AIRLINE MAINTENANCE PERFORMANCE AND PRODUCTIVITY MEASUREMENT: AN APPLICATION OF DATA ENVELOPMENT ANALYSIS

A THESIS SUBMITTED FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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2000

ABSTRACT

The assessment of airline maintenance performance and productivity measurement is the main focus of this thesis. Due to the immense investment in airline maintenance, management give this issue considerable attention for two main reasons: to control raising maintenance costs and to improve efficiency and performance in the workplace.

This thesis has two general aims. Firstly, to examine issues in improving efficiency and productivity, and secondly to examine the feasibility of applying Data Envelopment Analysis (DEA) to airline maintenance. To achieve the first of these aims, a survey was carried out to answer questions related to efficiency, performance and productivity in airline maintenance. The survey was carried out with two groups managers and technicians in the Shop, Hangar and Line.

The second concern of the thesis is to examine the practicability of the Data Envelopment Analysis techniques as a powerful tool to assess the relative efficiency of various fleets serviced by the maintenance department. Four DEA models were developed to address areas of high concern to maintenance management. DEA was used to identify the relative efficiency, targets, peers, best practice and most importantly the inefficient DMUs. Weight restriction was explored to compare the DEA result with the free weight model. A stepwise multiple regression analysis was carried out to examine the effect of input now on output in times to come. Lastly, a DEA analysis was carried out to assess the months in the low demand (non-significant) period separately. The reason being is that they were treated unfairly when compared with the set of months in the significant period. Moreover, in the target setting for the set of inefficient months the low demand (non-significant) period months were compared to each other. The result shows little difference for the target setting for the non-significant months when analysed separately.

A DEA based performance monitoring system for the A-300 fleet model one, was simulated, and showed that this would have caused maintenance managers to carry out some useful investigations of the causes of declines in efficiency.

It is concluded that the DEA productivity based system could be used successfully for Saudi Airlines maintenance department, perhaps after modification to the inputs and outputs used in the DEA models. Particularly, at a time when the carrier is being prepared for privatisation and a reliable method of measuring maintenance efficiency and productivity should be in place to show the improvements in efficiency. In addition, it is concluded the simulation analysis carried for the A-300 fleet could be of a great use as a tool for training maintenance management, and at the same time it allows them to improve their decision making over a period of time.

ACKNOWLEDGEMENTS

Many people have been a great support to me at all times have inspired the completion of this thesis.

My father has always been close to me, providing guidance and unlimited support. My mother has always cared for me and provided me with love. To both of them I am indebted. My wife's support and patience was present at all times. And I would like to thank my brothers and my lovely sister for their support.

My deepest gratitude goes to my supervisor Professor John Sharp, for his dedication, knowledge and continuous support to ease the difficulties in writing this thesis. He spent much time and effort in providing valuable advice. I am glad that I have had the chance to work with him.

I would like to express my thanks to all the members of the staff and technicians in the maintenance department. I would like to thank the many people in Saudi Airlines who I have worked with during the process of collected data.

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LIST OF ABBREVIATION

CRS	Constant Returns to Scale
VRS	Variable Returns to Scale
DEA	Data Envelopment Analysis
DMU	Decision Making units
ARP	Aircraft Reliability Programme
SV	Saudi Arabian Airlines
KLM	Royal Dutch Airlines
EO’s	Engineering Orders

CHAPTER ONE

INTRODUCTION

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1.0 INTRODUCTION

With the changing economic condition around the world, especially with the downfall of oil prices, airline managements are more concerned than ever with maintaining market competition through efficient maintenance service. Maintenance management stresses the maximum utilisation of all available resources in the most efficient way, in order to be able to provide a service which can be characterised as high in quality. This can be achieved through the application of more precise methods of performance and productivity measurement techniques. Therefore, airline maintenance managers are making a continuous effort to ensure airline maintenance facilities are able to manage maintenance activities rapidly and in the most economic way.

Greater efficiency will mean a higher quality of maintenance could be provided, as well as ensuring a stronger position in a competitive environment, with the minimum possible cost. With the increased market competition coupled with a wider range of services provided by the carriers, airlines cannot afford to have a high proportion of aircraft out of service, as this will have a strong impact on the image of the airlines. Customers are always demanding a service which is both prompt and efficient. This means that for an airline to achieve this goal, knowledge of how to implement the best tools to measure the effectiveness of the maintenance function becomes critical.

This chapter will provide a brief background to the thesis, the thesis objectives, the research aims, the research problem, the research programme.

This thesis will focus on Saudi Arabian Airline's maintenance department and its subdivisions of *line maintenance, shop* and *hangar*. The company started operations in 1945 with the first DC-3 aircraft arriving in the Kingdom on March 10. A few months later, two other DC-3s arrived to carry passengers and mail services between Jeddah, Riyadh and Dhahran. Saudi Airlines was formally established in September 1946 under the support of the Saudi Ministry of Defence. On March 14 1947 the first scheduled services were inaugurated between Jeddah, Riyadh, Hofuf and Dhahran. Today the Saudi Airline fleet is around 113 aircraft (Davis, 1995a).

After fifty years of progress, Saudi Airlines is still a state owned enterprise, however it is adapting to a new philosophy that will allow it to meet the global trend towards air transport liberalisation. This is part of the move towards the privatisation of State Owned Enterprises (SOE). Saudi Airlines has started a programme focusing on the commercialisation of the airline's activities and all aspects of the airline's operations (Bakr, 1995a).

At present, Saudi Airlines is pursuing a plan to re-engineer the work processes to meet the challenges of tomorrow. Performance measurement tools are needed at a time when the airline is trying to improve current performance and increase its productivity.

1.1 BACKGROUND TO THE THESIS

Airline Maintenance Operations can be characterised as indubitably sophisticated and extremely reliant upon engineering activities. These engineering activities include those work carried out at the Line, in the Hangar or in the Shop. The Line department is mainly concerned with the day-to-day operational activities conduct while the aircraft is getting ready for take-off, while at the Hangar long project take place, such as major repair and major overhaul, finally, at the Shop aircraft components are tested and overhauled if necessary these will be defined in greater details in Chapter Two. Such complex operations require a high level of personnel skill to reach the required level of specialisation set by management. Safety issues accompanied by government regulations have forced airlines around the world to seek measures to evaluate their operational performance in order to improve their efficiency. This thesis investigates the measurement of efficiency and performance in Saudi Airline maintenance departments using the methodology of Data Envelopment Analysis.

