REFERENCE
STAFF	UTILIZATION	UTILIZATION
BUYER 01	2.19	1.129484
MEDICAL TECHNOLOGIST CORE CHEMISTRY (Glucose, Ketone, Osmo, and Ur. Protein)	12.87	12.33
MEDICAL TECHNOLOGIST RIA (Vitamin D, BHCG, Folate, Homocytine)	13.48	23.51
MEDICAL TECHNOLOGIST SPECIAL CHEMISTRY (AAT, G6PD, HBAIC, VMA)	48.97	49.2
MEDICAL TECHNOLOGIST TDM (Carb, FK506, MTX, Opiates)	1.824	1.831827
PHLEBOTOMIST	54.37	54.85





6.6.2.2.3 Material Order Size

The material orders (Table 6.31) increased for all components by more than 100% for the calibrator and 5% for the reagent and the controller. As a reflection of not receiving the items on time that are requested. The lab requests more materials in high quantity to cover the supplier delay, which results of high quantity without usage.

Table 6.31
MATERIAL ORDER SIZE COMPARISON

SCENARIO		REFERENCE MODEL
NAME OF ORDER	NUMBER OF ORDERS	NUMBER OF ORDERS
CONTROL	415	393
CALIBRATOR	459	182
REAGENT	574	532

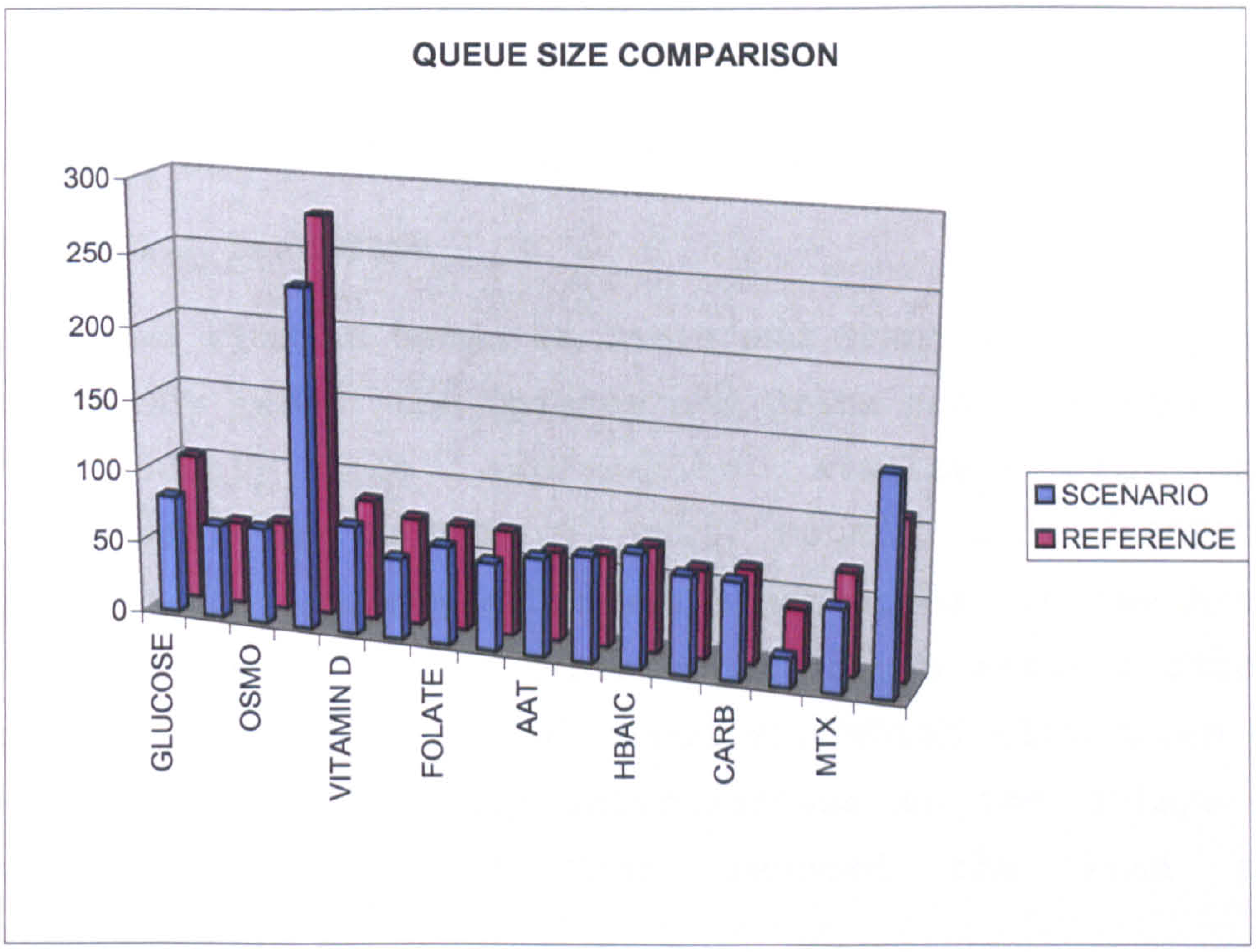
6.6.2.2.4 Queue Size

As discussed in the lead time, similarly the queue size (Table and Graph 6.32) fluctuated according to the availability of supplies. As it can be observed from the table, the queue size has increased for the materials used in certain tests and remained the same or decreased slightly for the materials that are available for some other tests.

Table and Graph 6.32
QUEUE SIZE COMPARISON(hour)

SCENARIO		REFERENCE MODEL
TEST	AVER	AVER
GLUCOSE	81	101
KETONE	64	57
OSMO	65	60
URINE	234	276
VITAMIN D	74	82
BHCG	55	73
FOLATE	67	72
HOMOCYSTINE	59	71
AAT	66	61
G6PD	71	63
HBAIC	77	72

VMA	66			60		
CARB	66			64		
FK506	19			41		
MTX	56			69		
OPIATES	147			108		



6.6.2.3 Conclusion

Suppliers are the essential part of the supply chain system and any problem with supply process, the whole chain would be affected. As we went through the performance metrics of this scenario, the throughput of the chemistry lab is relatively low. Therefore, there should be a safety stock for all the components used once needed by the patients. But as mention before this is not a cheap solution. The hospital management should seek help of the manufacturing tools and techniques, as discussed in the previous sections (2.4.2.2 and 3.3) to find alternative solutions which may be applicable to the health care industry to fill the gab between the hospital and the vendor or supplier.

6.6.3. Scenario Three: I_{MAX} Inventory Policy

I_{max} is an inventory policy, which orders a maximum quantity once the stock levels dropped to the re-order point. Some would argue making the inventory always full is a guarantee of material availability, but this comes with an expense and would increase the over-all costs.

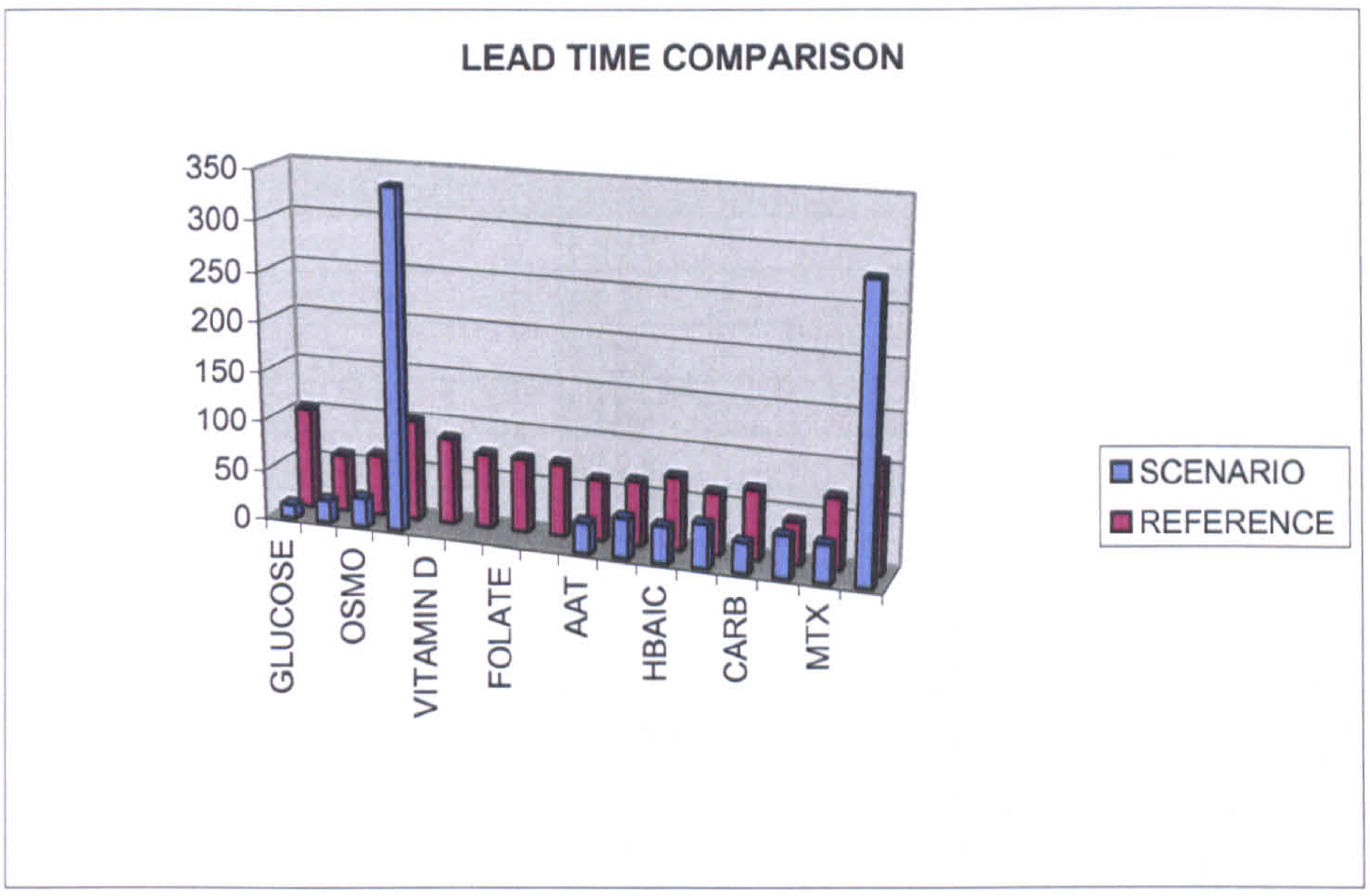
6.6.3.1 Primary Performance Measures

6.6.3.1.1 Lead Time

The lead time as shown in Table and Graph 6.33 dropped by 50 to 90% except the Opiates and Urine test has increased tremendously (no explanation available for this increase). The VITAMIN D, BHCG, FOLATE, and HOMOCYSTINE drop to the minimum which would not appear in the Arena. These decrease of the tests apparently a natural outcome of stock availability of supplies, which eliminates the short-of-stock and any interruptions so the delays are eliminated which in turn reduced the lead time considerably.

Table and Graph 6.33
LEAD TIME COMPARISON TO REFERENCE MODEL(hour)

SCENARIO:				REFERENCE MODEL		
TEST	MIN	AVR	MAX	MIN	AVR	MAX
GLUCOSE	0.3869	13.6517	139.04	0.4	102	733
KETONE	0.2411	22.3404	245.51	0.24	57.5	248
OSMO	0.2872	29.013	246.96	0.29	61	249
URINE	0.4128	339.491	5939.58	0.41	100	725
VITAMIN D	N/A	N/A	N/A	2.4	85.5	383
BHCG	N/A	N/A	N/A	0.47	74	369.5
FOLATE	N/A	N/A	N/A	1.5	73.7	380.3
HOMOCYSTINE	N/A	N/A	N/A	1.13	73	355
AAT	0.3873	30.6455	204.17	0.39	61.6	258
G6PD	0.4353	40.1356	200.22	0.42	64	268
HBAIC	0.5216	36.6455	319.5	0.52	73	399.8
VMA	0.6365	43.4815	189.3	0.64	61.5	266.4
CARB	0.4822	29.4835	187.12	0.48	69	280
FK506	0.4617	41.3743	194.38	0.46	41.8	175.2
MTX	0.3654	37.3901	186.44	0.37	69.9	219.3
OPIATES	0.2338	287.601	6427.96	0.23	108	899

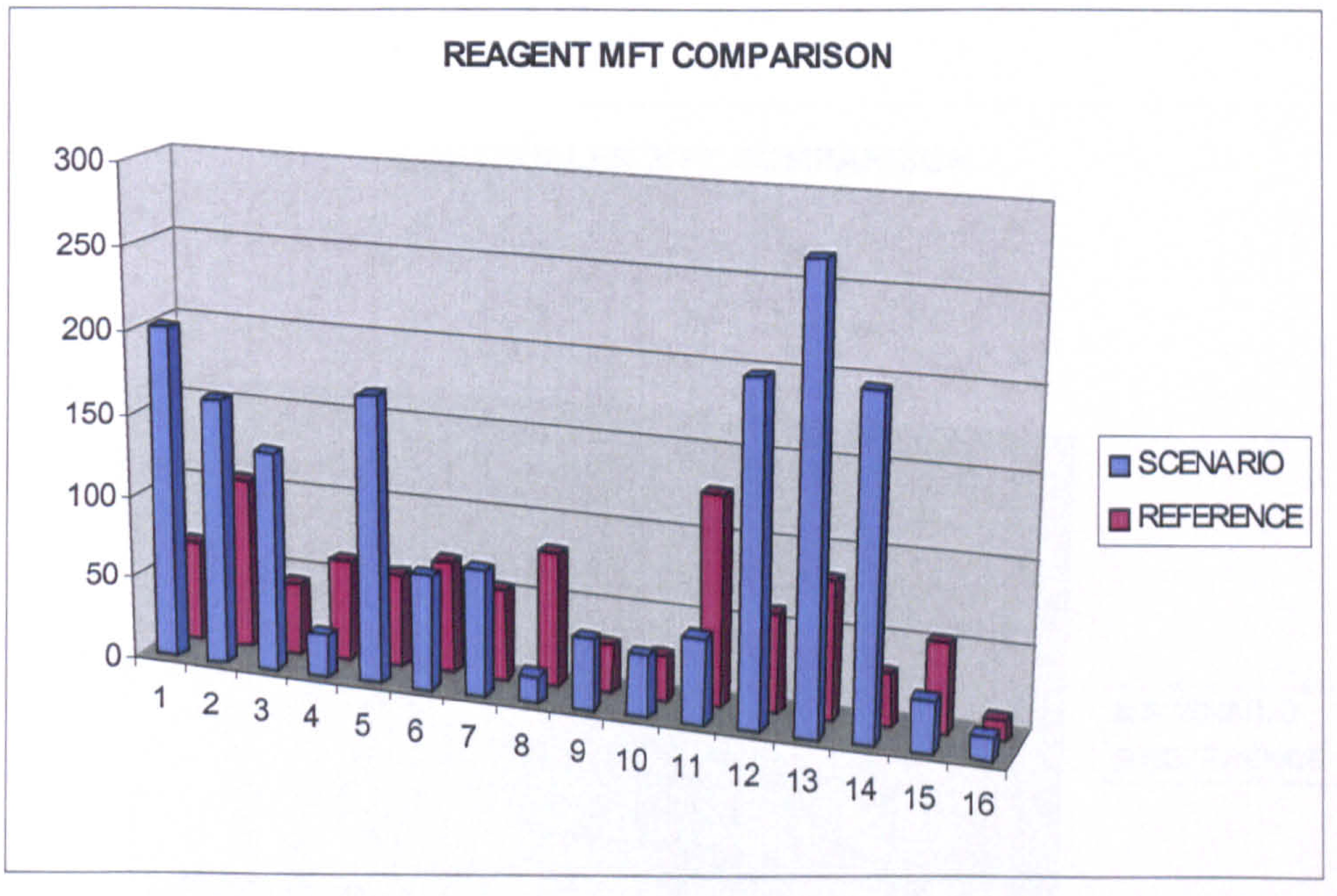


6.6.3.1.2 Material Flow time

More than 70% of all tests are affected by increasing the MFT while the other decreased as illustrated in Table and Graph 6.34 which consist of reagent, calibrator, and controller. One of the reason is the logistic can not cup with high quantity of supplies like the increase of inventory of Homocystine from 804 to 43812. Material with short shelf lives have increased by making sure that all the stock is always available most of time up to its maximum level. Therefore, when we include the shelf life into calculation of material flow time from procurement point to the consuming it, this gives rather a long flow time like GLUCOSE. However, when we start the flow time from the point of delivering it to the lab for any processing, this has dropped slightly as a result of less interruption and less idleness.

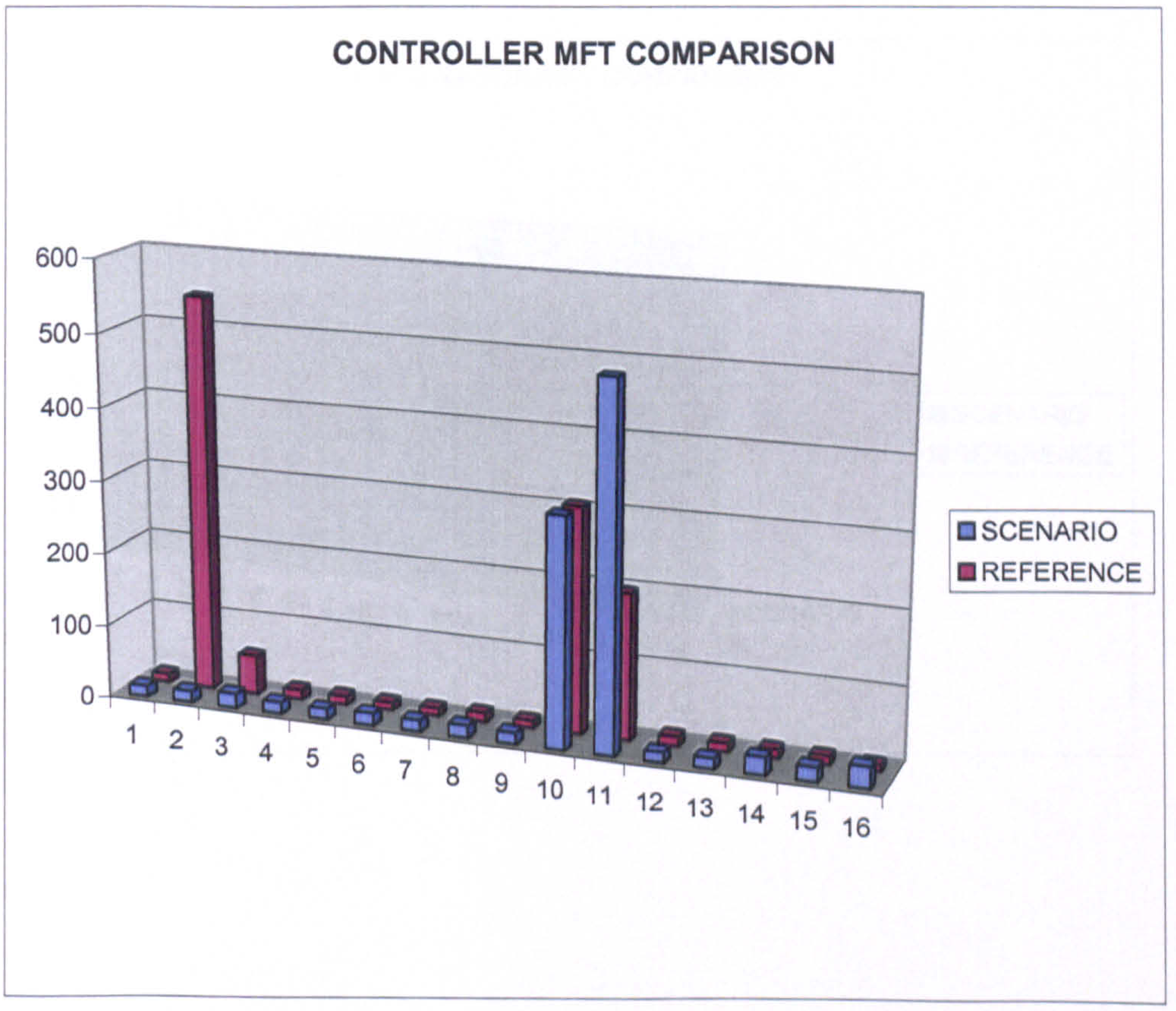
Table and Graph 6.34
REAGENT TABLE COMPARISON

SCENARIO			REFERENCE MODEL	
TEST	MFT(hour)	INV	MFT(hour)	INV
GLUCOSE	202.95	6597	62	5518
KETONE	161.8	953	104	772
OSMO	132.95	9371	43	8045
URINE	26.39	1403	62	1688
VITAMIN D	173.56	3228	57	2817
BHCG	69.34	1168	68	1081
FOLATE	76.96	25673	55	54196
HOMOCYSTINE	16.51	43812	81	804
AAT	43.422	14472	29	14193
G6PD	36.99	43498	26	31410
HBAIC	52	897	126	1074
VMA	204.86	2131	60	1963
CARB	272.86	183896	83	81096
FK506	202.96	36897	32	36331
MTX	31.7	14445	54	12447
OPIATES	14.53	67	13	353



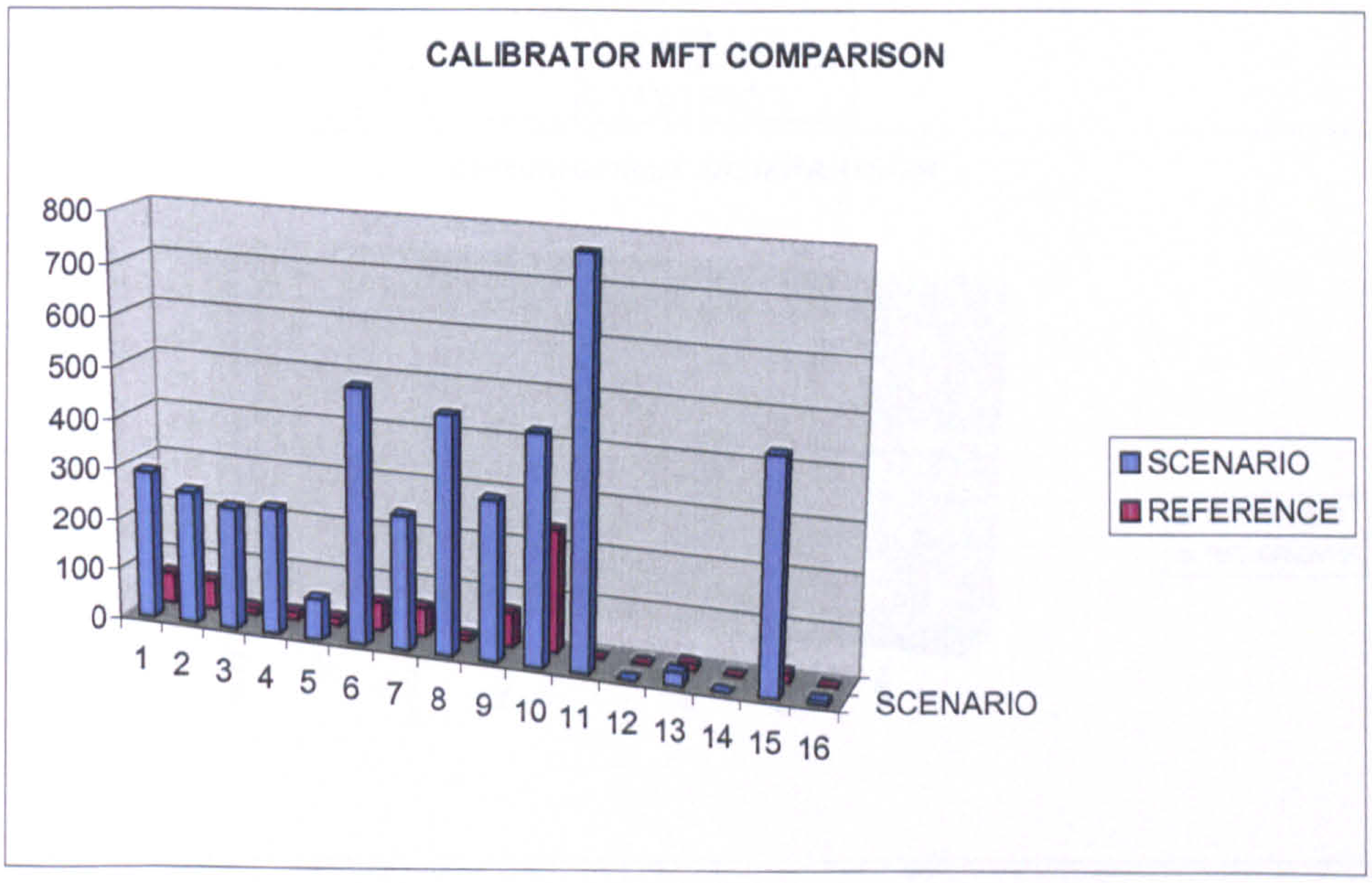
CONTROLLER COMPARISON TABLE

SCENARIO			REFERENCE	
TEST	MFT(hours)	INV	MFT(hours)	INV
GLUCOSE	15.2	38835	11	2203
KETONE	16	13290	542	2433
OSMO	20.8	16979	53	2559
URINE	16.96	2742	13	571
VITAMIN D	15.5	9111	12	941
BHCG	16.6	5831	11	382
FOLATE	15.5	109850	11	20107
HOMOCYSTINE	17	1466	13	238
AAT	15.7	51823	10	4637
G6PD	311.7	9824	306	17221
HBAIC	494.14	2623	197	316
VMA	14.418	2	13	392
CARB	14.22	296176	12	21692
FK506	24.26	2984	12	14687
MTX	19.72	36754	11	4089
OPIATES	29.06	912	8	805



CALIBRATOR TABLE

SCENARIO			REFERENCE MODEL	
TEST	MFT(hour)	INV	MFT(hour)	INV
GLUCOSE	292.6	636.45	62	2101
KETONE	261.6	36.28	58	286
OSMO	240.2	705.38	11	3028
URINE	249.7	110.58	14	613
VITAMIN D	78.1	187.09	14	1012
BHCG	501.6	66.91	56	377
FOLATE	263.4	6,120.73	55	20091
HOMOCYSTINE	465.2	46.05	10	254
AAT	311.1	1,323.46	68	4763
G6PD	447.4	4,064.01	239	16331
HBAIC	782.4	221.29	0	234
VMA	N/A	N/A	N/A	N/A
CARB	25.81	6,835.44	12	25469
FK506	N/A	N/A	N/A	N/A
MTX	450	901.78	16	4498
OPIATES	7.2	656.02	2	655



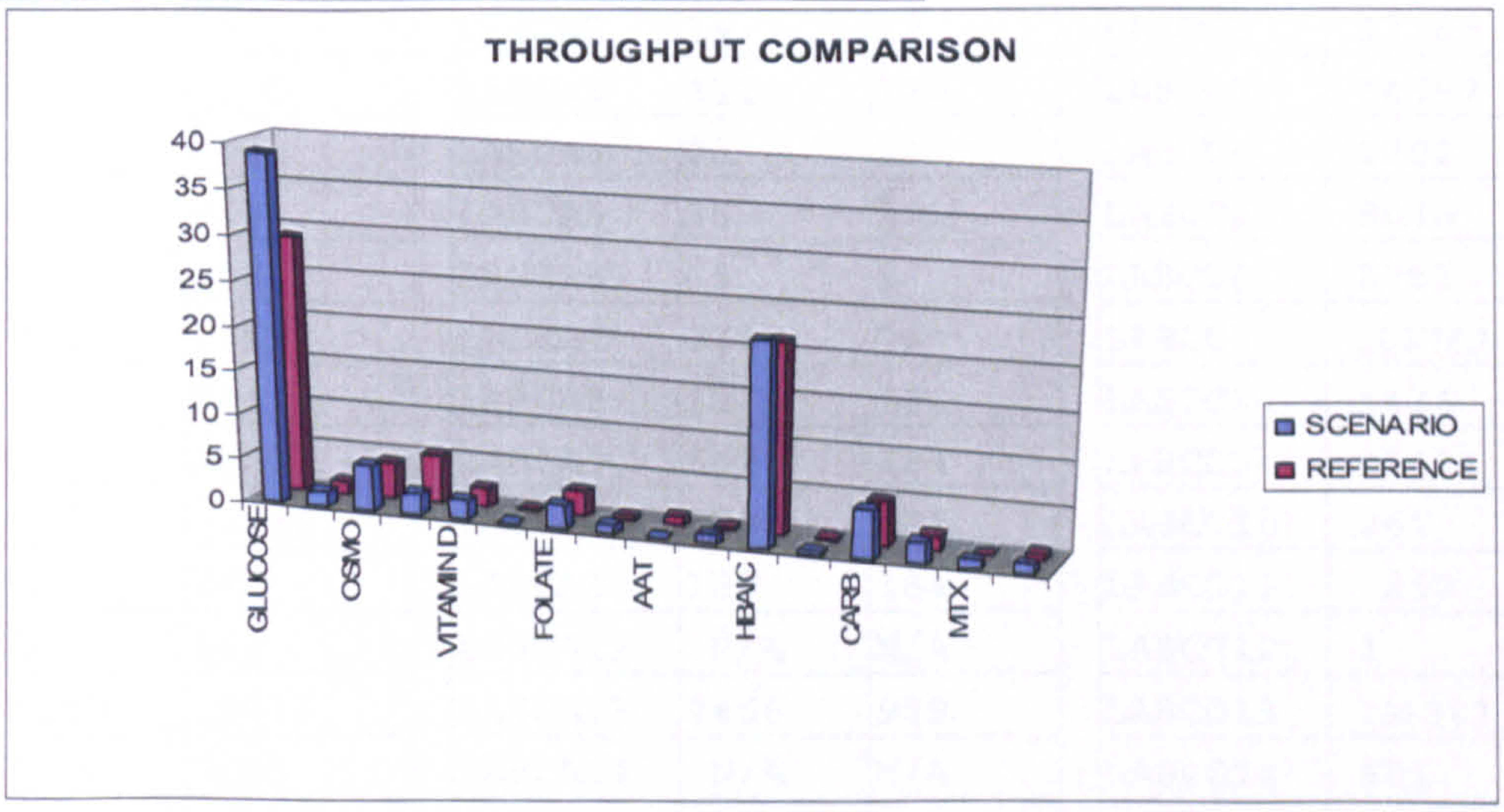
6.6.3.1.3 Throughput

Throughput of the test as indicated in Table and Graph 6.35 was effected positively in the most of the tests. This is a result of availability of the supplies.

Table and Graph 6.35

The Throughput (rate of test/hour)

SCENARIO		REFERENCE
TEST	THROUGHPUT	THROUGHPUT
GLUCOSE	39.07	29.118036
KETONE	1.68	1.3828767
OSMO	5.25	4.1858447
URINE	2.43	5.3260273
VITAMIN D	2.31	2.2187214
BHCG	0.04	0.2979452
FOLATE	2.85	2.9504566
HOMOCYSTINE	1.06	0.5760273
AAT	1.1	0.9703196
G6PD	1.05	0.4077625
HBAIC	22.49	21.281735
VMA	0.34	0.2605022
CARB	5.51	4.9803652
FK506	2.40	1.6050228
MTX	1.05	0.0821917
OPIATES	1.11 h	0.7038812



6.6.3.1.4 Inventory Status

According to Table 6.36, there is a serious amount of change in the inventory of all components whether in the Lab or Logistics in comparison to the Reference Model; it appears this is the worst scenario of handling the materials. This, in fact, expected results since the working mechanics of the adopted inventory policy concerns the maximum availability of the stock. Whenever any material stock level drops down to reorder level, the policy adopted immediately orders the item up to its maximum level ignoring the economic order quantity policy, which unnecessarily increase the level of stock mist of the time. This in turn causes a considerable amount of cost to the hospital. Some of the component like reagent (LABRE16) is less than the reference which may indicate to wrong calculation of safety threshold level.

Table 6.36

STORAGE COMPARISON (number of components)

LAB STORAGE TABLE

REAGENT

SCENARIO		REFER
COMPON	VALUE	VALUE
LABRE1	2373	1482
LABRE2	377	195
LABRE3	4814	1918
LABRE4	350	394
LABRE5	1345	640
LABRE6	500	248
LABRE7	24923	13663
LABRE8	227	284
LABRE9	5959	3258
LABRE10	13918	10988
LABRE11	291	242
LABRE12	868	442
LABRE13	145308	19076
LABRE14	15219	9125
LABRE15	6577	2893
LABRE16	37	55

CALIBRATOR

SCENARIO		REFER
COMPON	VALUE	VALUE
LABCA1	342	91
LABCA2	14	12
LABCA3	311	120
LABCA4	23	23
LABCA5	35	3
LABCA6	15	1
LABCA7	3337	76
LABCA8	12	10
LABCA9	662	183
LABCA10	2290	671
LABCA11	180	184
LABCA12	N/A	N/A
LABCA13	2466	989
LABCA14	N/A	N/A
LABCA15	351	167
LABCA16	156	38

CONTROLLER

SCENARIO		REFER
COMPON	VALUE	VALUE
LABCO1	37156	142
LABCO2	13189	142
LABCO3	14997	183
LABCO4	2702	39
LABCO5	9046	64
LABCO6	5781	24
LABCO7	108769	1448
LABCO8	1436	15
LABCO9	51414	335
LABCO10	267	28
LABCO11	242	3
LABCO12	1	34
LABCO13	295387	1680
LABCO14	901	875
LABCO15	33971	267
LABCO16	194	39

LOG STORAGE TABLE

REAGENT

CALIBRATOR

CONTROLLER

SCENARIO		REFER
COMPON	VALUE	VALUE
LOGRE1	4223	4036
LOGRE2	575	577
LOGRE3	4557	6127
LOGRE4	1053	1294
LOGRE5	1883	2177
LOGRE6	667	833
LOGRE7	750	40533
LOGRE8	43584	520
LOGRE9	8513	10935
LOGRE10	29579	20422
LOGRE11	606	832
LOGRE12	1263	1521
LOGRE13	3588	62020
LOGRE14	21678	27206
LOGRE15	7867	9608
LOGRE16	30	298

SCENARIO		REFER
COMPON	VALUE	VALUE
LOGCA1	293.76	2010
LOGCA2	22.1	274
LOGCA3	393.61	2908
LOGCA4	87.1008	590
LOGCA5	151.23	975
LOGCA6	51.5157	362
LOGCA7	2,783.0	19325
LOGCA8	33.5154	244
LOGCA9	661.44	4580
LOGCA10	1,773.1	15660
LOGCA11	41.2702	50
LOGCA12		N/A
LOGCA13	4,369.0	24480
LOGCA14		N/A
LOGCA15	550.02	4331
LOGCA16	500.01	617

SCENARIO		REFER
COMPON	VALUE	VALUE
LOGCO1	1679	2061
LOGCO2	101	2291
LOGCO3	1982	2376
LOGCO4	40	532
LOGCO5	65	877
LOGCO6	50	358
LOGCO7	1081	18659
LOGCO8	30	223
LOGCO9	409	4302
LOGCO10	9556	17193
LOGCO11	2381	313
LOGCO12	1	358
LOGCO13	789	20012
LOGCO14	2082	13812
LOGCO15	2783	3822
LOGCO16	717	766

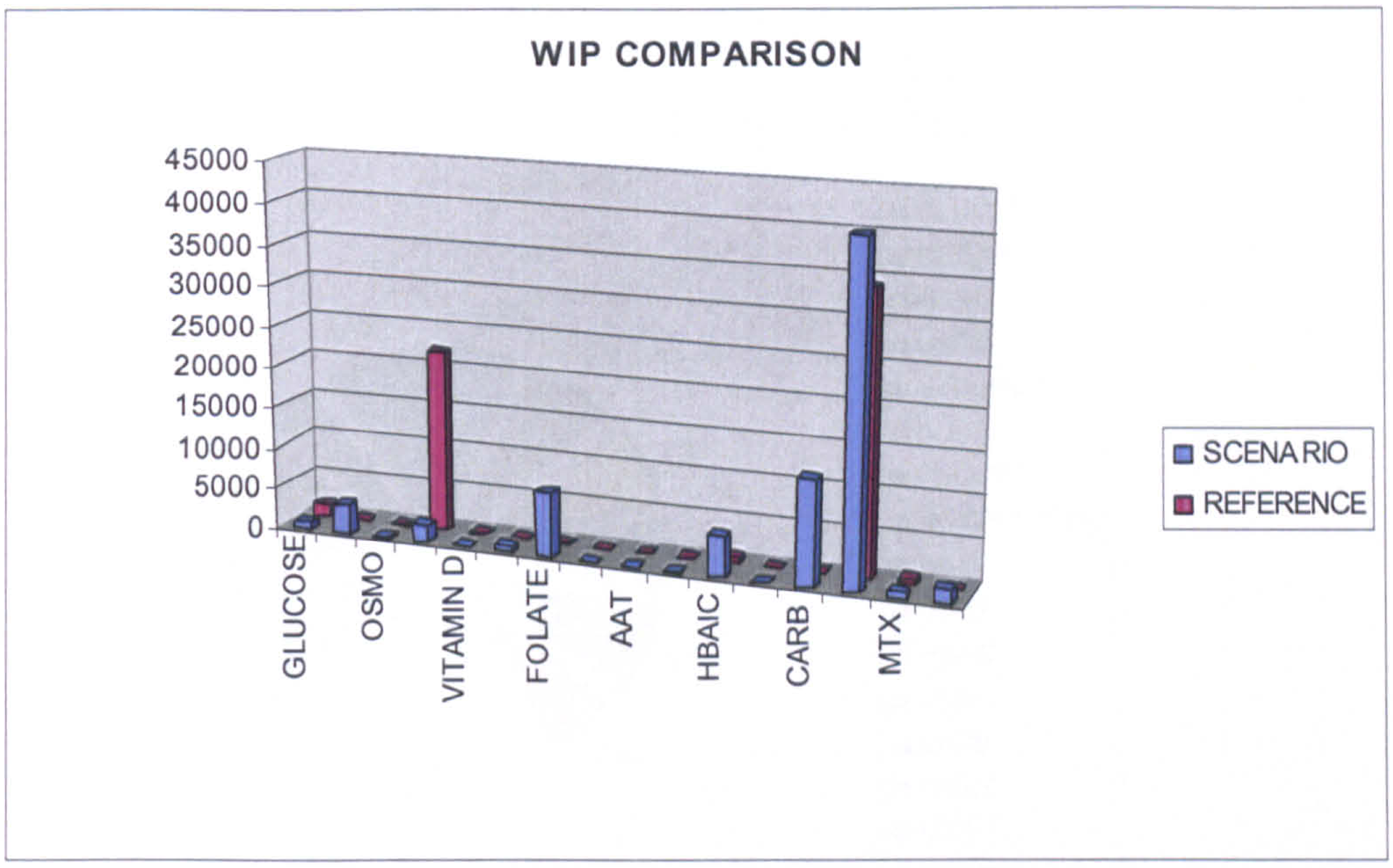
6.6.3.1.5 WIP

Table and Graph 6.37 indicates work in process. The materials used in tests have fluctuated increased items and decreasing other considerably; as a result of the I_{MAX} policy, which appears to be not applicable to healthcare because it do not proved a solution to the inventory rather increasing the work in process for some of the tests. However, this policy may be used for the strategic items, which shortage of them may cause serious consequences such as human life or serious illnesses.

Table and Graph 6.37
WIP COMPARISON(number of unfinished tests)

SCENARIO		REFERENCE MODEL
TEST	AVERAGE	AVERAGE
GLUCOSE	873	1487
KETONE	3544	39
OSMO	58	127
URINE	2112	2208
VITAMIN D	46	94
BHCG	759	11
FOLATE	7728	108
HOMOCYSTINE	14	21

AAT	24	29
G6PD	46	13
HBAIC	4934	776
VMA	0.3	8
CARB	1284	161
FK506	4085	3398
MTX	736	499
OPIATES	1701	38



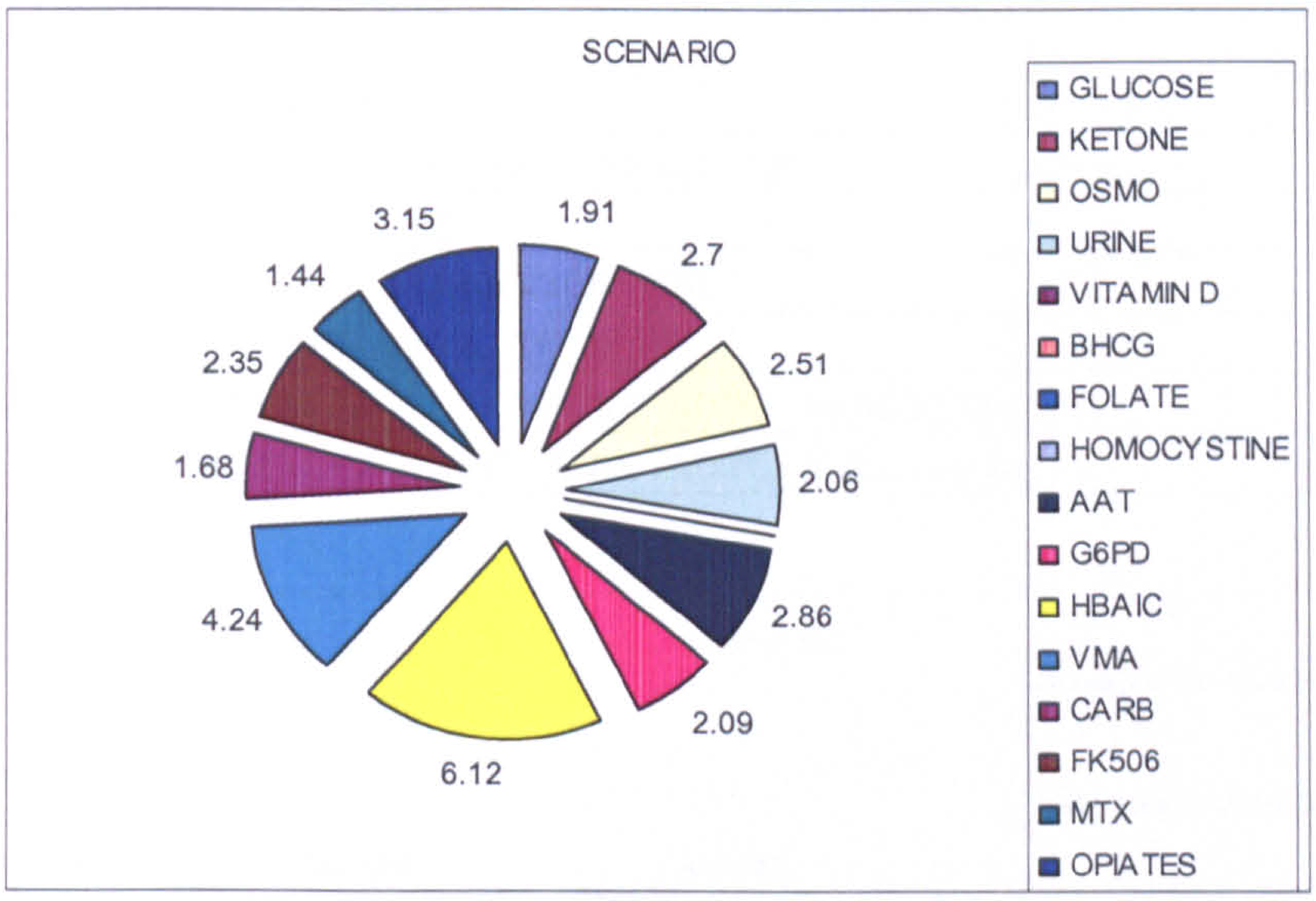
6.6.3.1.6 Cost of Test

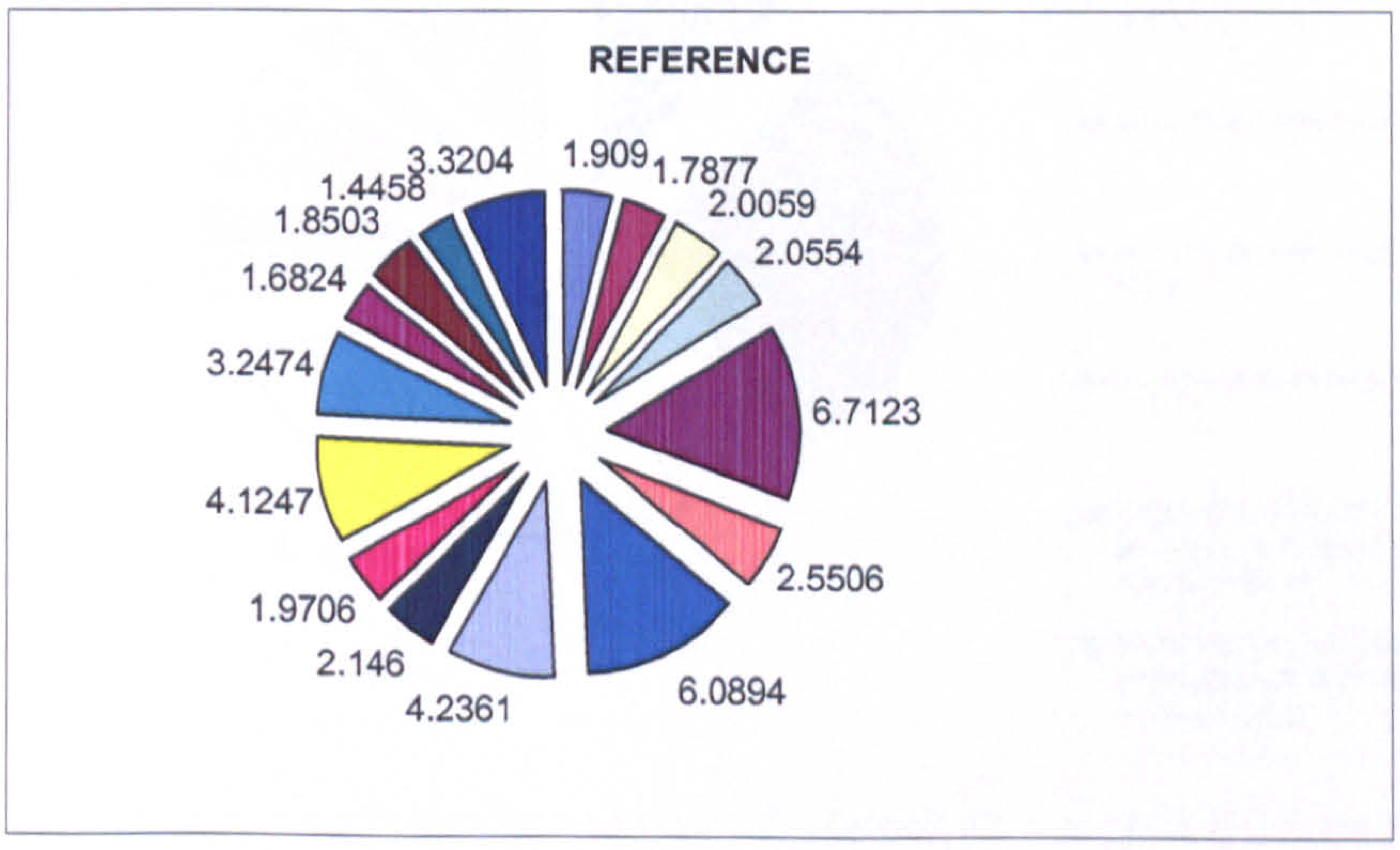
The costs of each test are higher than the Reference Model (Table and Graph 6.38) because of the Imax policy is very costly, need more staff and resources to monitor and order the needed quantity. All recourses are included in the test value calculation. RIA Section cost did not appear.

Table and Graph 6.38
COST COMPARISON OF EACH TEST(in sterling Pound)

SCENARIO				REFERENCE MODEL		
TEST	AVE	MIN	MAX	AVE	MIN	MAX
GLUCOSE	1.91	1.34	2.86	1.909	1.3069	2.9198
KETONE	2.70	1.28	2.76	1.7877	1.2774	2.6887
OSMO	2.51	1.44	2.95	2.0059	1.4676	2.9917
URINE	2.06	1.48	3.07	2.0554	1.5012	3.0116

VITAMIN D	N/A	N/A	N/A	6.7123	5.028	1442.09
BHCG	N/A	N/A	N/A	2.5506	1.9726	3.409
FOLATE	N/A	N/A	N/A	6.0894	4.8963	7.6853
HOMOCYSTINE	N/A	N/A	N/A	4.2361	3.487	5.3294
AAT	2.86	1.64	3.07	2.146	1.5995	3.0629
G6PD	2.09	1.44	2.83	1.9706	1.4252	2.9165
HBAIC	6.12	3.15	11.75	4.1247	3.0526	11.6439
VMA	4.24	2.46	4.41	3.2474	2.4026	4.1936
CARB	1.68	1.19	2.56	1.6824	1.1864	2.6089
FK506	2.35	1.34	2.81	1.8503	1.3458	2.7603
MTX	1.44	1.00	2.12	1.4458	0.9949	2.1895
OPIATES	3.15	2.13	3.24	3.3204	2.1464	3.3417





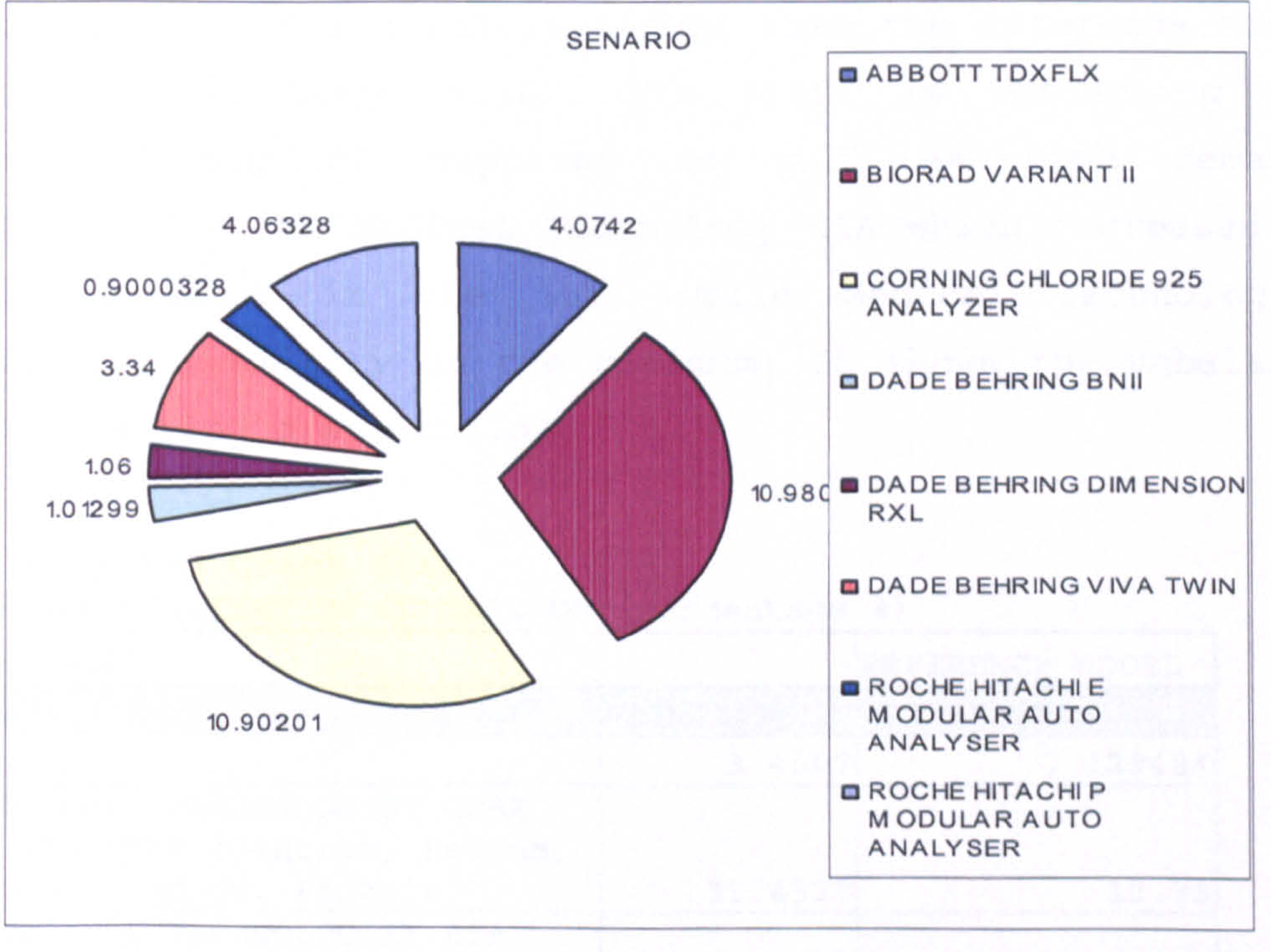
6.6.3.2 Secondary Performance Measures

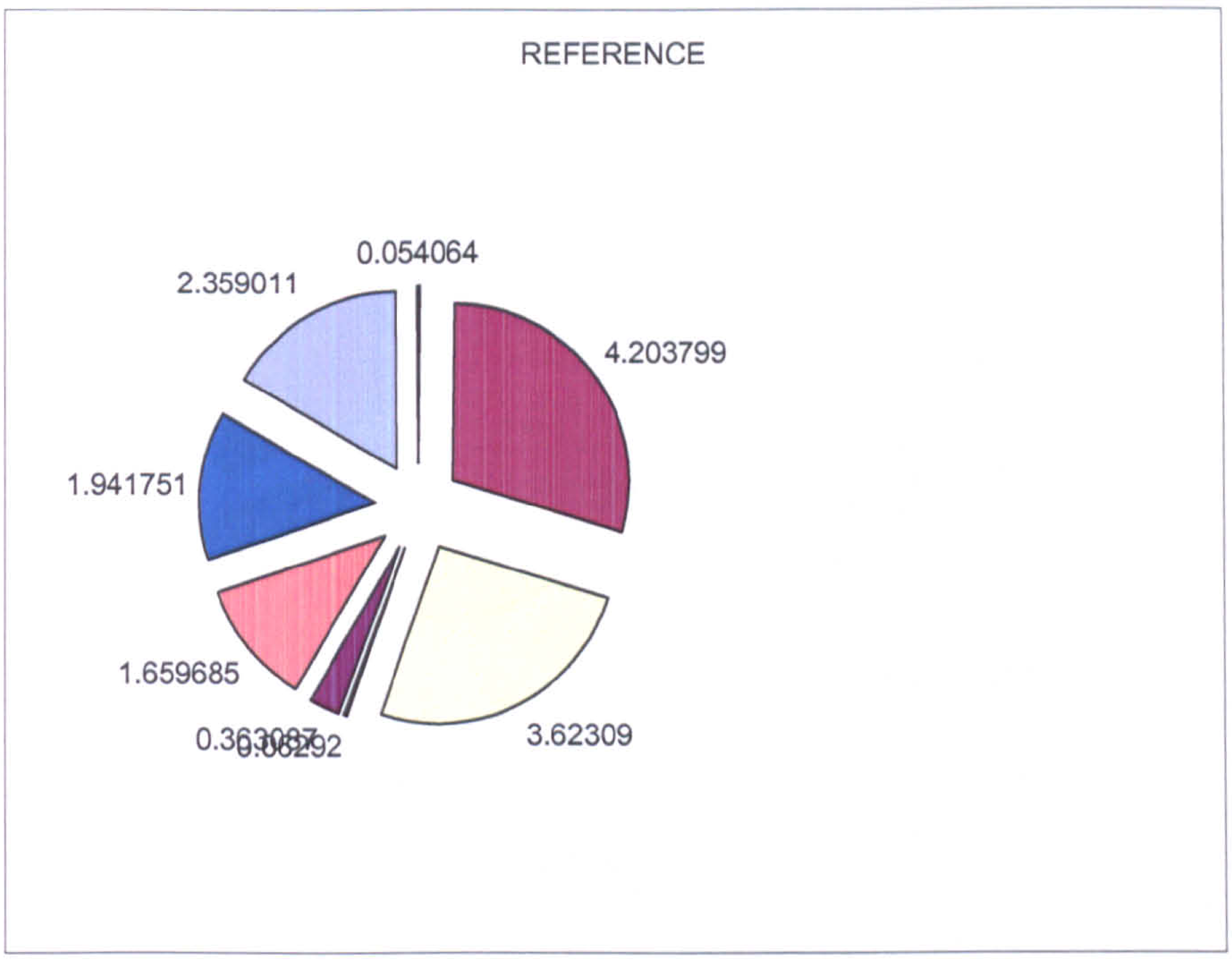
6.6.3.2.1 Equipment Utilization

The equipment utilization is increased as the supplies and staffs are available. The maximum was the Biorad Vaviant II Analyzer (Table and Graph 6.39)

Table and Graph 6.39
EQUIPMENT UTILIZATION COMPARISON (percentage %)

SCENARIO	REFERENCE MODEL	
EQUIPMENT	UTILIZATION	UTILIZATION
ABBOTT TDXFLX	4.1	0.1
BIORAD VARIANT II	10.98	4.2
CORNING CHLORIDE 925 ANALYZER	10.9	3.6
DADE BEHRING BNII	1.01	0.1
DADE BEHRING DIMENSION RXL	1.1	0.4
DADE BEHRING VIVA TWIN	3.34	1.7
ROCHE HITACHI E MODULAR AUTO ANALYSER	0.9	1.94
ROCHE HITACHI P MODULAR AUTO ANALYSER	4.1	2.4



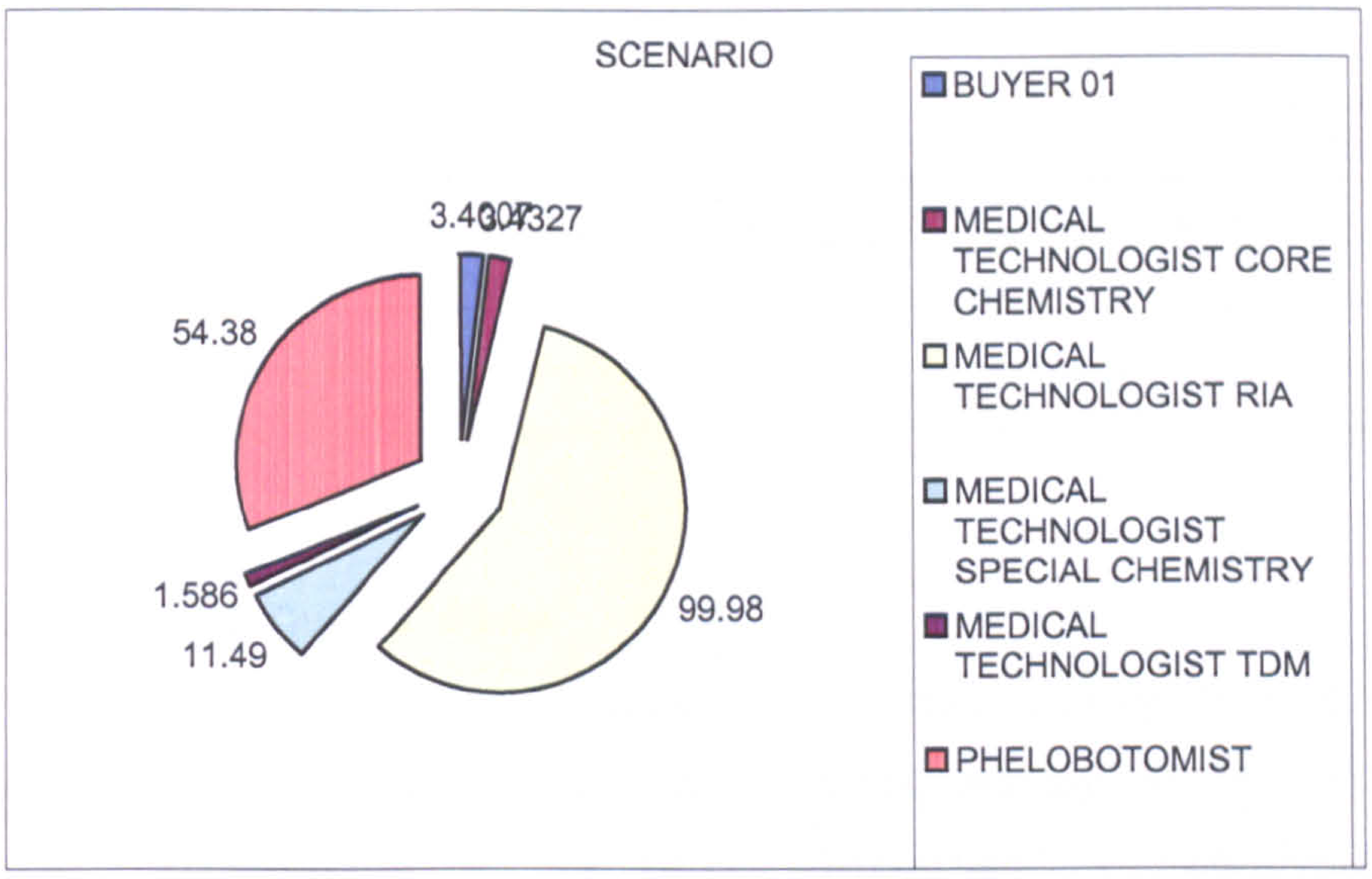


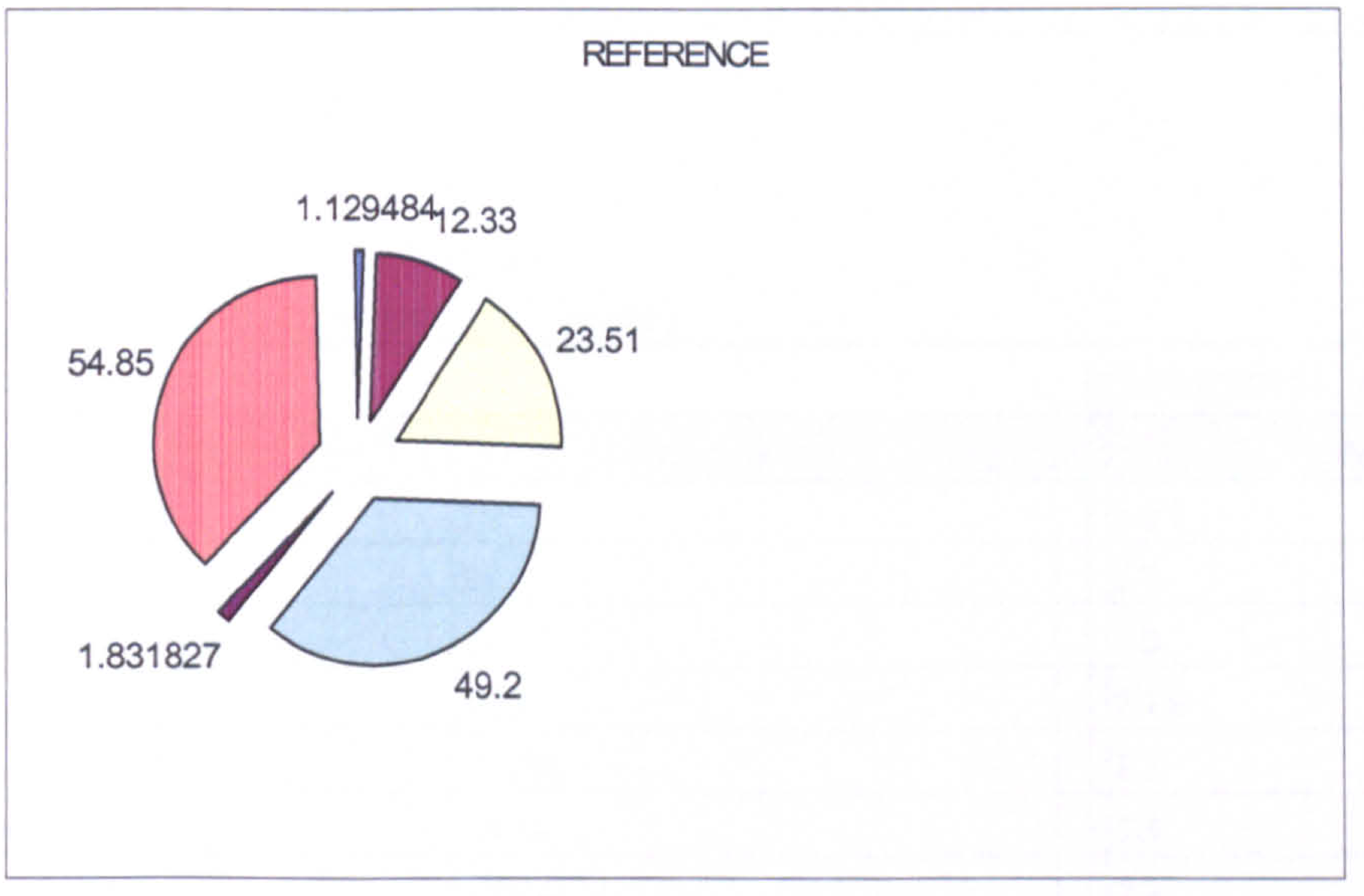
6.6.3.2.2 Staff Utilization

The staff utilization is higher than the Reference Model (Table and Graph 6.40). The staff is reflecting the availability of supplies as well as high demand, especially the Medical Technology RIA which increased to the maximum in the lab, while Medical Technologist special chemistry to the minimum. It shows the unbalance of staffing distribution.

Table and Graph 6.40
STAFF UTILIZATION COMPARISON (percentage %)

SCENARIO		REFERENCE MODEL
STAFF	UTILIZATION	UTILIZATION
BUYER 01	3.4007	1.129484
MEDICAL TECHNOLOGIST CORE CHEMISTRY (Glucose, Ketone, Osmo, and Ur. Protein)	33.4327	12.33
MEDICAL TECHNOLOGIST RIA (Vitamin D, BHCG, Folate, Homocytine)	99.98	23.51
MEDICAL TECHNOLOGIST SPECIAL CHEMISTRY (AAT, G6PD, HBAIC, VMA)	11.49	49.2
MEDICAL TECHNOLOGIST TDM (Carb, FK506, MTX, Opiates)	13.586	1.831827
PHLEBOTOMIST	74.38	54.85





6.6.3.2.3 Material Order Size

The material orders are (Table 6.41) fluctuated, the controller increased from 393 to 3494 which is a huge increase, the calibrator dropped by more than 70% and the reagent reduced by 5%. The number of orders does not indicate the quantity of each. The Imax policy requests the maximum quantity which may reduce the number of orders according to reorder level of each item.

Table 6.41
MATERIAL ORDER SIZE COMPARISON

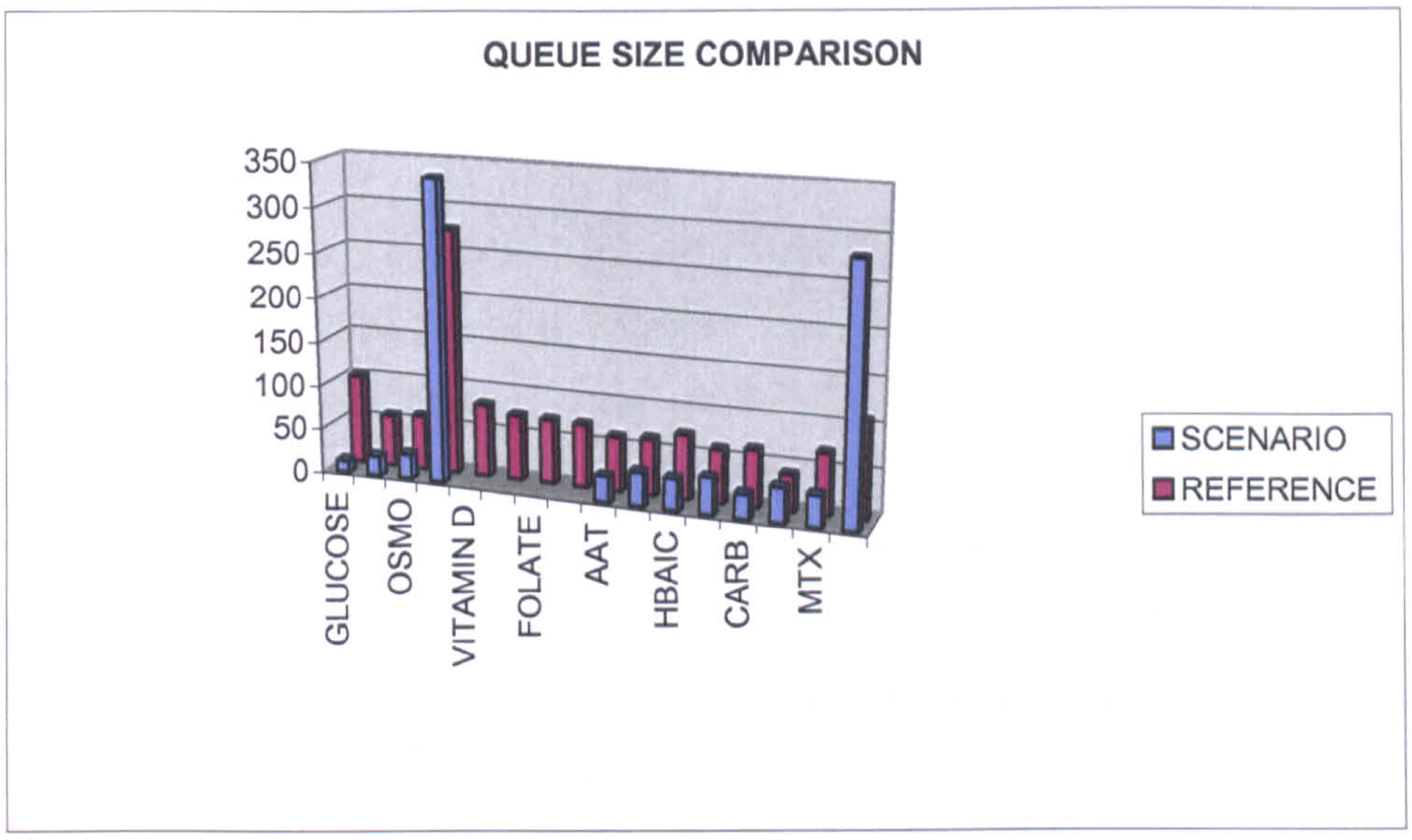
SCENARIO		REFERENCE MODEL
NAME OF ORDER	NUMBER OF ORDERS	NUMBER OF ORDERS
CONTROL	3,494	393
CALIBRATOR	29	182
REAGENT	511	532

6.6.3.2.4 Queue Size

As discussed in the lead time, similarly the queue size (Table and Graph 6.42) been reduced by 50 to 90% except the Opiates test which increased tremendously. The VITAMIN D, BHCG, FOLATE, and HOMOCYTINE tests are dropped to the minimum.

Table and Graph 6.42
QUEUE SIZE COMPARISON(hour)

SCENARIO		REFERENCE MODEL
TEST	AVER	AVER
GLUCOSE	13	101
KETONE	22	57
OSMO	28	60
URINE	339	276
VITAMIN D	N/A	82
BHCG	N/A	73
FOLATE	N/A	72
HOMOCYSTINE	N/A	71
AAT	30	61
G6PD	39	63
HBAIC	36	72
VMA	42	60
CARB	28	64
FK506	40	41
MTX	36	6
OPIATES	287	108



6.6.3.3 Conclusion

The lead time dropped tremendously except the Opiates tests. Inventory of component is very high in the reagent and calibration but controller is depleted. The cost of the inventory is very high, but on the other hand, the throughput is better than the Reference Model, WIP is fluctuated because the ratio of the available components and the material shelf life. Utilization of equipment and staff are increased representing the availability of supplies and other resources. This scenario show two important points, the first is the compatibility of the lab with the changes, as can be seen more component result of better throughput and short lead and queue times. But the other point need to be indicated is that the increase in the inventory level to the maximum. As a result of maximum inventory, more items are disposed because of expired item lives. The solution could be shifting the inventory toward the supplier to manage it by sharing some of the cost, so that the total cost would be reduced.

Chapter 7

Discussion of the Results

7.1 Introduction

In this chapter the work on both the modeling and research experiments are discussed in order to allow a set of conclusions to be reached in chapter 8. The comments are made on the effectiveness of the experimental software. The competitive elements of the results produced in the research experiments reported in chapter 6 are further assessed.

7.2 Modeling of Health Care Supply Chain

Supply Chain concept was introduced in the manufacture industry in late 1950's. Over the time the concept has been implemented and improved to be as we know today, integrated supply chain with the help of the advances in information technology. On the other hand, healthcare supply chain has been extremely slow of adapting the concept, resulting in poor planning and increasing the overall cost.

The first step in health care supply chain management is to identify the potential problems within the system. The literature in this field as reviewed in section 3.3 is relatively very poor. The available ones mainly point out the problems like high cost, supply waste, high inventory and inventory cost, poor response level, long waiting lists, nowadays; it became a routine to hear that patient lives have been under jeopardy because of unavailability of supplies or poor management of the assets.

Health care setting is very complicated and dynamic. To model the health care supply chain system, there is a strong need for a deeper study of all the processes and relationships of all parties. However, modeling the system at this scale is difficult, challenging and the data needed is beyond a PhD study. Therefore, this study covers a portion of the overall health care supply chain system and is centered on a chemistry lab in a local hospital considering all the relationships with the wider supply chain system. A case study in chemistry lab of King Faisal Specialist Hospital and Research Centre has been chosen. Several extensive interviews and close monitoring of the Lab took place to establish the true relationships with the other units of the hospital as well as other components of the health care supply chain system. A structure of the Lab has been developed involving all resources like staff, equipment, materials (See Section 5.5.4.2). This study concentrates on 16 tests that represent the major activities and possible variations of them in the chemistry Lab.

The broad aim of this study is to improve the efficiency of healthcare supply chain while reducing the escalated cost. To measure the system performance a set of metrics have been identified. Based on the Literature recommendations as it is introduced in section 3.5 and the author experience a selection of these performance metrics have been done, the motivation for is to observe the system performance within the organization as individual and interacting activities, so that a better picture could be obtained in understanding the system behavior. The classification of the performance metrics is based on the level of explanation about the system behavior they could provide. The first set of metrics is used to measure the direct relationships of activities such as throughput, lead time, flow time and WIP with the factors such as supply level and quality, inventory level, and demand pattern that affect the quality and dimension of aforementioned activities. The second set of metrics are used to measure the secondary activities such as staff and equipment utilization, queue size and supply order size with the general supply chain factors that influence the overall system performance. These metrics are needed to get a better picture about the system behavior as well as to understand the interactions between the different elements of the processes to recommend a better solution. The followings are the two categories of these metrics used in this thesis:

1) Primary performance measures, which consist of lead time, material flow time, throughput for component and test, inventory status, work-in-process (WIP), and cost of each test.

2) Secondary performance measures are: equipment utilization, staff utilization, material order size and queue size.

As this is the first large scale simulation model centered around the chemistry Lab, which connects all participants of healthcare supply chain, its general goal is to understand the working mechanics of this very complicated network, identify the possible problem areas, measure the dimension and effect of these areas and to recommend a suitable solution to these possible problems and improve the overall efficiency of the healthcare supply chain in general.

For this scale study a model, which brings all the major elements of the health care supply chain has been created. However, this model has been built with an integrated structure, so all the performance of individual elements can be identified but at the same time, their interactions with each other could be observed using the performance metrics explained above. The integration among all elements is achieved in two ways. First, the information flows from patient to the rest of the supply chain. The Second is the flow of material from the supplier to the rest of the supply chain. The mechanism to organize such the flow of information and the order of the supply is presented in section 5.5.4 and figure 5.2.

It is worth noting that the past studies (see section 3.5) in this field have severely limited focusing only on one element of the supply chain such as purchasing, inventory or cost without connecting all the participating supply chain elements together.

On reflection it is considered that the model developed in this study (section 5.3) is more effective than any other approaches traced in the current literature (see section 3.4.3 for literature review on health care). There are many authors (such as Jun et al, 1999; Weinstein et al, 2003; Issenberg et al, 1999; Wong 2004; McLaughlin et al, 2002; Bond and Spillane 2002; Murray et al, 2005) that have produced partial solutions, some analytical, some using simulation modeling, but none of them has embraced the whole issue of health care supply chain system as the work reported in this thesis.

The professionals that try to solve health care problems, most of the time, are not equipped with the right tools and techniques as operations research or operations management practitioners do. They may be experts in health care but, health care system does not produce its own solution tools and techniques such as performance modeling, optimization, inventory control or supply chain management, and these must be borrowed from operations management / industrial engineering disciplines. This study uses one of these proven tools and techniques that have been used by the aforementioned disciplines in manufacturing or service sectors for a long time, which is the simulation technique.

The issue must be pointed out that the model created is based on a number of scenario-based models (See Chapter 6) each of one of which is regarded as a certain aspect of the supply chain system as discussed in section 6.4.

However, in practice there may be much more different problems and these may be experienced in a different way, even the same problem that is covered in this model, would generate different output. Therefore, these models, in practice, may need some certain degree of modifications to accommodate the operational guidelines required by a particular supply chain system for adequate operation.

7.2.1 Software

This research models the system performance along with cost performance. Simulation has initially been chosen because of modeling the details of complex systems such as health care supply chain, better than any other modeling tools such as analytical or artificial intelligent-based modeling tools, the need to interface the performance modeling to cost modeling was an obstacle whether simulation should be chosen as sole modeling tool or not (See Chapter 5 for detailed discussion). However, the cost modeling ability of the commercially available simulation software, Arena, has provided a powerful reason why this software tool needed to be chosen. Indeed the software used in modeling of health care supply chain has made a tremendous contribution to modeling effort spent to create this study by providing an excellent platform to model both the system performance and cost together so that tiresome interfacing different software systems and further coding are eliminated. Further, the cost of any activity take place within the system could be modeled separately as well as modeling the integrated parameters of the system give the facility to identify isolated or integrated cost of the actions taken in the system as part of the supply chain activities.

7.3 Comparative Assessment of Scenarios

The work on scenarios has been reported in Chapter 6. A reference model has been created initially assuming that the entire supply chain system including the lab which is considered as a place where some core supply chain activities take place runs smoothly without any interruptions which may affect the system performance in a negative way. This has been needed to compare and understand the system performance under possible different operational obstacles which each may represents a specific problem experienced by the system occasionally or frequently.

Each scenario targets a specific case in the supply chain operation. While keeping the rest of the parameters fixed one parameter is changed according to a possible variation in the operation of the supply chain. For example, depending on the season or extra-ordinary development such as outbreak of certain diseases, demand for certain tests for a certain time period may increase. Since this is not usual way of operating of the system, the supply chain would react to this new situation in a different way in comparison to normal way of operation of the system. Every new case is treated as an opportunity to understand the behavior of the supply chain system and is included into analysis.

The reference model was run for twelve months and all the statistics collected are tabulated or graphically displayed using the primary or secondary performance metrics.

The scenarios are designed to answer the research questions whether each new case would affect the overall system performance adversely or not. In another words, how all these variations in operation of the system would affect the rest of the parameters and different performance measures.

The primary and secondary performance metrics are used to understand the behavior of the system. The following is the detailed analysis of these metrics based on the different scenarios measurements comparing with the reference model.

These scenarios are grouped as follows:

A) Test demand fluctuation
- Low customers
- High customers
- High demand
- Some tests are lower
- Some tests are higher
- Longer lead time
- Special line for emergency cases

B) Resource Reliability
- Unreliable equipment
- Unreliable supplier
- Short of staff
- Repair is longer

C) Inventory/Purchasing of supplies
- Periodic review
- Continuous review
- Imax policy
- Batches policy in purchasing
- No funding

7.3.1 Comparisons of Scenarios

The First scenario is designed to see the system reaction to low flow of patients, as it would happen in long holidays. Apparently, this would cause underutilization of the equipment, staff and the available materials. Since some of the materials used in health care have a very short shelf life, some of the items in stock would become obsolete, which in turn caused some extra cost to the system. System had to cancel some of the regular orders from several suppliers, which are based on some certain level of patient flow level expectations. Although it is not considered here, if there is contract between suppliers and the health care system for cancelled or unfulfilled deliveries, it would bring extra cost to the health care system. Therefore, it would be advisable that the system should sign more flexible contracts with its suppliers not face this kind of extra costs.

All the system performance such as lead time, WIP and mean flow time have improved. This is simply because there is not pressure on the system now and all the required tests, which are comparably less, can now be done more quickly without any delay.

The Second scenario was designed to measure the effects of unreliable suppliers on the system performance. As it would be expected the system has been affected from the irregular deliveries and long lead times in a negative way generating long lead times, longer queues, longer mean flow times, low throughput and very irregular stock movements in the organization. The late deliveries have interrupted some of the routine activities because of stock outs. The organization must ensure that the ordered materials arrive to the system within the promised time window. Otherwise, as it was experienced in the system the performance would suffer from these late or irregular deliveries. The solution would be working with dedicated suppliers for the critical materials. This may bring an extra cost to the system but system must calculate the cost of interruptions and cancellations as well as delays and must find out an acceptable threshold for the critical materials.

Third scenario is designed to analyze the system performance under a different inventory policy, which is I_{MAX}. I_{MAX} is concerned setting the reorder point at maximum inventory level so that end of the determined inventory period placing an order is guaranteed. This policy, similar to the previous inventory policy, has guaranteed the material availability, which in turn affected some of the system performance metrics positively. One may wonder why inventory policies that guarantee the stock availability have been picked as inventory policies in this study. The justification comes from the strategic role of the health care systems and one of the very major parameters needs to be considered here is in fact a human life. Since there is no compensation for human life, these systems are forced to implement costly inventory policies to maximize the material availability. I_{MAX} has also improved the throughput by guaranteeing an uninterrupted material flow, but as it happened in continuous inventory policy it came with a cost. When this policy is compared to continuous policy it is realized that I_{MAX} is more costly because of forced maximum stock availability. This also generated high equipment and staff utilization. The lead time and WIP have not changed much due to keeping the system operational conditions the same with the reference model. Another scenario presented below showing the inventory policy which can be implemented in the healthcare setting are selected with the above scenarios as it is important to see the feasibility of adapting it. The rest of scenarios are presented in the Appendix C.

Scenario number thirteen is designed to analyze the system performance under continuous inventory policy. The continuous inventory policy makes sure that company monitors the inventory level continuously and whenever the inventory level drops down to reorder level or below.

This policy makes sure that the materials needed are always available. However, because of the special circumstances of the health care system, this must be guaranteed through a contract with the suppliers. Otherwise, suppliers are forced to keep continuous inventory as well, which many suppliers would not be willing to do so. Material availability certainly improved some of the system performance such as throughput, staff and equipment utilization. However, this uninterrupted lab activities come with a cost and the overall cost has increased dramatically because of high inventory carrying cost as well as more frequently ordering the needed items. The company must strike a balance between the guaranteed availability of the materials and the cost of carrying such load all the time. This is a crucial point from the cost aspect and probably some further study is needed to determine the optimum level of inventory for the hospital items which are more delicate and strategic in comparison to industrial items.

7.4 Final Overview

The work reported in this thesis falls into two subsections. The first is the introduction of a simulation modeling, which is being implemented in experimental software and has been shown to be a powerful aid to health care supply chain analysis. However, of course this does not attempt to cover all the issues in health care supply chain systems but does offer a major experimental study in which over 250 instances have been computed in order to develop a basis for understanding the performance of individual health care supply chain operational problems and their relative merits.

The modeling method will be more effective if it is enhanced to include higher levels of supply chain activities take place in other part of the supply chain network.

The work on the use of scenarios has shown that a clear position can be taken on the relative value of a particular operational strategy in the health care supply chain system.

It is thought possible to take the work beyond the point reached in this thesis in the development of these fifteen scenarios and in particular it is thought it might be possible to blend these scenarios together to produce a definitive and highly economic solution for the management of supply chain for the health care system. The following are the overview notes and recommendations

- Any minor changing in any part of the supply chain network, this case in a chemistry lab, can be seen in remote parts of the network. The healthcare supply chain is very sensitive to all kind of effect wither is a malfunction of one of the component in the system or sudden fluctuation of the usage of cretin supply, which may create different reactions at different levels in different part of the network system. Therefore, it is strongly recommended that the supply chain parameters should be considered in a holistic manner when any action is taken within the system, which forces all the players of the supply chain to work closely or consult each other not to cause any serious outcome in any part of the system.

- The suppliers, especially, play a crucial role in the network and their timeliness is absolutely important for the success of the entire network. Since the issue is a human life here, any interruption in the flow of materials, if the system is not supported with a healthy stock policy, may end up with a disastrous result.

- The supply chain network must secure the smooth flow of materials. This could be secured in two ways. One is to work with a set of dedicated suppliers by guaranteeing the purchases from them. This would force them to keep a certain level of inventory which takes the stock burden from the hospital but comes with a cost since bargaining is eliminated through elimination of alternatives. The second way is to keep a safety stock for the items that have longer shelf lives. However, these items are limited in health care and the company must generate a kind of pipeline-like supply system not to face any interruptions in its everyday operations and eliminate the excessive stock for many items. However, this needs a very careful planning and control and hospitals must create a separate unit to look after this vital issue.

- The hospital system should always keep some extra suppliers that are quicker in supplying the requested materials. This, apparently a costly operation, however, it is necessary. Another solution for the hospitals would be to develop an emergency plan and identify the supplies shelf lives and order the items according to the importance of these items and their shelf lives. A simple ABC inventory plan could be a starting point to classify the stored items and more sophisticated solutions can be obtained following the inventory optimization models for perishable items.

- The health care system should make necessary arrangements such as timely supply of the material considering the shelf lives, or these short-shelf-life items should be ordered in small lots probably more frequently, with its suppliers not to face this kind of costs.

- The healthcare supply chain system should consider all scenario cases and a proper plan to overcome any unexpected situation. For example of low inventory of the supplies is to find alternative suppliers or keep certain amount of safety stock depending on the shelf lives of these items. Another solution would be to force the suppliers to keep these items in their stock to respond quickly when requested by guaranteeing periodic purchases. But, since there is no guarantee that the demand for these items would be same all the time, the health care system and the suppliers should share the risk.

- The availability of the equipment is absolutely vital for the timely activities within the system such as tests that use delicate chemical materials.

- Therefore, as it was stressed in unreliable equipment scenario, the organization would keep a regular maintenance team to look after all the equipment periodically especially during the low season not to interrupt the system's activities to keep the equipment alive.

Chapter 8
Conclusions

Two major innovations are reported. The first concerns the use of a comprehensive simulation based model to support scenario-oriented operational policies. The results of the experiments based on this approach have produced a significant step forward the formal understanding of supply chain in health care systems. The second major step has been the inclusion of the simultaneous cost calculation using ABC model (see Section 3.6.2) alongside performance modeling efforts.

The study of HCSCS, up to supplier level, is feasible and a comprehensive understanding of the system modeling can be achieved. It is also possible to achieve considerable economic benefits for supply chain operation through this work especially by identifying the possible inventory and supplier problems (see Chapter 6). Nevertheless, in order to gain the best results it is important that future work should be extended to include all the parameters that consider total health care supply chain systems.

8.1 Contribution of this study to the health care research

The conclusions drawn from the simulation model created are listed below:

- **Understand the supply chain management in manufacture and adapt it to the healthcare.**

  Healthcare is suffering of the un-efficient mechanism of controlling the supplies. The needs to learn from the experience of manufacture how to best organize and optimize the supplies. By understanding the manufacturing process, it can be adapted to be used in the healthcare setting.

- **Most of the problems experienced in health care systems are very similar to manufacturing problems.**

  The manufacturing systems have been using some tools, techniques and methods that have been proven to be very efficient and effective in solving such problems. Therefore, the health care sector specialists should be trained to use these proven tools and techniques to solve their own problems and learn the best practices in manufacturing. This would definitely improve the efficiency of the problem solving techniques used in today's health care industry.

- **Inventory plays a vital role within the Healthcare supply chain system. Unlike manufacturing.**

  Although it is very costly to keep inventory for thousands of items used in the system, two issues force the health care institutions to plan their inventory policies more carefully than any other organization in manufacturing. The first one is the sensitivity of dealing with human life and the second issue is the delicacy of the items that need to be stocked. The health organizations must find a balance to keep inventory for the short-life supplies and not affecting the healthcare provided to patients with reduced cost. Inventory optimization techniques can play crucial roles here to find this delicate balance.

- **It is certainly possible to have a smoothly run health care organization in terms of system performance and cost.**

  This needs an extensive coordination between all the major players of the health care supply chain network and unlike manufacturing supply chain the interruption in information and material flow cause vital consequences.

- **Supply chain is complicated need a model to capture all activities**

  Healthcare systems are complex to be dealt with from an analytical point-of-view, especially when processes have characteristics like high variety and low quantity need, unexpected events, lack of planning, high cost, etc. In such scenarios, simulation comes up as a powerful tool for performance analysis and optimization.

- **Solution as an Integrated Health Care Supply Chain Model is needed to streamline the process and the environment of healthcare supply system.**

  An integrated supply chain model is developed in the healthcare environment, in particular focusing on the Chemistry Laboratory. It focuses on relative performance modeling through cost and system performance modeling. It is not only giving particular benefit to reduce the cost or to improve the quality or to have an overall improved system, but a continuous monitoring mechanism is developed to measure all of these parameters for adjustment as required. Also, it provides a basis to know the effect of any change, like manpower or selling cost of a material, on the entire system.

The developed model can be beneficial for other Healthcare services as well.

8.2 Further work

This study has based on the activities take place in the chemistry lab within a large hospital and coordinated the supply chain activities according to its own priorities. From this point of view, even this study can be counted as a limited study at the health care supply chain scale.

- The further work should include some more activities take place in a health care organization such as all the logistical activities, all the stock movements and all the supplier and manufacturers activities so that a better and holistic picture can be created to understand the further problems and generate better solutions to improve the system performance overall.

- Since the stock keeping is very costly and very sensitive because of the delicacy of both materials and the consequence, the health care systems should ask experts to come up with a secure inventory policy probably using some analytical techniques such as operations research or industrial engineering methods and integrate it to its supply chain activities.

- The cost calculation has been kept limited with including only the major cost items in this study, therefore, the cost found here, although they give an idea about the possible cost figure, is not precise cost figure. A further study is needed to identify the actual cost figures including all the activities, activity drivers, materials, labor and non-operational activities such as support and utility work as well as detailed overhead including equipment and premises depreciation.

REFERENCES

Al-Mashari, M. and Zairi, M (2000), Supply chain re-engineering using enterprise resource planning (ERP) software of a SAP R/3 implementation case. *International Journal of Physical Distribution and Logistics Management* 3/4, 296-313.

Angelis, Felici, Impelluso (2003). Integrating Simulation and Optimisation in Health Care Centre Management.
AORN Journal, 68 (1): 68-72

AORN Journal (1999), 70 (2): 268-271, 273-276

Appold K. (2002). The Pros and Cons of Point-of-Care and Core Laboratory Testing. Clinical Laboratory Management Association.

Aptel, Oliver and Pourjalali, Hamid (2001). *Improving Activities and Decreasing Costs of Logistics in Hospitals: A Comparison of U.S. and French Hospitals*

Arntzen, B. C., G. G. Brown, T. P. Harrison, and L. Trafton (1995), Global Supply Chain Management at Digital Equipment Corporation *Interfaces*.

Ashayeri and Rongen, J. Ashayeri and J.M.J. Rongen, 1997. Central distribution in Europe: A multi-criteria approach to location selection. *The International Journal of Logistics Management* 91, 97-106.

Asubonteng, Patrick; McCleary, Karl J; and Munchus, George (1996). *The Evolution of Quality in the U.S. Healthcare Industry: An Old Wine in a New Bottle.*

Ayers J (1999). Supply chain strategies. Information systems Management, spring.

Ayers J. (2000). Supply chain information system: putting the process first. CRC PRESS LLC.

Baldwin, Eldabi, Paul (2004). Simulation in Healthcare Management: a soft approach (MAPIU)

Baumol and Vinod, W.J. Baumol and H.D. Vinod (1970). An inventory theoretic model of freight transport demand. *Management Science* 16 7, 413-421.

Beamon, B.M. Beamon (1998). Supply chain design and analysis: Models and methods. *International Journal of Production Economics* 55, 281-294.

Bond and Spillane (2002). The use of simulation for emergency medicine resident assessment. Acad. Emerg. Med.,9,1295-1299.

Bowersox and Closs, 1996. D.J. Bowersox and D.J. Closs *Logisticsal management: The integrated supply chain process*, McGraw-Hill, New York, NY.

Bradley et al, 1977. S.P. Bradley, A.C. Hax and T.L. Magnanti (1977) *Applied mathematical programming*, Addison-Wesley, Reading, MA.

Brennan, Charles D, (1998). *Integrating the Healthcare Supply Chain Healthcare Financial Management.*

Burt, T, Seeing the Future: Innovative Supply Chain Management Strategies (Healthcare Executive: Jan/Feb 2006, 1; ABI/INFORM Research), 16.

Cagwin and Bouwman (2002). The association between activity-based costing and improvement in financial performance. Management Accounting Research,13,1-3

Canby, J. (1995), Applying Activity-Based Costing to Healthcare Settings (Healthcare Financial Management, 49, 2; Health Module, 50)

Camm et al, J.D. Camm, T.E. Chorman, F.A. Dill, J.R. Evans, D.J. Sweeney and G.W. Wegryn, (1997).Blending OR/MS judgment, and GIS: Restructuring P&G's supply chain. *Interfaces* 27, pp. 128-142.

Chopra and Meindl, 2001. S. Chopra and P. Meindl *Supply chain management: Strategy, planning and operation,* Prentice-Hall, Upper Saddle River, NJ.

Cleverley W. (2000). Calculating the true value of healthcare organizations. Healthcare Financial Management,4,5.

Cohen and Lee, 1989. M.A. Cohen and H.L. Lee, Resource deployment analysis of global manufacturing and distribution networks. *Journal of Manufacturing and Operations Management* 2 (1989), 81-104.

Cokins, G., Why is Traditional Accounting Failing Managers? (Hospital Materiel Management Quarterly; Nov 1998; 20, 2; Health Module, 72)

Cook, Jack S; BeBree, Kathy and Feroleto, Amie. *Supply Chains Healthcare Industry* (2001)

Cook, J, DeBree, K., Feroleto A. (2001) From Raw Materials to Customers: Supply Chain Management in the Service Industry,

Cooper M.C., Ellram L., Gardner J., Hank A. (1997). Meshing multiple alliances. *Journal of Business Logistics* 18 1,67-89.

Cooper M.C. Cooper, Lambert D., Pagh J. (1997). Supply chain management: More than a new name for Logistics. *The International Journal of Logistics Management* 8 1,1-13.

Craig, A.L. (1989). EDI increases producitivity and competitiveness. Journal of Electronic Data Interchange, 133-137.

Croom, S., Romano, P., Giannakis, M. (2000). Supply Chain Management: An Analytical Framework for Critical Literature Review (European Journal of Purchasing & Supply Chain Management 6, 67-83

Croom, S., Supply Chain Management: An Analytical Framework for Critical Literature Review (2000)

Das C. (1974) Choice of transport service: An inventory theoretic approach. *The Logistics and Transportation Review* 10 2,181-187.

Das C. (1975) Supply and redistribution rules for two-location inventory systems: One-period analysis. *Management Science* 21,7 ,765-776.

Drucker, (1998). P.F. Drucker, Management's new paradigms. *Forbes* October,152-177.

Eastaugh S. (2001). Hospital costs and specialization: Benefits of trimming product lines,28,61-71.

Felix chan (2003). A conceptual model of performance measurement for supply chains. Management decision, Vol 41,7,635-642.

Ferrier, David E.(1984). Devloping a Materiel Management Program for a New Facility, Hospital Materiel Management Quarterly Vol 5, Iss 4.

Fokker, L.B, Mendez D., Hershauer J.C (1998). *Total Quality Management in the Supply Chain; What is its Impact on Performance.*

Gourley, C. (1998). What's driving the automotive supply chain? Warehousing Management, 44-48.

Hansen, J.V., & Hill, NM.C. (1989). Control and audit of electronic data interchange. MIS Quarterly, 403-413.

Harland C. & Knight L; Lamming, R; Walker, H; Outsourcing: Assessing the Risks and Benefits for Organizations, Sectors and Nations

Health Care Finance Journal (2001). 28 (1): 61-71

Herron, (1983). D.P. Herron, Management science in industrial Logistics. *Applications of Management Science* 3, pp. 49-85.

Hill, N.C., & Swenson, M.J. (1994). THE IMPACT OF ELECTRONIC DATA INTERCHANGE ON THE SALES FUNCTION. Journal of Personal Selling & Sales Management XIV (3).

Hillier and Lieberman, (2001). F.S. Hillier and G.J. Lieberman *Introduction to operations research* (7th ed.), McGraw-Hill, New York, NY (2001).

Huang, Z. & Gangopadhyay, A, A simulation Study of Supply Chain Management to Measure the Impact of Information Sharing

International of Operation and Production Management (2002). 22 (4): 381-393

Issenberg S. (1999). Simulation technology for healthcare professional skills training and assessment. The Journal of the American medical association,282,861-866.

Jain, J, Supply Chain Management Tradeoffs Analysis

Jarett, P. Gary (1998). Logistics in the health care industry. International Journal of Physical distribution & Logistics Management, Vol. 28 No. 9/10, pp.741-772.

Jun J., Jacobson S.,Swisher J. (1999). Application of discrete-event simulation in healthcare clinics. Journal of the operational research society, Vol 50,2,109-123.

Karlsson, M, Ohman, D. (2005), Material Consumption in the Healthcare Sector: Strategies to Reduce its Impact on Climate Change- The Case of Region Scania in South Sweden.

Kelton W., Sadowski R, and Sturrock D. (2004). Simulation with Arena, Third edition.

Kimberley, P. (1991). Electronic Data interchange. New York: McGraw-Hill.

Kumar, A.; Ozdamar, L. (2005), Procurement Performance Measurement System in the Healthcare Industry (International Journal of Health Care Quality Assurance, Volume 18 Number 2,152-166)

Lake C. (2005). Simulation in cardiology and cardiothoracic and vascular surgery. Seminar in cardiothoracic and vascular anesthesia, Vol.9, No.4,325-333.

Lambert and Cooper, (2000). D.M. Lambert and M.C. Cooper, Issues in supply chain management. *Industrial Marketing Management* 29 65-83.

Lambert D., Lambert M., Emmelhainz G.(1996). Developing and implementing supply chain partnerships. *The International Journal of Logistics Management* 7 2,1-17.

Lambert et al, (1998). D.M. Lambert, M.C. Cooper and J.D. Pagh, Supply chain management: Implementation issues and research opportunities. *The International Journal of Logistics Management* 9 2,1-19.

Lancioni, R., Smith R., Oliva, T. (2000). The Role of the Internet in Supply Chain Management.

Lancioni, Lancioni R., (2000), New developments in supply chain management for the millennium. *Industrial Marketing Management* 29 1-6.

Langabeer (2005). The Evolving Role of Supply Chain Management Technology in Healthcare. Journal of Healthcare Information Management Vol. 19, 27 - 33.