To illustrate how government and regulative authorities can impose an extra cost on airline operators, the U.S. aviation industry will have to spend more than $300 million to comply with a new FAA rule demanding the installation of fire detection and suppression equipment in all Class D cargo aircraft over the next three years (Anonymous, 1998a). This rule, which was issued on Feb.17, 1998 will eventually affect nearly 3,700 aircraft already in service and all newly manufactured aircraft as well. The reason for this rule is because of the crash of *ValueJet* DC-9, which killed 100 people, as oxygen generators which were in the cargo compartment were ignited and supplied the oxygen for the fire that led to the plan crash. Eventually, the airline carriers will have to incur the capital cost for installing the system, the lost revenue caused by lost baggage space and the cost of maintaining the system.

Efficiency in not-for-profit entities needs to be sought in different ways, e.g. by reducing costs and improving the business processes. A problem for airline carriers who operate under government supervision is how to allocate their available resources in a way that will reduce costs and generate more revenue to enable them to achieve a higher level of efficiency. This means that the state-owned enterprises have to utilise their resources (manpower, fleet, equipment, facilities etc.) to improve productivity which will help reduce the cost associated with their operations, e.g. by improving manpower technical skills and by assigning the right person in the right place. Furthermore, an airline needs to develop a minimum cost strategy for the route structure by allocating the right aircraft size to a specific route, which helps increase the load factor, reduce cost per seat kilometre and minimise the number of staff required for operations. Consequently, a thorough market analysis must be carried out to determine the type of aircraft needed as well as the frequency for each route. From the researcher's experience the main reason for the poor assignment of the appropriate aircraft to a specific route is the absence of the profit motive.

Consequently, this sector lacks the ability to provide a measurement system that links efficiency and performance levels to revenue. If such a system existed, the whole process of doing business would eventually be changed; otherwise there would be no strong basis for survival among rivals in the same market. This will eventually mean for state owned enterprises that they should become more competent. Productivity and efficiency measurements are therefore considered important tools to help managers in the private and more specifically in the public sector, to view the broader picture of doing business in today's global market. Being a state owned enterprise, Saudi Airlines lacks a good performance measurement system for airline maintenance, one that includes the resources used to produce an output.

There are several programmes and methods adopted by airline maintenance managers around the world to measure the efficiency and productivity of airline maintenance units. In order to achieve a high level of performance and efficiency, airlines have established what is called an 'Aircraft Reliability Programme' which ensures the continuous gathering and analysing of pre-selected operational data and the initiation of corrective action if needed. However, this process is time consuming and labour intensive. In the real world, some airlines devote more effort to data collection than to initiating corrective action. The following are some of the typical data that are monitored by maintenance officials on a continuous basis.

1. *Technical cancellation* - Elimination of scheduled flight due to a known or suspected malfunction and/or defect, or lack of aircraft due to maintenance action (KLM, 1996).

2. *Technical substitution* - Substitutions are not counted as interruptions unless an interruption occurs (interruption is defined as any technical problem which will cause the scheduled flight to be delayed). When an interruption involves a substitute aeroplane, the interruption is counted as though it occurred with the originally scheduled aeroplane (Boeing, 1996).

3. *Number of system defects* - It is the responsibility of the Aircraft Reliability Control Section to monitor the fleet system reliability by prescribing the criteria for selecting the reliability performance parameters which are used to measure aircraft, powerplants, structure and components, in order to identify systems with a lower reliability rate (Saudi Airlines, 1996).

4. *Technical diversion* - The landing of an aircraft at an airport for a technical reason other than the airport of origin or destination (KLM, 1996).

5. *Technical incident* - This is mainly concerned with the number of incidents occurring on the ground when handling the aircraft for loading or pushback (KLM, 1996).

6. *Dispatch reliability* - This is the percentage of scheduled revenue flights started and completed without an interruption (cancellation, air turnback, diverted landing, or delays greater than fifteen minutes) chargeable to an airplane system or component primary malfunction (Boeing, 1996).

In Saudi Airlines, as in many other non-profit making organisations, there was no motive to achieve profit in the early stages when the airline was first established, due to the absence of domestic competition in the market it served, yet in recent years the focus on generating revenue has been emphasised more. This could be for three reasons: first, the absence of competition may not last for long; second, the fact that government policies together with the bureaucratic system prevents them from making quick decisions. Therefore, it takes time for the airline to be able to response to market conditions in a more flexible way; third, the lack of capital, particularly in an industry where a considerable amount of investment is needed.

One of the methods of performance measurement used by airline maintenance is to use previous data as a standard for performance. These data make it possible to compare current performance or productivity levels with past productivity levels. The following are some examples of the productivity measurement information used by the airline industry:

1. *Available man hours* - Is the monthly attendance multiplied by a factor of 6.5 hours, which is the assumed actual number of hours that the employee will produce, rather than using eight hours (less break time) (Saudi Airlines, 1998).

2. *Planned ground time* - Is the estimated ground time for scheduled maintenance (Saudi Airlines, 1998).

3. *Actual ground time* - Is the actual ground time for scheduled maintenance (Saudi Airlines, 1998).

4. *Planned man-hours* - Are the estimated man-hours provided by the aircraft production planning and control department (Saudi Airlines, 1998).

5. *Total standard man-hours* - Are the assumption of estimated man-hours per unit multiplied by the activity count (number of units) (Saudi Airlines, 1998).

6. *Logged man-hours* - Are the reported man-hours chargeable to completed work in progress for the month (Saudi Airlines, 1998).

What needs to be mentioned here is that the fact that the data being used by various airlines for performance measurements may reflect recurring problems. In order to avoid using these data airline operators must use an industry average against which to measure current performance and productivity.

According to Lawlor (1985) in order to improve productivity it makes more sense to measure current productivity levels to check whether performance has increased or not. In addition, Lawlor emphasises that in order to get the right productivity improvement programme the organisation has to enforce a dependable measurement system. Such a performance measurement system must illustrate how efficiently attainable resources are being used to produce useful outputs. Lawlor suggests that a reliable system of measurement should lead to an actual improvement in productivity. Information gathering should be an ongoing process and the measurement system should be under continuous revision by the management to keep it in line with the organisation's aims (Lawlor, 1985).

Lawlor adds that it is helpful to use a selection of input and output mixes to measure corporate productivity and performance. Examples of the *primary output measures* used include gross sales revenue, profit, and gross total earnings, gross value added and net value added. Example of the *secondary output measures* used at the 'shop floor level' include cars produced, numbers of sales calls, number of customers serviced, number of patients seen, operations performed and passengers carried. These outputs represent some examples of output measures used in retailing, health care and transport. On the other hand, *input measures,* include gross factor costs, throughput of materials, wages, salaries, and conversion costs. Other common input measures include: total number of people working, physical space used, time and stock or inventory which is considered important for retailers and manufacturers (Lawlor, 1985).

1.2 THESIS OBJECTIVES

The main objectives of the thesis are:

1. To examine what is meant by the performance of airline maintenance units.

2. To examine the factors that affect this performance.

3. To assess the feasibility of using DEA for airline maintenance department performance measurement.

a) To identify targets for the different fleets as well as identifying efficient and inefficient months.
b) To measure the ability of each maintenance department to control all facets of their operations given the range and the volume of services they offer.
c) To evaluate maintenance efficiency and performance based on a monthly five year period.

4. To examine the acceptability of DEA based performance measurement systems.

The broader objective of this research is to provide a more effective means for assessing efficiency and performance in not-for-profit entities. Prior to this day, there has not been a study of efficiency measures in Saudi Airlines' maintenance department. This thesis attempts to provide a way for measuring performance and efficiency in the maintenance department of Saudi Airlines. The airline still operates under the term 'Flag Carrier' and therefore does not seek to make a profit. Furthermore, at the current time competition has no impact on the airline so it cannot improve its efficiency and the performance of its operations; however, the future could be different.

To obtain a greater understanding of operational and managerial efficiency measures in the public sector, the Data Envelopment Analysis (DEA) methodology will be applied. DEA is a mathematical technique, which relies on the linear programming theory developed by A. Charnes, W.W. Cooper, and E. Rhodes (1978, 1979) to assess the firm, its organisation and the efficiency of the various units within it. In this thesis, the performance of the maintenance of fleets in Saudi Airlines over a five-year period will be discussed to give a broader view of operational performance. DEA will be applied to each fleet to generate efficiency measures, which reflect how efficient, the maintenance units are in achieving their goals. The principles of Data Envelopment Analysis will be discussed further in Chapter Six.

In the last five years there has been an increased interest from the government of Saudi Arabia in improving the efficiency and performance of the public sector. Several decisions have been taken, such as initiating privatisation programmes to achieve this goal. Saudi Airlines was one of the first and most important sectors of the economy to be given close attention to improve its overall performance so as to enable it to stand strong among other international competing airlines.

1.3 RESEARCH AIMS

Because more emphasis is being directed towards the importance of assessing efficiency in airline maintenance departments, the industry has adopted several ways of means to achieve accurate measures of efficiency and performance. Different managerial techniques have been implemented to ensure that efficiency is improving and to make sure that the organisation's objectives have been modified in line with the changing trends in efficiency measurement (Rossi, 1995).

As an employee in Saudi Airlines Technical Services Department the research aims are:

- To examine what is meant by the efficiency and performance of Saudi Airlines' maintenance units.
- To evaluate the efficiency and performance of maintenance through the use of DEA.
- To evaluate the impact of operational performance during different times of the year on the relative efficiency obtained.
- To consider the relationship between the efficiency of the maintenance units and the performance of Saudi Airlines.
- To apply DEA as a tool of measurement for investigating efficient and inefficient months with the aim of achieving optimum targets.
- To allow maintenance management to examine the application of weight restrictions.
- To advise on a DEA based system for measuring maintenance performance that can be implemented successfully by maintenance management.
- To evaluate maintenance efficiency for the non-significant period only.

1.4 RESEARCH PROBLEMS

Airline maintenance performance and efficiency is difficult to measure due to the complex technology involved, these are highlighted in the different levels of operations being undertaken at any one time such as, fulfilling a high reliability requirement and maintaining a wide range of different types of aircraft. With the increasing interest of airline maintenance operators in improving overall maintenance efficiency, airline management have considered several techniques that could help them improve the efficiency of maintenance units. One technique used is to execute a strict preventative maintenance programme. Such a programme can help to reduce the rate of unexpected failures in systems or components in the aircraft. Such programmes can be categorised into two main types. The first type is designed by the aircraft manufacturers to define the time intervals at which the aircraft must be serviced. The second is a preventative maintenance program, which is designed and scheduled by the airline operator to reduce unexpected failures (Saudi Airline, 1997a).

Other methods applied in this area are to set performance indicators and efficiency measures. These indicators are pre-set by top management in order to detect inefficiencies and to make it possible to initiate immediate corrective action to amend poor performance. One of the performance measurement indicators used is *percentage on-time performance.* This measure involves two main factors - the first involves the total number of departures, while the second involves the total number of delays.
Another useful performance indicator used by aircraft engineering personnel is the *number of cycles.* This utilises the number of times that a particular aircraft engine is started without the need for maintenance (Friend, 1992).

Table 1.1. indicates some of the typical data that are monitored by major airline maintenance officials on a continuous basis. The data in the table include:

1. *Technical Delays* - Usually delays are counted if they are over fifteen minutes (KLM, 1996a).
2. *Total Pilot Reports* - Is an aircraft reliability performance parameter which would give a general indication of the status of the aircraft (Saudi Airlines, 1996a).
3. *Component Exceeders* - A monthly list of selected aircraft components, provided by the engineering department and these components are being monitored if they are to be changed quite often (more than usual), which tells the engineer that there is something wrong and any action which needs to be taken. In general this list is being prepared in order to monitor the reliability of these components (Saudi Airlines, 1996).
4. *Unscheduled Out of Service* - Is the process of monitoring all the aircraft unscheduled out of service, and identifying the cause (Saudi Airlines, 1996).

Table 1.1 Typical Data Monitored On A Continuous Basis By Different Carriers

Airline	Performance Summary*	Technical Cancellation	Technical Substitution	Number of System Defects	Technical Diversion	Annual Work Load	Technical Incident	Dispatch Reliability	Number of Landings
Saudia	X					X	X	X	X
Swiss Air	X	X	X		X		X		
KLM	X	X	X		X		X		
Garuda	X	X	X		X		X		
LTU	X		X		X		X		
Thai International	X	X	X		X		X		
Singapore Airline	X			X					X
JAL	X	X						X	

Source: Engineering Monthly Report 1997c.

* Performance Summary includes the following:

Number of aircraft in the Fleet, Flying Hours

Take Off, Daily Utilisation, Technical Delays.