Lehmann and Leiken, (2000). Diagnostic Technology for Laboratories in an Integrated Delivery System. *Clinical Leadership and Management Review,* 118-120.

Lindahl F. (1997). Activity-based costing implementation and adaptation. Human Resource Planning Society,2,62-65.

Lim, D, Palvia, P, EDI in Strategic Supply Chain: Impact on Customer Service (2001)

Li S. (2002) Developing Measures of Supply Chain Management Performance (Decision Sciences Institute. Annual Meeting Proceedings)

Marino, Anthony P (1998). *Healthcare Industry Materials Management.*

McKone-Sweet K., Hamilton P., Willis,(2005) The Ailing Healthcare Supply Chain: A Prescription for Change.

Mclaughlin (2002). Acad. Emerg. Med., 9,1137-1142

Mentzer and Schuster, (1983). J.T. Mentzer and A.D. Schuster, Computer modeling in Logistics: Existing models and future outlook. *Journal of Business Logistics* 3 2,1-55.

Messelbeck, J. and Whaley, M. (1999). Greening the Health Care Supply Chain: Triggers of Change, Model for Success.

Midler, 1969. J.L. Midler (1969), A stochastic multi-period multimode transportation model. *Transportation Science* 3, 8-29.

Milton C, O'Brien B, Homberger J. (2003). Principles of good practice for decision analytic modeling in healthcare evaluation. Value in health, Vol 6,9.

Min, H and Zhou, G., (2002). *Supply Chain Modeling: Past, Present and Future*. Computers and industrial engineering,43,231-249.

Modernising supply in the NHS (2002).NHS Purchasing and Supply Agency.

Monden Yasuhiro (1997). The Beak: Toyta prodction systems

Moynihan, James J. *Improving the Healthcare Supply Chain Using EDI Healthcare Financial Management* (1997)

Murry D., Boult J., Krasa J, Mcallister J, Cox T. (2005). A simulation-based acute skills performance assessment for anesthesia training. Aneshanalg,Vol 101,1127-1134.

Nathan Jay (1996). *Improving Healthcare Means Spending More Time with Patients and Less Time with Inventory.*

Nicholson L., Vakharia A., Erenguc S. (2004). Outsourcing inventory management decisions in healthcare: Models and application. European journal of operational research.,154,271-290.

Ozbayrak, Mustafa and Roger-Jones, Lois. E. (2000). Cost Estimation in a JIT-Based Advanced Manufacturing Cell. *16th International Conference on Production Research - ICPR-16, 29 July - 3rd August, Prague, Czech Republic.*

Papadopoulou and Ozbayrak (2005). Leanness: experiences from the journey to date. Journal of manufacturing technology management,Vol 16-7;8,784-807.

Parvinen, P.,Halonen M. (2000). Industrial Process Management Principles in Healthcare Research: A Bibliometric Study

Petrovic D., Roy R., Petrovic R. (1998). Modelling and simulation of a supply chain in an uncertain environment. European journal of operational research,109,299-309.

Power, D. (2005). Supply Chain Management Integration and Implementation: A Literature Review. Supply chain management: An international journal,10/4,252-263.

Richmond, Peters B., Richmond, Peters, Warehouse E.(1998) management systems technologies: Technology-enabled warehouse excellence. *Strategic supply chain alignment: Best practice in supply chain management*, 393-406.

Rivard-Royer, Hugo Rivard & Landry, Sylvain, & Beaulieu Martin (2002). Hybrid stockless: a case study - Lessons for health-care supply chain integration. International Journal of Operations & Production Management, Volume 22 Number 4,412-424

Ross, T.K.(2004). Analyzing Health Care Operations Using ABC (Journal of Health Care Finance; Spring, 30, 3; Health Module, pg.1)

Scalese R. (2005). Effective use of siulations for the teaching and acquisition of veterinary professional and clinical skills. Journal of Veterinary medical education, Vol 32, Issue 4,461-467.

Schau, H.J, Smith, M.F., Schau, P. (2005). The Healthcare Netwrok Economy: The Role of Internet Information Transfer and Implication for Pricing

Schwarz, (1981). L.B. Schwarz, Physical distribution: The analysis of inventory and location. *AIIE Transactions*. 13, 2, 138-150.

Shah N. (2004). Pharmaceutical Supply Chains: Key issues and Strategies for Optimisation (2004).

Shapiro J. (2001). *Modeling the supply chain*, Wadsworth Group, Pacific Grove.

Silver E. (1981). Operations research in inventory management: A review and critique. *Operations Research* 29,628-645.

Soin, Critical Success Factors in Supply Chain Management at High Technologies Companies

Stefanou, C., Revanoglou A.(2006) ERP Integration in a Healthcare Environment: A case study (Journal of Enterprise Information Management, Vol. 19 No. 1,115-130)

Swaminathan J., Tayur S. (1999). Stochastic programming models for managing product variety.

Swain, J. (2003). Simulation Reloaded.

Swinehart K., Smith A (2005). Internal supply chain performance measurement. International Journal of health care quality assurance, Vol 18,7,533-542.

Talluri S., Talluri (2000). An IT/IS acquisition and justification model for supply chain management. *International Journal of Physical Distribution and Logistics Management* 30 3/4 221-237.

Tayur S., R. Ganeshan and M. Magazine (1999). *Quantitative models for supply chain management*, Kluwer Academic Publishers,585-622.

Travers-Naugthon, J. (2001). Activity-Based Costing: The New Management Tool (Mar/Apr 2001; 21, 2; Health Module)

Weng, Mark 1, & Houshmand, Ali A (1999). Health Care Simulation : A Case Study at a Local Clinic. Proceedings of the 1999 Winter Simulation Conference,1577-1584.

Wisnosky, Dennis E., Jones, Anne, (2000). *Beyond the Supply Chain: A Step by Step Guide to Radically Improving Healthcare Delivery with Electronic Transactions*. Wizdom Systems Inc.

Wolf, (2002). Wolf, Emily, 2002, Healthcare's Supply Chain Reaction. *Healthcare Executive*.

Wong c., (2004). Full scale computer simulation in ansthesia training and evaluation. The Journal of the American medical association,51,455-464.

Zipkin, 2000. P.H. Zipkin *Foundations of inventory management*, McGraw-Hill

APPENDIX A: Notation and Variables

Variable name	Type & Size	It Represents	When and why is it used	Affected by	Initial or default value
Ca Multiplier	fixed value (1)	a factor that represents the percentage of Calibrator usage in comparison to Reagents. i.e. if a calibrator is used one fourth the reagents then: **Ca Multiplier = 0.25**	This variable is used to set initial storage and order size of Calibrators by multiplying it by the **Reagent demand in a year**	The value of this variable is entered manually and is not later changed during real	0.06
CaLabOrder					
CalibratorsCosts	fixed value (1)	*Accumlative* costs of purchased Calibrators. (Money paid to buy)	This is used to calculate the purchasing costs. This variable is used by the **Purchased Components Costs.**	This variable is only affected by itself. It updates itself every time an entity passes by the **Costs of new arrivals Ca** Assign module. (CalibratorsCosts+(CalibratorsPrice*OrderSize))	0
CalibratorsPrice	fixed value (1)	The price of one Calibrator unit. That is the amount of Calibrator enough for one calibration only.	This is used to calculate the purchasing costs. This variable is used by the **Calibrators Costs.**	The value of this variable is entered manually and is not later changed during real	0.25

Co Multiplier	fixed value (1)	a factor that represents the percentage of Control usage in comparison to Reagents. i.e. if a Control is used one fourth the reagents then: **Co Multiplier = 0.25**	This variable is used to set initial storage and order size of Controls by multiplying it by the **Reagent demand in a year**	The value of this variable is entered manually and is not later changed during real	0.1
Ca#Ordered	0,1 value	It is set to 1 if an order has been issued. And when the order arrives it is set back to 0. # is 1,2..11,13,15 or 16.	It is being altered when an order of Calibrator# is issued, by lab or by logistics.	Its value is altered by an Assign module when the order is issued and when the stock arrives and stored, during the simulation.	0
Co#Ordered	0,1 value	It is set to 1 if an order has been issued. And when the order arrives it is set back to 0. # is 1,2..or 16.	It is being altered when an order of Control# is issued, by lab or by logistics.	Its value is altered by an Assign module when the order is issued and when the stock arrives and stored, during the simulation.	0
CoLabOrder					
ControlsCosts	fixed value (1)	Accumulative costs of purchased Controls (Money paid to buy)	This is used to calculate the purchasing costs. This variable is used by the **PurchasedComponentsCosts.**	This variable is only affected by itself. It updates itself every time an entity passes by the **Costs of new arrivals Co** Assign module. (ControlrsCosts+(Controlrs	0

				Price*OrderSize))	
ControlsPrice		The price of one Control unit. That is the amount of Control enough for one control operation only.	This is used to calculate the purchasing costs. This variable is used by the **ControlsCosts.**	The value of this variable is entered manually and is not later changed during real	0.15
LabCa#Storage	Real value (1)	Represents the Lab storage of component Calibrator #.	These variable are used (being adjusted) all over the simulation to indicate the variability of the amounts of components in this storage	It is affected by the analysis being processed, as these analysis withdraw these components from Lab Storage to be performed.	
LabCo1Storage	Real value (1)	Represents the Lab storage of component Control #.	These variable are used (being adjusted) all over the simulation to indicate the variability of the amounts of components in this storage	It is affected by the analysis being processed, as these analysis withdraw these components from Lab Storage to be performed.	

LabRe1Storage	Real value (1)	Represents the Lab storage of component Reagent #.	These variable are used (being adjusted) all over the simulation to indicate the variability of the amounts of components in this storage	It is affected by the analysis being processed, as these analysis withdraw these components from Lab Storage to be performed.	
LogCa16Storage	Real value (1)	Represents the Logistics storage of component Calibrator #.	These variables are used (being adjusted) during the simulation when the logistics deliver components to the lab, or when they issue a purchasing ordered to refill their storage.	Its value is only changed when the logistics respond to a lab order or when a new stock arrives.	
LogCo1Storage	Real value (1)	Represents the Logistics storage of component Control #.	These variables are used (being adjusted) during the simulation when the logistics deliver components to the lab, or when they issue a purchasing ordered to	Its value is only changed when the logistics respond to a lab order or when a new stock arrives.	

			refill their storage.		
LogRelStorage	Real value (1)	Represents the Logistics storage of component Reagent #.	These variables are used (being adjusted) during the simulation when the logistics deliver components to the lab, or when they issue a purchasing ordered to refill their storage.	Its value is only changed when the logistics respond to a lab order or when a new stock arrives.	
LogOrderedCal	0,1 value	It is set to 1 if an order has been issued. And when the order arrives it is set back to 0. # Is 1,2..11,13,15 or 16.	It is being altered when an order of Calibrator# is issued, by lab or by logistics.	Its value is altered by an Assign module when the order is issued and when the stock arrives and stored, during the simulation.	0
LogOrderedCol	0,1 value	It is set to 1 if an order has been issued. And when the order arrives it is set back to 0. # is 1,2..or 16.	It is being altered when an order of Control# is issued, by lab or by logistics.	Its value is altered by an Assign module when the order is issued and when the stock arrives and stored, during the simulation.	0
LogOrderedRel	0,1 value	It is set to 1 if an order has been issued. And when the order arrives it is set	It is being altered when an order of Reagent # is issued, by lab or	Its value is altered by an Assign module when the order is issued and when the	0

		back to 0. # is 1,2..15 or 16.	by logistics.	stock arrives and stored, during the simulation.	
Order Calibrator 1	Real value (1)	A counter to determine if enough number of tests have passed and it is time to apply Calibration now	It is used in Assign module called "control # application counter" in every test line.	It is used as counter, so it increases itself by one with each test, and when the targeted value is reached the variable resets itself to zero and starts counting again for next calibration	0
Order control 1	Real value (1)	A counter to determine if enough number of tests have passed and it is time to apply Control now	It is used in Assign module called "control # application counter" in every test line.	It is used as counter, so it increases itself by one with each test, and when the targeted value is reached the variable resets itself to zero and starts counting again for next calibration	1
PurchasedComponentsCosts	Real value (1)	Total money paid to purchase components	It takes the value of the expression: "Components Costs".		0
Re Multiplier	fixed value (1)	a factor that represents the percentage of Reagents	This variable is used to set initial storage and	The value of this variable is entered manually and is not later	0.1

		usage for about two months in comparison to Reagents usage for one year.	order size of Reagents by multiplying it by the **Reagent demand in a year**	changed during real	
Re#Ordered	0,1 value	It is set to 1 if an order has been issued. And when the order arrives it is set back to 0. # is 1..15 or 16.	It is being altered when an order of Reagent1# is issued, by lab or by logistics.	Its value is altered by an Assign module when the order is issued and when the stock arrives and stored, during the simulation.	0
Reagent demand in a year	fixed value array (16)	A given data describes the number of analysis performed in a year for each of the 16 tests.			
ReagentsCosts	fixed value (1)	Accumulative costs of purchased Reagents (Money paid to buy)	This is used to calculate the purchasing costs. This variable is used by the **PurchasedComponentsCosts.**	This variable is only affected by itself. It updates itself every time an entity passes by the **Costs of new arrivals Re** Assign module. (ReagentsCosts+(ReagentsPrice*OrderSize))	0
ReagentsPrice		The price of one Reagent unit. That is the amount of Reagent enough for one test only.	This is used to calculate the purchasing costs. This variable is used by the **ReagentsCos**	The value of this variable is entered manually and is not later changed during real	0.1

			ts.		
ReLabOrder					
Safety Multiplier	fixed value (1)	Defines the safety level in Lab, with respect to order size.	To set safety levels, so orders can be issued early enough.	The value of this variable is entered manually and is not later changed during real	0.5

LabReSafty	Safety Multiplier*Re Multiplier*Reagent demand in a year (#,1)	Sets Safety level for Reagents in the Lab
Re Order size in lab	Re Multiplier*Reagent demand in a year (#,1)	Sets the Order size the lab issues to request a Reagent
LabCoSafety	Safety Multiplier*Co Multiplier*Reagent demand in a year (#, 1)	Sets Safety level for Control in the Lab
Co Order size in lab	Co Multiplier*Reagent demand in a year (#, 1)	Sets the Order size the lab issues to request a Control
LabCaSafety	Safety Multiplier*Ca Multiplier*Reagent demand in a year (#, 1)	Sets Safety level for Calibrators in the Lab
Ca Order size in lab	Ca Multiplier*Reagent demand in a year (#, 1)	Sets the Order size the lab issues to request a Calibrator
ReLogOrder	.5*Reagent demand in a year (#,1)	Sets the Order size (the Logistics issues to request a Reagent from a supplier) to 0.5 of the annual performed number of tests
CoLogOrder	.25*Reagent demand in a year (#,1)	Sets the Order size (the Logistics issues to request a Control from a supplier) to 0.25 of the annual performed number of tests
CaLogOrder	.25*Reagent demand in a year (#,1)	Sets the Order size (the Logistics issues to request a Calibrator from a supplier) to 0.25 of the annual performed number of tests
Re LogisticsSafety	3*Safety Multiplier*Re Multiplier*Reagent demand in a year (#, 1)	Set safety level of the logistics for the Reagents to 3 times the safety of the

		Lab.
Co LogisticsSafty	3*Safety Multiplier*Re Multiplier*Reagent demand in a year (#, 1)	Set safety level of the logistics for the Reagents to 3 times the safety of the Lab.
Ca LogisticsSafety	3*Safety Multiplier*Re Multiplier*Reagent demand in a year (#, 1)	Set safety level of the logistics for the Reagents to 3 times the safety of the Lab.
ComponentsCosts	ReagentsCosts+ControlsCosts+CalibratorsCosts	Sums the purchasing costs (money paid to buy components)

APPENDIX B: The Chemistry Lab Tests by ARENA

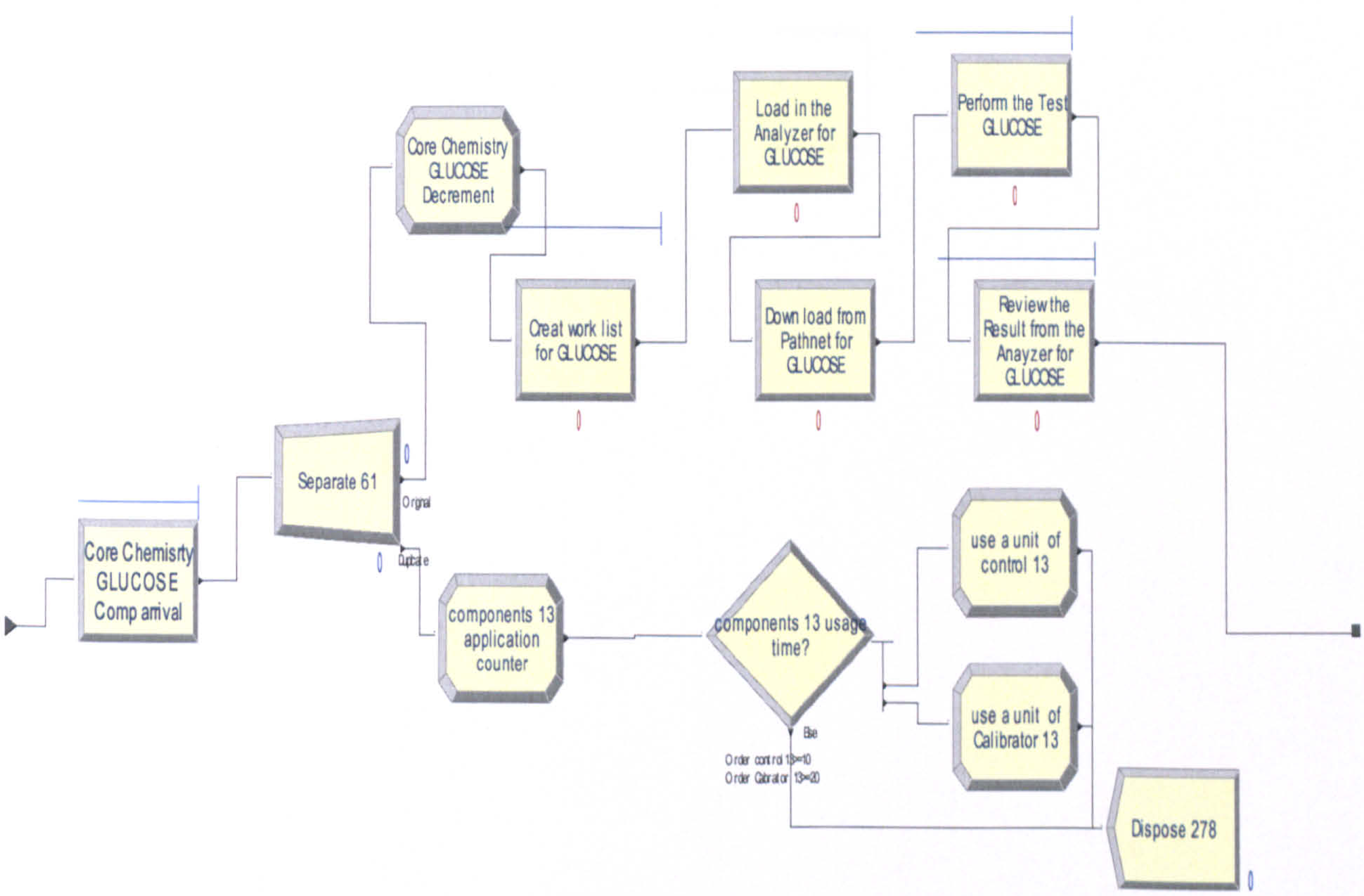
The section of Clinical Biochemistry is a major Section in the Department of Pathology Laboratory Medicine. Its value is the measurement and analysis of blood and urine Chemistry, it consist of four sections as follow:

A) Core Chemistry Section:

It is measuring General Chemistry assays, Renal Profile, Hepatic Profile, Lipid Profile, Cardiac Profile, Osmolalities, and Urine Chemistry.

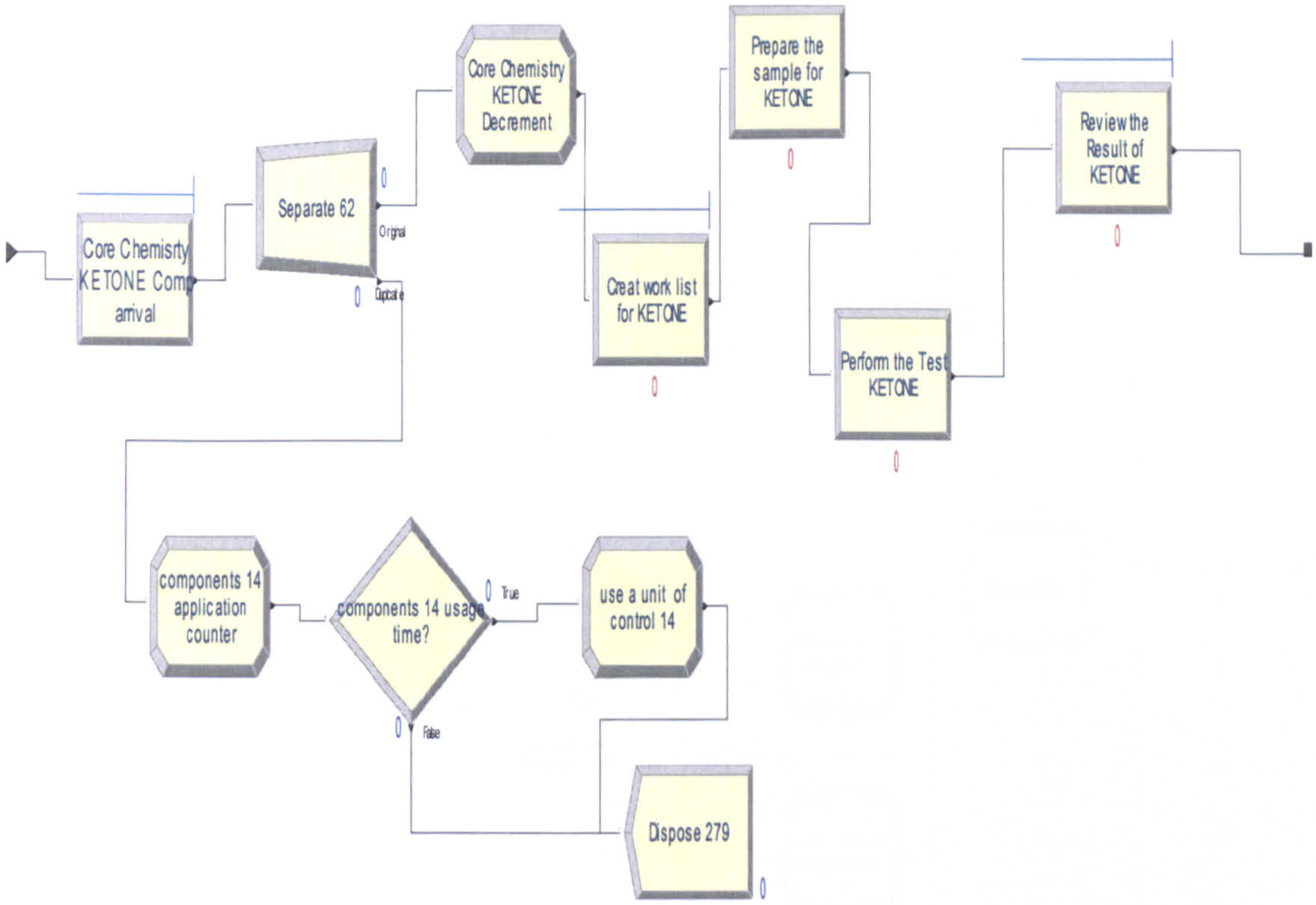
1. Glucose Assays :

The function of the test is checking for glucose level for diabetic and non-diabetic patient.



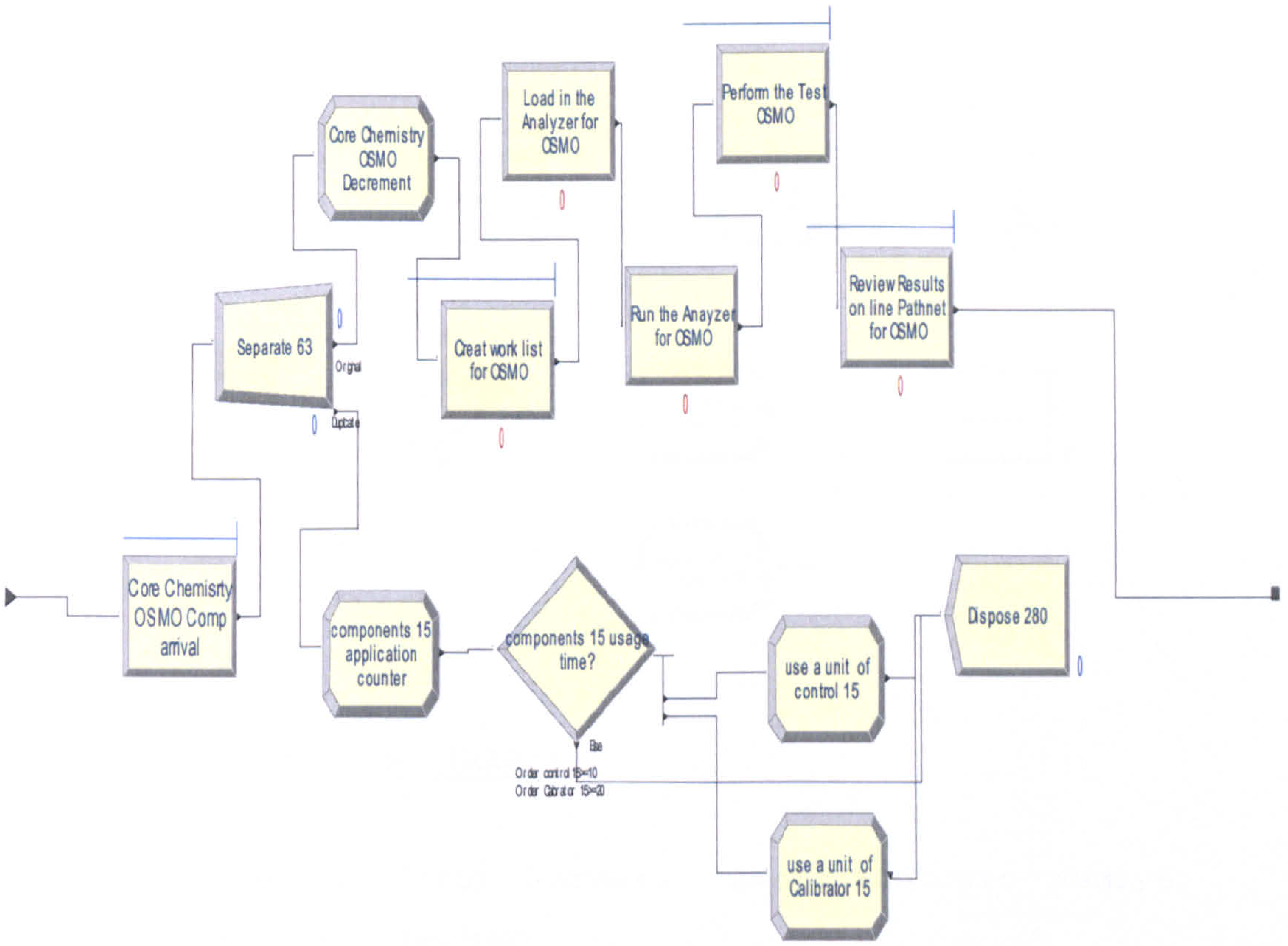
2. <u>**Ketone**</u>:

It is one of the glucose derivatives used for diabetic patient and newborn babies.



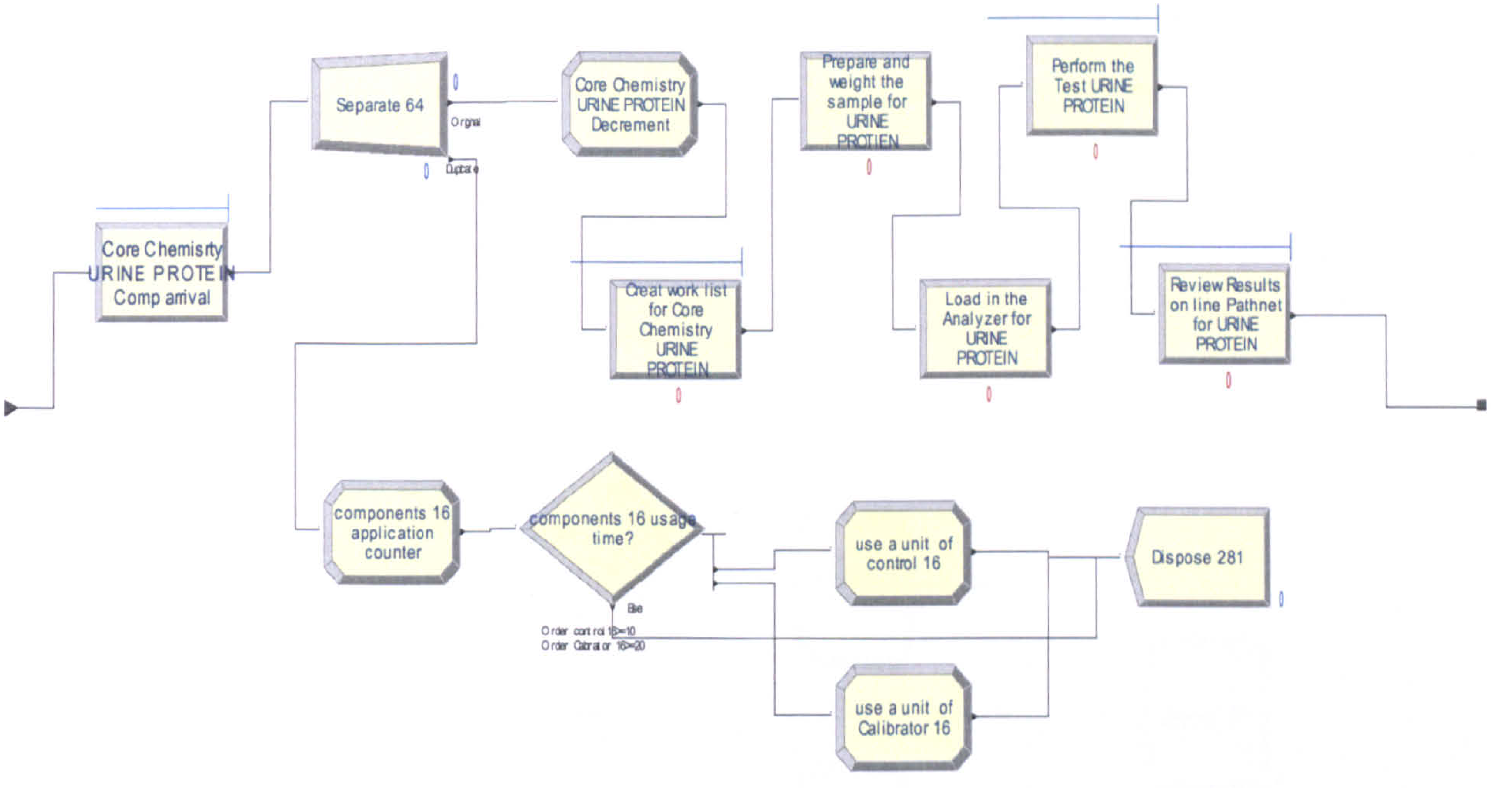
3. Osmo :

It is used as an indicator for hypertension and measuring osmolality after dialysis.



4. **Urine Protein :**

It is used as an indicator for kidney function.

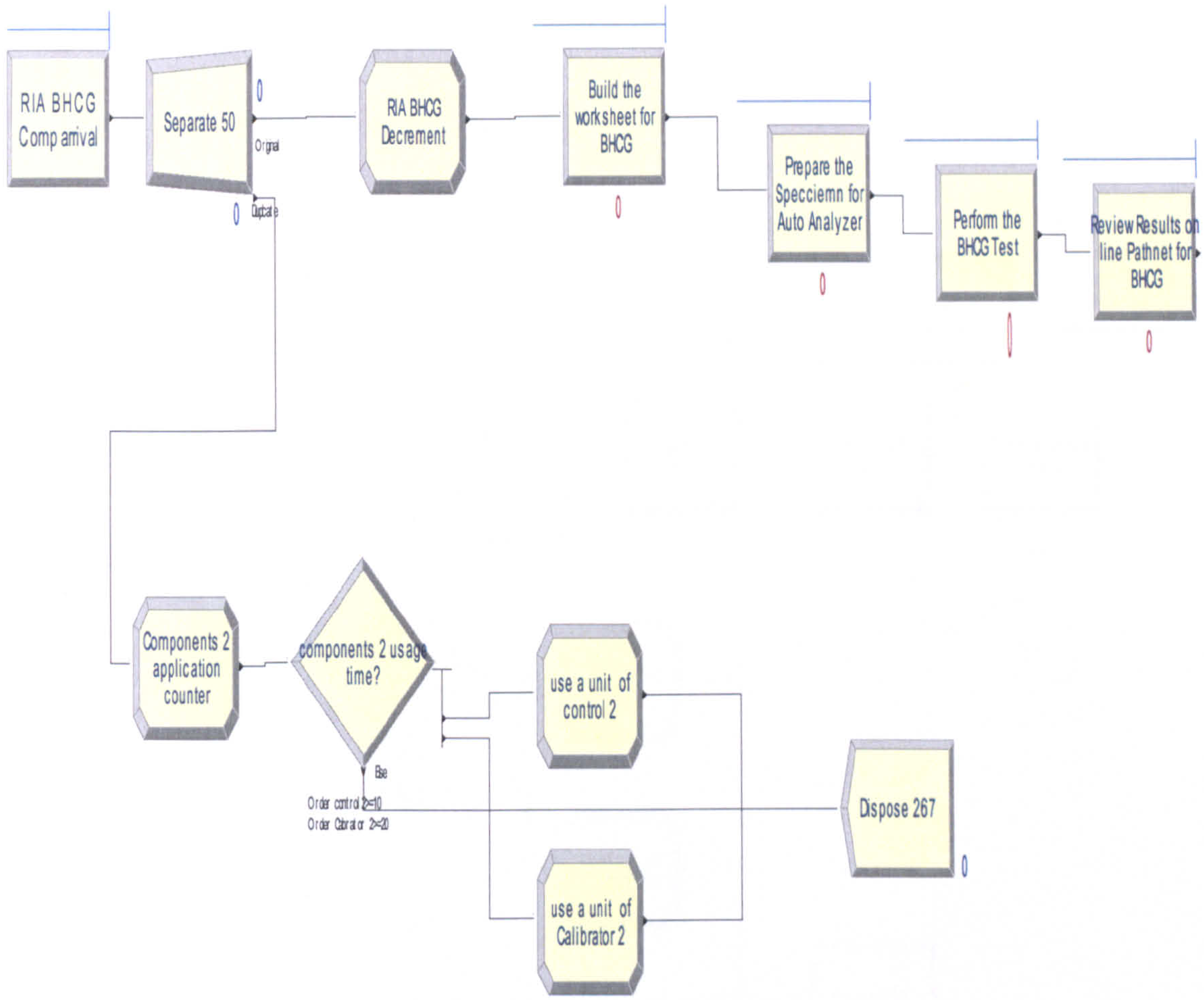


B) Radio Immunoassay Section (RIA):

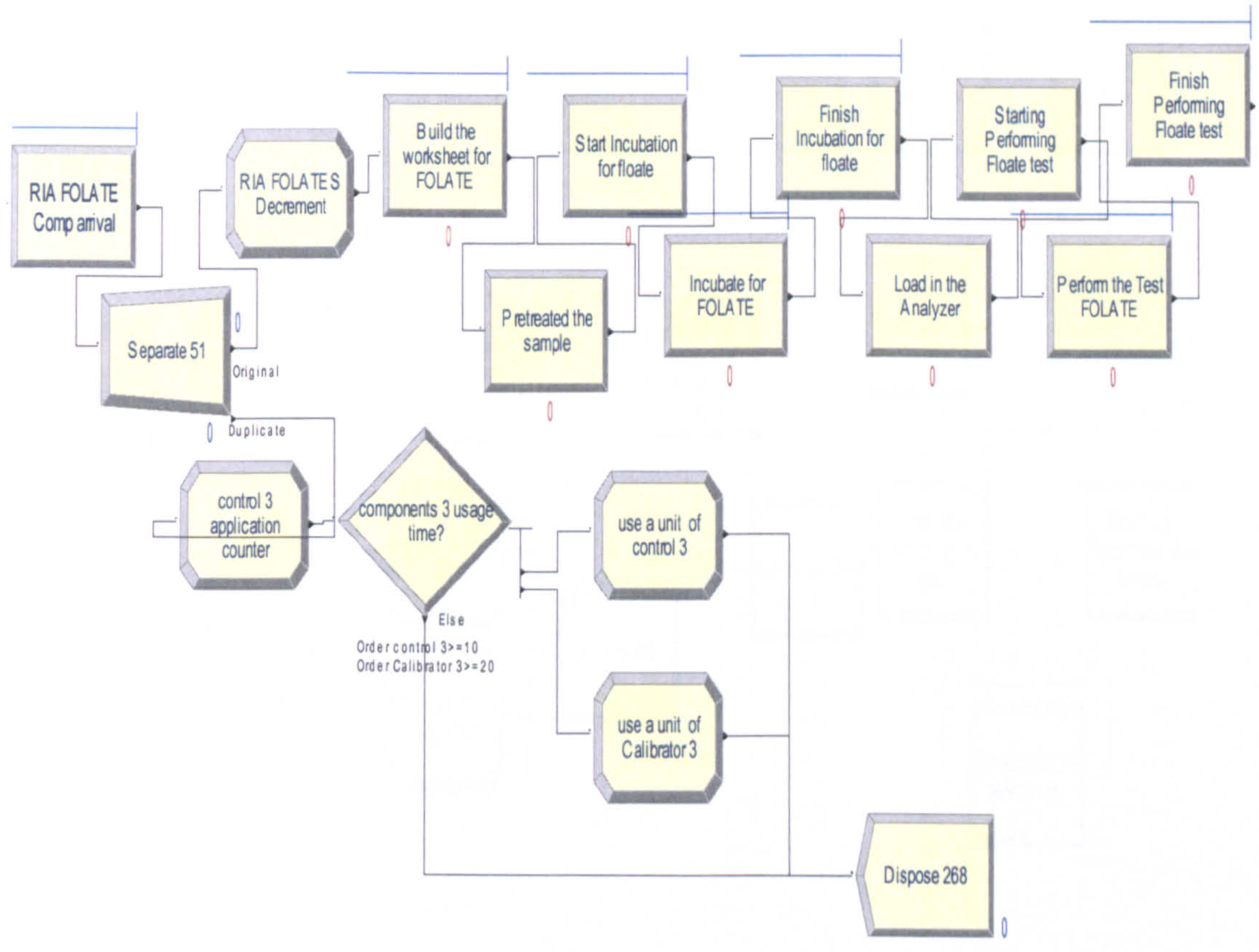
It is testing Hormones, Tumor Markers, Radio-isotopic assays, Cardiac markers and Anemia markers.

5. **BHCG1:**

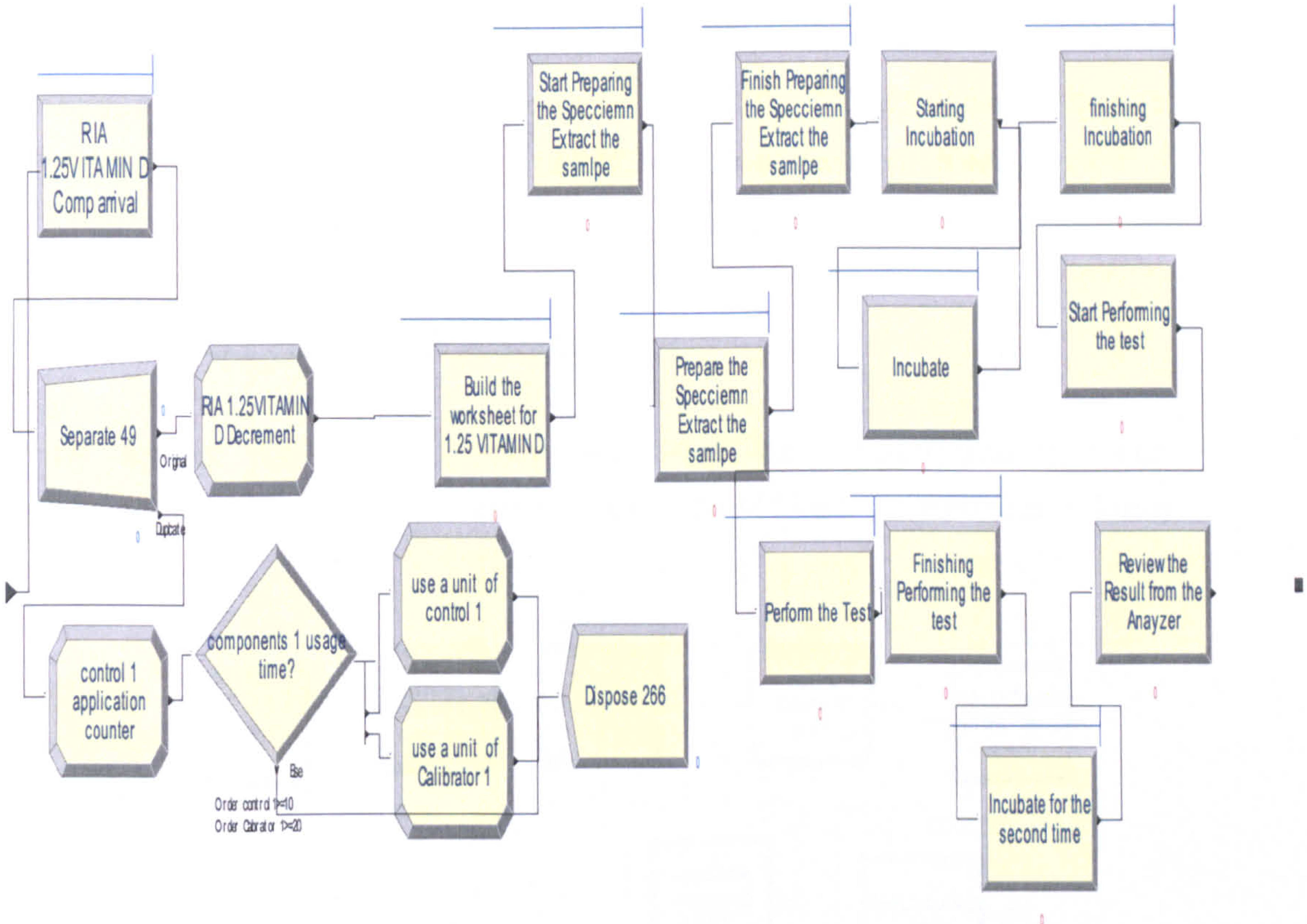
The function is Tumor marker and to determine pregnancy.


RIA BHCG Comp arrival
Separate 50
0
Original
0
Duplicate
RIA BHCG Decrement
Build the worksheet for BHCG
0
Prepare the Specciemn for Auto Analyzer
0
Perform the BHCG Test
0
Review Results on line Pathnet for BHCG
0
Components 2 application counter
components 2 usage time?
Else
Order control 2>=10
Order Calibrator 2>=20
use a unit of control 2
use a unit of Calibrator 2
Dispose 267
0

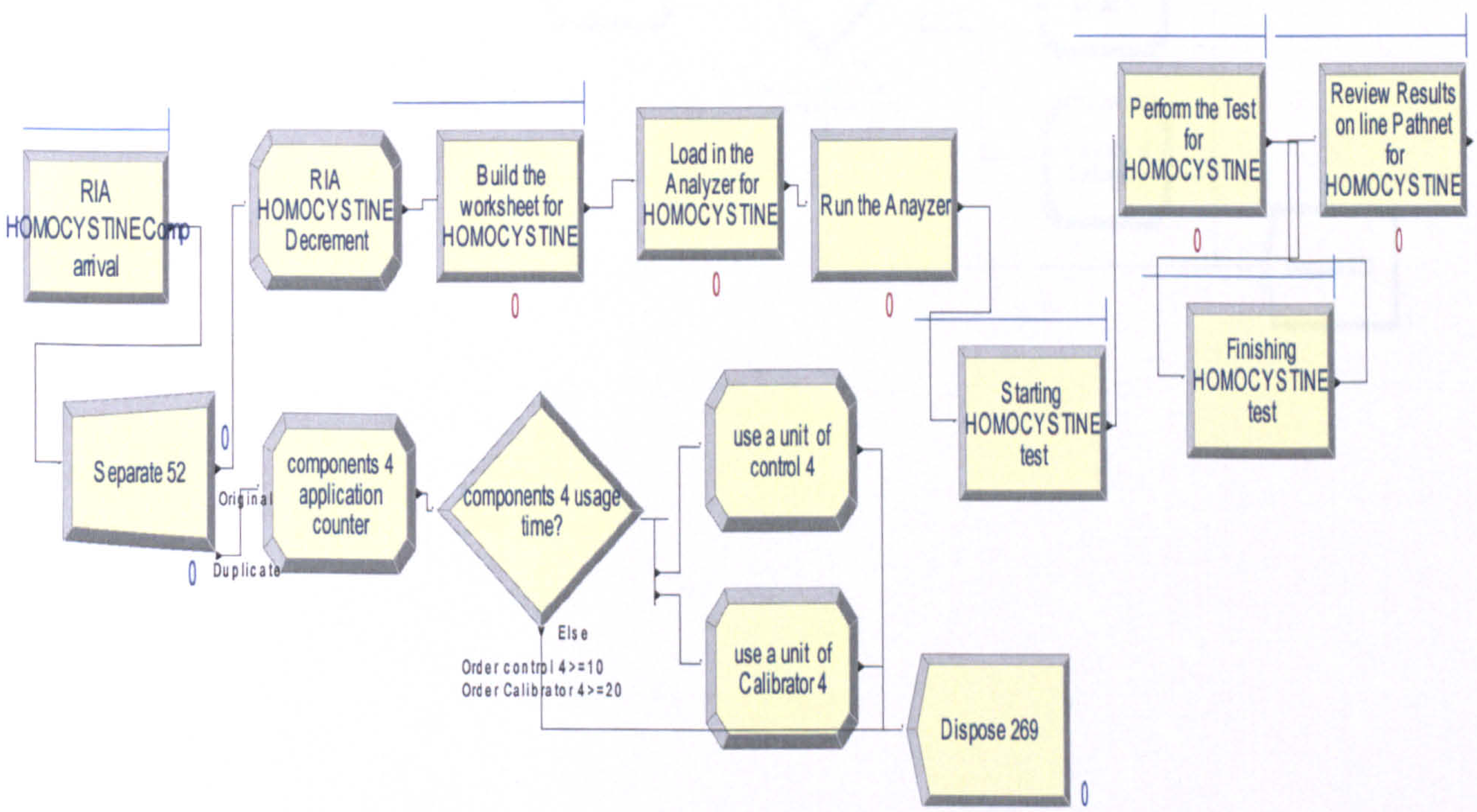
6. **Folate (Red Cell):** Anemia marker.



7. **1.25 vitamin D:** Bone development marker.



8. **Homocystine:** Cardiac risk marker.

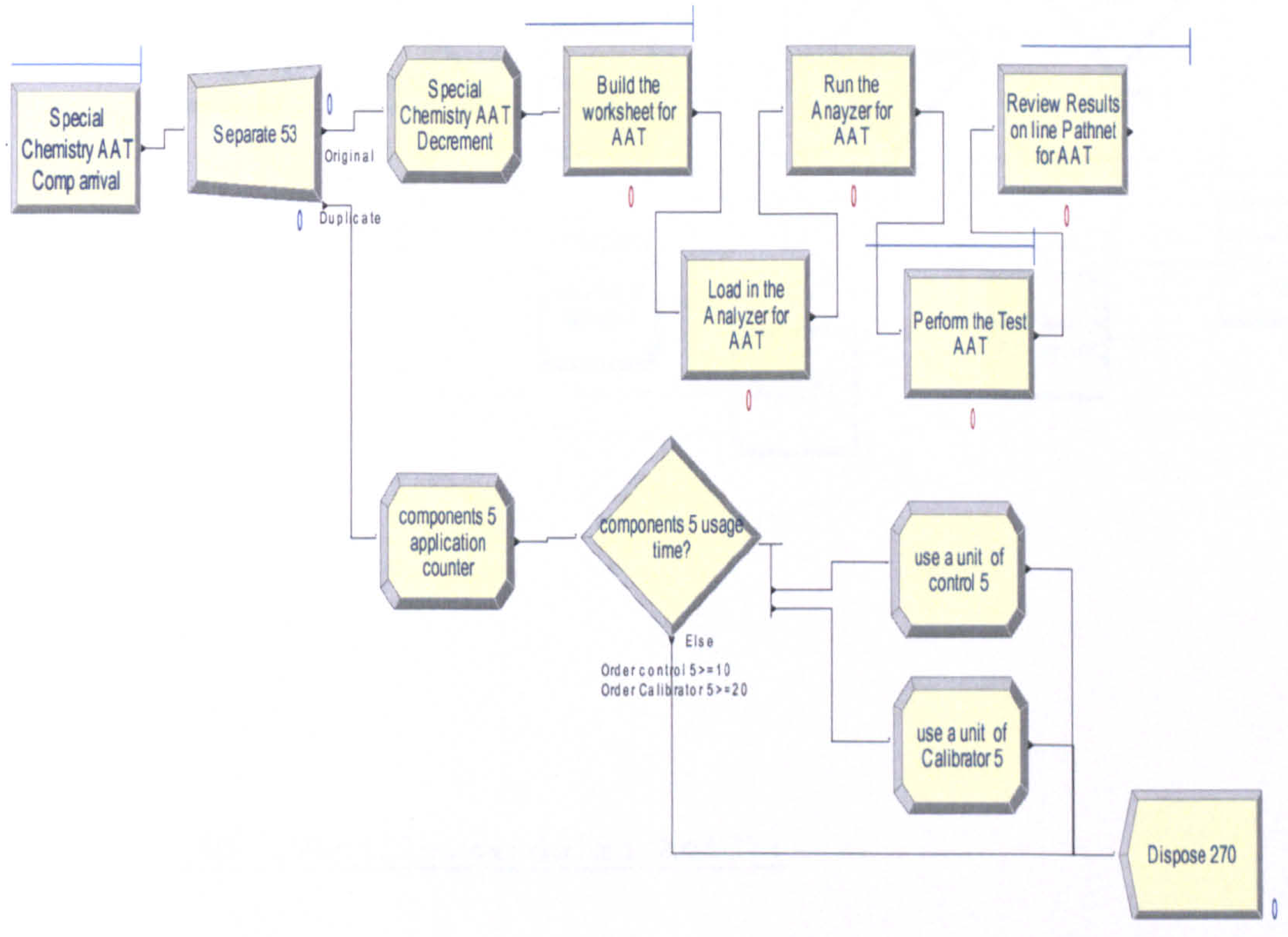


C) Special Chemistry Section:

It is measuring Special Proteins, HbA1C, Caffeine, Sweat chlorides, and Extensive menu of miscellaneous manual assays.

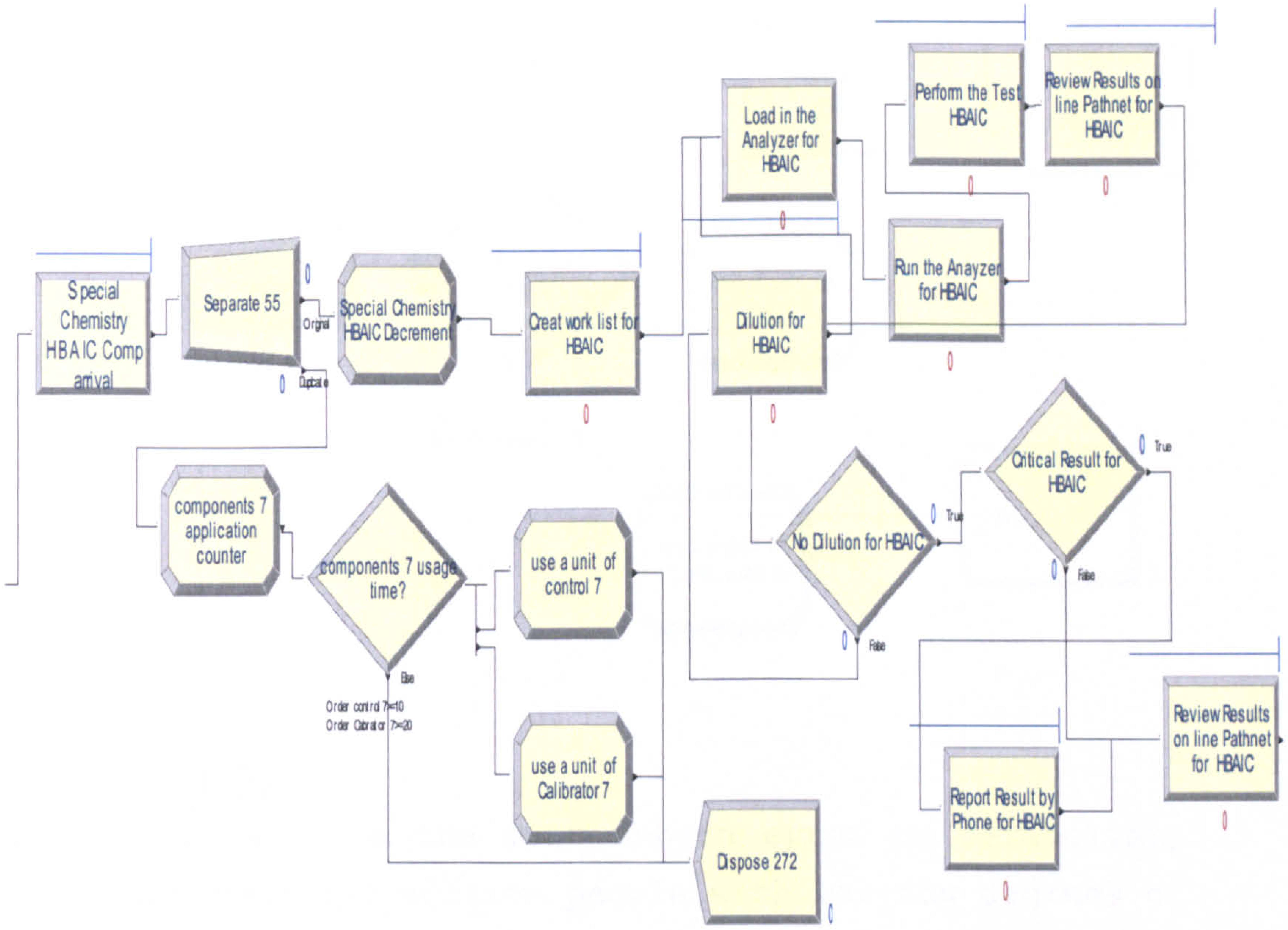
9. Alpha-1-antitrypsin (AAT):

This assay is useful for work-up of individuals with suspected disorders such as familial chronic lung disease.



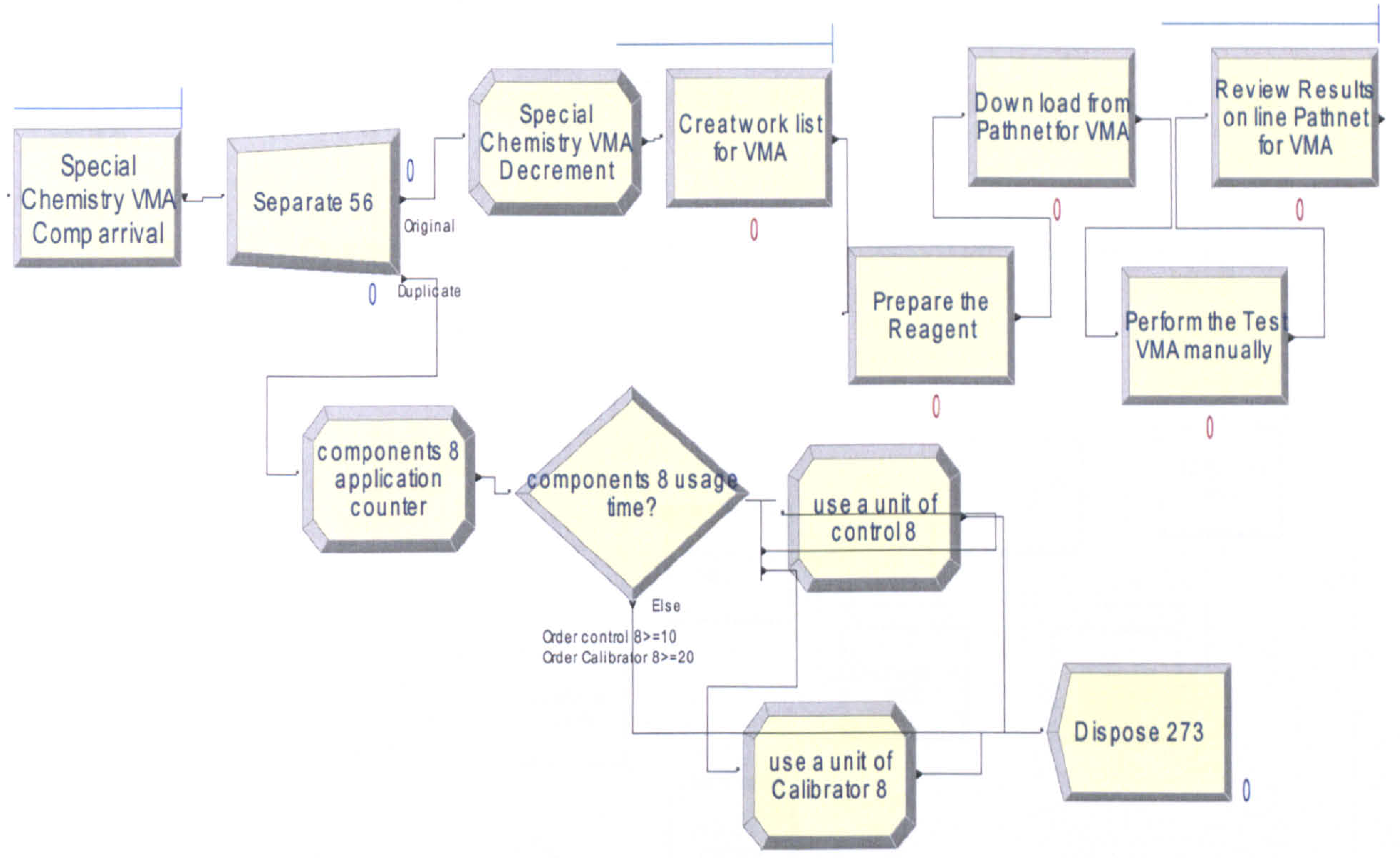
10. **HBAIC:**

It is useful in evaluating the long-term control of blood glucose concentrations in diabetic patients.



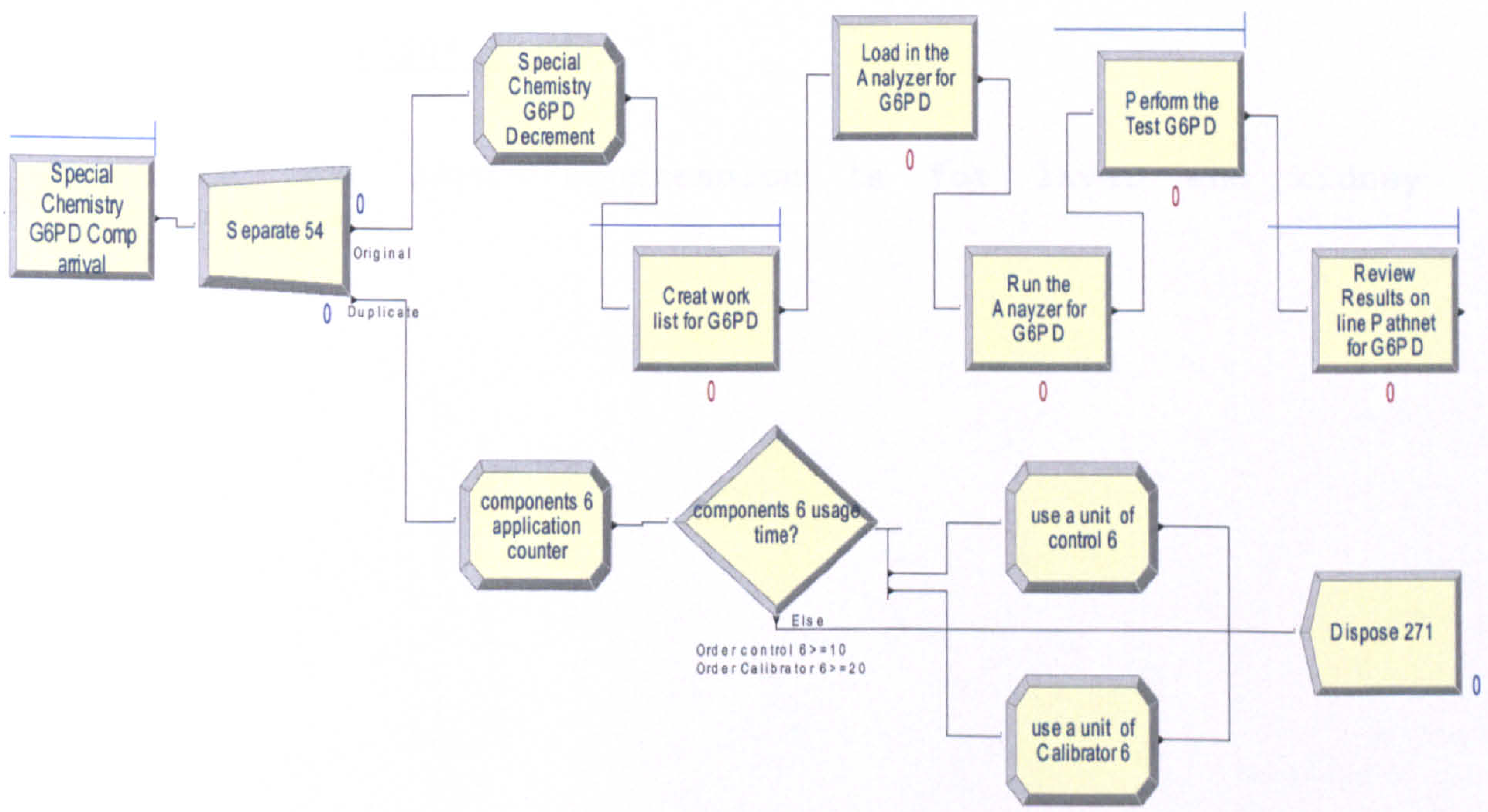
11. **VMA (Vanillylmandelic Acid):**

It is useful for screening fro vascular tumor.



12. <u>G6PD:</u>

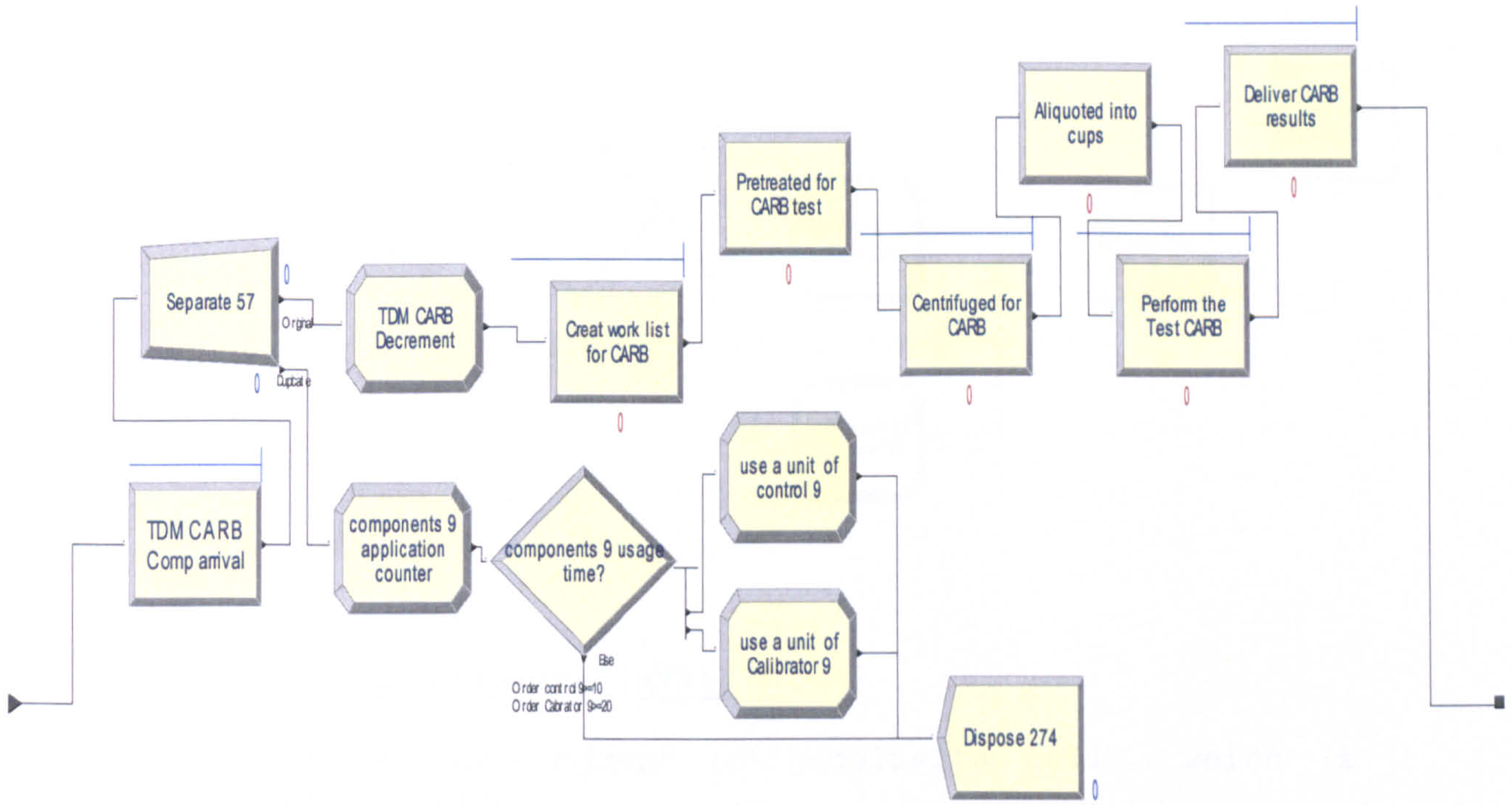
G6PD deficiency is the most inborn error or metabolism, affecting over 100 million people with varying degrees of hemolytic disease.



D) TDM Section:

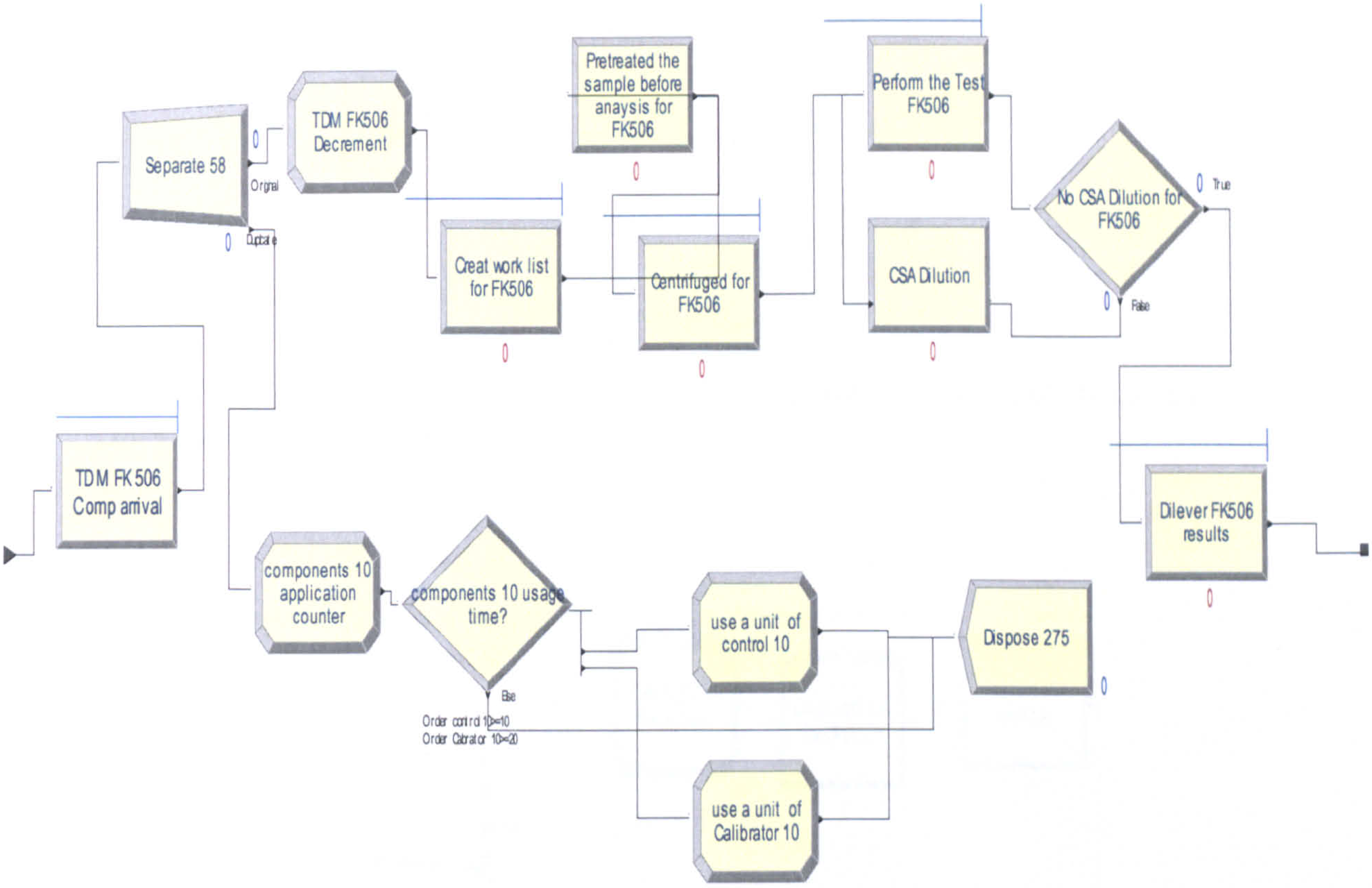
It is measuring Therapeutic Drug and Monitoring Drugs of Abuse.

13. **Carbamazepine (Carb):** Anti-convulsion marker.



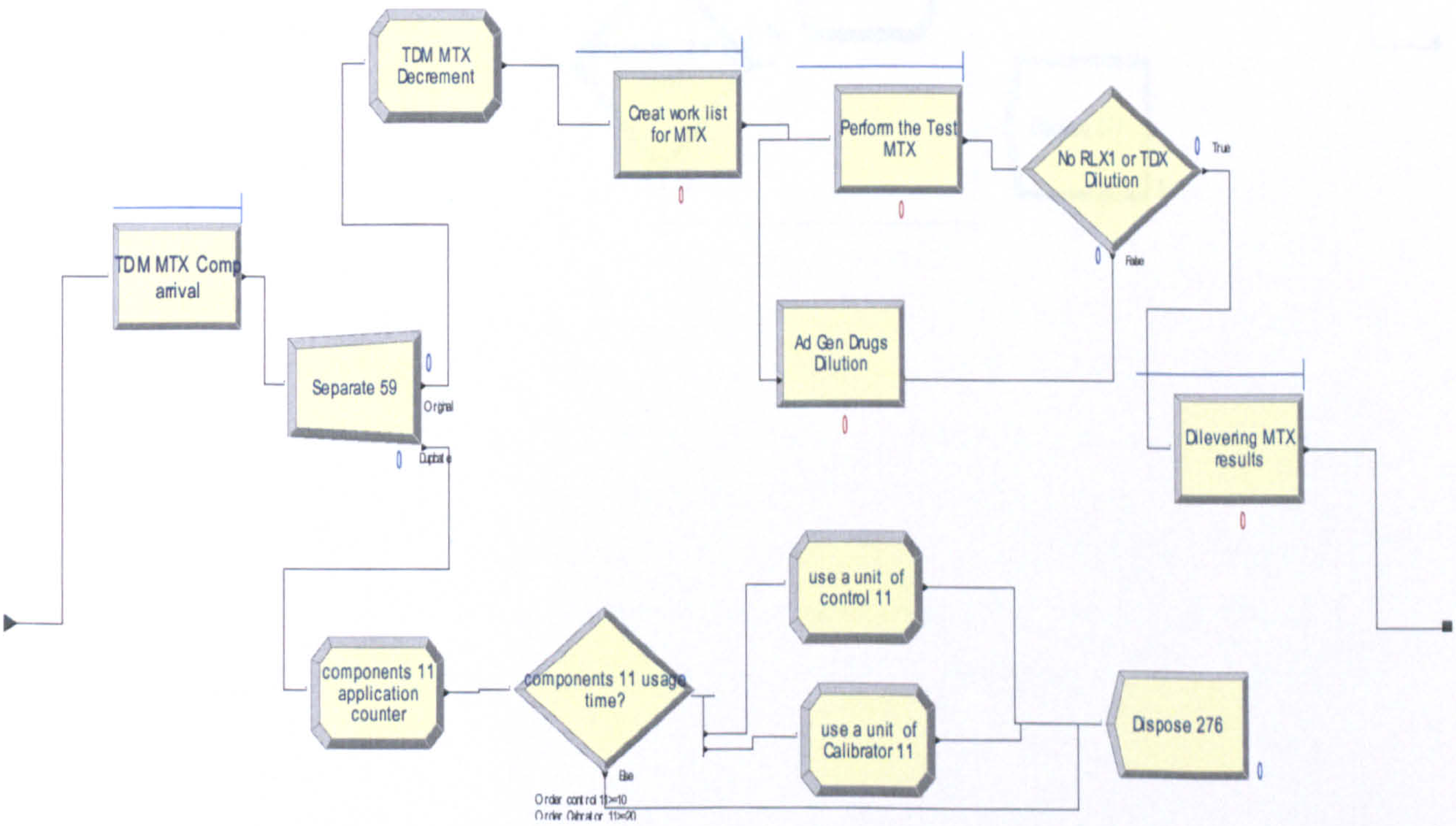
14. **FK506 :**

The test Immuno-suppression is for liver and kidney transplant.



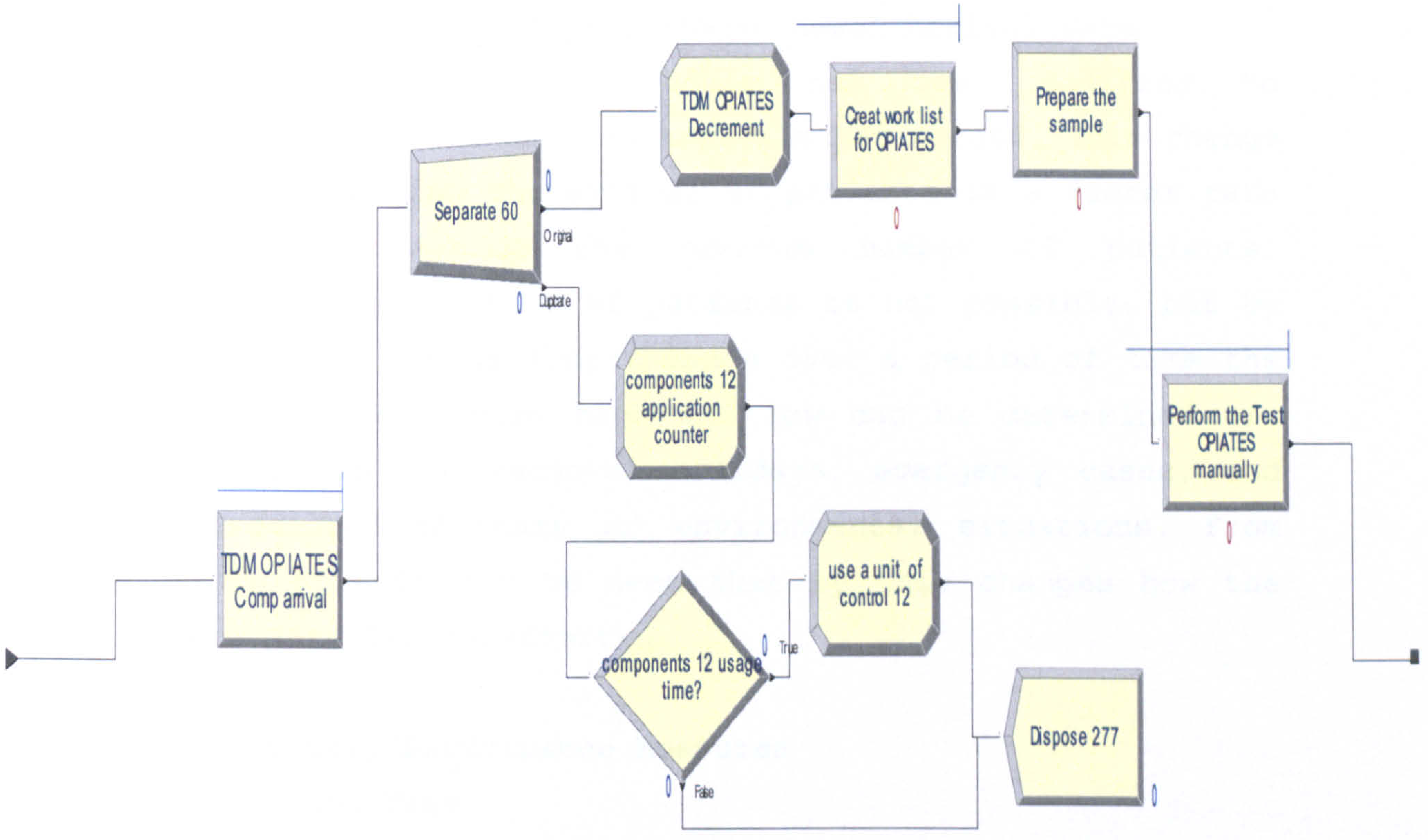
15. Methotrexate (MTX):

Inhibit the development of neoplasm's cells, which is related to cancer.



16. <u>Opiates :</u>

This test is checking of drug abuse for psychiatric patients.



APPENDIX C: Scenarios from Number Four to Number Fifteen

The scenarios have been designed as part of the simulation modeling of health care supply chain. However, because the size of the output, we have put only selected scenarios to the main chapter that reports the modeling efforts (Chapter 6), the remaining scenarios has been given in this Appendix for the further explanation and insight.

1. Scenario Four: High Customer Level Arrival Rate

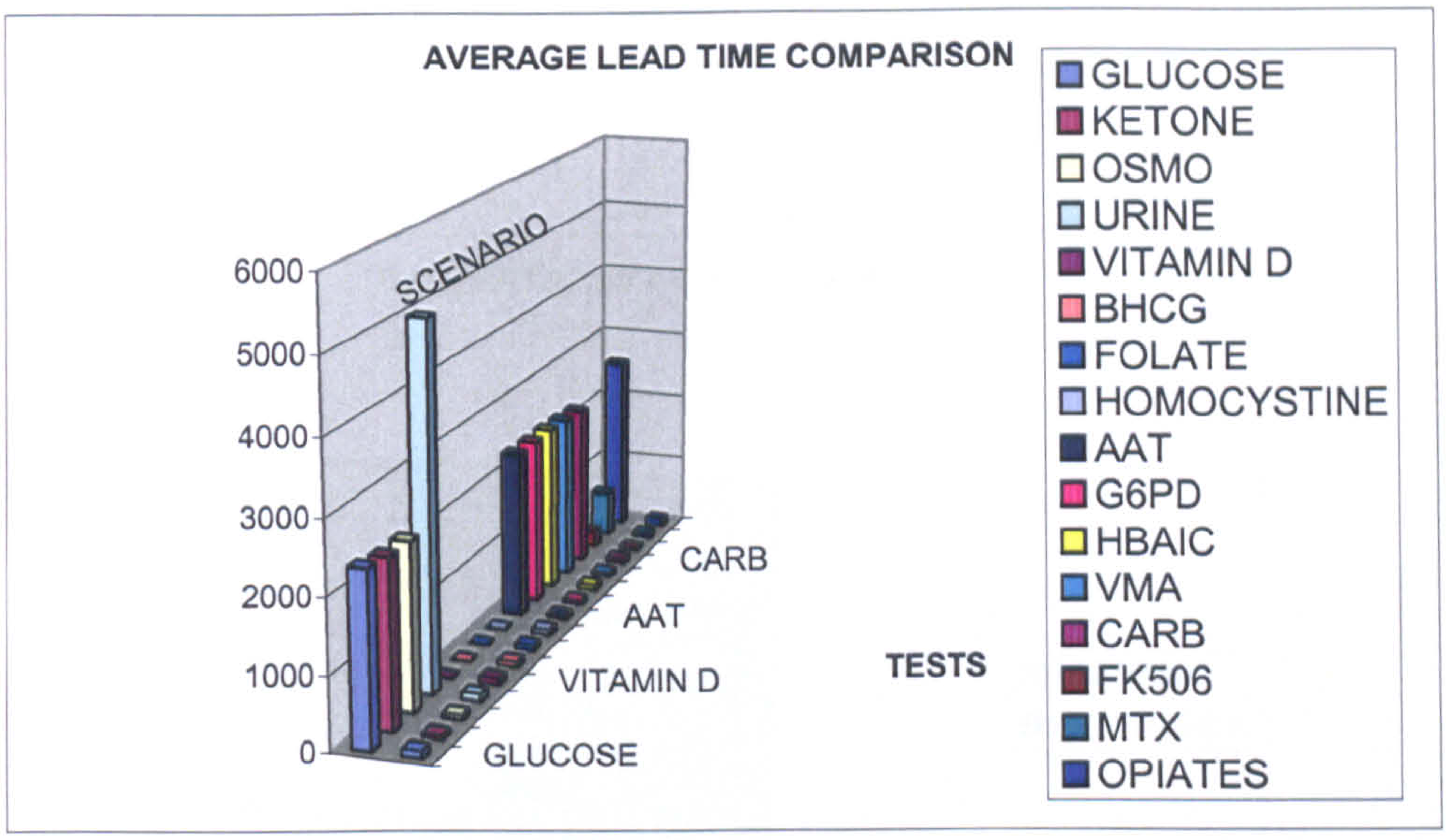
The patient arrival module has been modified to exponential with mean 10 arrivals per second. This change is representing the arrival of patients in a faster rate while maintaining the maximum number of patients. Controlling the flow of patients is not possible, but by monitoring the patient demands over a period of time the fluctuation between high and low can be determined. It depends on the seasonal holidays, emergency cases, and unpredicted military or environmental situations. From Table 6.14 it can be seen that by this changes how the Chemistry Lab is affected.

1.1 Primary Performance Measures

1.1.1 Lead Time

Increasing patient by requesting more tests as it is shown in Graph 1, the Lab cannot cope up with this sharp increase. It appears that longer the lead time some tests like BHCG, Vitamin D, Folate, and Homocystime are done less because of the staff time. The longer test times (lead times) kept the staff busy with relatively few test types only and these tests have consumed all the allotted time of the staff which in turn resulted with not accepting more tests.

Graph 1

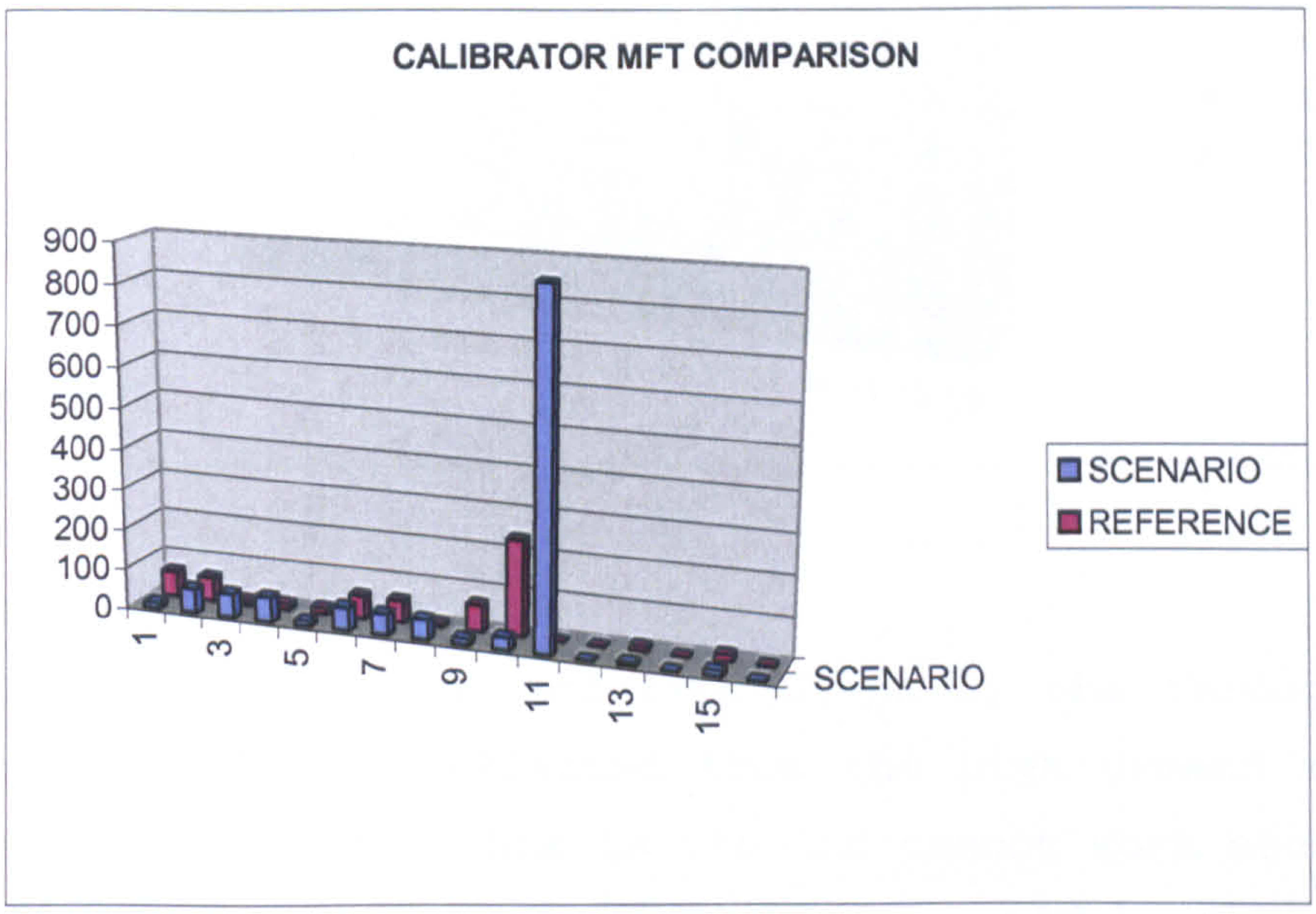


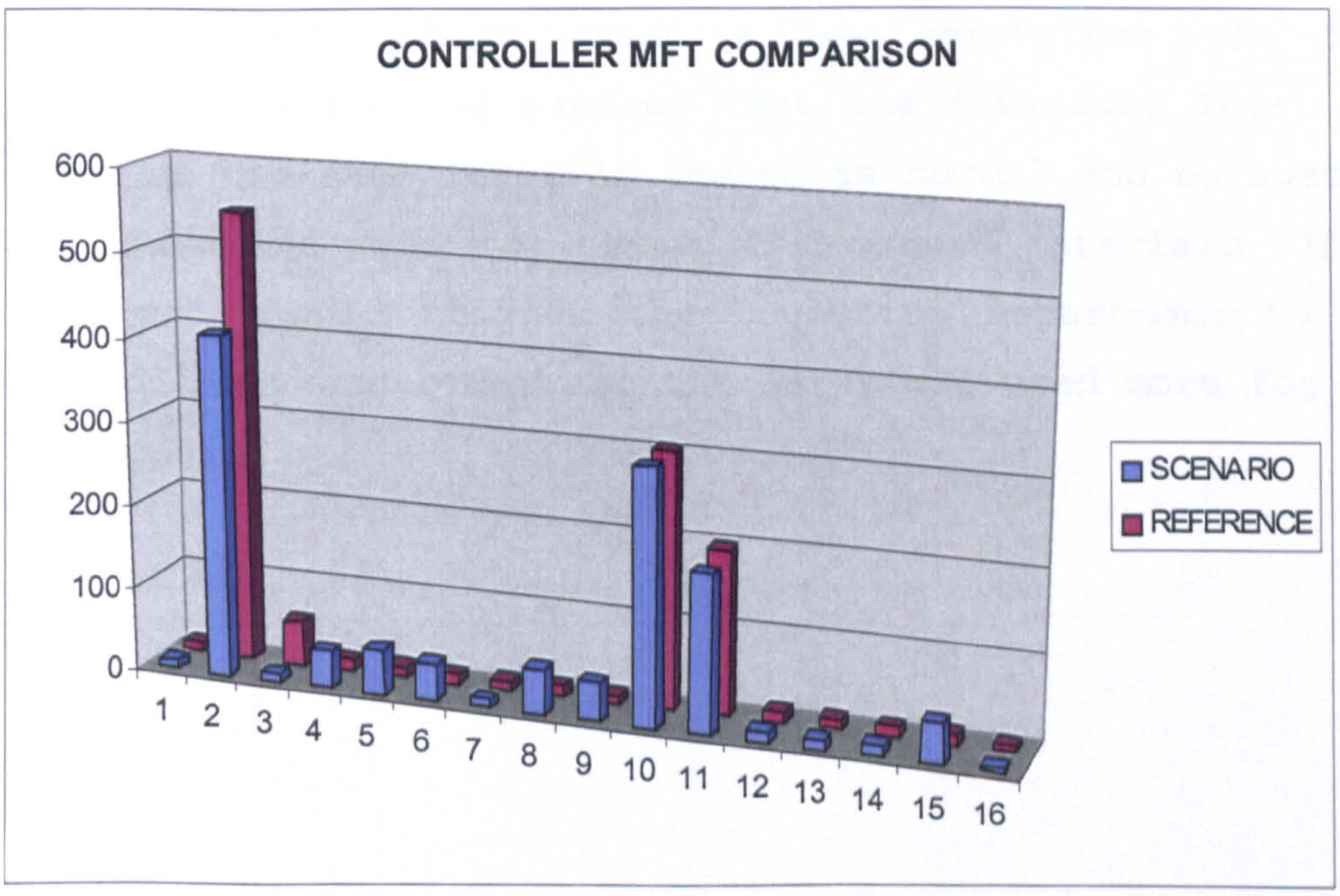
1.1.2 Material Flow Time

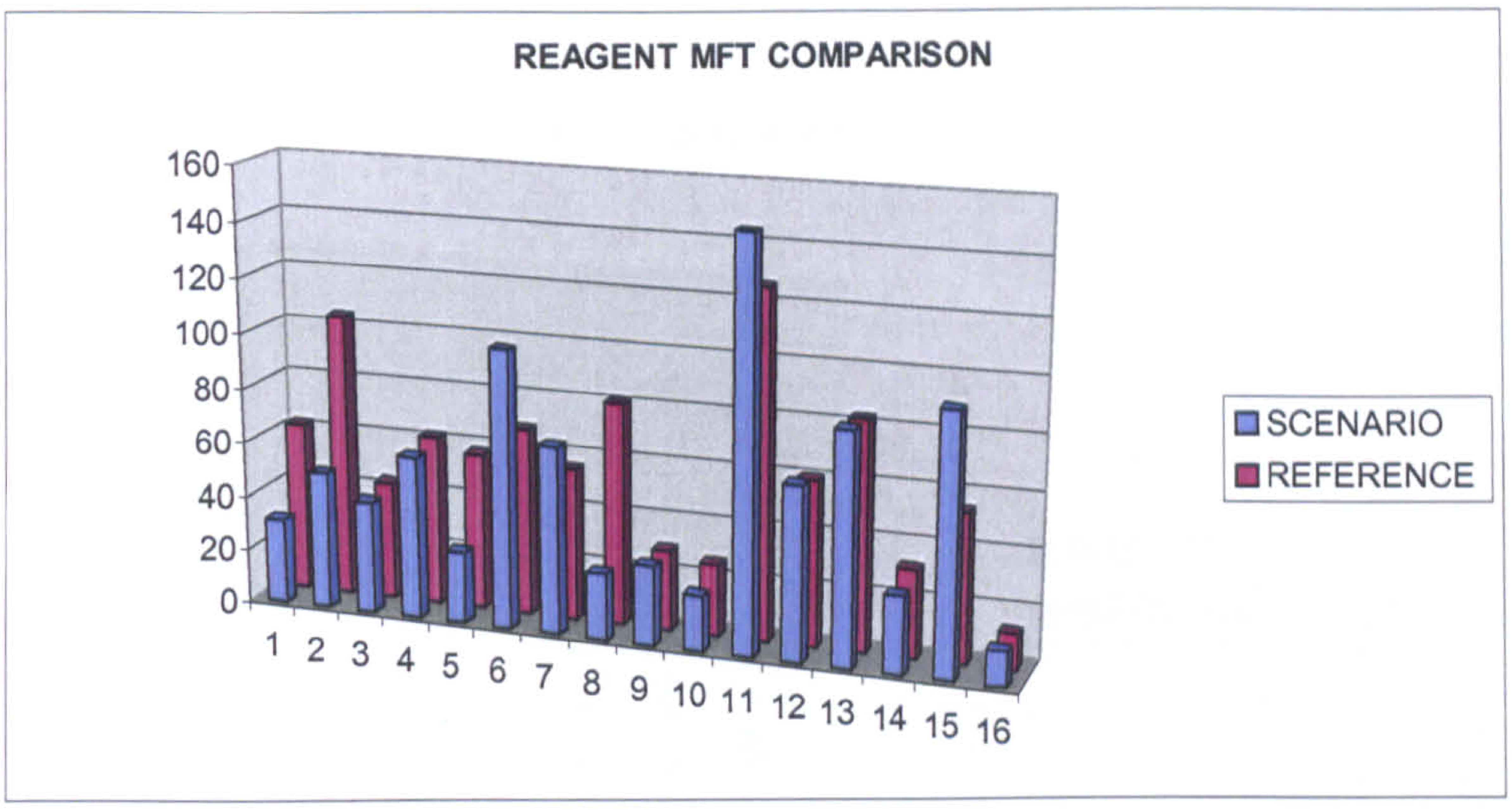
To perform any test indicated in Graph 5.1, there should be three components except for Test 12 & 14, which have only 2 components each, material flow time is very essential. It affects the level of inventory and the throughput. The fluctuation between decreasing and increasing affect the outcome of the Lab.

Graph 2 consists of three parts; one is calibrator to indicate maximum difference in the reference in Test # 11, the special chemistry HBAIC with difference of 635. Second is controller; as we can note the similarity with the Reference Model. The third is the reagent which generally was average. As illustrated in the Table and Graphs, the materials that are used in certain tests have dramatically increased because of the high number of tests done as a result of increasing demand. Apparently, these materials need to be ordered either more frequently or in bulk, which in turn may cause high inventory cost. The inventory section must come up with a plan to answer this high demand case not to cause any interruption in the tests, which may be very costly for the organization, such as lose of human life.

Graph 2



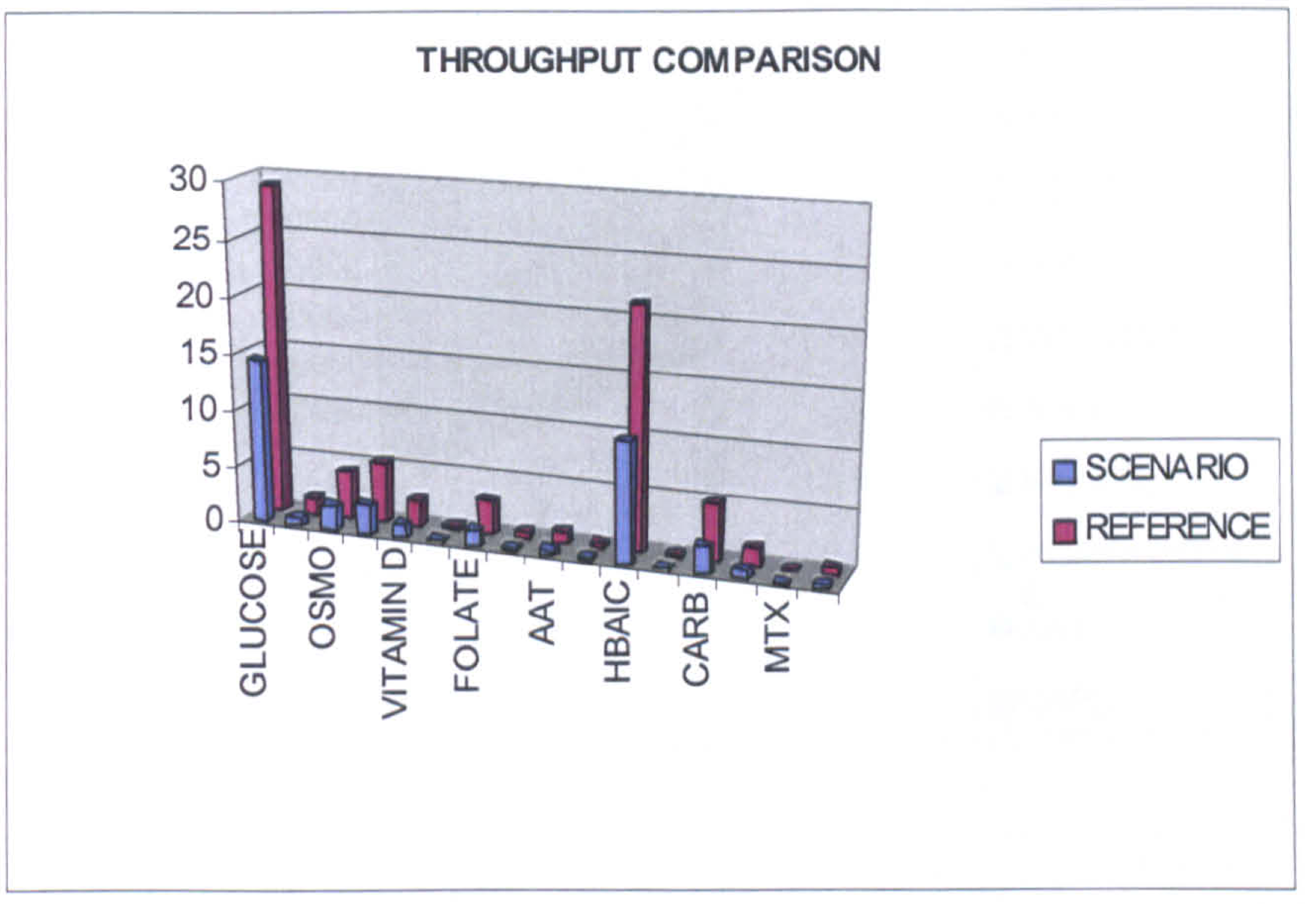




1.1.3 Throughput

As it can be observed from Graph 3, the throughput has been negatively affected from the high demand rate. One major reason for this is the Lab cannot work productively under the pressure. Another reason could be the Logistics Department is not prepared for this high demand and some of the materials used in the tests are not available to do the test, which cause a low throughput. In this experimentation, we assumed that the inventory level was kept at the same level as demand is normal and no special purchase was made for the high demanded materials. This, in fact should trigger the Logistics Department to act immediately and order all the materials used more for the new case.

Graph 3



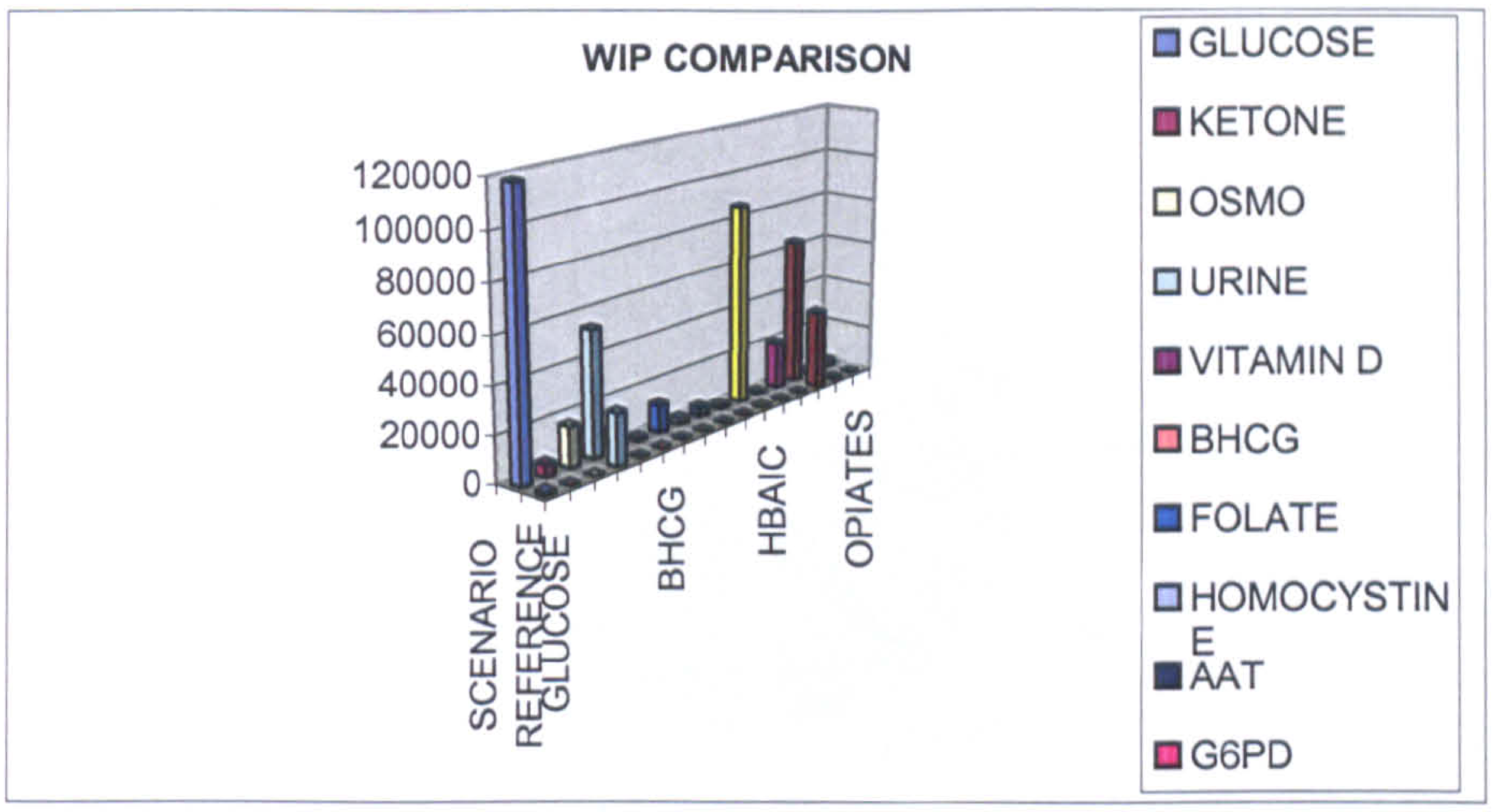
1.1.4 Inventory Status

Most of the component inventory has increased because of the high order of some materials with increasing demand, but some still have low inventories, while the demand is high. This will be discussed at the end of this scenario in the conclusion.

1.1.5 WIP

Without any doubt, a high percentage of work lagged behind, as the Lab could not match with the high demand as we can see in Graph 4. There is a very dramatic increase in the number of WIP generated by high demand level.

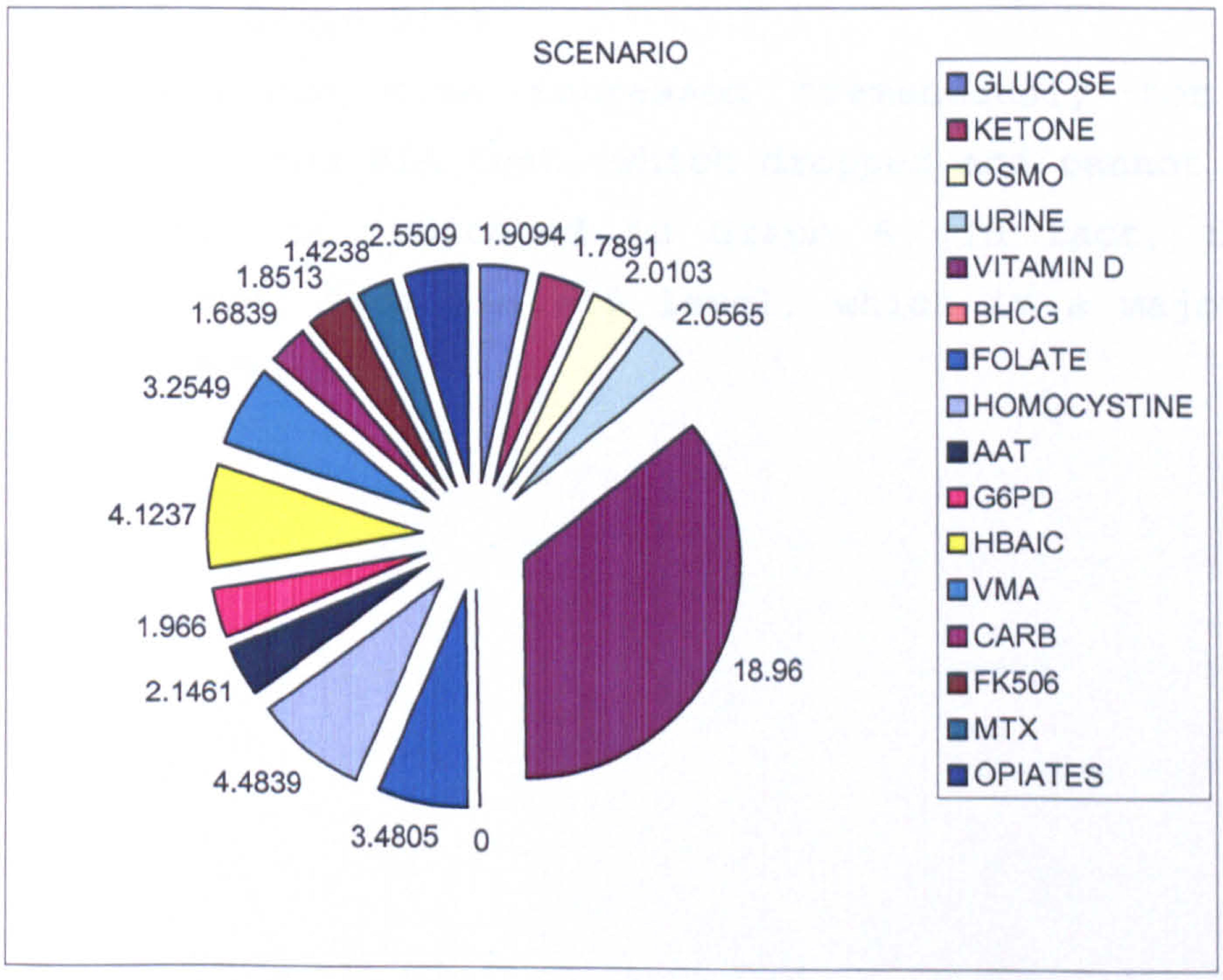
Graph 4

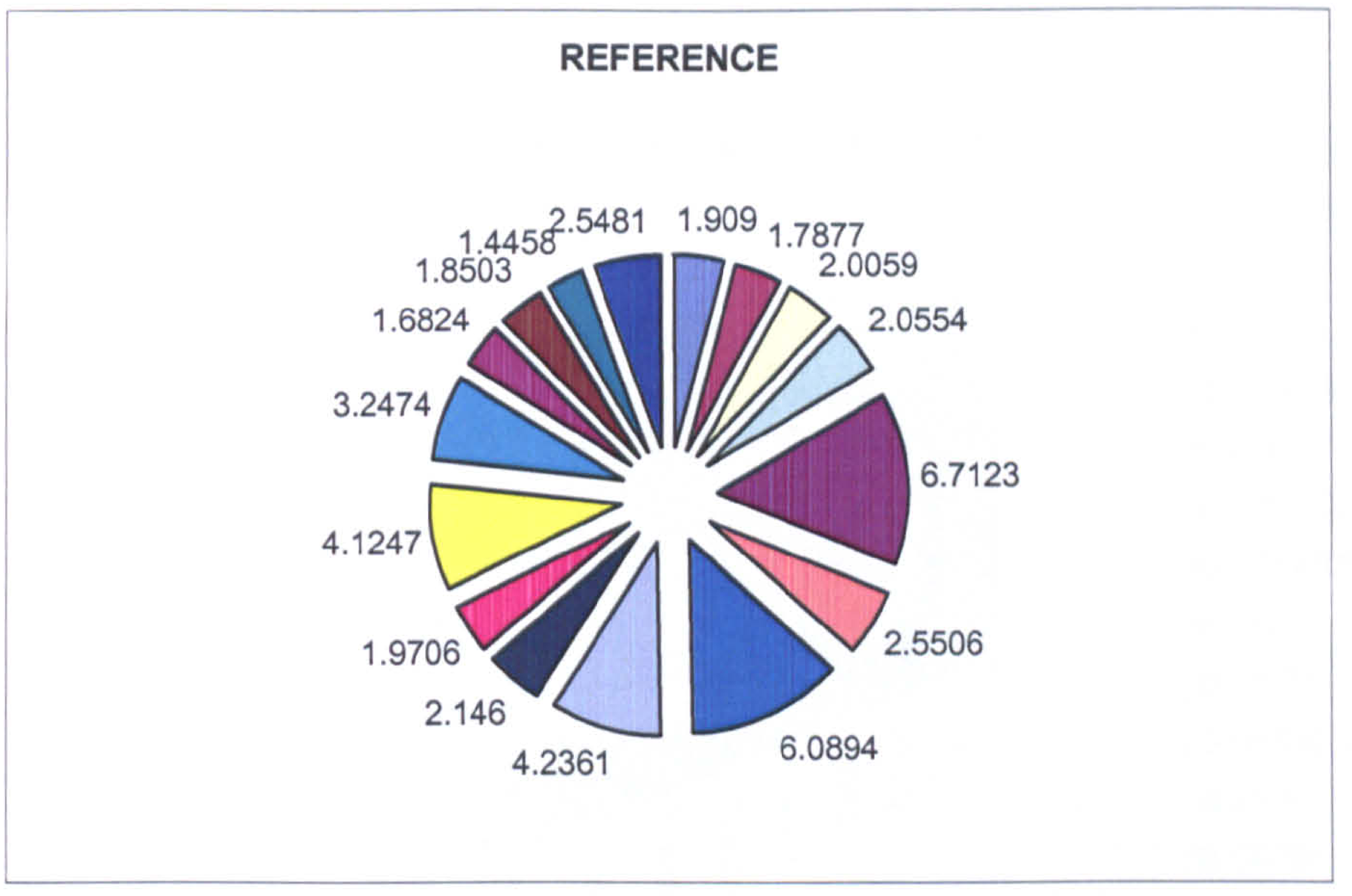


1.1.6 Cost of Test

Graph 5 shows that there are only limited number of tests, which were effected by high demand, such as Vitamin D increased three times, while the other test, Folate decreased by half. This, in fact, is a result of the high demand for some of the tests.

Graph 5





1.2 Secondary Performance Measures

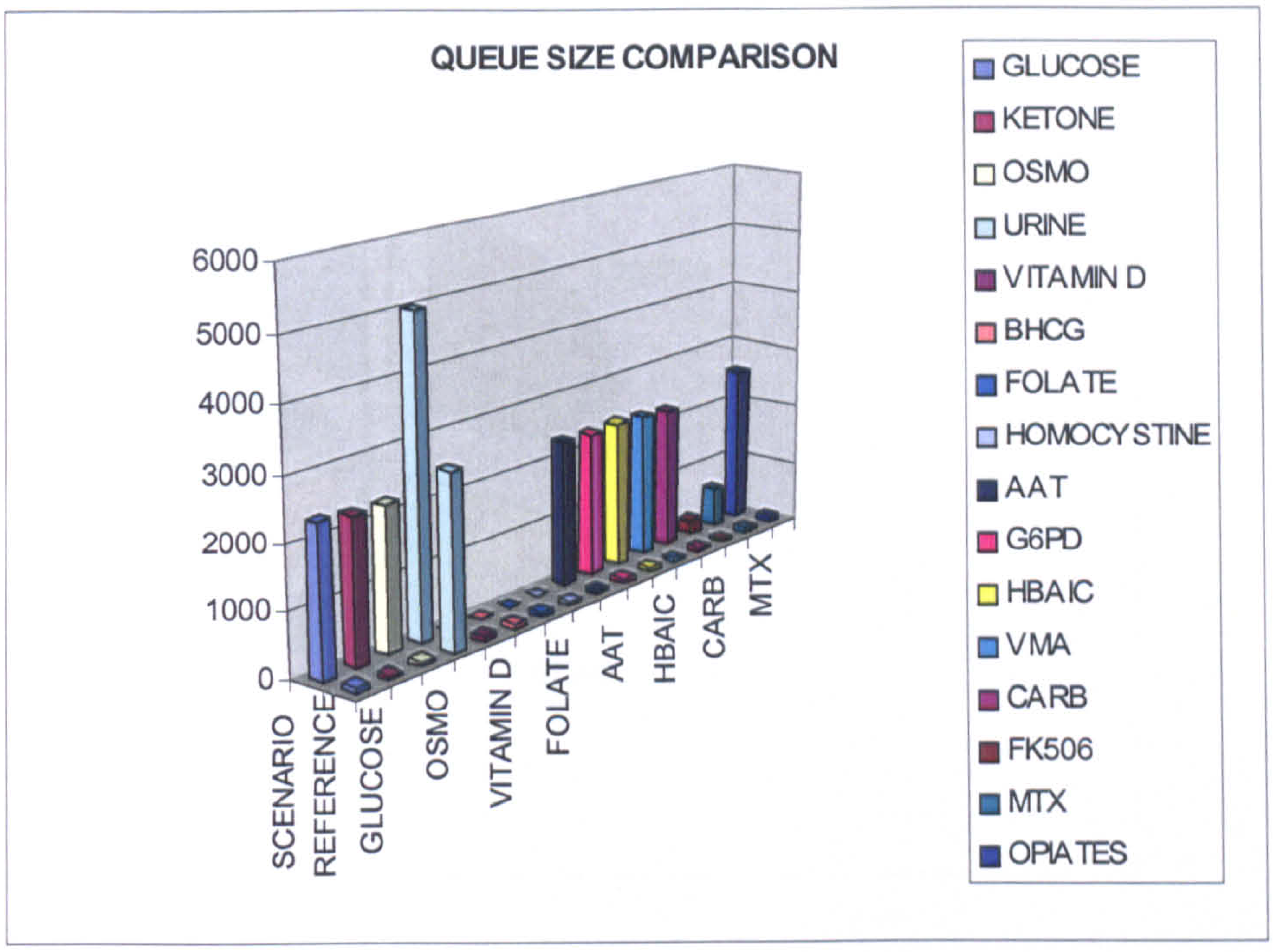
1.2.1 Material Order Size

There are two components have high number of order size, the reagent and the controller, while the calibrator decreases from 182 to 154.

1.2.2 Queue Size

The queue size increased tremendously for all tests except the RIA test, which dropped and cannot handle more tests, as indicated in Graph 6. In fact, this can be observed from the WIP level, which is a major source of queue size.

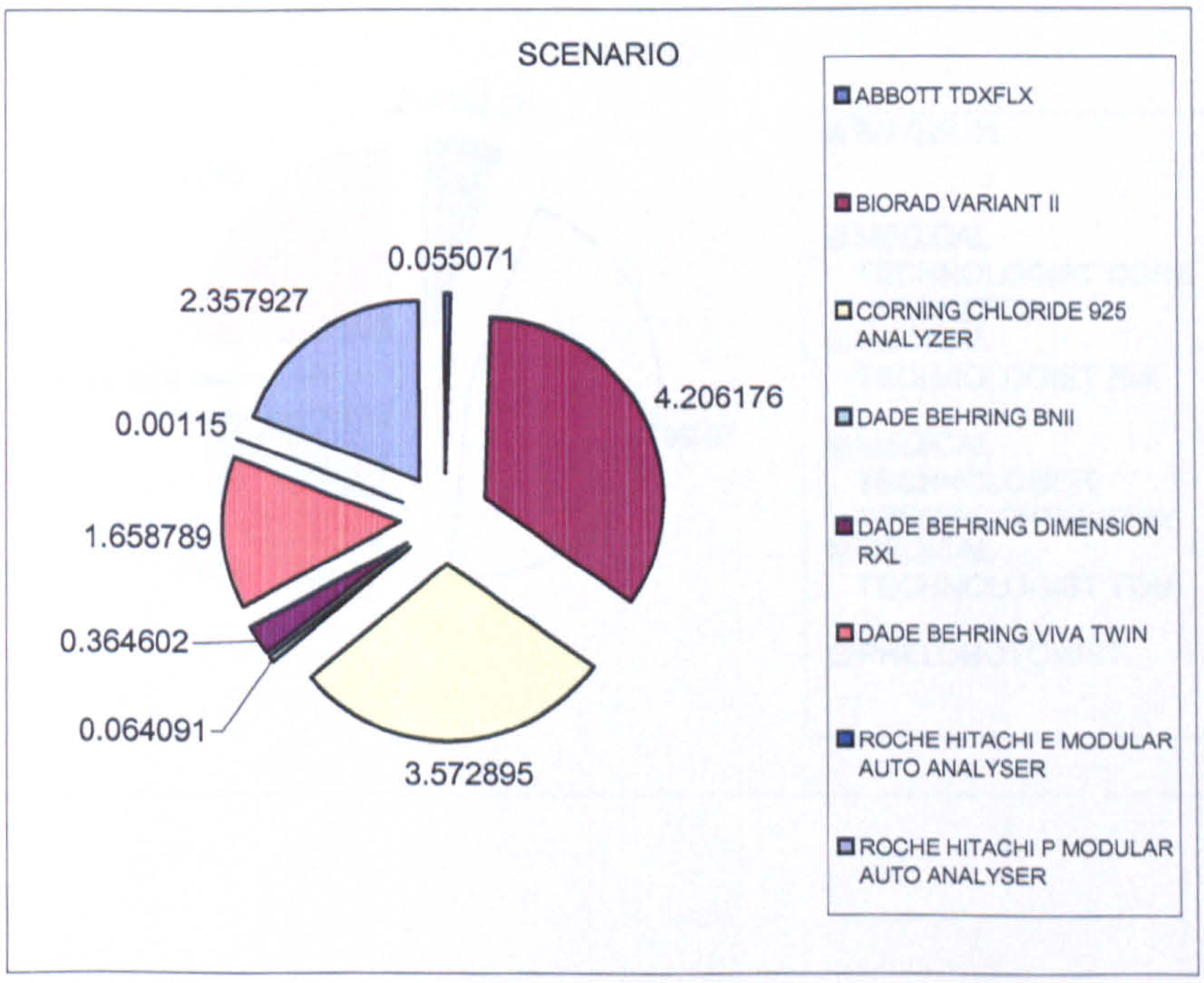
Graph 6

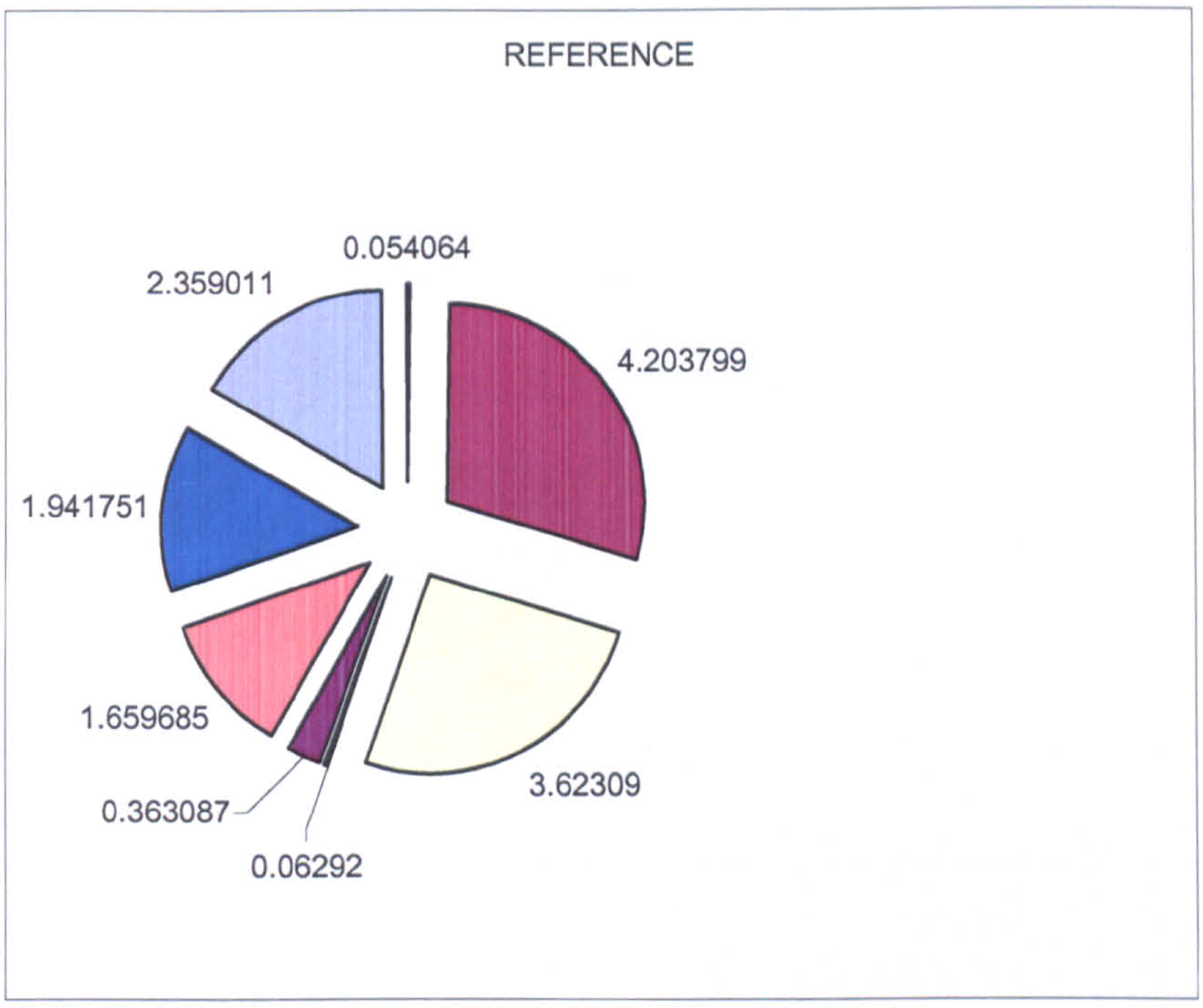


1.2.3 Equipment Utilization

There is not much difference in the utilization of equipment (Graph 7), only the Roche Auto Analyzer dropped from 1.9 to 0.001.

Graph 7

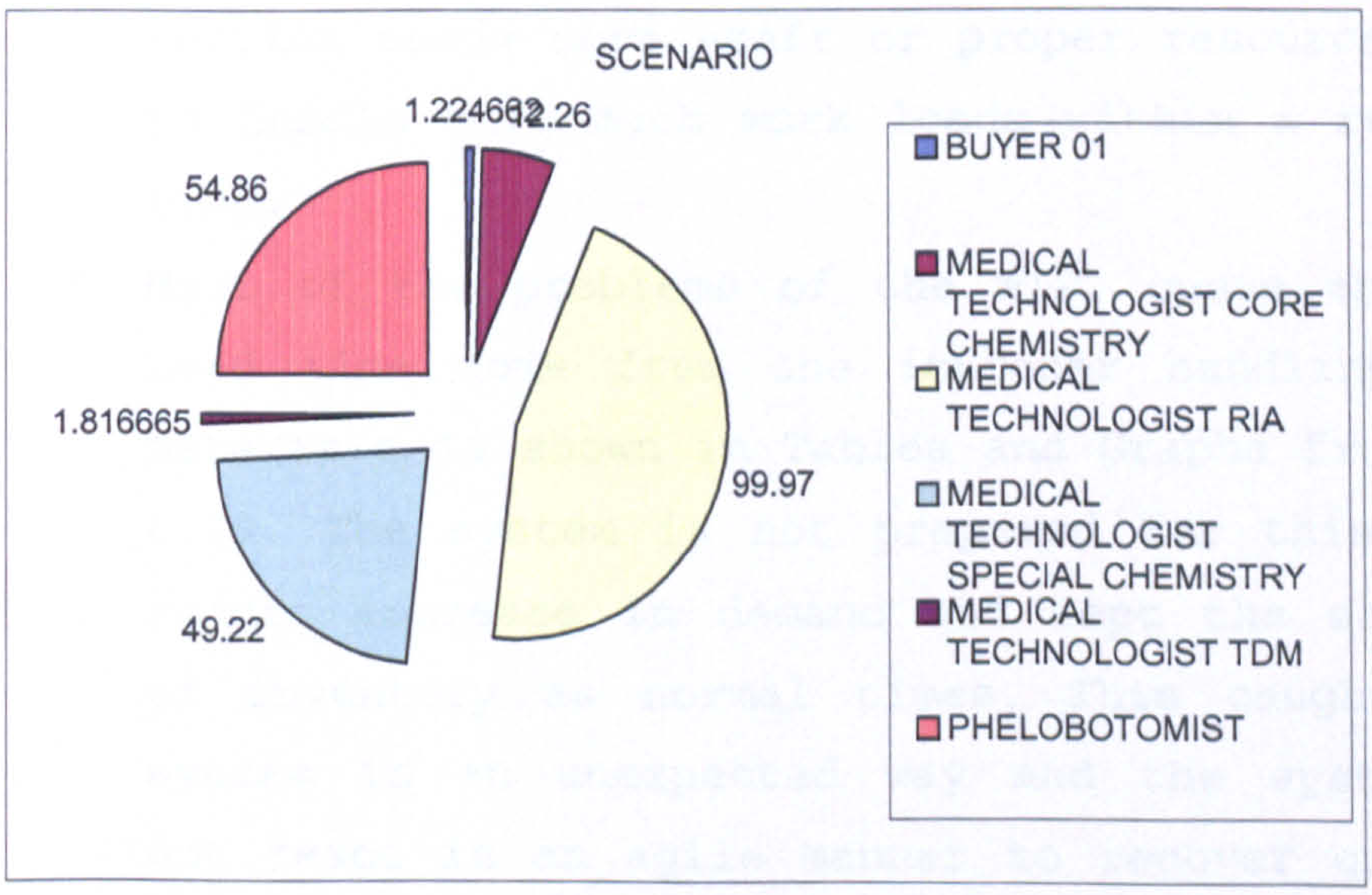


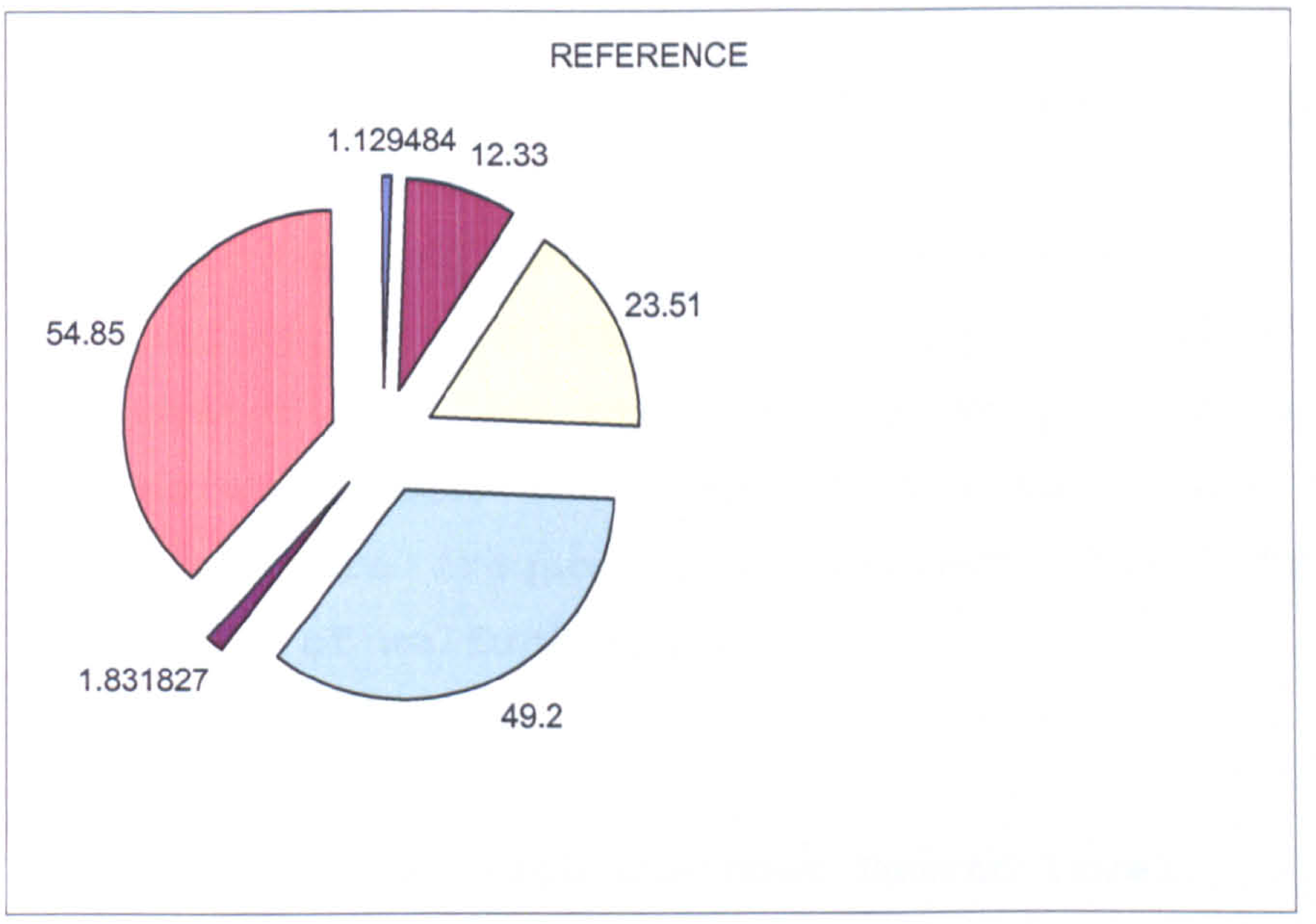


1.2.4 Staff Utilization

From Graph 8, the staff utilization is almost the same with the utilization level observed in the Reference Model, but Medical Technologist RIA work utilization has jumped to 99.97 from 23.51.

Graph 8





1.3 Conclusion

Ten performance measures have been studied for in case number of patient has increased dramatically because of any reason. The Chemistry Lab reacted differently as stated in the following points:

- RIA section cannot handle the load, as the number of staff allocated for this job is limited. This section needs more staff or proper resource sharing to handle this much work loads within a reasonable time.
- Most of the problems of the WIP, queue and longer lead time come from the improper handling of the materials as shown in Tables and Graphs from 6.16 - 6.19. The system is not prepared for this kind of sudden increase in demand and kept the same level of inventory as normal times. This caught up the system in an unexpected way and the system could not react in an agile manner to recover quickly by ordering more materials of needed type in a short time. Since each material has a certain lead time

to deliver, during some period of the time the system had to work without any proper supply which in turn caused some serious delay in process leading long lead times, high WIP and queue levels and under utilization of equipment and staff. The system may be prepared to keep some amount of safety stock for some of the materials that are used more frequently to protect itself from these kinds of malfunctions.

2. Scenario Five: High Customer Demand Level

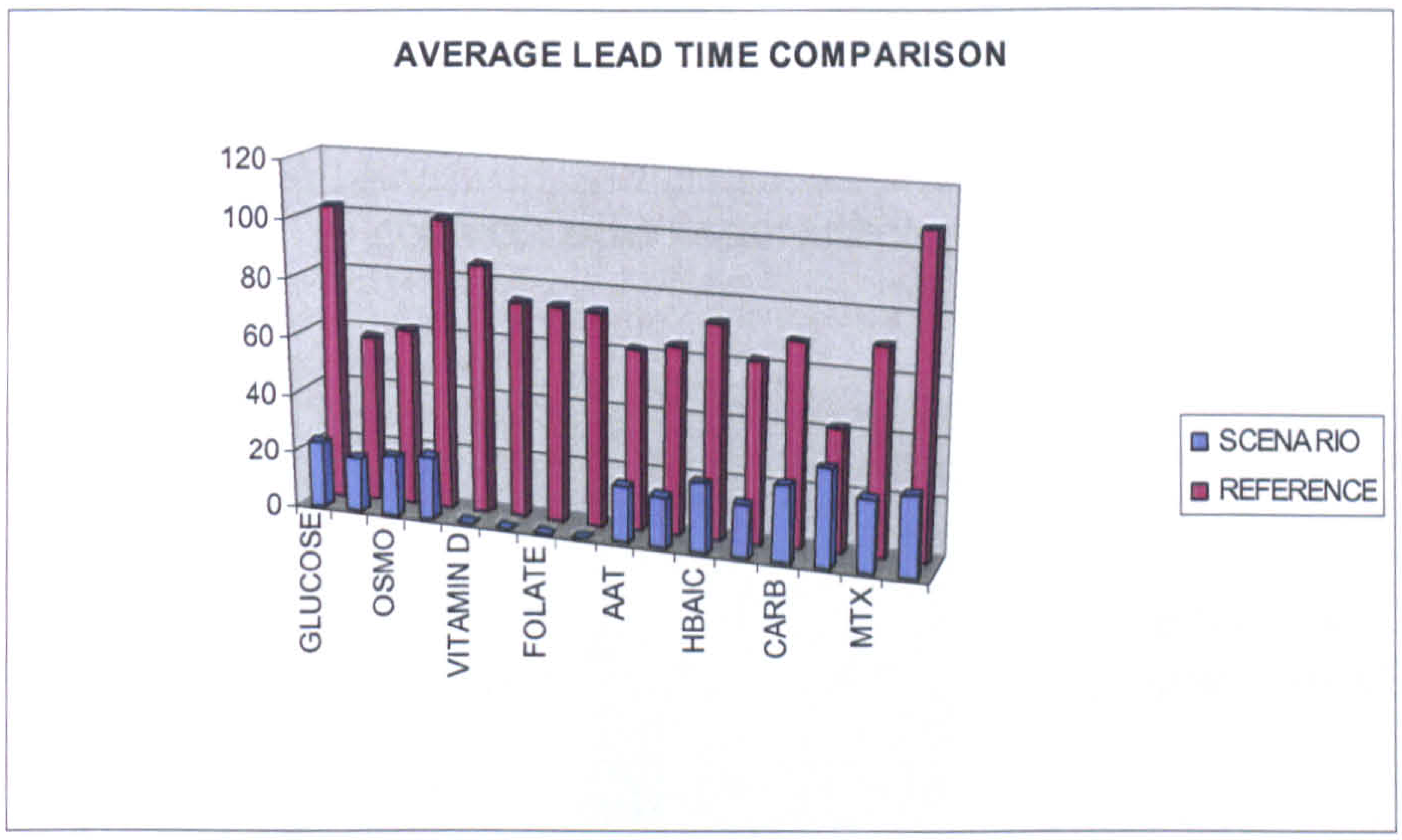
Patient's arrival module has been changed for this scenario to normal (1.5) arrival per minute. It is hard to predict patient's arrival, but having more scenarios will cover most of the patient arrival pattern. This scenario will provide a platform for understanding of steady flow of patient, at the same time high percentage of test requested, and how the system will react to it.

2.1 Primary Performance Measures

2.1.1 Lead Time

The constant arrival of patients has a big effect to lead-time; it is the same as we have low demand with exponential arrival. Graph 9 proves this except for protein analysis.

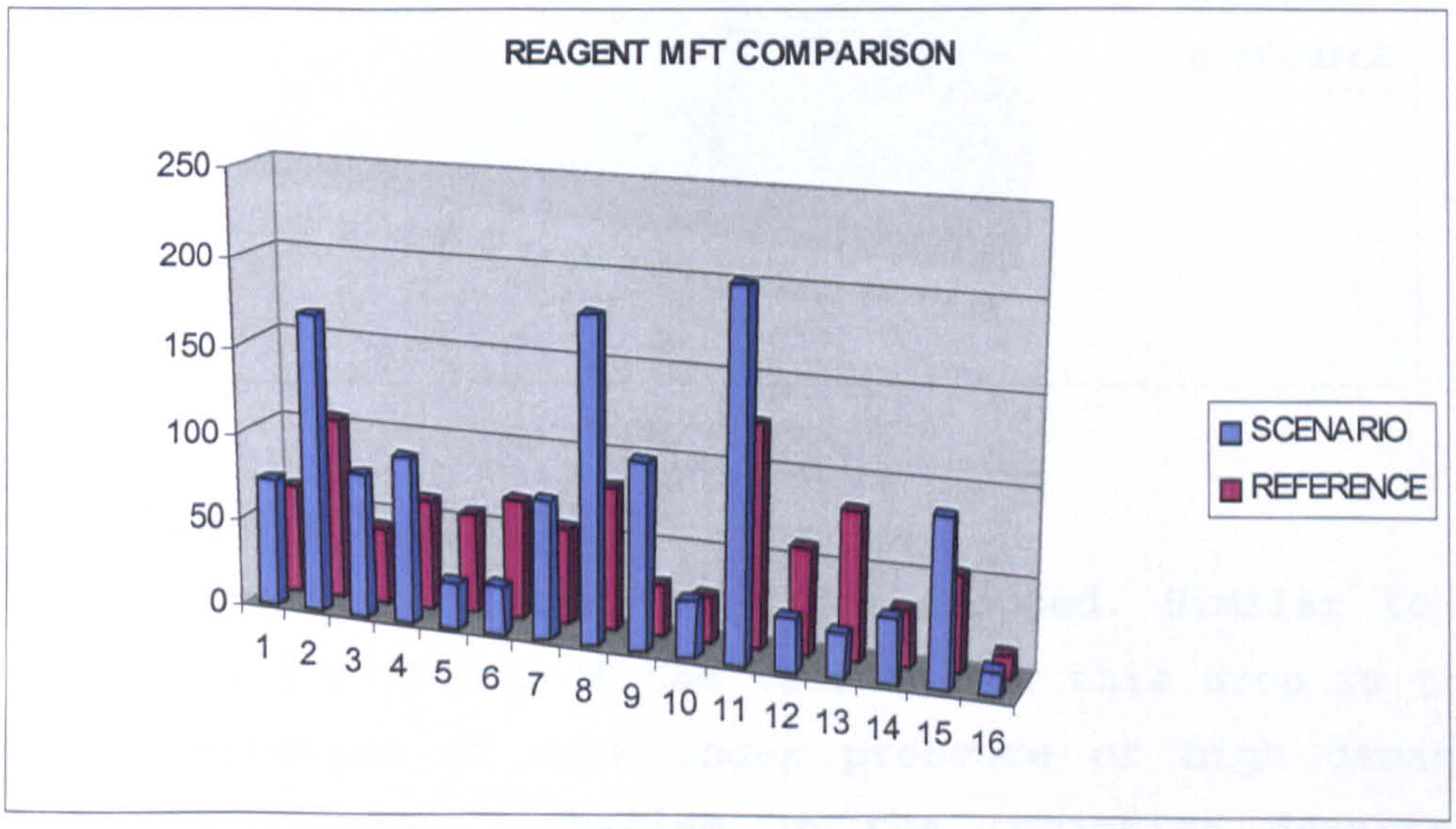
Graph 9

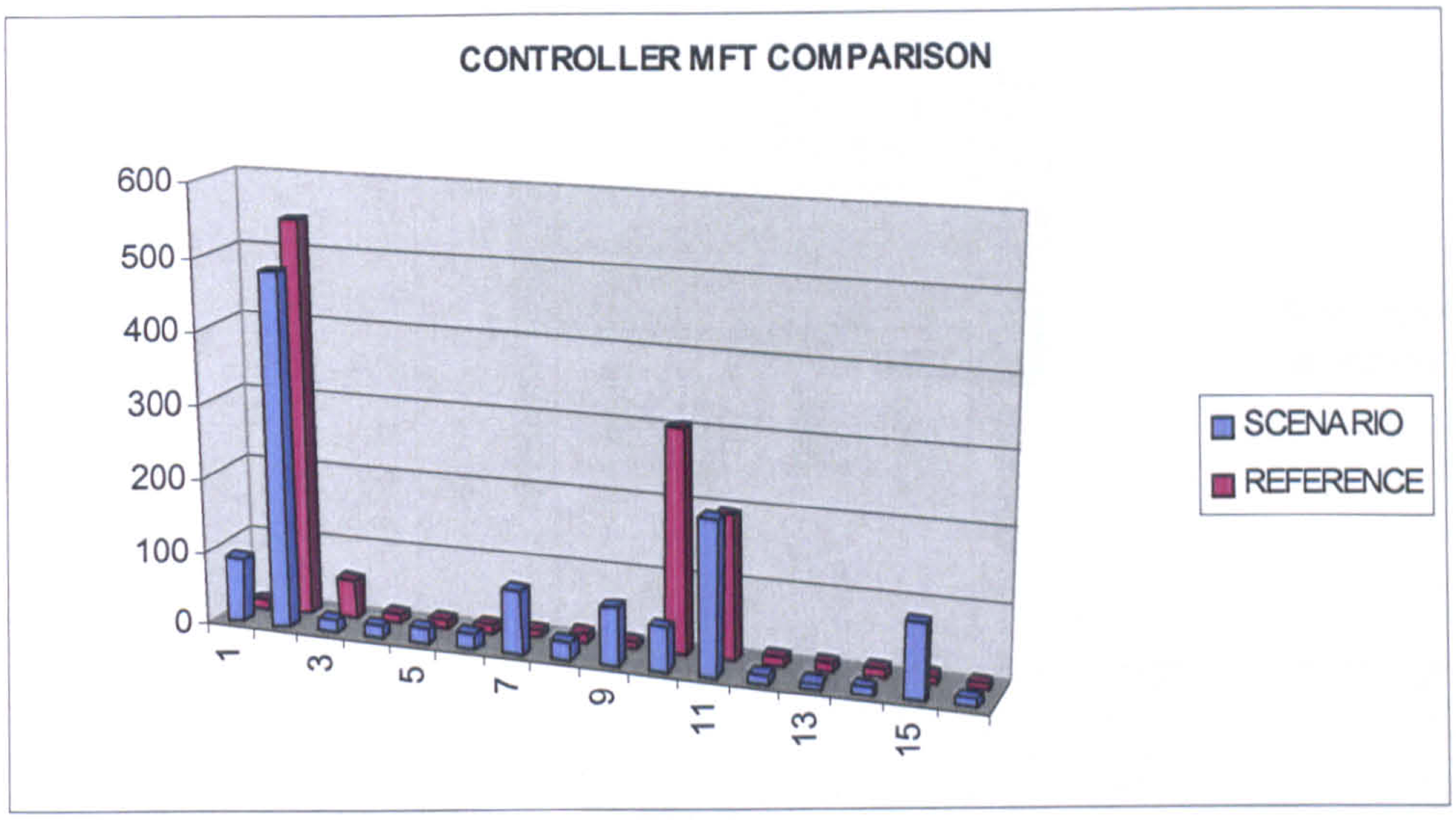


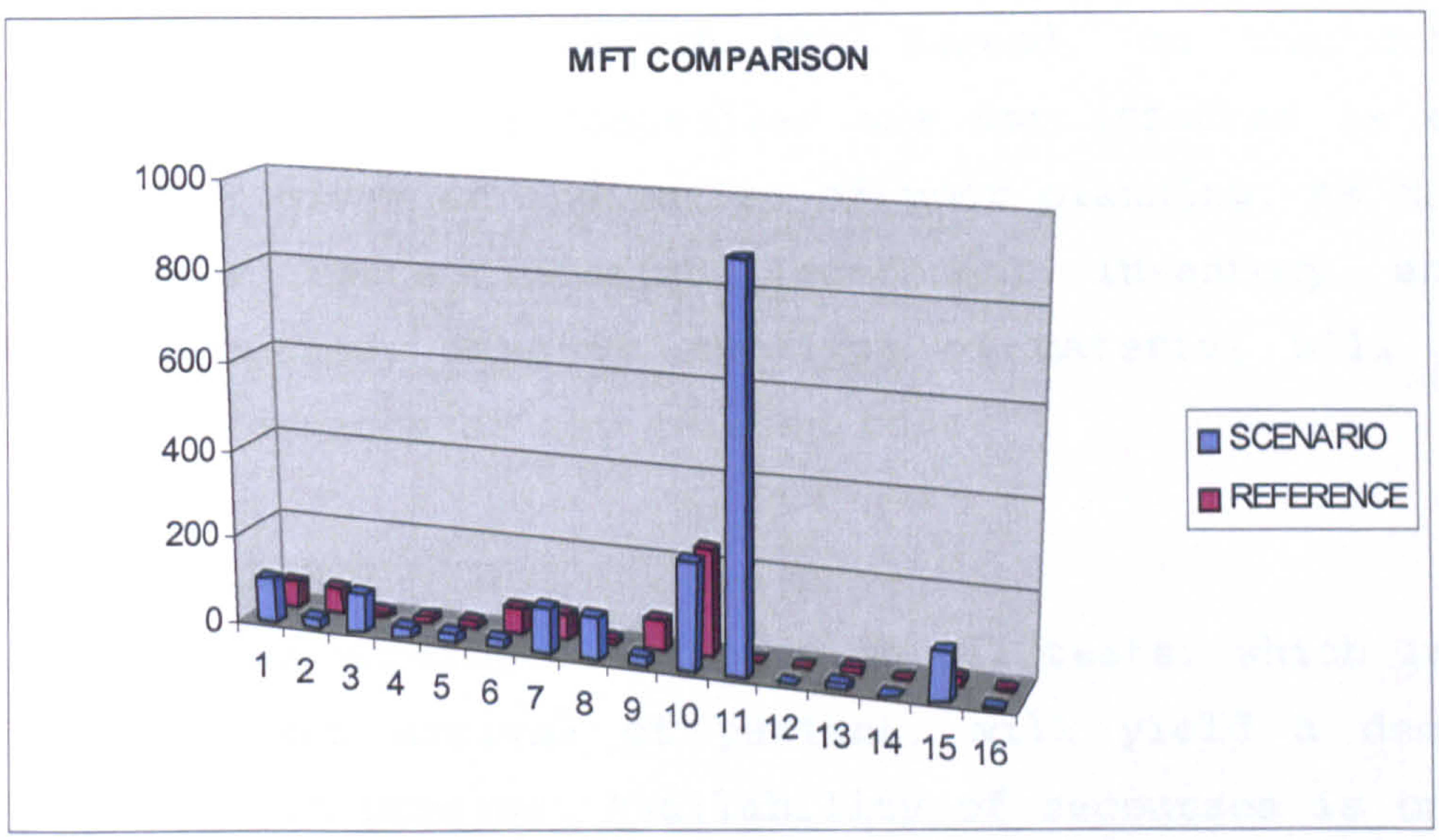
2.1.2 Material Flow Time

Material flow time for the three components (reagent, calibrator, and controller) have the same pattern as increased MFT, with the exception of some items. This expectation was the same as any manufacture with high demand flow of material got slower. (Graph 10)

Graph 10



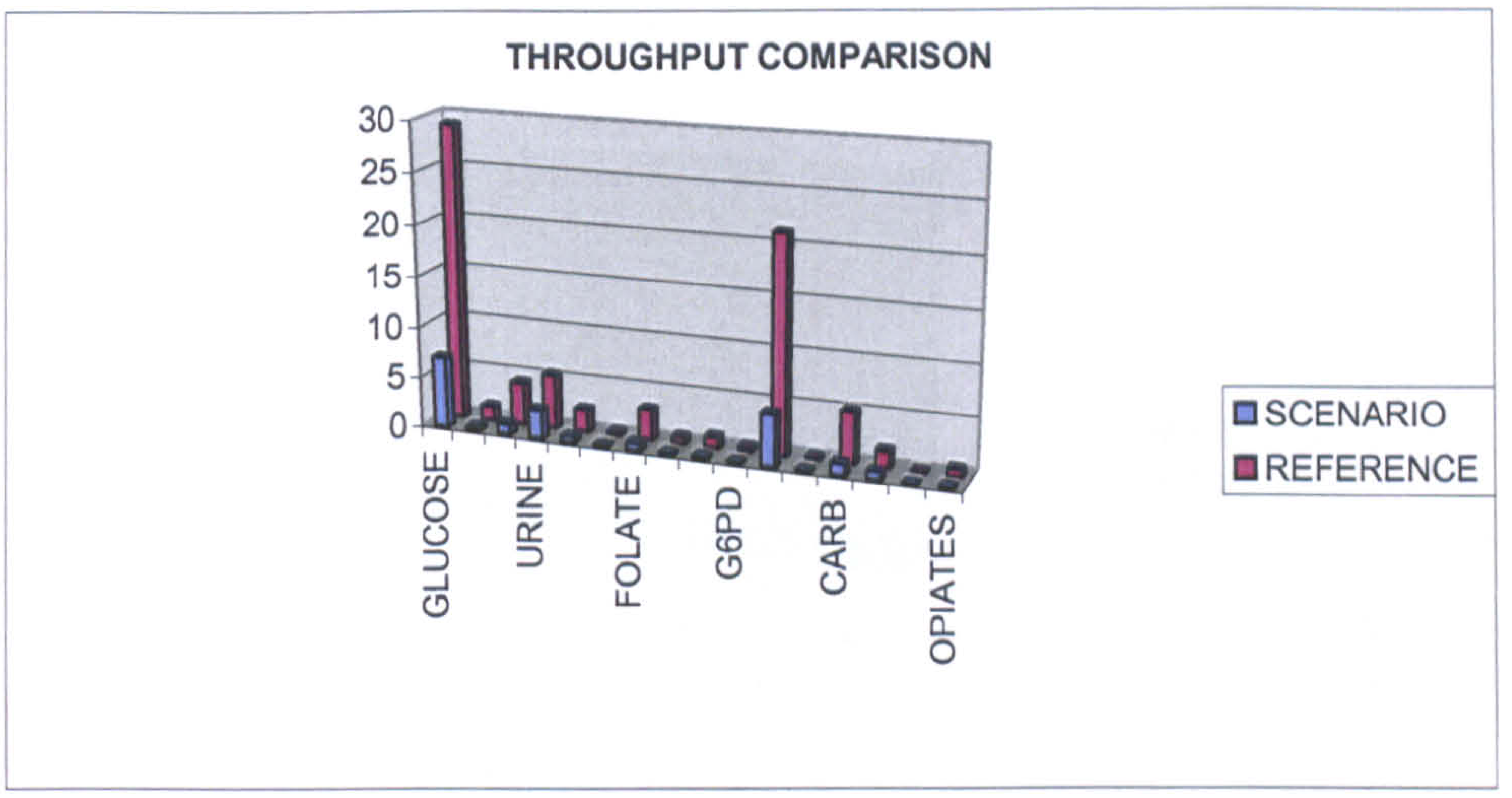




2.1.3 Throughput

Throughput of the tests has dropped. Similar to section (6.6.1.1.3) one of the reasons for this drop is the staff limitation of work under pressure of high demand, also the reorder mechanism in the Logistics department and unavailability of the items can be the cause of low throughput. (Graph 11)

Graph 11



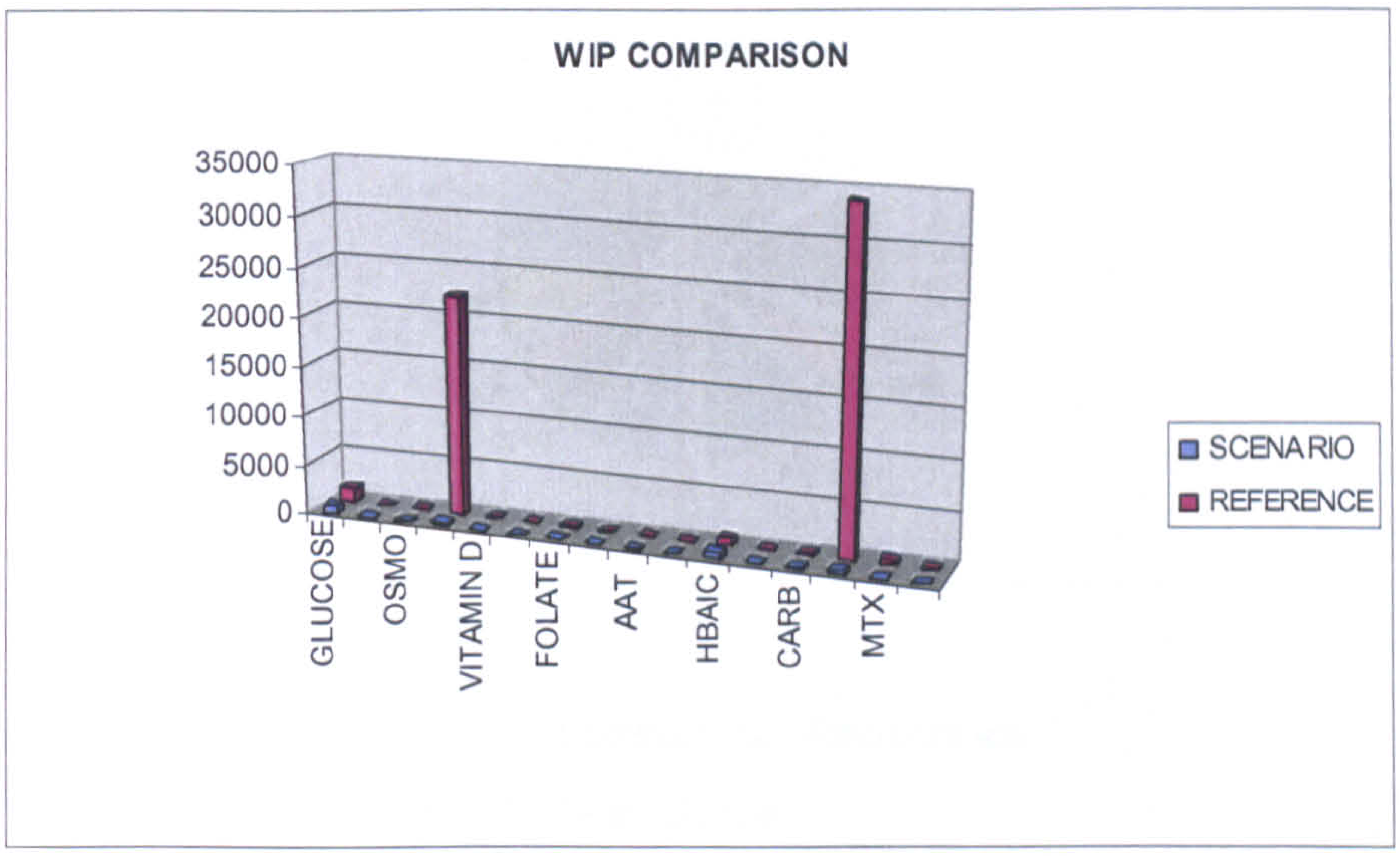
2.1.4 Inventory Status

The information indicates the reagents for all test are compensated to match the demand, on the other hand calibrator and controller are not affected as expected. This gives an indication of poor planning. As demand for more tests increase, component inventory should be increased. Missing one type of material will stop the performance of any related test.

2.1.5 WIP

WIP is showing a decrease in all tests, which indicate a constant arrival of patient, will yield a decrease of work in process. Availability of recourses is one of the reasons of this result. (Graph 12)

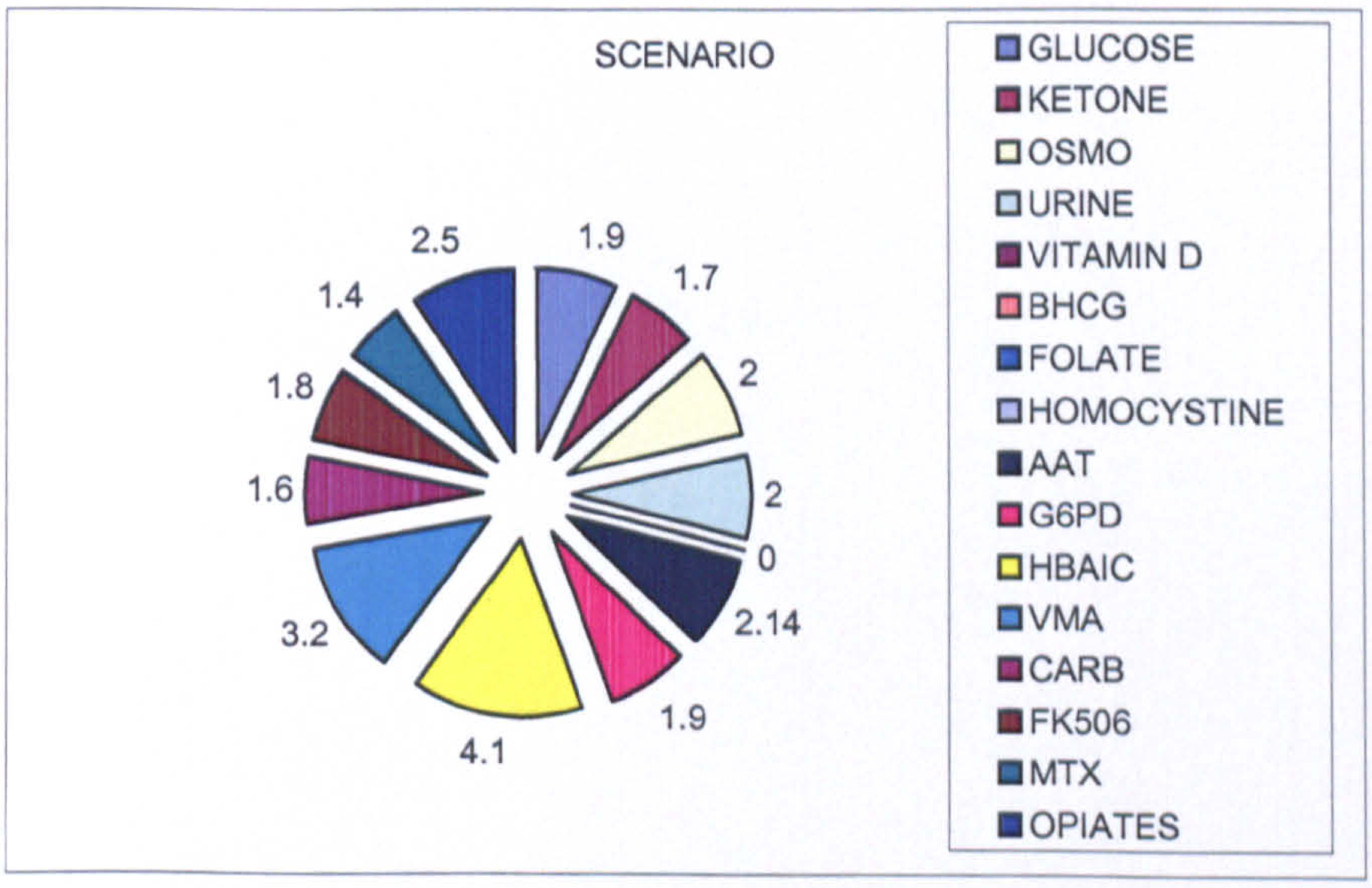
Graph 12

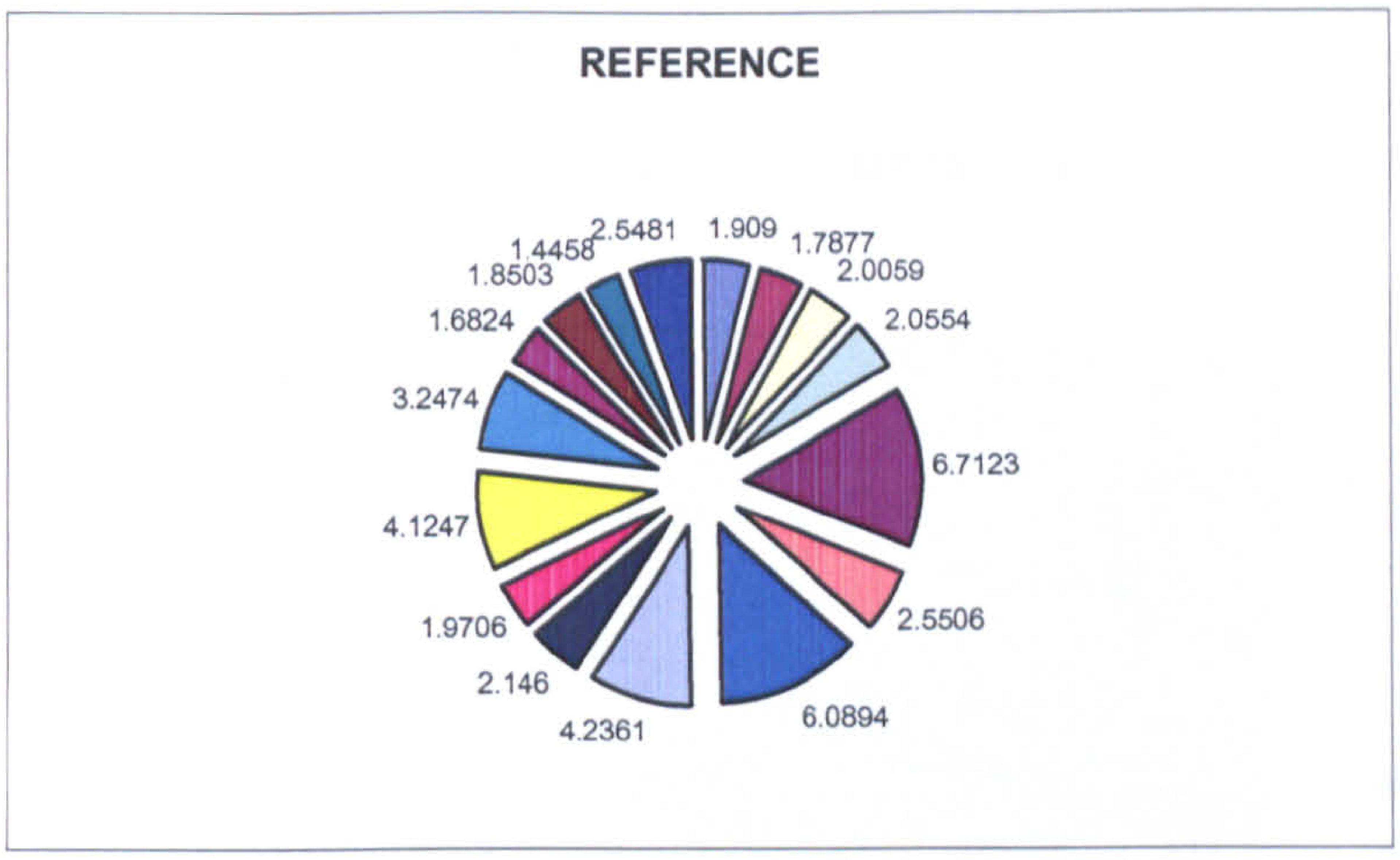


2.1.6 Cost of Test

The cost of each test is not much different than the Reference Model (Graph 13) because of the throughput of the tests are less than the Reference Model. As the price was expected to be less but the staff and resources are still included which raise the cost to be the same as Reference Model. Also the RIA test did not appear as an indication of not performing the tests.

Graph 13





2.2 Secondary Performance Measures

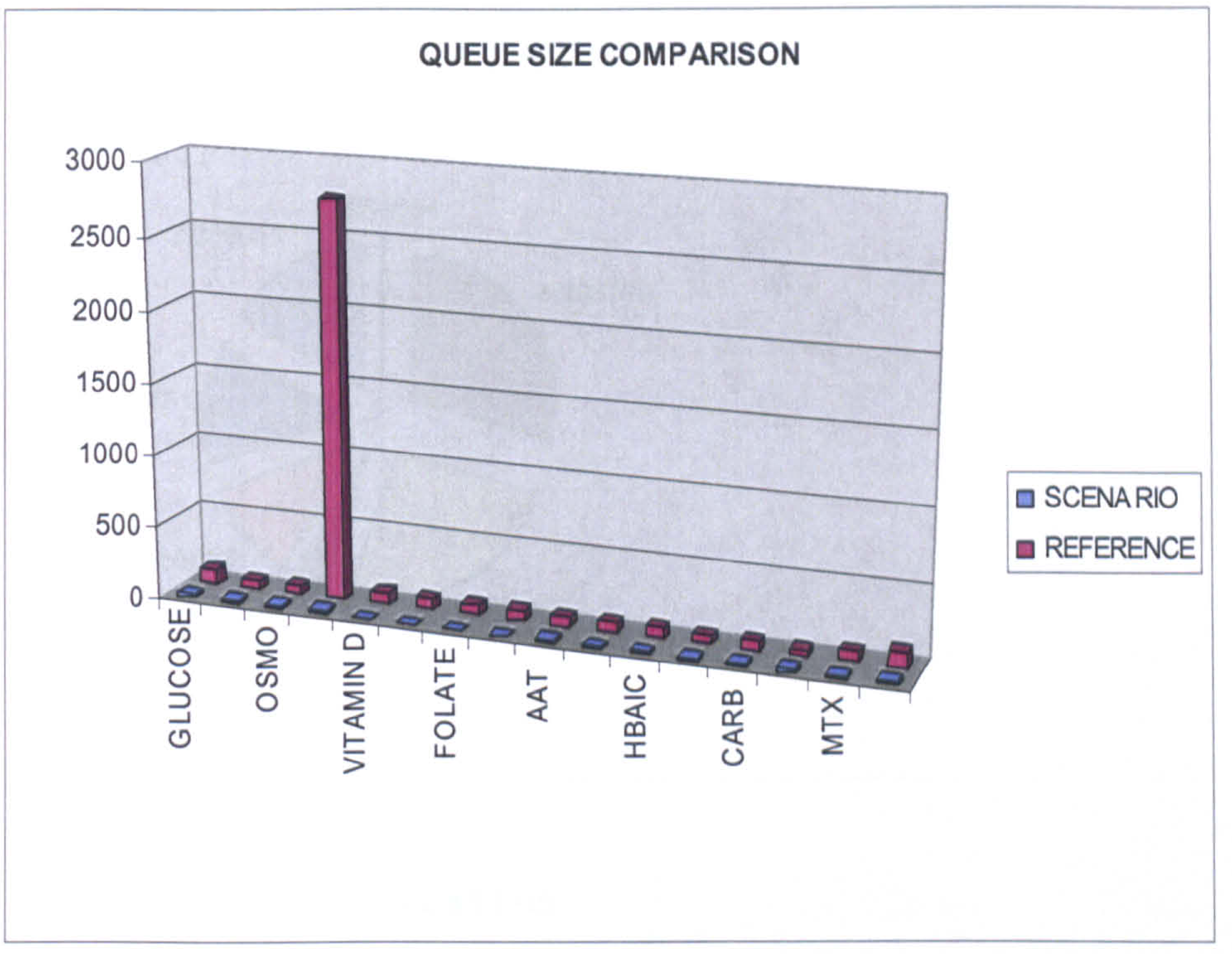
2.2.1 Material Order Size

The material orders have been dropped by more than 20%. This indicates the availability of materials is high and because of poor planning and less throughput the order of material was less.

2.2.2 Queue Size

As discussed in the lead-time, similarly the queue size (Graph 14) has been reduced to more than a third in some test, while RIA section did not produce any result.

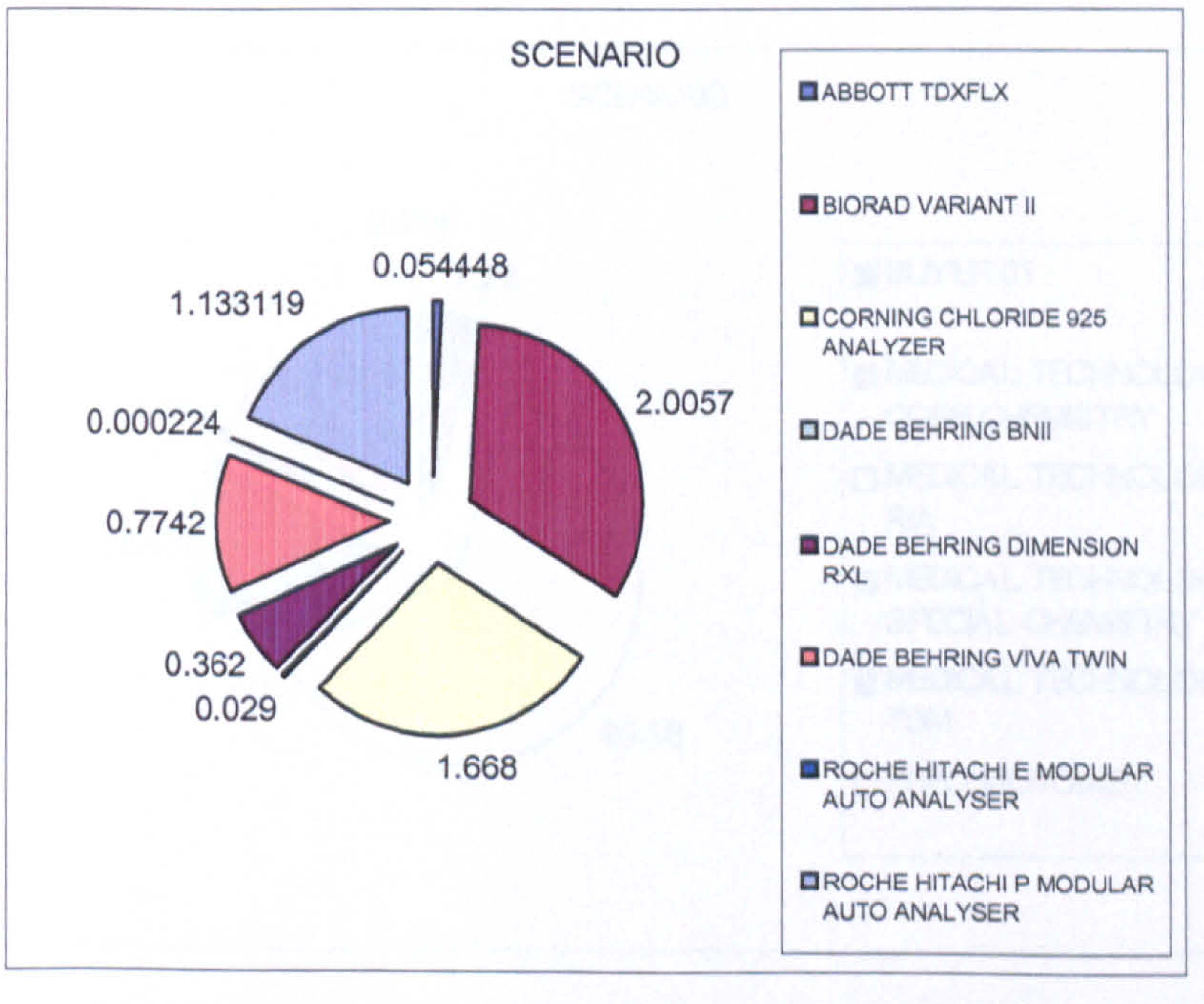
Graph 14

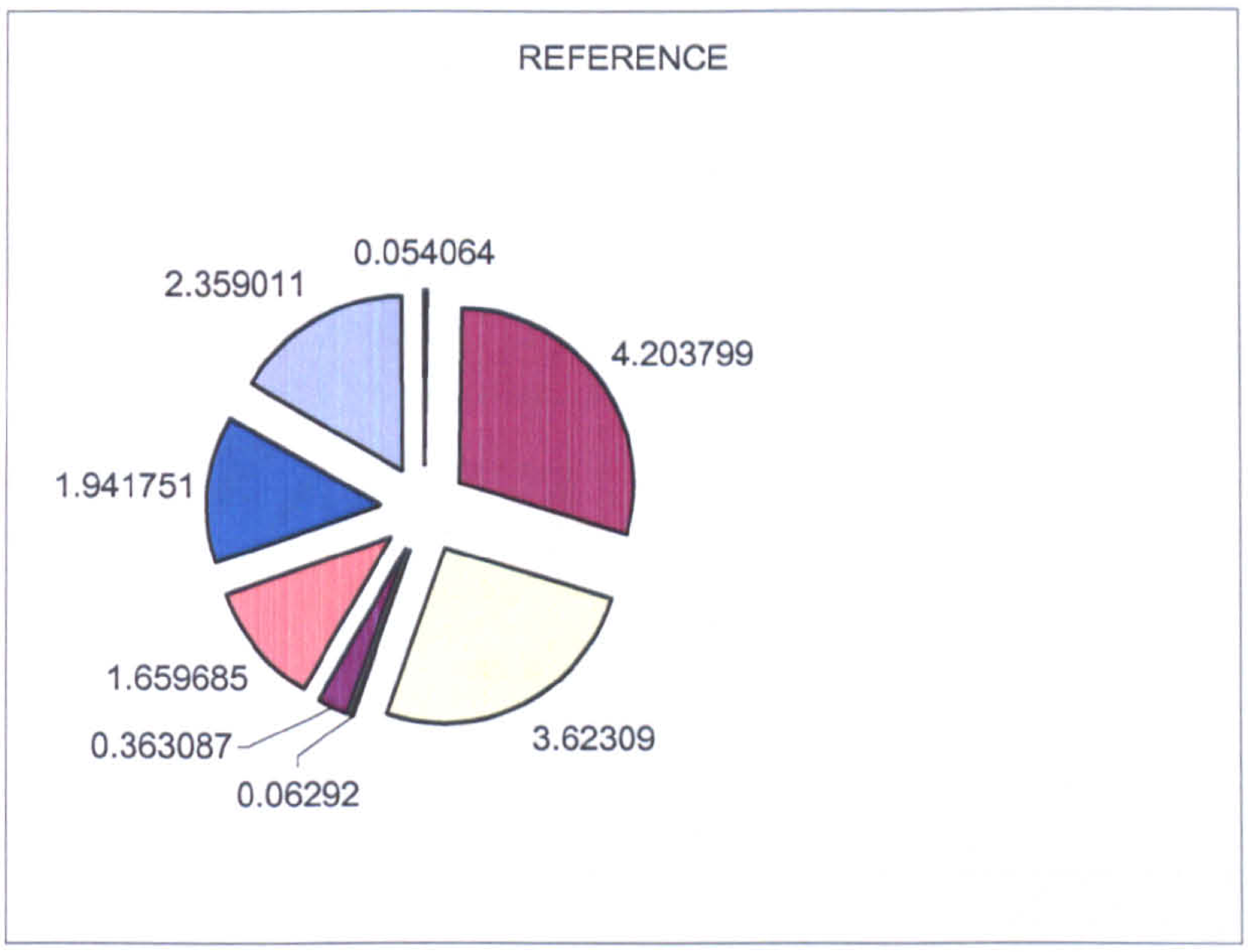


2.2.3 Equipment Utilization

The utilization of the equipment (Graph 15) has been dropped. It is not expected to be lower while the demand is high, but the increase of WIP and decrease of output make the equipment under utilized as intended to be.

Graph 15

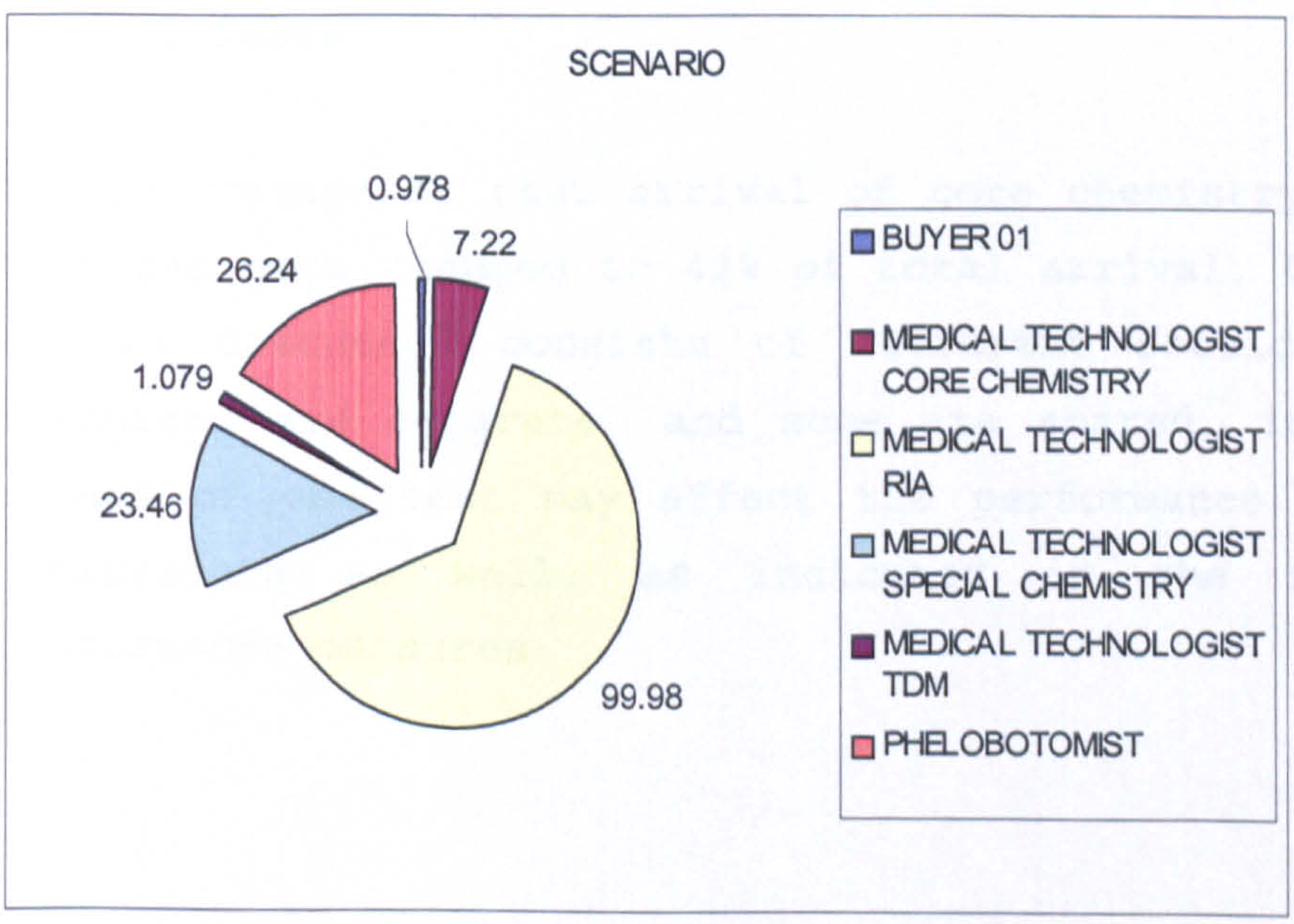


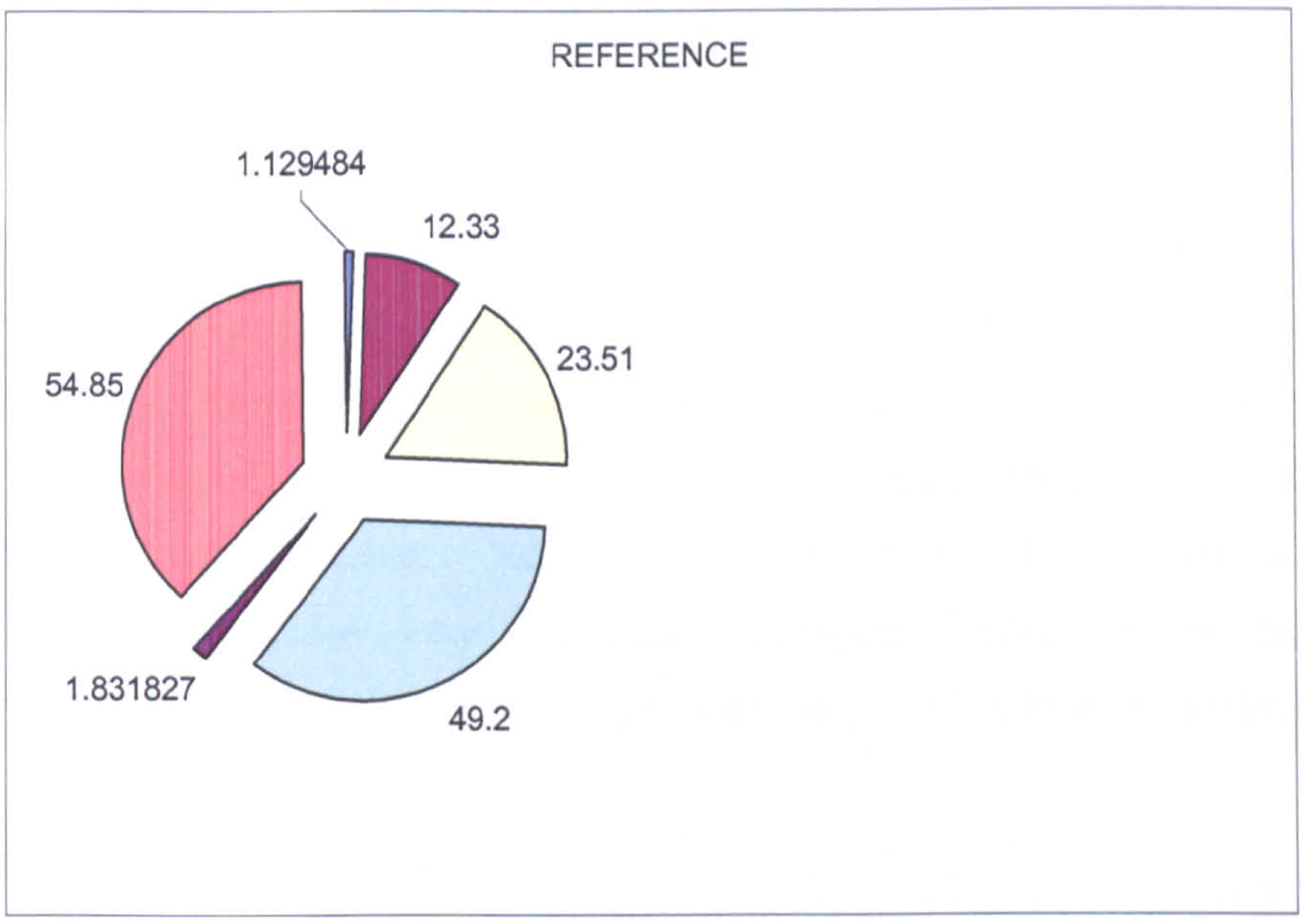


2.2.4 Staff Utilization

The staff utilization is lower than the Reference Model (Graph 16) except medical technology RIA which increased to the maximum, showing the imbalance of staffing distribution. It is expected with high demand to utilize the staff to the maximum. Staffing may not be the only reason of low outcome, it may be the supplies.

Graph 16





2.3 Conclusion

With high demand and a steady flow of patient the lead-time is becoming lower, but the inventory and WIP are higher. It is very unique situation, having a high demand for tests, under utilization of staff, and reducing the number of materials order. The best explanation of this situation is lacking of planning and not preparing for extreme situations in the Chemistry Lab.

3. Scenario Six: Some Tests are Severely Higher than the Rest of Tests

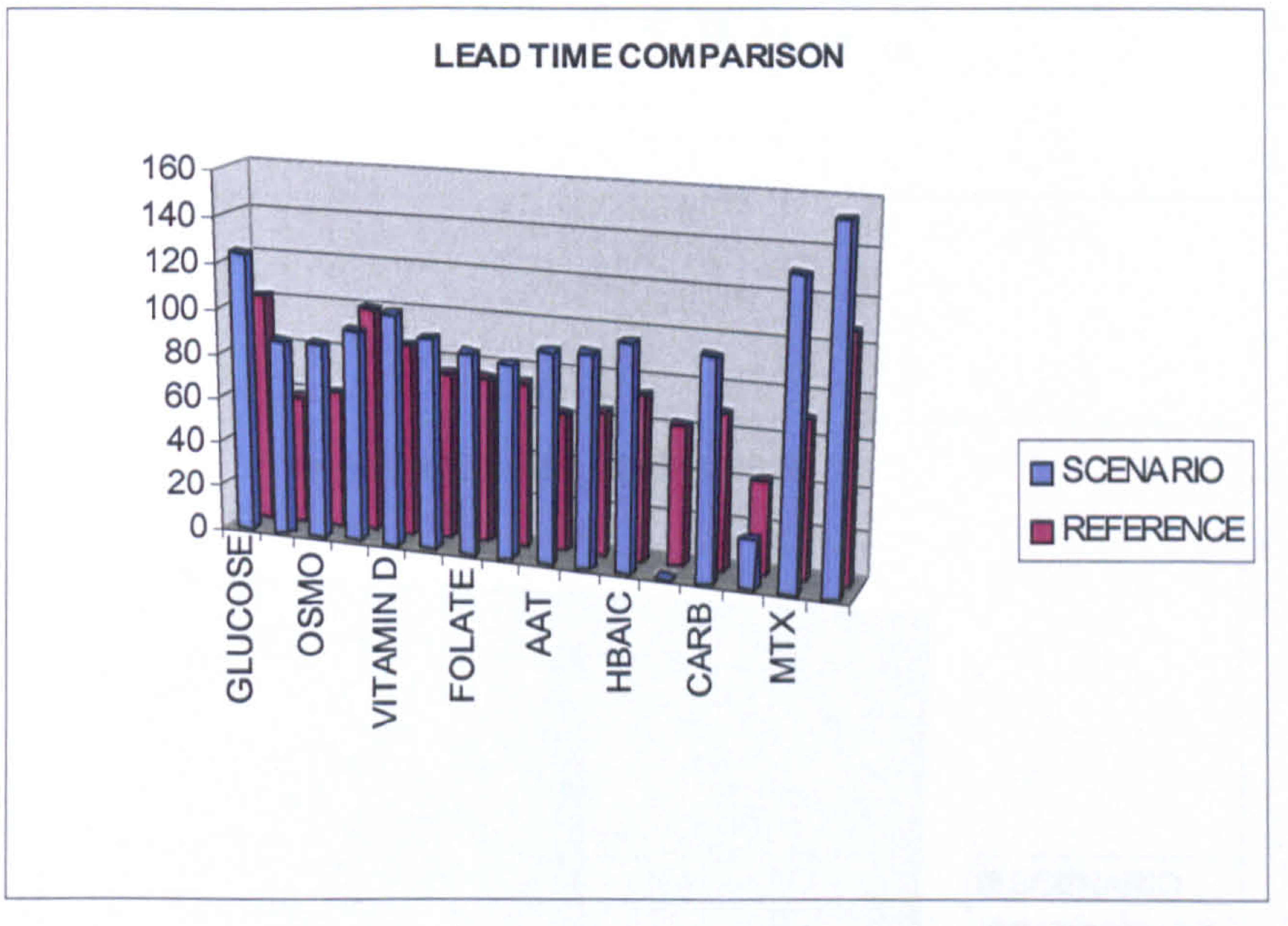
The percentage of test arrival of core chemistry glucose test has been changed to 42% of total arrival. Chemistry Lab as discussed consists of different sections. Some resources are separate, and some are shared, increasing demand of one test may affect the performance of other departments as well, as indicated in the following performance measures:

3.1 Primary Performance Measures

3.1.1 Lead Time

As shown in Graph 17 the average lead-time is slightly higher by 5 to 10%. The effect of the increasing demand of the Glucose test dose not make a major change to rest of the tests. It does effect the core chemistry section because of the more staff are utilized more to perform the Glucose test. However, the other tests were affected in a negative way causing longer lead times because of the disturbance of the percentage of demand tests.

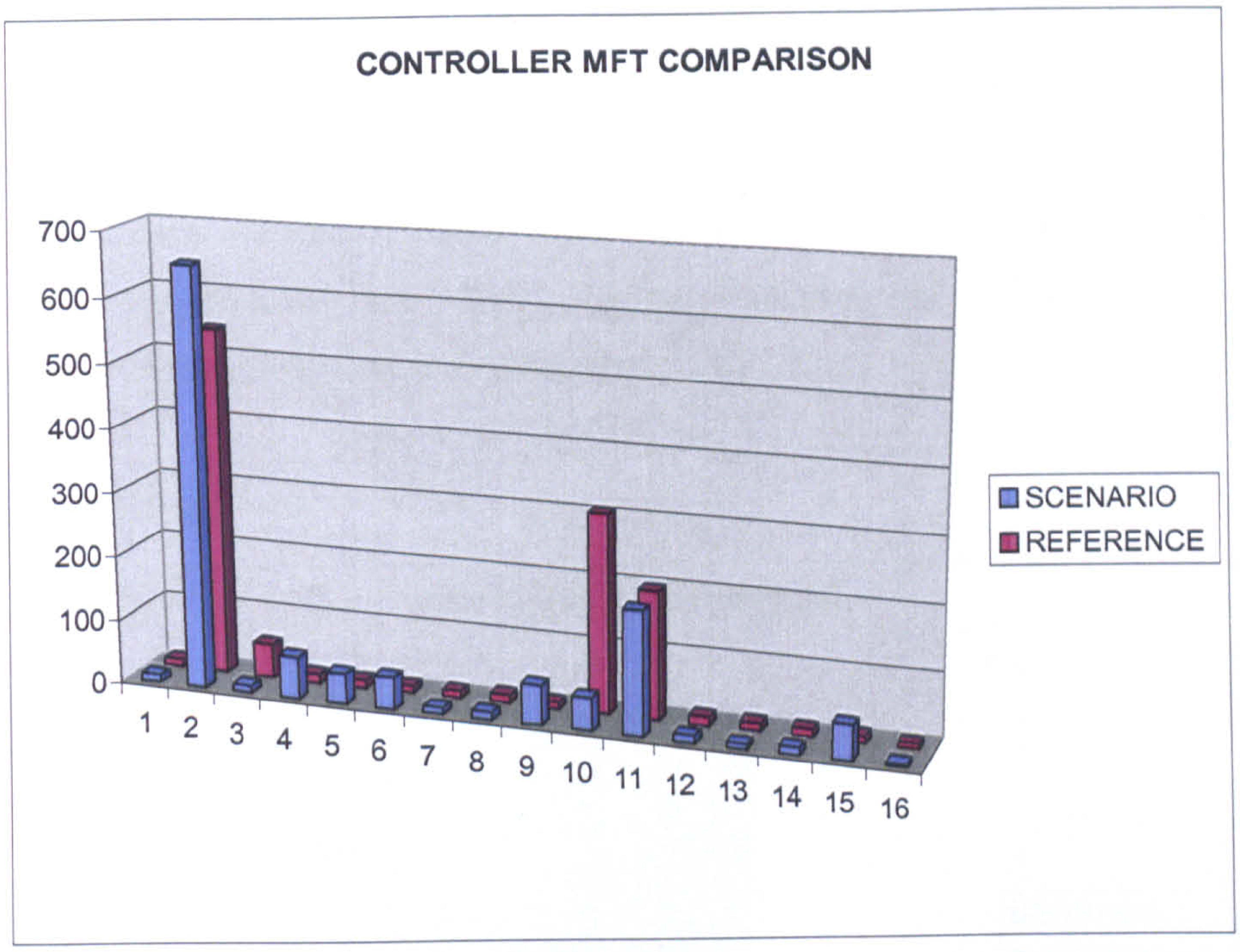
Graph 17

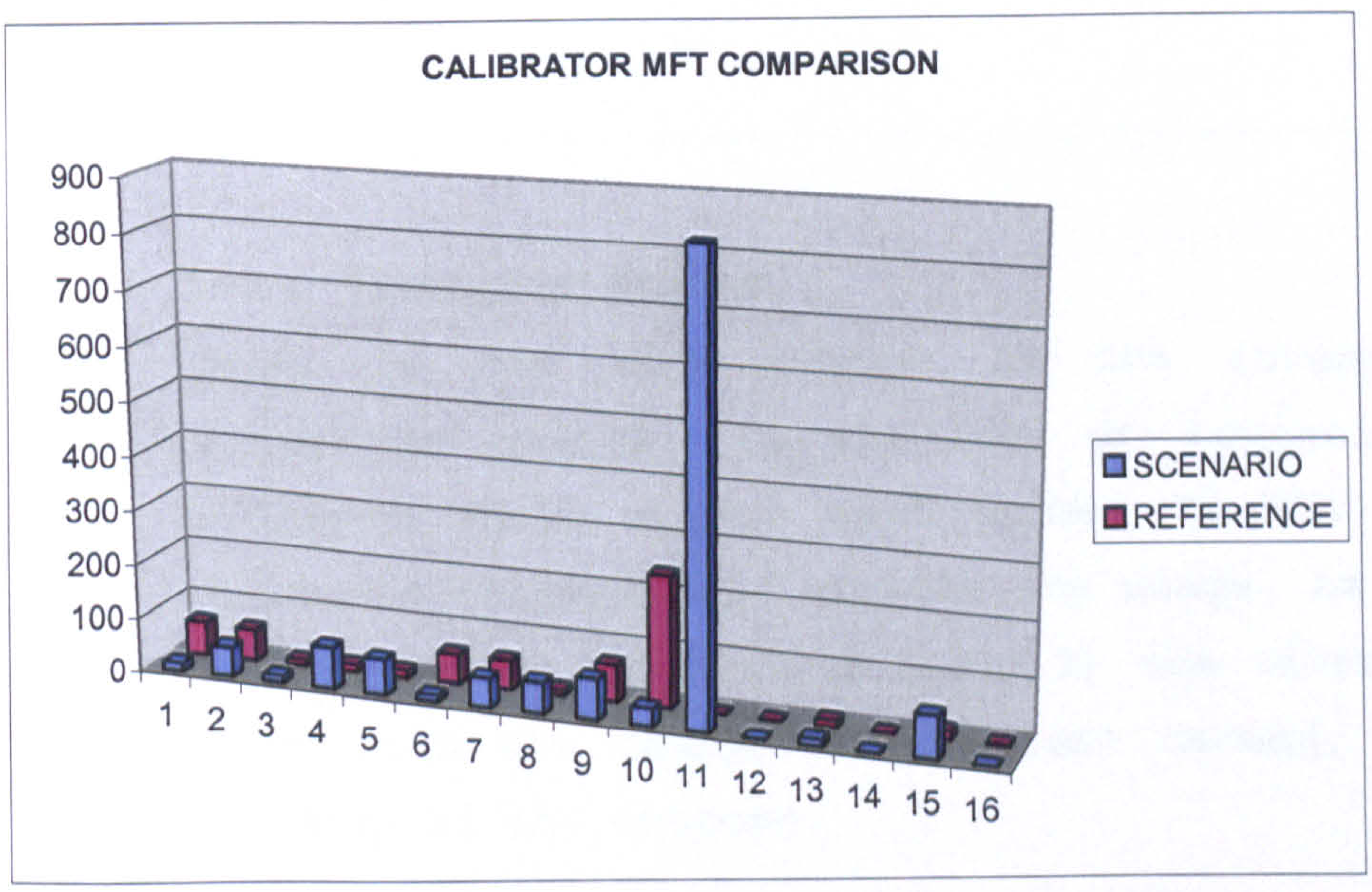


3.1.2 Material Flow Time

More than 70% of all tests are positively affected, which means less materials move around as result of dropped demand, by the Glucose test increase. This is valid for the reagent and calibrator. Controller on the other hand is less by the same percentage. This is indicated in the Graph 18, which consists of reagent, calibrator, and controller.

Graph 18

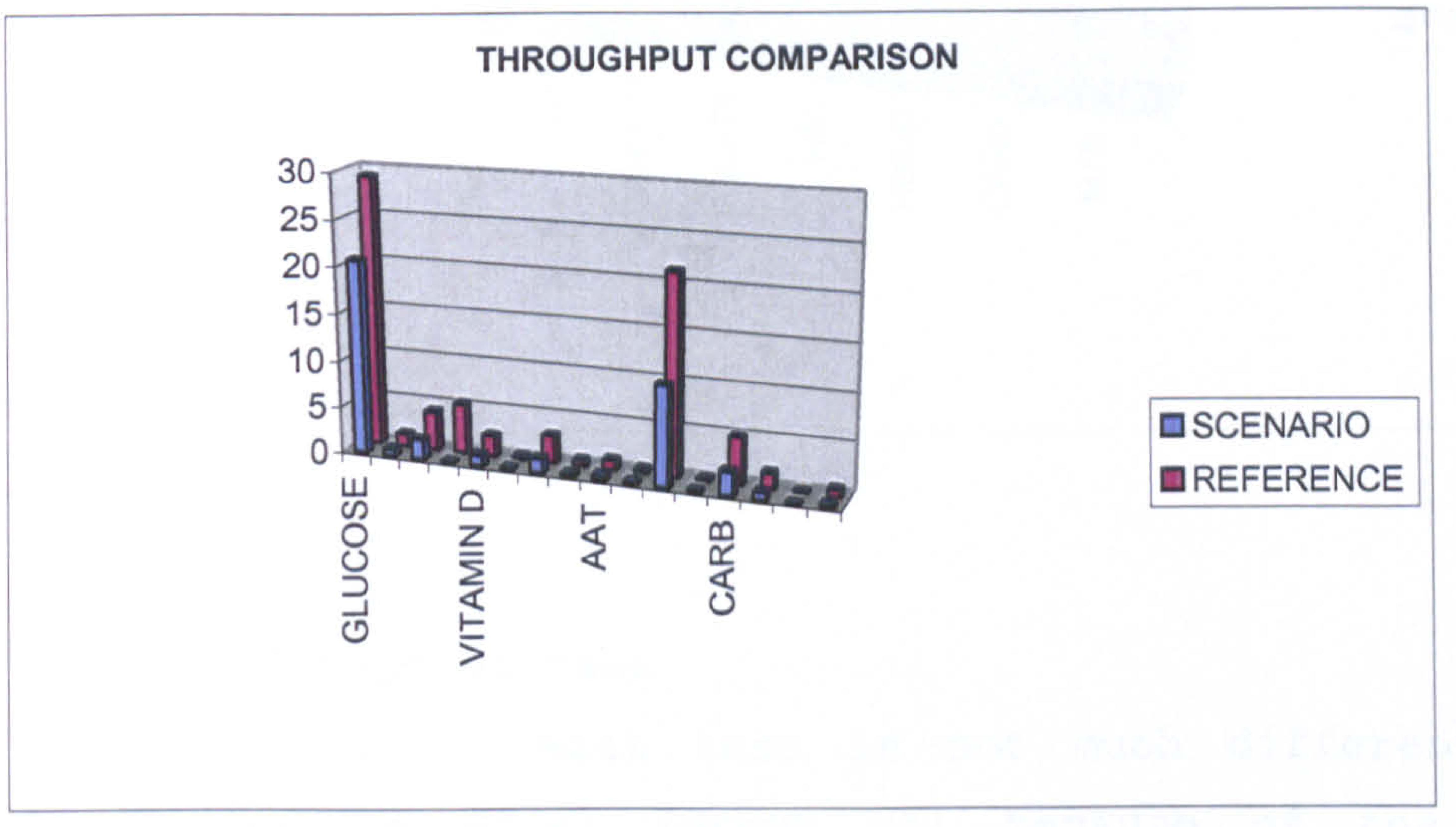

CONTROLLER MFT COMPARISON
700
600
500
400
300
200
100
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
SCENARIO
REFERENCE


CALIBRATOR MFT COMPARISON
900
800
700
600
500
400
300
200
100
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
SCENARIO
REFERENCE

3.1.3 Throughput

Throughput of the test as indicated in the Graph 19 was effected negatively; the flow of material was high with limited component inventory causing the drop not only in the Glucose test but in all of the tests. Availability of supplies is the major cause of this problem, better planning could prevent it.