Another problem that airline maintenance managers are faced with is defining the most appropriate variables for each unit to comprise the efficiency and performance measures. As will be shown later, the Data Envelopment Analysis (DEA) technique offers a new approach to measuring the efficiency of the airline maintenance and allows the use of multiple input and output variables. The DEA methodology attempts to provide a model for efficiency measures that will identify efficiency and inefficiency as well as identifying the level and source of inefficiency, if it exist. Furthermore, DEA techniques allow target setting and the identification of peers. More details of DEA will be given in Chapter Six.

Management is sometimes unable to break down maintenance costs in a way it would wish, by speciality for example, the cost of maintenance tasks completed in the shop, hangar or line. This can lead to corrective action that does not solve the original problem. Often breaking down cost by specialities, i.e. Line, Hangar, and Shop by fleet is a good means to identify the sources of and the level of maintenance inefficiency.

In the airline maintenance industry, performance measurement tools quite often tend to reveal areas of maintenance where personnel delays occur frequently. In such cases training courses should be considered to boost performance and productivity levels. Delays caused by personnel are very critical to on-time performance and can cause a significant loss of revenue. From the researcher's experience with the frequent introduction of new technologies, training often plays a significant role in generating high performance. The continuous monitoring of employees who work in the Line, Hangar or on the Shop floor means that managers are able to define the areas which are causing frequent failures and therefore, initiating the required training program, or revising the work process. This issue will be discussed further in Chapter Five.

One of the most critical issues in airline maintenance operations is the supply of material and the availability of spare parts. This is due to the high cost of inventory. Airline operators around the world therefore try to keep the minimum number of spare parts in stock (Eleuteri, 1994).

From the researcher's view this can be confirmed in that when a need arises for parts that are not available they will be ordered on the basis of 'aircraft on ground' (AOG) which can guarantee delivery within twenty-four hours in most cases. If the aircraft is scheduled to be in the Hangar, for servicing for example, then parts should obviously be delivered at a later date to avoid the extra charges involved in prompt delivery since the Hangar service usually takes between two to six weeks. In order to avoid a lengthy wait for parts delivery beyond the scheduled time, airline operators tend to bring the aircraft back in service as soon as possible by 'stealing' parts from another aircraft which is scheduled to stay in the hangar for two or three weeks for maintenance checks. This policy does not work every time because a spare aircraft is not always available. In this case the aircraft is grounded whilst waiting for parts, thus causing a loss in revenue which can be extremely high depending on the time spent on the ground and the type of the aircraft.

Baiada (1995) states that if the airline operators think of each aircraft as a factory, and this *factory* (aircraft) setting idle at the gate, then more effort could be exerted at minimising the A.O.G time. The author states that *Operation High Ground*, a programme which was started at USAir was aimed at minimising the aircraft on ground time. The carrier was able to add 12,500 seats per day to its system. USAir therefore used its equipment and personnel more productively.

Lam (1995) illustrates the severity of A.O.G on the airline by stating that, for example, losing a service for a B-747 for a day could eventually cost the airline as much as $300,000 in lost revenue.

To avoid a long interruption of service, airline operators tend to lease an aircraft to work as a substitute. The cost of leasing depends on the type of aircraft its size and the type of the contract, whether it is a *wet lease,* or a *dry lease.* Table 1.2 shows some lease figures for different types of aircraft.

Table 1.2 Lease Figures For Different Types Of Aircraft By Block Hours*

Aircraft Type	Wet Lease Cost ($)*
MD-11	6,000 to 6,300 / Block Hours
A-300	4,500 to 5,100 / Block Hours
B-747-100	6,000 to 6,100 / Block Hours
B-747-300	6,300 to 6,500 / Block Hours

Source: Saudi Airline, Finance Manual, 1997d.

* Cost is based on a one-month lease.
* Block hours: is the total hours flown from the time the aircraft leave the gate to time it reaches the other gate.

Dry Lease is a lease under which the lessor leases only the aircraft to the lessee without any crew, maintenance, insurance etc., while a *wet lease* is a lease under which the lessor leases the aircraft, cockpits and cabin crew, maintenance, insurance, and is often called (ACMI) (Saudi Finance Manual, 1997d).

1.5 RESEARCH PROGRAMME

The Data Envelopment Analysis methodology was chosen to assess the efficiency and performance of Saudi Airline's maintenance department. The basic idea of the DEA method is that it is capable of making a multi-comparison of units and producing relative efficiency scores. The DEA analysis produces what is called a 'best practice frontier' formed by the set of efficient units (Charnes *et al.*, 1994). This concept will be explored in more detail in Chapter Six. Furthermore, one of the benefits of using DEA analysis techniques is that it allows target settings for inefficient units, as well as for identifying peers units. Inefficiency levels and the sources of inefficiency will be identified through the DEA analysis, which will be discussed in more detail in Chapter Eight. The following highlights in brief the steps that are described in this thesis.

1. The opportunity was taken to highlight and quantify some of the obvious negative impacts brought about by operations, which affect the performance and productivity of the work. This will be achieved through the distribution of survey questionnaires to both maintenance employees and maintenance managers, to obtain their view in this regard. It is hoped that the survey questionnaire will answer the following questions:

   A. Since effective communication can enhance workers' ability to express their concerns to management, about the impact of the lack of communication on work performance.
   B. Whether providing the appropriate tools and materials to its workers could achieve a positive impact on the speed and the quality of the accomplished work.

C. Whether the employees' knowledge of what is meant by performance and productivity in the workplace can help them to better understand how to implement them in their daily work.

D. Whether sharing and accepting workers' ideas may have a positive impact on the way work is being carried out.

E. Whether the unequal treatment of workers could have a negative impact on productivity.

F. How a lack of management understanding of the combined factors that affect workers' ability to perform the job correctly can have a negative impact on quality and performance.

G. Whether management that pays attention to the affect of shift change is associated with high performance.

H. Whether there are any significant difference between obvious groups such as the Line, Shop and Hangar.

2. An open-ended interview was carried out with top maintenance managers, as well as follow up interviews with employees and mangers on the outcome of the results. These will be analysed in terms of managers and employee comment analysis.

3. A thorough investigation was carried out to explore the differences between managers' and employees' views towards factors which are believed to affect the performance and productivity of the maintenance tasks.

4. A DEA model was constructed for each fleet to analyse it according to the different four criteria set in Chapter Eight. The variables for each fleet will be selected and defined as either inputs or outputs in order to measure the fleet's efficiency and performance.

1. After constructing the DEA model for each fleet, these different models are examined through the DEA methodology to analyse them.