Graph 19



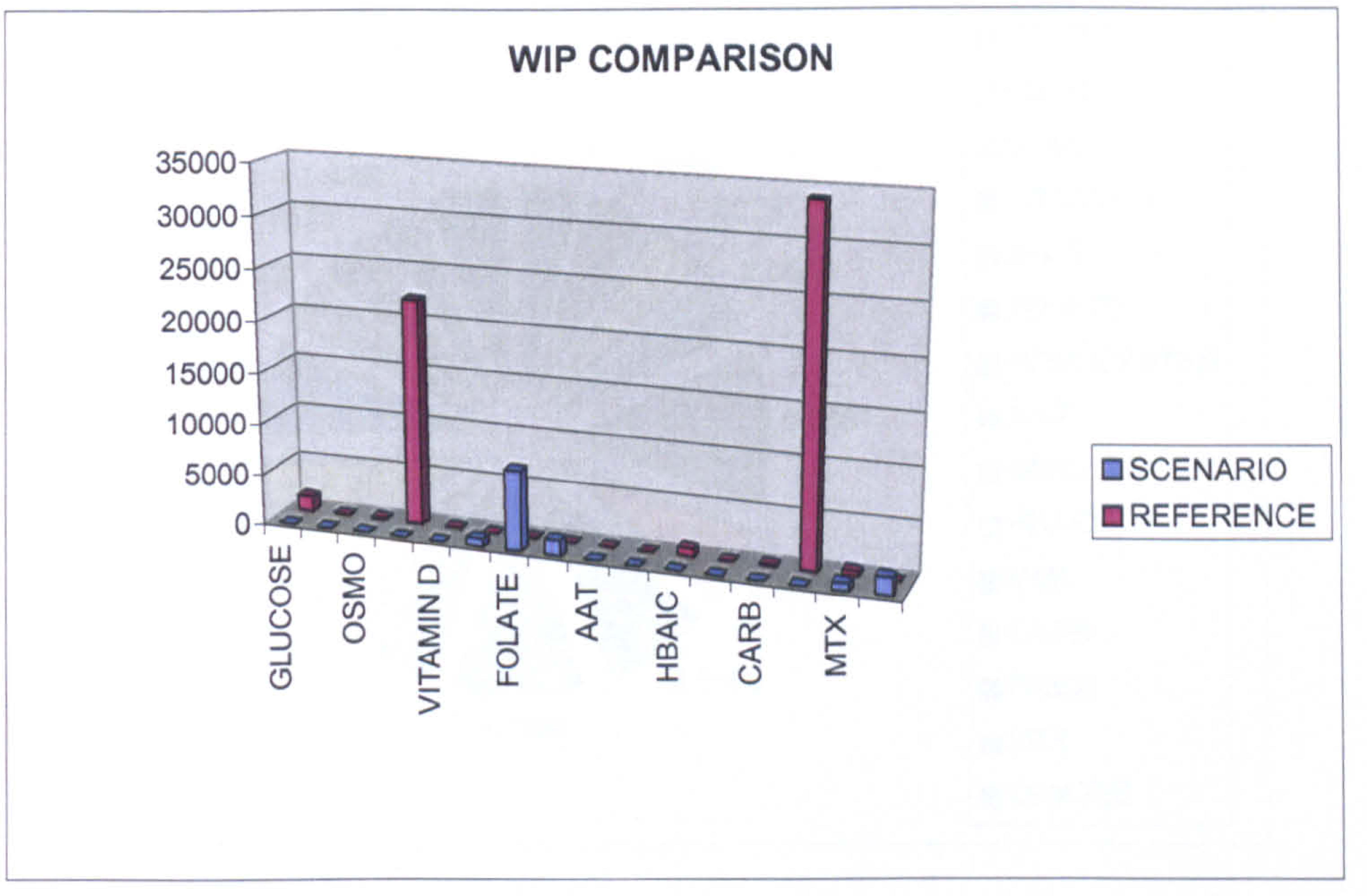
3.1.4 Inventory Status

There is not much change in the inventory of all components whether in the Lab or Logistics with the Reference Model except test number 16 TDM Opiate which increased tremendously without any usage. As indicated in the throughput section (6.6.4.1.3) the inventory did not match with the change in the test demand, which caused the drop of the outcome.

3.1.5 WIP

Graph 20 indicates work in process for all tests. As expected with high demand and low outcome the specimen will be waiting to perform the test in the Lab causing the increase of WIP except for one test, the Protein Urine Analysis.

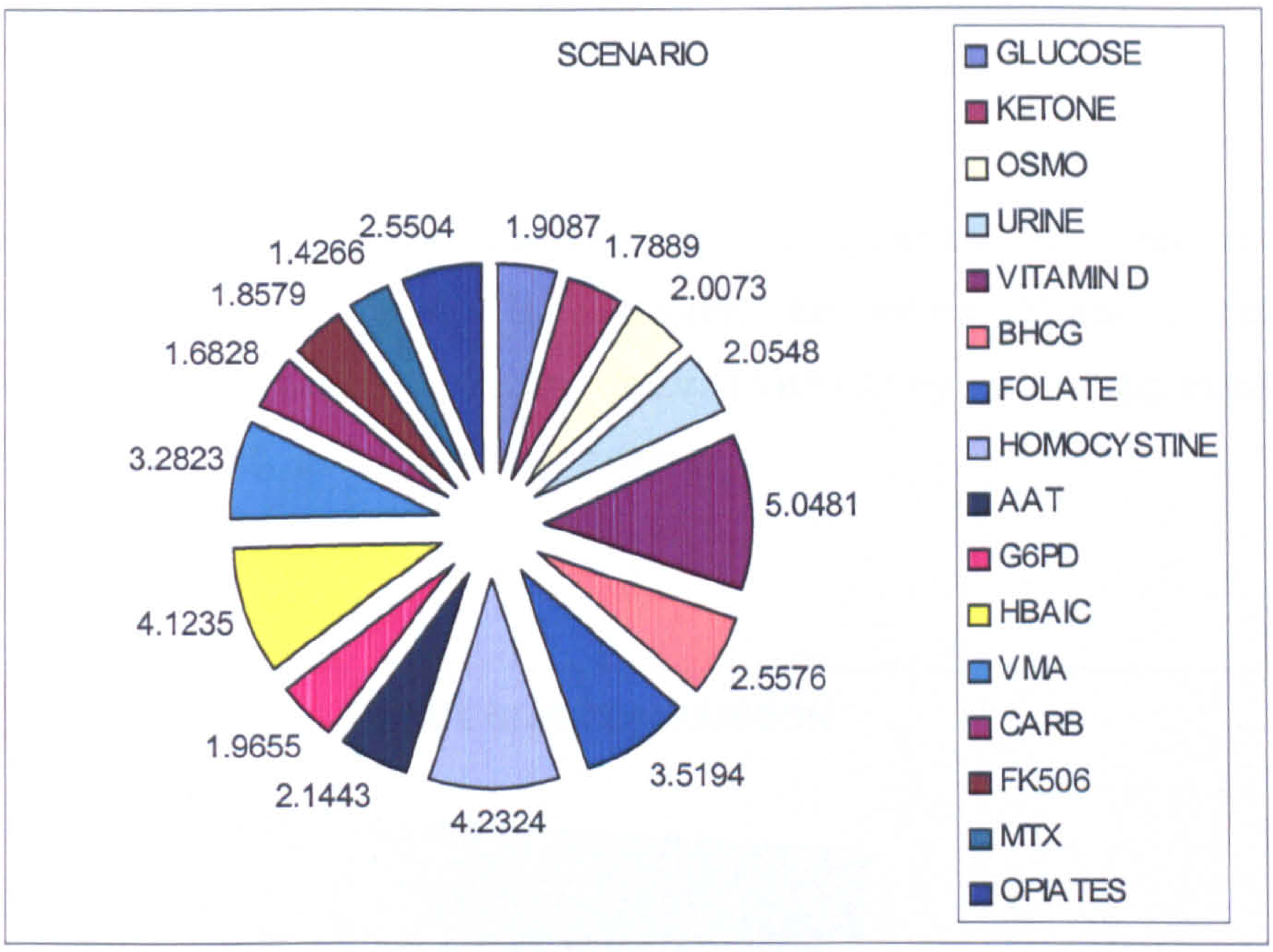
Graph 20

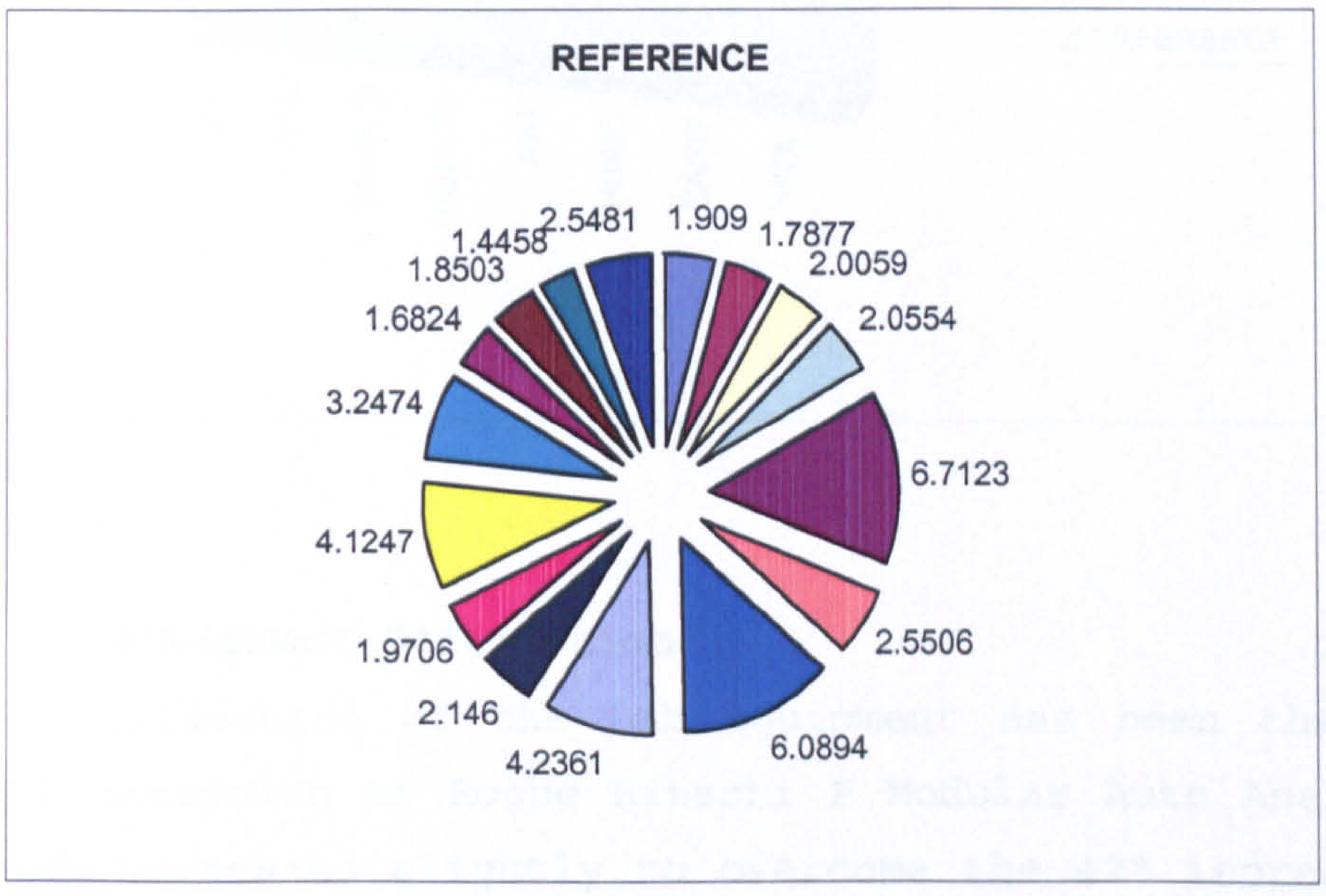


3.1.6 Cost of Test

The cost of each test is not much different than the Reference Model (Graph 21) because of the staff and resources are still included in the test cost calculation. Two tests are lower; Vitamin D, and Folate which may relate to the mean flow time which less for these two tests than the Reference Model.

Graph 21





3.2 Secondary performance metrics

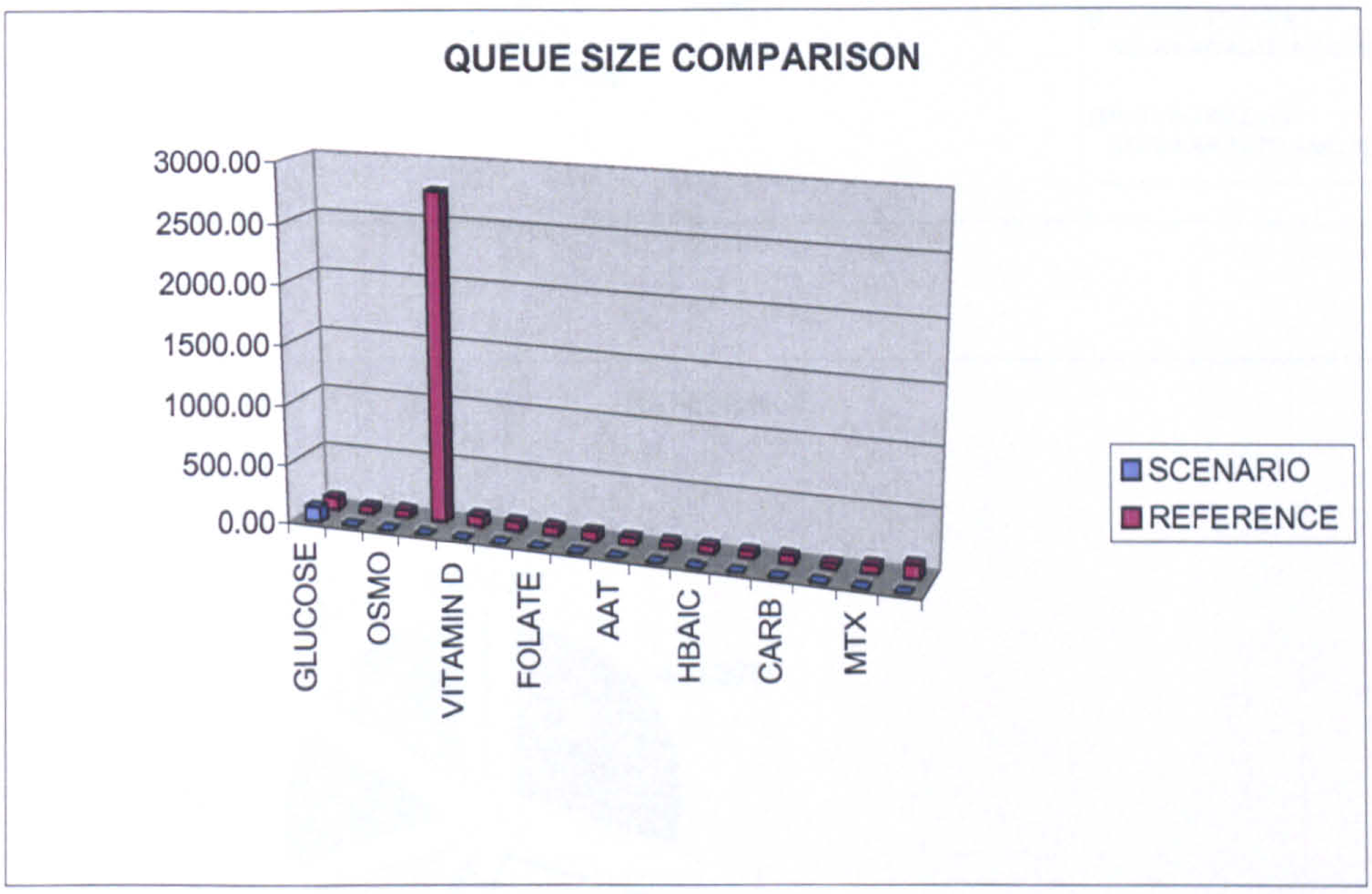
3.2.1 Material Order Size

The material orders have been the same without any effect of the high Glucose test demand related to lacking the proper reorder mechanism for both Chemistry Lab and Logistics Department.

3.2.2 Queue Size

As discussed in the lead time, similarly the queue size (Graph 22) has been increased to more than a third in some tests, which prove unavailability of supplies cause the delay of performing tests.

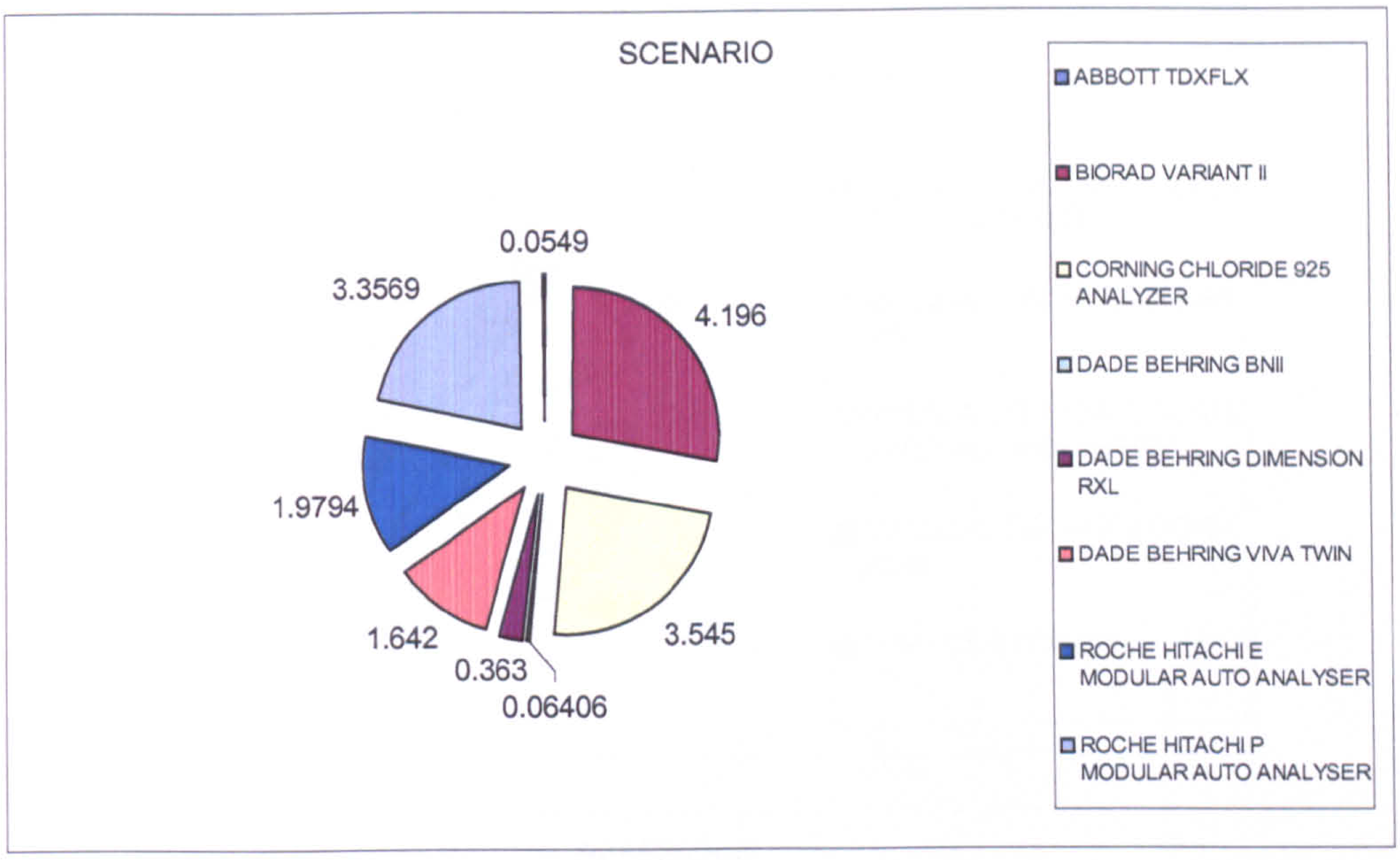
Graph 22

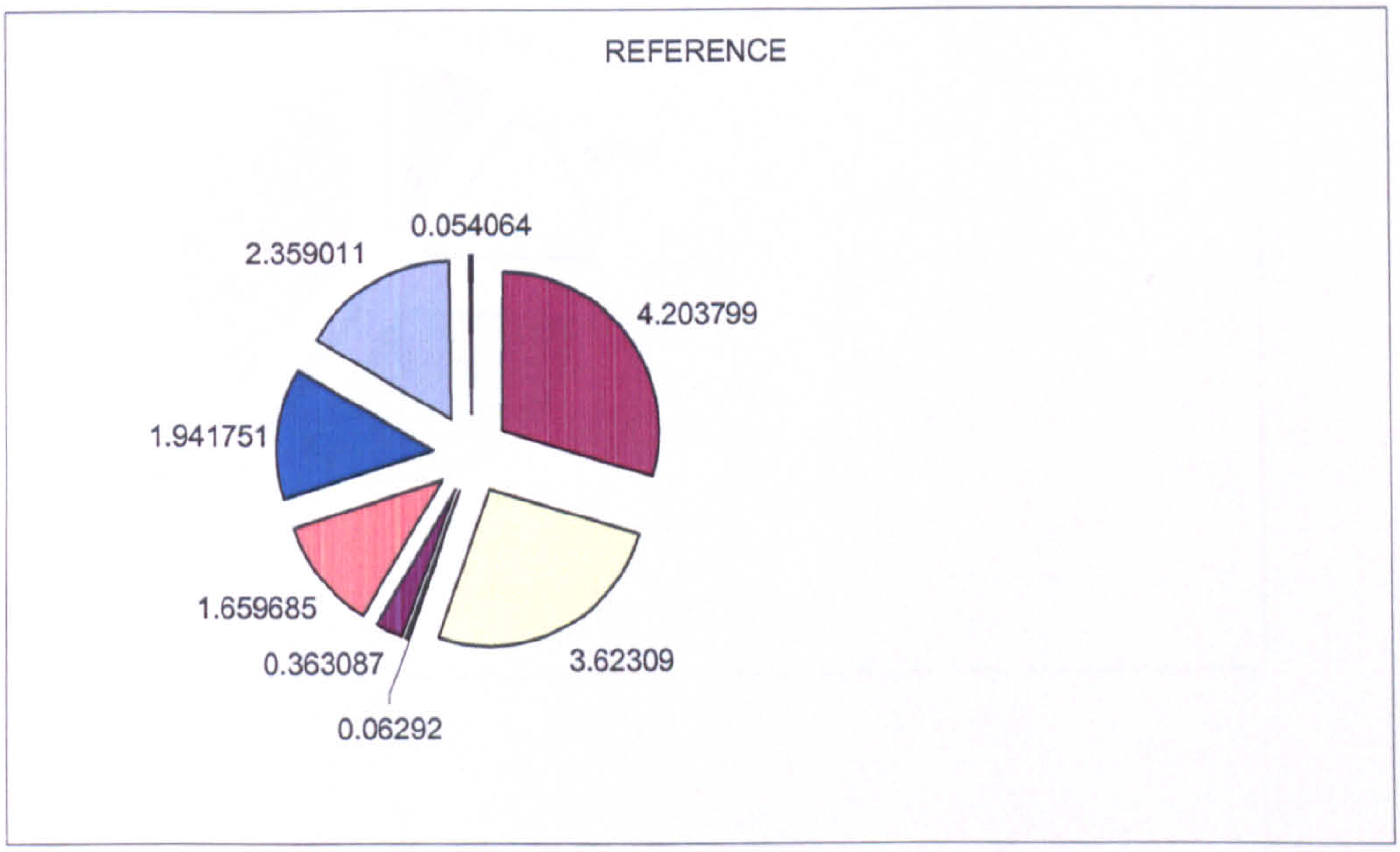


3.2.3 Equipment Utilization

The utilization of the Lab equipment has been the same with exception of Roche Hitachi P Modular Auto Analyzer, which increased slightly to overcome the 42% increase of Glucose test. (Graph 23)

Graph 23

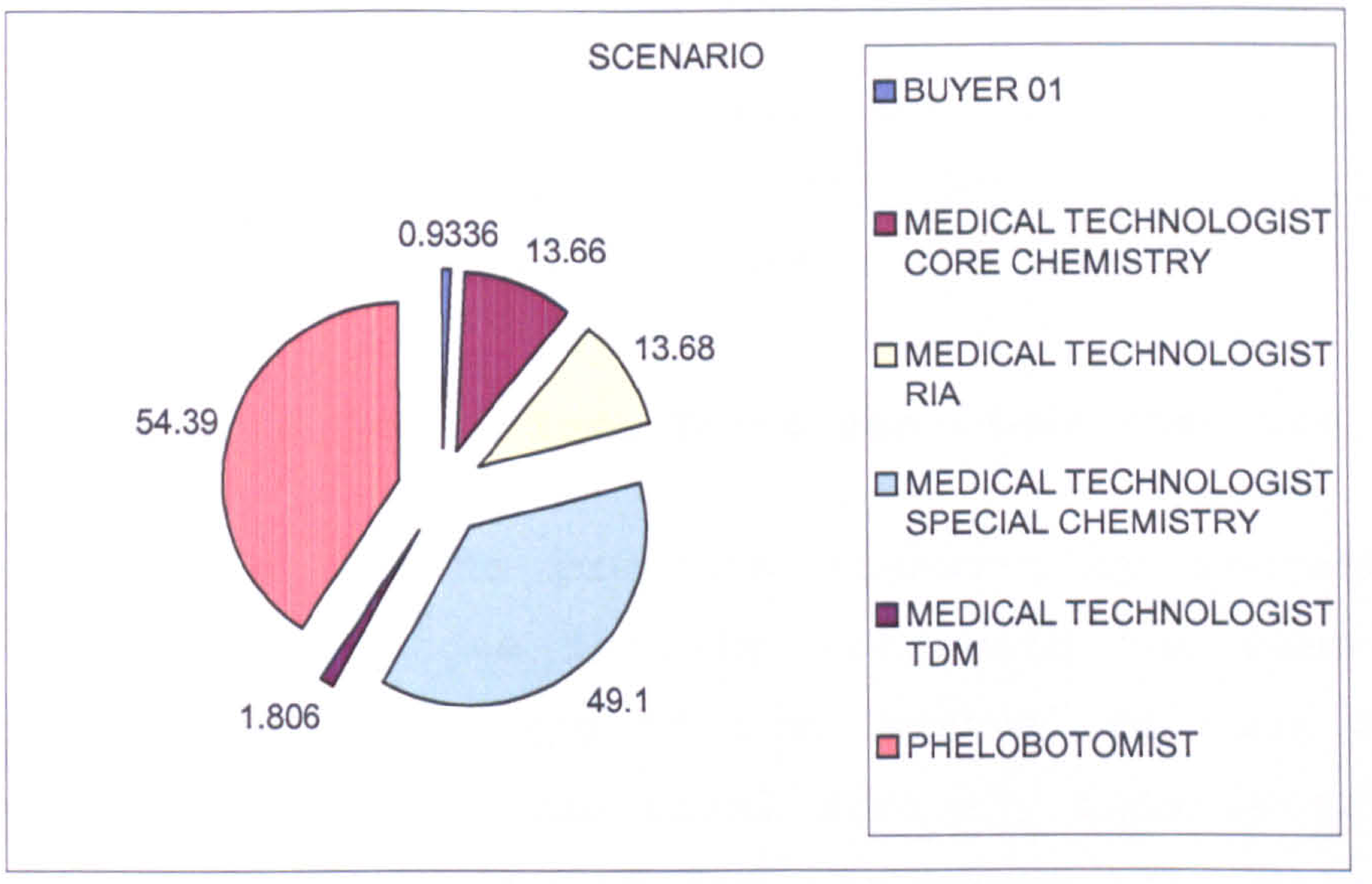


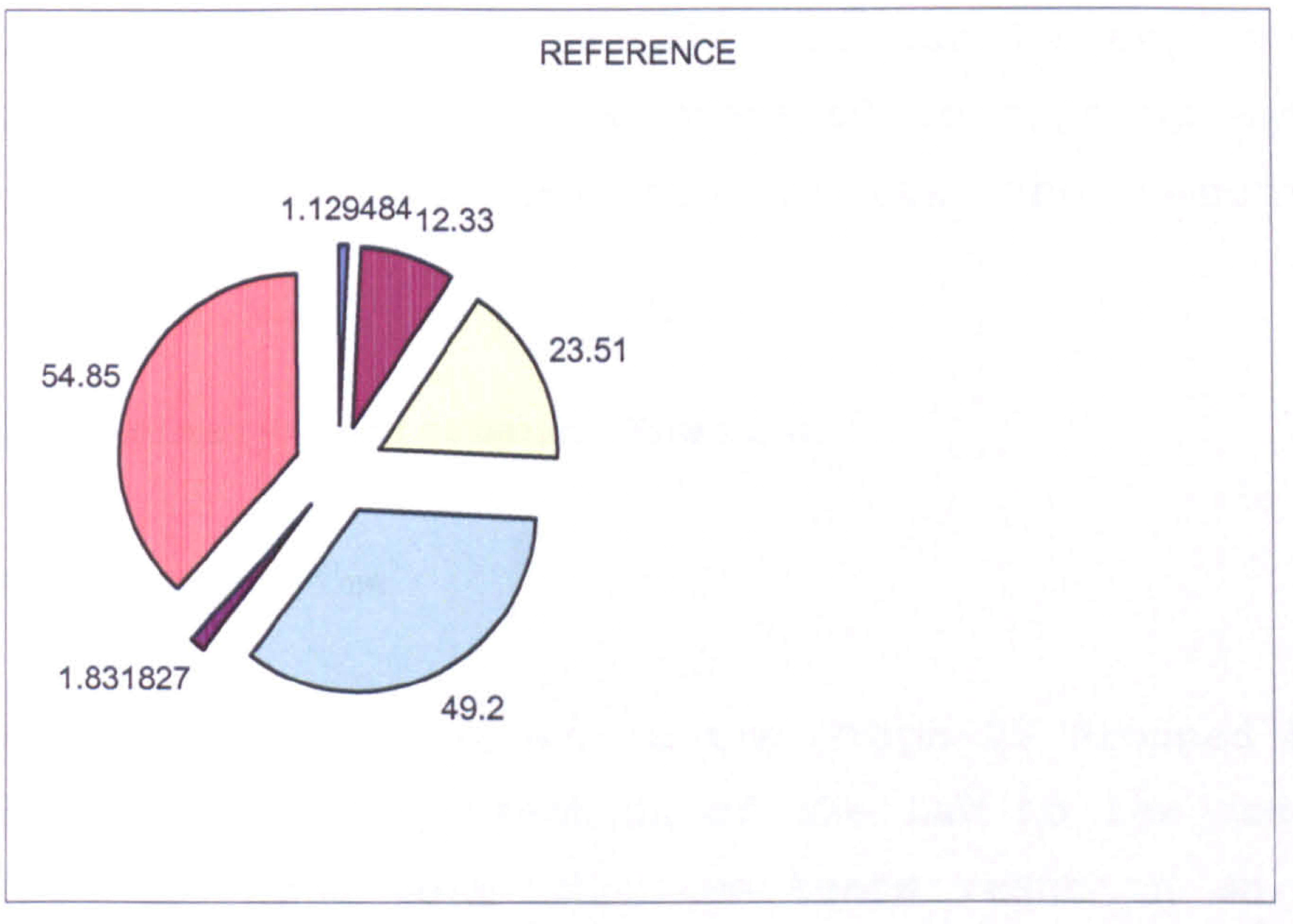


3.2.4 Staff Utilization

The staff utilization is the same as in reference (Graph 24) except the Medical Technology RIA that decreased by 50% as a result of low outcome.

Graph 24





3.3 Conclusion

The first thing we noticed was the increase of lead-time by 20% for glucose testing and in the rest of the tests.

- Throughput of the tests effected negatively while staff utilization did not change except the Medical Technologist RIA which showed a slight change.
- Supplies play a major role of the end result. As we can see; short of component which can not **match** the

demand increase causing drop of the number of result the Lab can produce.

- Unavailability of supplies related to reorder mechanism in the Chemistry Lab and in the Logistics Department show an inefficient system.

4. Scenario Seven: Some Tests are lower than the rest

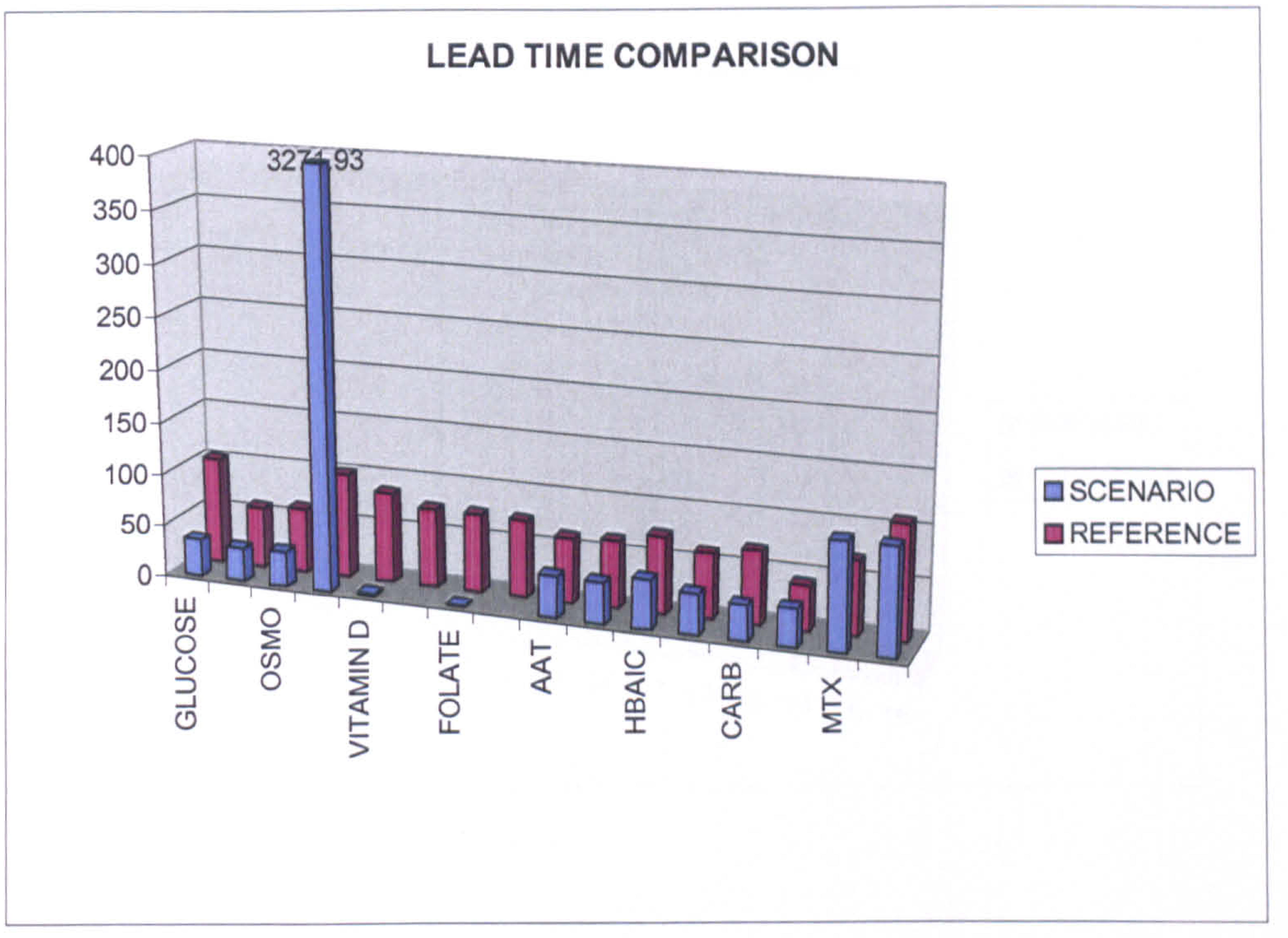
As we did in the previous scenario by increasing the demand for Glucose test by 42%, with the same test we change the percentage of test arrival of core chemistry glucose to 10% of the total arrival; this is to see the effects on the outcome for the whole Lab. Selection of Glucose test as an example (it can be any test). The chemistry Lab should be prepared to cope up with these kinds of changes and to utilize the resources as required.

4.1 Primary Performance Measures

4.1.1 Lead Time

The lead-time as shown in the Graph 25 dropped by 30 to 50%, showing the reaction of the Lab to low demand even from just one test. But two tests react in an opposite manner, with an increase in lead time; MTX and Protein analysis. Other factors like inventory of the components can cause a drop in the lead-time.

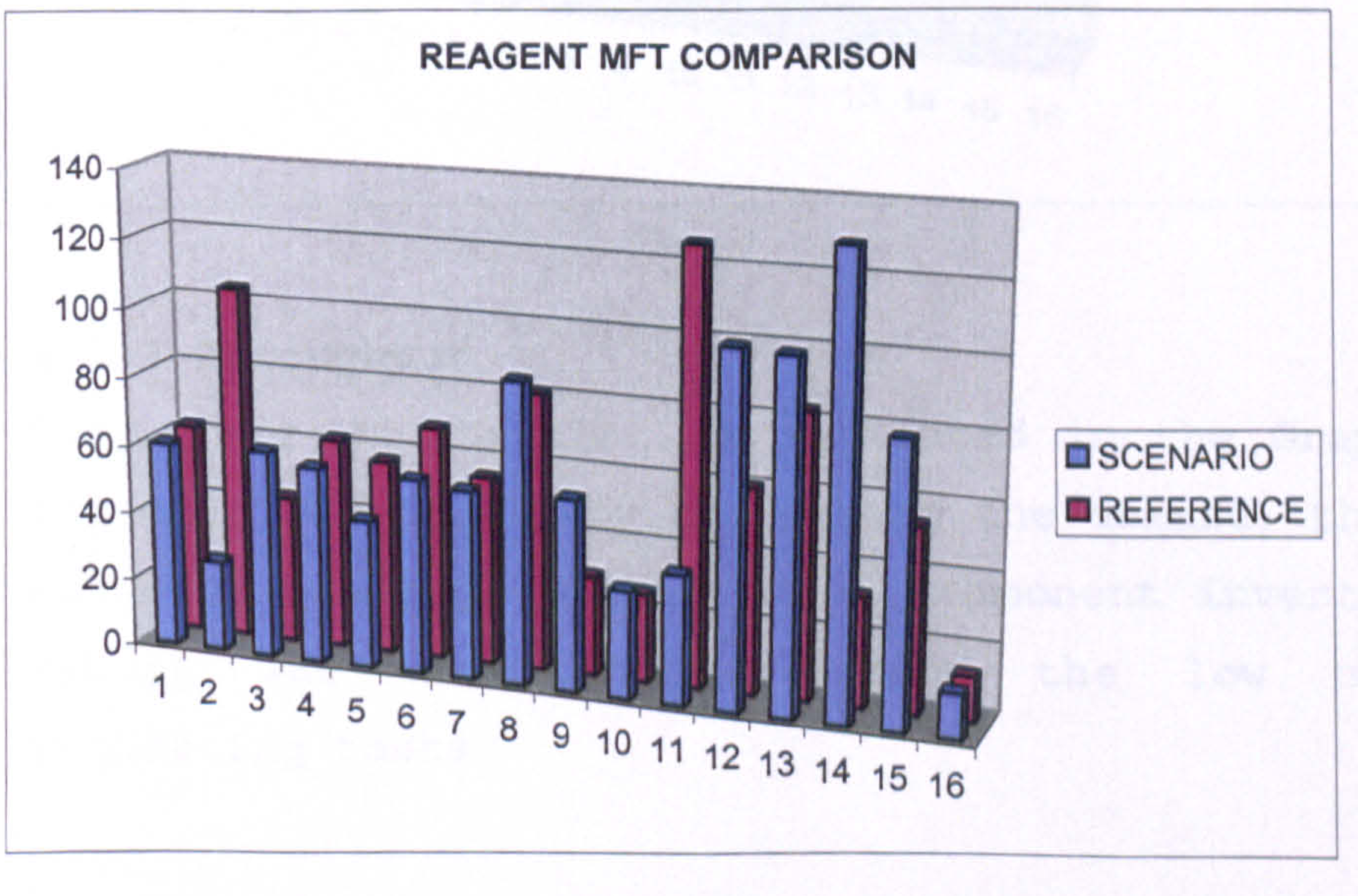
Graph 25

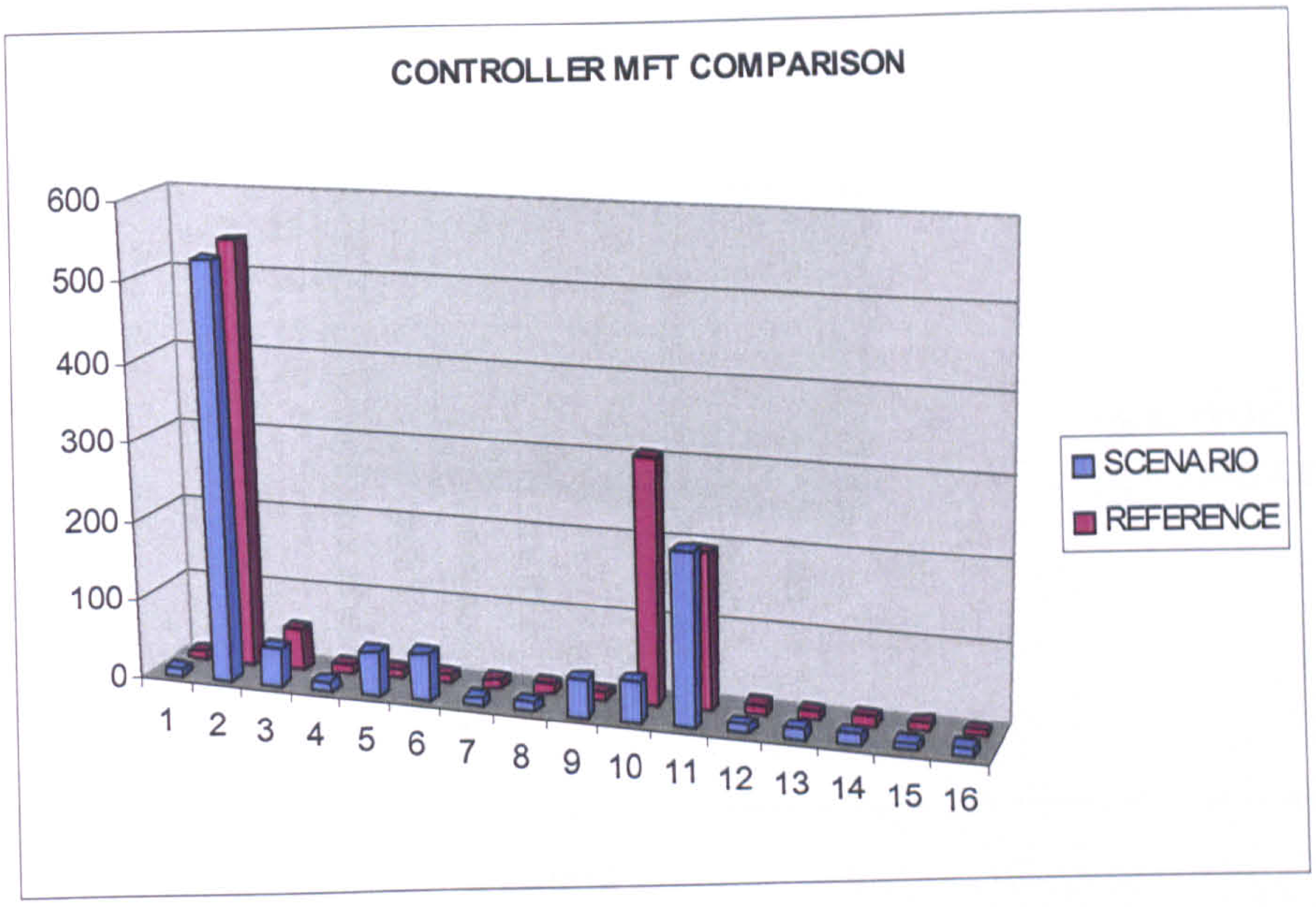


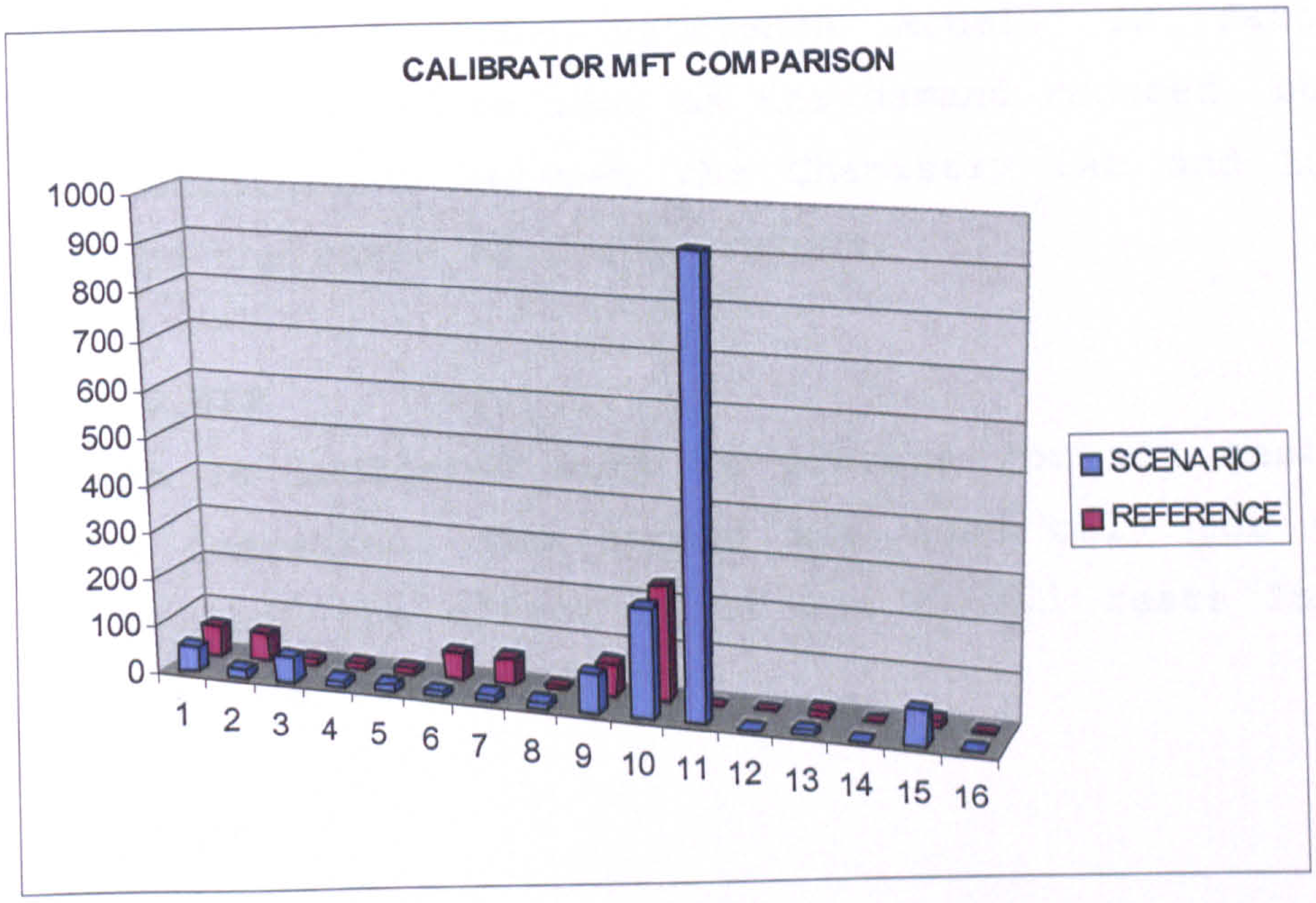
4.1.2 Material Flow

Two sections in the Lab are effected, Core Chemistry and RIA for the reagent, while the calibrator and the controller were not targeting any section but rather individual test as illustrated in Graph 26 which consist of; reagent, calibrator, and controller.

Graph 26



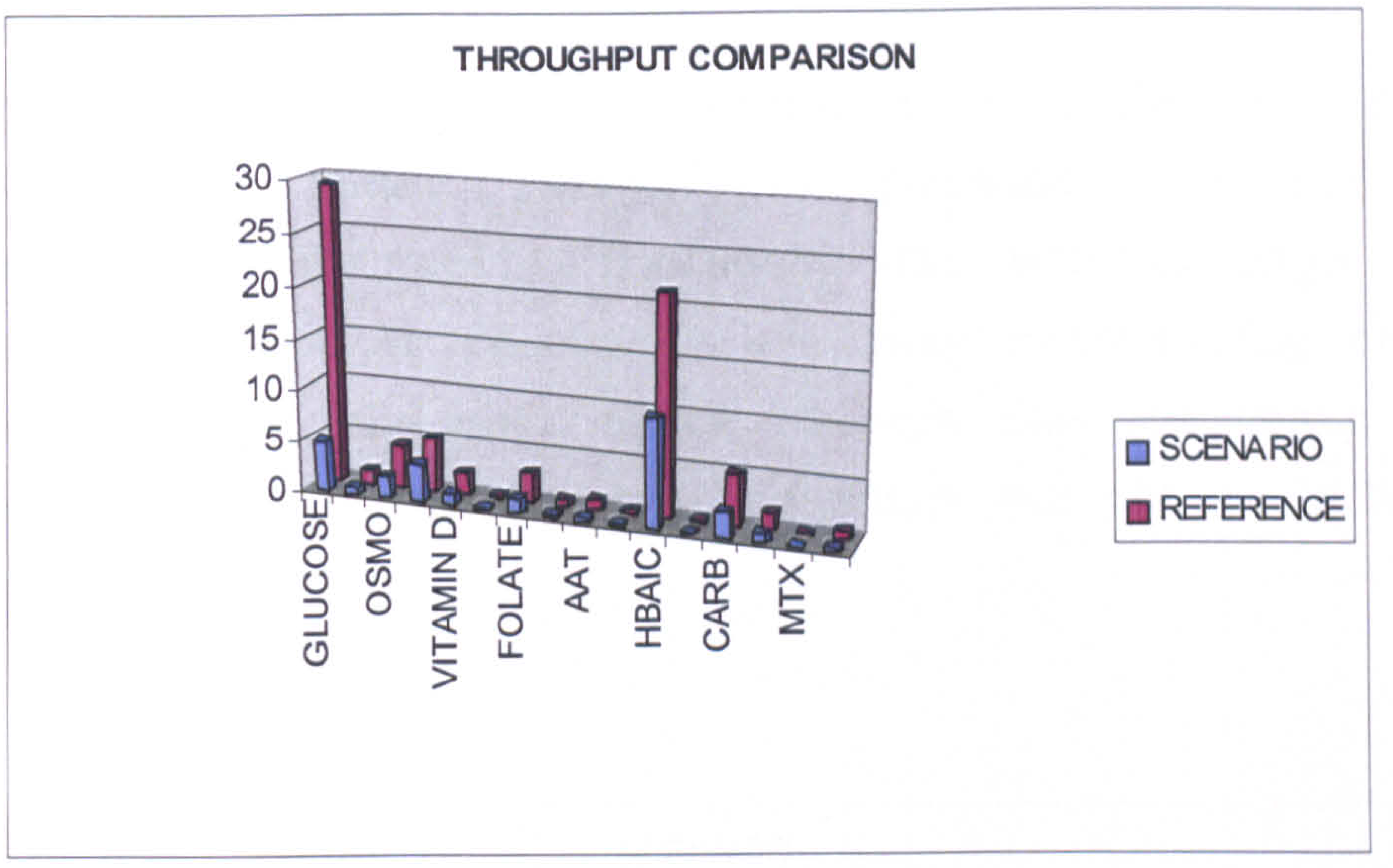




4.1.3 Throughput

Throughput of the test as indicated in the Graph 27 was effected negatively by decreasing the demand; the flow of material was high with limited component inventory. This result was expected reflecting the low number of requesting tests.

Graph 27



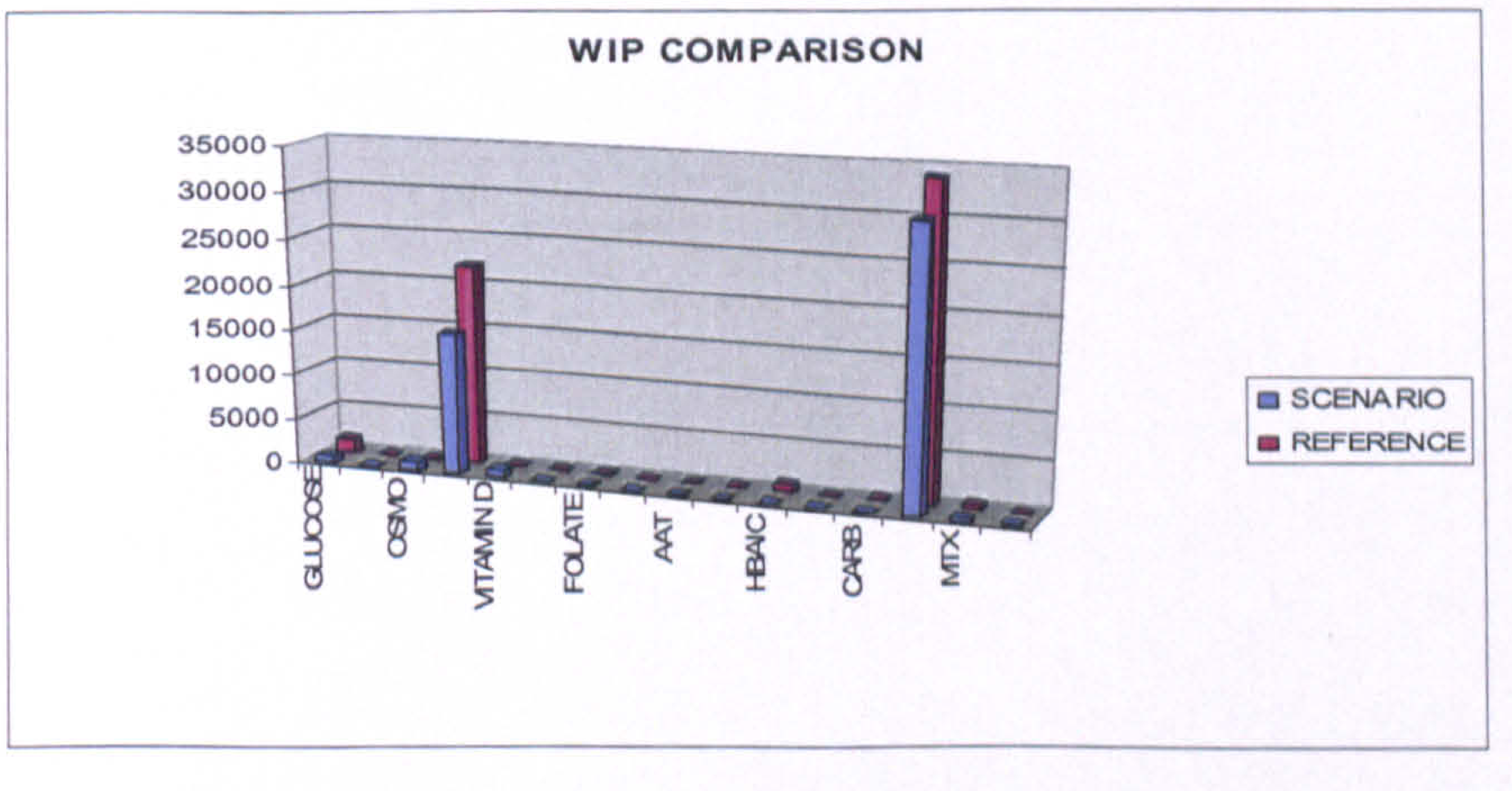
4.1.4 Inventory Status

According to the data, there is little change in the inventory of all components whether in the Lab or Logistics with the Reference Model. In fact, the inventory should be less as the demand reduced, but lack of coordination between the Chemistry Lab and Logistic can be the cause of the overstock.

4.1.5 WIP

Graph 28 indicates work in process for all tests have been decreased. The demand was less only for Glucose tests, but the effect of it was to all tests including Glucose for WIP.

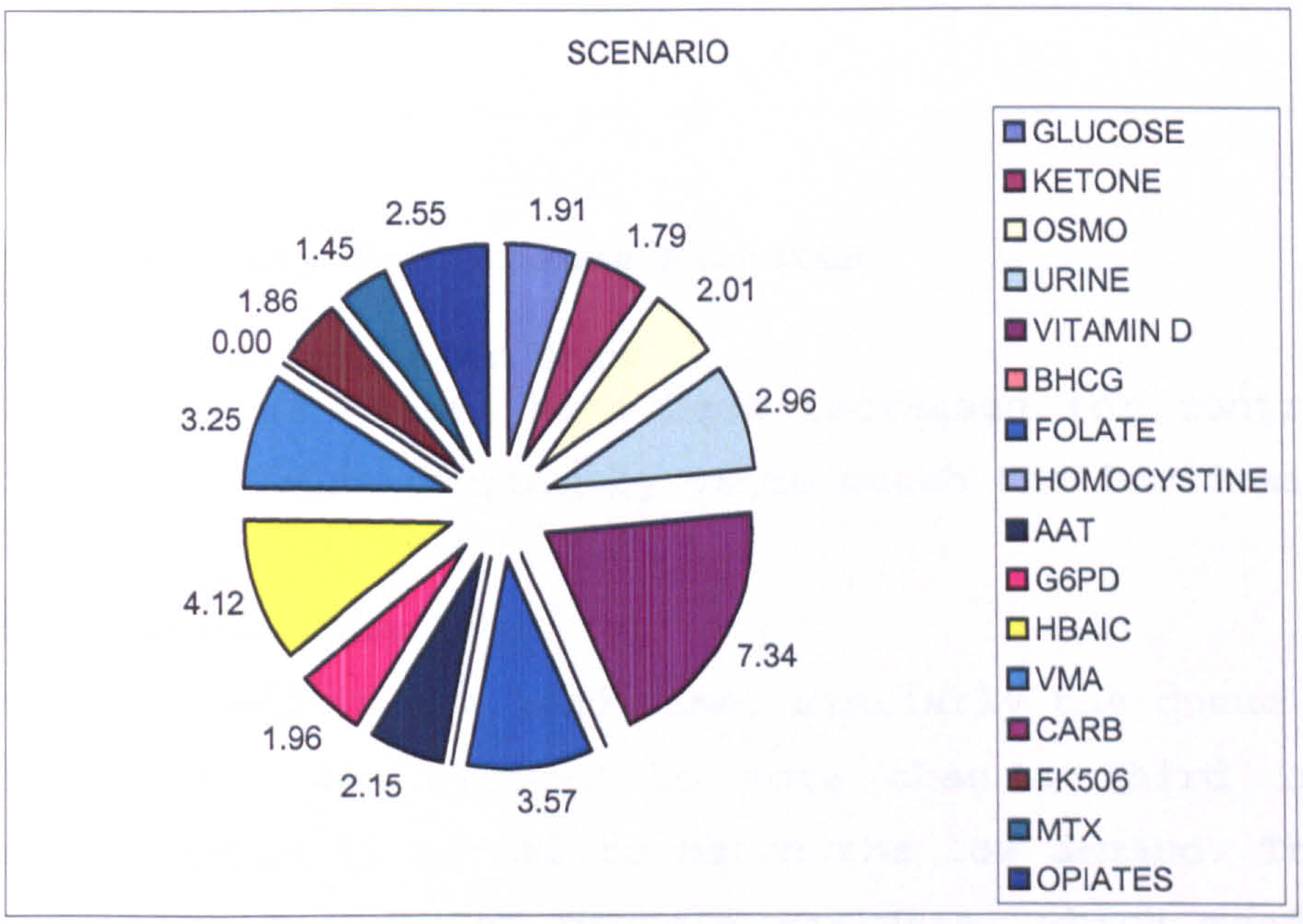
Graph 28

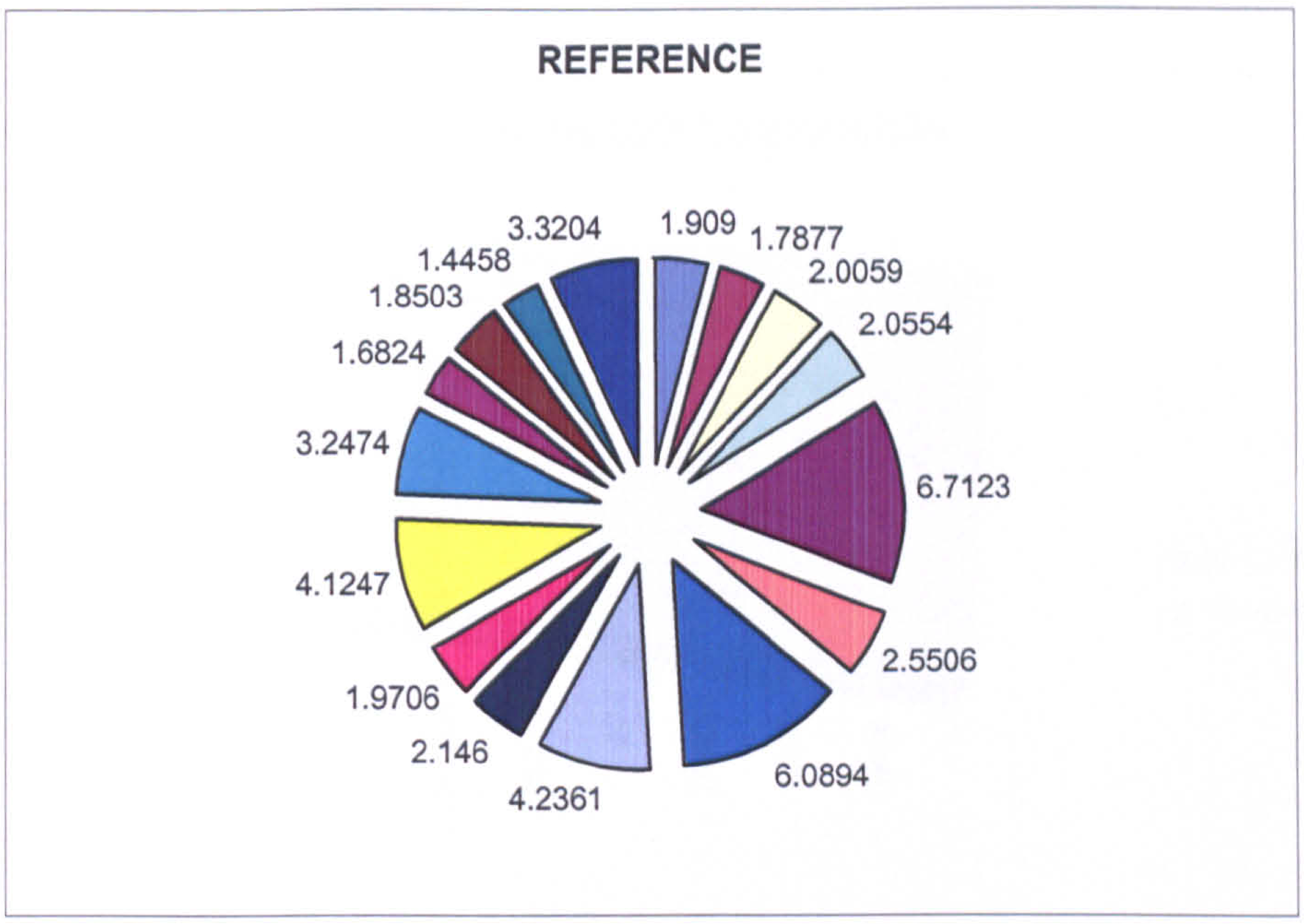


4.1.6 Cost of Test

The cost of each test is not much different than the Reference Model (Graph 29) because the staff and resources are still included. The WIP is high so the staff and other resources are busy maintaining the cost constant of the most tests. Except the tow tests of RIA section; BHCG and Homocystine which can not calculate the cost for them.

Graph 29





4.2 Secondary Performance Measures

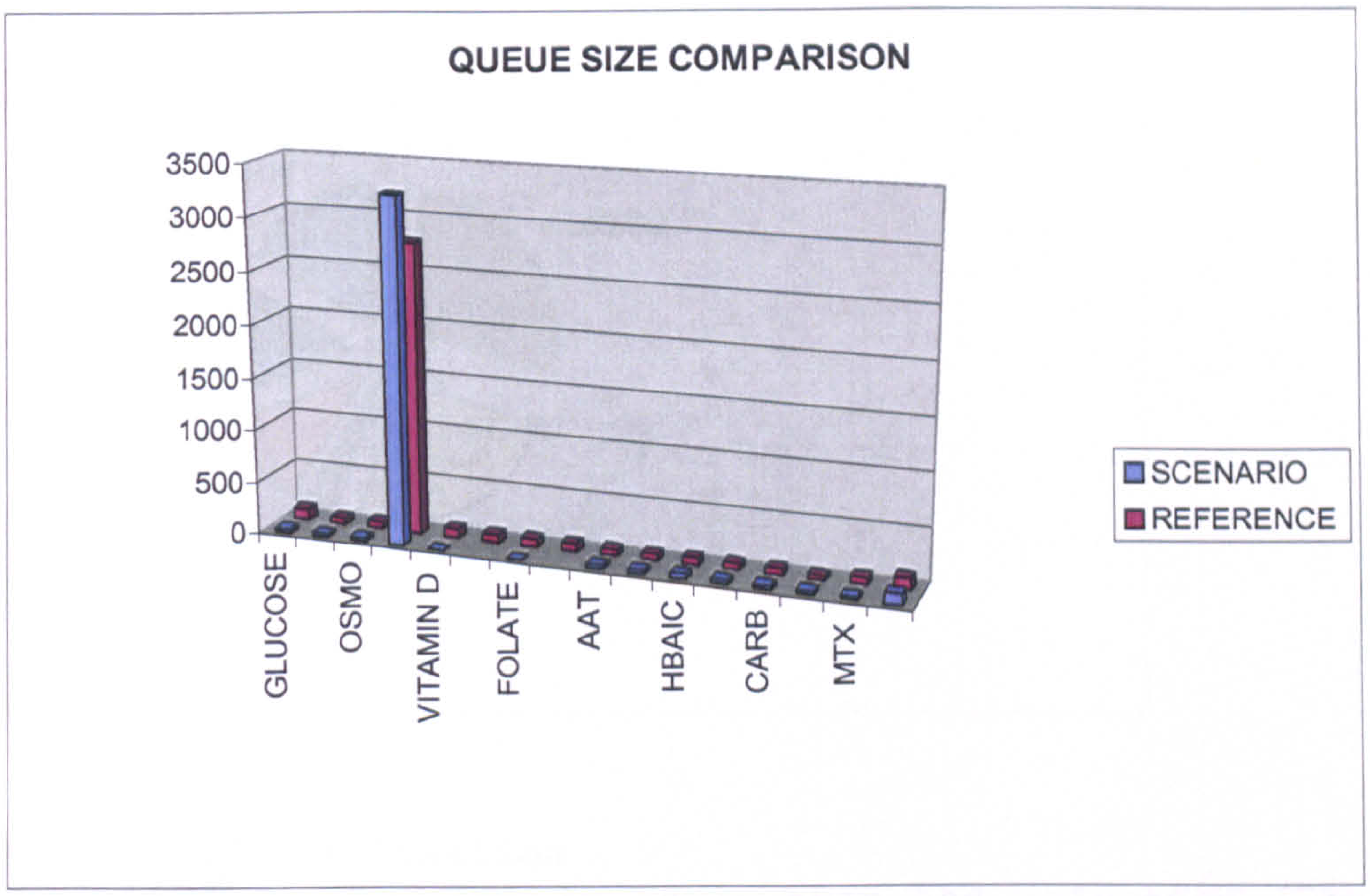
4.2.1 Material Order Size

The material orders have been increased for control and calibrator also dropped by 5% to match the low demand.

4.2.2 Queue Size

As discussed in the lead time, similarly the queue size (Graph 30) was reduced to more than a third in some tests, which is normal to match the low demand. There is a particular problem protein analysis, which needs more study.

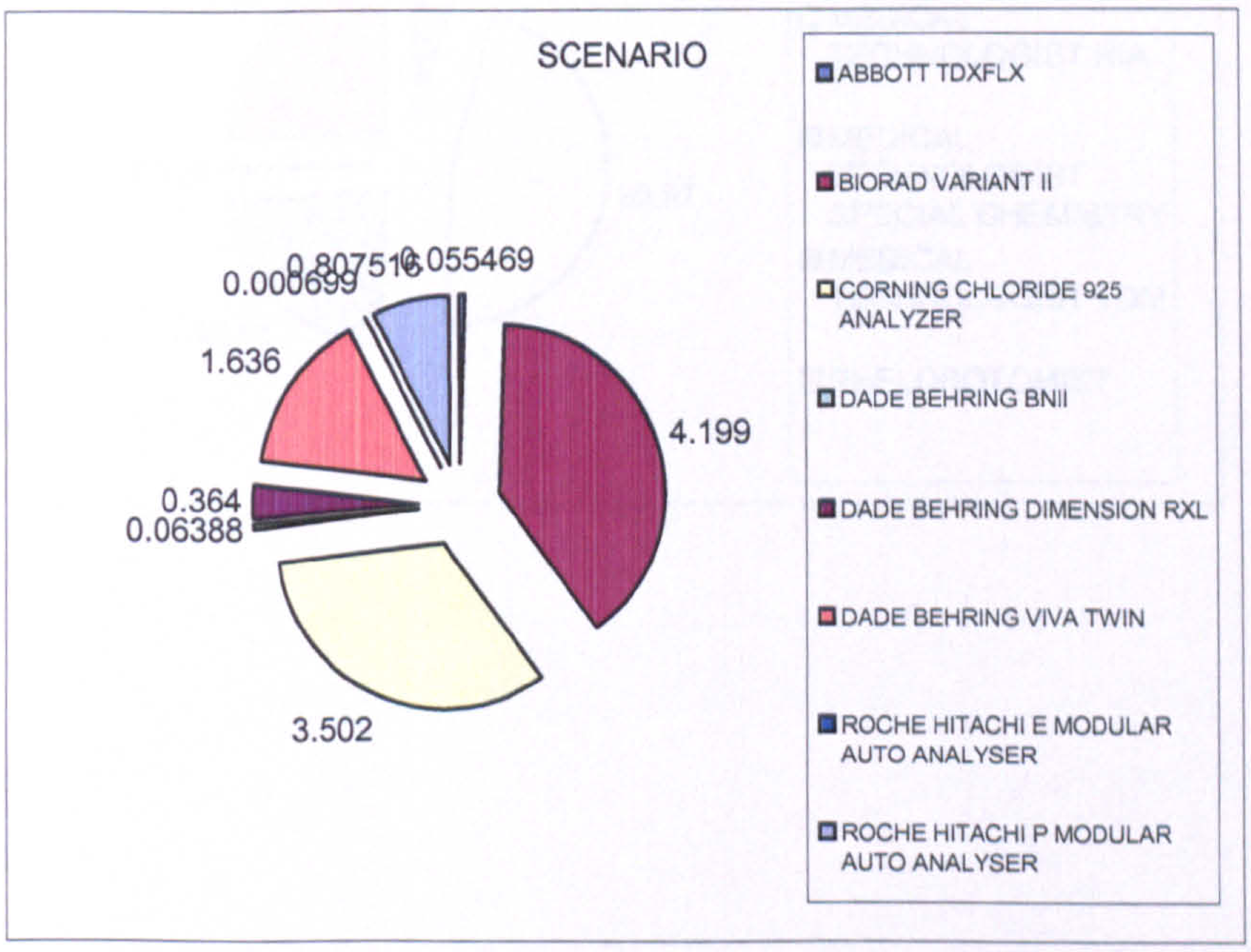
Graph 30

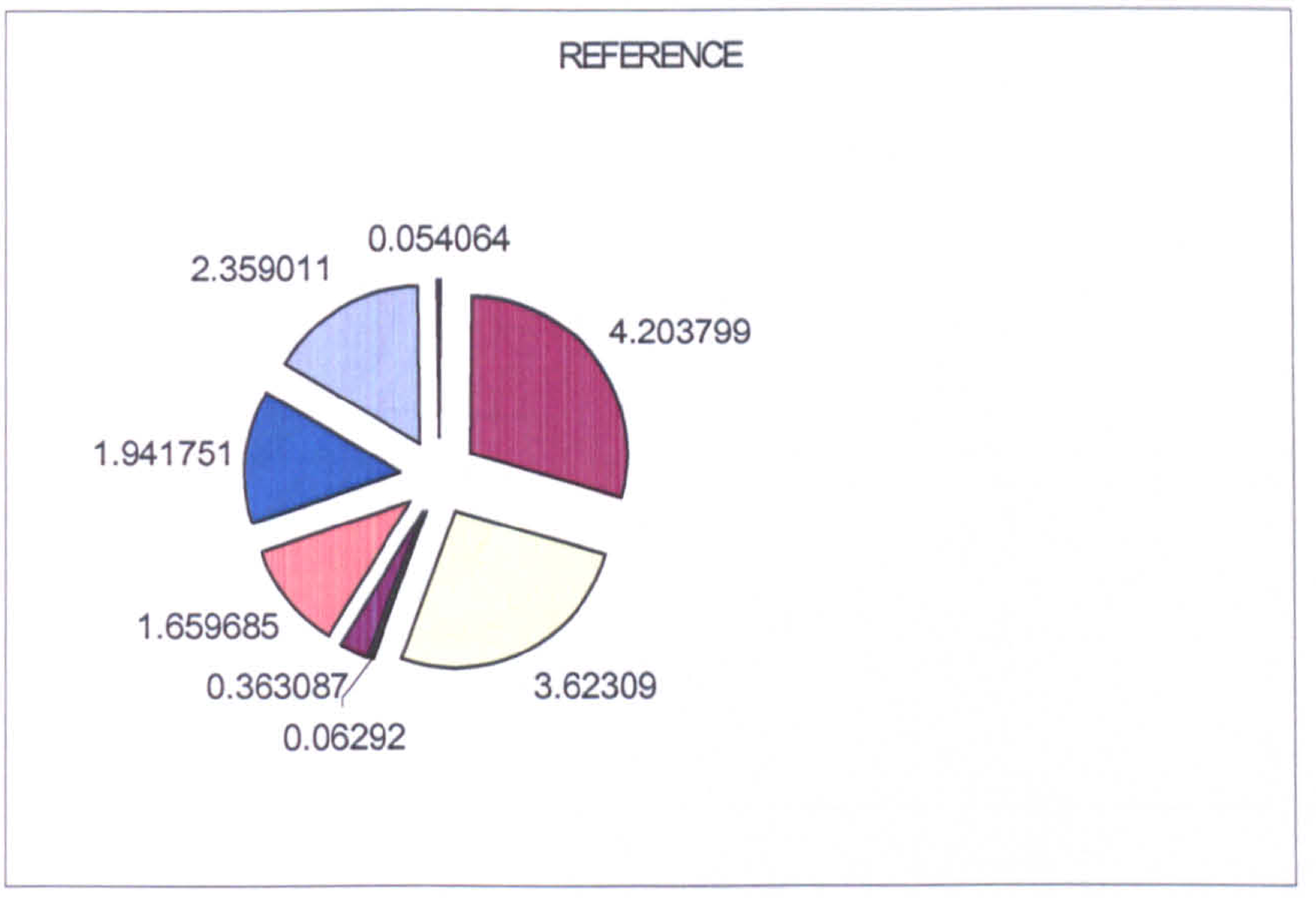


4.2.3 Equipment Utilization

The utilization has dropped matching to patient reduction. Both Roche Hitachi Analyzer E & P dropped in a high percentage as these particular tests have been reduced. (Graph 31)

Graph 31

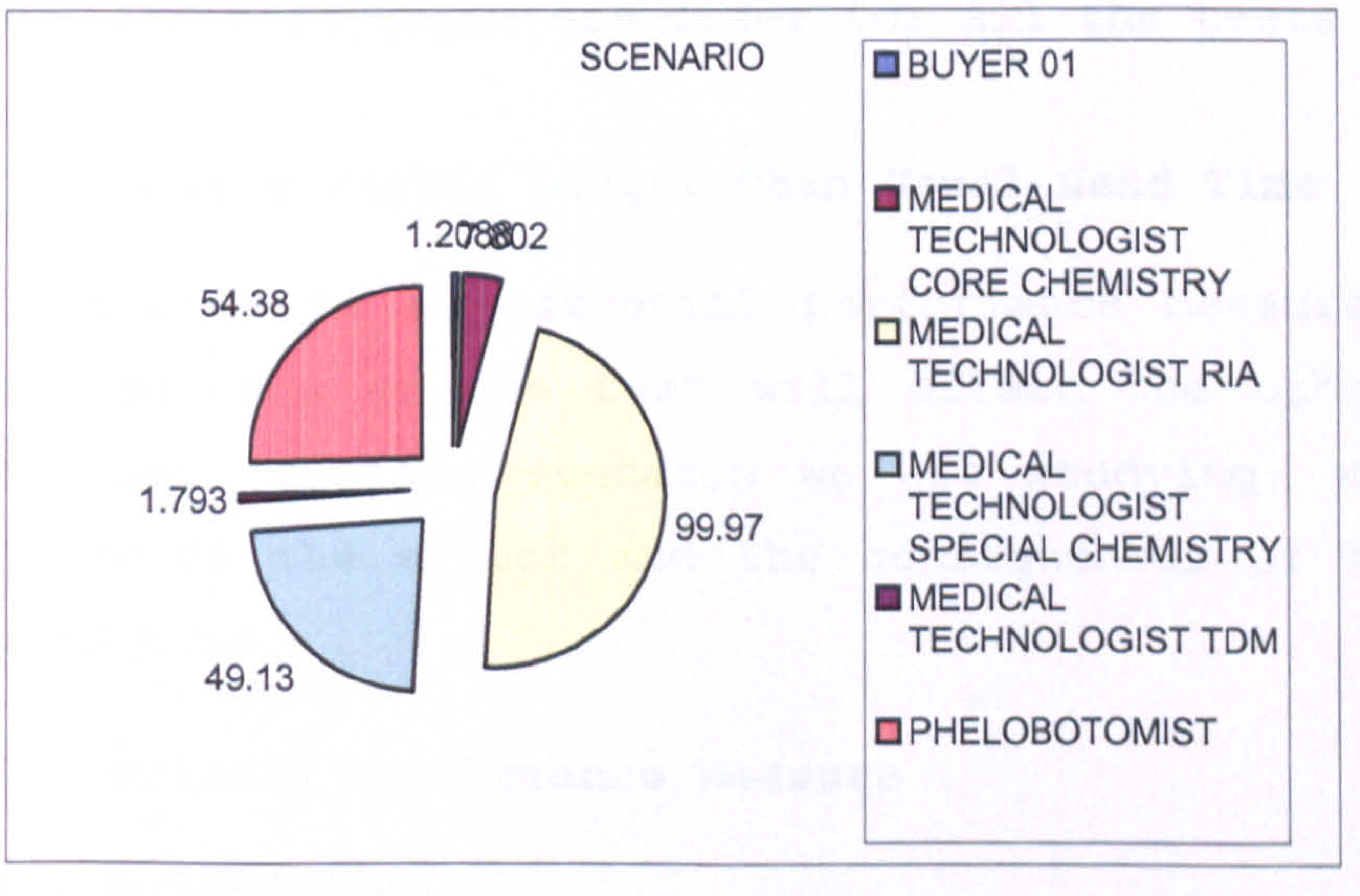


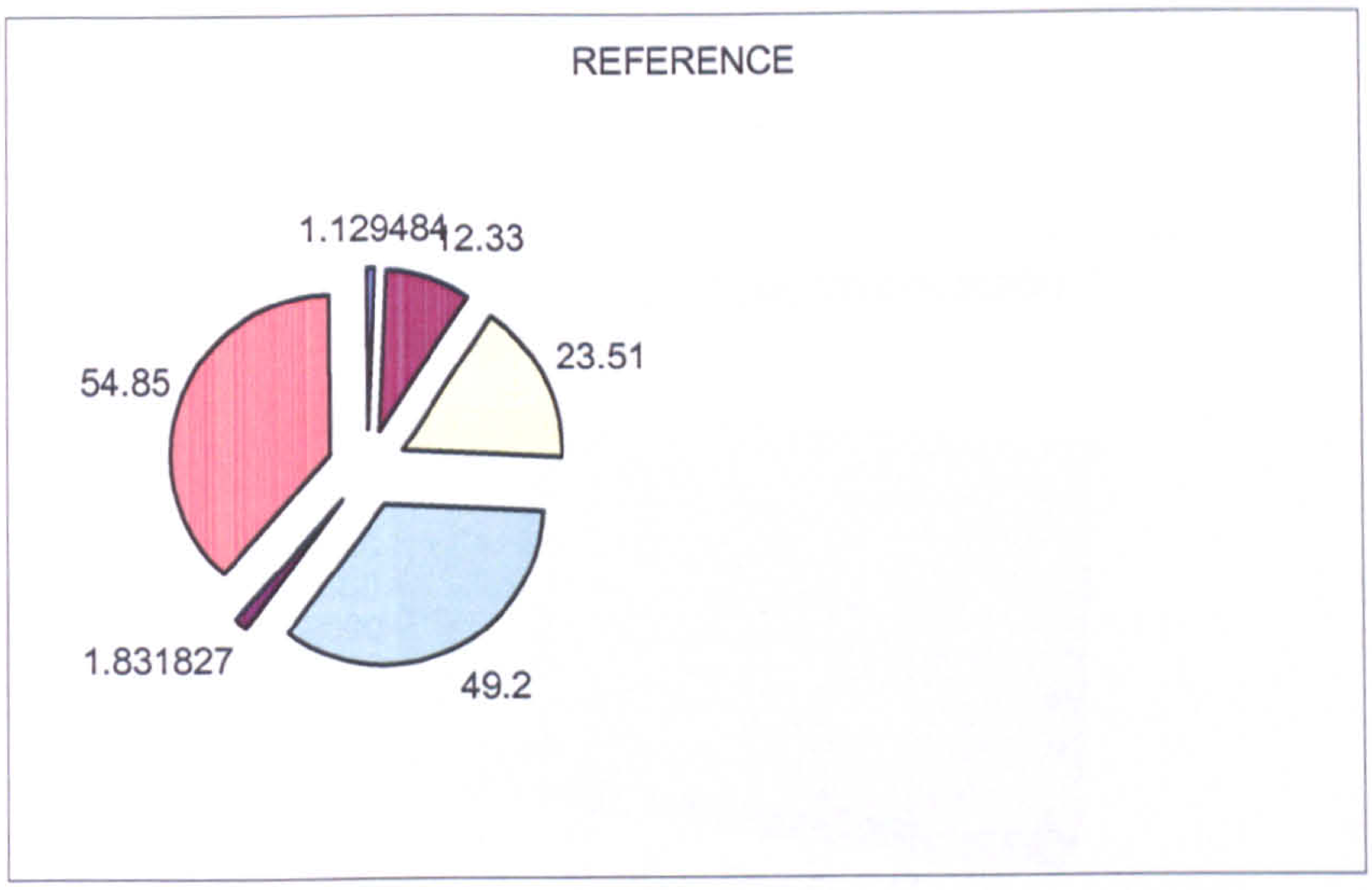


4.2.4 Staff Utilization

The staff utilization is lower than the reference (Graph 32) except for the Medical Technology RIA which increased to the maximum, showing the unbalance of staffing distribution.

Graph 32





4.3 Conclusion

This scenario provide us with an indication of the effect one test by decreasing the demand will effect the whole chemistry lab. Lead-time which is very important shows a decrease by two-thirds in some test like glucose, while we have lower lead time; the WIP is lower than the Reference Model. As we know, almost the same inventory and the throughput are lower for all the tests.

5. Scenario Eight: Longer Than Usual Lead Time

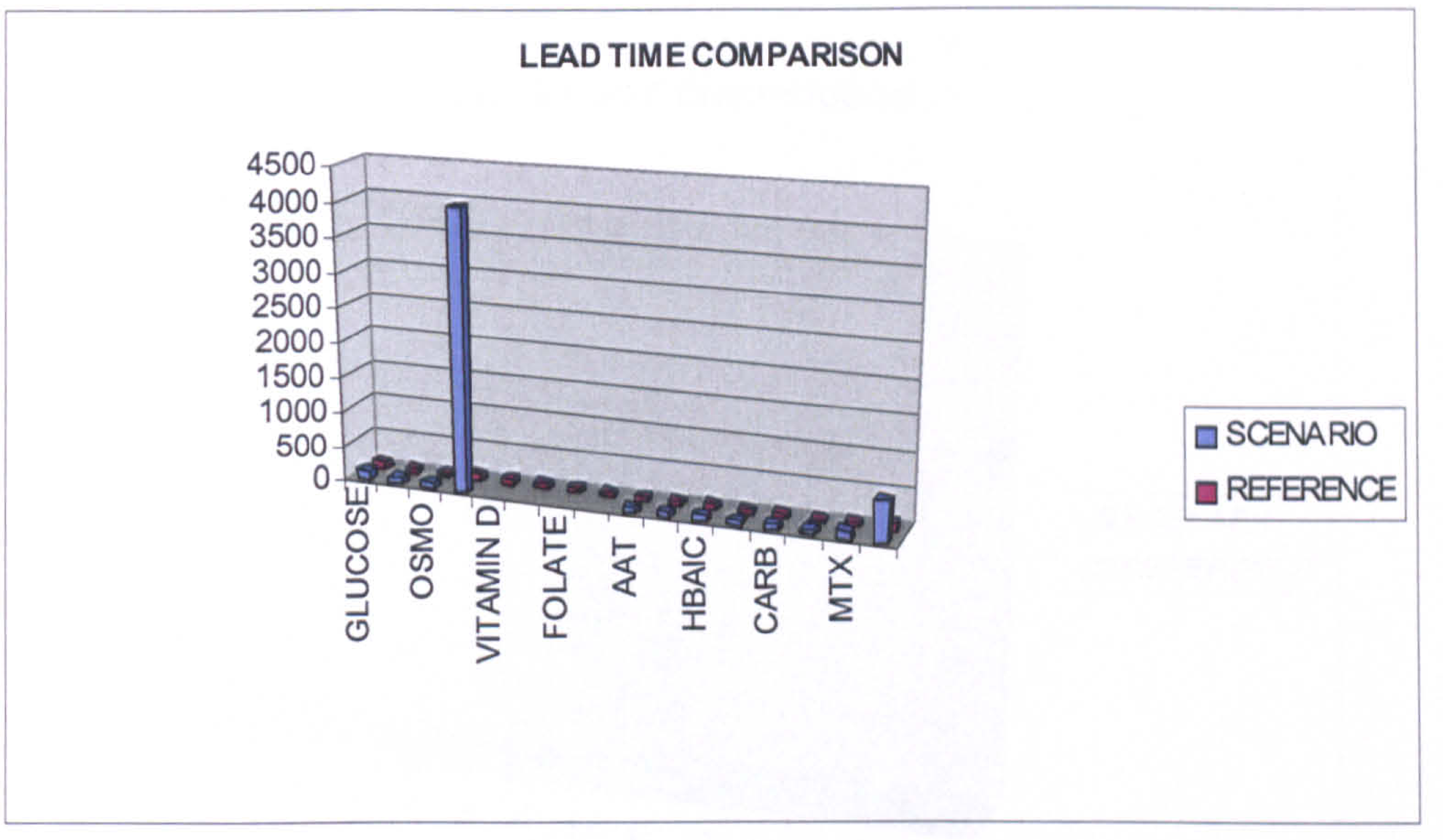
Lead time is an essential performance measure. Delaying the process of the test will effect the other measures outcome. In this scenario we are studying; what is the value of the effect and the consequences of having long lead time.

5.1 Primary Performance Measure

5.1.1 Lead Time

The lead time as shown in the Graph 33 increased by 20 to 90%. Other factors like inventory of the components can cause a drop in the lead time. RIA section failed to report the result.

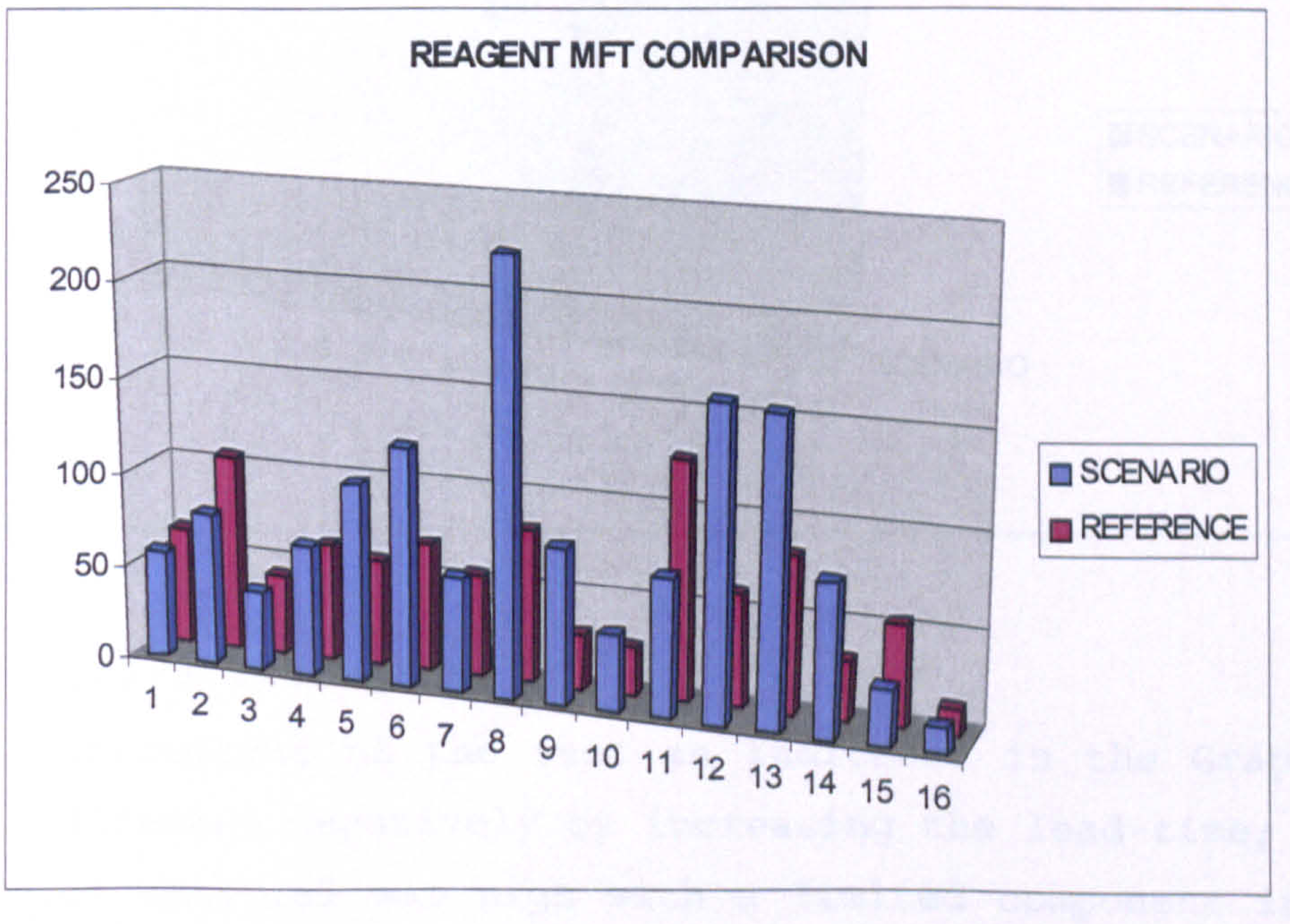
Graph 33

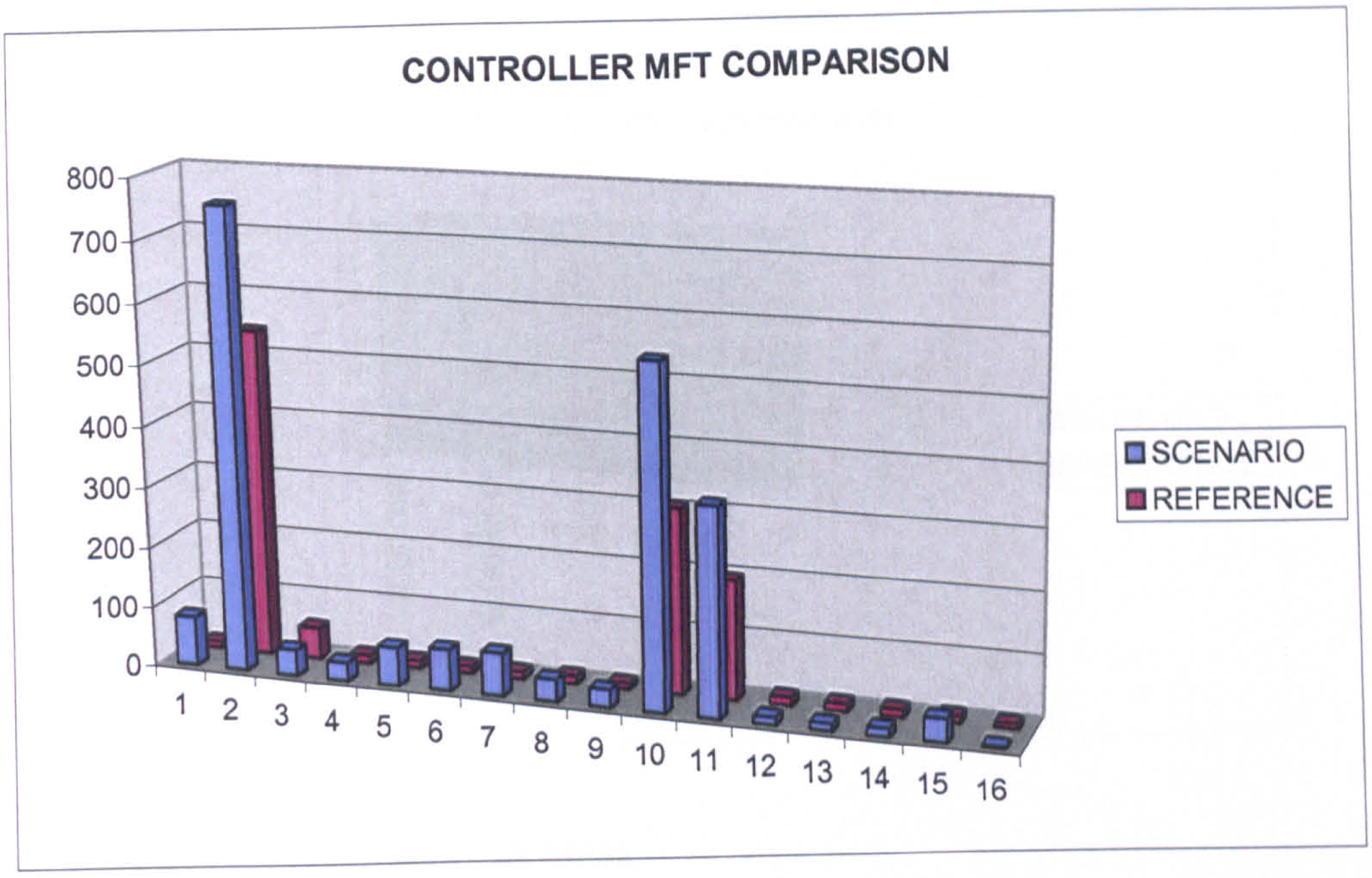


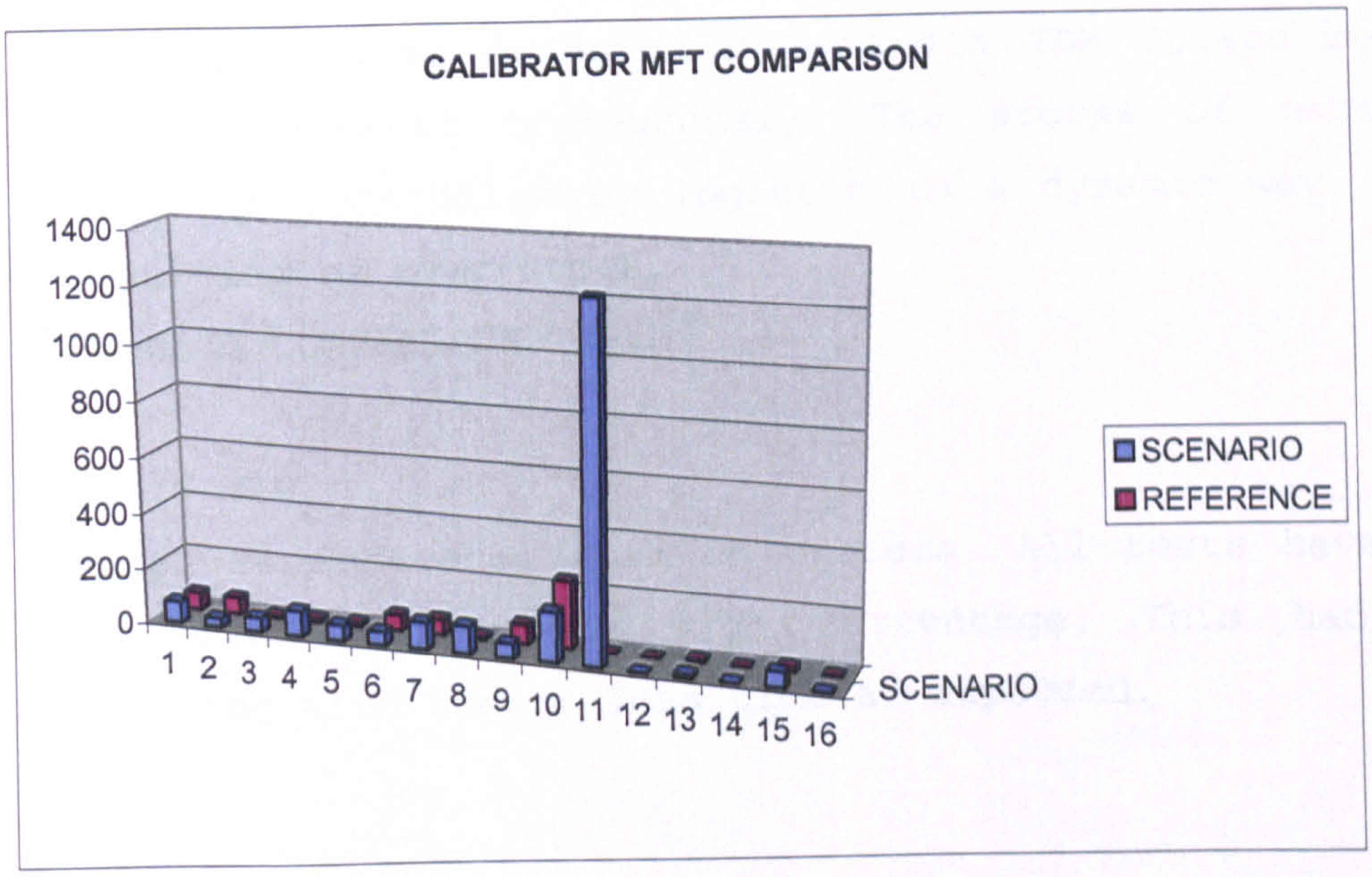
5.1.2 Materials Flow time

More than 60% of all tests are affected by the change through increasing the material flow time, as illustrated in Graph 34 which consist of reagent, calibrator, and controller.