2. Following this an interpretation of the research results was carried out.

3. A survey was carried out to discuss the research results with each unit manager. This will also find out what DEA offers managers as a tool for measuring efficiency and performance and how it might help them in the decision-making process.

1.6 SUMMARY AND OUTLINE OF THE THESIS

This chapter started by introducing the main objectives of the study followed by an introduction and a brief background to the research. The airline maintenance problem was explored in detail. An outline of the research aims and problems were shown as well as the research methodology. The significance of the research was stated, which also illustrated the justification for the thesis.

This thesis is arranged as follows. *Chapter Two* provides an overview and a brief background about Saudi Airlines focusing on the maintenance services departments. Each of the selected units, Line, Hangar and Shop, will have a separate section which will include the different activities carried out that define the unit objectives.

Chapter Three provides the literature review, which focuses on the measurement of productivity and performance. A special section will focus on Air Force and civil airline maintenance measurement of performance. In addition, factors affecting performance and efficiency will be discussed, as well as discussing productivity measurement in the public sectors.

Chapter Four will discuss the process of the survey data collection and the accessibility and availability of data will be explained. Also, information on the activities that have been carried out in each maintenance unit will be detailed. It will show how the survey was conducted.

Chapter Five provides a detailed analysis and discussion of the survey, for both the managers and the employees. In addition, a thorough analysis will be carried out to investigate differences between managers and employees on a variety of maintenance related issues. The employee and manager comments will be analysed, highlighting the main differences between managers and employees based on the factors that affect performance the most will be discussed.

Chapter Six will discuss the fundamentals of DEA analysis. The methodology and the concept of Data Envelopment Analysis will be explored. The selection of variables and setting performance indicators in general will be discussed. Data Envelopment Analysis models are set up for each fleet to test its relative efficiency and provide performance measurements for it. A highlight of the research design is presented, as these will be explored more in Chapters Four and Seven.

Chapter Seven discusses the process of the DEA data collection and the accessibility and availability of data. Information on the activities that have been carried out in the maintenance department to collect the necessary data are explored.

Chapter Eight explores the feasibility of assessing airline maintenance through the application of DEA, efficient and inefficient months will be identified, best practice, peer groups, target setting and overall possible improvements will be explored. In addition, weight restriction will also be explored, and a non-significant period analysis will be conducted.

Chapter Nine is aimed at providing maintenance managers with the way of applying DEA in practice to help assess the efficiency of the maintenance department. The process of applying DEA in the workplace is provided for maintenance managers ready to be implemented. In addition, various outputs that could be used by managers which was generated by the DEA analysis are discussed, in order to illustrate to them how they could make use of the different outputs from the DEA analysis. How maintenance managers could use these outputs to assess them in making the right decision is also discussed.

Chapter Ten provides a conclusion of the thesis, as well as highlighting possible future research activities. In addition, an interview with the managers will be carried out to get their feedback on the findings of the DEA analysis when applied to airline maintenance activities for the purpose of measuring performance and productivity.

CHAPTER TWO

FOCUS OF THE RESEARCH

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2.0 INTRODUCTION

This chapter will focus on the different activities conducted in an airline maintenance department. Saudi Airlines' maintenance department's organisational structure is illustrated. The three maintenance departments concerned Shop, Hangar and Line are discussed to illustrate the different activities carried out in each of them as well as showing the relationship between them. Airline maintenance philosophy is discussed as well as an exploration of the need to study airline maintenance.

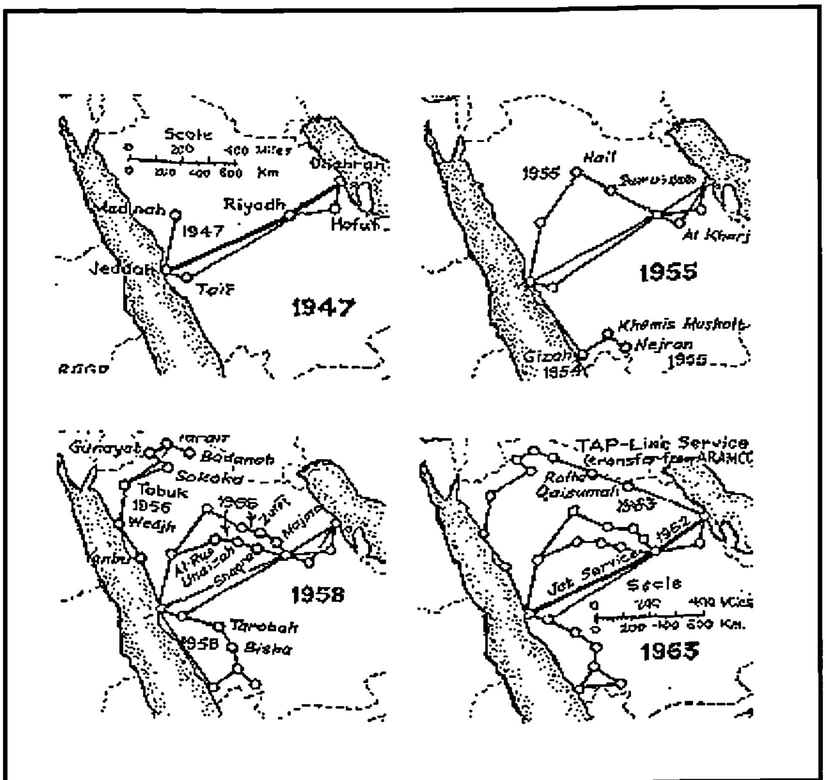
2.1 BRIEF HISTORY OF SAUDI AIRLINES

The date of 27 May 1945 marks the birth of Saudi Arabian Airlines with the landing of President Franklin Roosevelt's gift, a twin-engined Douglas DC-3, on Saudi soil. In 1946 the Kingdom's first aviation authority began operating under the sponsorship of the Ministry of Defence, and a regular air service was launched for the transport of passengers, mail and cargo.

The airline was first known in as Saudi Arabian Airlines SAA, but later changed to SDI to avoid conflict with South African Airways, which had a prior claim to the initials. Aircraft maintenance was carried out in the open air as no indoor facilities were available at that time. Not until the early 1950's, were maintenance shops were built in the city of Jeddah (Anonymous, 1999).

The lack of adequate surface communications in the Arabian Peninsula was a great drawback to the economy in transporting goods and freight of all kinds. Saudi Airlines introduced two Douglas freight aircraft in 1964. Later, more cargo planes arrived which were used to transfer mail and freight to help to supply the needs of the Kingdom at that time. Saudi Airlines' operations has grown dramatically since it started in 1945. The network of services in Saudi Arabia is shown in Figure 2.1 and 2.2. Air transportation in Saudi Arabia has played an important role in communications terms because of the wide network. By the late 1970s', Saudi Arabia had undergone a complete social and demographic transformation. Twenty-five years before, apart from the Holy Cities of Makkah and Madinah, the Kingdom had only two urban communities – Jeddah and Riyadh that could even be described as small cities.

Figure 2.1 Map Of The Domestic Route Structure Changes 1947-63



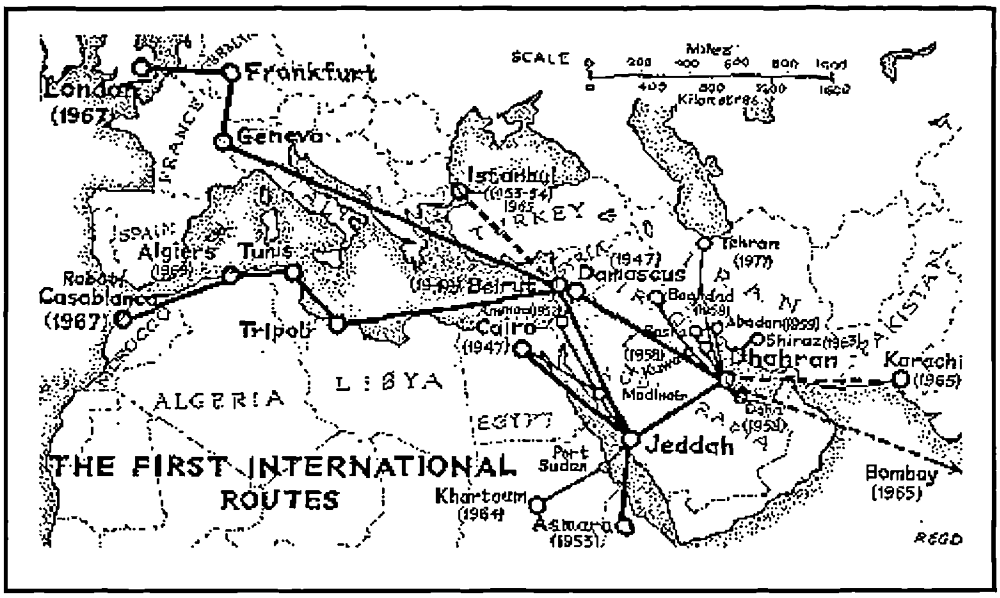
Source: Davies, 1995:16.

During that period the Saudi government paid considerable attention to the air transport industry and therefore, placed it under the supervision of the Ministry of Defence. The

Presidency of Civil Aviation (PCA) acts as the regulatory agency for the airline, in Saudi Arabia, to assure that the airline is implementing safety requirements as well as providing the proper technical assistance for the fleet (Davies, 1995). The national carrier (Saudi Airlines) carried more than 12.5 million passengers in 1997 to domestic and international destinations (Anonymous, 1998b).

Regulatory bodies exercise a degree of control over business activities such as enforcing adequate standards of safety. This is done to ensure public safety, protect firms engaged in activities conducted in the national interest and finally, to protect government investments. Moreover, depending on its political and economic philosophies, governments can vary the regulations imposed on the national carriers (Shearman1994).

<u>Figure 2.2</u> Map Of The Domestic And International Route Structure Up Until 1967



Source: Davies, 1995:26.

The importance of the carrier arises from modernisation, when the country was starting to build its infrastructure, and people needed to travel from one place to another for business or pleasure. Its importance in economic terms comes from the contribution that it makes to the economy by employing 24,112 employees in 1994 (AAC, 1994).

One of the economic benefits that comes from airlines is airport construction. They are major users of construction companies in the building airports themselves along with terminals and runways. Furthermore, the government ownership usually provides a sense of security for the airline, thus making it easier for the carrier to obtain credits (Shearman 1994). Table 2.1 shows the growth of the international network

Table 2.1 Growth Of Saudi Airlines International Network (Europe and Asia)

ASIA ROUTE EXPANSION

Sep 1952	Karachi	Apr 1983	Seoul
1 Jan 1965	Bombay	11 Apr 1984	Colombo
1 Nov 1980	Bangkok	28 Oct 1985	Jakarta
29 Mar 1981	Delhi	16 Dec 1986	Lahore
4 Apr 1981	Dhaka	25 Oct 1987	Kuala Lumpur
30 Mar 1982	Singapore	1988	Taipei
30 Jun 1982	Manila	1990	Tokyo
1 Nov 1982	Islamabad	1 Apr 1991	Madras

Source: Davies, May 1995: 34.

EUROPE ROUTE EXPANSION

1 May 1967	London	1 Nov 1978	Stockholm
1 Jun 1971	Rome	31 Mar 1981	Madrid
18 Jun 1974	Paris	3 Jun 1982	Nice
2 Jun 1978	Athens	2 Jun 1986	Amsterdam

Source: Davies, May 1995: 34.

The author believes that government ownership of the airline can have other objectives, which are seen as more important than making profit, these are:

A. Supporting the national tourist industry.
B. Generate foreign currency to buy in foreign goods.
C. Maintaining overseas relations with other countries, which is important politically.
D. Using the aircraft to show the country's name as so called "Flag-carriers".

For many years the Saudi government provided sense of security for the airline by not allowing another competitive carrier to exist. This was done to allow the airline to have the chance to establish itself and be able to provide services for the public at an affordable rate, as well as a high quality of service. Yet, in recent years the government has allowed the competition to come into existence for the first time by the formation of a private carrier, which uses small corporate jets targeting business customers only, who may have different needs.

Shearman (1994) stated that airlines world-wide started to develop alliances which could vary from joint marketing, equity exchange, joint maintenance activities or joint part purchase. The author lists some advantages and disadvantages of alliances. Some of the advantages include:

A. The possibility to increase marketing strength.
B. If the two networks are complementary, an alliance can increase network synergy.
C. Bulk purchase and joint negotiation, may provide economies of scale.
D. Achieving cost savings through the implementation of joint operations of one of the partner's aircraft.
E. In congested airports the use of slot sharing and ground operation support to reduce cost.

Some of the disadvantages include:

A. The lower quality of one carrier may damage the image of other partners.
B. Agreement on integrating schedules or on market tickets may be difficult to achieve and is time consuming.
C. Different company cultures and management styles may cause disputes.
D. The expected benefits may not be equal for both partners.
E. Government intervention fearing a reduction in competition and fare increases.