Graph 34





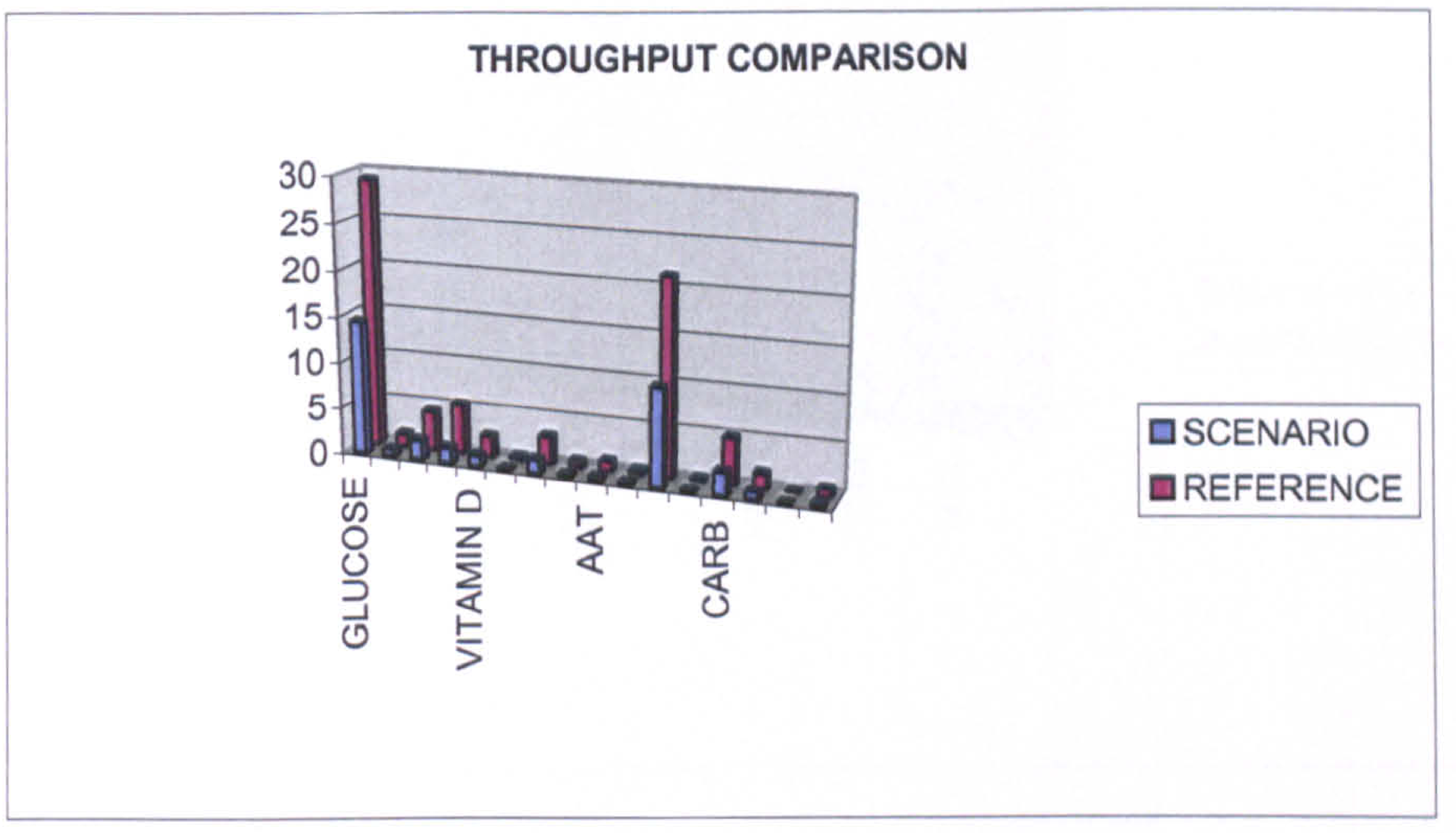


5.1.3 Throughput

Throughput of the test as indicated in the Graph 35 was effected negatively by increasing the lead-time; the flow of material was high with a limited component inventory.

It is expected by longer the lead-time for some of the components used less the number of performed test.

Graph 35



5.1.4 Inventory Status

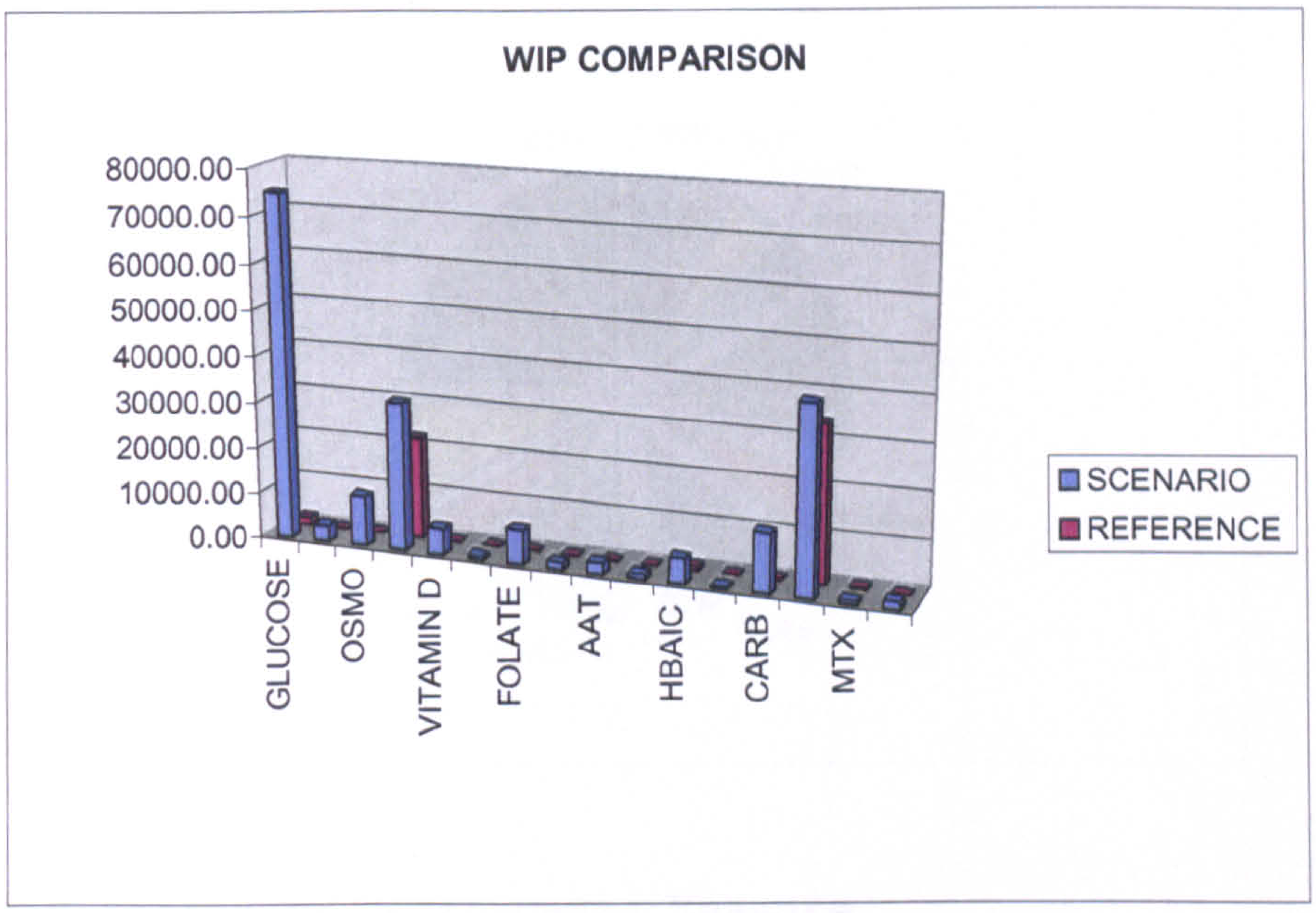
There is not much change in the inventory of all components whether in the Lab or Logistics with the Reference Model except for Test #16 TDM Opiate reagent which decreased tremendously. The stocks of materials were not controlled by logistic in a dynamic way, which resulting of over stock.

STORAGE COMPARISON TABLE

5.1.5 WIP

Graph 36 indicates work in process. All tests have been increased to a very high percentage. This had been matching with longer lead time as expected.

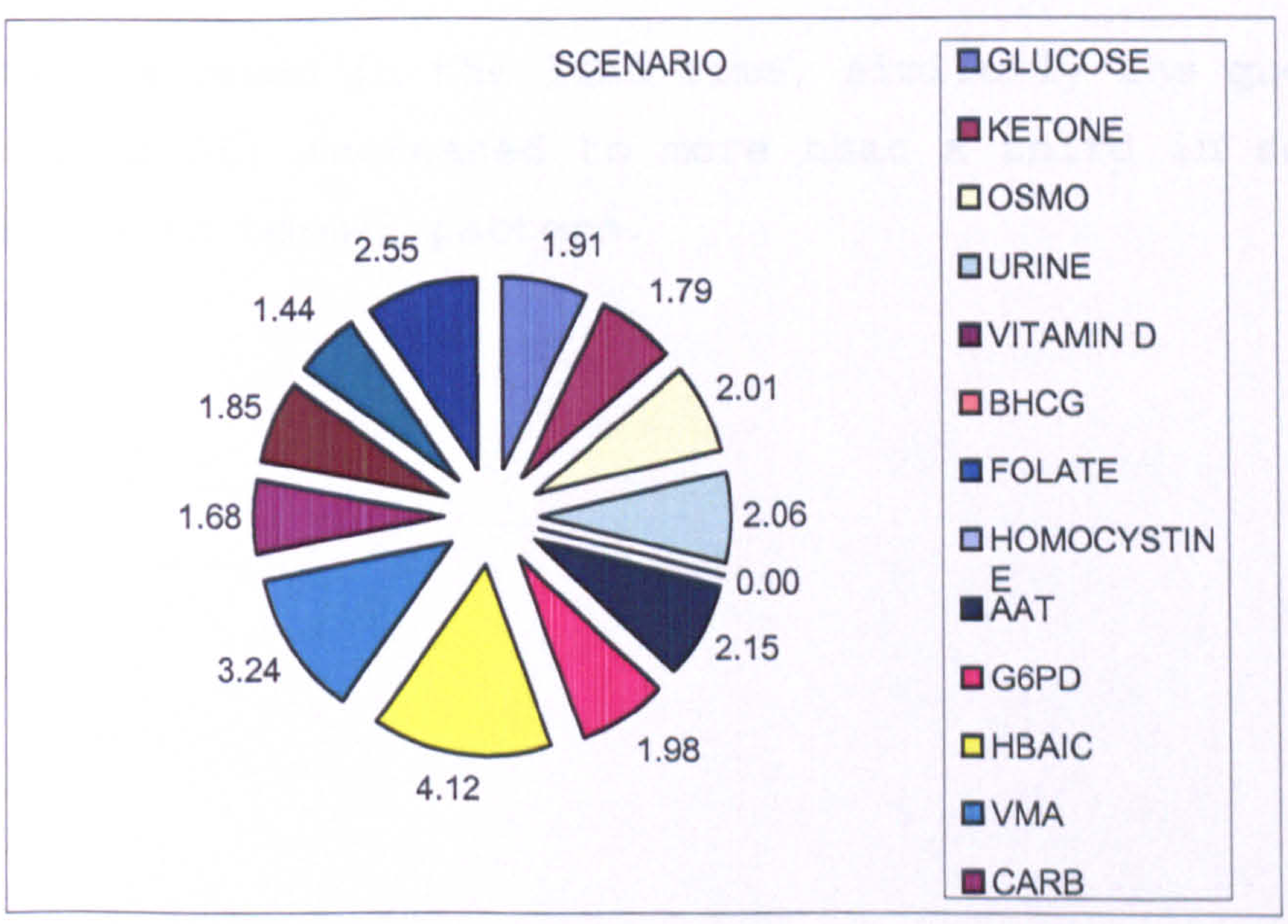
Graph 36

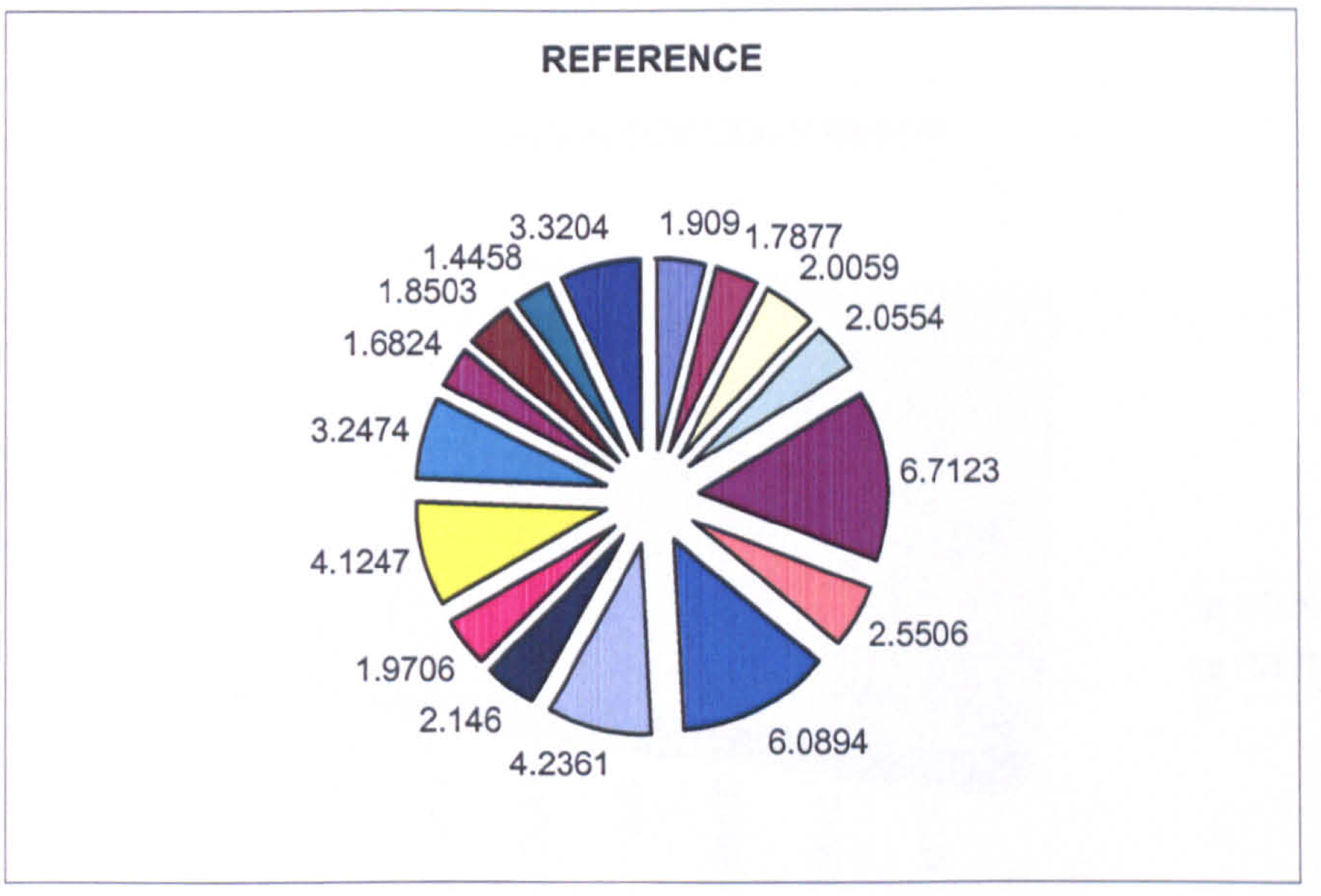


5.1.6 Cost of Test

The cost of each test is not much different than the Reference Model (Graph 37) because the staff and resources are still included in the calculation.

Graph 37





5.2 Secondary Performance Measure

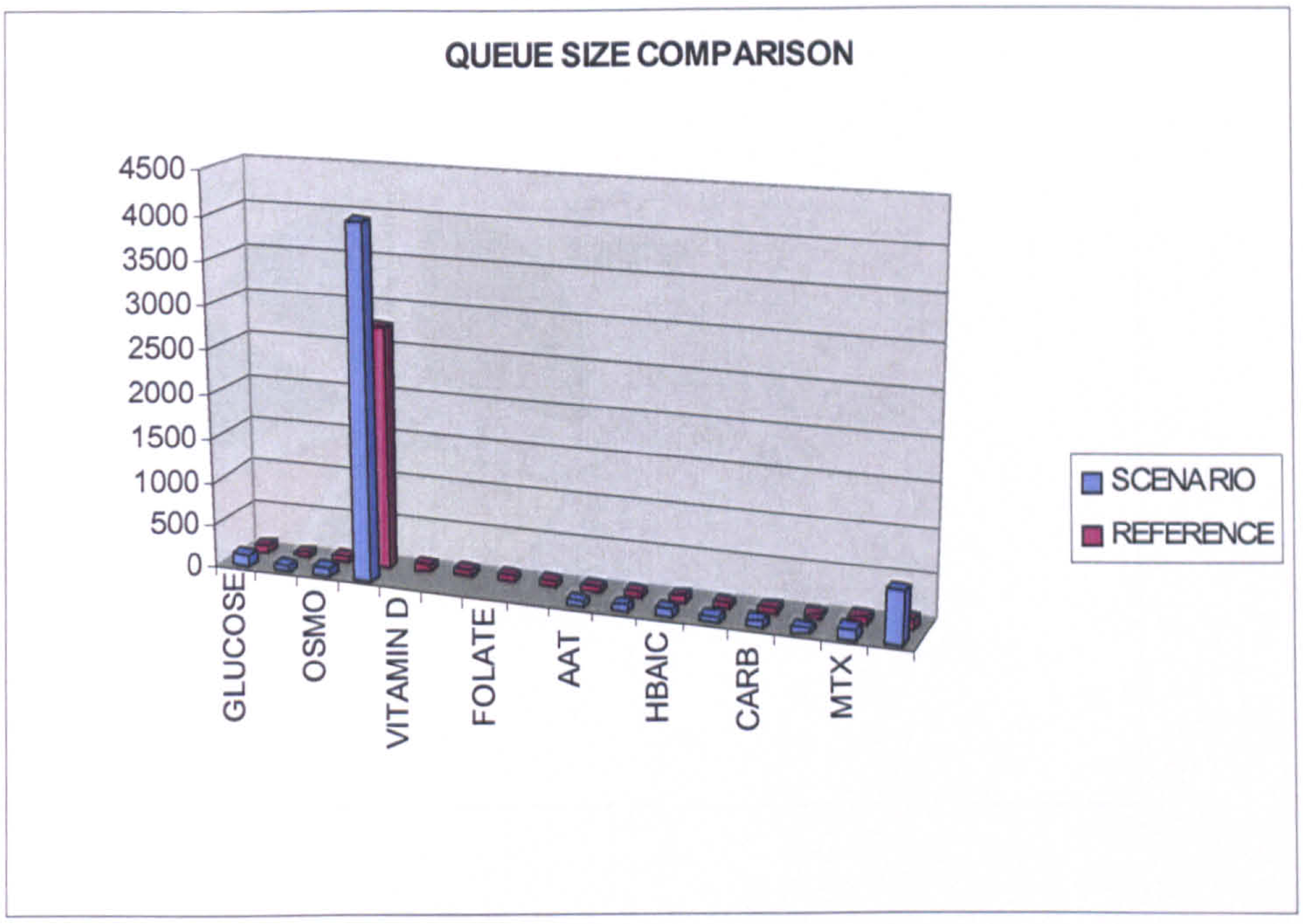
5.2.1 Material Order Size

Orders of the materials have been dropped 5% for the calibrator whiles the reagent and controller by 10 to 20 percent. This is normal of decreasing all components but the percentage is not expected, as it should be high with the reagent and less with calibrator and controller.

5.2.2 Queue Size

As discussed in the lead time, similarly the queue size (Graph 38) increased to more than a third in some tests, which is normal pattern.

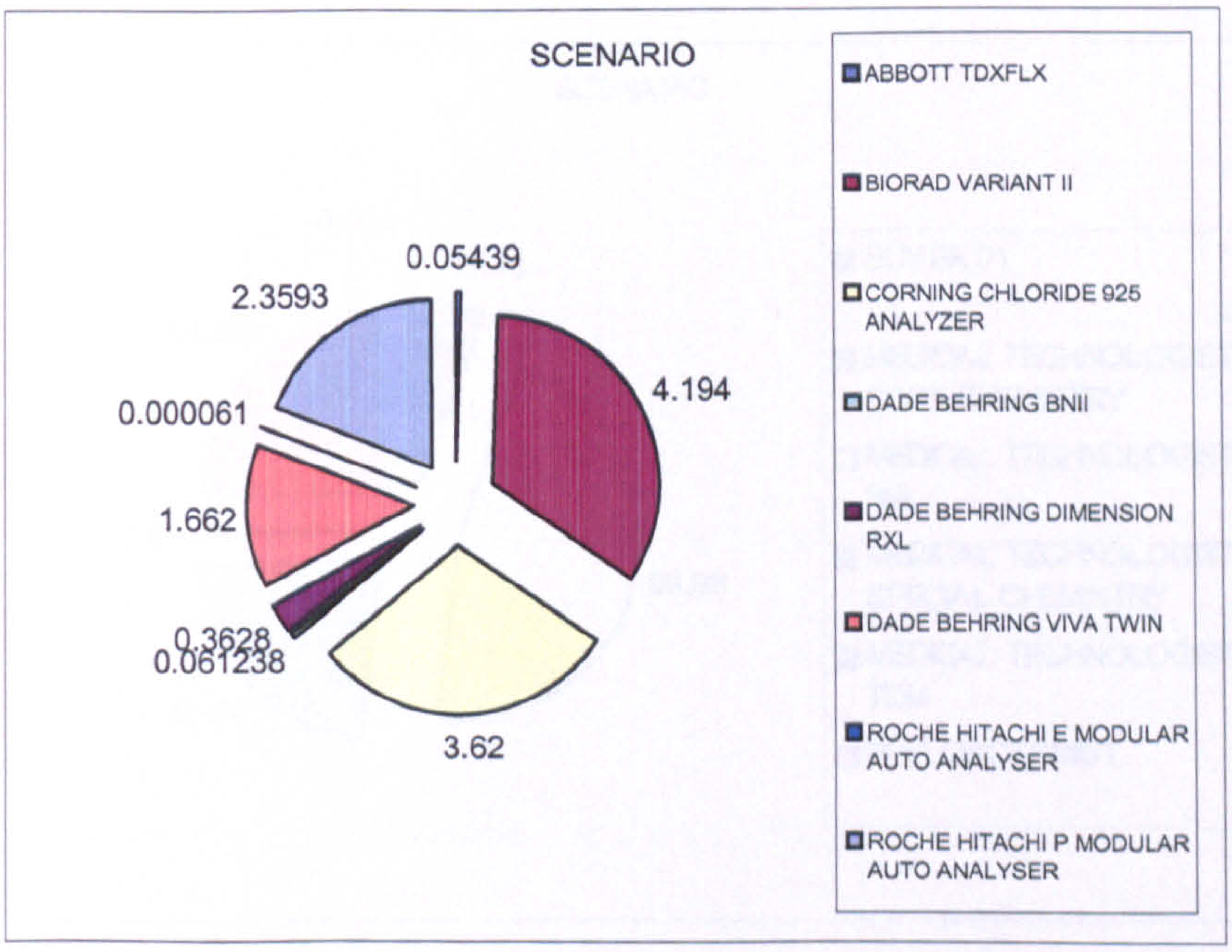
Graph 38

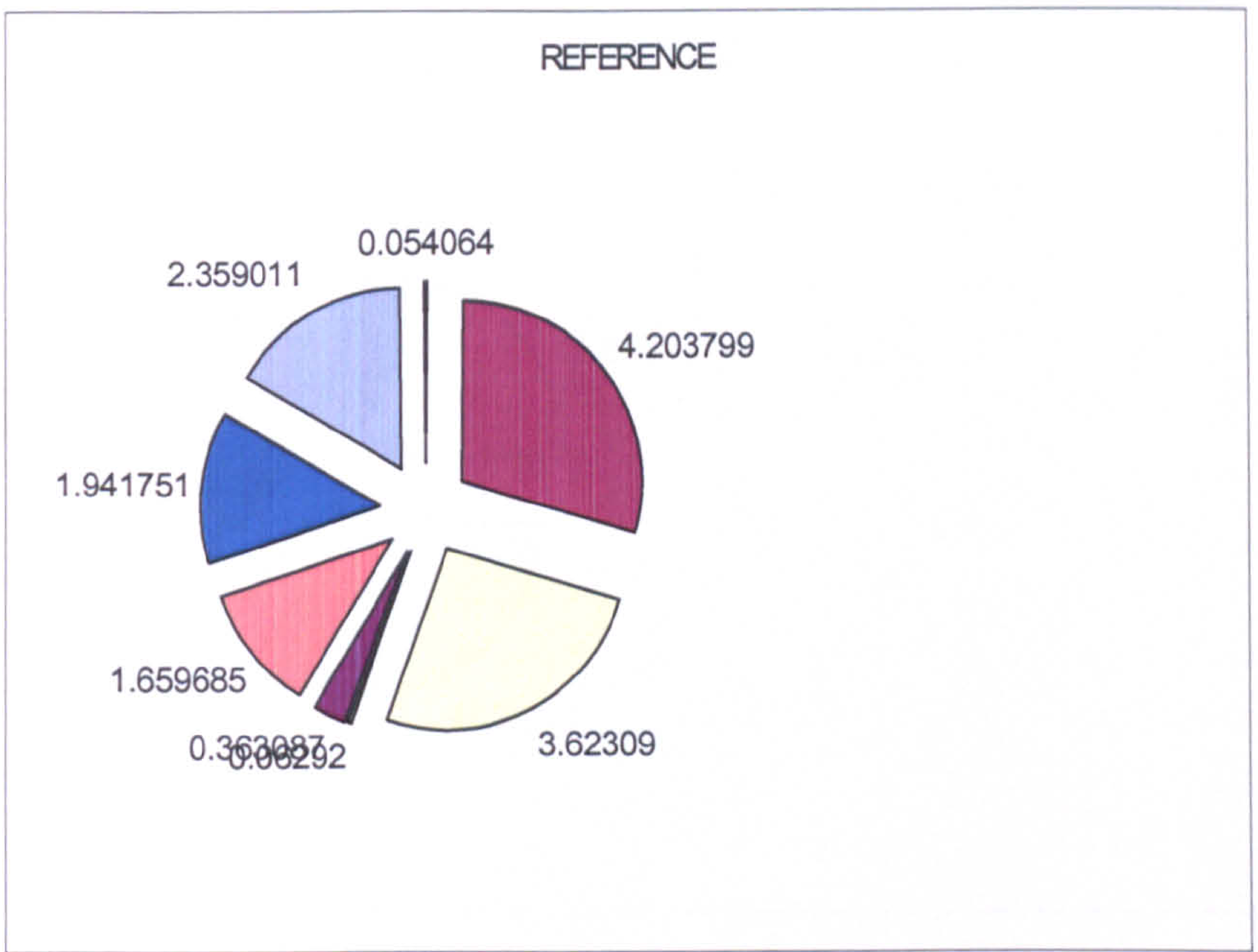


5.2.3 Equipment Utilization

The utilization has been the same. The maximum dropped for the Roche Hitachi E Modular Auto Analyzer. (Graph 39)

Graph 39

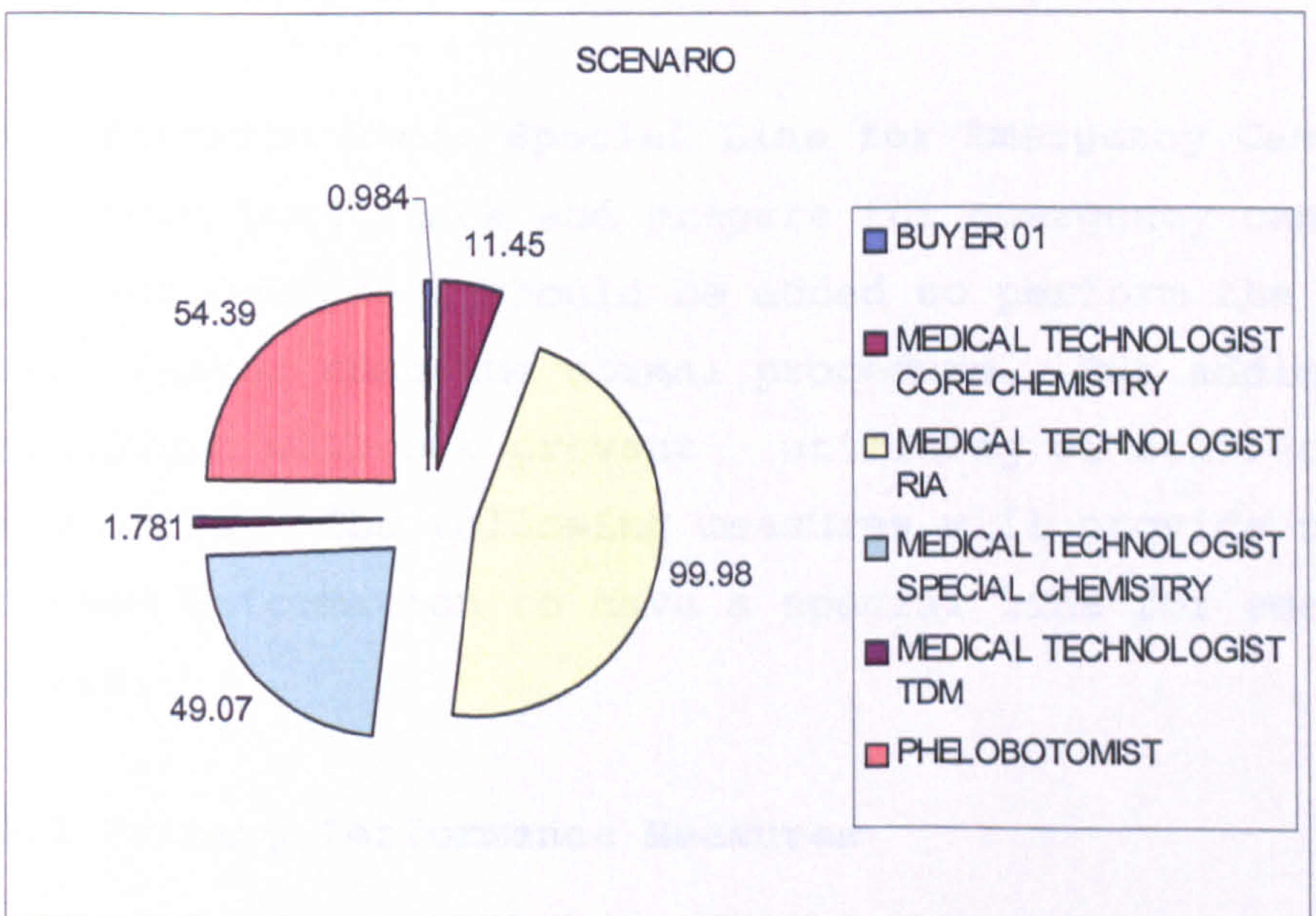


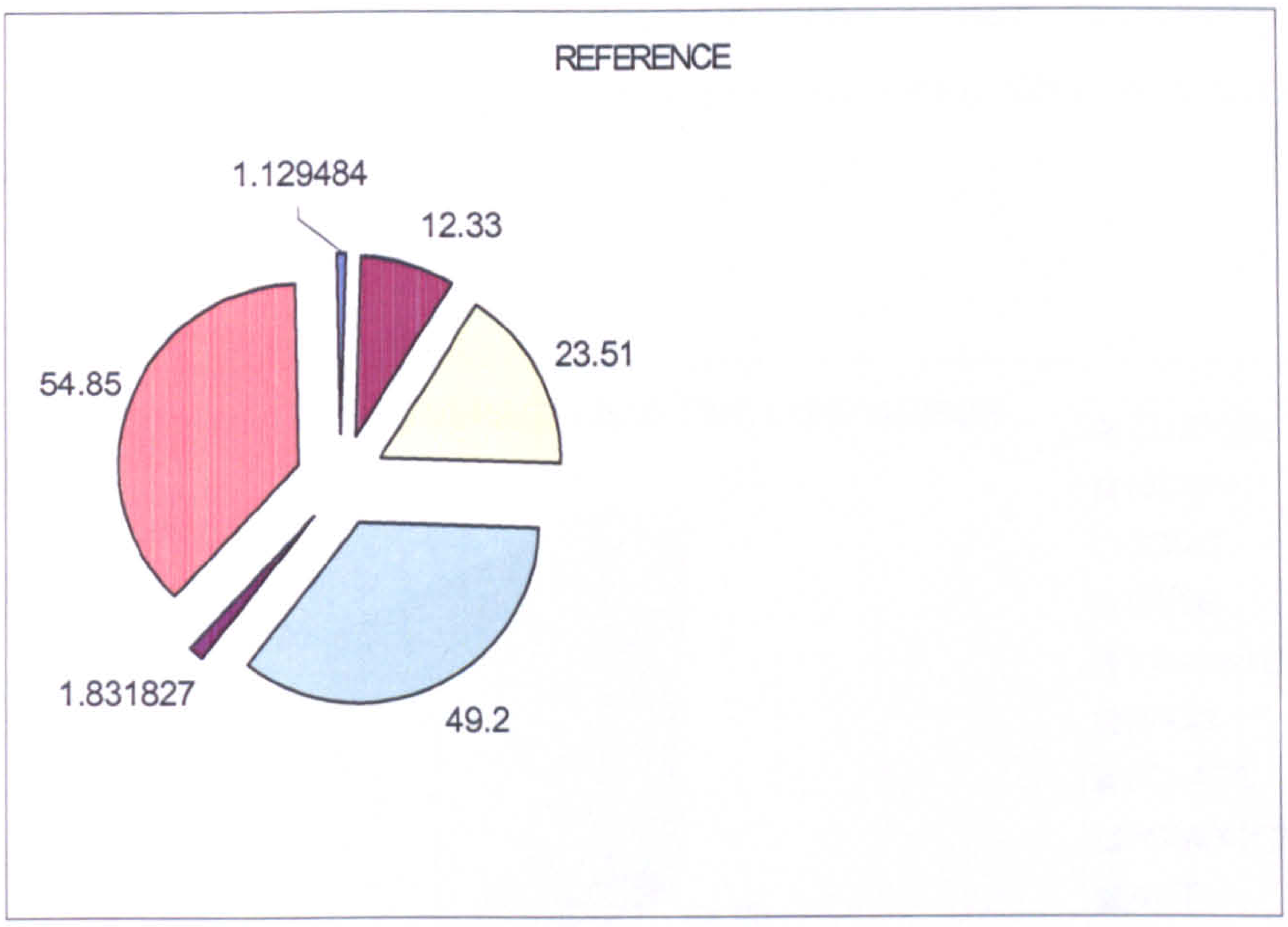


5.2.4 Staff Utilization

The staff utilization is slightly lower than the reference (Graph 40) except for the Medical Technology RIA, which increased to the maximum, showing the unbalance of staffing distribution.

Graph 40





5.3 Conclusion

As we increase the lead time for some of the materials purchased, all chemistry lab section have reduce there outcome Inventory for the Lab and Logistics has increased, throughput decreased, utilization of the staff remains the same and the flow of component is higher. The scenario produces what expected result, which indicates to a normal pattern.

6. Scenario Nine: Special Line for Emergency Cases

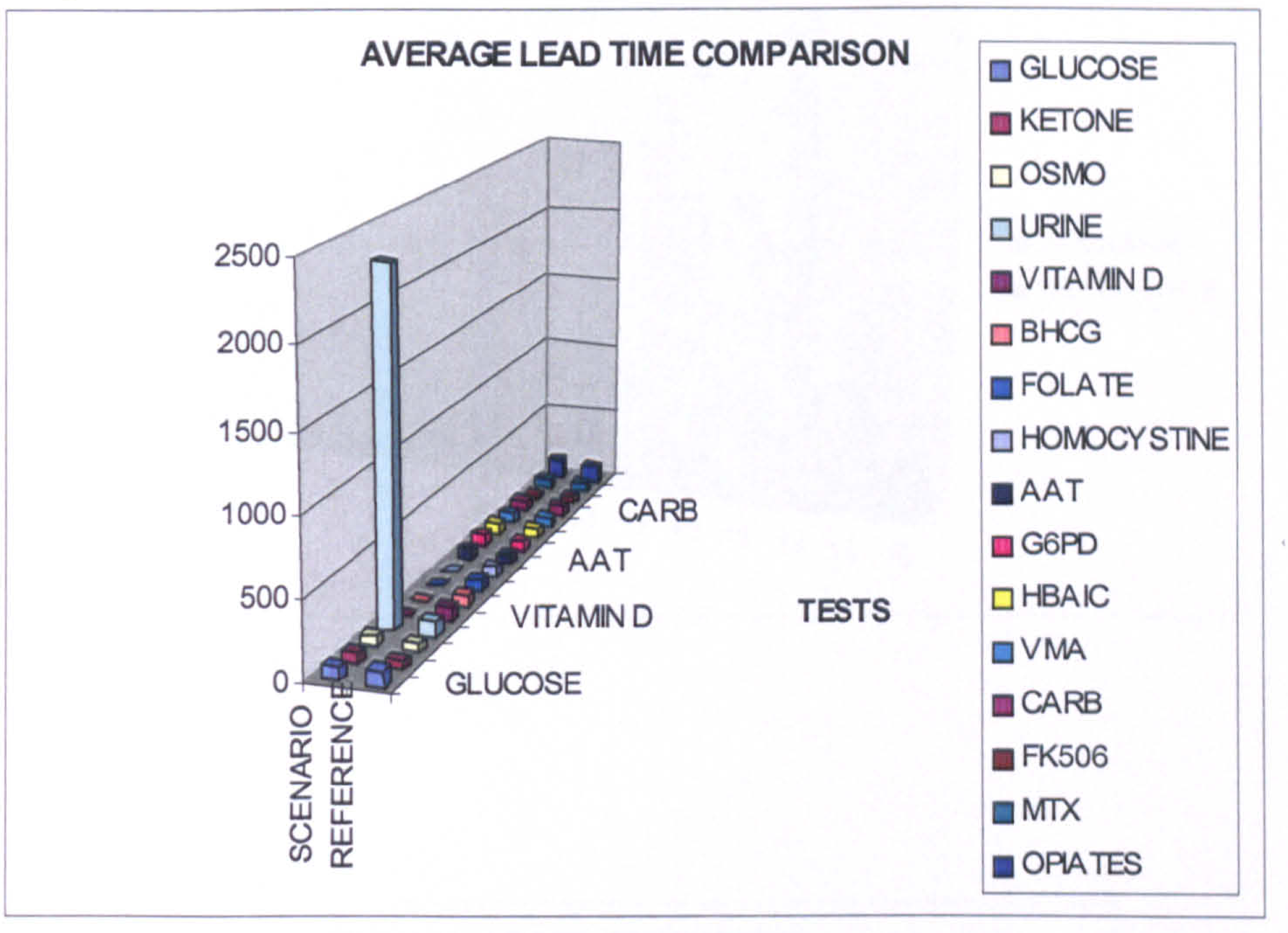
To avoid bottleneck and prepare for emergency cases, back-up equipment should be added to perform the needed test faster than the normal procedure. But adding equipment will not prevent utilizing of staff or other resources. The following measures will provide us the needed information to have a special line for emergency cases.

6.1 Primary Performance Measures

6.1.1 Lead Time

The lead time as shown in the Graph 41 fluctuated. Most of the tests of the Core Chemistry section are less while the RIA dropped tremendously. The other sections did not changed much, except the Opiates test which increased by 25%.

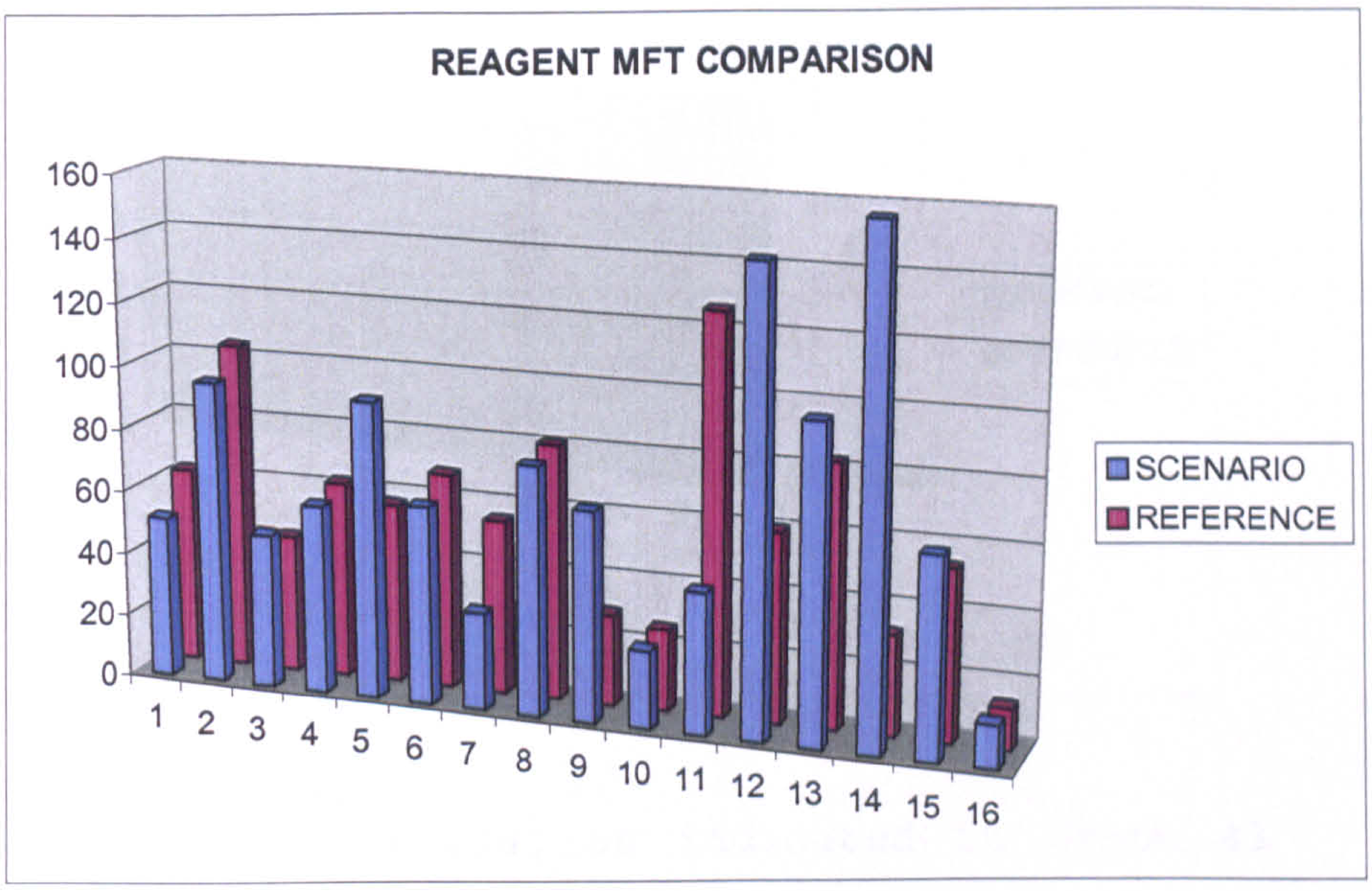
Graph 41

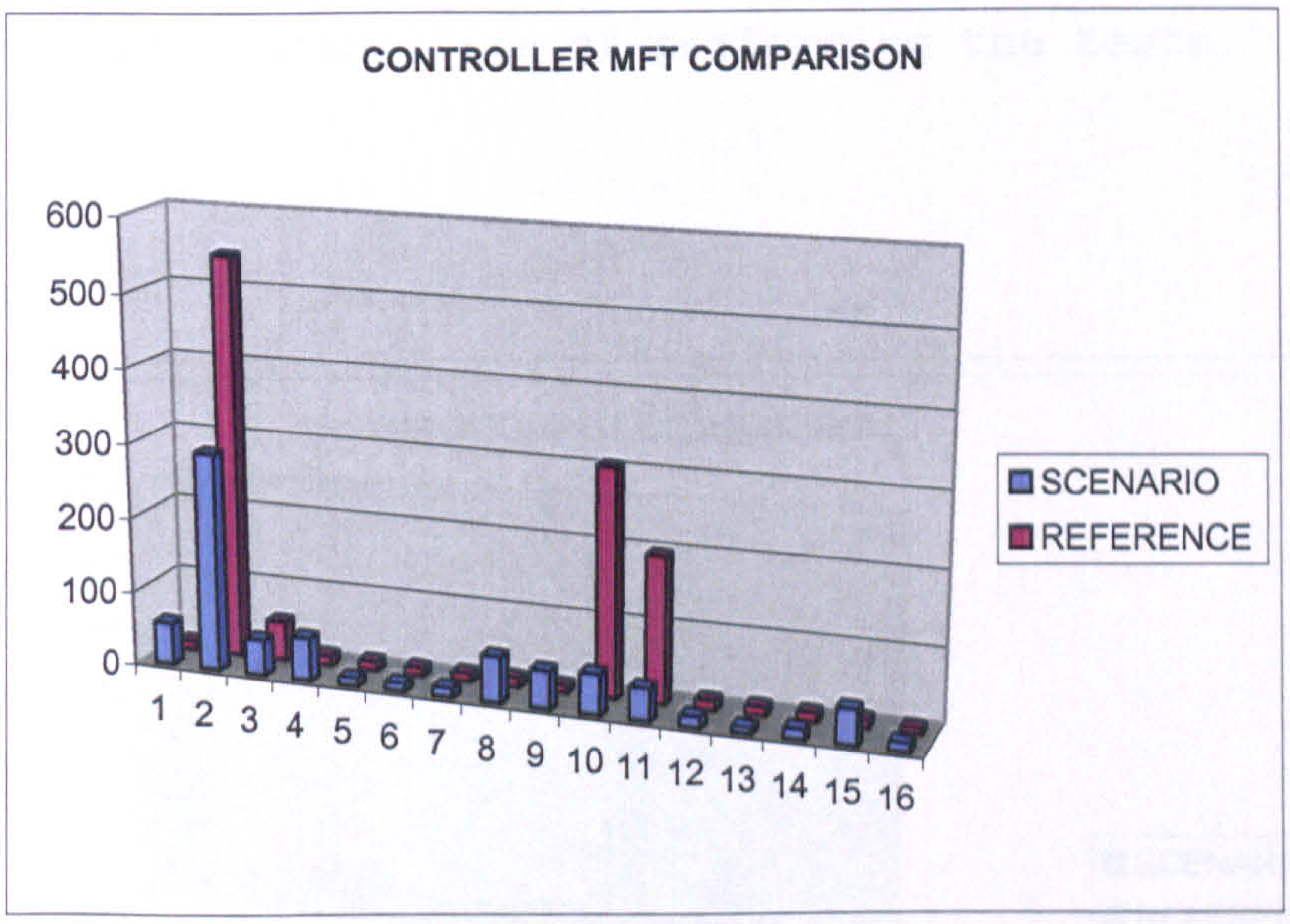


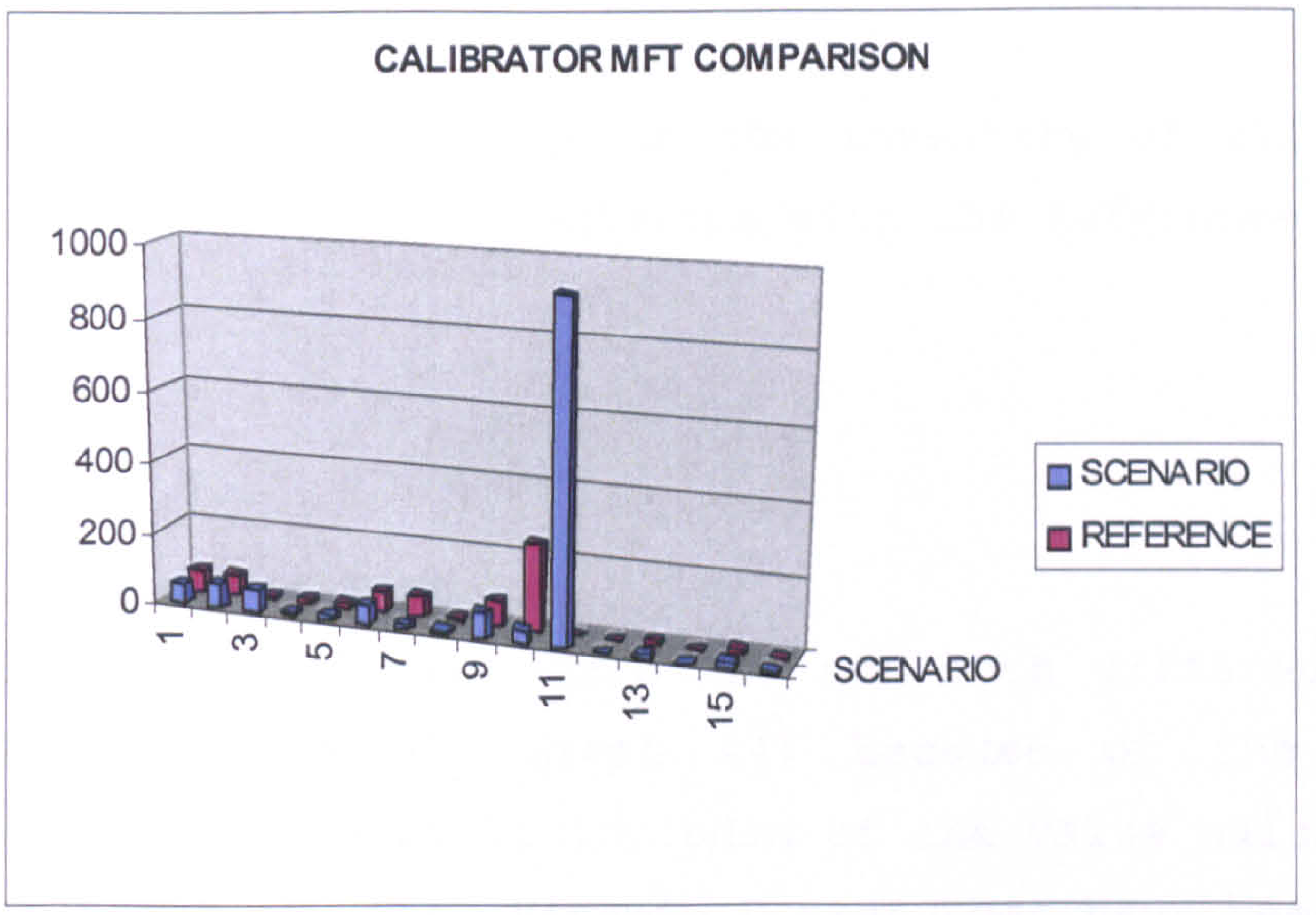
6.1.2 Material Flow Time

More than 50% of all tests are less while the rest were higher. This indicates there is no defined pattern for the MFT. This is illustrated in Graph 42, which consist of reagent, calibrator, and controller.

Graph 42


REAGENT MFT COMPARISON
160
140
120
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
SCENARIO
REFERENCE

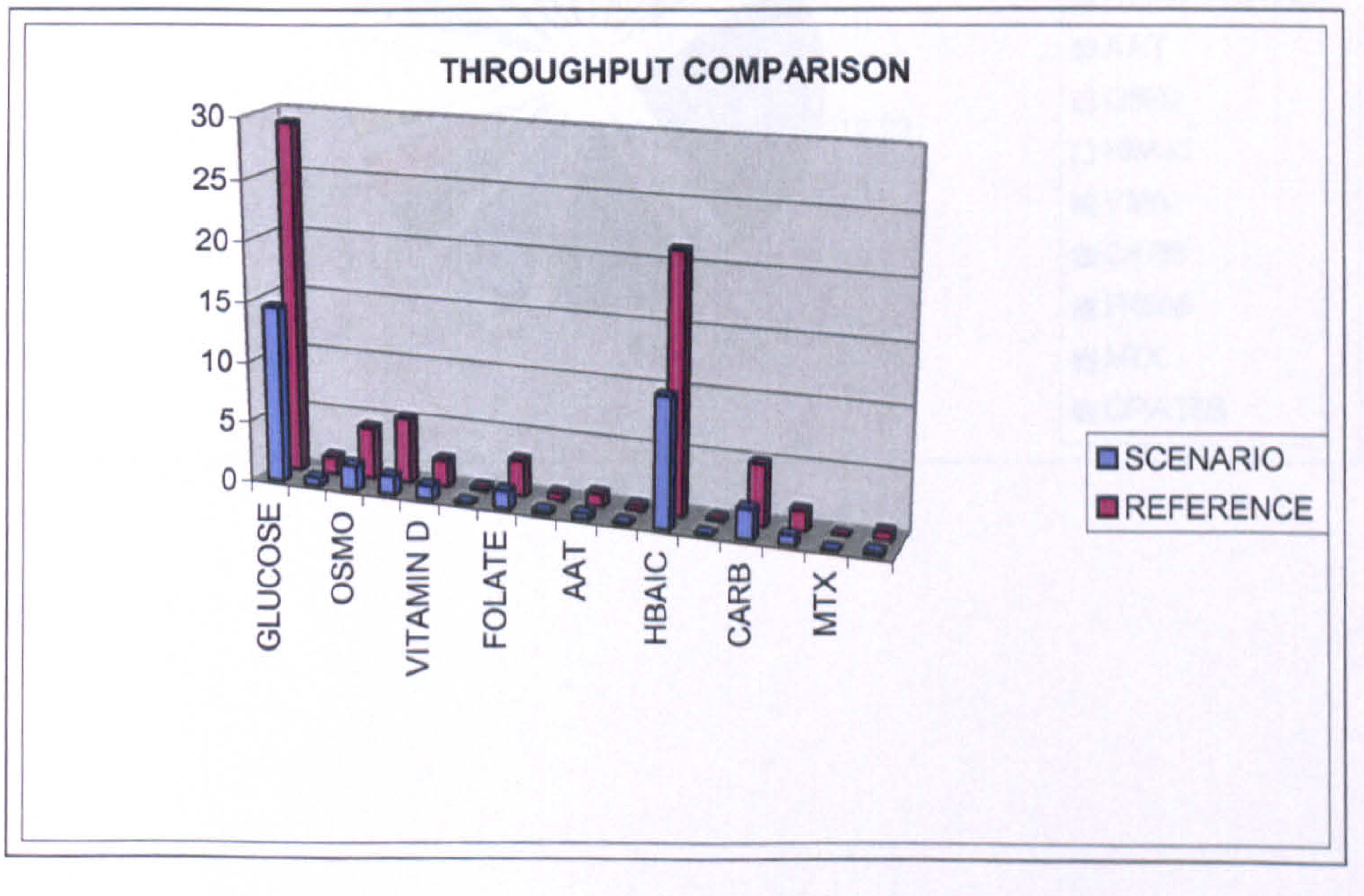

CONTROLLER MFT COMPARISON
600
500
400
300
200
100
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
SCENARIO
REFERENCE



6.1.3 Throughput

Throughput of the test as indicated in Graph 43 was effected negatively. As may the busy resources and the fluctuation of the MFT is the result of this drop. Concentrating the recourses including staff and equipments to the emergency line will delay the routine line of performing the tests.

Graph 43



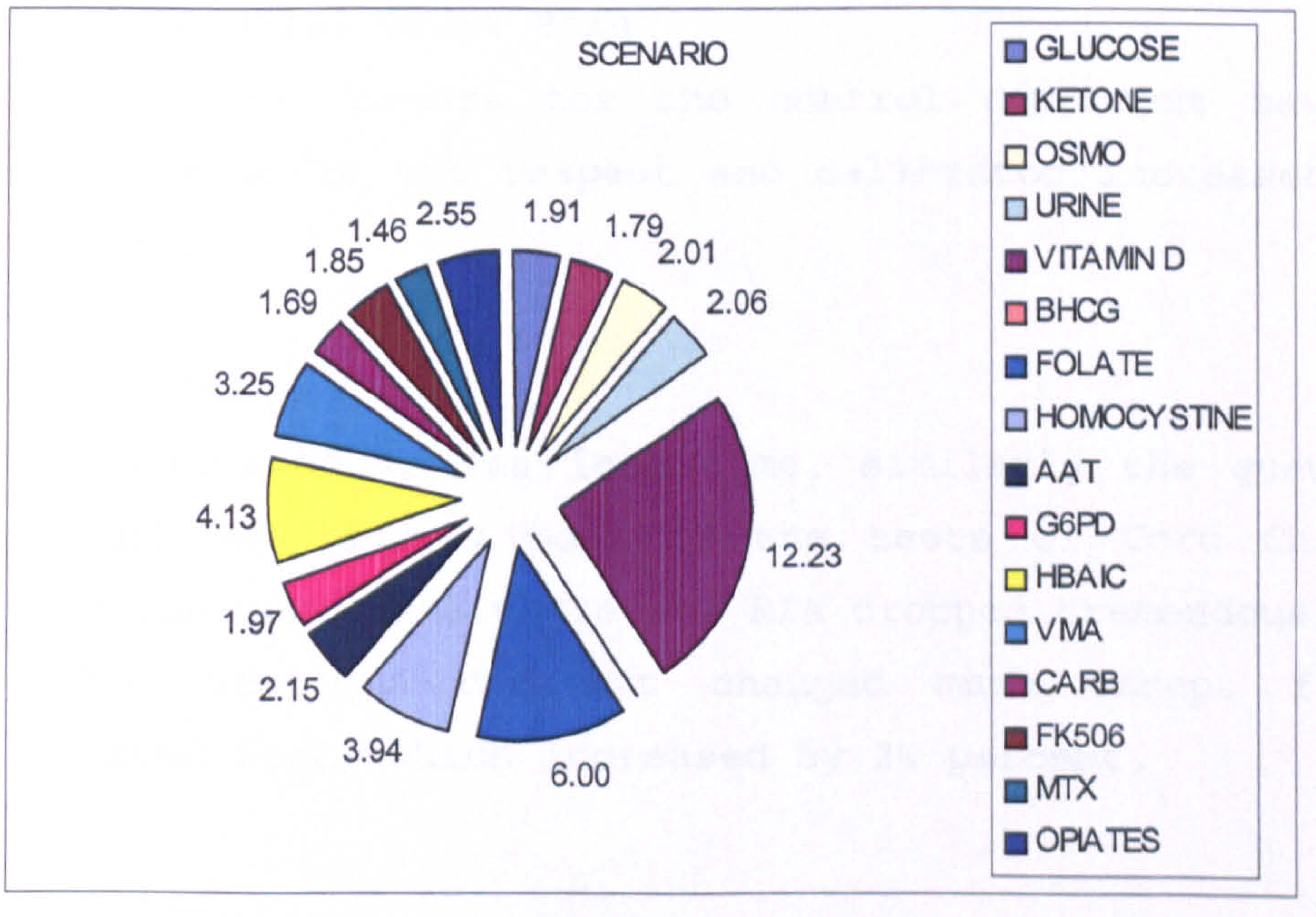
6.1.4 Inventory Status

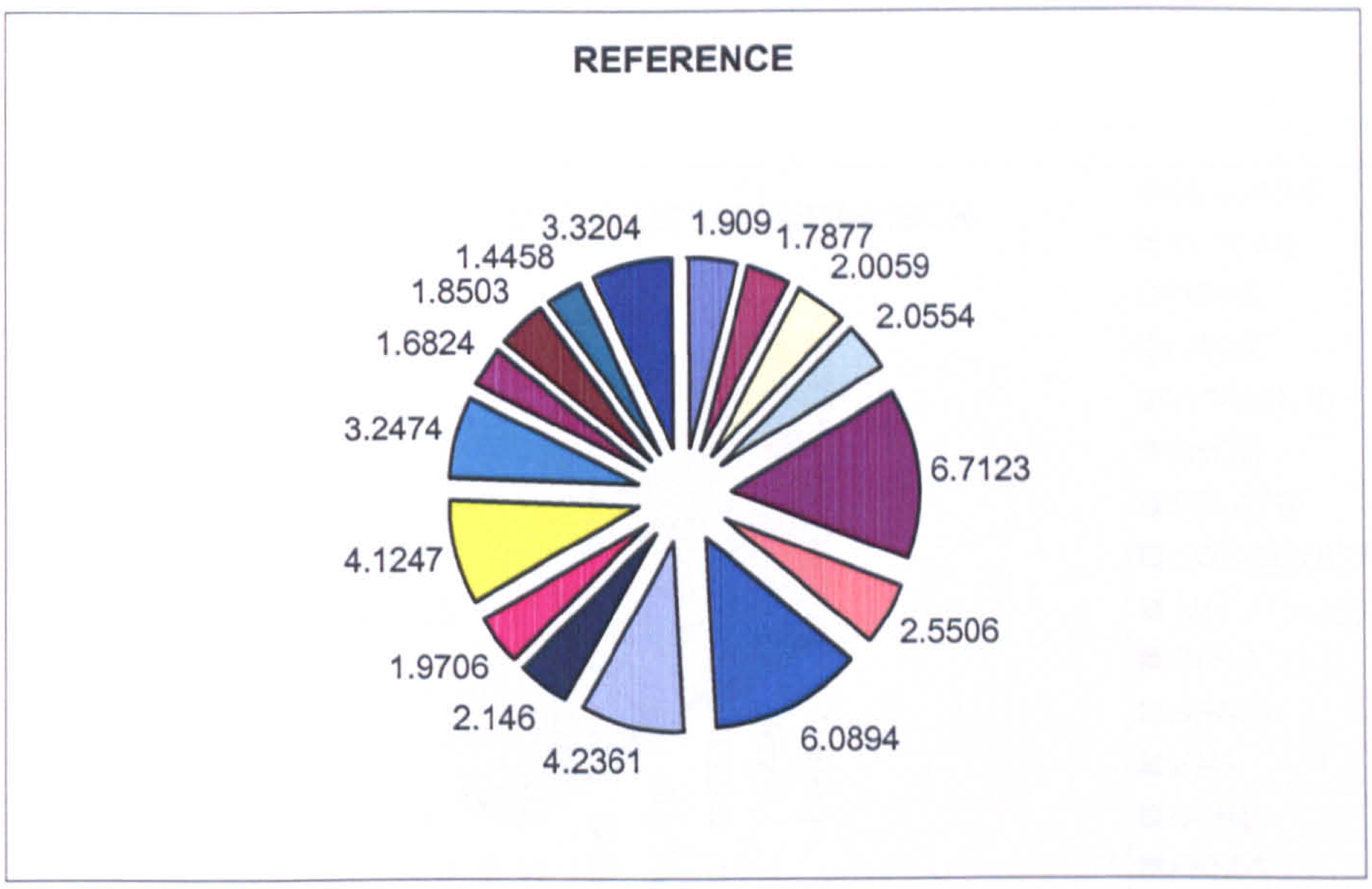
There is not much change in the inventory of all components whether in the Lab or Logistics with the Reference Model.

6.1.6 Cost of Test

The costs of each test are not much different than the Reference Model (Graph 44) because of the staff and resources are still included of the value calculation. It is worth to note, Vitamin D test cost have been increased by double, which may indicate an increasing of emergency cases.

Graph 44





6.2 Secondary Performance Measures

6.2.1 Material Order Size

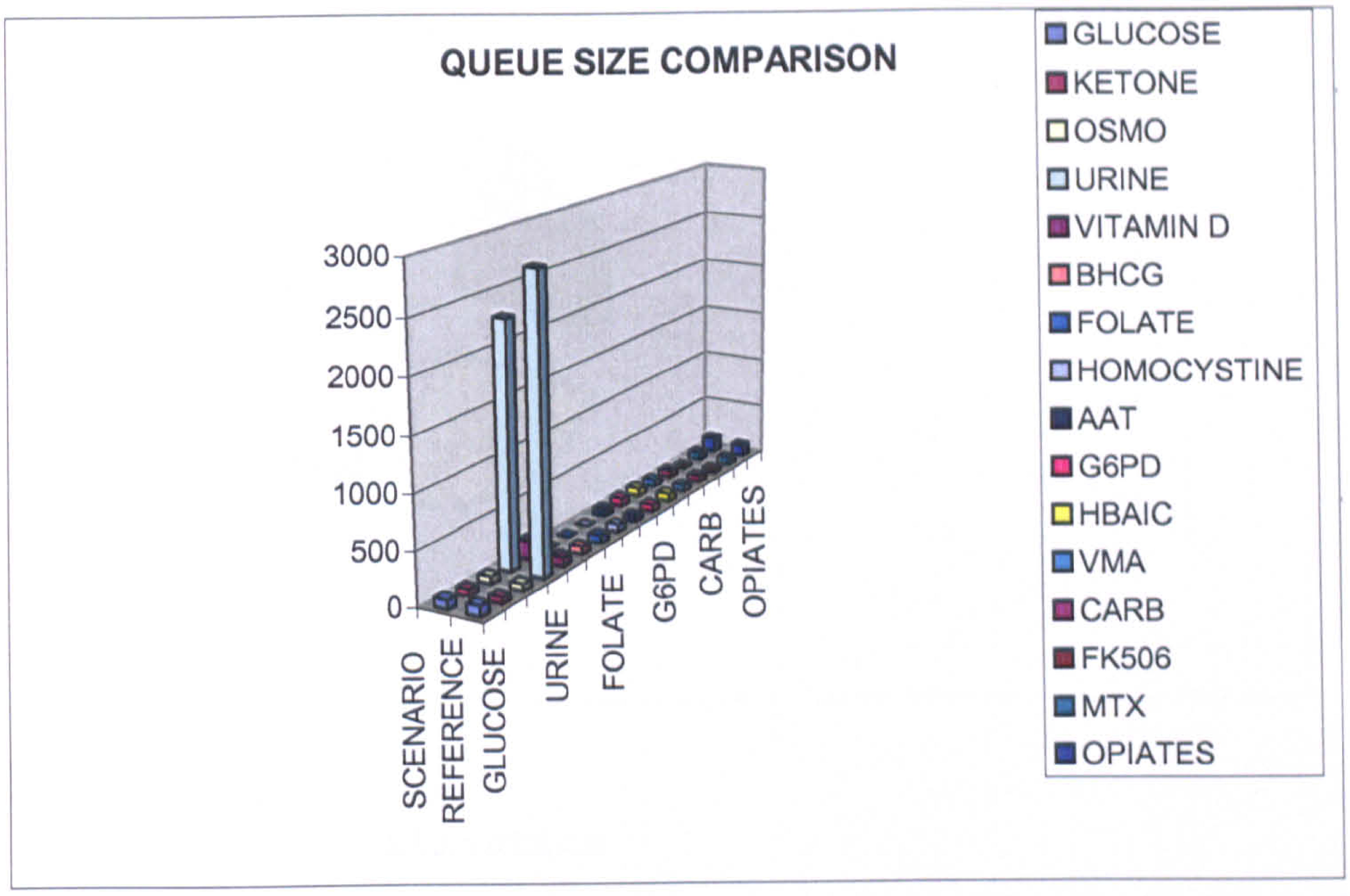
The material orders for the control component have been the same while the reagent and calibrator increased by 10 percent.

6.2.2 Queue Size

As discussed in the lead time, similarly the queue size (Graph 45) show's most of the tests of Core Chemistry section were less while the RIA dropped tremendously. The other sections did not changed much except for the Opiates test, which increased by 25 percent.

Graph 45

Queue size

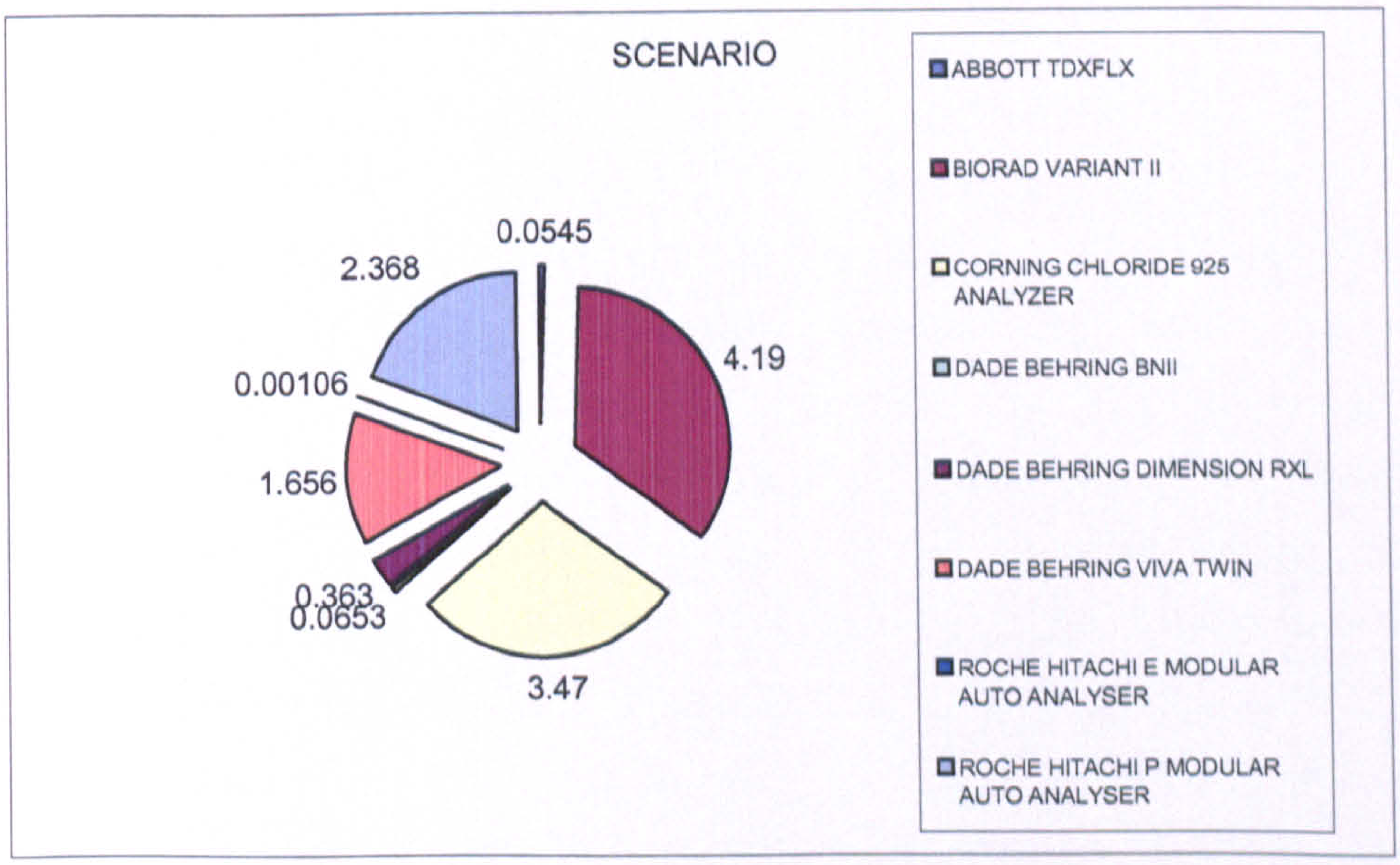


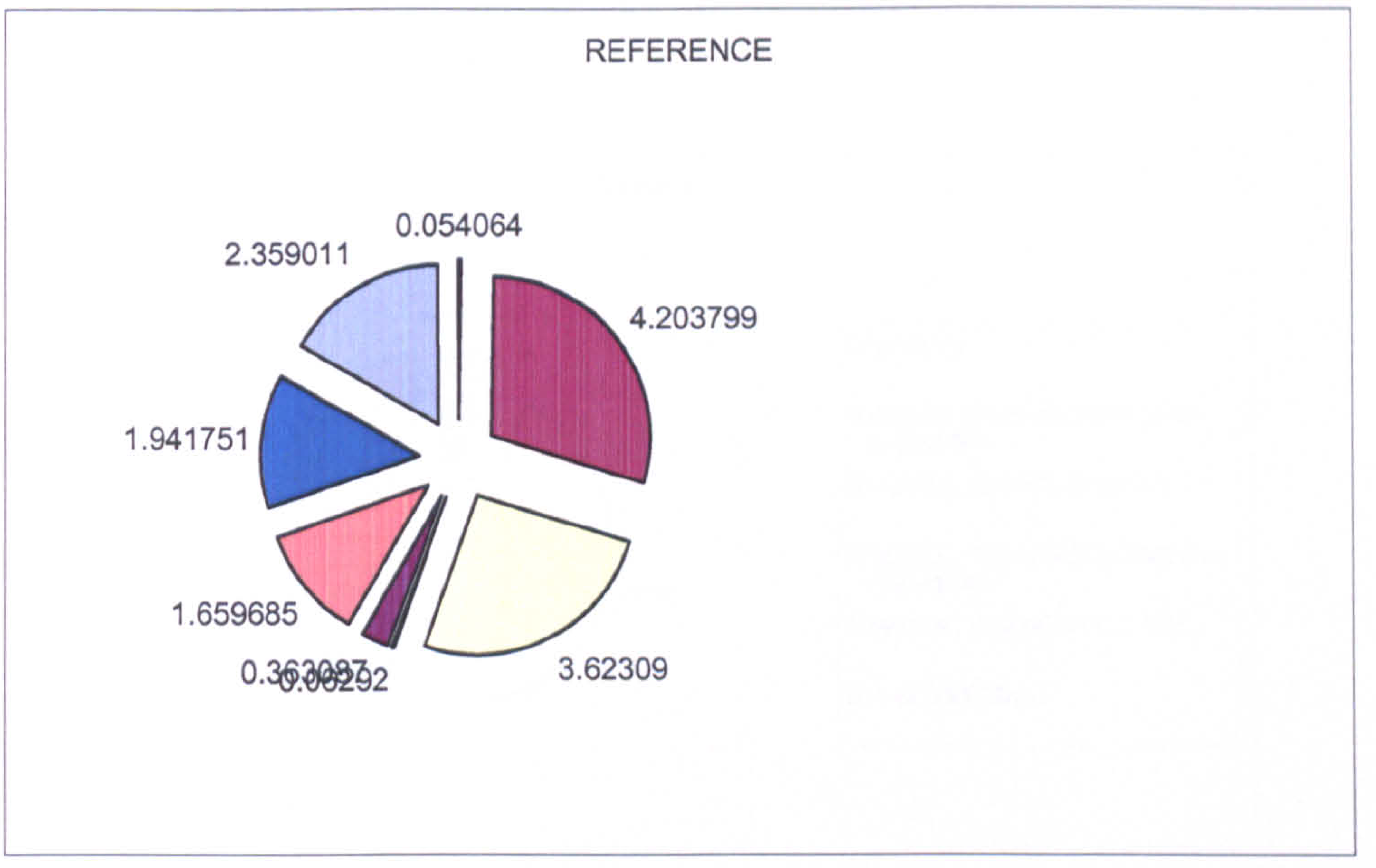
6.2.3 Equipment Utilization

The utilization has been the same except for the Roche Hitachi E modular Auto Analyzer which decrease to the minimum. (Graph 46)

Graph 46

Equipment utilization %



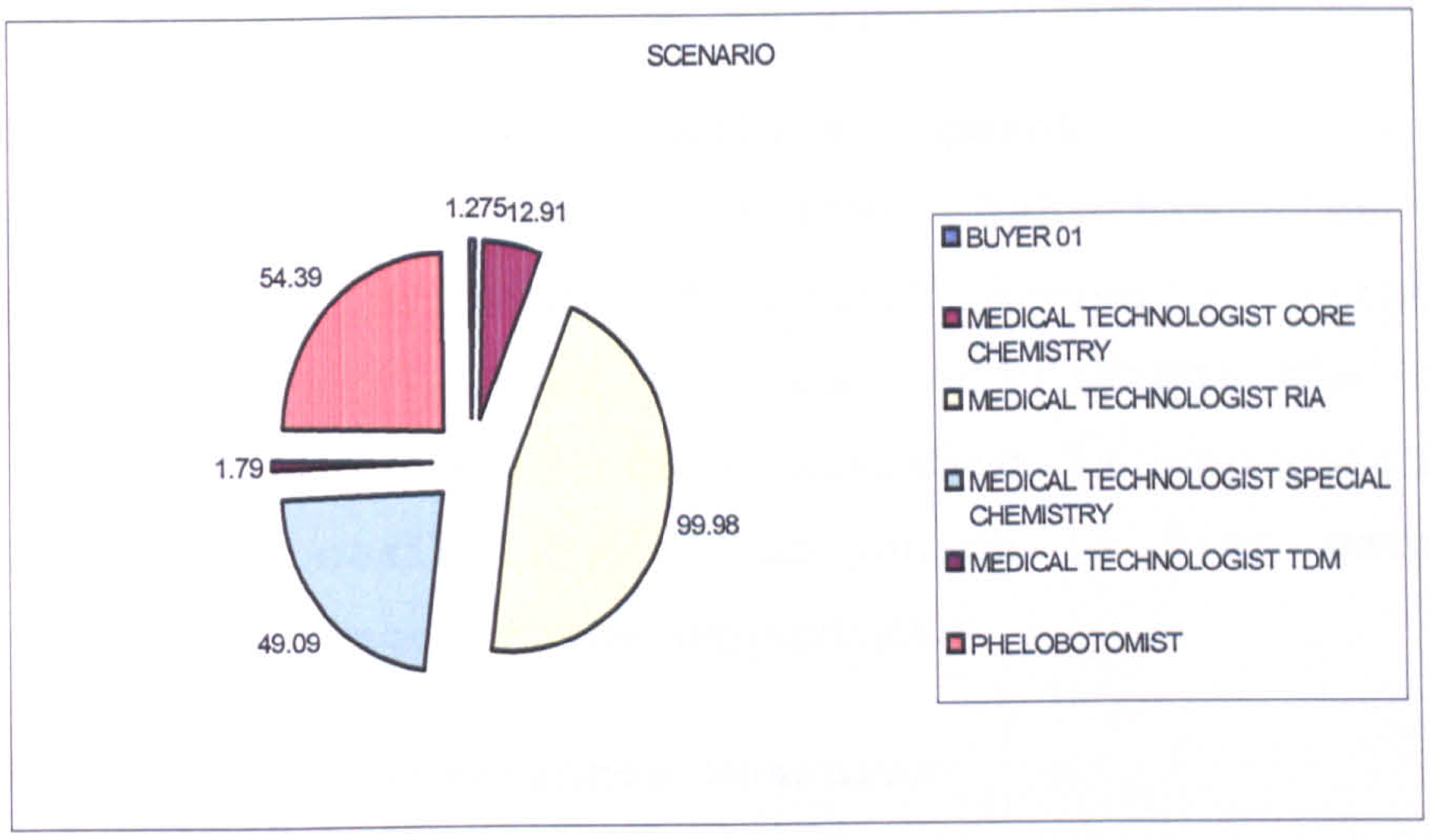


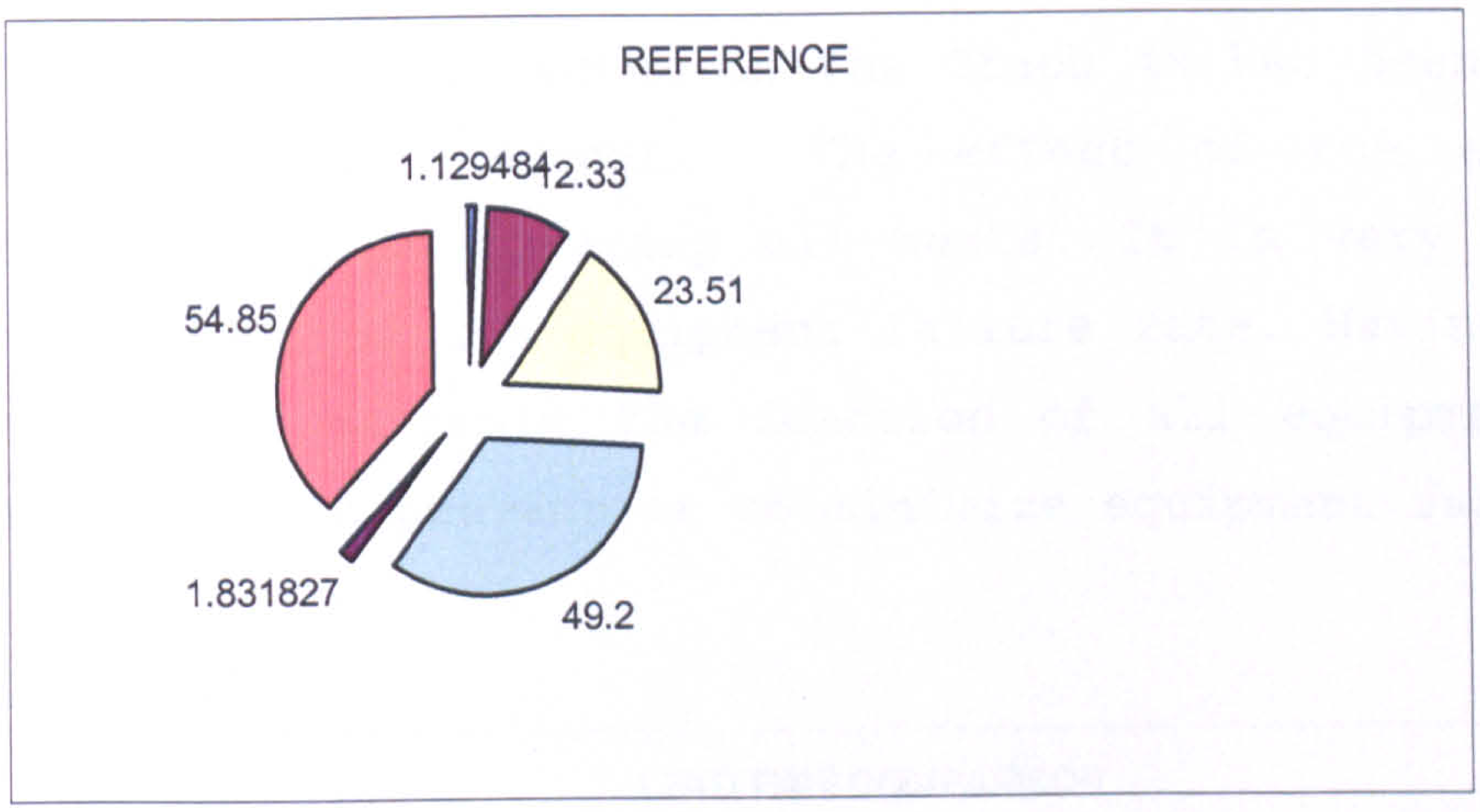
6.2.4 Staff Utilization

The staff utilization is lower than the Reference Model (Graph 47) except for the Medical Technology RIA, which increased to the maximum, showing the unbalance of staffing distribution.

Graph 47

Staff utilization %





6.3 Conclusion

This scenario is very important for some cases like emergency or VIP samples, which need faster process as well as quality of work. To have this kind of service needs more investment of recourses like new employee and new equipment and necessary space. If not one of the requirements is available, the service can provide but it will hinder the other line of service, which is the routine or normal line. The effect of the emergency line was longer lead-time as shown in the lead-time table. Likewise, WIP is very high while the utilization of staff and equipment are the same. It is important to measure the outcome before changing the setup of the chemistry

Lab, because the effect is not only to a certain test path but it will effect the entire lab operation as showing in the previous performance measures.

7. Scenario Ten: Unreliable Equipment

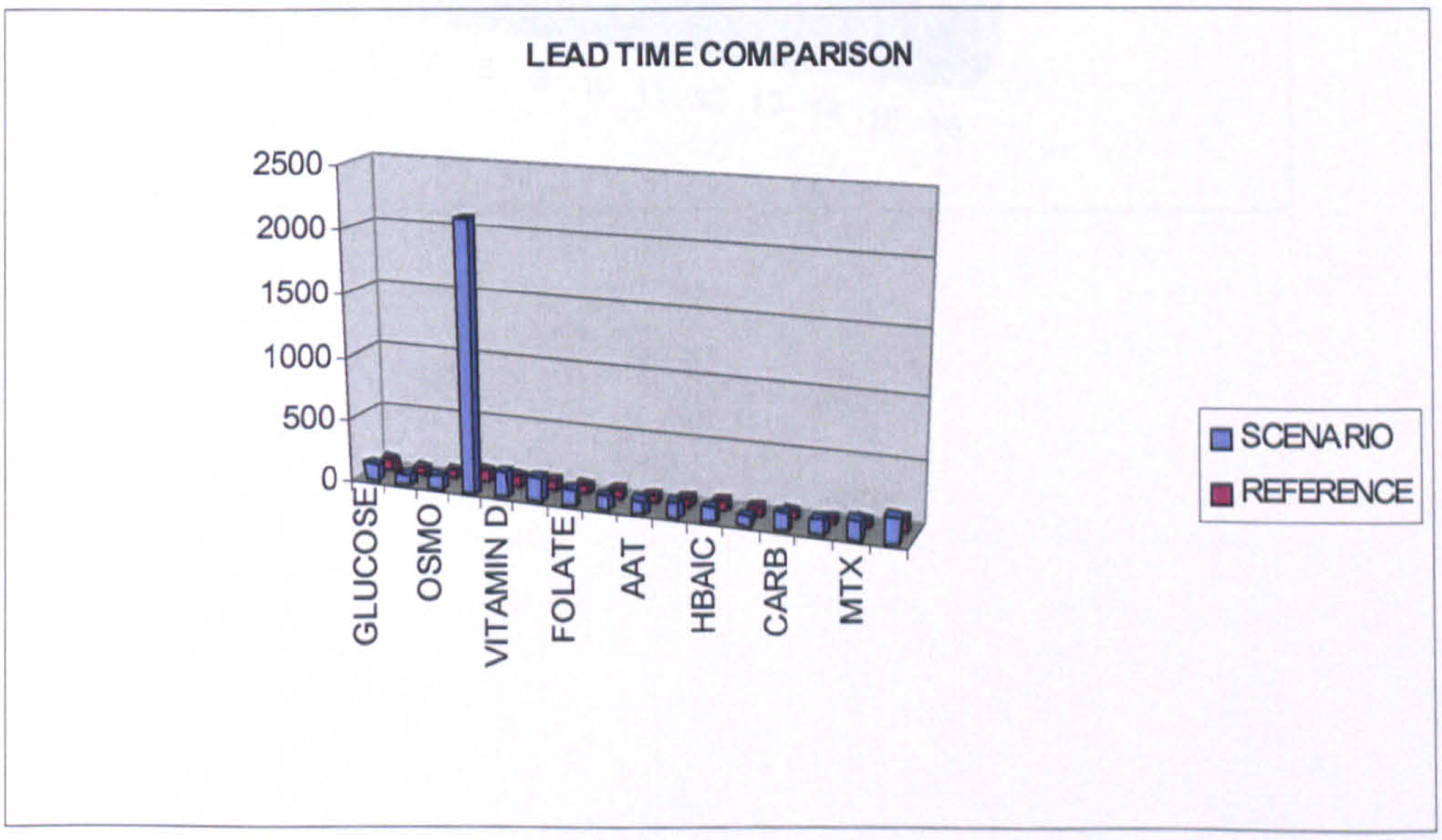
Equipments in the Chemistry lab are the essential resources, can not function properly without them. Therefore any effect to them will change the outcome of the Lab in general. This scenario is unpredicted in the lab; the possibility of happening is high parallel with the heavy usage of the equipments.

7.1 Primary Performance Measures

7.1.1 Lead Time

The lead time as shown in the Graph 48 had been increased by 50 to 90 percent. The effect of the equipment's reliability is covering all tests. It is very noticeable the effect of the equipment failure rate. Having a proper system to maintain the function of all equipments is an essential to prevent or to minimize equipment failure.

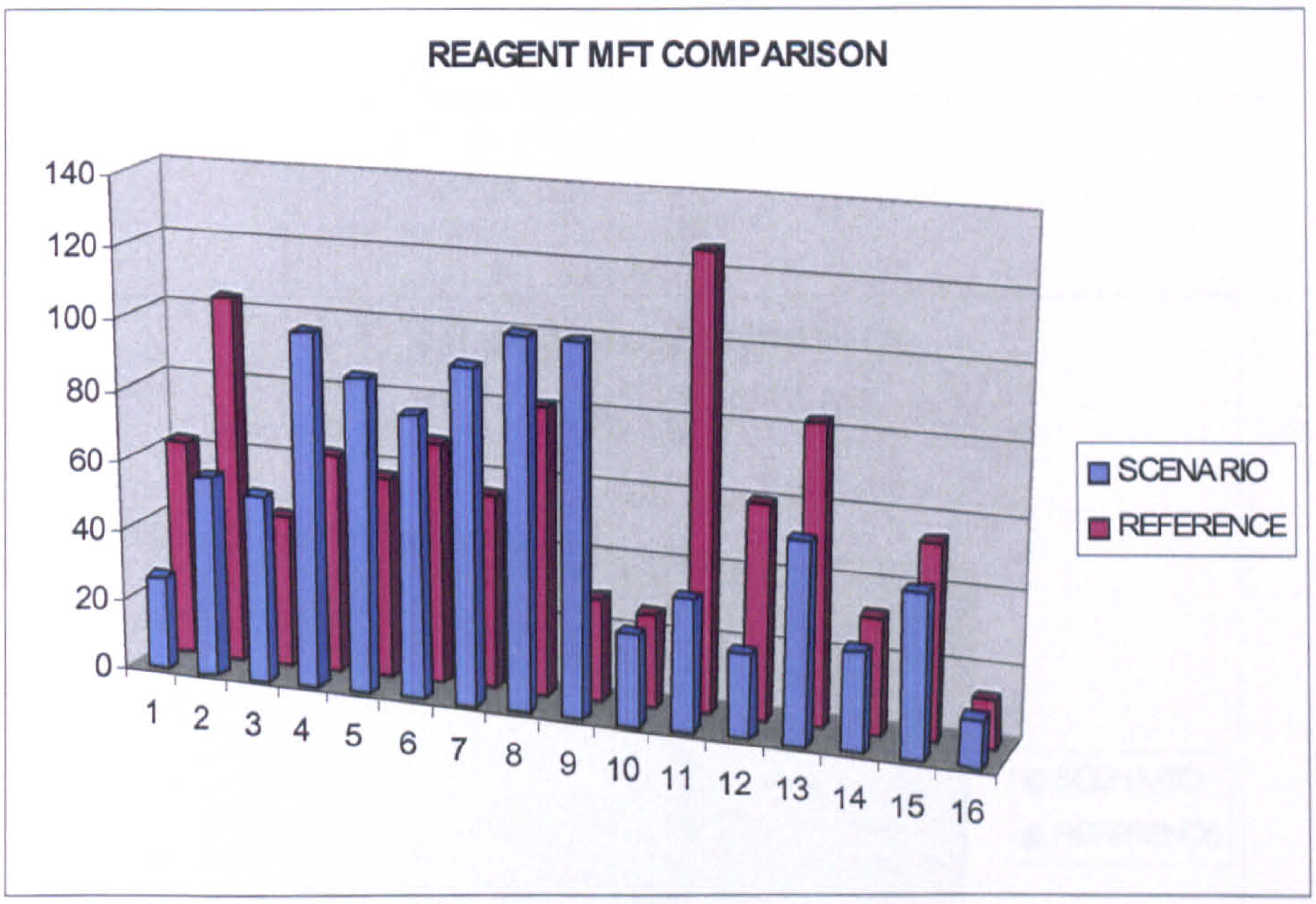
Graph 48

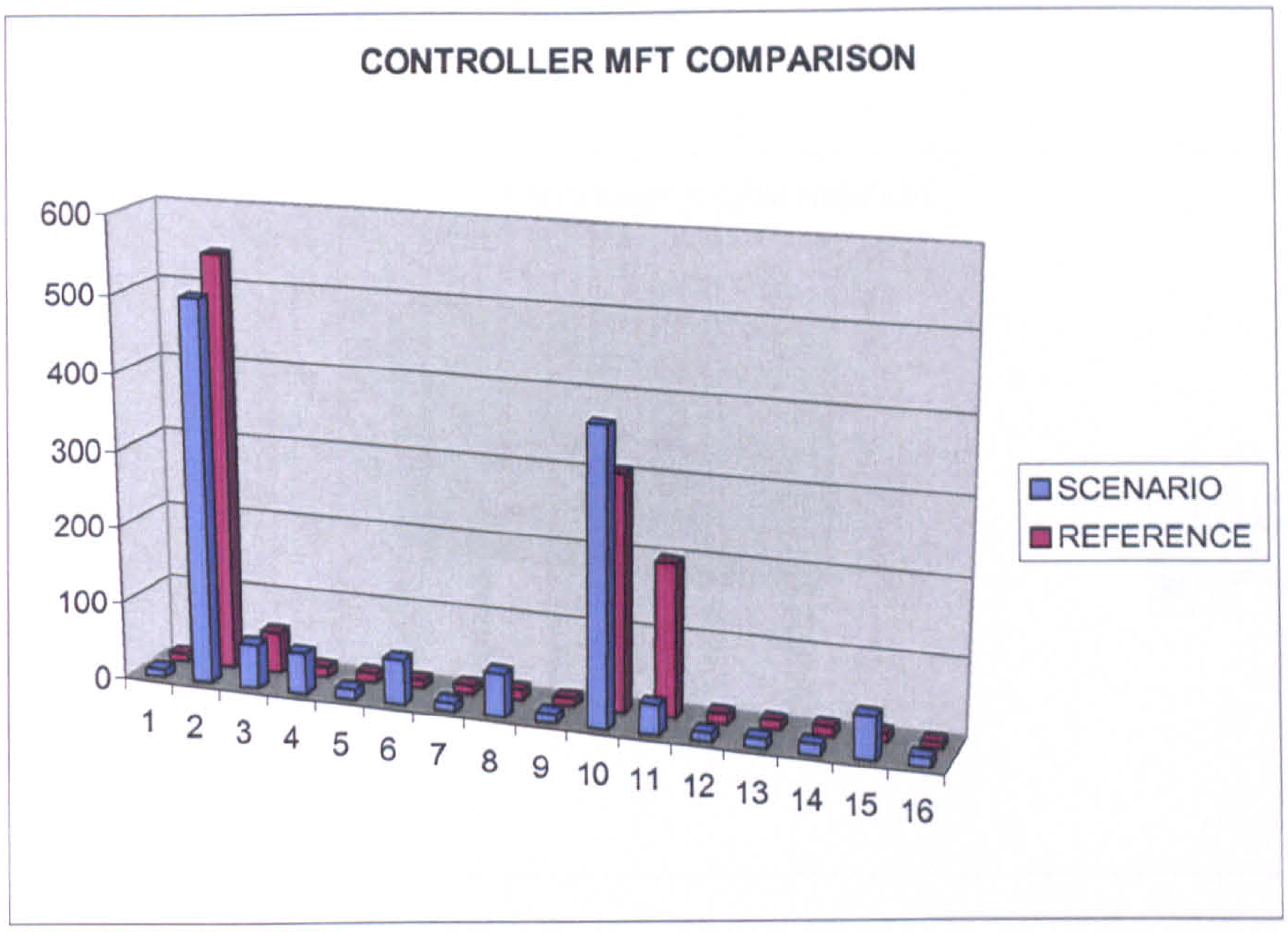


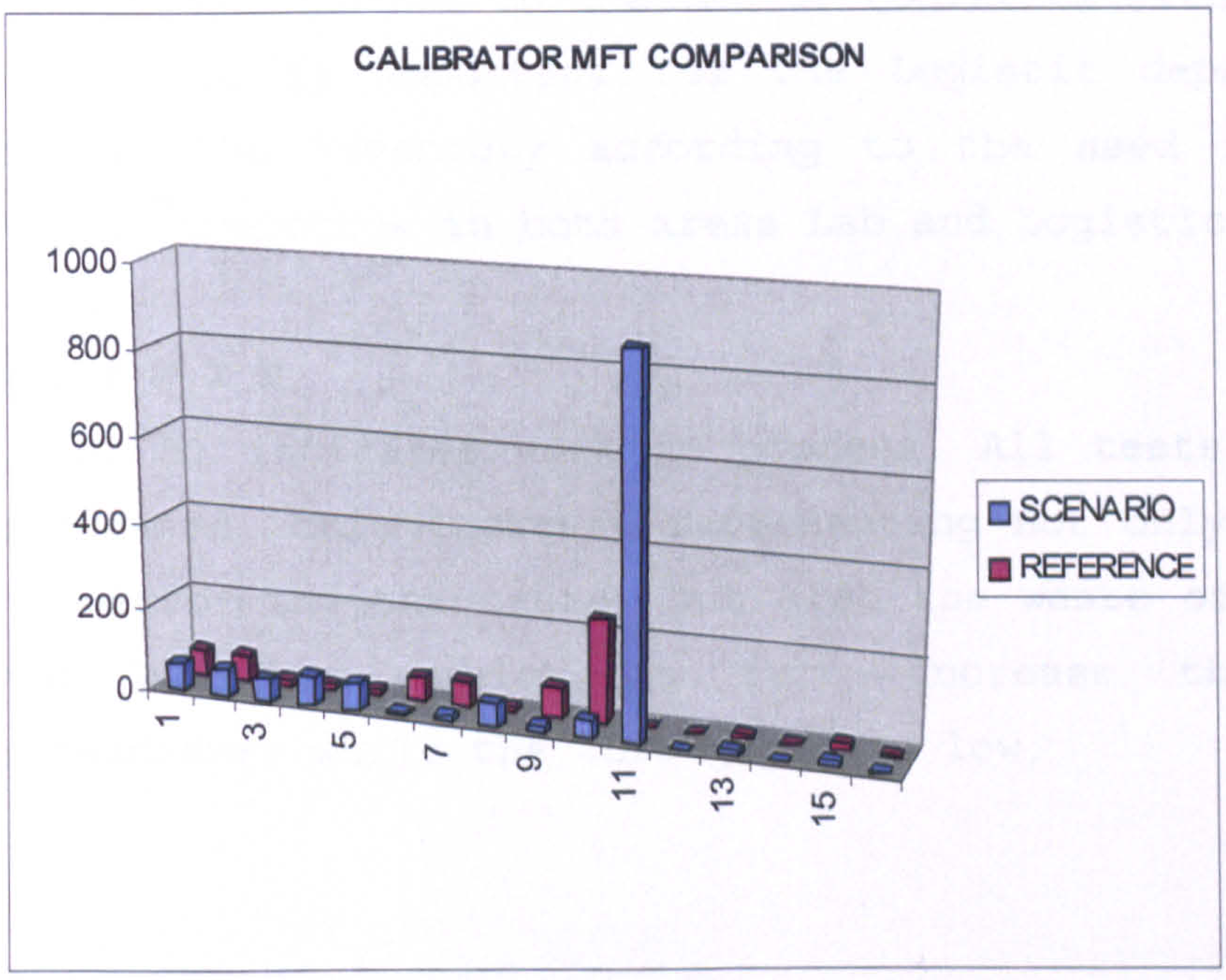
7.1.2 Material Flow time

All tests are affected by the unreliability of equipment. Half of them increased while the other decreased, it is according to the equipment utilization of the materials, as the equipment breakdown the flow of material were delayed comparing with other equipment which working normally the flow of materials will be faster. As illustrated in Graph 49, which consist of reagent, calibrator, and controller.