Shearman (1994) notes that airline operators seek to differentiate their products with added improvements such as special business fares. Furthermore, many airlines tend to spend a large amount of investment trying to improve customer service; yet few can achieve it, because of the severe competition in the market.

2.2 AIRLINE MAINTENANCE AN INDUSTRY OVERVIEW

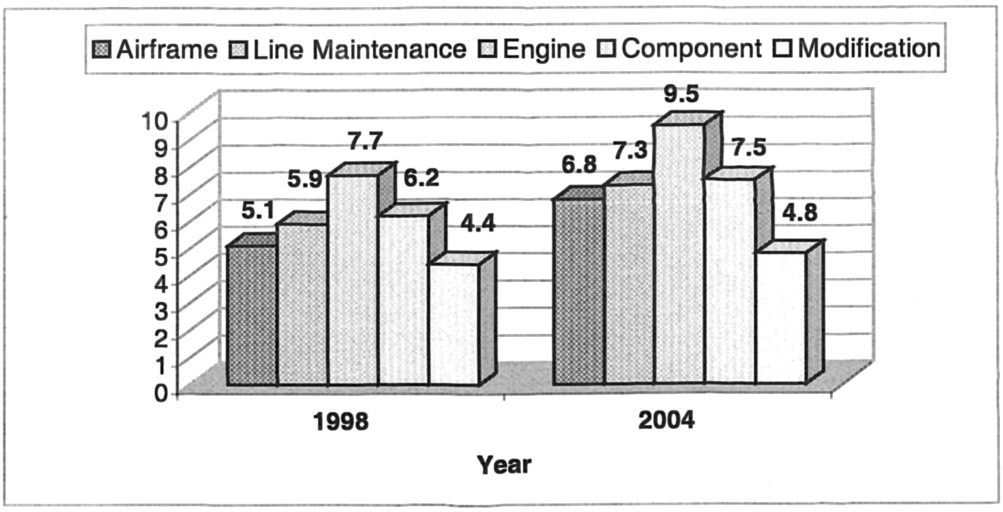
Lam (1995) stated that in the U.S. there were small numbers of major carriers that dominated the market, and were able to provide a maintenance service for its fleet and other small carriers. However, after deregulation in 1978, a number of the large carriers have gone, and new entrants have taken their place. This had an impact on maintenance:

A. It introduced a series of small carriers lacking maintenance infrastructure.
B. A series of independent maintenance providers sought contracted maintenance.

In Europe the case was different, with the introduction of the B-747 in the seventies. The cost of maintaining the aircraft is great for the carriers in Europe. To overcome this problem and be more competitive in reducing maintenance cost, a number of airlines formed maintenance consortia, ATLAS (Alitalia, Iberia, Lufthansa, Air France, Sabena).

With the increase in the size and the technical complexity of world commercial air transport, so, too, will there be an increase the size of the international maintenance, Repair and Overhaul (MRO) market (Jackman, 1999). According to a market forecast conducted by The Canaan Group for *Overhaul & Maintenance,* the value of the commercial jet transport MRO market will grow more than 22.5% from its 1998 level of \$29.3 billion to \$35.9 billion in 2004, the end of the forecast period, see Figure 2.3.

Figure 2.3 Breakdown Of Commercial MRO Market



Source: Jackman, Apr 1999:22.

The largest percentage increase will be in the *airframe* heavy maintenance segment, which is forecasted to grow 33% to \$6.8 billion.

Aircraft *engine* repair remains the largest segment in the MRO industry, with a projected increase of 23.4 % to $9.4 billion. The value of the Component overhaul & repair segment will also increase 21% to $ 7.5 billion.

The *Modification* segment will experience a relatively modest growth of 9% to $ 4.8 billion by 2004. Finally *Line* maintenance will grow 23.7% to $7.3 billion, yet this is still largely the domain of the airlines and is only infrequently outsourced.

The growth rate of the world commercial fleet is significant to the MRO industry. One problem which will face MRO industry is the supply of new airline maintenance technicians. According to the National Air Transport Association (NATA), the U.S. Department of labour has forecasted a demand of 12,000 new mechanics per year, yet in 1997 the Federal Aviation Administration (FAA), has issued fewer than 7,500 new certificates for technicians (Jackman, 1999).

The importance of the airline maintenance department not only arises from its role in providing airworthy aircraft, but also from its handling of immense physical and financial resources which are operated on a daily basis. Thus airlines are concerned about how efficiently these resources are being used and how they stand among other competitive carriers in providing a service that is high on quality and safety. Therefore, efficiency measurement techniques act as a tool to provide top management with a clear picture of how well the carrier is performing in terms of providing a proper safe and efficient technical service.

Foley (1977) states that the cost of maintenance will never be reduced, unless performance measurement schemes are set up. Such a performance measurement programme should include job tasks to find out how effectively maintenance is performing their maintenance tasks. The lack of implementation of such a measurement of performance is considered to be the reason behind the deficiency. In general, improvement in the maintenance department will be achieved when technicians understand the pre-defined performance standards required from them.

Civil Aircraft maintenance operations have become complicated, incorporating numerous technologies within a single airframe. This complex technology has increased the workload assigned to aircraft maintenance technicians in term of the required training and knowledge. The maintainability improvement, which has been integrated into the aircraft design, represents a perpetual effort to reduce the maintenance element of the aircraft life cycle (Docker, 1991). Aircraft cycle is defined as a completed take-off and landing sequence (one take-off and landing) (Saudi Airlines, 1996b).

Stewart (1963) defines the job of maintenance managers in the following context:

1. Establish the economic objectives of the maintenance work;
2. Initiate requisite maintenance at the right time;
3. While maintaining high levels of safety and quality, minimise the labour and material cost of all maintenance work.

One of the problems that has been done in the past with regard to technicians' development in the airline maintenance departments, is that there are no defined career path for maintenance professionals (Chandler, 2000). The author also states that most of the airline maintenance professionals get their licence to work on fixing aeroplanes, and then they work in the Shop basically for life. The job will not change dramatically for a long time. In addition, the author argues that what maintenance managers should be doing is developing a career path for the professional technicians, one that could make the career in the airline maintenance profession a mobile one and therefore, it should be progressive. It is very difficult to reward an experience technician by making him a Line maintenance manager for example. A proper career path would require well experienced and talented technicians to go through a series of airline maintenance management programmes aimed at preparing them to progress further in the field of airline maintenance operations.