Graph 49



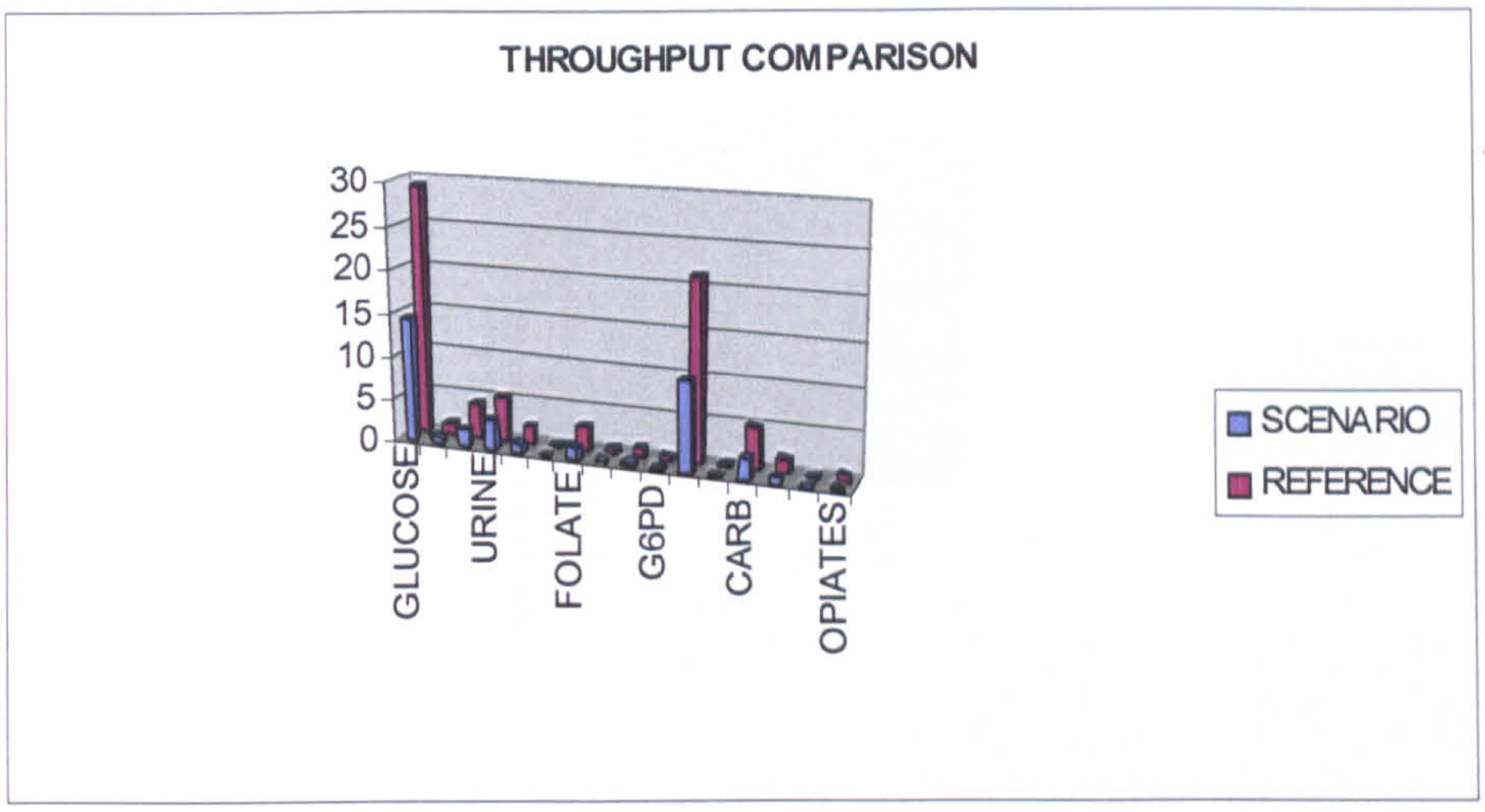




7.1.3 Throughput

Throughput of the test as indicated in the Graph 50 was effected negatively by the equipments break down. Which is expected? The percentage of outcome will depend on the failure rate of the chemistry lab equipments.

Graph 50



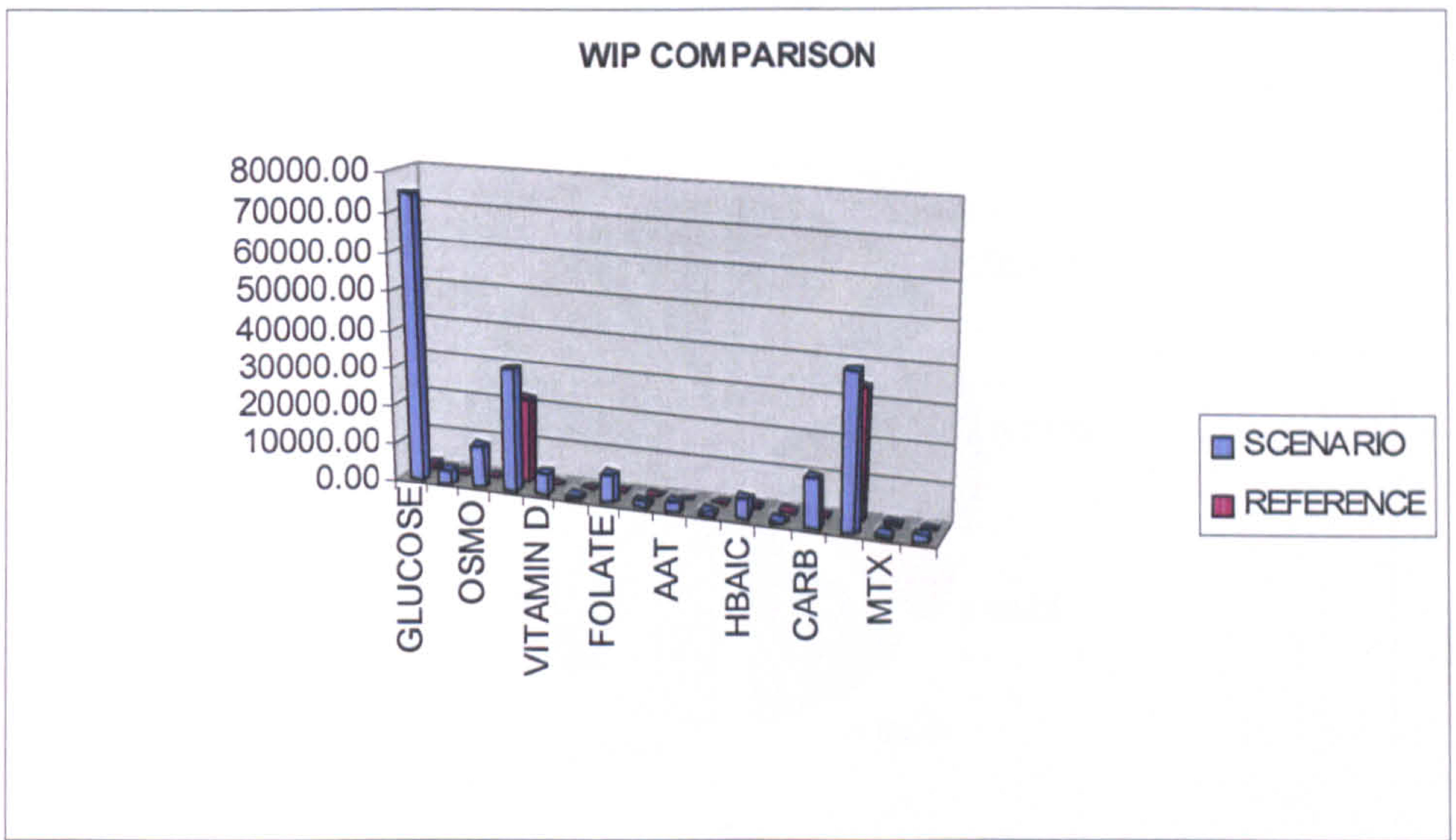
7.1.4 Inventory Status

There is not much change in the inventory of all components whether in the Lab or Logistics with Reference Model. It is important for the Logistic department to adjust the inventory according to the need instead of having overstock in both areas Lab and Logistic.

7.1.5 W I P

Graph 51 indicates work in process. All tests have been increased, this increase representing not only the delay of performing the tests, but also the waste of resources and supplies, which in turn increase the overall expenditure while the throughput is low.

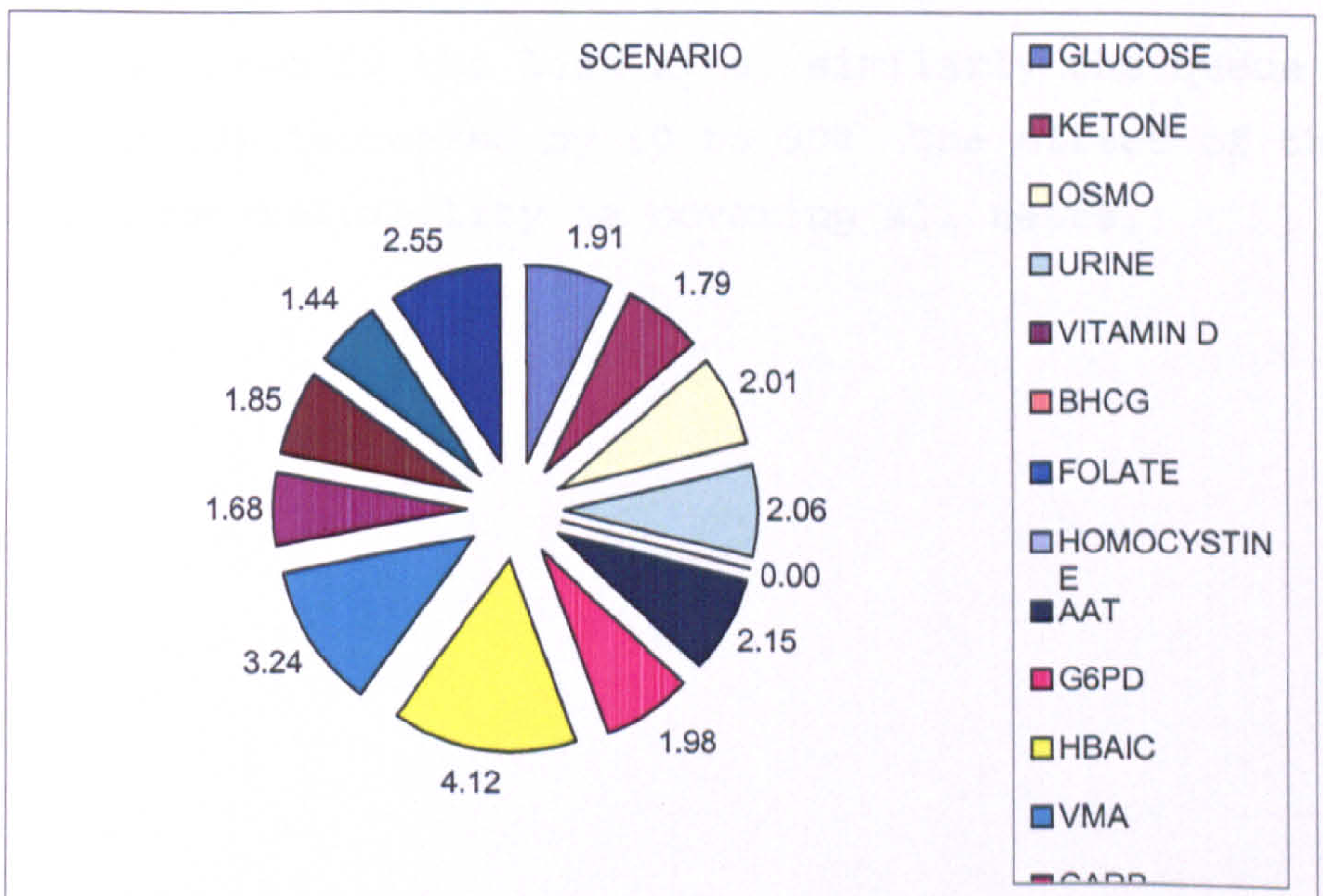
Graph 51

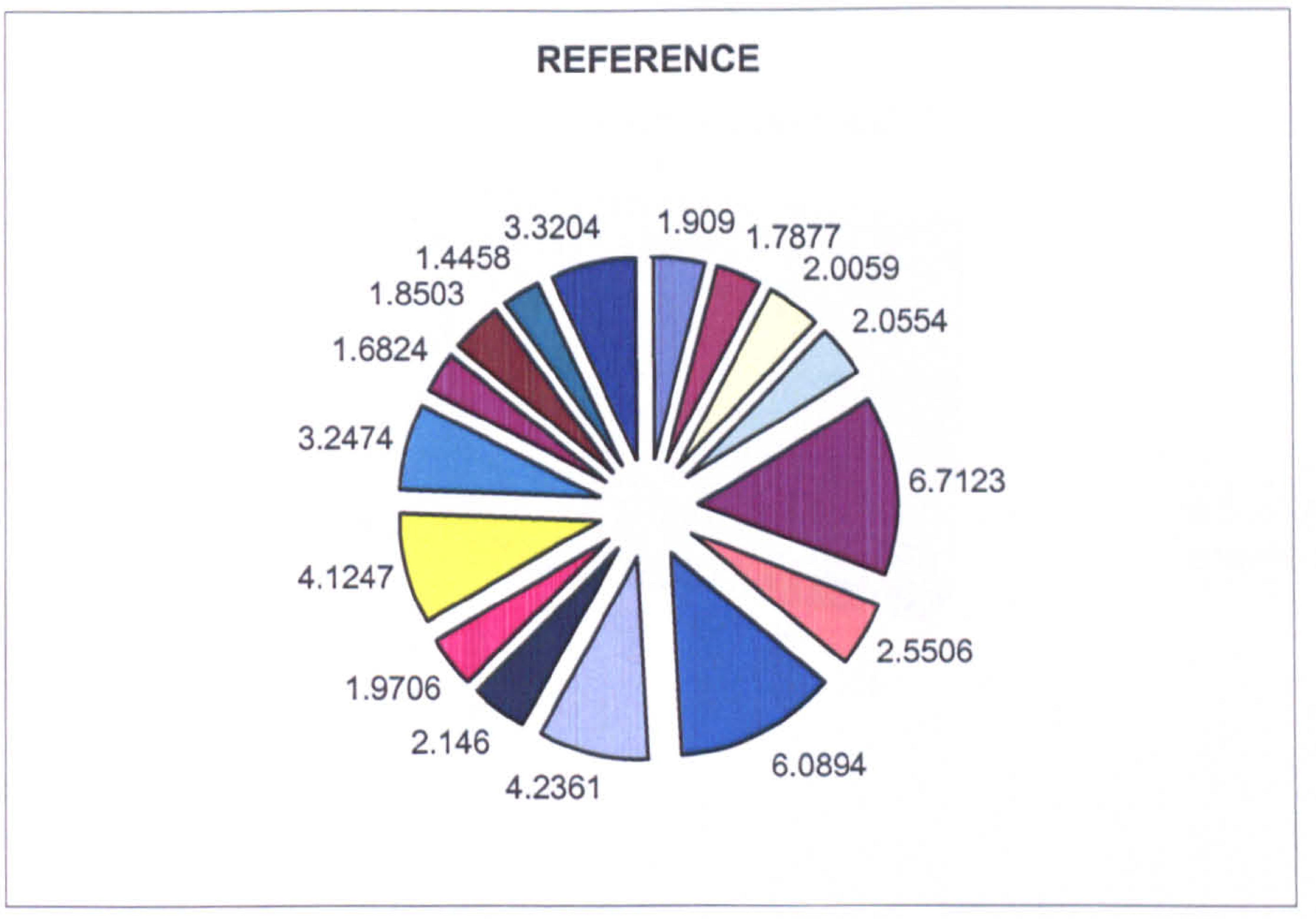


7.1.6 Cost of Test

The costs of each test are not much different than the Reference Model (Graph 52) because of the staff and resources are still included in the calculation the tests value. The RIA section has not represented the calculation of their cost. The time spent to perform the test related to the functionality of the equipment. The total cost should be covering all expenses including equipment failure.

Graph 52





7.2 Secondary Performance Measures

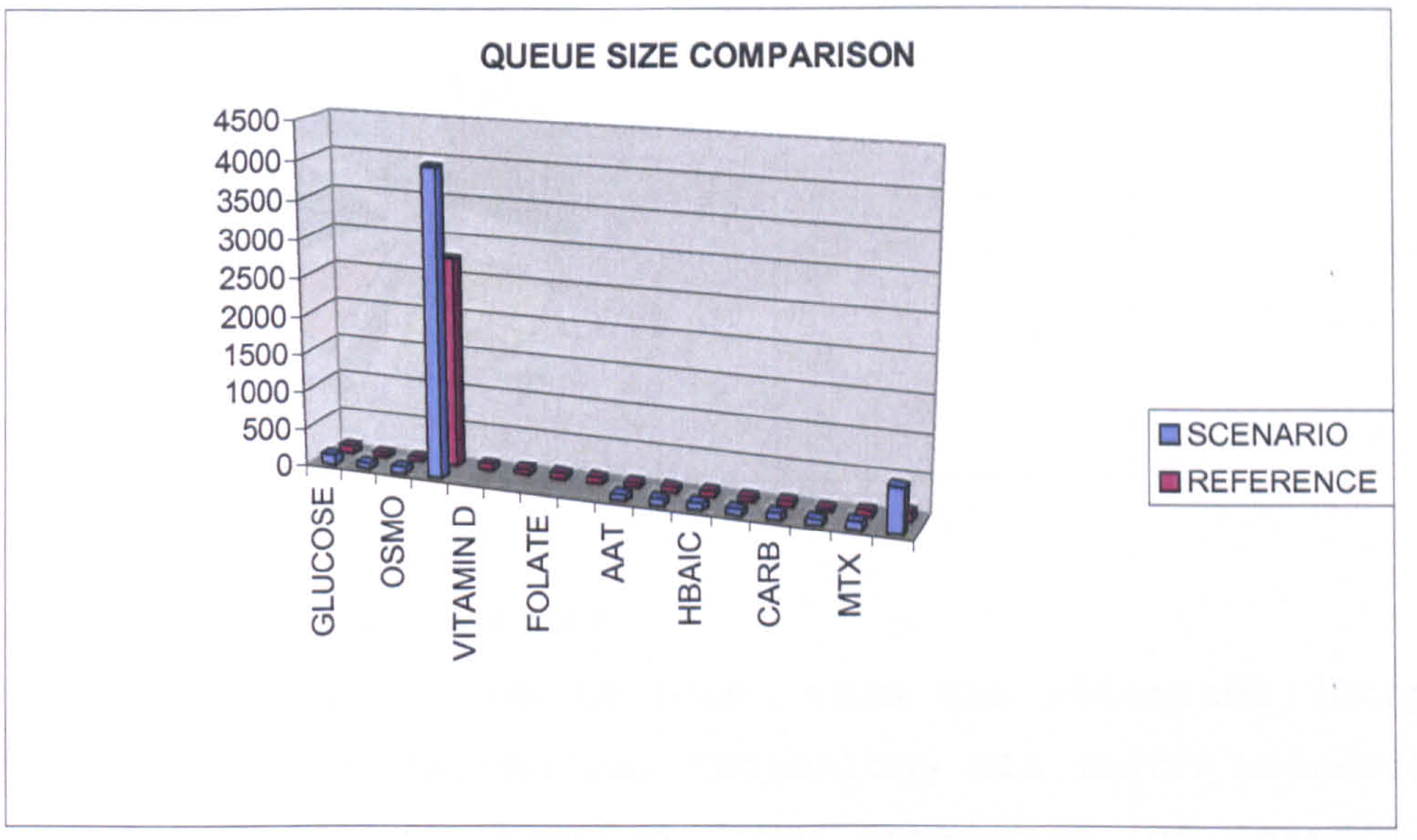
7.2.1 Material Order Size

The orders for reagent and control materials were increased by 20 to 30 percent while calibrator by 5 percent. This is an indication of mismanagement of the supplies, as we have unreliable equipment the Lab and Logistic ordering more materials which will be an over stock.

7.2.2 Queue Size

As discussed in the lead-time, similarly the queue size (Graph 53) increased by 50 to 90%. The effect of the equipment reliability is covering all tests.

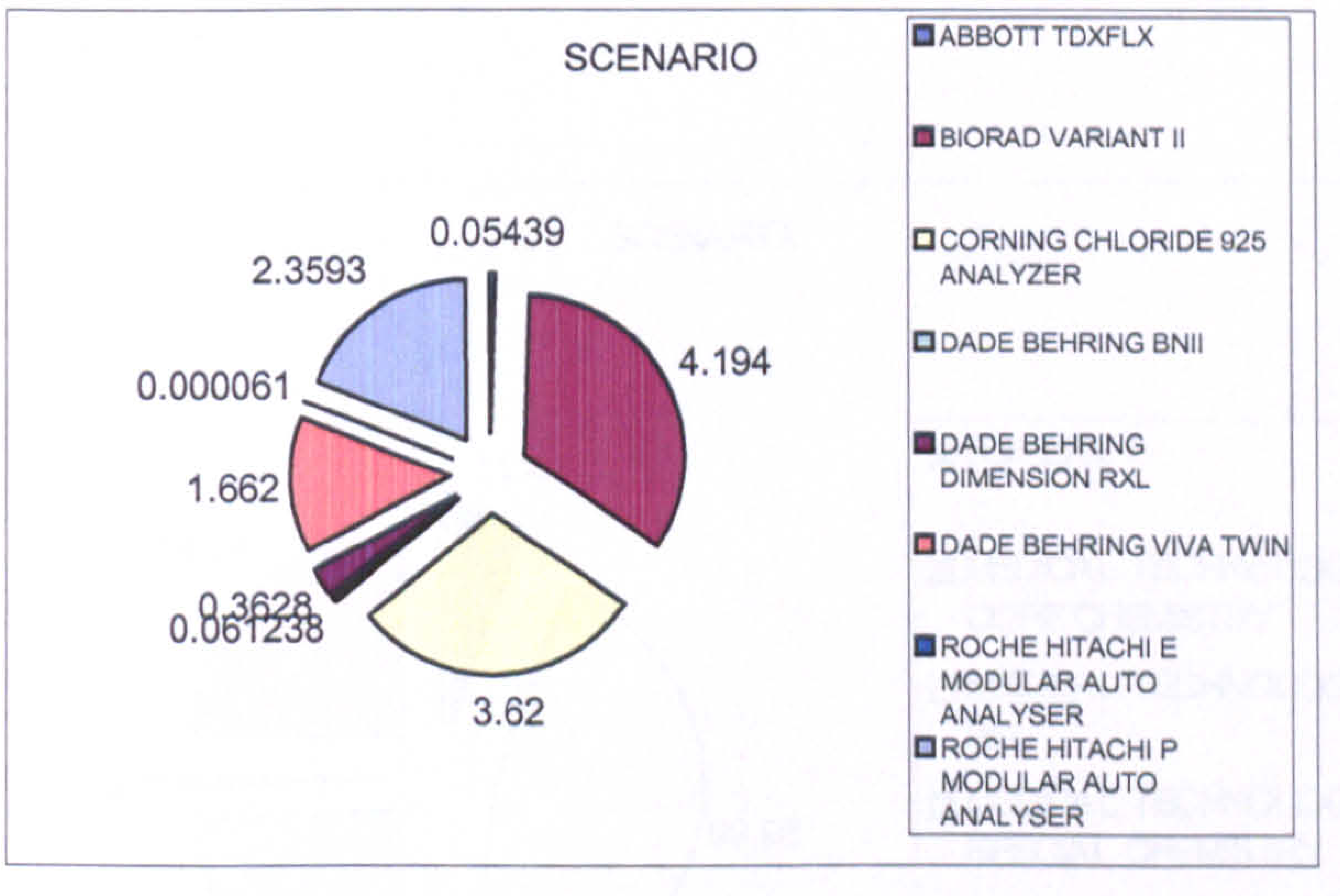
Graph 53

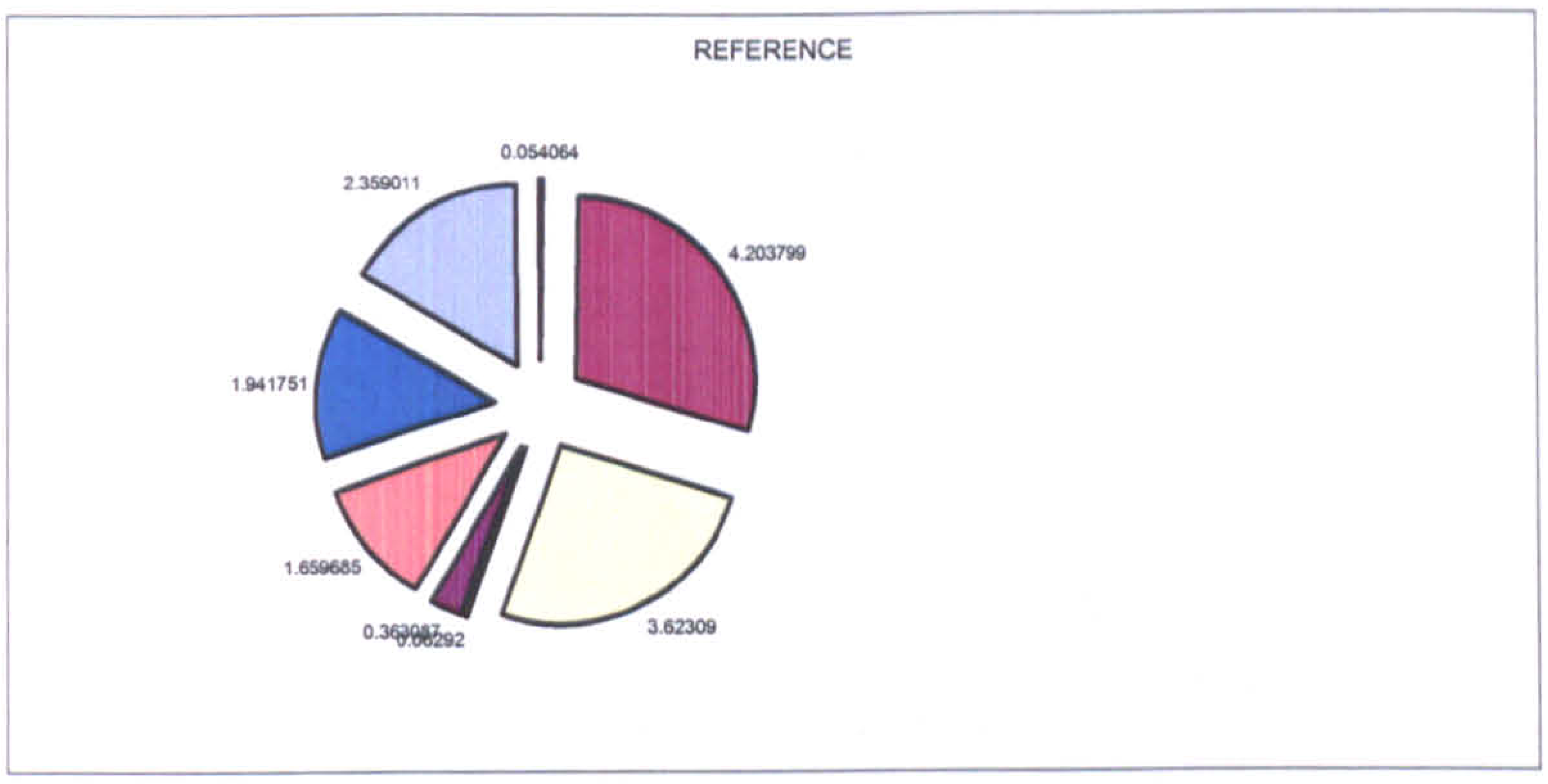


7.2.3 Equipment Utilization

The equipment utilization has been the same with only a drop in the Roche E Analyzer. (Graph 54)

Graph 54

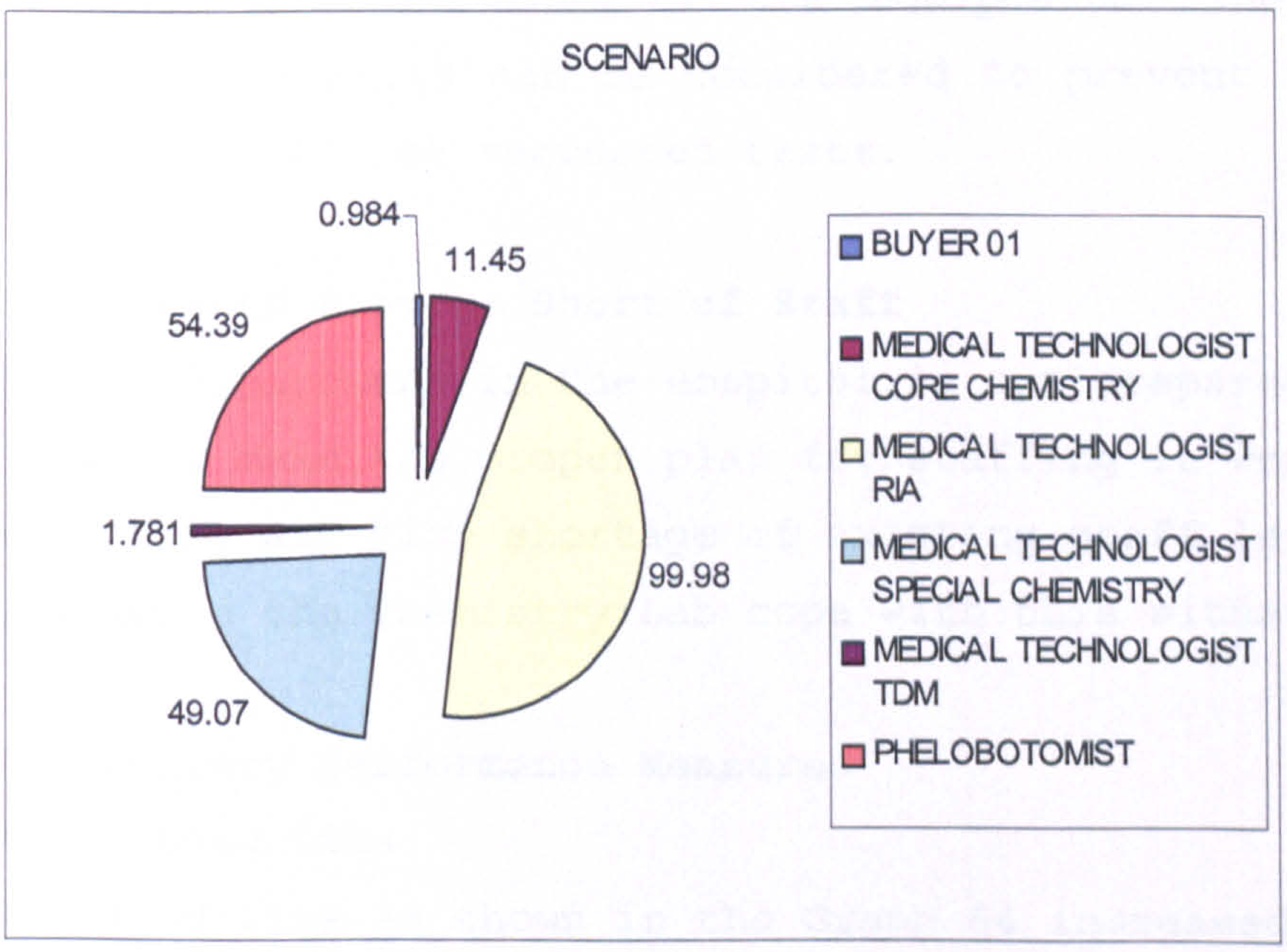


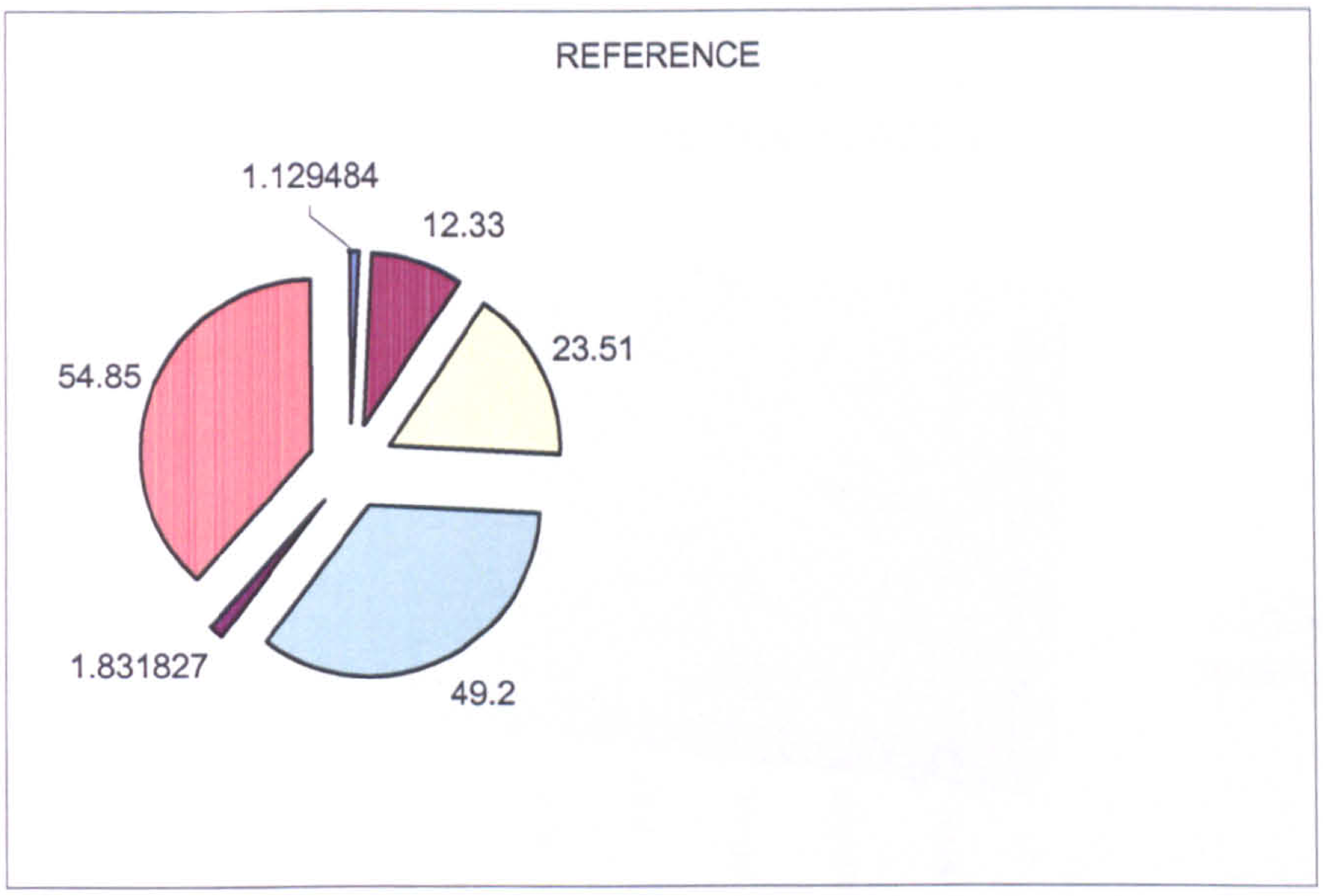


7.2.4 Staff Utilization

The staff utilization is lower than the reference (Graph 55) except for the Medical Technology RIA which increased to the maximum, showing the unbalance of staffing distribution. Another reason for this would be the interruption in the equipment availability. During equipment downtime and repair time workers have no choice but wait until the machine becomes up and running, which in turn causes the low utilization of the staff.

Graph 55





7.3 Conclusion

The lead time increased by 70-100% and throughput decreased for all tests while the WIP increased tremendously. There is not much change in the inventory but the utilization of staff remained low. The effect of the equipment's reliability is very high. The hospital should make necessary steps to prevent or at least minimize any breakdown of the equipments. The plan to have backup units can be considered to prevent any delay of performing the requested tests.

8. Scenario Eleven: Short of Staff

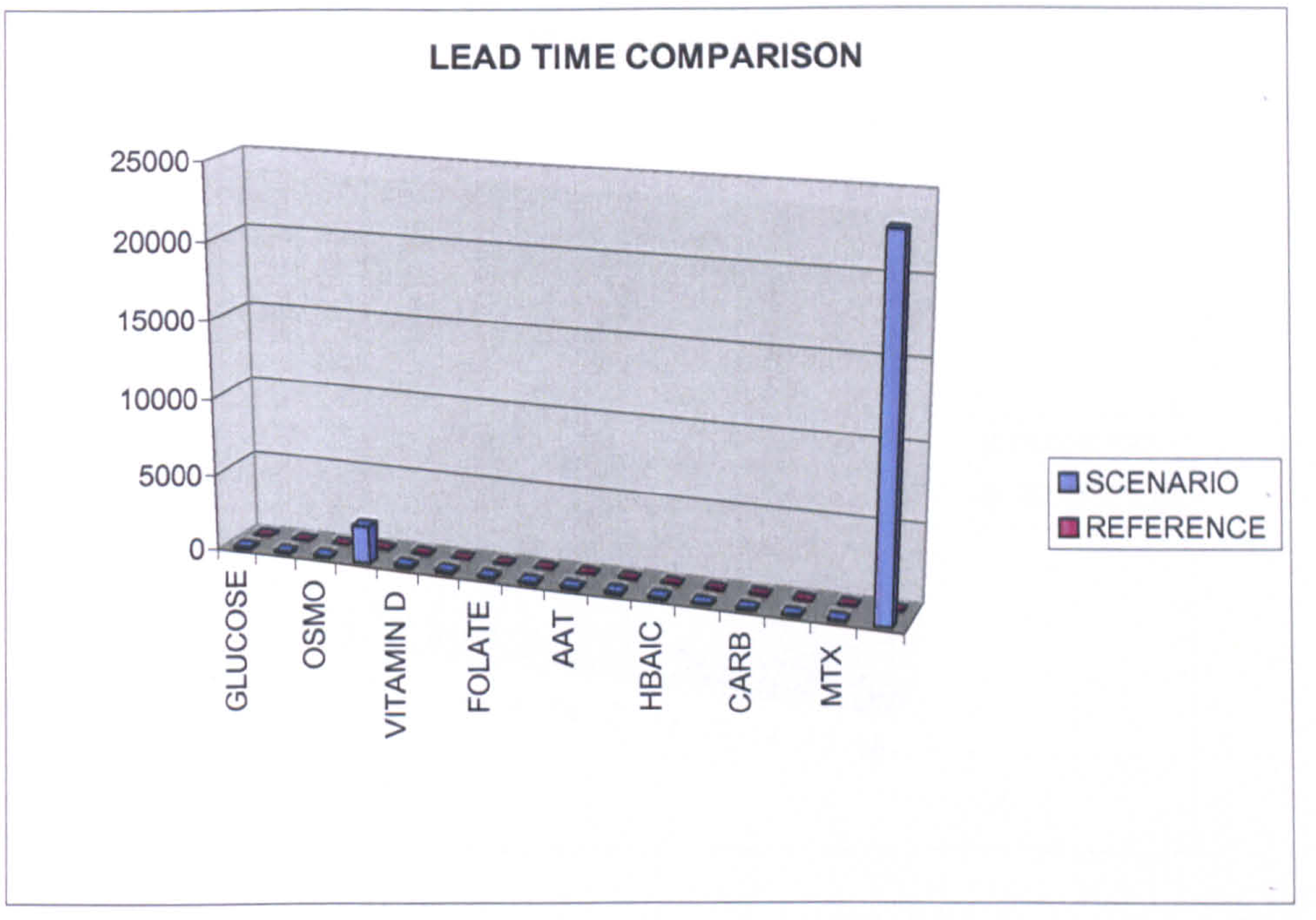
If any department in the Hospital is not prepared and does not make the proper plan for staffing it would effect by any time shortage of existing staff levels. How would the Chemistry Lab cope with this situation?

8.1 Primary Performance Measures

8.1.1 Lead Time

The lead time as shown in the Graph 56 increased by 50 to 90% and also tremendously high in the OPIATES test. The staff effect to the overall outcome is very noticeable after the material shortage.

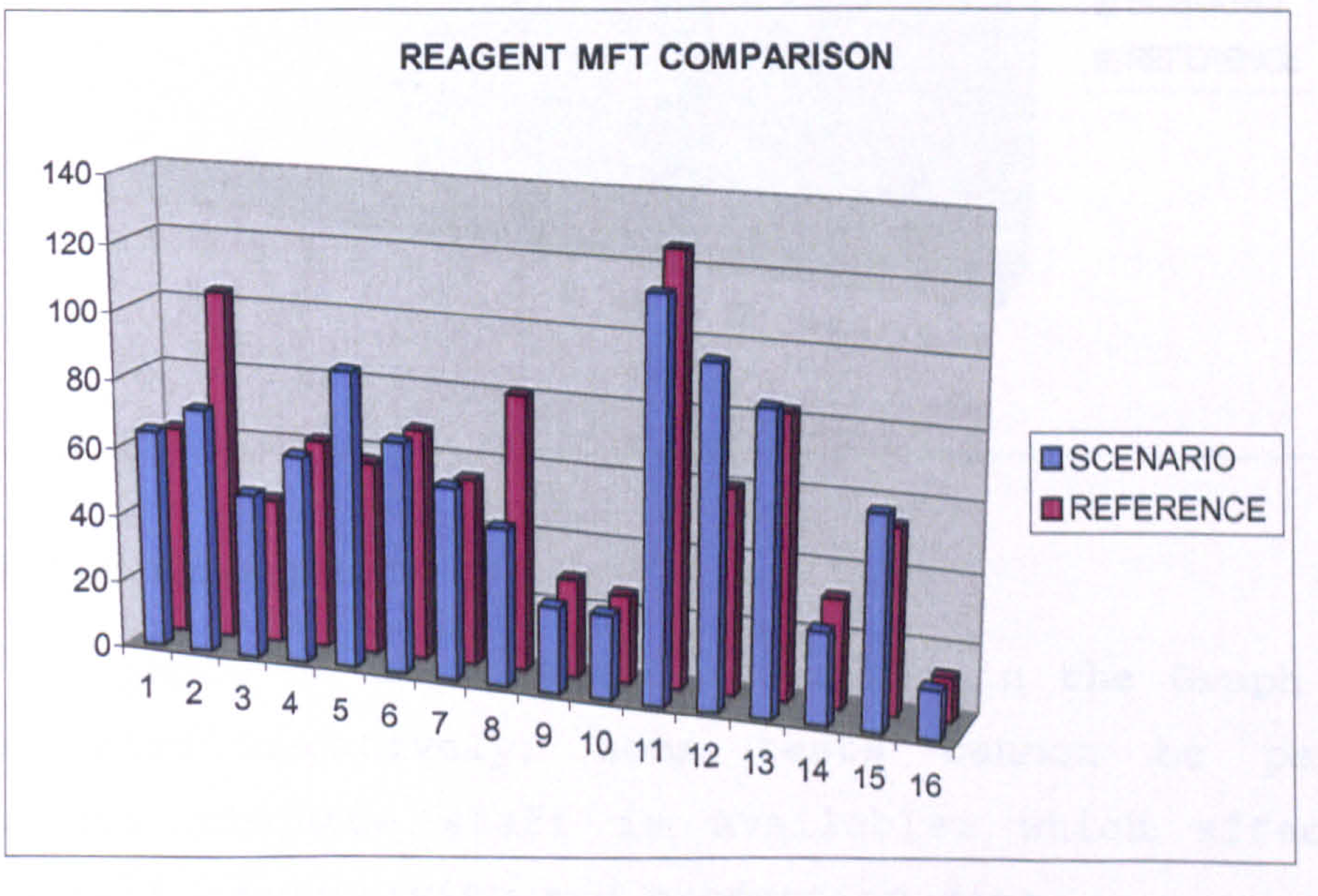
Graph 56

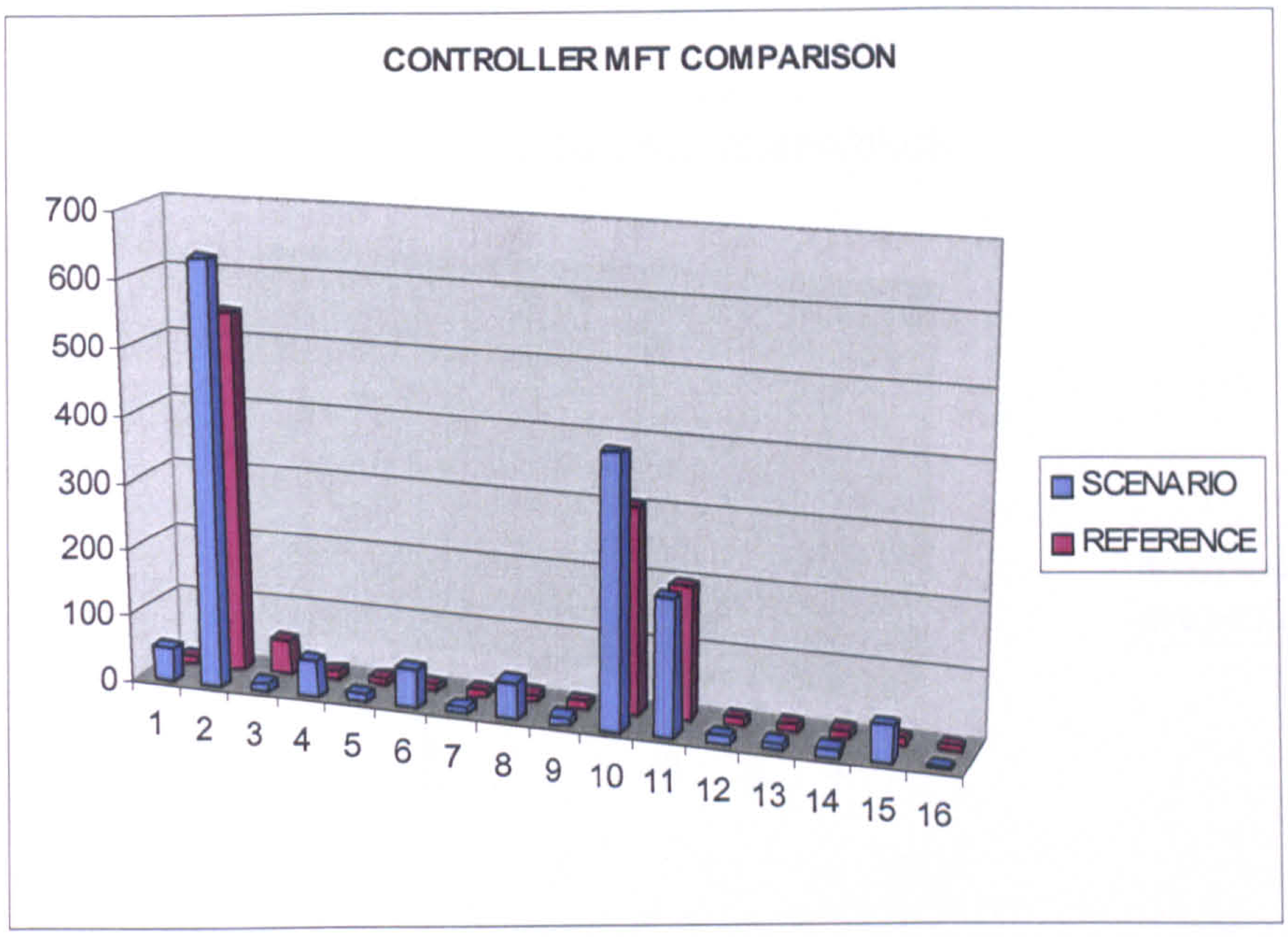


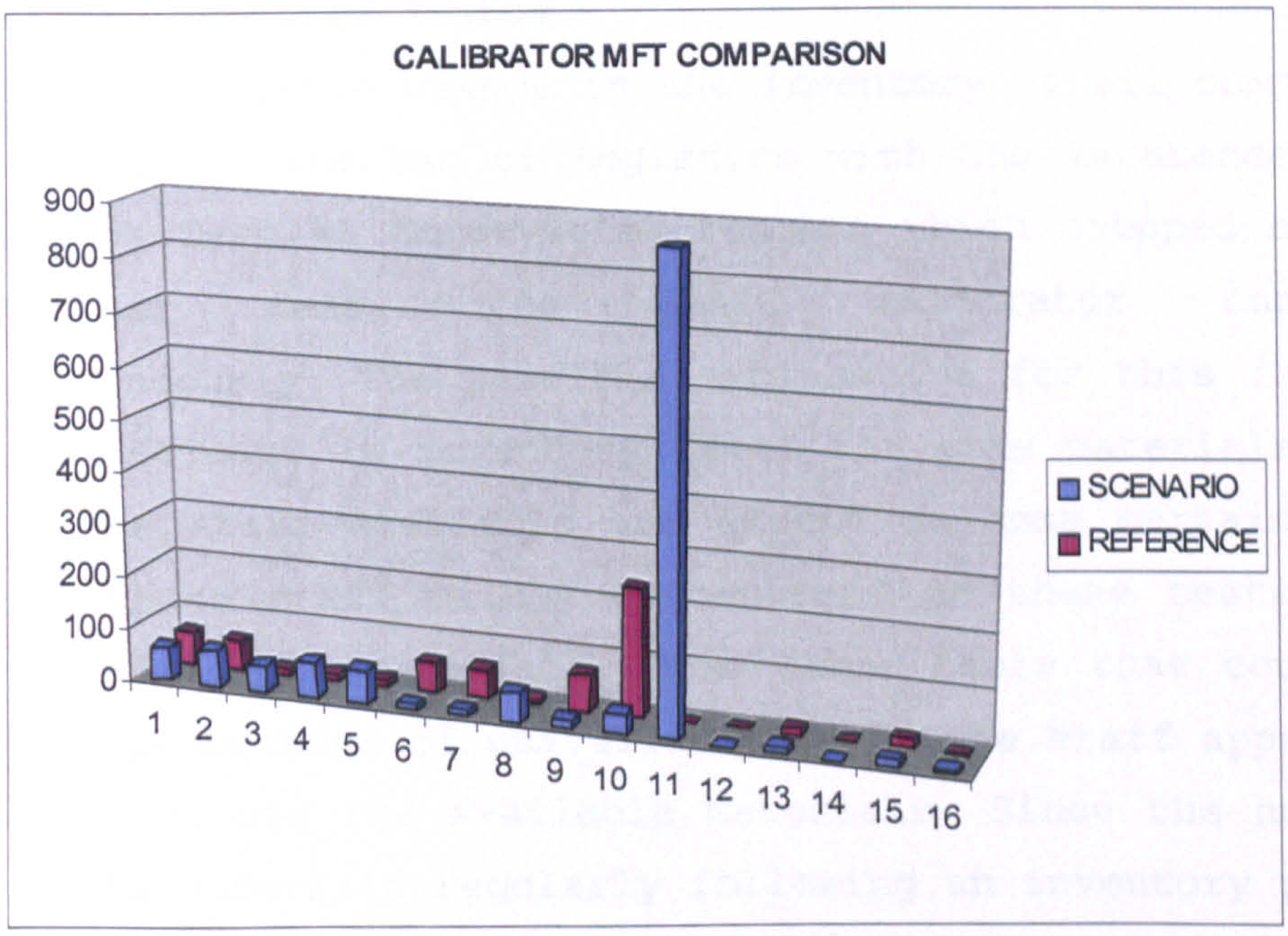
8.1.2 Material Flow time

Most of the tests were not affected by staffing shortages to the degree they were affected by material inventory as illustrated in Graph 57 which consist of reagent, calibrator, and controller.

Graph 57



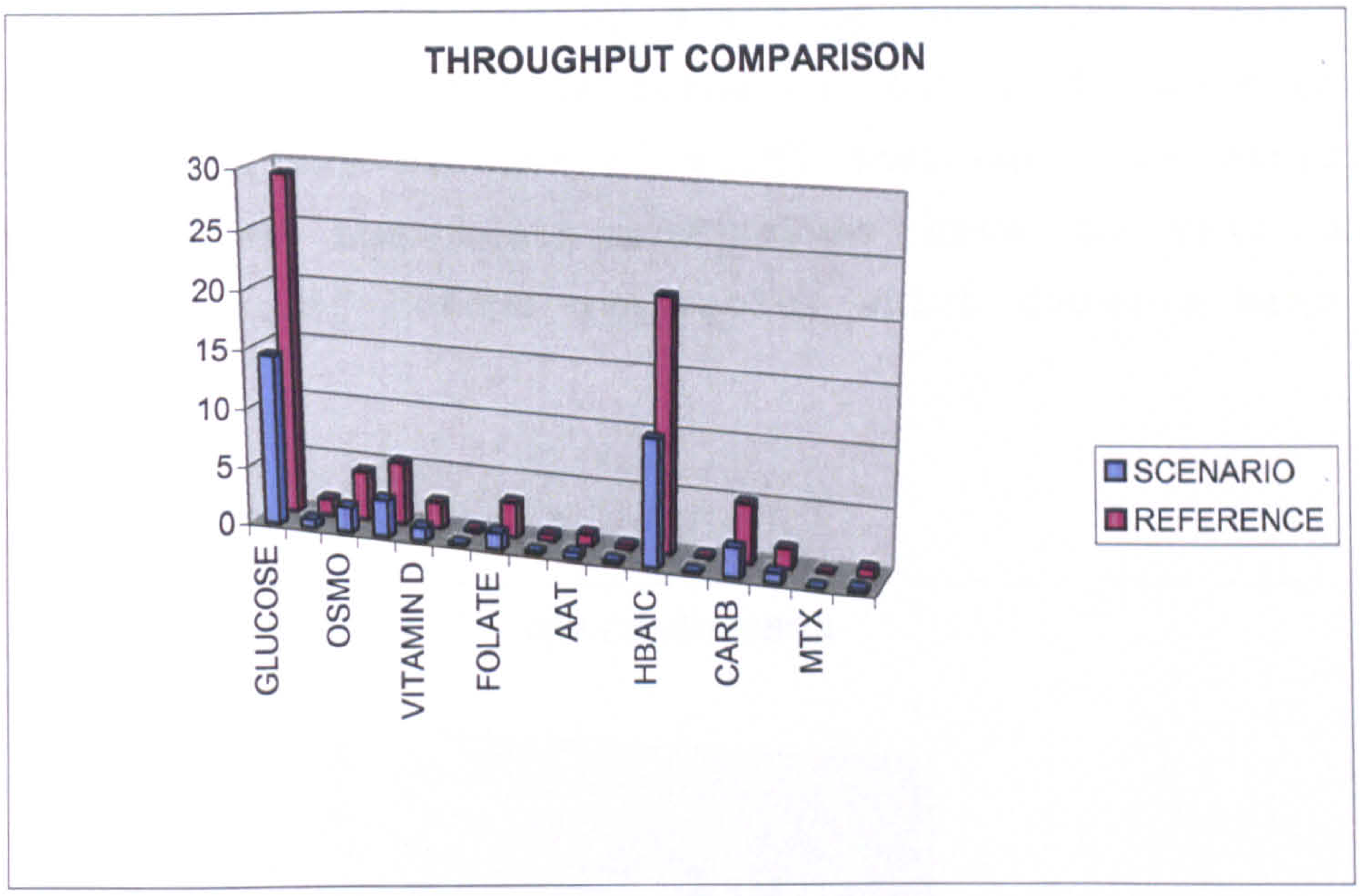




8.1.3 Throughput

Throughput of the test as indicated in the Graph 58 was effected negatively; some tests cannot be performed unless adequate staff is available, which affects the overall productivity and production rate.

Graph 58



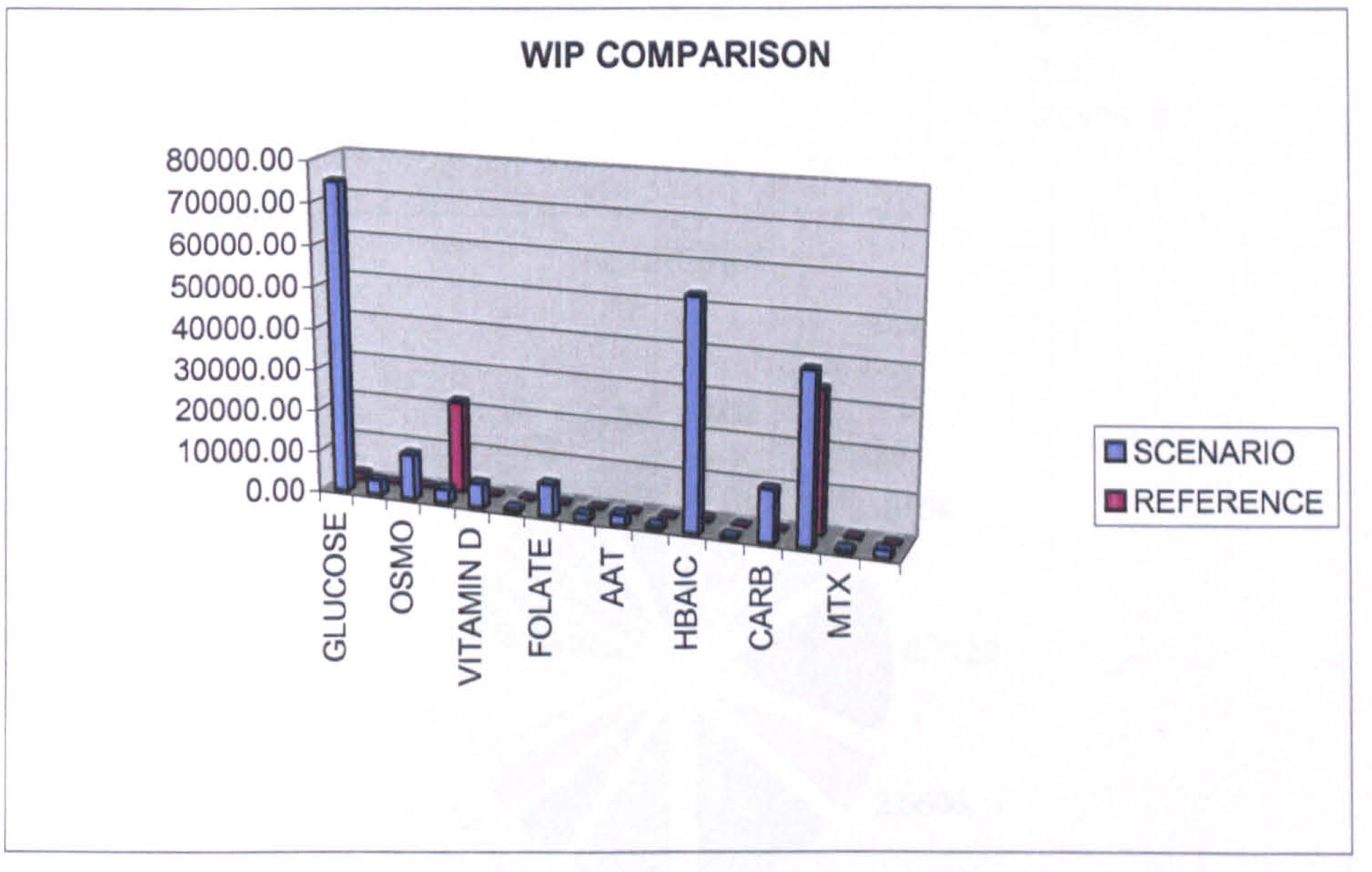
8.1.4 Inventory Status

There is little change in the inventory of all components whether in the Lab or Logistics with the Reference Model except Test #8 Homocystime reagent which dropped by 50%. Another test, the HBAIC calibrator increased tremendously. The possible explanation for this increase and decrease in inventory level for some materials would be the staff available are expert on some certain tests and these staff mainly concentrate on these tests using the available materials. Some other tests that could not be made because of unavailability of the staff apparently will not use the available materials. Since the hospital orders materials regularly following an inventory policy, the inventory level for these materials that are not used in some tests because of staff shortage, accumulate and cause a high inventory level for these materials.

8.1.5 W I P

Graph 59 indicates work in process. All tests have been increased as expected by staffing shortages. This is a natural outcome of this scenario. Since the work cannot be done timely because of staff shortage, the materials as well as the tests themselves have to wait until required staff become available, which cause a high WIP level.

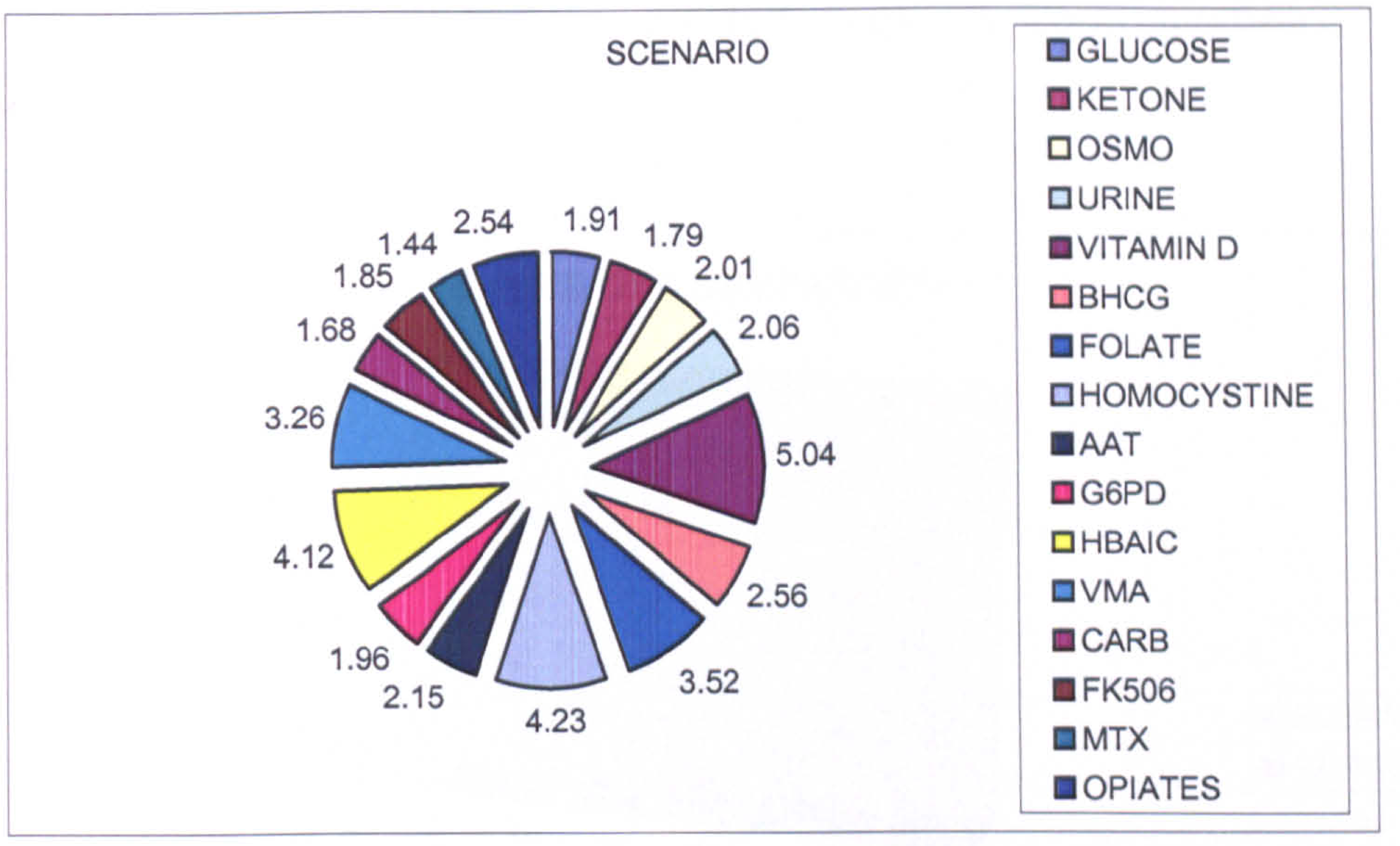
Graph 59

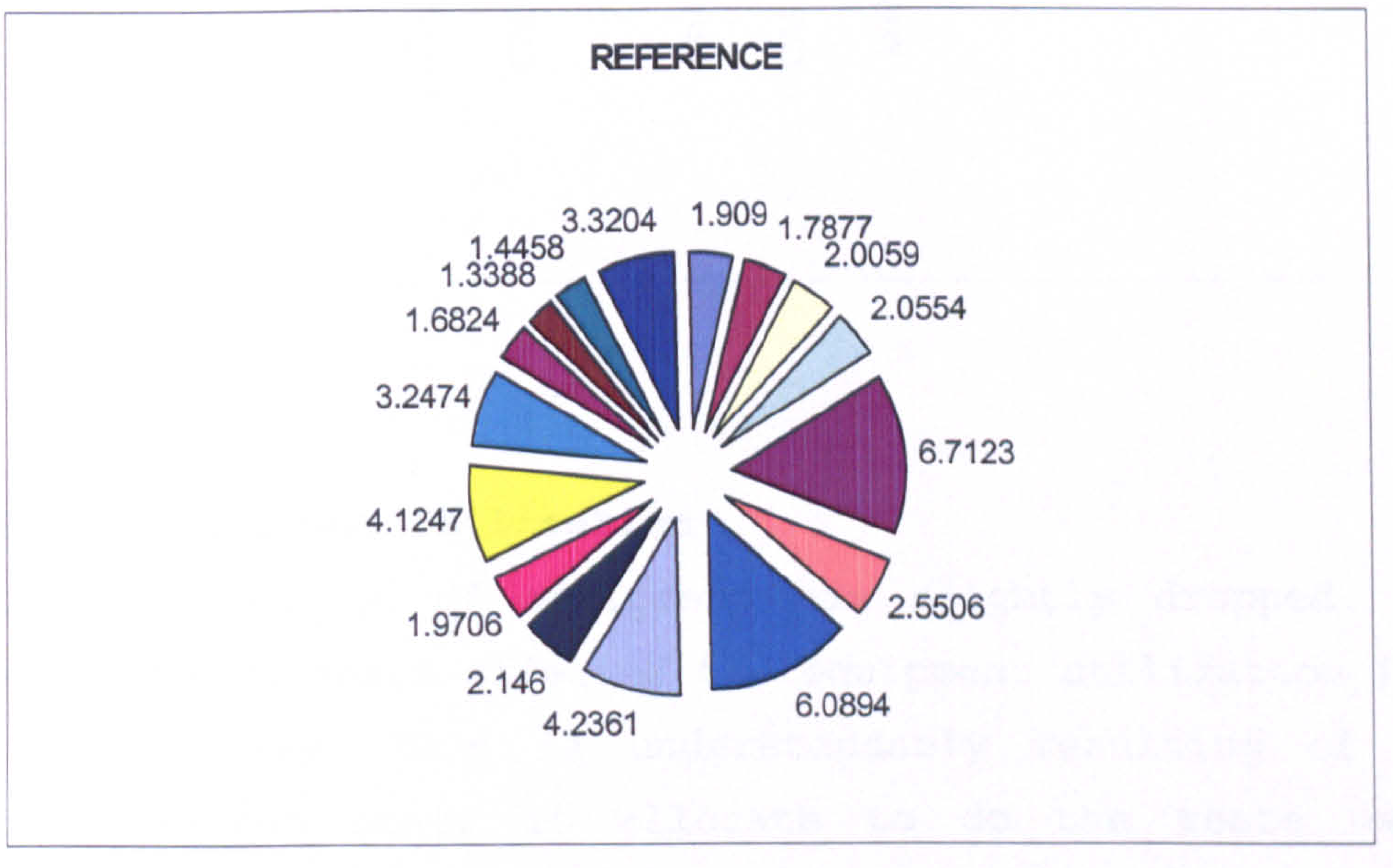


8.1.6 Cost of Test

The costs of each test are not much different than the Reference Model (Graph 60) because of the staff and resources are still included.

Graph 60





8.2 Secondary Performance Measures

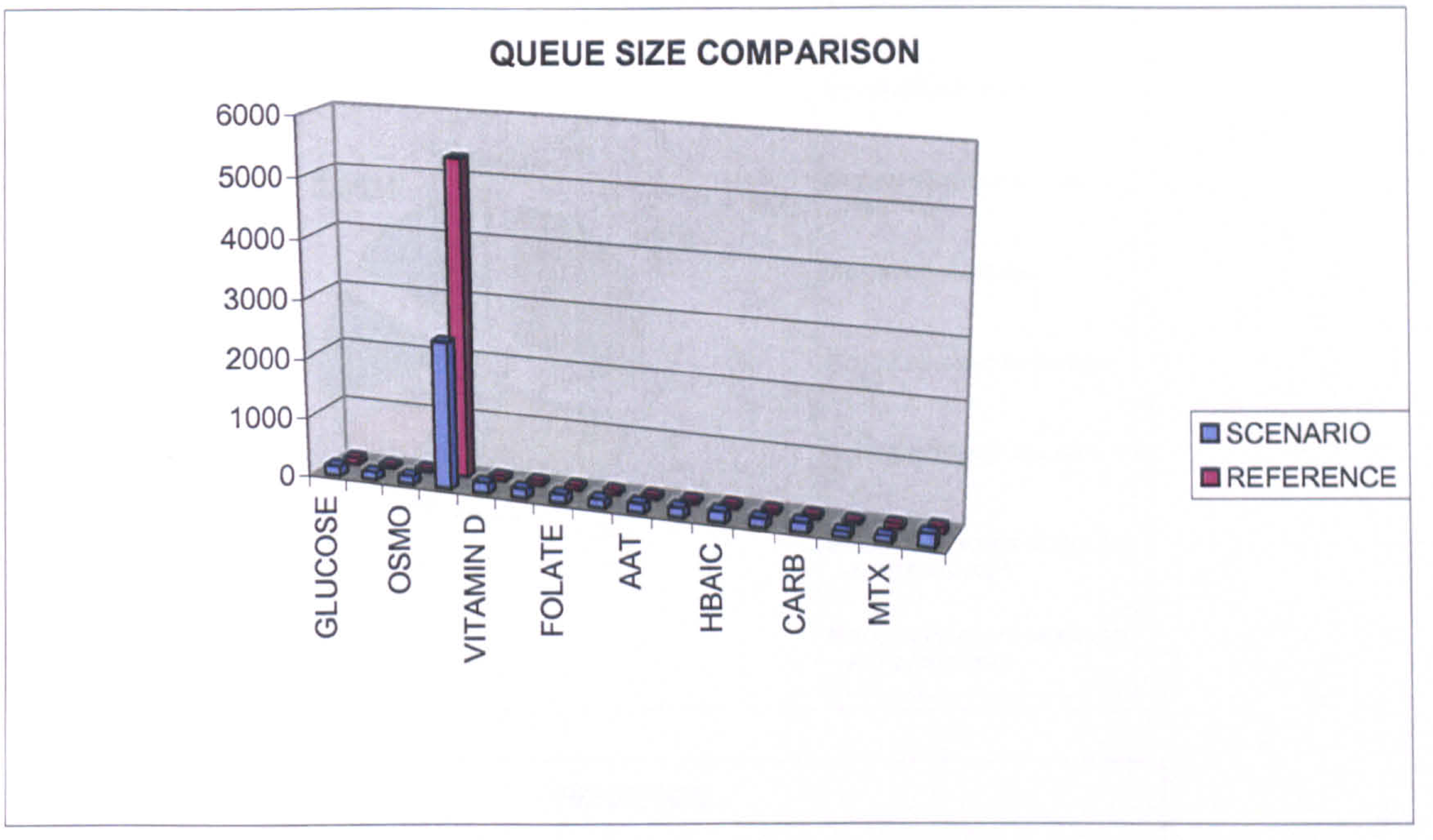
8.2.1 Materials Order Size

The material orders for the calibrator and controller are increased by 20%, while the reagent has increased by the same %.

8.2.2 Queue Sizes

As discussed in the lead time, similarly the queue size (Graph 61) been increased by 50 to 90% and was tremendously high in the Opiates test. The staff shortage affects the overall outcome and creates long queues.

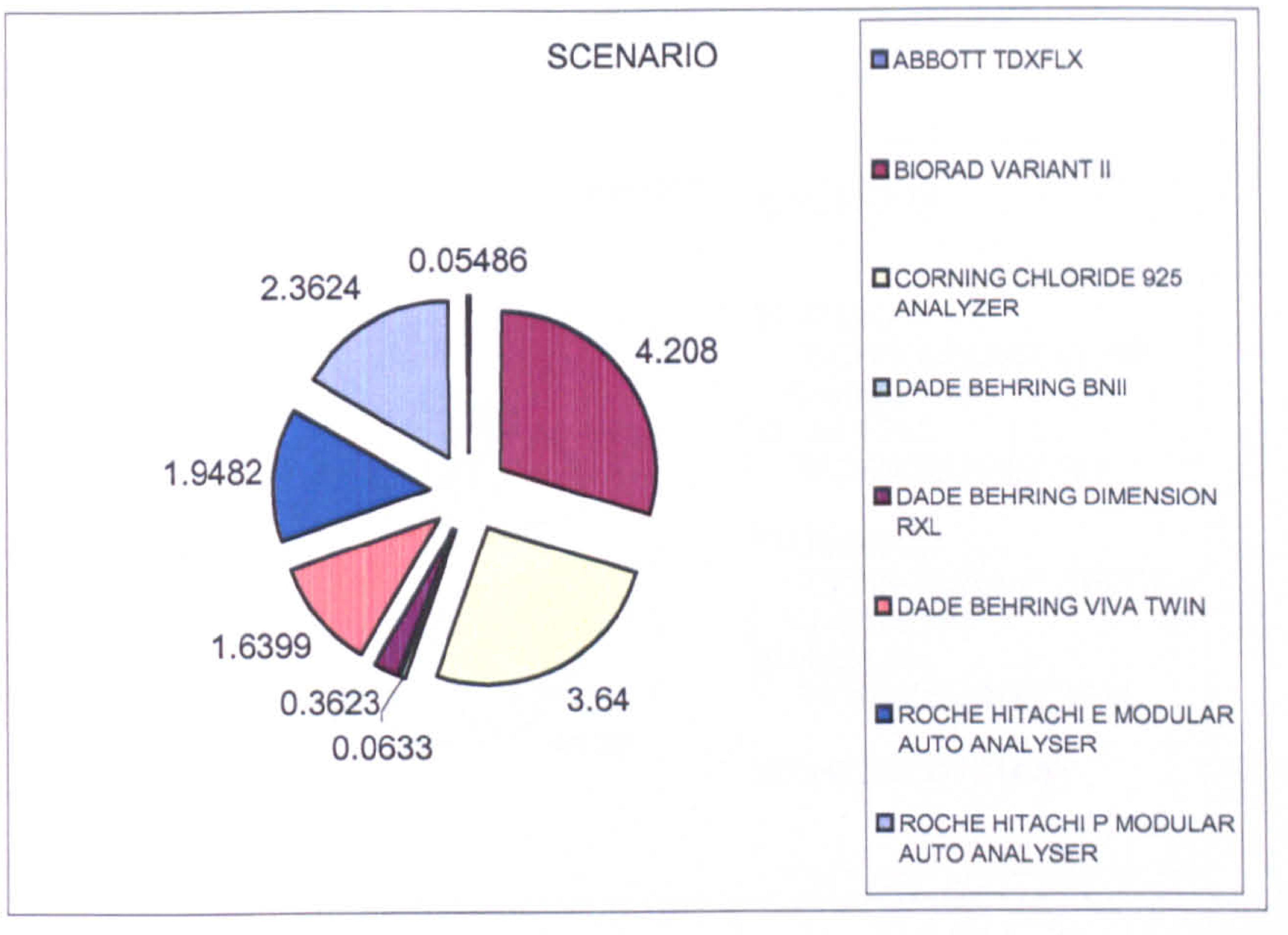
Graph 61

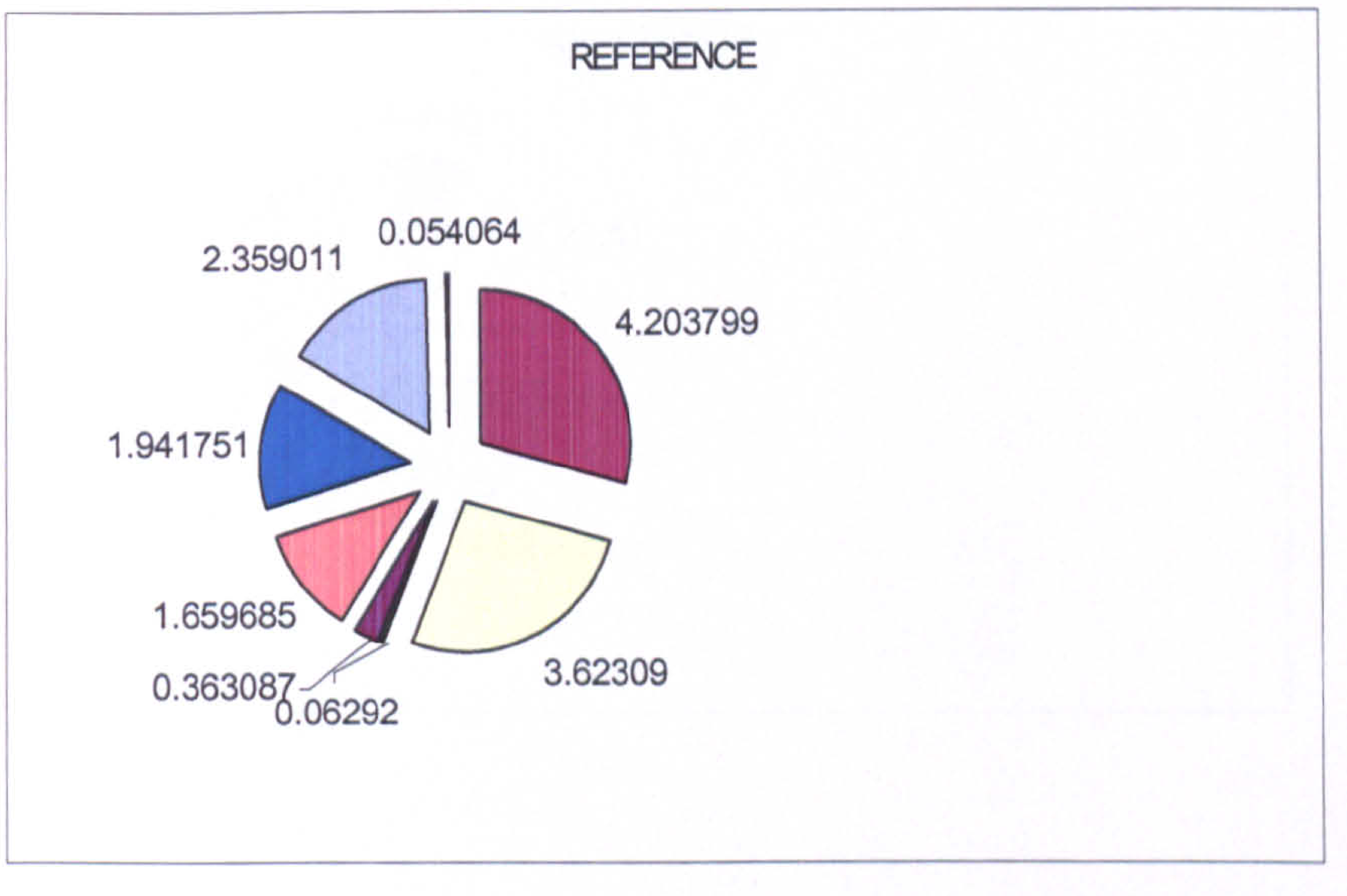


8.2.3 Equipment Utilization

The utilization of equipment has slightly dropped. The shortage of staff affected the equipment utilization in a negative way. This is understandably resulting of the insufficient staff to allocate to do the tests using available equipment (Graph 62). Therefore, time to time equipment becomes idle which decreases the overall utilization of the equipment.

Graph 62
EQUIPMENT UTILIZATION % COMPARISON

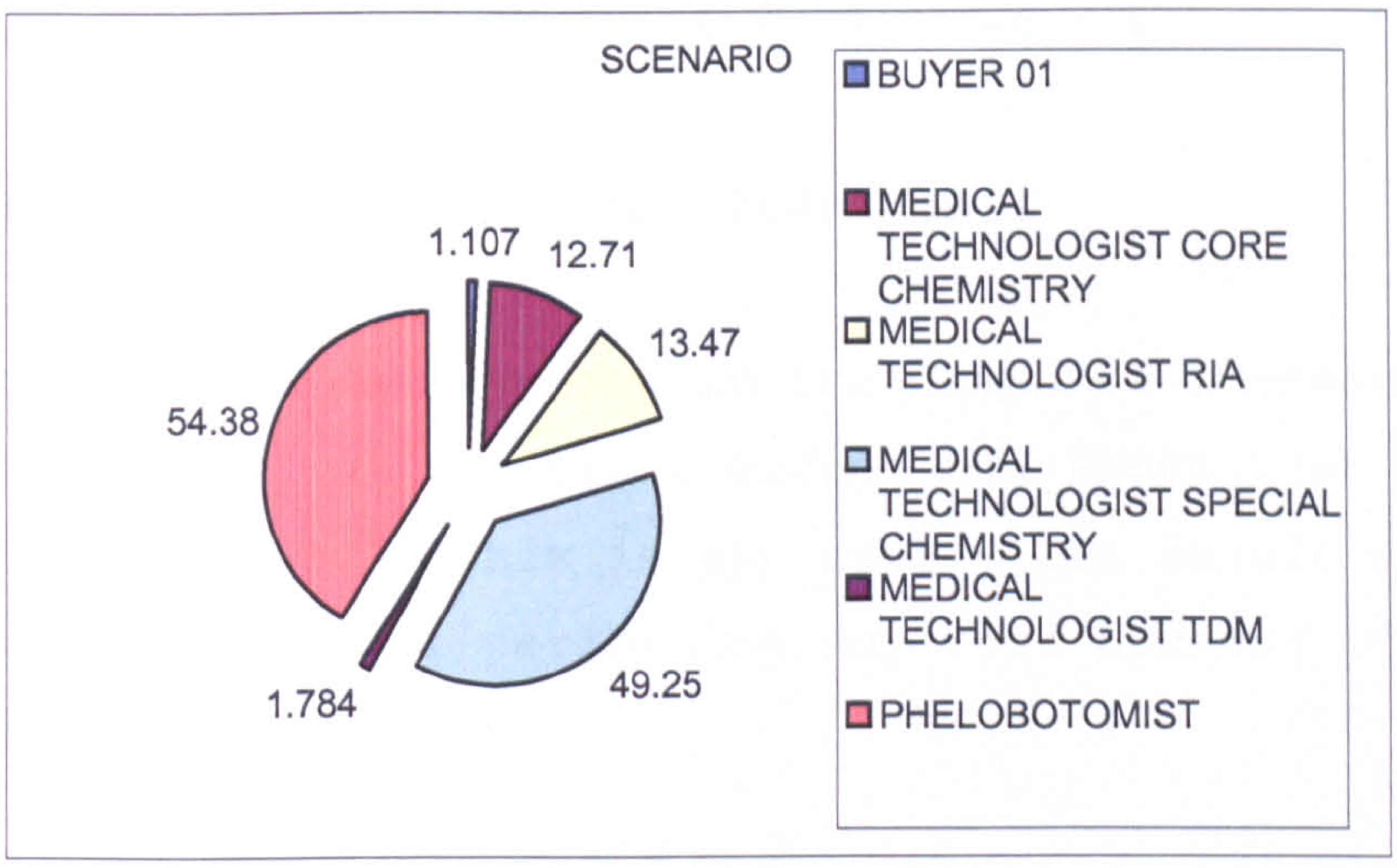


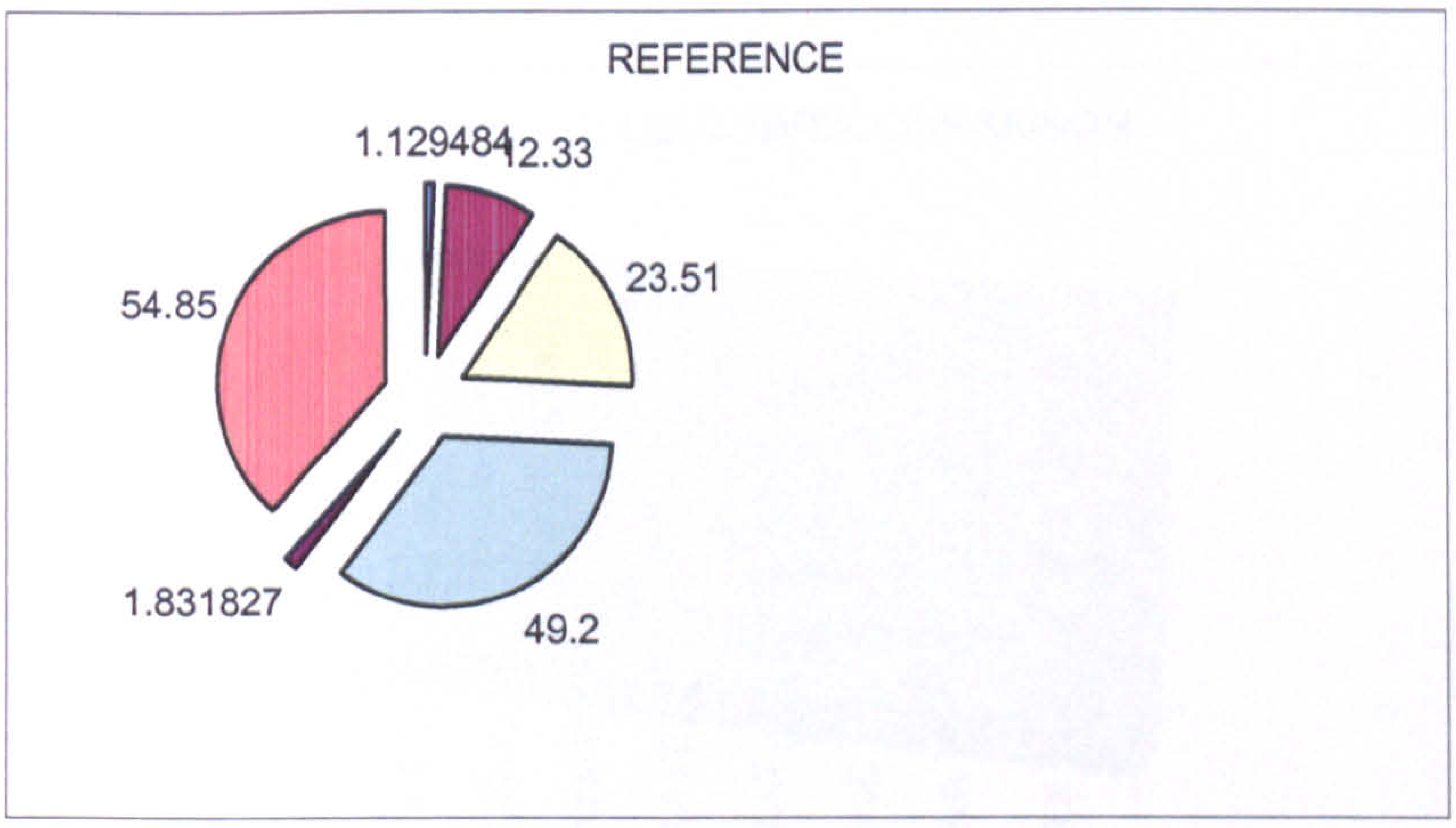


8.2.4 Staff Utilization

The staff utilization is not effected as expected of the change (Graph 63) except the Medical Technology RIA which decreased by 50%, showing the unbalance of staffing distribution. In fact, the performance result is based on the available staff. The available staffs do their own work as usual with everyday pace. Therefore, the utilization has not changed. However, when this measurement is based on the whole staff, then a lower level of average staff utilization would be expected.

Graph 63





8.3 Conclusion

Lead time increased by 70-100%. Throughput of all tests has been affected in a negative way by 50%. WIP increased considerably as there is not enough staff to perform the tests. The management of the Lab should be prepared for any shortage of staff not to cause any interruption in performing everyday operations, which may be very costly in urgent cases.

9. Scenario Twelve: Repair Time Longer Than Expected

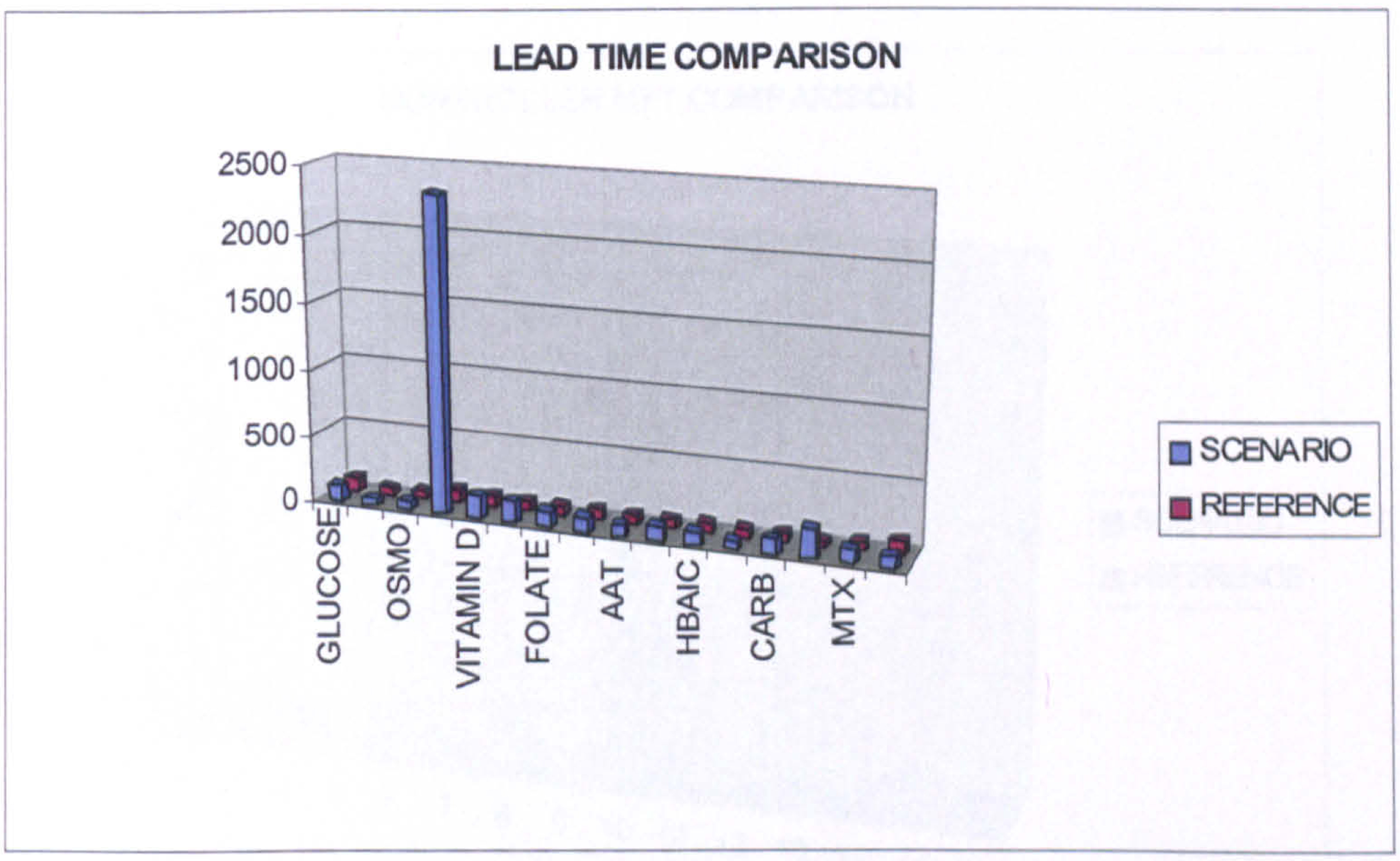
Failure rate is always calculated by the department depending on the equipment but the rate can be 1 to 99%. We put a high percentage for this scenario to know the Lab reaction if the rate is around 50%.

9.1 Primary Performance Measures

9.1.1 Lead Time

The lead time as shown in the Graph 64 increased by 10 to 50% in all of the tests except the FK506 test which increase 400%. This is apparently the result of long interruption of performing any test because of lengthy repair times.

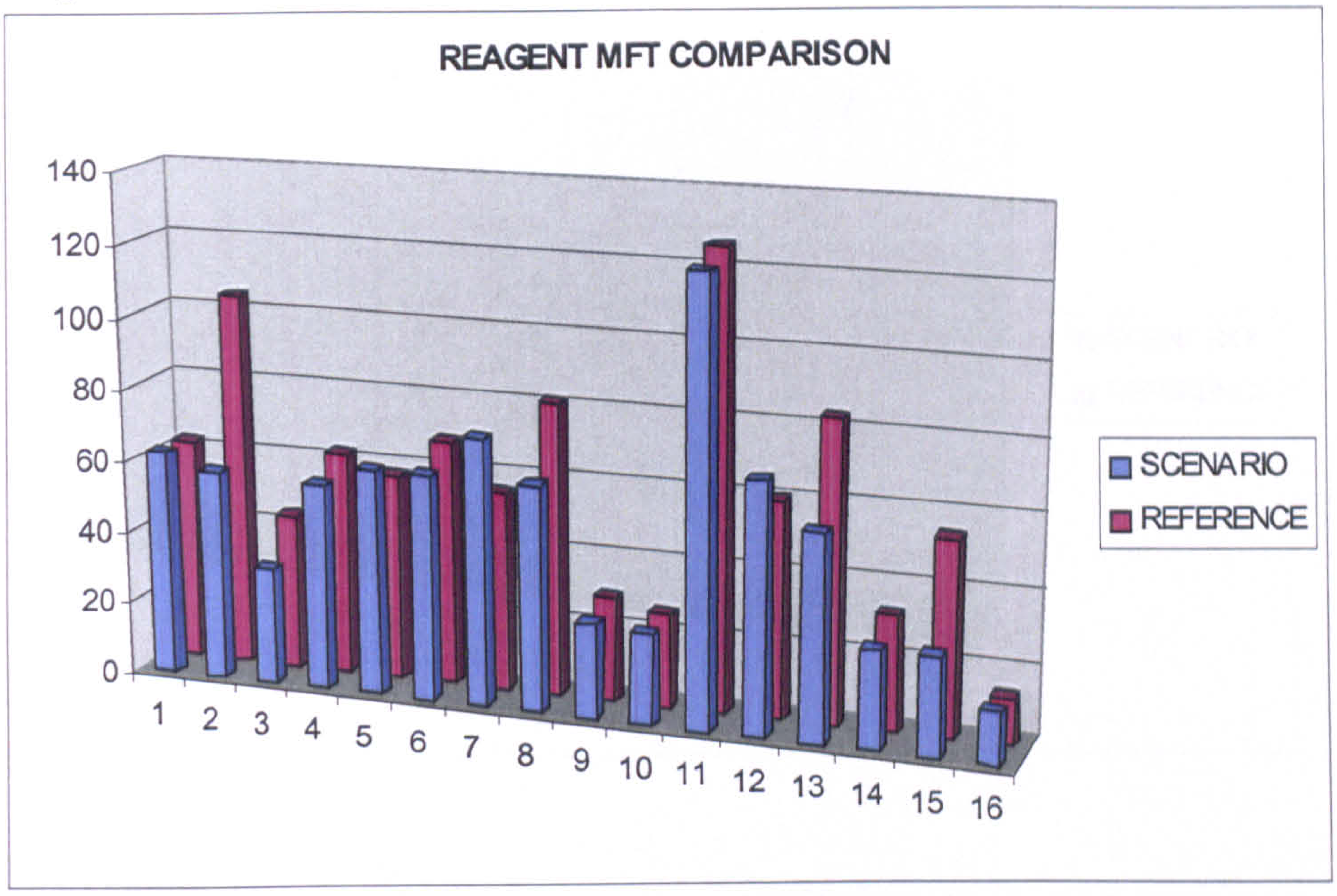
Graph 64

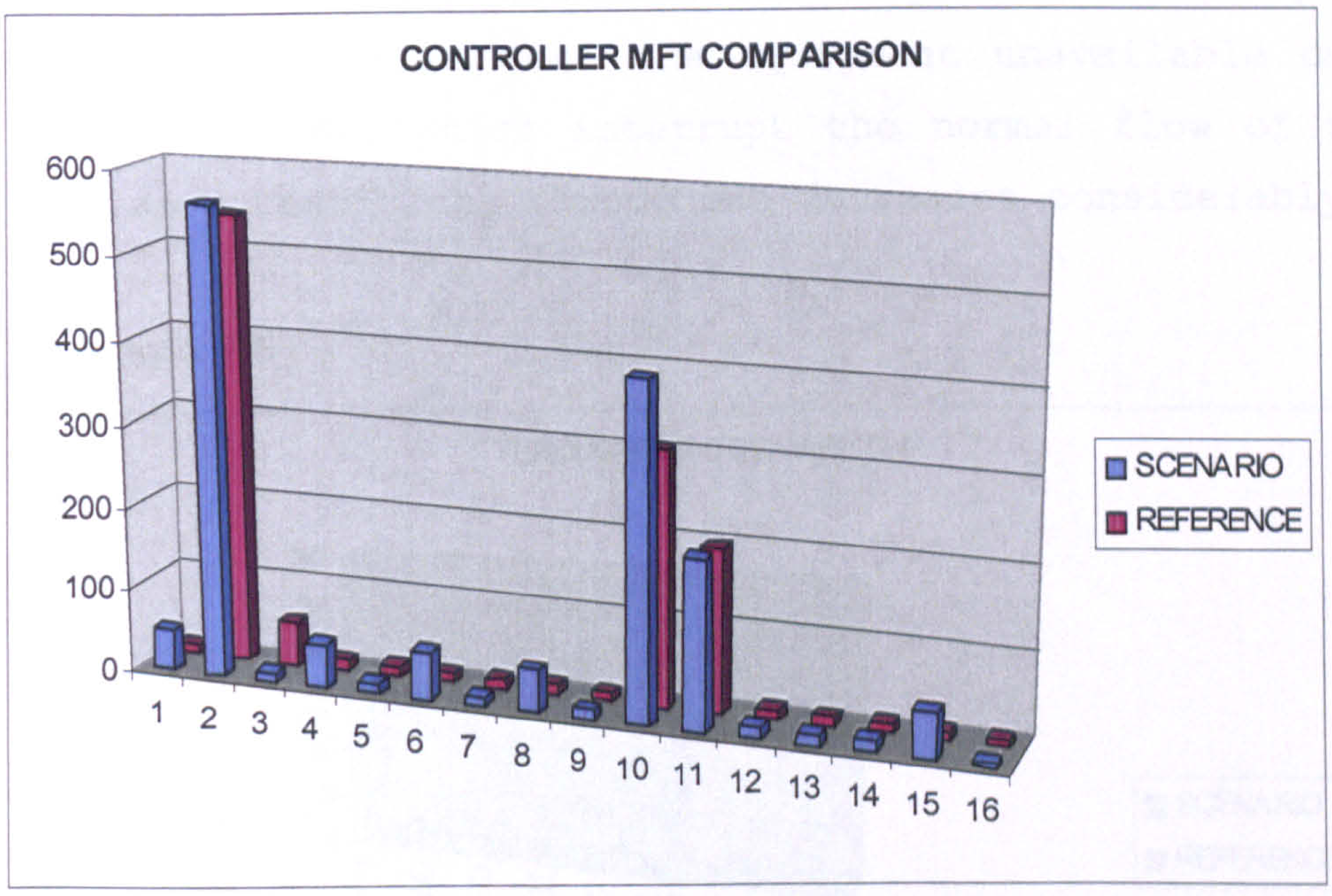


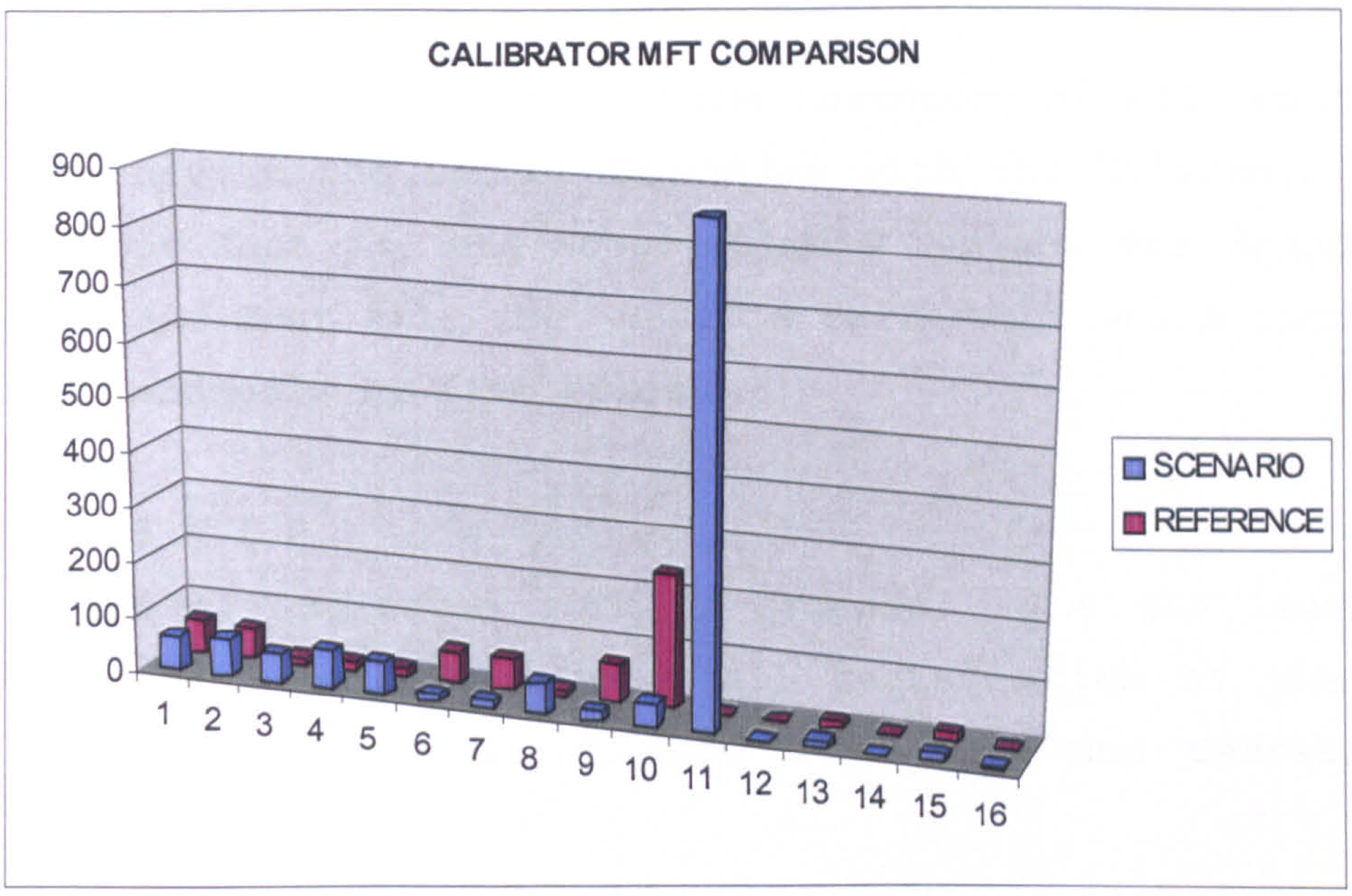
9.1.2 Material Flow time

More than 70% of all were tests are affected from the equipment failures. Most of the change from the increasing of both calibrator and controller components as illustrated in Graph 65, which consist of reagent, calibrator, and controller.

Graph 65


REAGENT MFT COMPARISON
140
120
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
SCENARIO
REFERENCE

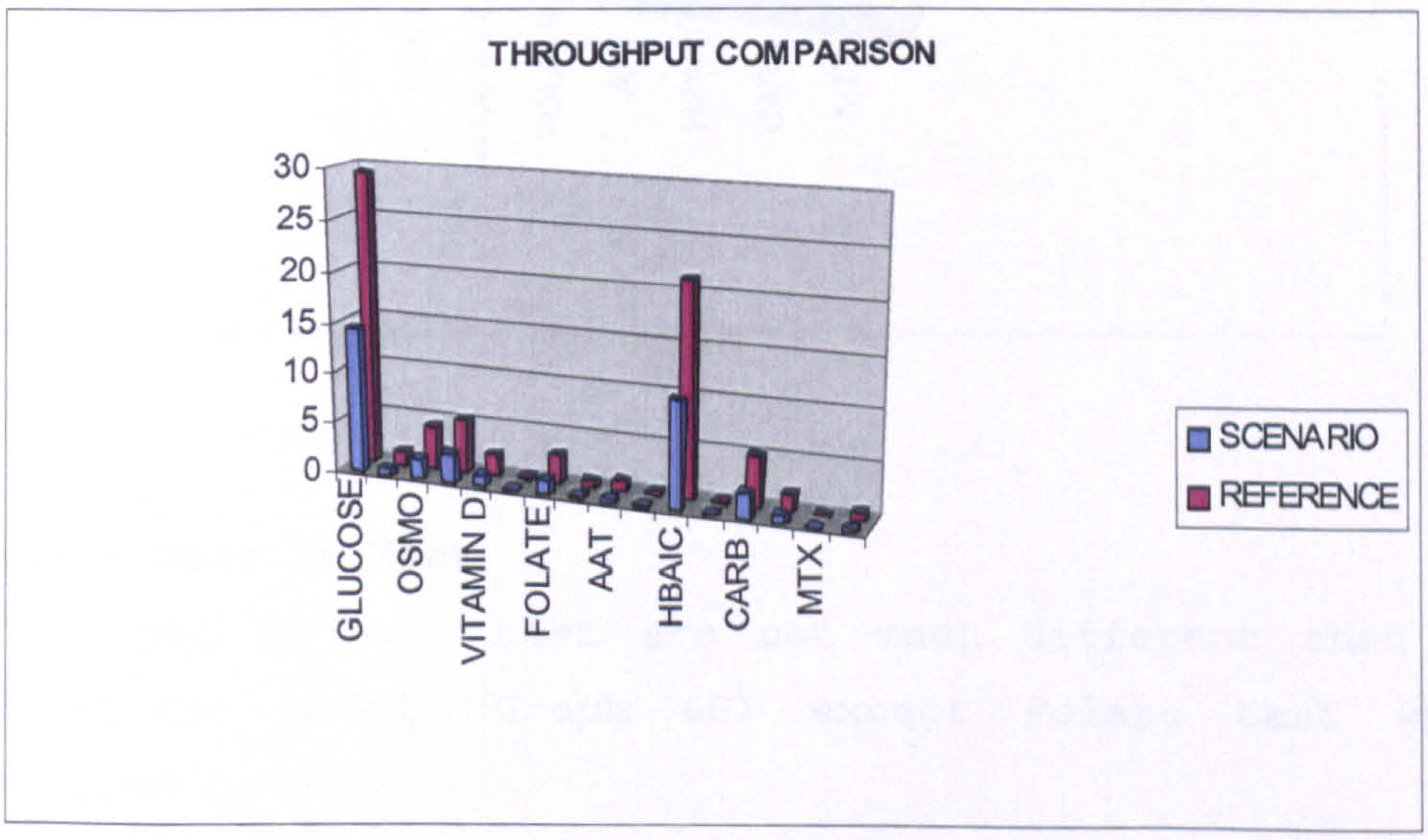

CONTROLLER MFT COMPARISON
600
500
400
300
200
100
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
SCENARIO
REFERENCE



9.1.3 Throughput

Throughput of the test as indicated in Graph 66 was effected negatively by equipment failures; the flow of material was high with limited component inventory. The long repair times make the equipment unavailable during these periods, which interrupt the normal flow of work, and as a result the throughput decreases considerably.

Graph 66



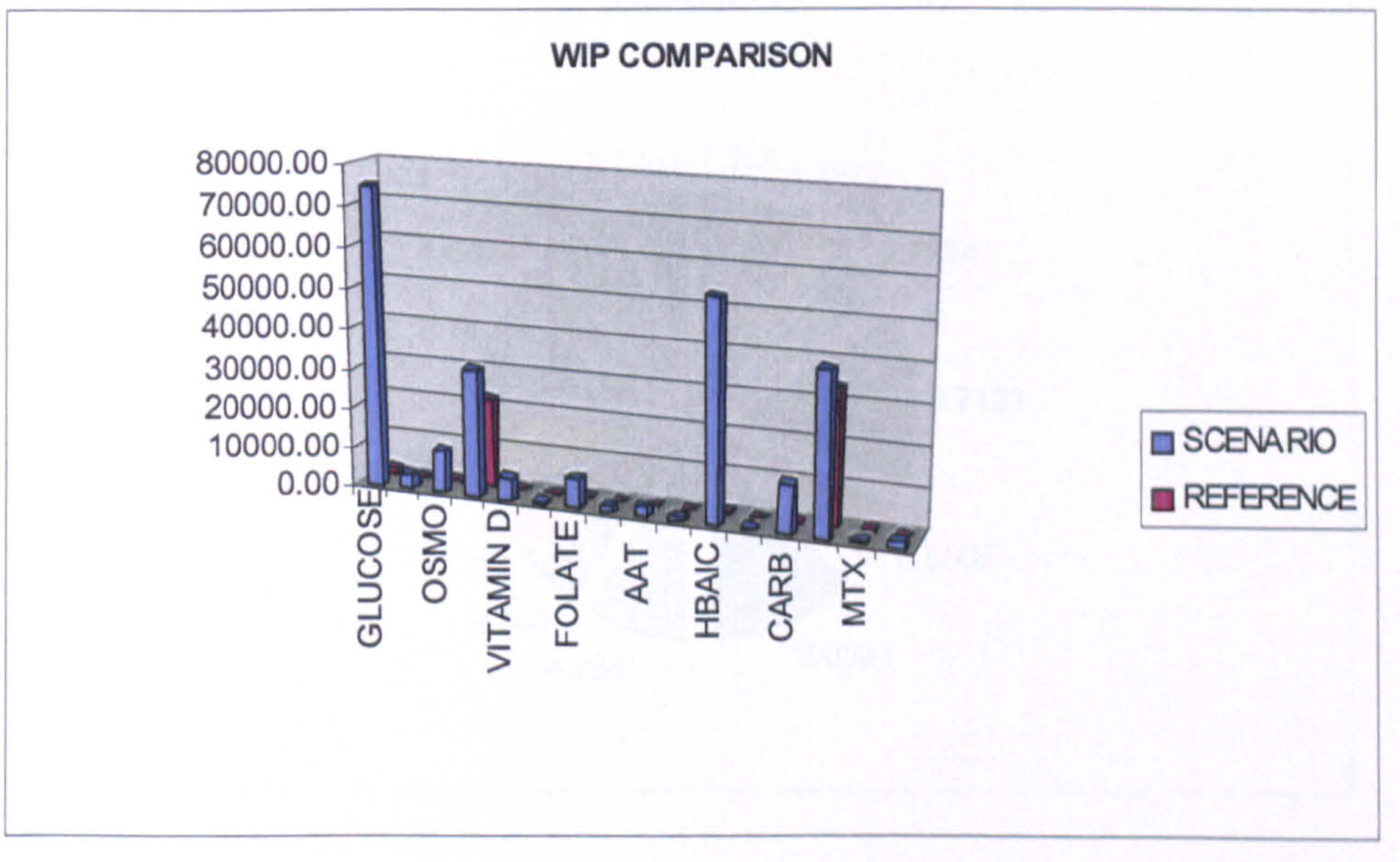
9.1.4 Inventory Status

There is little change in the inventory of all components whether in the Lab or Logistics with the Reference Model except Test #8, the Homocystime's reagent was dropped by 50% and Test #11, the HBAIC's calibrator which increased tremendously by five times.

9.1.5 W I P

Graph 67 indicates work in process. The WIP level has increased considerably in all tests, which at the same time an indication of long lead time and decrease in throughput.

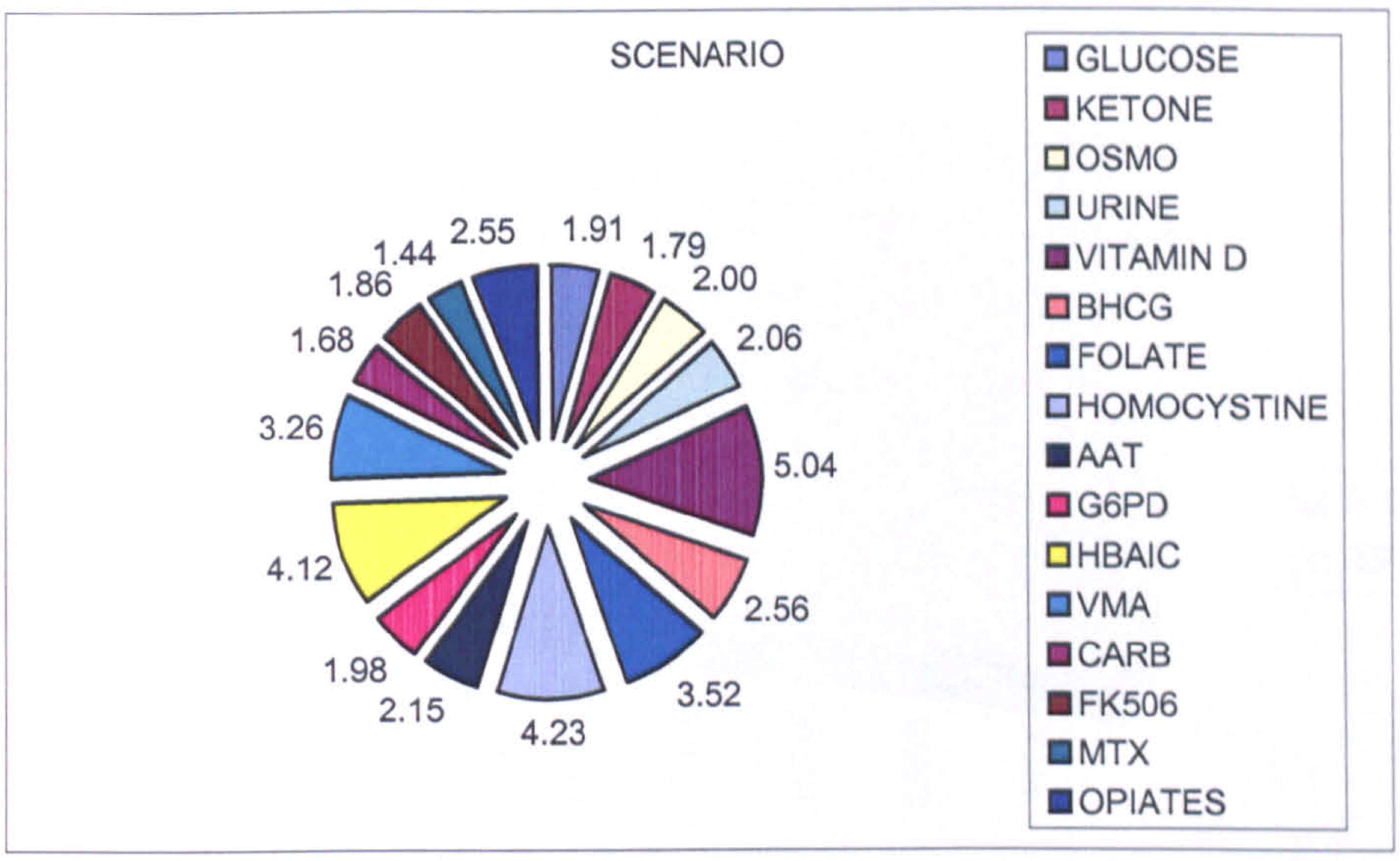
Graph 67
WIP COMPARISON

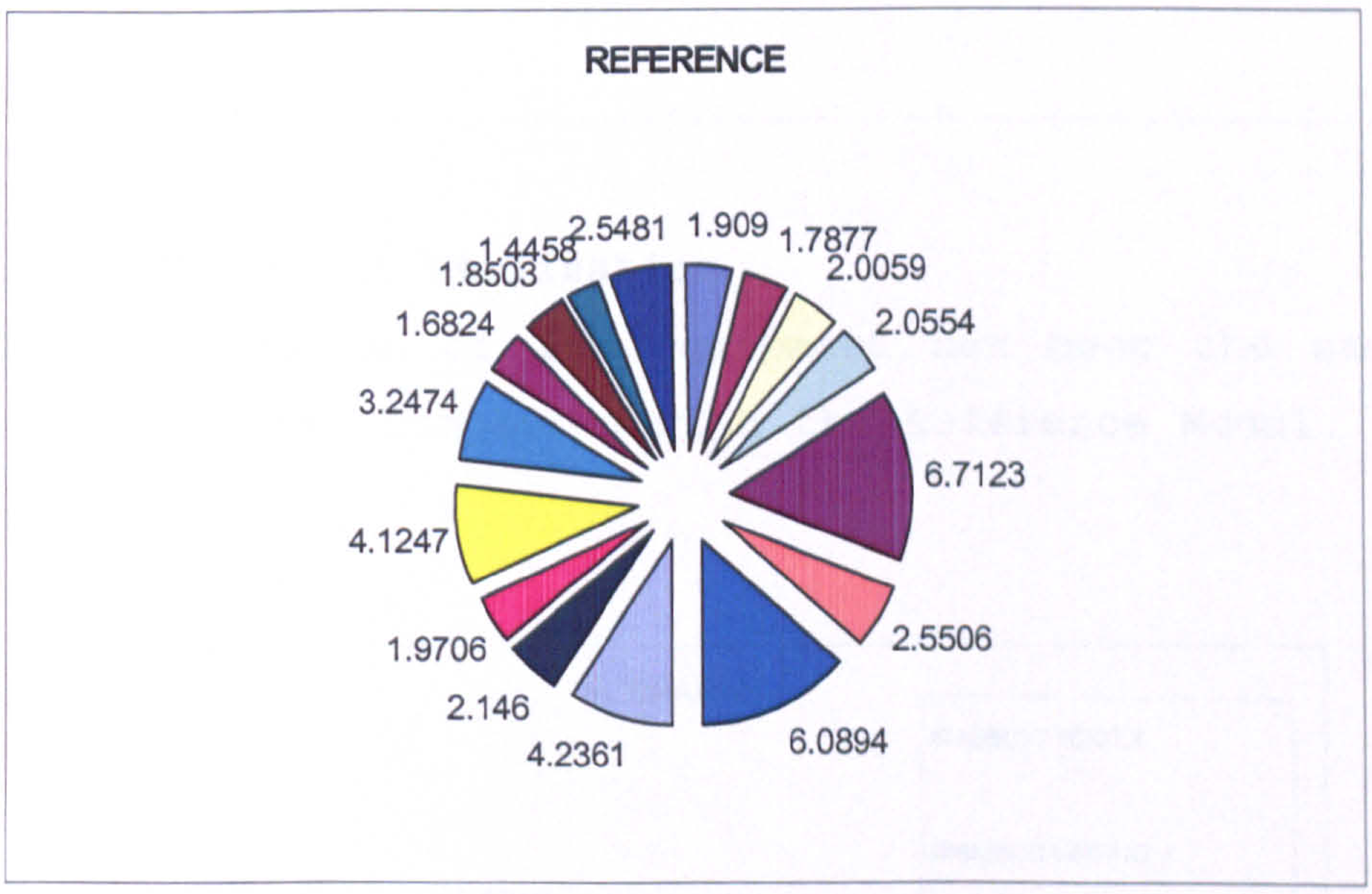


9.1.6 Cost of Test

The cost of each test are not much different than the Reference Model (Graph 68) except Folate test which dropped by 50%.

Graph 68





9.2 Secondary Performance Measures

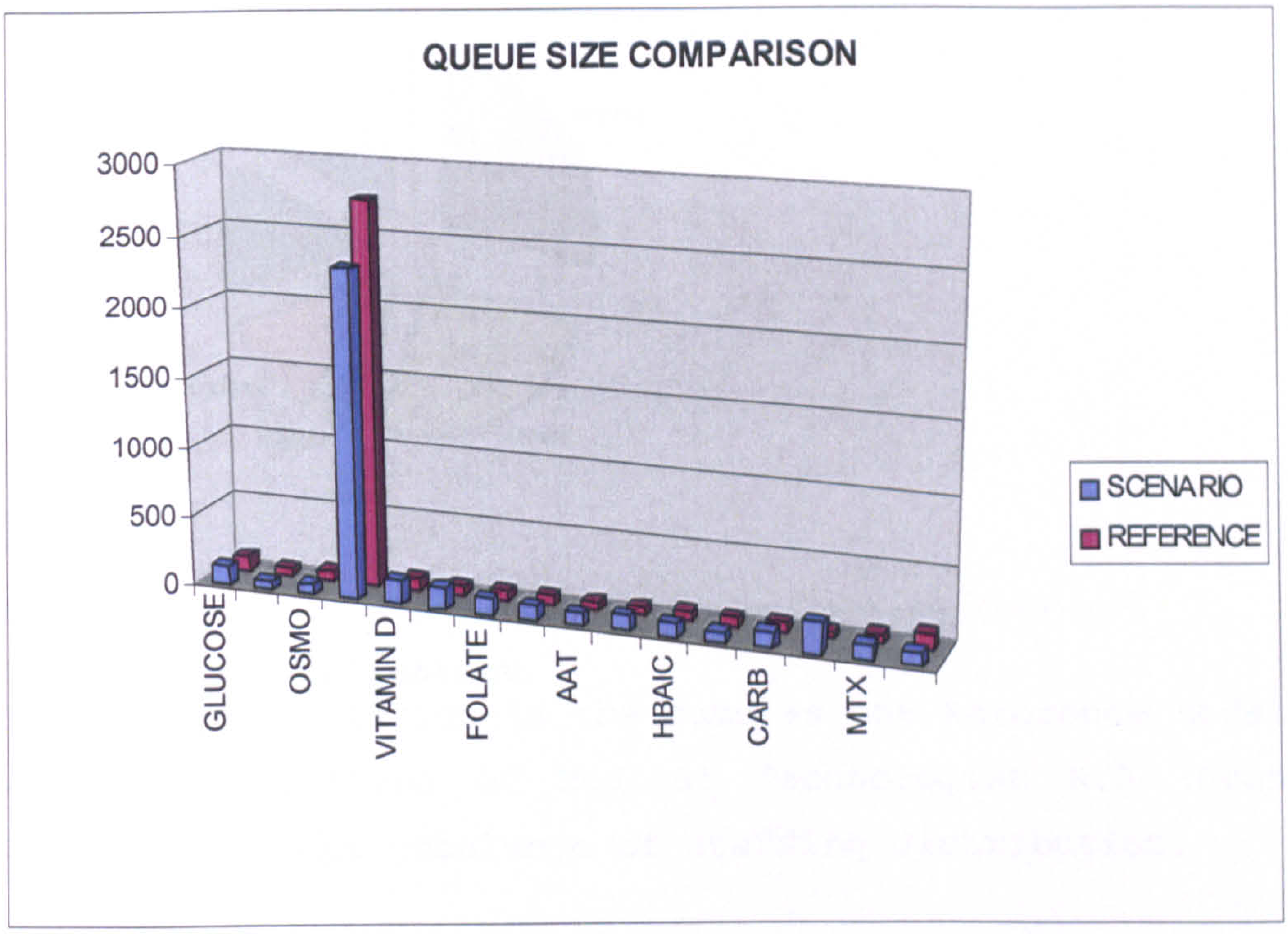
9.2.1 Material Order Sizes

The material orders were the same as expected.

9.2.2 Queue Sizes

As discussed in the lead time, similarly the queue size (Graph 69) been increased by 10 to 50% in all of the tests except FK506 test which increase 400%.

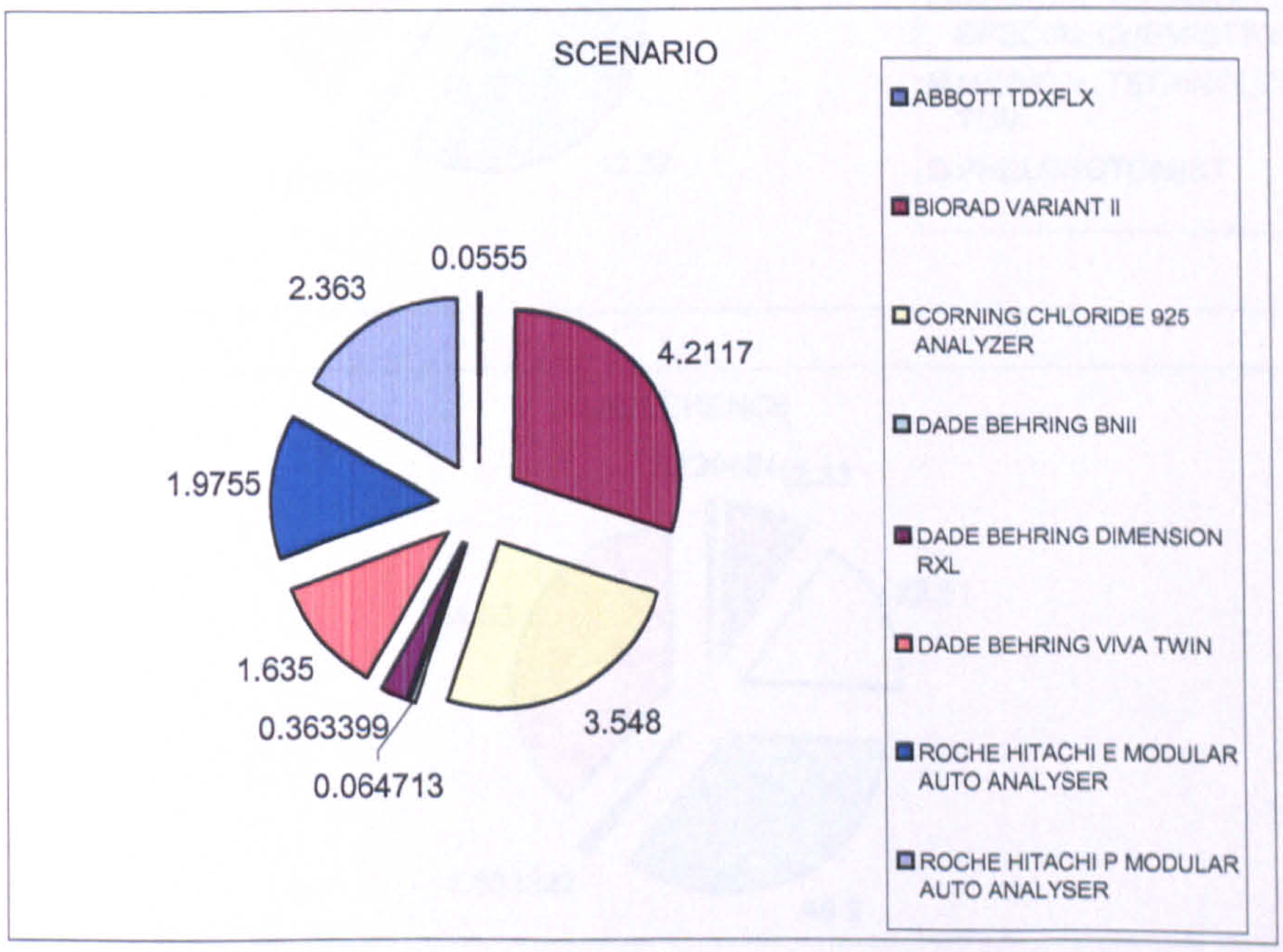
Graph 69

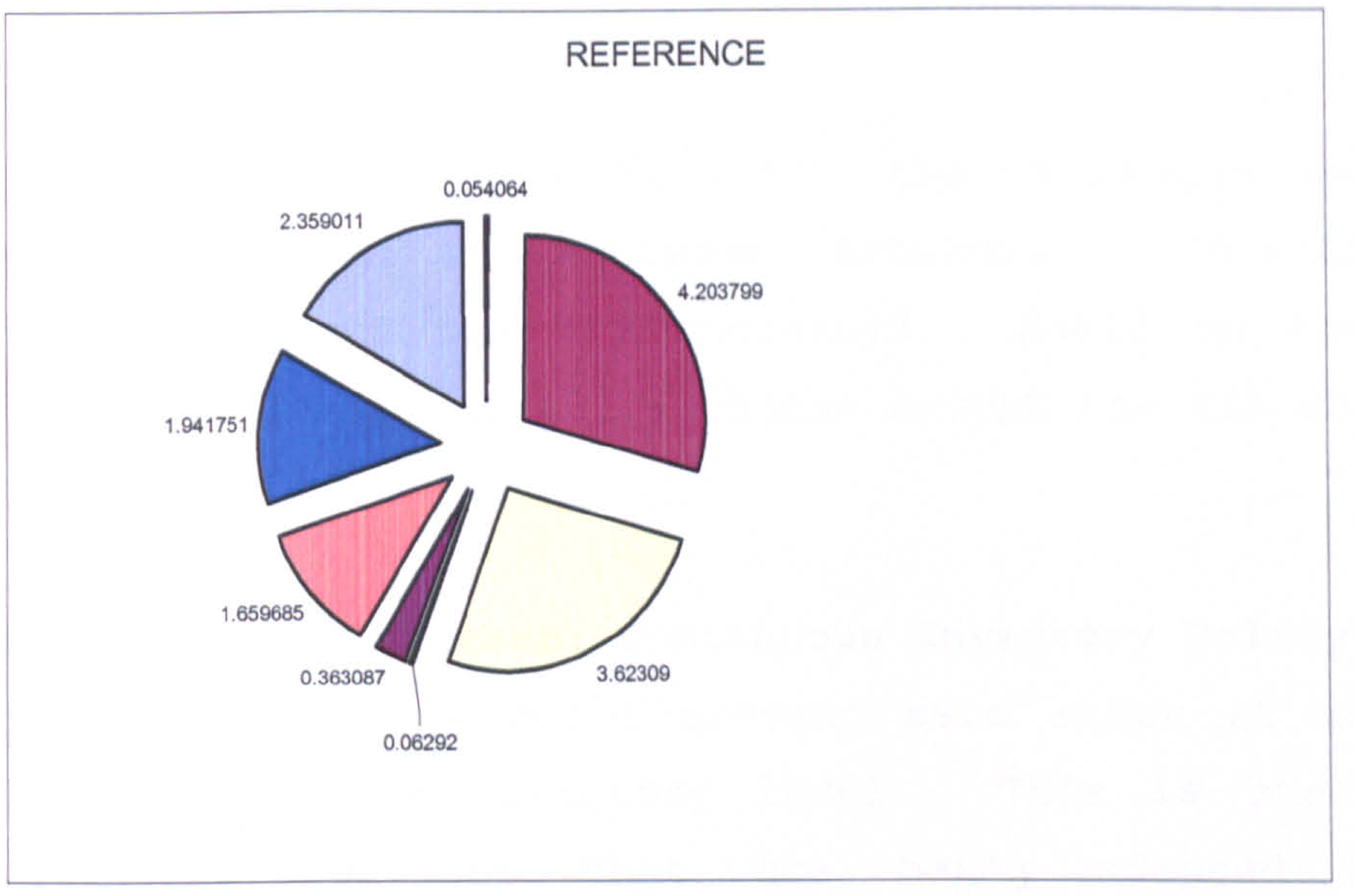


9.2.3 Equipment Utilization

The utilization of the equipment has been the same for all resources comparing with the Reference Model. (Graph 70)

Graph 70

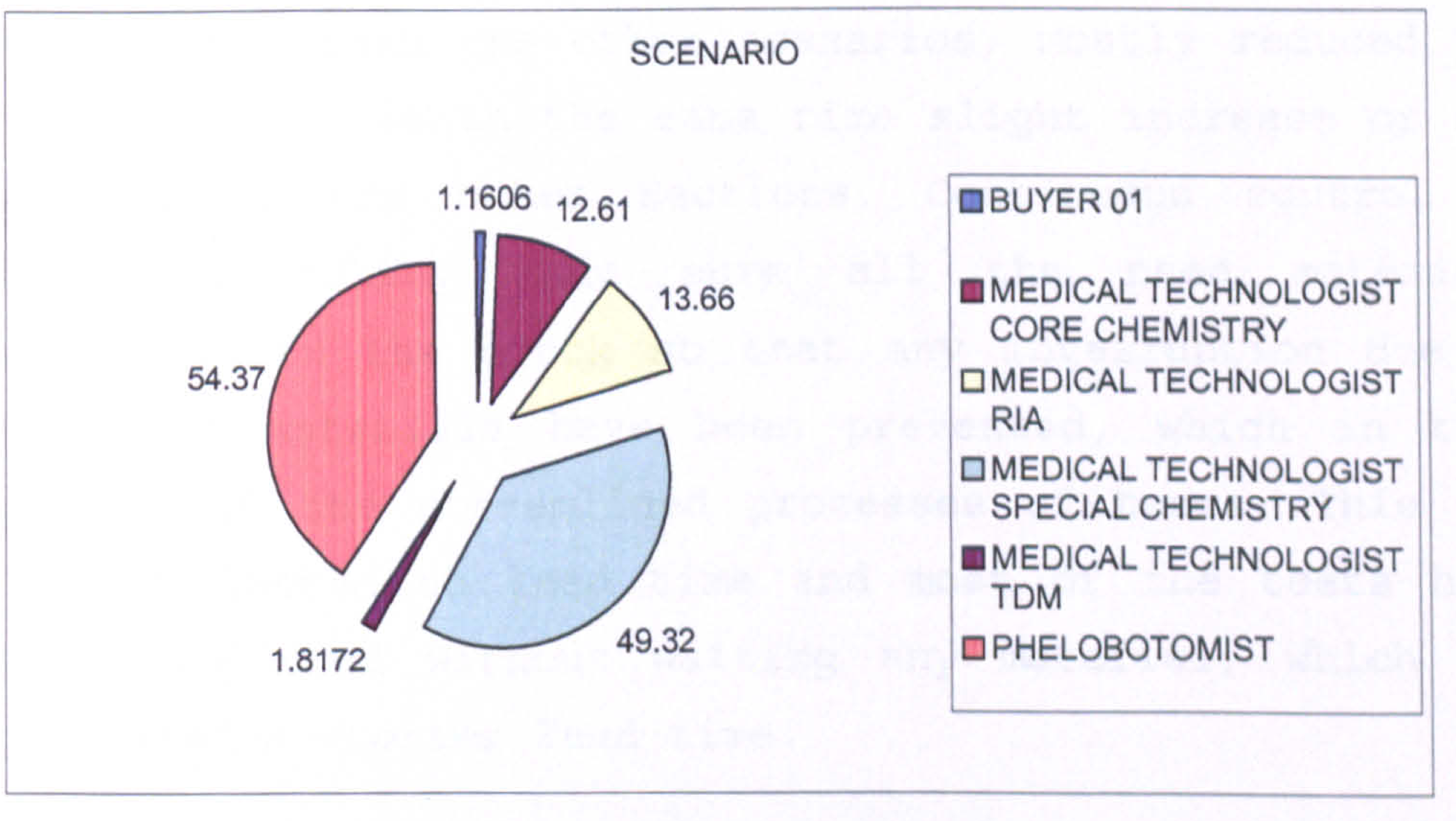


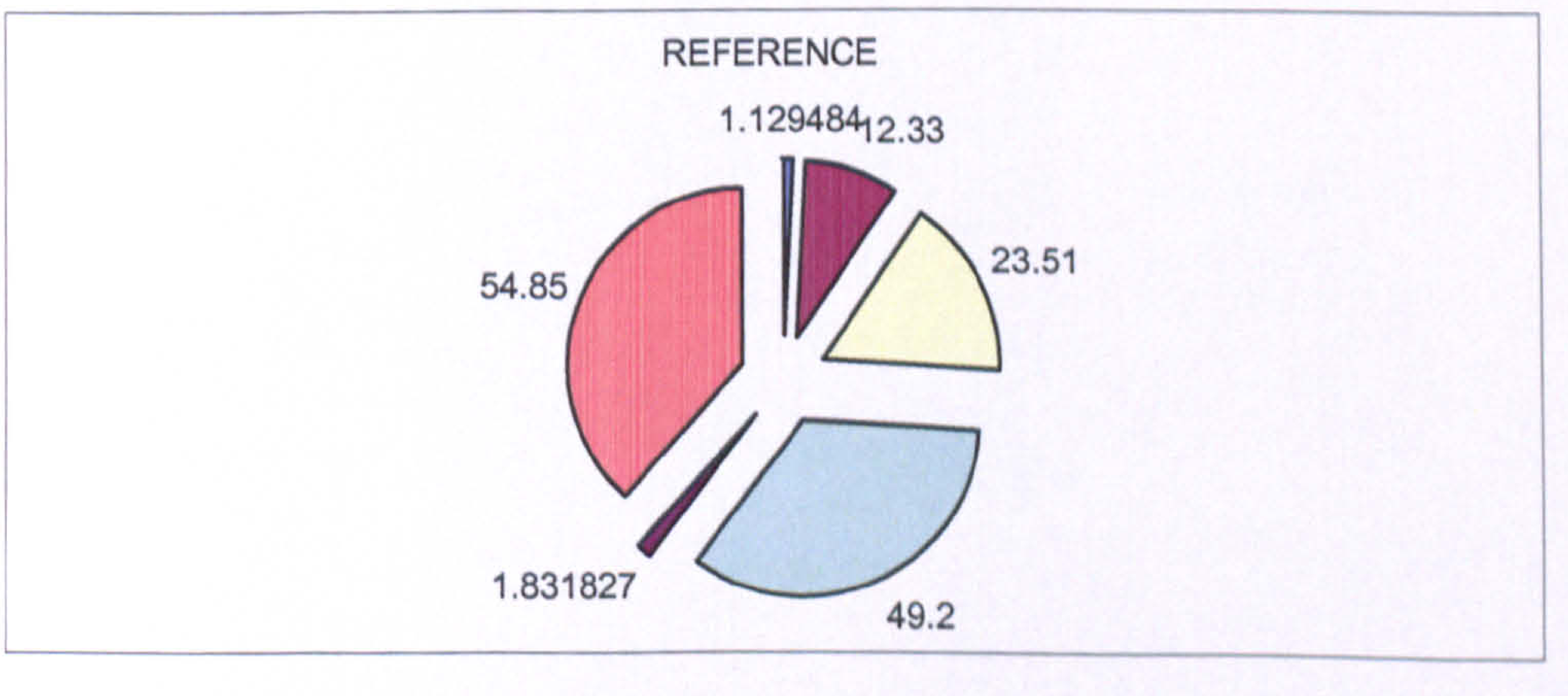


9.2.4 Staff Utilization

The staff utilization is the same as the Reference Model, with the exception of Medical Technologist RIA (Graph 71), showing the unbalance of staffing distribution.

Graph 71





9.3 Conclusion

Lead time increased by 30 - 50%, the throughput decreased as a result of the equipment breakdown. Inventory did not change but the WIP increased. Staff on the other hand; remain low in all sections except the RIA which was reduced by half.

10. Scenario Thirteen: Continuous Inventory Policy

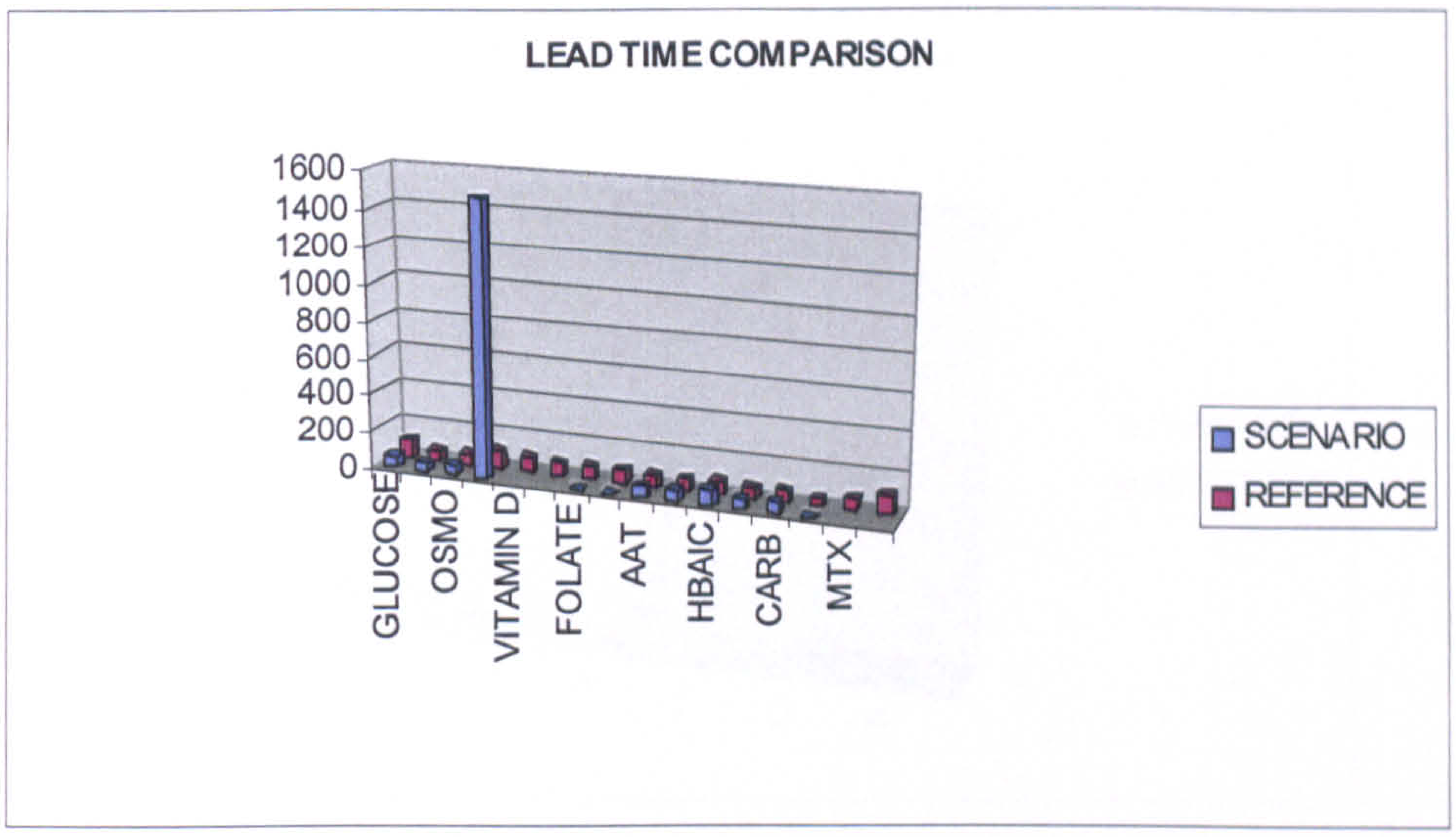
Continuous review would prevent zero stock at the same time reduce the inventory level. This is one of the inventory policies that are being adapted by the manufacturers.

10.1 Primary Performance Measures

10.1.1 Lead Time

The lead time as shown in the Graph 72 is acting differently than the other scenarios; mostly reduced the different values in the same time slight increase or not showing of the other Sections. Continuous control of inventory policy made sure all the need materials available in the stock so that any interruption due to short of materials have been prevented, which in turn guaranteed the streamlined processes of tests. This has been reflected to lead time and most of the tests have been completed without waiting any material, which has generated a shorter lead time.

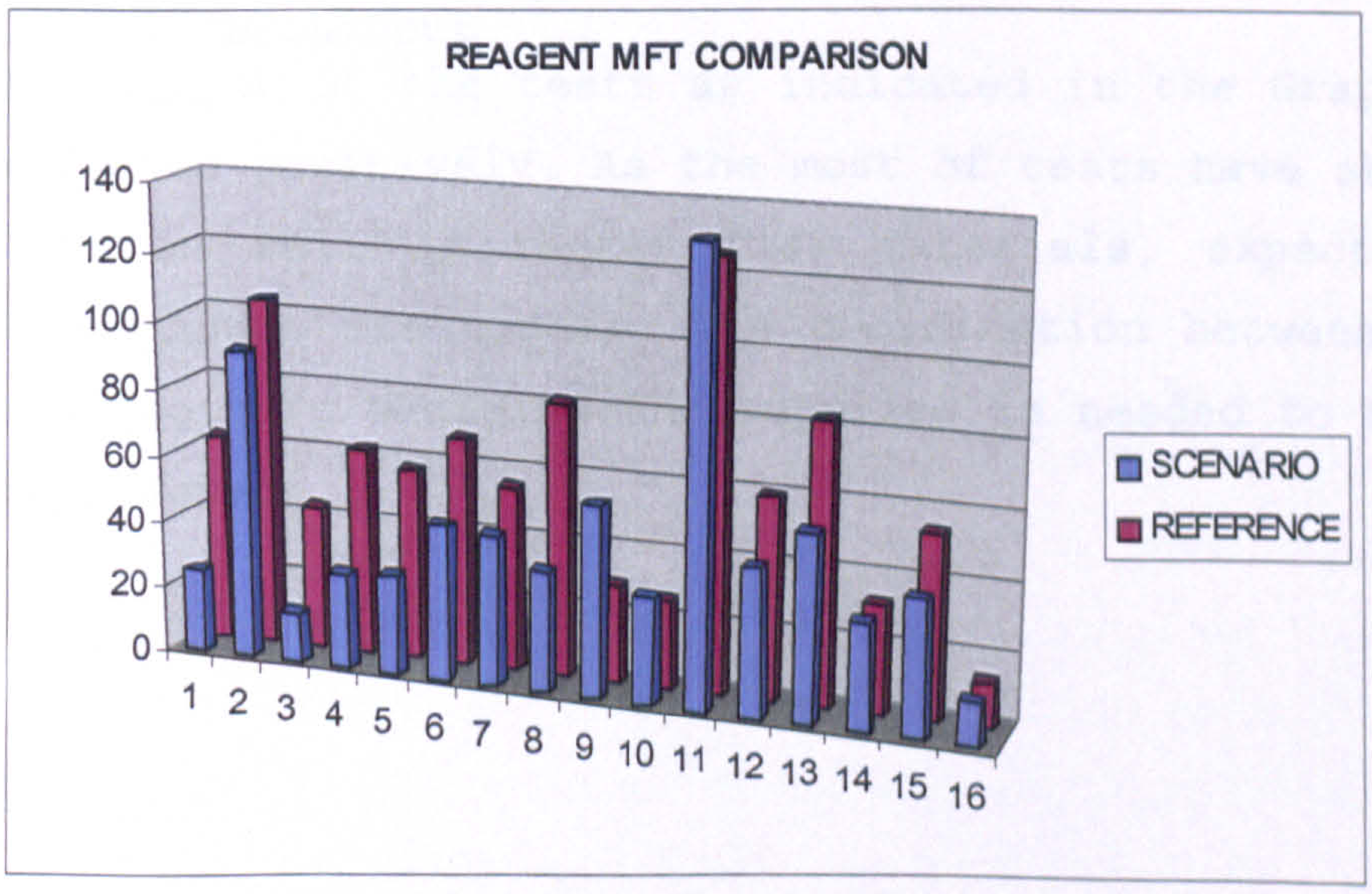
Graph 72

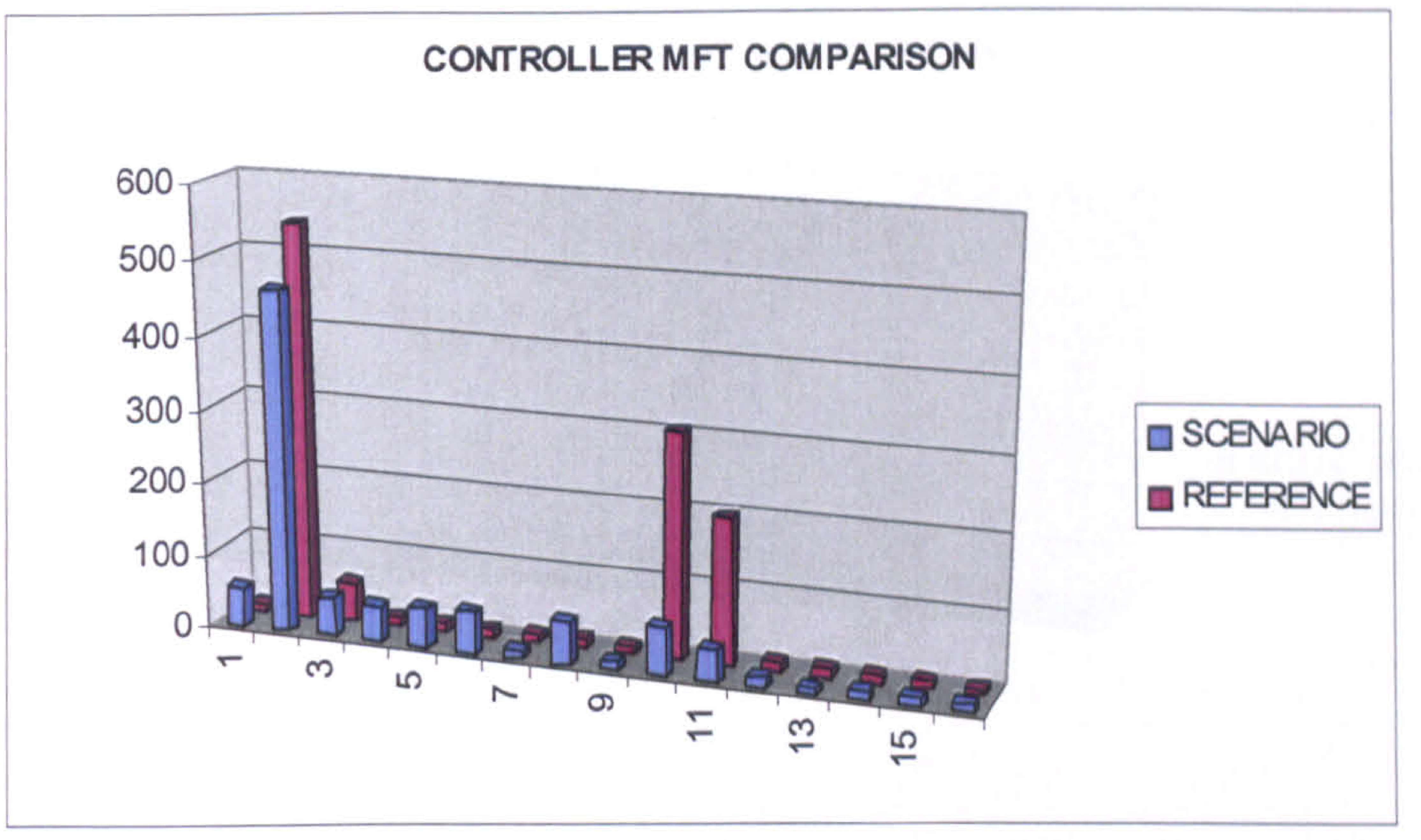


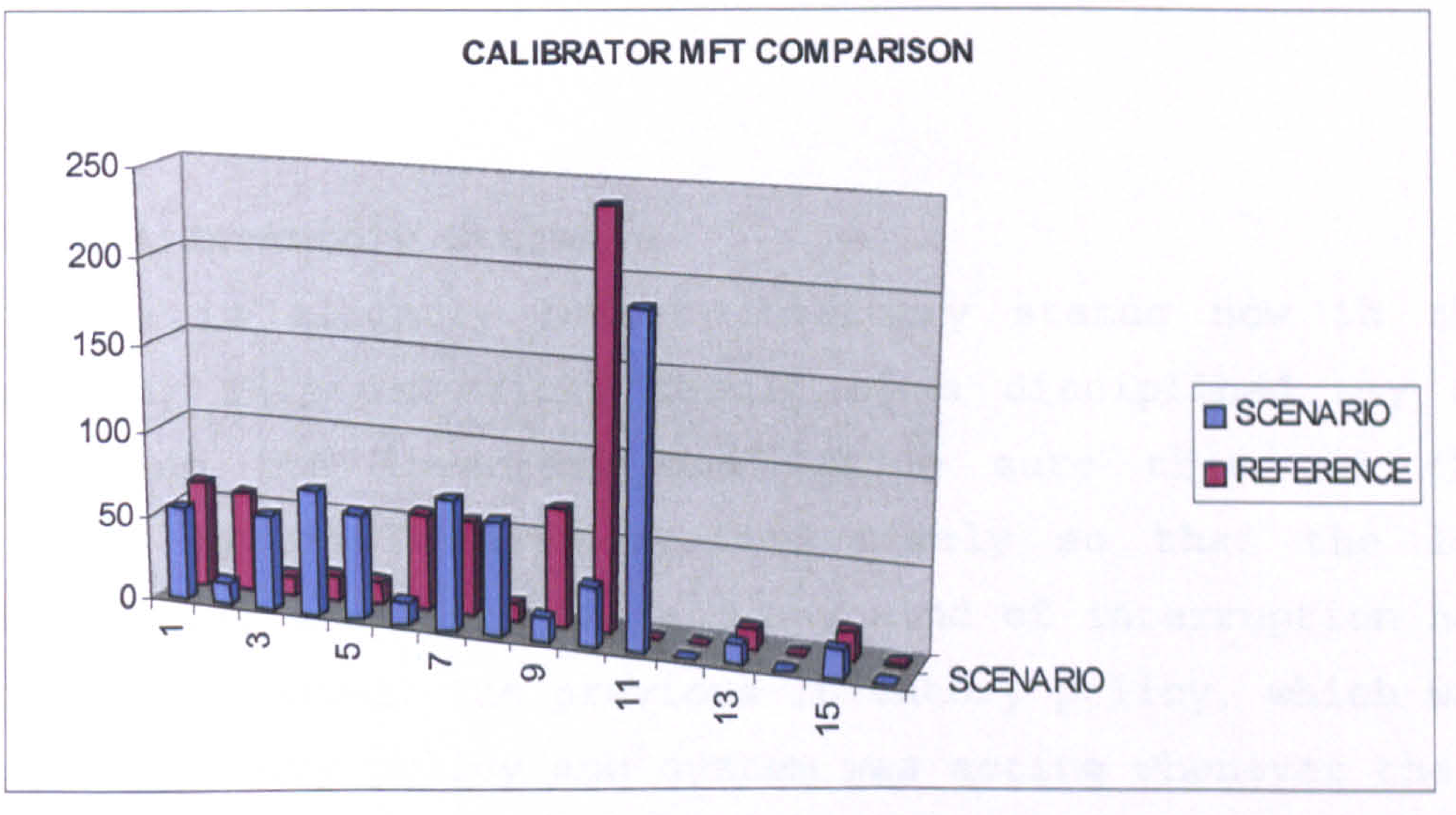
10.1.2 Material Flow time

Materials flow time become faster positively for some of materials for the reagents, impacting on the throughput positively as illustrated in Graph 73 which consist of reagent, calibrator, and controller. The continuous availability of the materials resulted in supplying the needed materials internally more quickly and more smoothly, which has generated a shorter flow time in comparison to reference model.

Graph 73



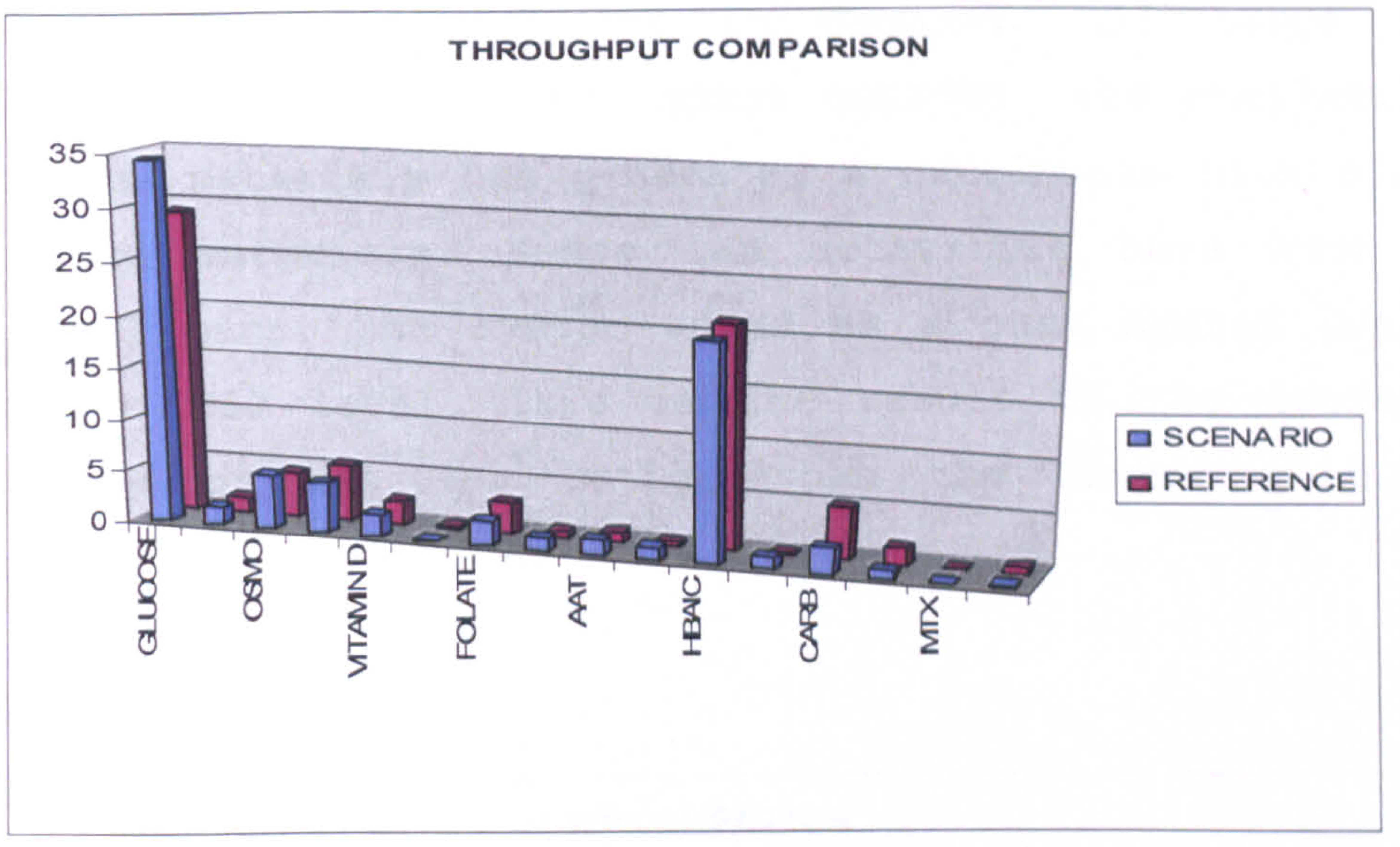




10.1.3 Throughput

Throughput of the tests as indicated in the Graph 74 was affected positively. As the most of tests have short lead time as well as faster flow materials, expectedly the throughputs are higher. The coordination between the lab and logistic managing the supplies is needed to have more improvement.

Graph 74



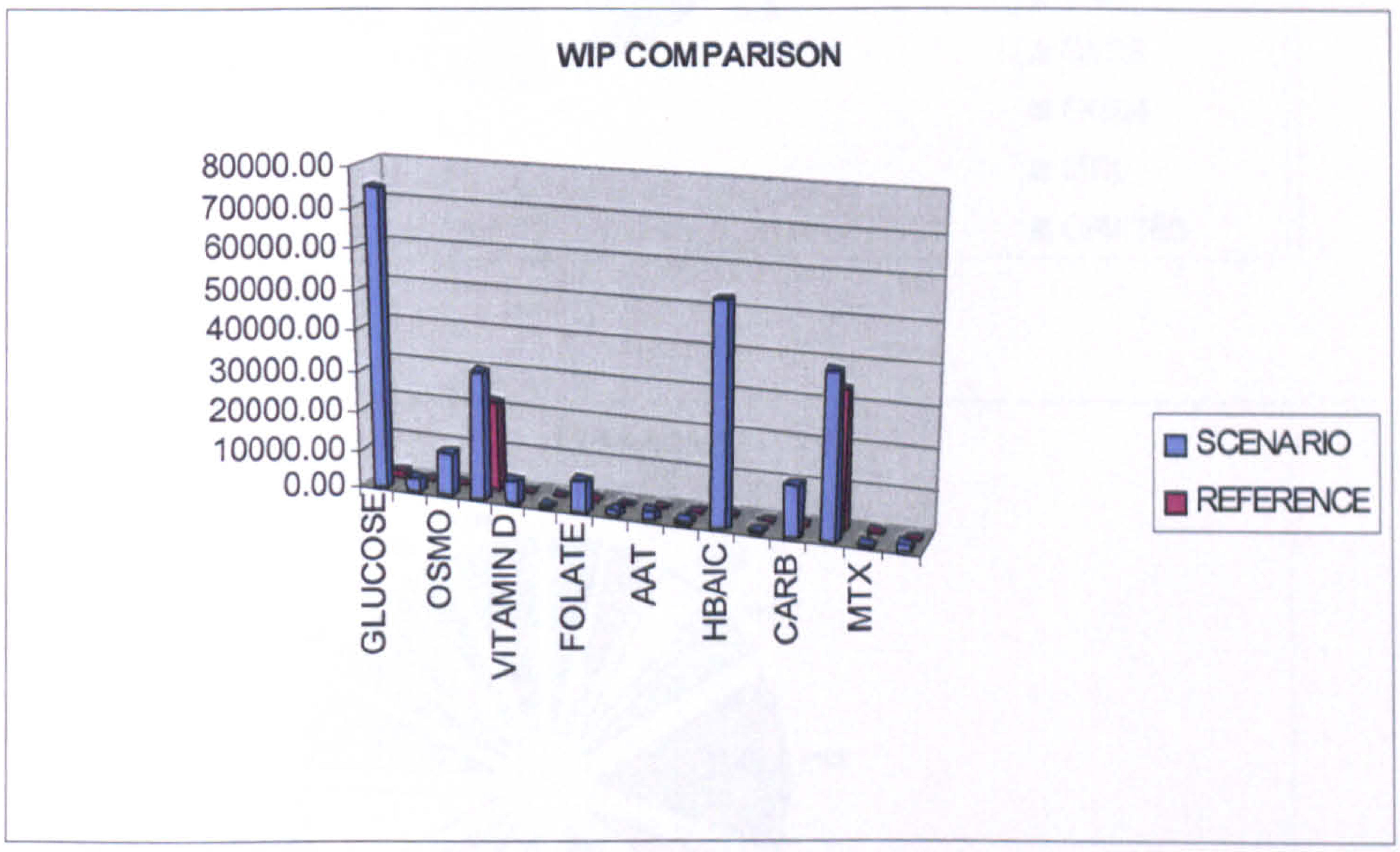
10.1.4 Inventory Status

There is slightly better inventory status now in the system. This is mainly result of a disciplined way of treating the inventory and making sure that all the needed materials are obtained timely so that the lab activities are sustained and any kind of interruption has been eliminated. The previous inventory policy, which was a reactionary policy and system was acting whenever there is a need for a material and was being ordered. Since system was triggered most of the time based on a need, the longer procurement periods caused late deliveries as well as irregular deliveries causing serious interruption in the lab activities, in turn causing very poor performance in the system. The continuous policy has created a discipline in the order time and quantity considering the need of the system as well as the supplier lead time so that material availability has restored and interruptions generated by poor supply chain activities have been eliminated, in turn generated better system performance in terms of all major metrics.

10.1.5 W I P

Graph 75 indicates work in process. All tests have increased WIP with the impact outcome. The availability of the materials has generated a continuous flow of the needed materials. Since lab activities have kept its normal pace, the system acted as a push system causing higher WIP level. This is the result of the operation policy of the lab rather than the inventory policy adopted in the system

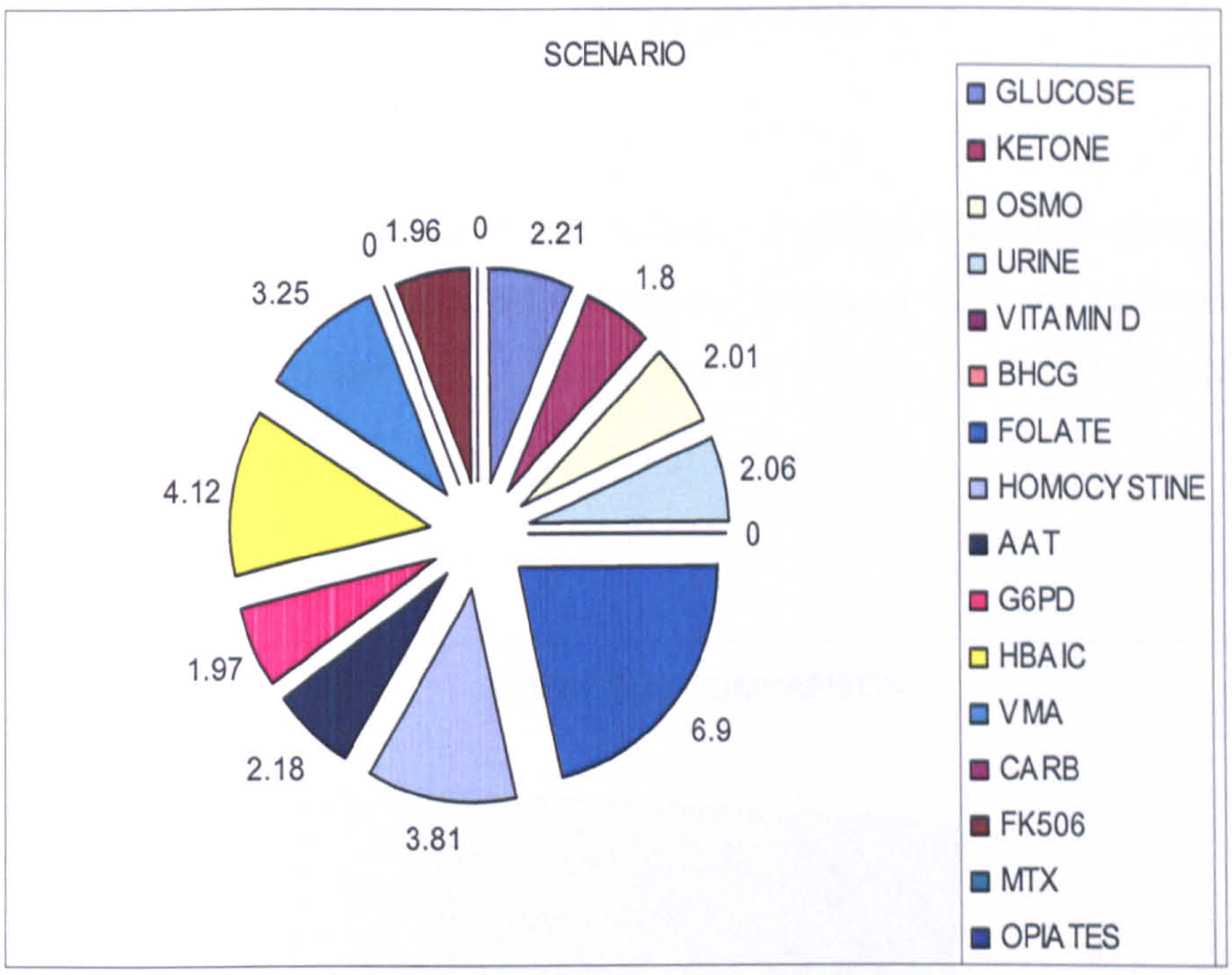
Graph 75

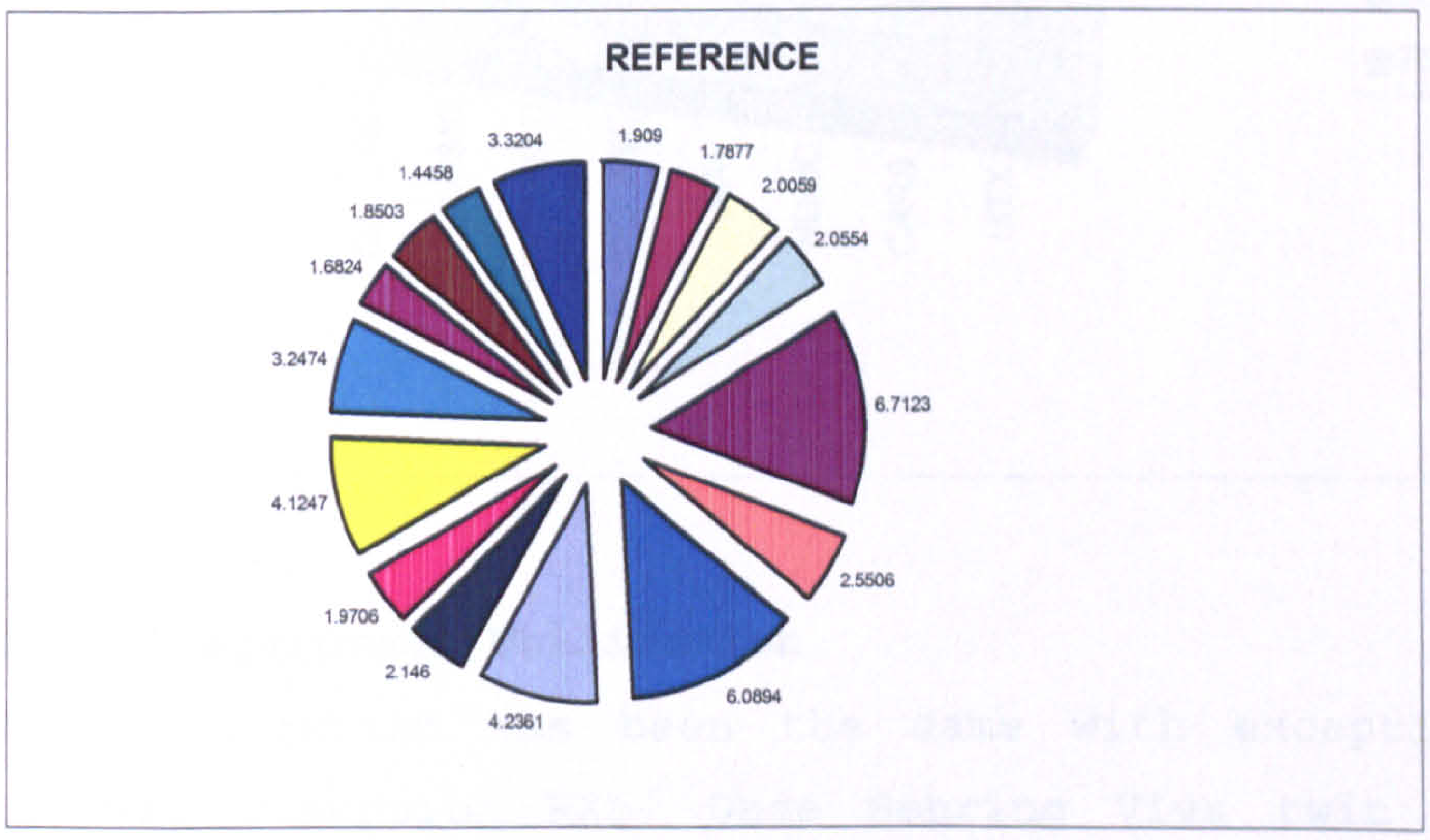


10.1.6 Cost of Test

The costs of each test are higher than the Reference Model (Graph 76) because of the staff and resources are spending more time for continuously monitoring the inventory. It is noted that five tests not showing the result; Vitamin D, BHCG, Carb, MTX, and Opiates.

Graph 76





10.2 Secondary Performance Measures

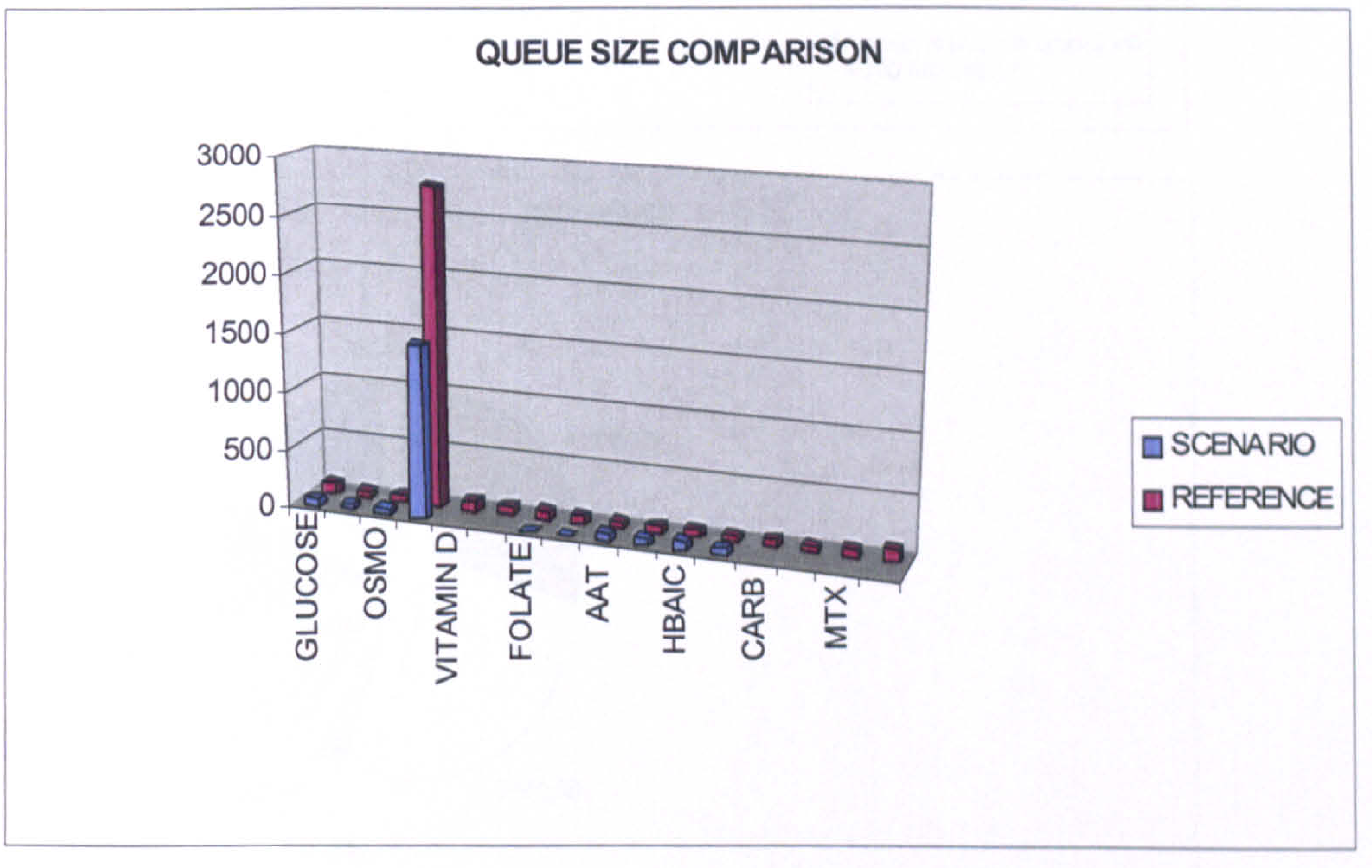
10.2.1 Material Order Size

The material orders have increased by more than 65% for the reagent whiles the calibrator and the controller by 30%. This is because the inventory kept its maximum level and an order is placed for any item that is less than its required level. This naturally has affected the level of inventory and increased considerably.

10.2.2 Queue Size

As discussed in the lead-time, similarly the queue size (Graph 77) was reduced to more than a third in some tests with the greatest change in the special Chemistry Section.

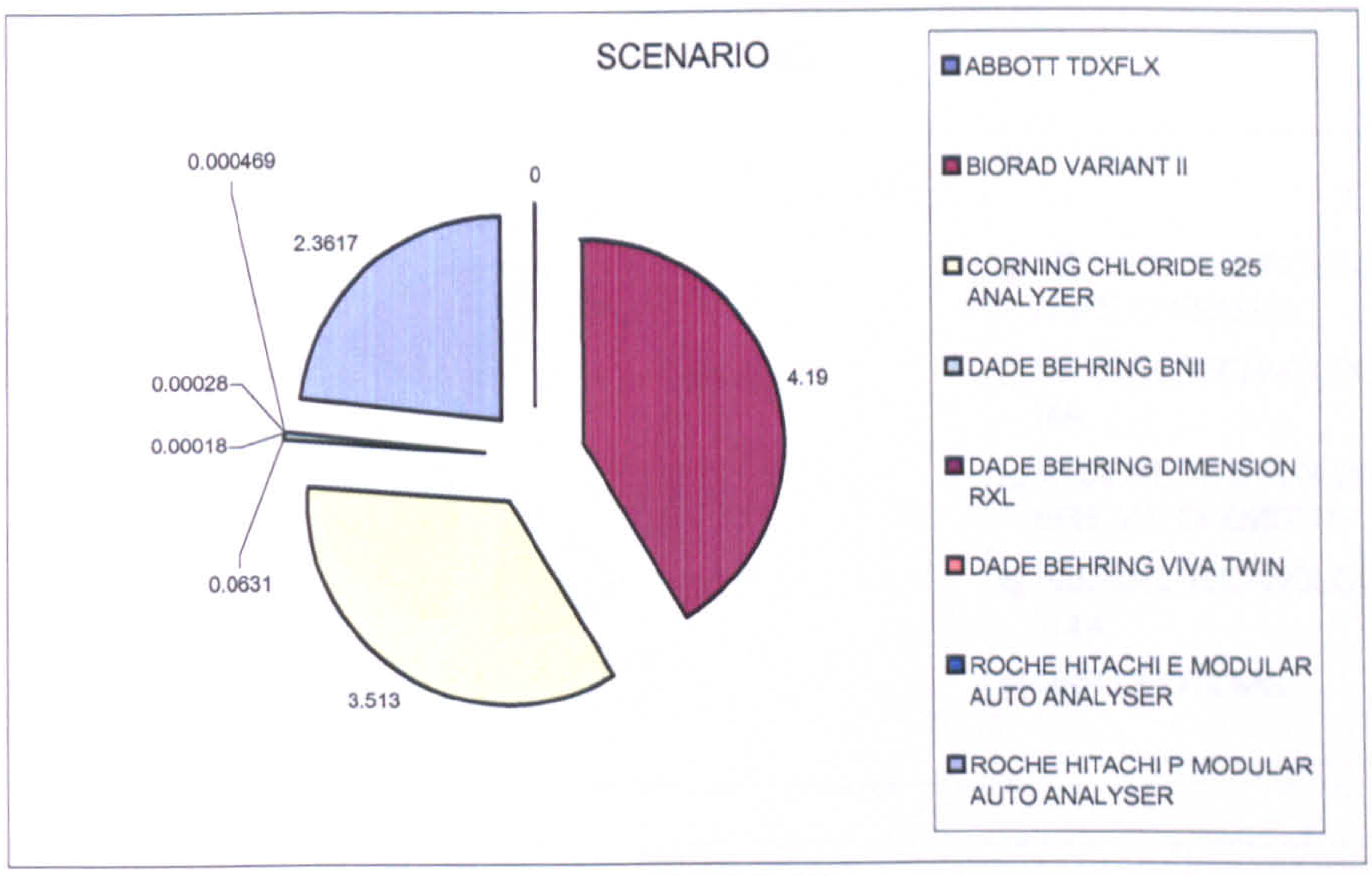
Graph 77

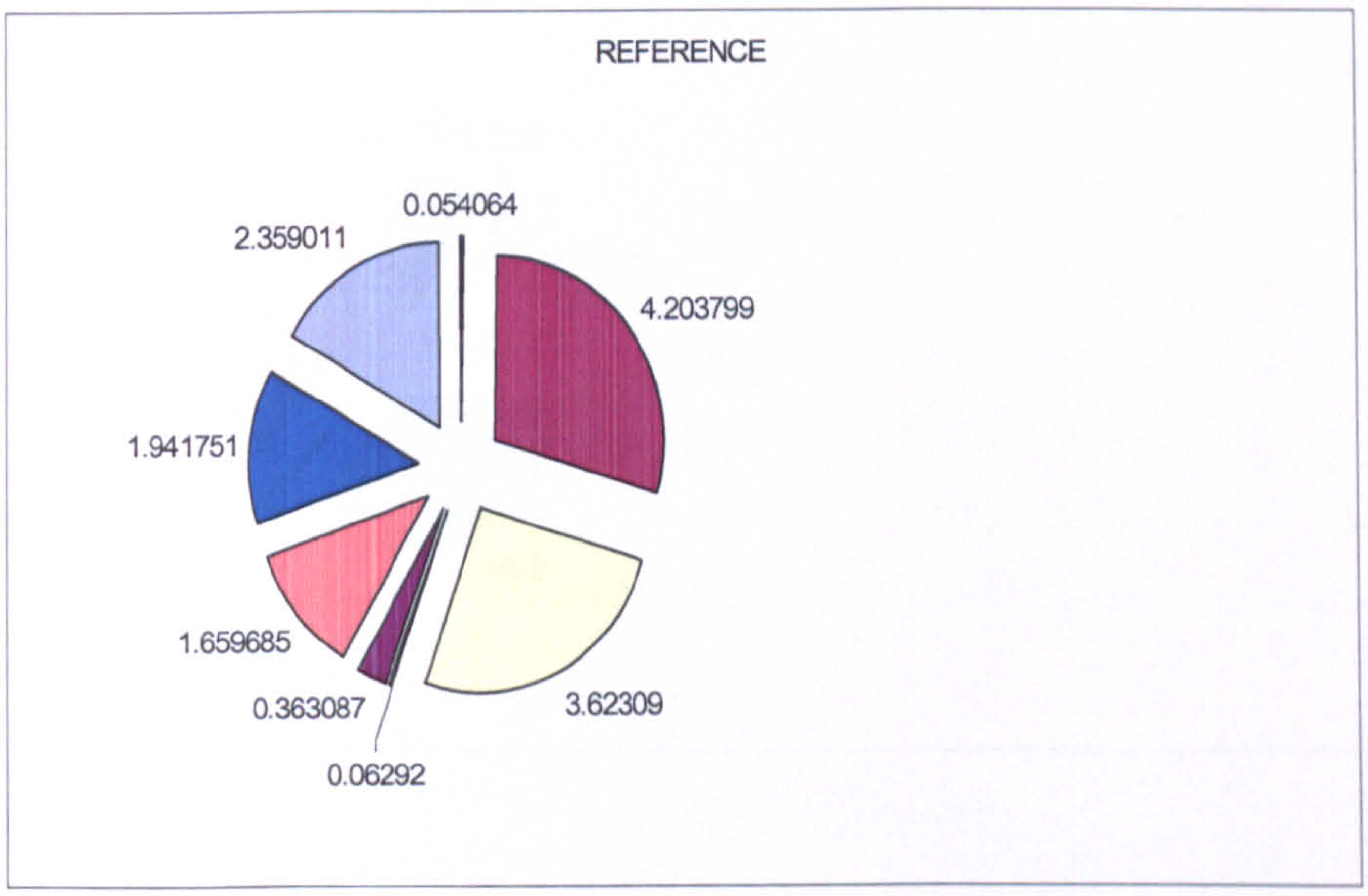


10.2.3 Equipment Utilization

The utilization has been the same with exception Dade Behring Dimension RXL, Dade Behring Viva twin and the Roche Hitachi E modular Auto Analyzer. (Graph 78)

Graph 78

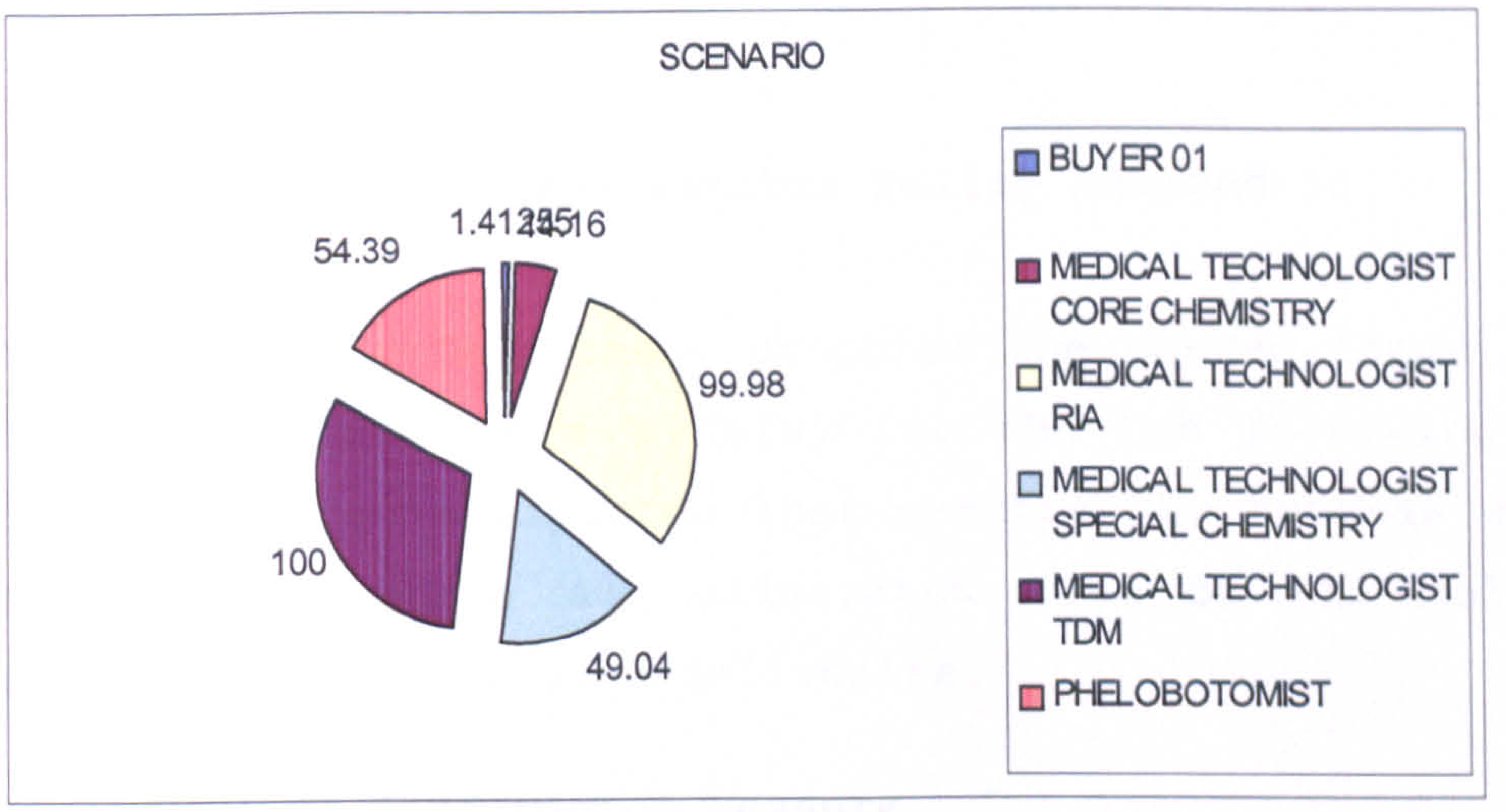


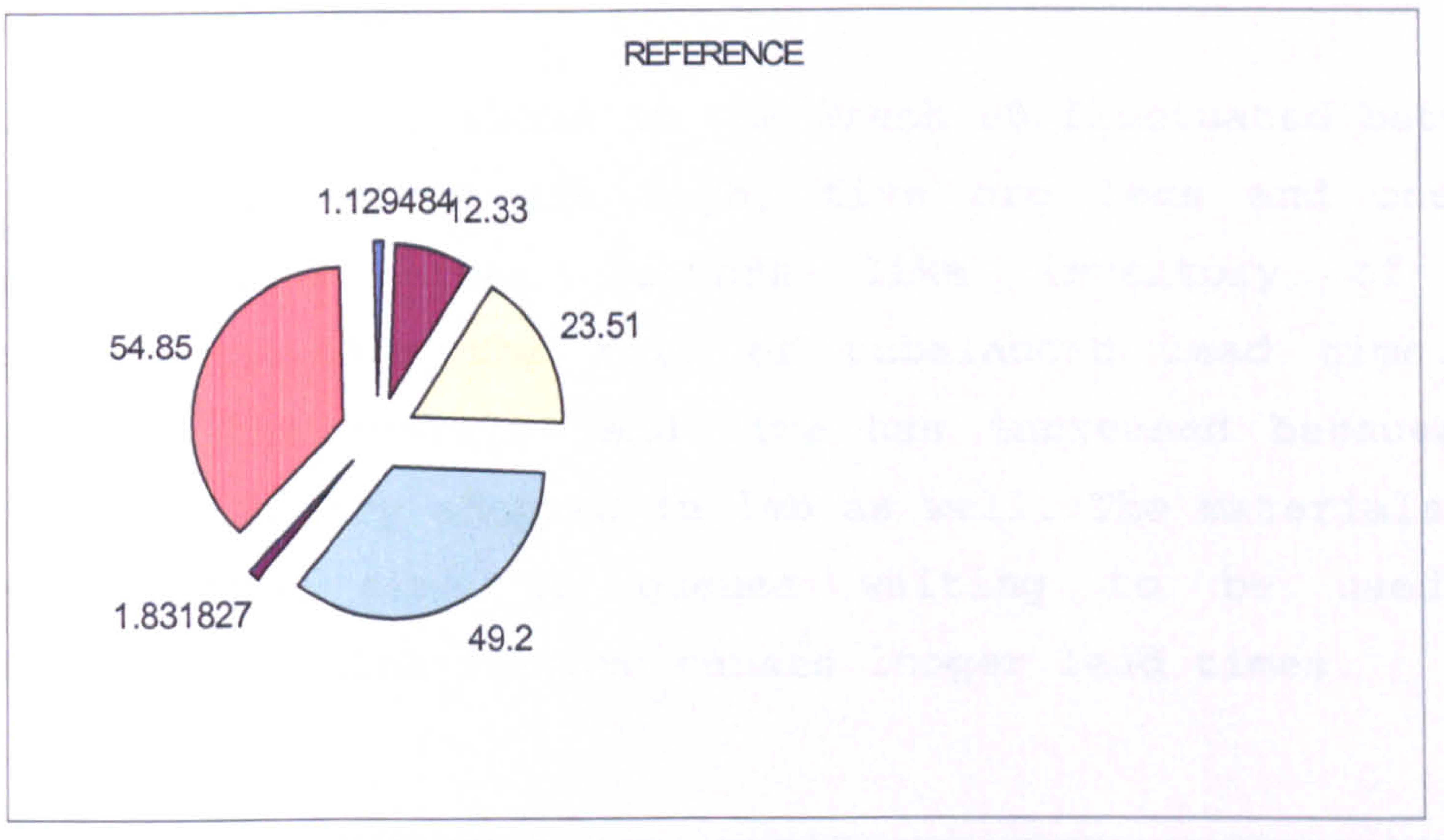


10.2.4 Staff Utilization

The staff utilization is lower than the Reference Model (Graph 79) except the Medical Technology RIA which increased to the maximum; also the Medical Techno lost TDM showing the unbalance of staffing distribution.

Graph 79





10.3 Conclusion

Improvement in the lead time in general, but in the RIA Section, it was very low because of free staff because the Vitamin D & BH tests were not performed. The mean material flow time is much better as reduced by 30-50%, throughput of all components are high relatively to the throughput of the tests that were become higher. This indicates that the material availability has affected the system performance positively especially for the metrics that are heavily depended on the availability of material or uninterrupted supply of needed materials, which eliminated the delays or idleness for equipment and staff utilization.

11. Scenario Fourteen: Batches Policy Adapted in Purchasing

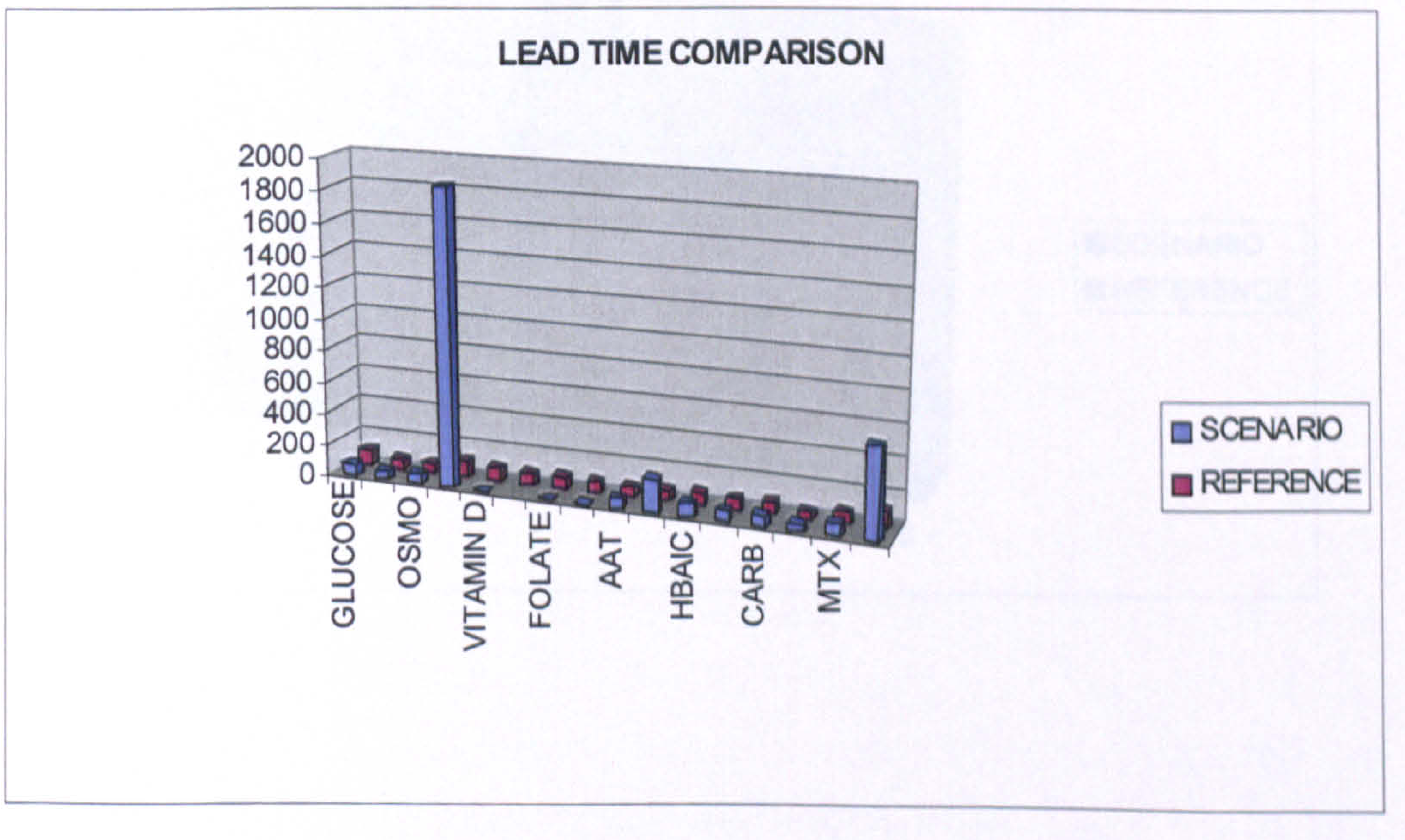
The Purchasing Department procures the needed items case by case which causes a delay for the Lab receiving the component. It is expected that purchase by batches would speed the process and eliminates some of the delayed generated by small size deliveries.

11.1 Primary Performance Measure

11.1.1 Lead Time

The lead time as shown in the Graph 80 fluctuated between ten of the tests are high; five are less and one no record. The other factors like inventory of the components have the role of unbalanced lead time. On average the overall lead time has increased because of batching policy adopted in lab as well. The materials now spend more time in queues waiting to be used in processes, which in turn causes longer lead times.

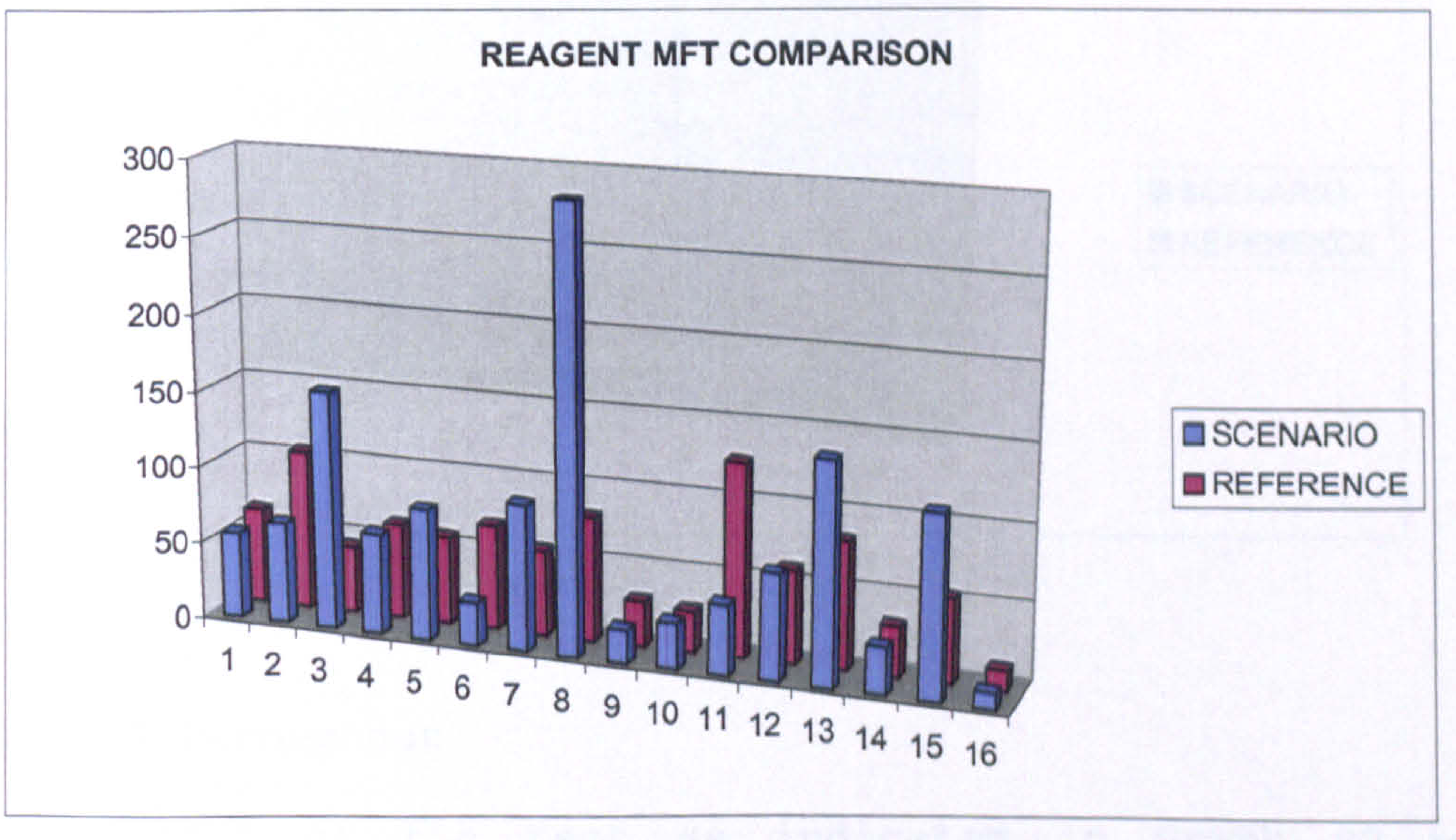
Graph 80

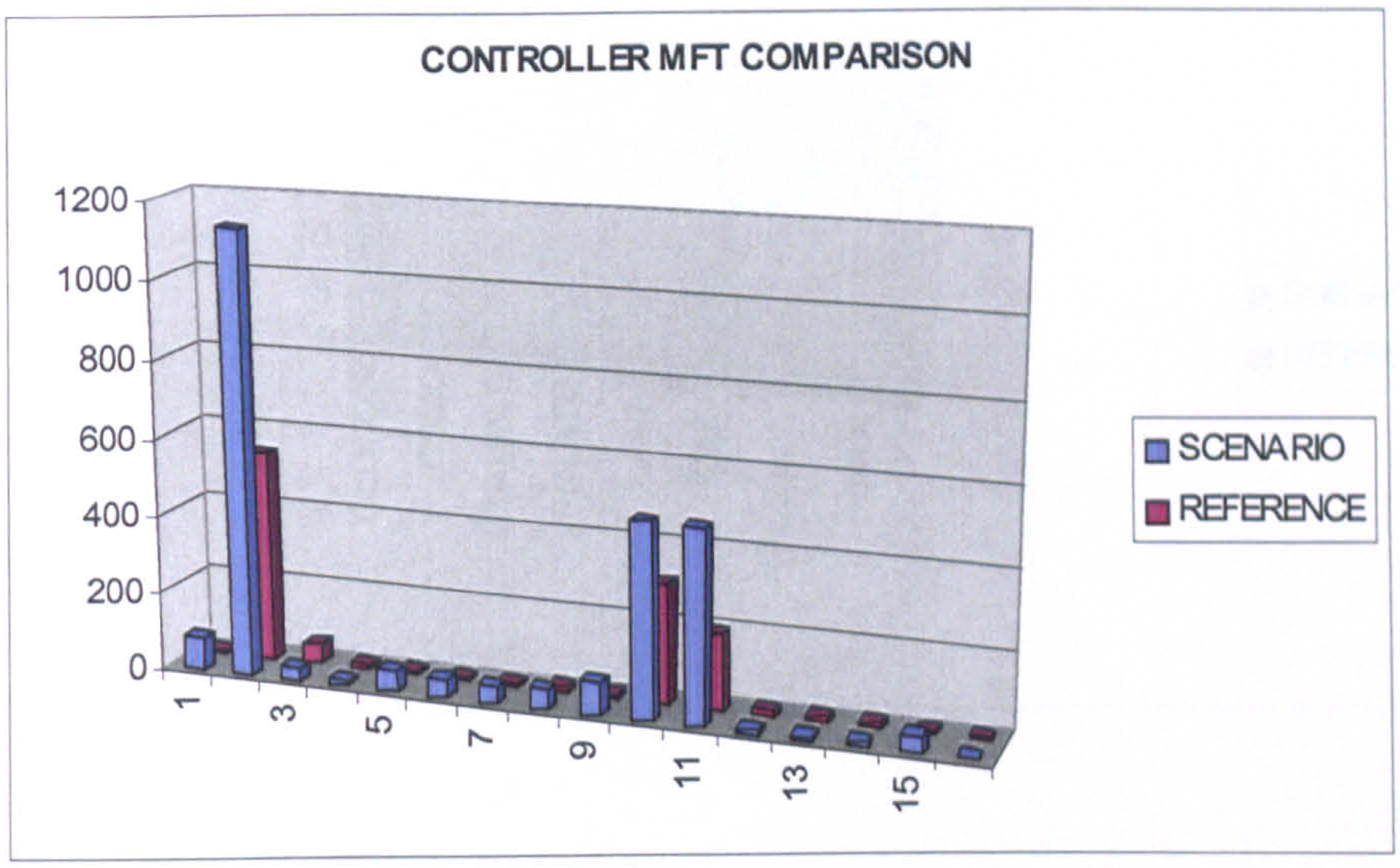


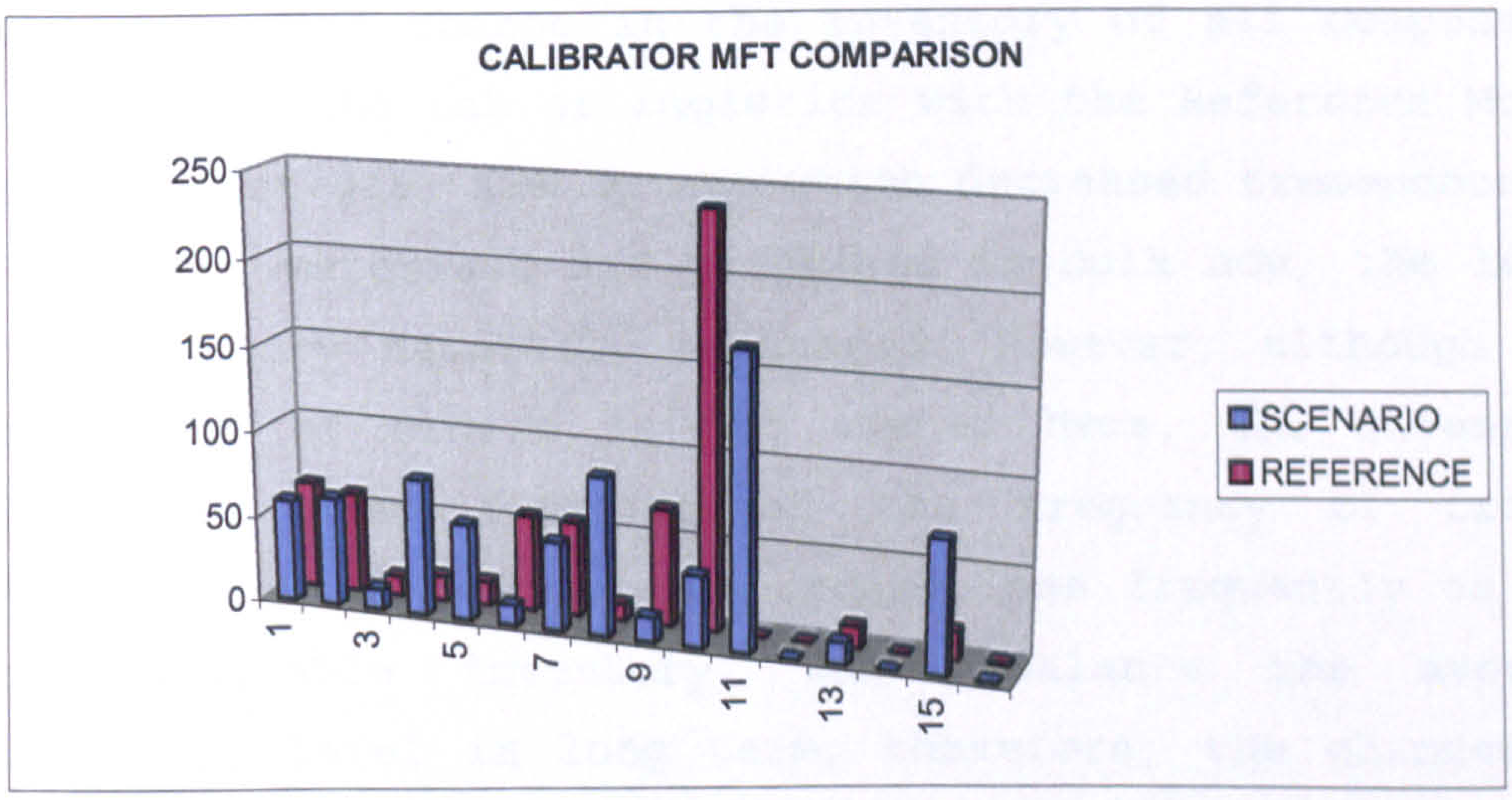
11.1.2 Material Flow time

More than 60% of all tests are affected in a negative way by this change as illustrated in Graph 81 which consistS of reagent, calibrator, and controller. As it is experienced in manufacturing organizations, although batch policy keeps the system busy all the time but cause serious WIP and longer lead times as well as longer mean flow time. The same result has been experienced in the health care system and when we ordered needed materials in batches and sent the needed materials in batches to the lab. This has generated more material availability in the stock, which eliminated some of the interruptions caused inadequate deliveries or shortage of materials, but delivering the needed materials to the lab in bulk (batch) has caused serious problems with some of the performance metrics, such as lead time, WIP and mean flow time.

Graph 81



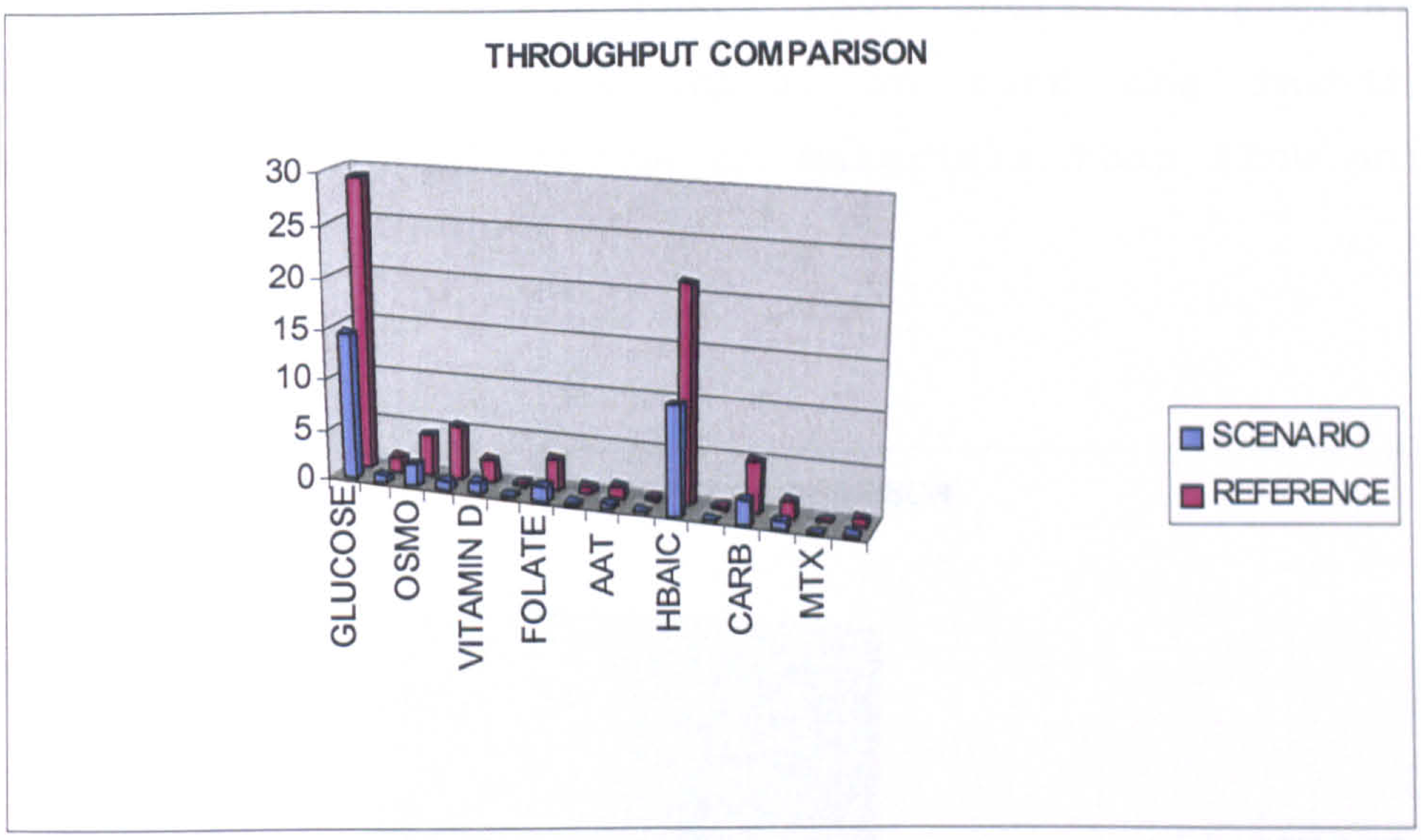




11.1.3 Throughput

Throughput of the test as indicated in Graph 82 was effected negatively by the batch policy; the flow of material was high waiting in front of the processing stations, causing longer queues and WIP.

Graph 82



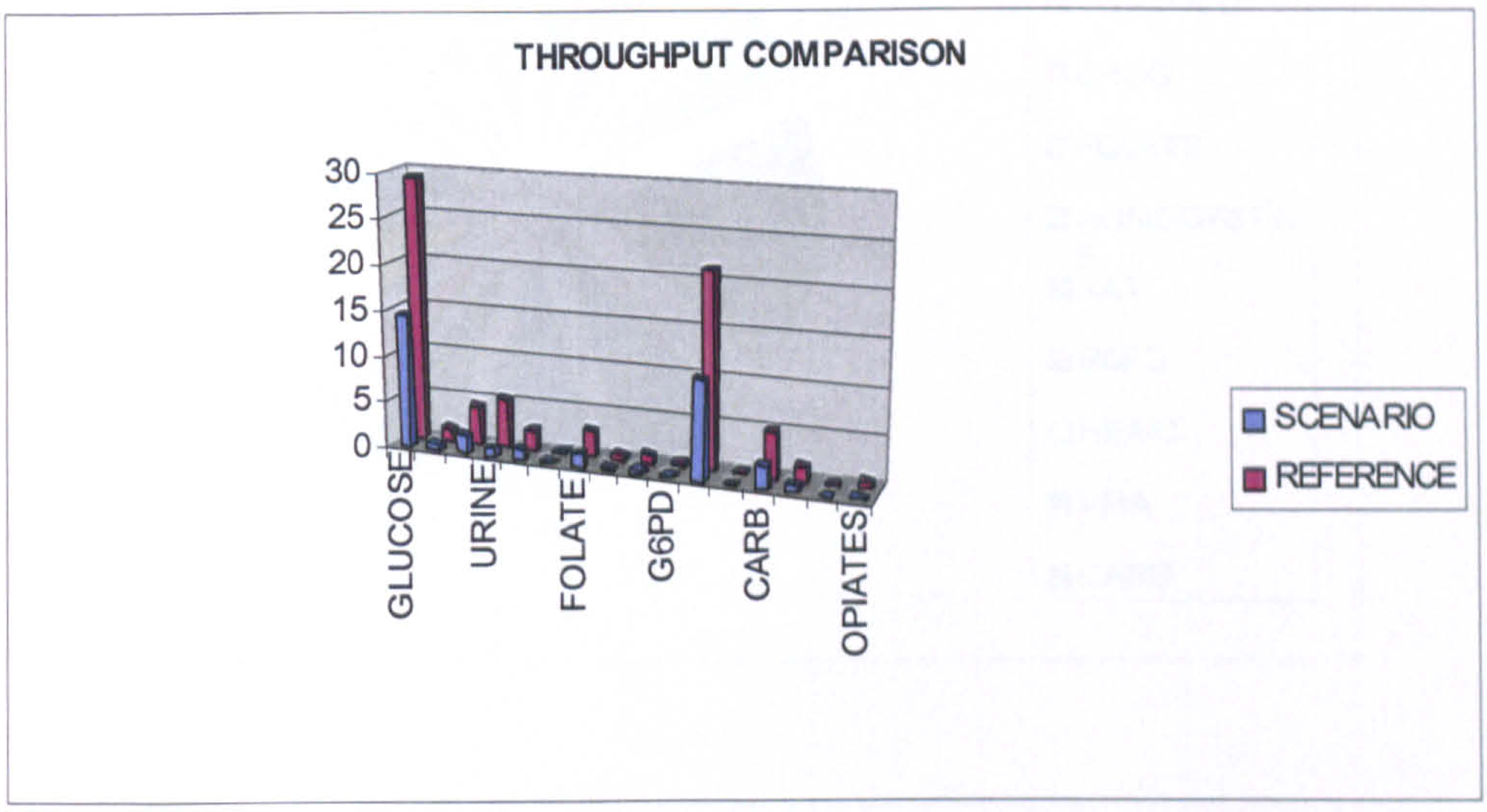
11.1.4 Inventory Status

There is some change in the inventory of all components whether in the Lab or Logistics with the Reference Model except Test #16, TDM Opiate which decreased tremendously. Since the materials are purchased in bulk now, the level of inventory naturally increased. However, although the frequency of orders is not stated here, the inventory level is also function of the frequency of order. Apparently the company now orders less frequently to use the available inventory, which balance the average inventory level in long term, therefore, the changes in inventory is not as dramatic as it is expected.

11.1.5 W I P

Graph 83 indicates work in process. WIP levels for the materials used in all tests have increased similar to some of the scenarios which, in turn the result of increased level of volume of materials that flow within the system.

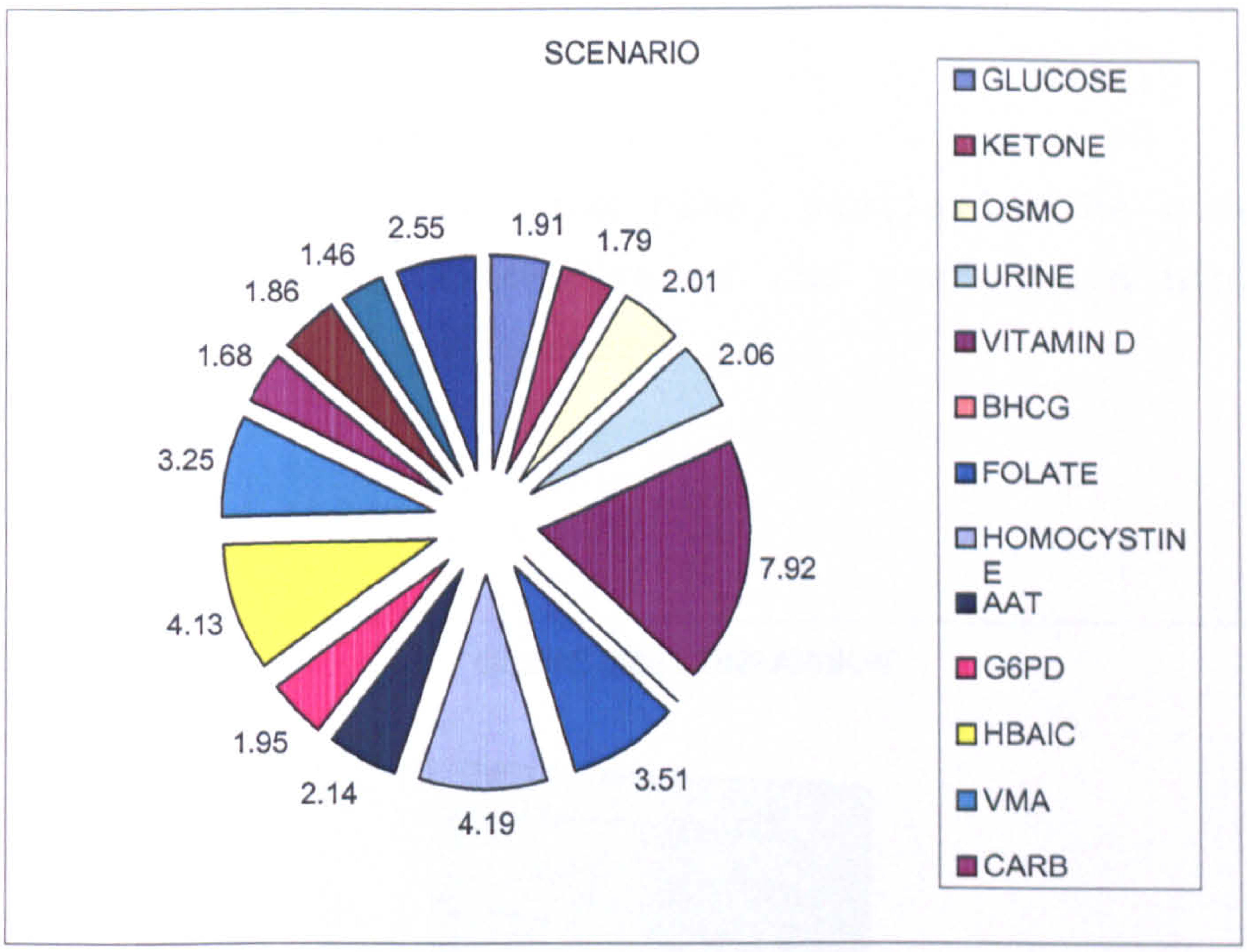
Graph 83

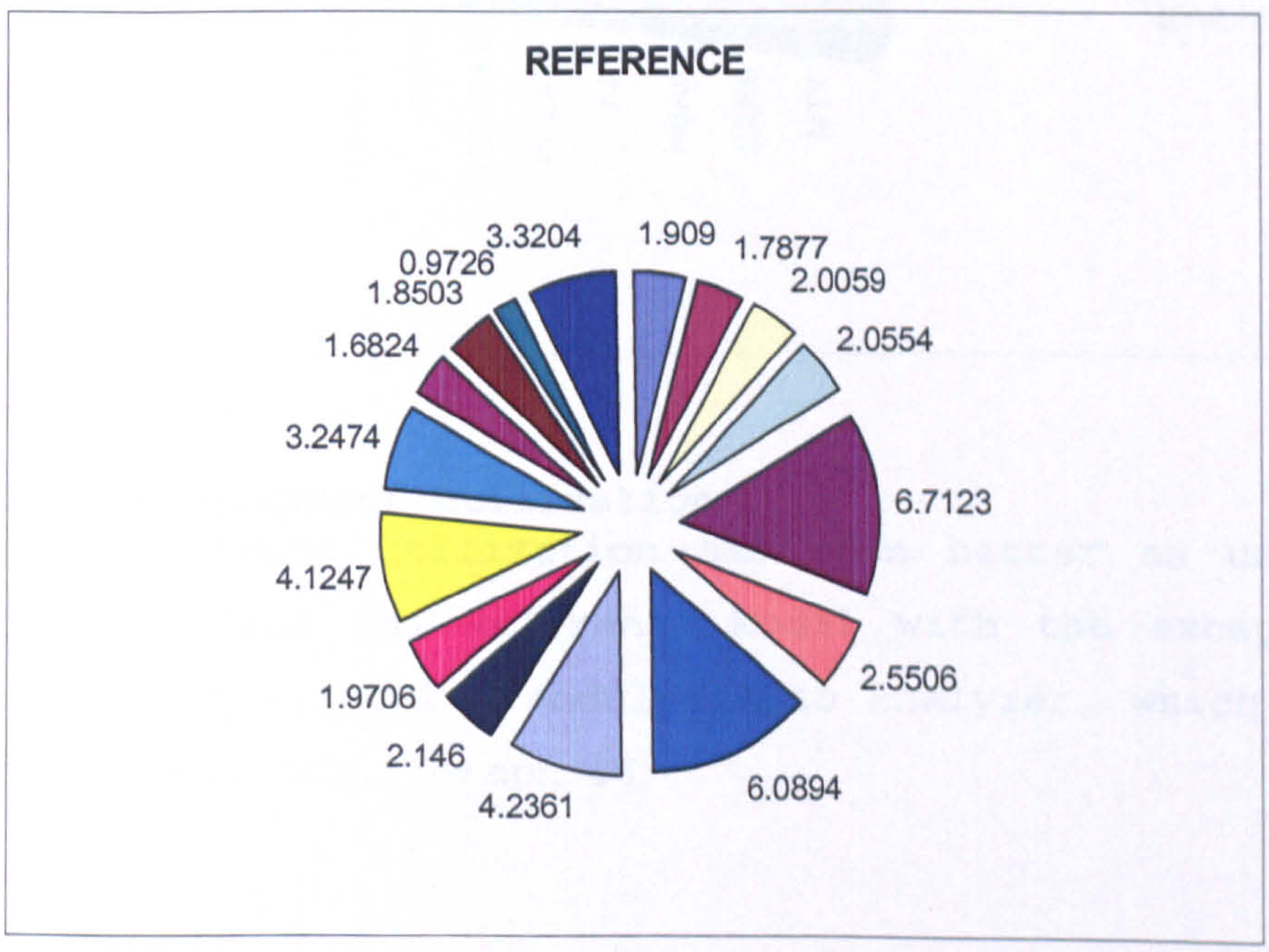


11.1.6 Cost of Test

The costs of each test are not much different than the Reference Model (Graph 84) because the staff and resources are still included in the test calculation. However, the increased level of material purchase has brought some advantages. There are two advantages here. One is that company gets some price discounts since it purchases the needed materials in bulk, and the second advantage is that the orders are made less frequently which reduces the order cost considerably. On the other hand, the increased level of quantities cause a high cost in inventory carrying cost. Therefore, in long term, these two positive and negative points balanced each other and the overall cost has not changed as normally expected as a result of bulk purchases.

Graph 84





11.2 Secondary Performance Measure

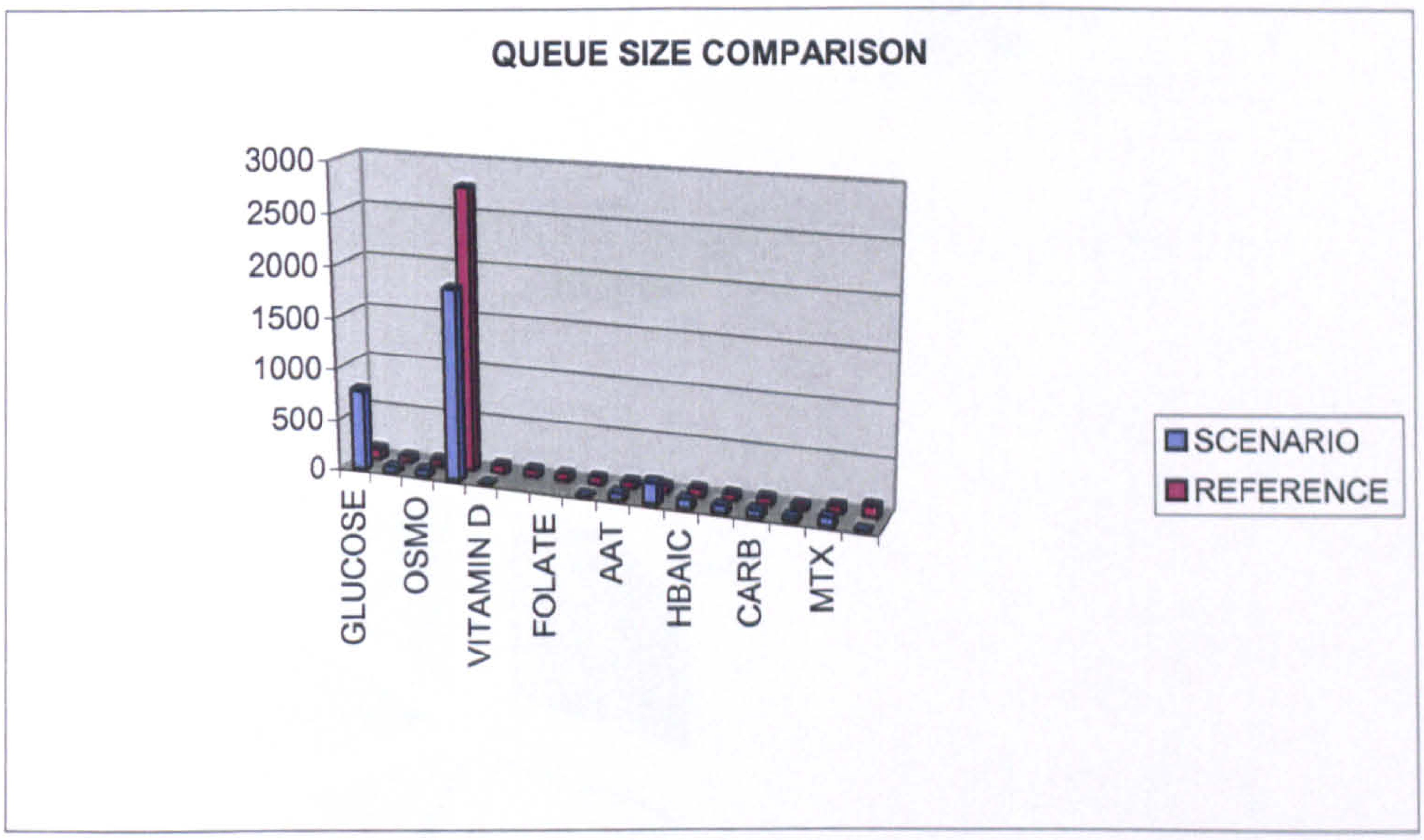
11.2.1 Material Order Size

The material order for the controller materials increased 25%. The same as reagent, while the calibrator reduced by 10%.

11.2.2 Queue Size

As discussed in the lead time, similarly the queue size (Graph 85) fluctuated; ten of the tests were high, five were less and one no record.

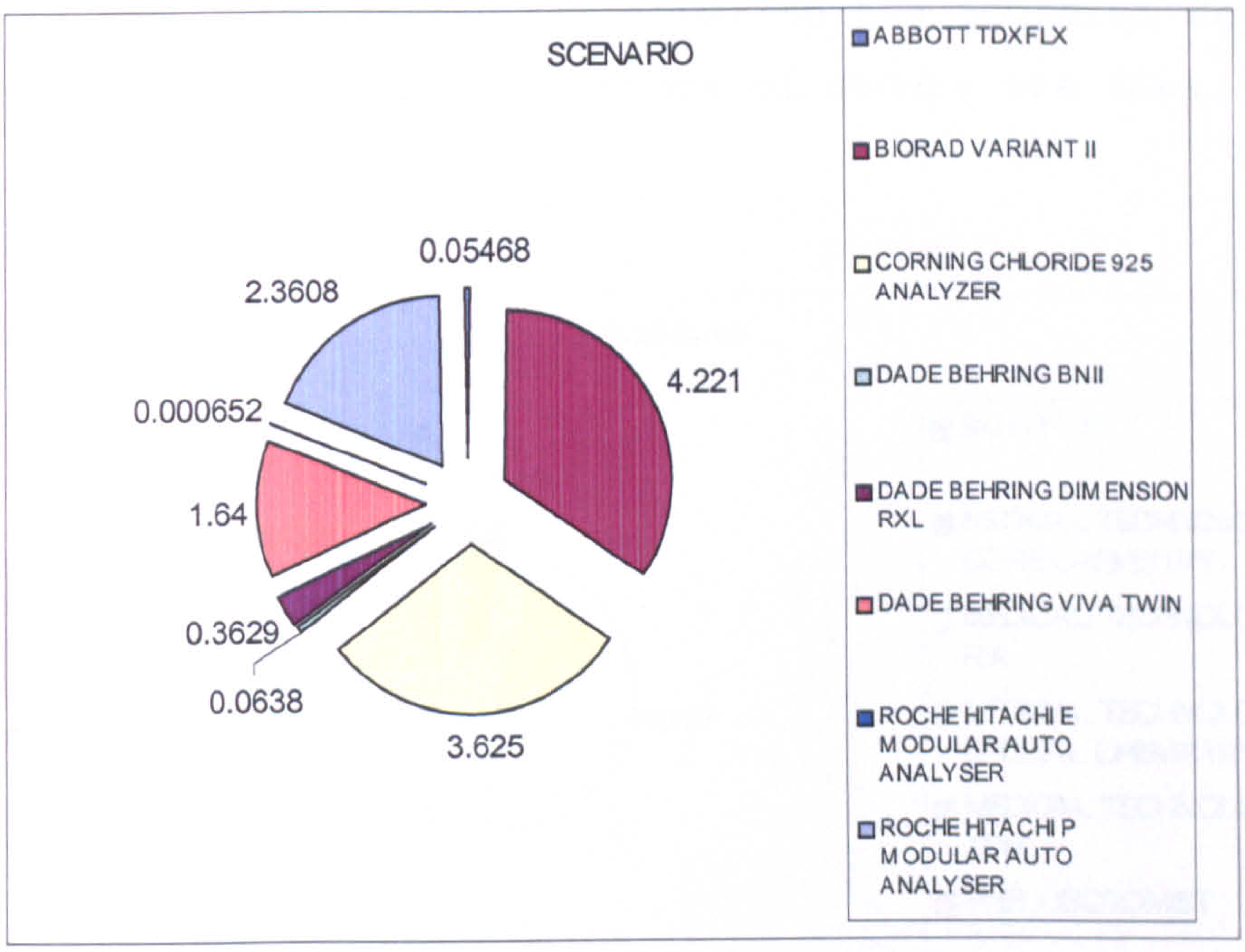
Graph 85

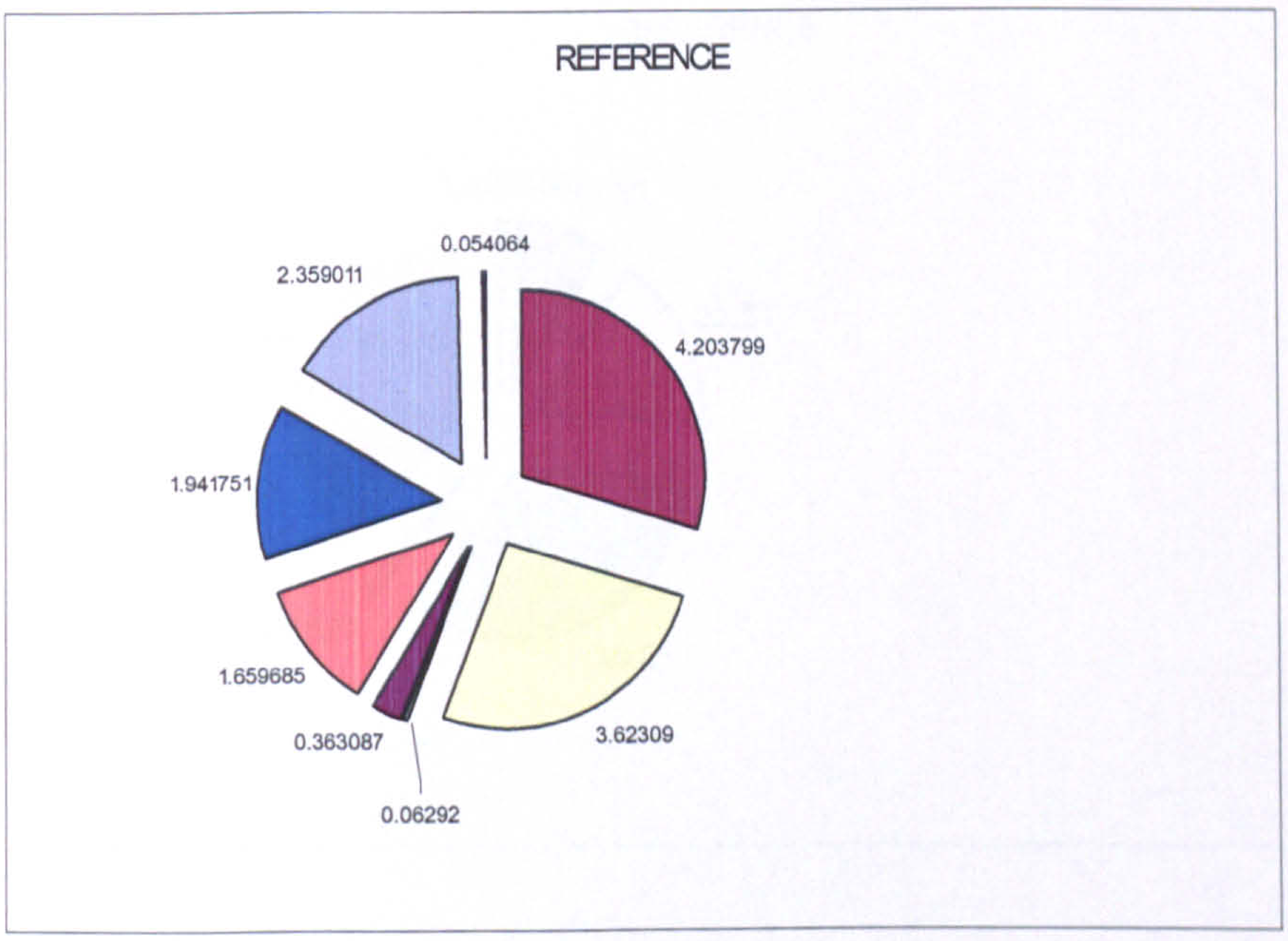


11.2.3 Equipment Utilization

The equipment utilization has been better as using the batches from the Reference Model with the exception of the Roche Hitachi E modular Auto Analyzer, which dropped to the minimum. (Graph 86)

Graph 86

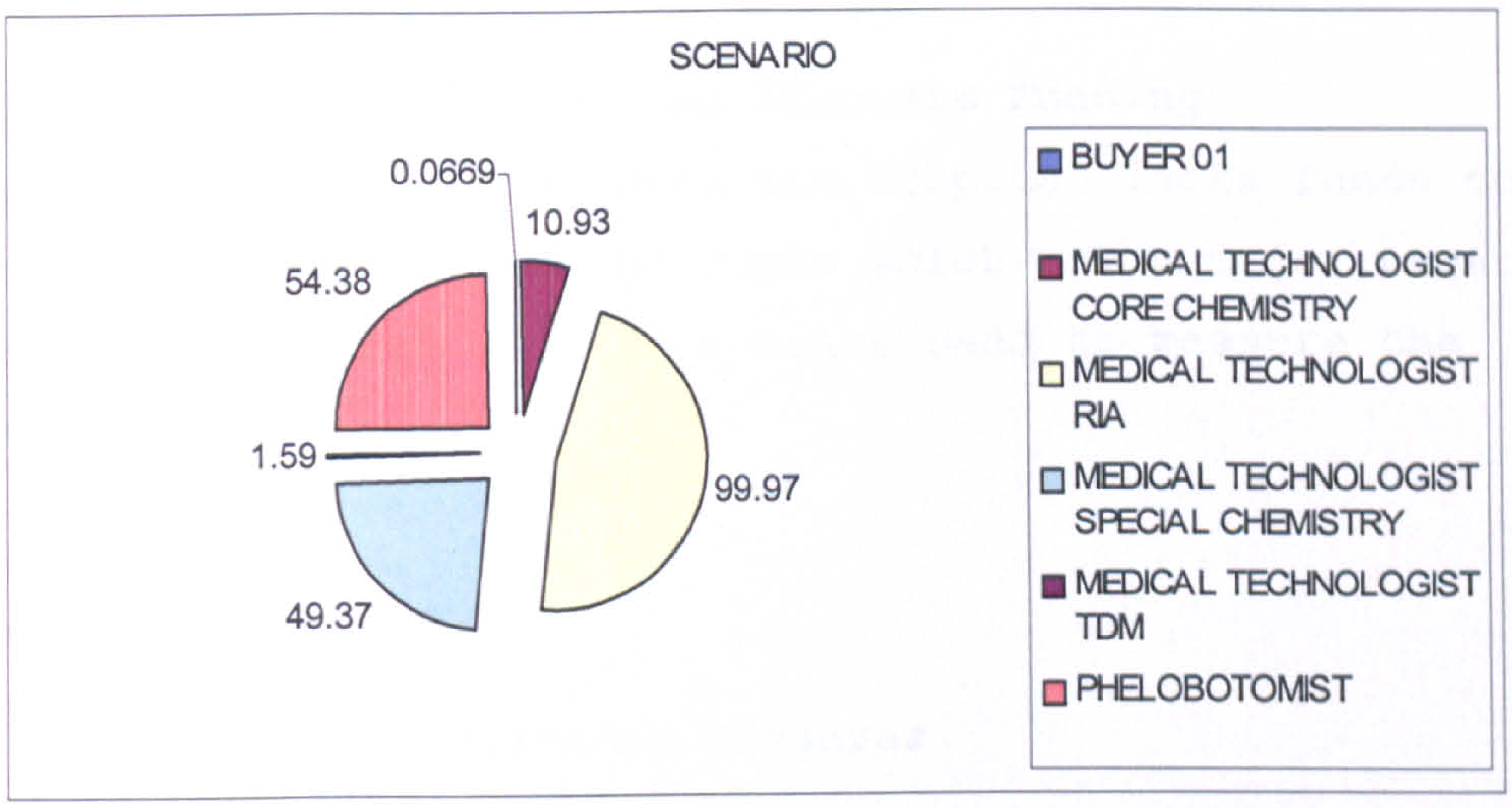


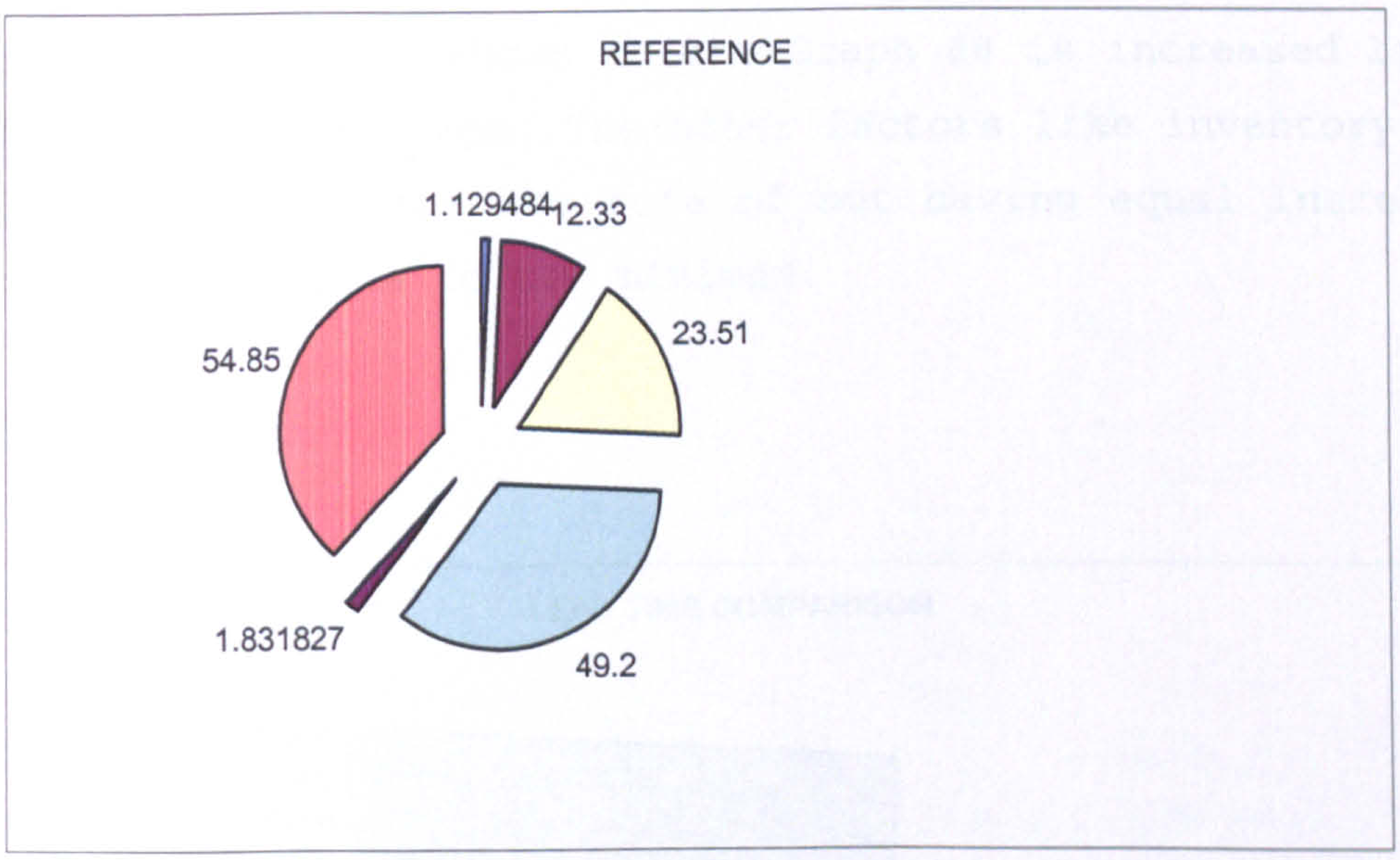


11.2.4 Staff Utilization

The staff utilization is more or less the same with Reference Model (Graph 87) except for the Medical Technology RIA which increased to the maximum, showing the unbalance of staffing distribution. Further, availability of materials in bulk kept the system busy and generated almost the same level of utilization with the reference model. The buyer in the Logistic department has less work, as the numbers of orders are less.

Graph 87





11.3 Conclusion

In general, the lead time increased by 20 to 30% as well as inventory level for all components; material flow time is high effecting the throughput of the tests, staff utilization is the same except the RIA section that increased to 99%. This is normally an expected outcome when a batching policy adopted. As it is explained under different performance metrics, batching has pros and cons and sometimes these two may balance each other generating much more acceptable results, which are the case for this study.

12. Scenario Fifteen: No Adequate Funding

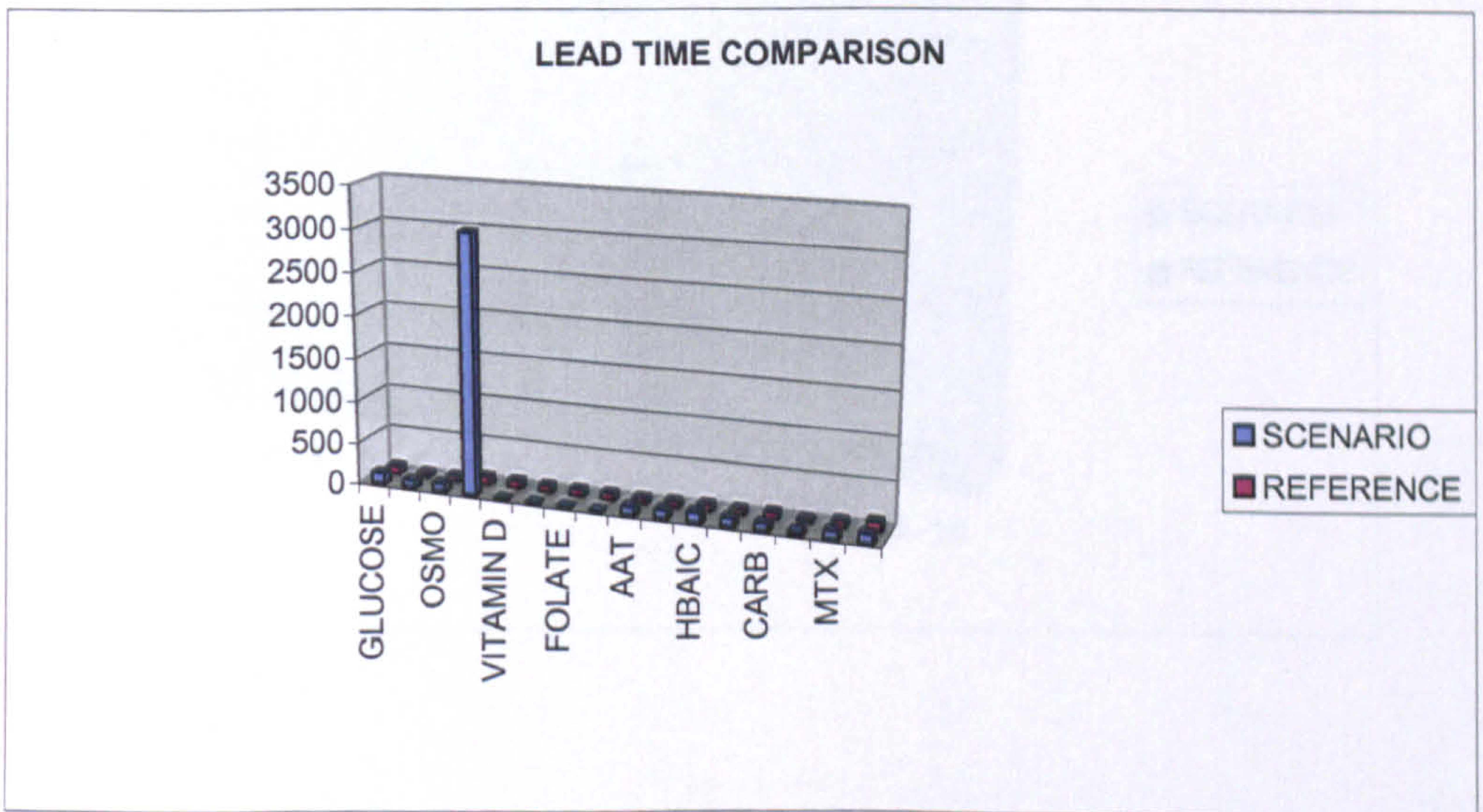
There is comes a time were the Hospital lacks funds to cope with the increasing costs which has a major negative effect on almost all the metrics used to measure the system performance.

12. Primary Performance Measures

12.1 Lead Time

The lead time as shown in the Graph 88 is increased by a different percentage. The other factors like inventory of the components has the role of not having equal increase of the lead time to the minimum.

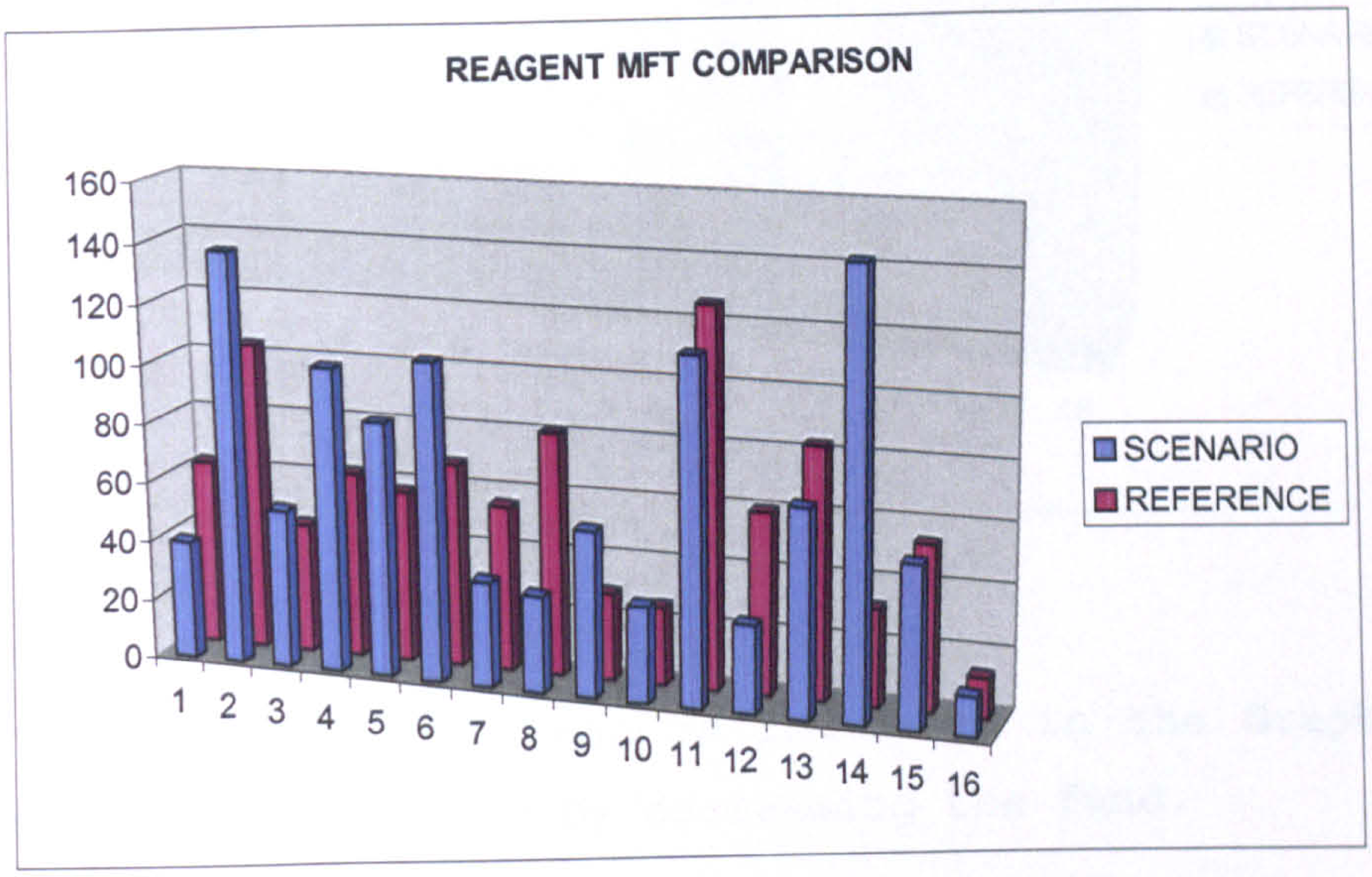
Graph 88

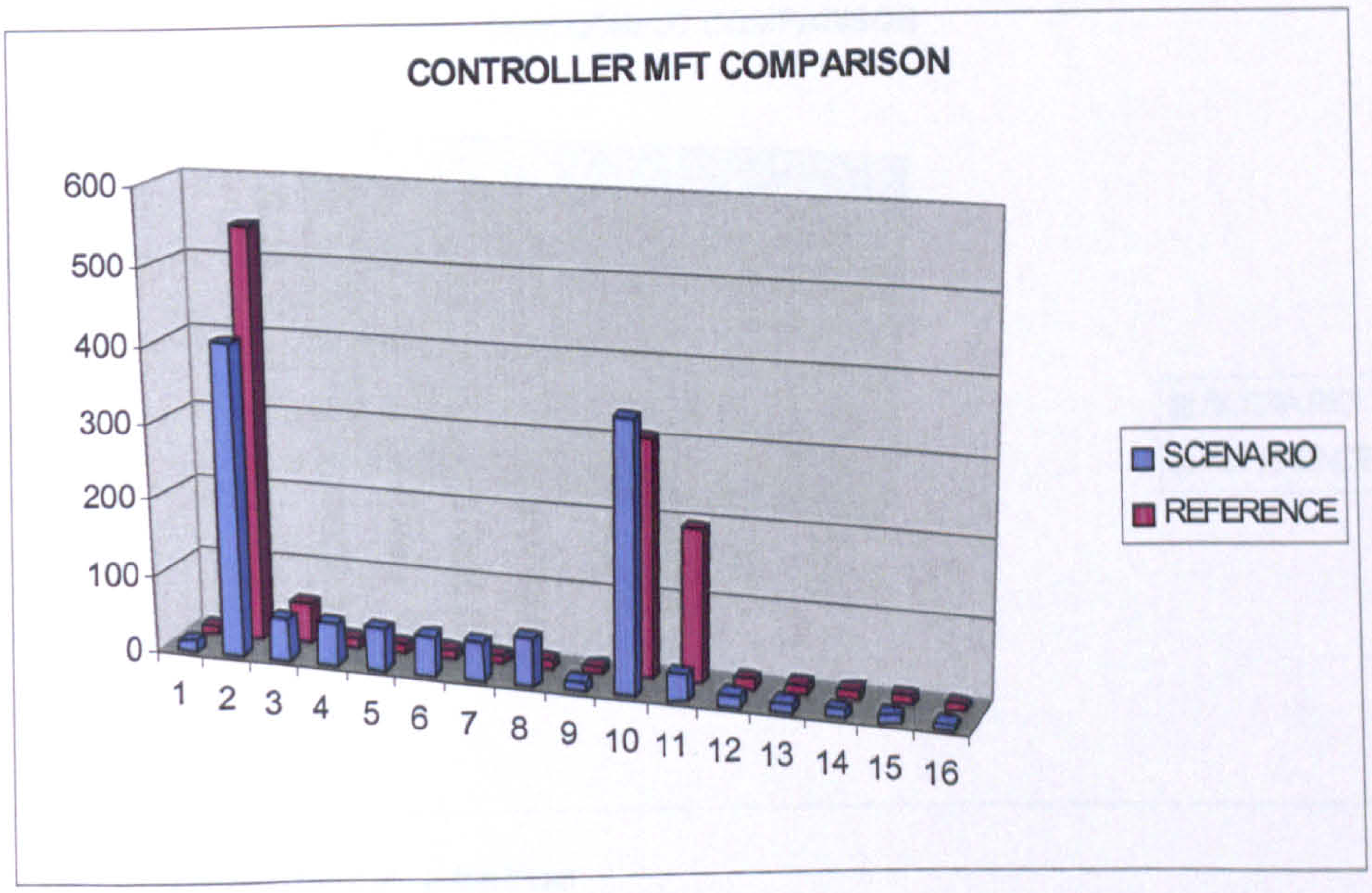


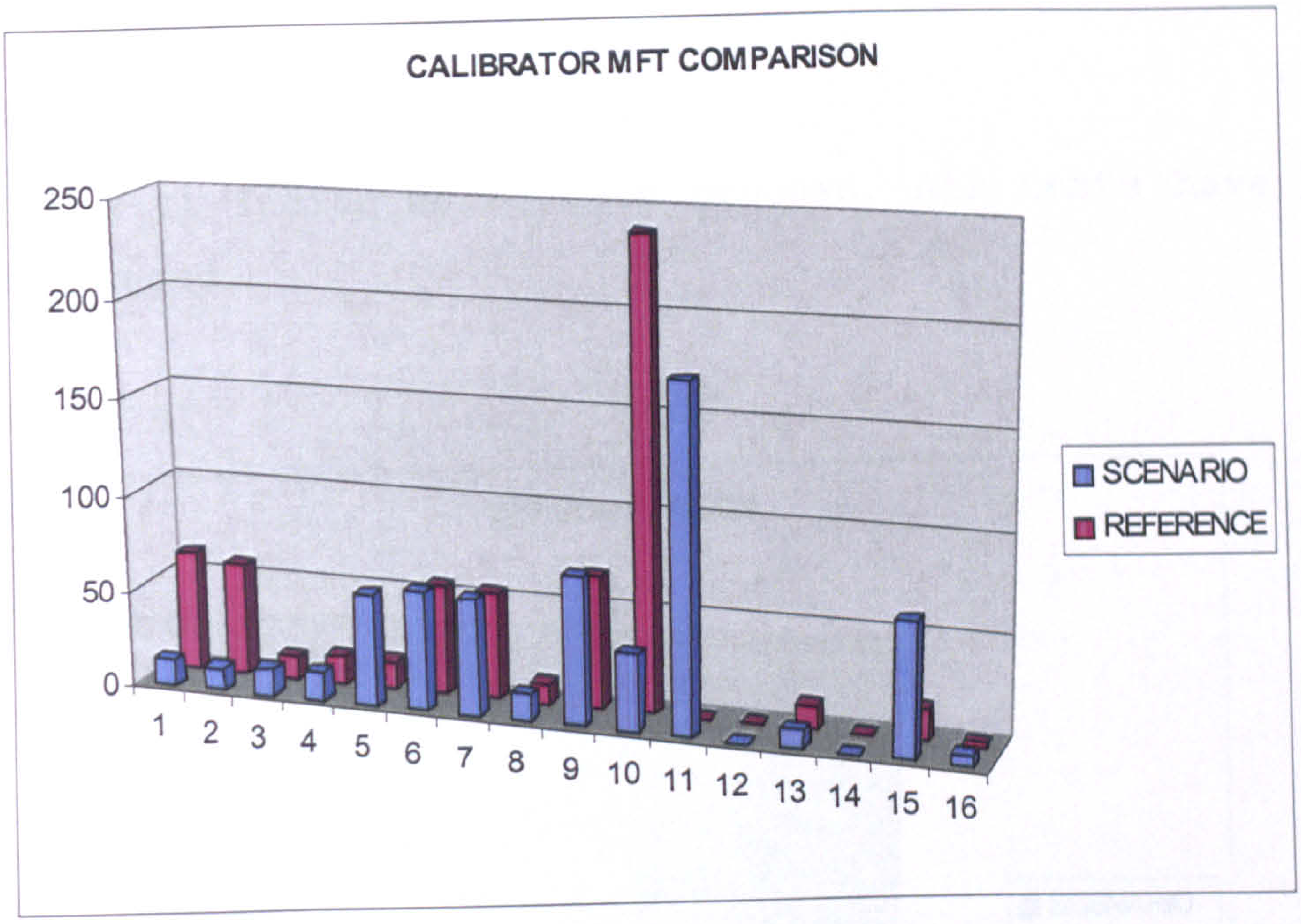
12.2 Material Flow time

More than 80% of all tests were affected by low funds as this affected material inventory as illustrated in Graph 89 which consist of reagent, calibrator, and controller.

Graph 89



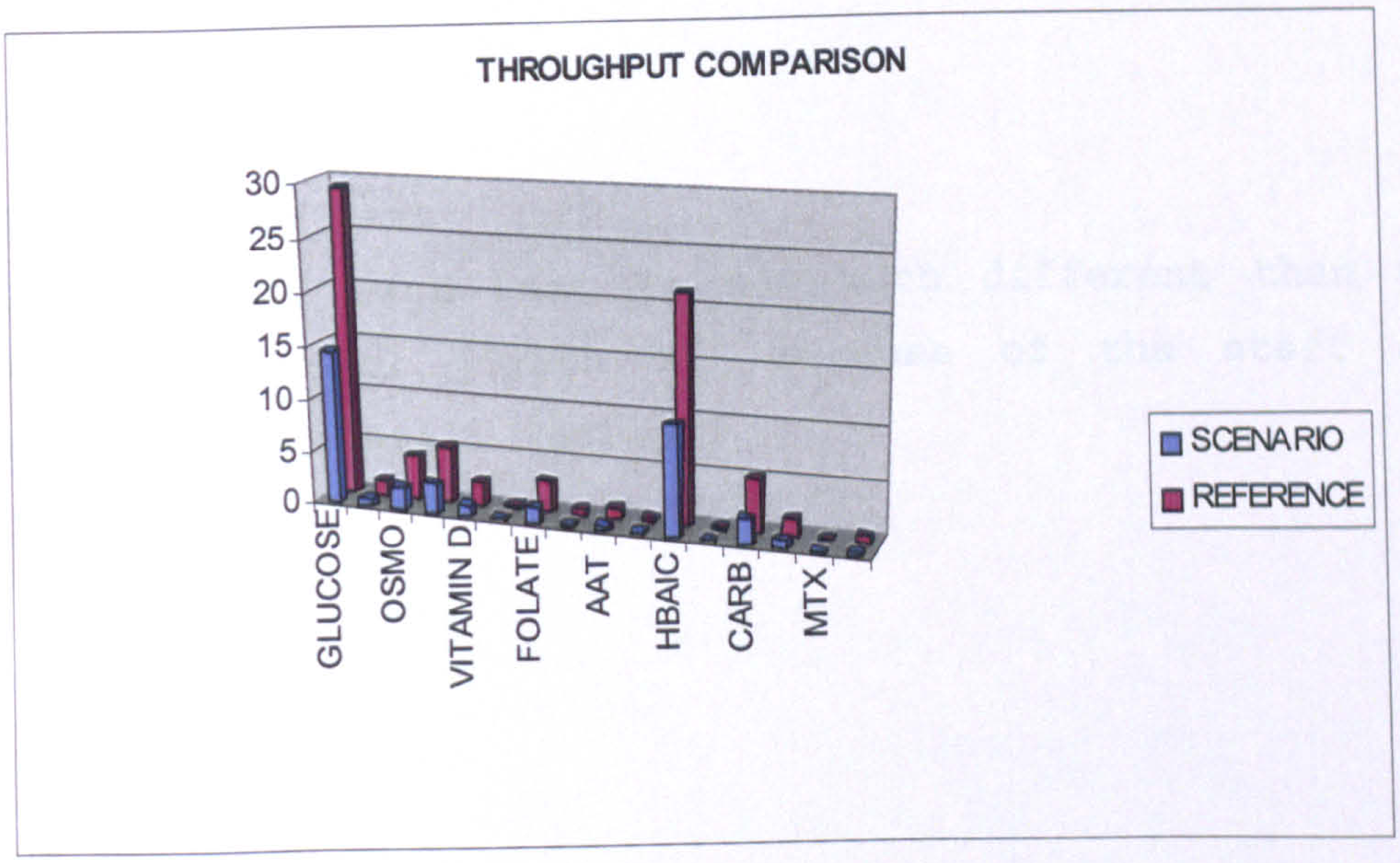




12.3 Throughput

Throughput of the test as indicated in the Graph 90 was effected negatively by decreasing the fund.

Graph 90



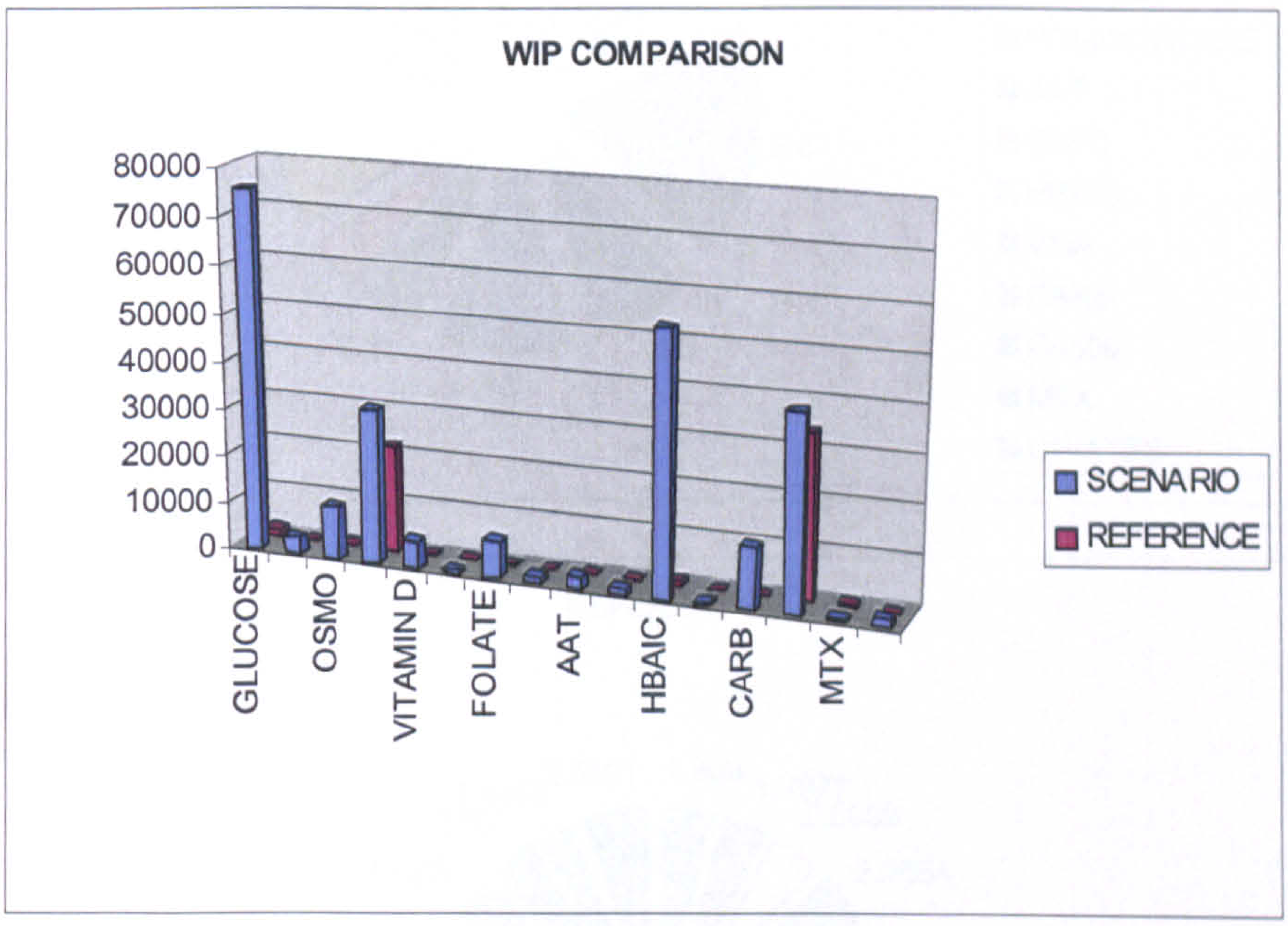
12.4 Inventory Status

There is not much change in the inventory of all components whether in the Lab or Logistics with Reference Model except test number 16 TDM Opiate which increased without any usage.

12.5 W I P

Graph 91 indicates work in process. All tests have been increased.

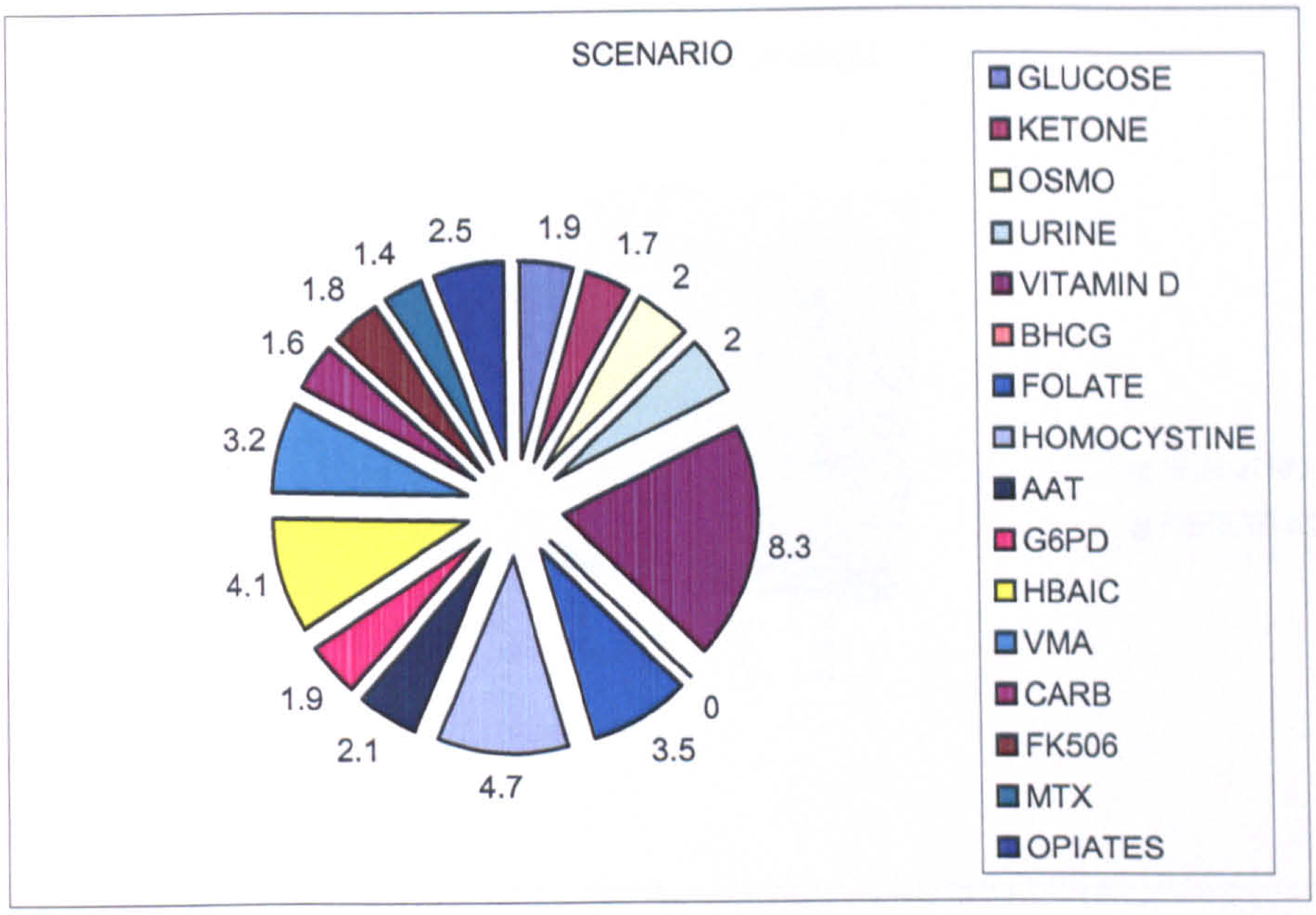
Graph 91

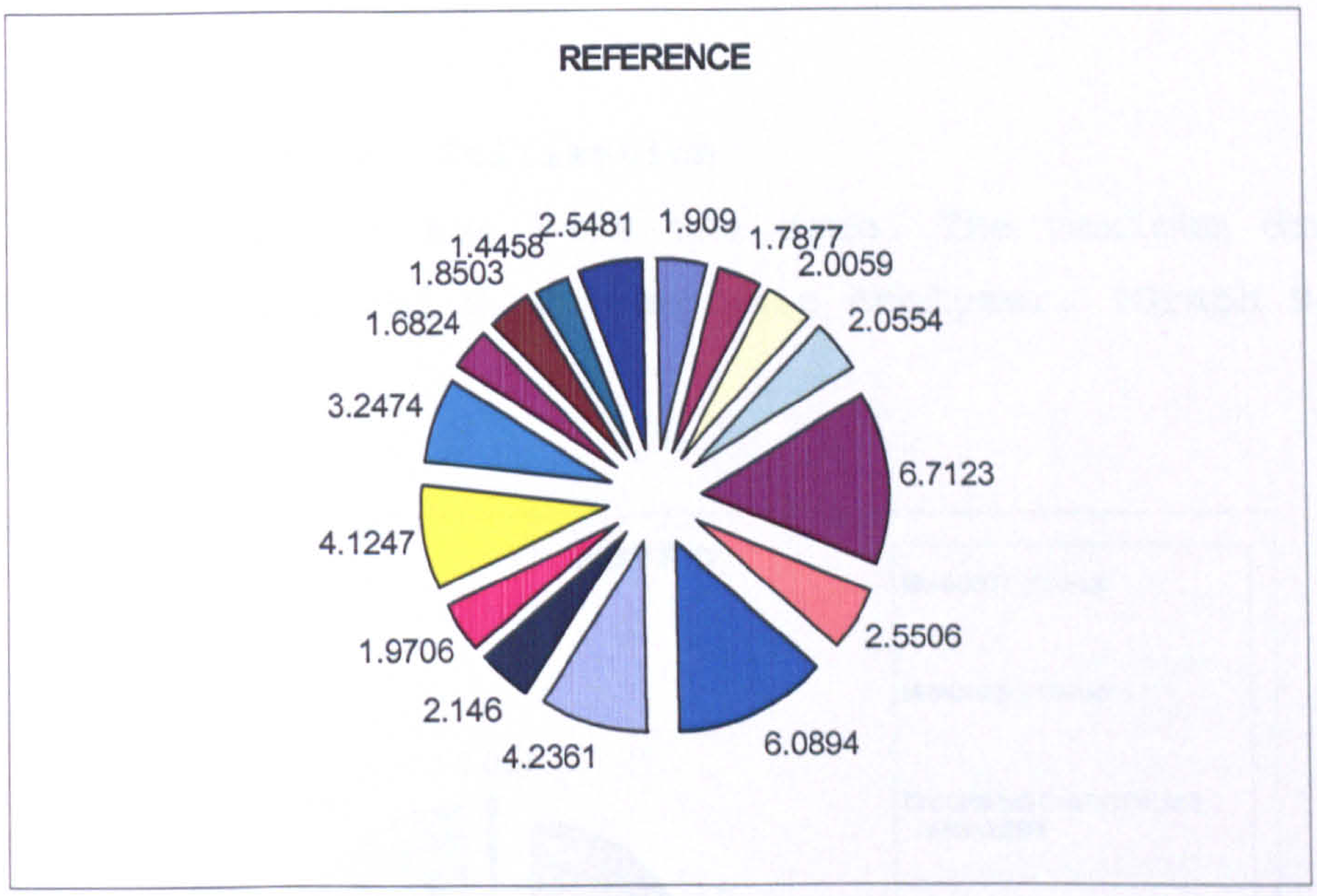


12.6 Cost of Test

The cost of each test is not much different than the Reference Model (Graph 92) because of the staff and resources are still included.

Graph 92





12.2 Secondary Performance Measures

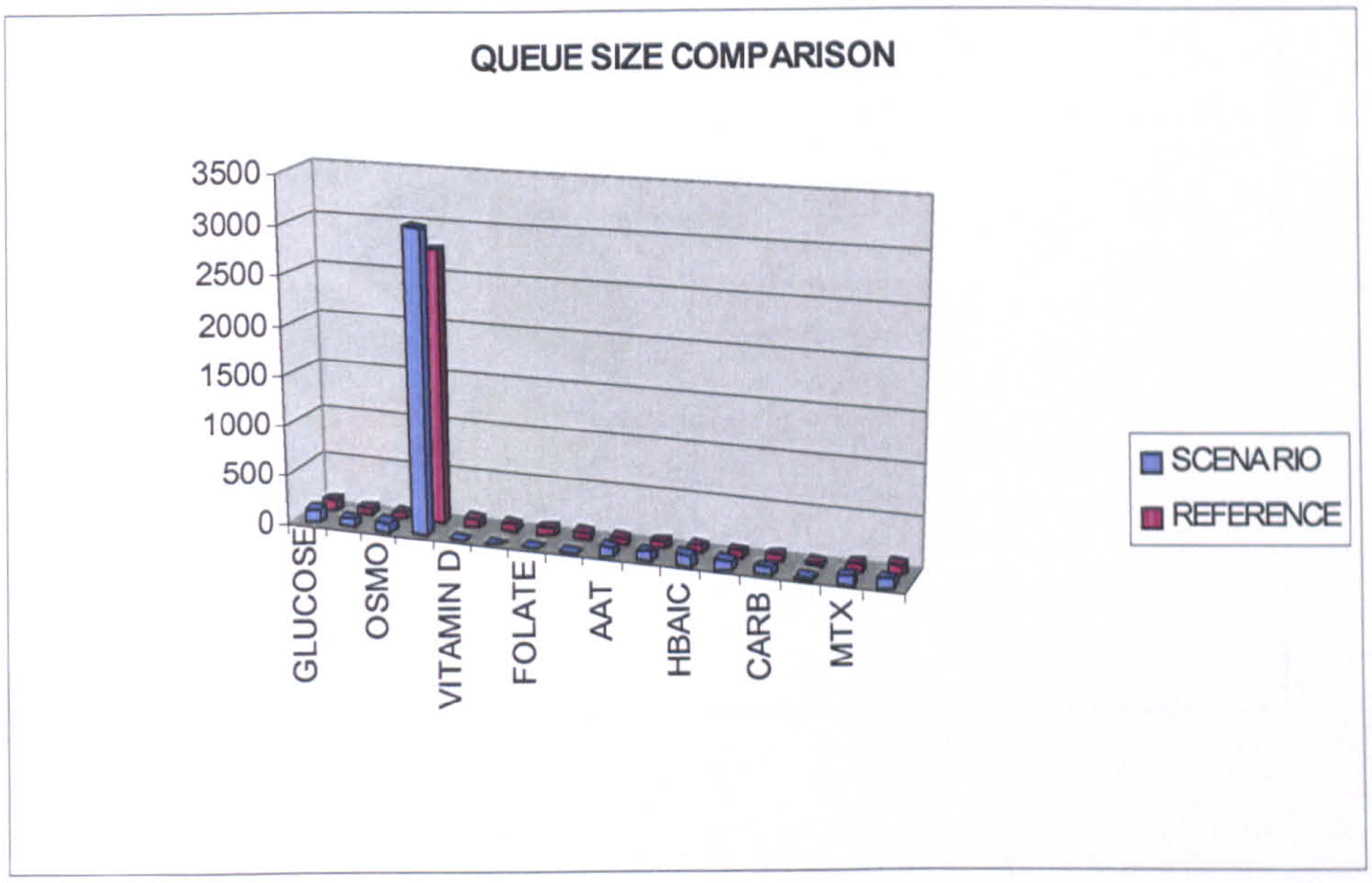
12.2.1 Material Order Size

The material orders slightly increased for the Lab control while the other decreased by 5%.

12.2.2 Queue size

As discussed in the lead time, similarly the queue size (Graph 93) been increased by a different percentage.

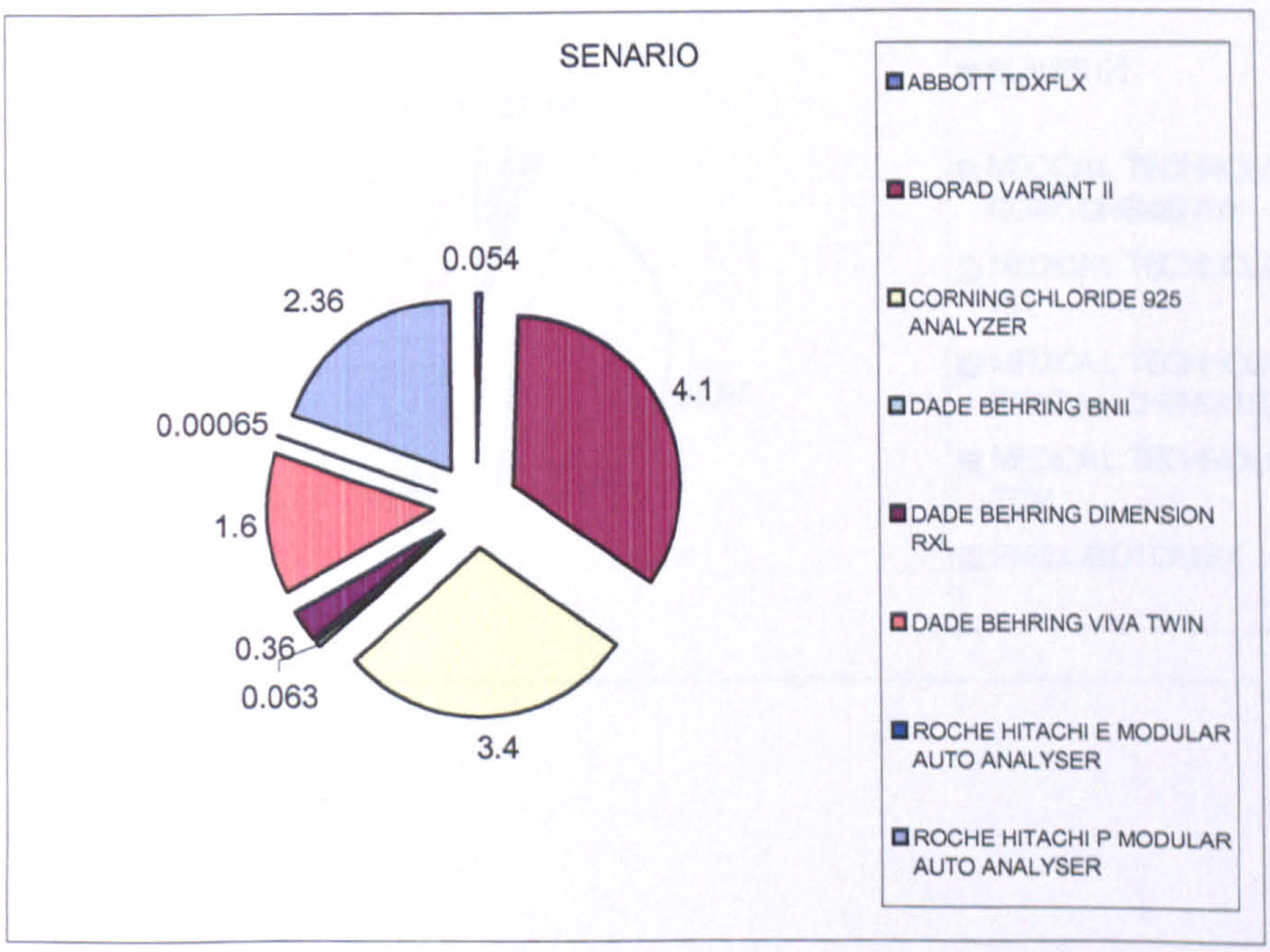
Graph 93

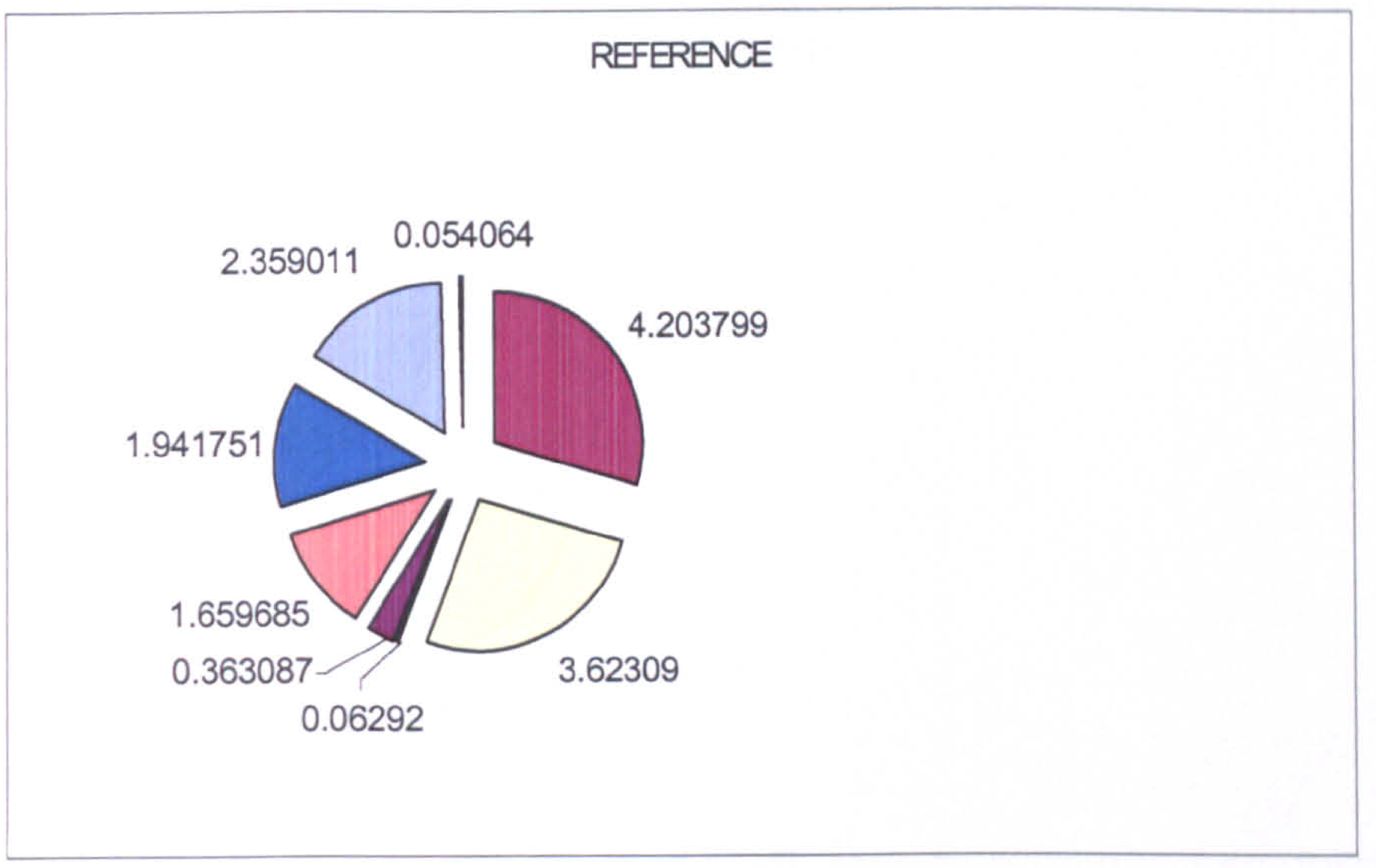


12.2.3 Equipment Utilization

The utilization has been the same. The maximum drop was the Roche Hitachi E modular auto Analyzer. (Graph 94)

Graph 94

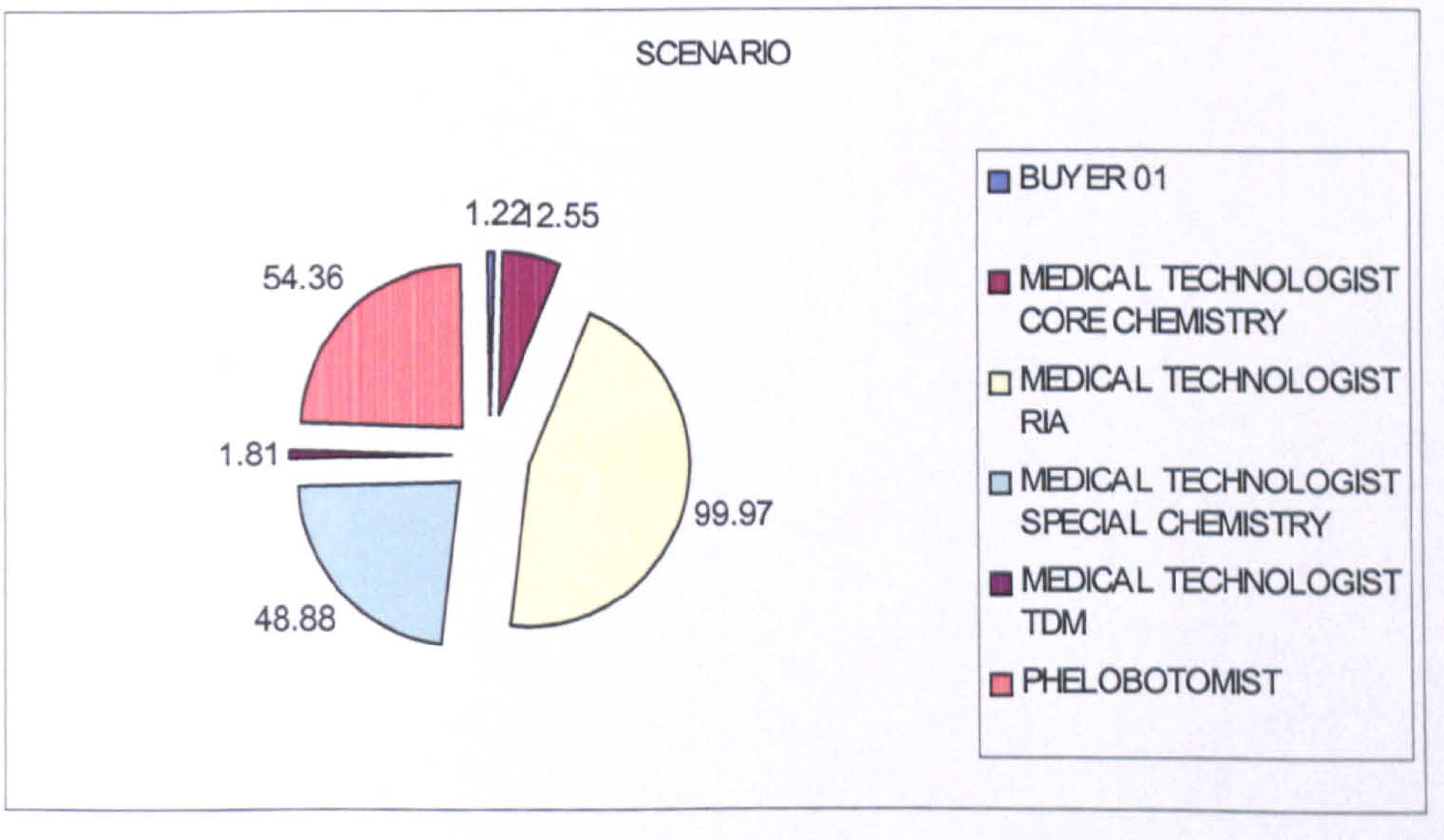


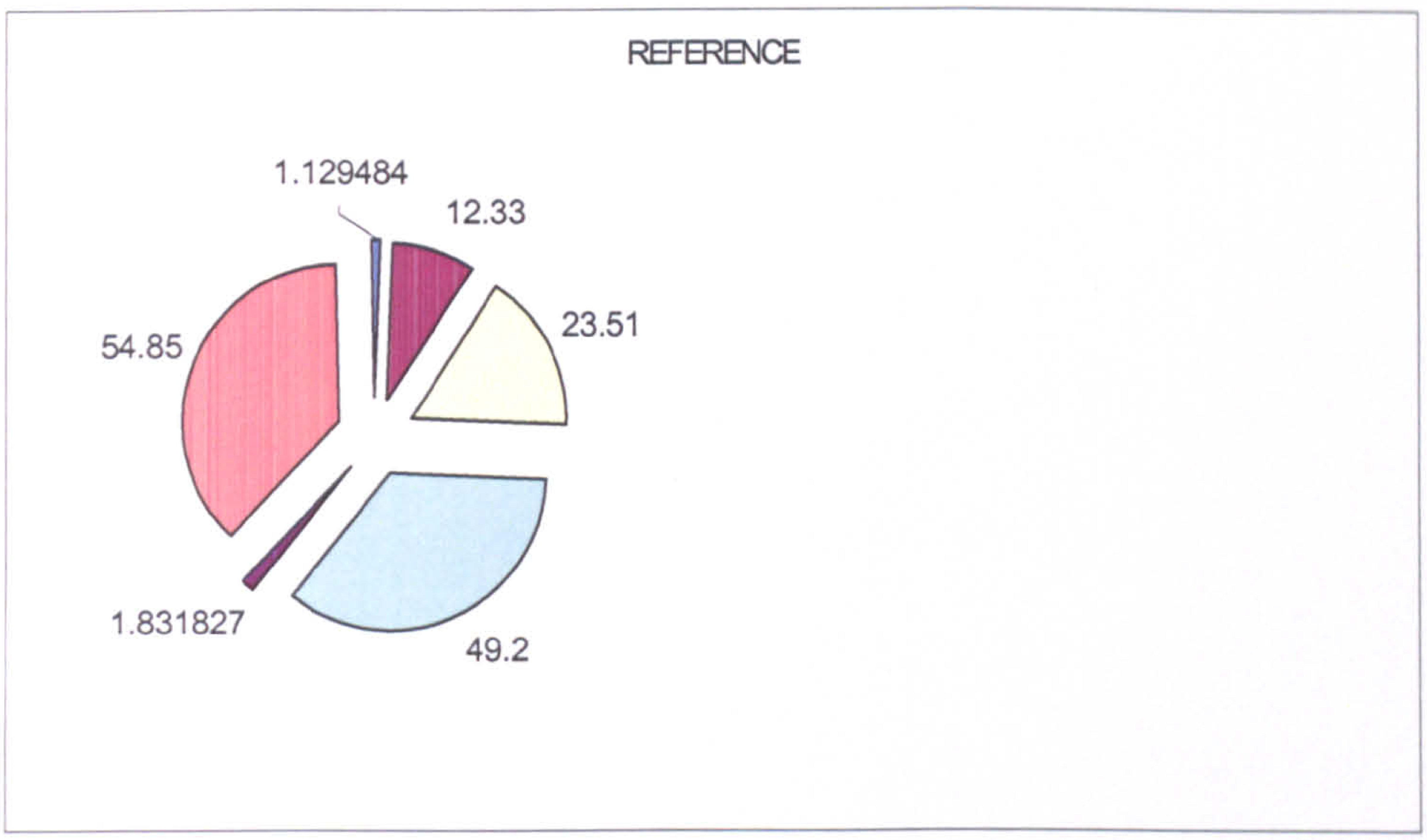


12.2.4 Staff Utilization

The staff utilization is lower than the reference (Graph 95) except medical technology RIA which increased to the maximum, showing the unbalance of staffing distribution.

Graph 95





12.3 Conclusion

Lead time jumped to 10-30%, material flow time fluctuates among all components, throughput of the tests are lower while the WIP is high, which indicate the queue is long to perform the tests, utilization is the same except RIA which reached to 99%.