The pressure continues to be applied to aircraft maintenance organisations, with the aim of improving productivity, efficiency and reducing aircraft spare parts held (Docker 1991). The increase in airline size coupled with the limited availability of resources (Specialised manpower) to meet the commitment, has forced airline maintenance management to re-evaluate their efficiency measurement procedures. In order to maintain an aircraft in an airworthy condition, substantial investments are required. Two key resources in airline maintenance are technical personnel and aircraft spare parts which comprise the largest share of the maintenance budget (Docker, 1991). The author notes that the maintenance function is considered more than a cost centre, since it has direct affects on aircraft availability. In civil operations this will directly affect revenue-earning potential and therefore profitability. With the increase in demand for air transport capacity, the number of new aircraft entering service is also increasing, which means an increase in maintenance workload.

However, with all this in mind, White (1982) states that from a line manager's point of view the advantages of improving maintenance methods include:

1. Increasing utilisation and minimising downtime.
2. Control over labour force.
3. Maximum utilisation of resources.
4. Higher levels of safety.
5. Preventing waste of tools, spares and materials.
6. Improving technician communication.
7. Measuring performance as a guide for future policies.

The mission of the Chief Executive Officer of Engineering and Maintenance (E & M) in any major carrier is to keep the company's equipment at a high level of safety and to provide "Salable" air transportation. "Salable" means a quick reliable service with an adequate furnishings and decoration in conformation with the carrier's own operating specifications as well as conforming to all other applicable directions and regulations of the local authority (Wells, 1989). The author notes that airline maintenance departments through the years have developed a technical support operation, which deals with numerous activities performed at different facilities of widely different capabilities. Furthermore, the author describes how an airline maintenance operation, typically divides its many stations into different types. These are Maintenance Base, Major Station, Service stations and other stations (Wells 1989).

1. *Maintenance base* - This has the best equipment, often it is the largest and most versatile. The maintenance bases service the carrier's entire fleet including overhaul and modification operations. Furthermore, the maintenance base must include the facility to conduct a repair on almost all of the components fitted on the aircraft. Some of the components require certain types of test equipment, which are not

economically feasible for the carrier to purchase, therefore, they are sent to the manufacturer or other service shops for repair or overhaul.

2. *Major station* - This station will include the airline's largest hub cities. Because it is a large hub, very often it will include a relatively large number of technical personnel as well as supporting facilities and equipment. Consequently, because this station is set to receive a large number of flights per day it also maintains the largest number of spare parts, supplied by the maintenance base. This makes it ready at all times for the replacement of parts in order to minimise the ground time of the aircraft. The major station is also capable of conducting complete line maintenance requirements of specific types of equipment (Wells, 1989).

3. *Service station* - This is classified as a large station served by the carrier, but not located at a major hub city with a large number of connecting flights. Although this station is well equipped and well staffed with line maintenance people it is smaller than the major stations.

4. *Other stations* - In a typical carrier, these stations can be given be divided into Classes 1, 2 and 3. Class 1 can be characterised by having the minimum number of licensed technicians to ensure maintenance coverage for each flight from arrival to departure. To provide the necessary support, airline management allocates the minimum number of spare parts and facilities to conduct specific types of maintenance activities, for certain types of aircraft. Class 2 stations are even smaller than Class 1 with only enough technicians and facilities to conduct work such as de-icing and towing the aircraft, which involves the lightest equipment. Consequently, the number of flights to and from these destinations is quite low. Class 3 stations do not have any licensed maintenance people, therefore, no maintenance is conducted at this type of station. The only aircraft servicing carried out is cargo handling and passenger movements (Wells, 1989).

Friend (1992) stated that maintenance personnel in the airline industry vary from one airline to another depending on the nature and size of the operation performed by the carriers. The result from looking at twenty-four different carriers shows that maintenance and overhaul employee who typically comprised from fourteen per cent to twenty-four per cent of the total staff in the airline, with some notable exceptions for very large carriers. Table 2.2 lists the result for the twenty-four carriers selected, which represented sixty-eight percent of the total International Air Travel Association (IATA) membership of employee in 1989. The average for all twenty-four carriers selected was eighteen percent of employee in maintenance and overhaul.

Table 2.2 IATA Members 1989, Maintenance And Overhaul Staff

IATA members 1989 (Ranked by total Managers)	Maintenance & Overhaul Employee	Total Employees	% M&O
Federal Express	2,756	82,611	3
American Airlines	9,361	75.086	12
United Airlines	8,420	65,099	13
British Airways	9,847	50,959	19
USAir	7,767	49,948	16
Lufthansa	10,890	43,565	25
Air France	9,773	39,111	25
TWA	5,044	33,299	15
Continental Airlines	5,746	32,011	18
Iberia	5,466	29,001	19
Pan American	5,755	28,784	20
KLM	5,285	25,000	21
VARIG	4,674	24,638	19
Saudi Arabian Airlines	6,271	24,064	26
Alitalia	5,492	22,719	24
Japan Air Lines	4,843	21,142	23
Air Canada	6,182	21,022	29
Swissair	3,300	20,917	16
Indian Airlines	8,055	20,905	39
Pakistan International	4,643	19,691	24
Qantas Airways	4,400	17,481	25
Air-India	4,479	17,293	26
Eastern Air Lines	3,191	15,468	21
Canadian Airlines International	2,045	15,262	13

Source: Friend, 1992:41.

2.2.1 The Philosophy Of Airline Maintenance Sharing

Inter-airline maintenance sharing contracts is one way for airline operators to cut down on maintenance costs (Friend, 1992). The author provides an example of two well-known groups in Europe ATLAS and KSSU. ATLAS comprises the following major carriers Air France, Alitalia, Iberia, Lufthansa and Sabena, while the KSSU consists of KLM, SAS, SWISSAIR and UTA. Friend (1992) notes that the main purpose of forming these maintenance sharing facilities was to support wide-body jets in the 1970's. In

order to obtain the optimum benefit of these agreements, airline operators made several co-operative accords on several maintenance issues such as cockpit layout and training standards. Furthermore, the author stated that the benefits of maintenance sharing were apparent in use of spare parts as three-quarters of the major spares that are common among the group are routable for maximum benefits.
The distribution of maintenance tasks is conducted in the following manner. One partner in the group will be the main provider of major airframe maintenance checks for one type of aircraft, another for electrical component repair and overhaul, another partner will cover overhaul of one engine model or manufacturer and so on.

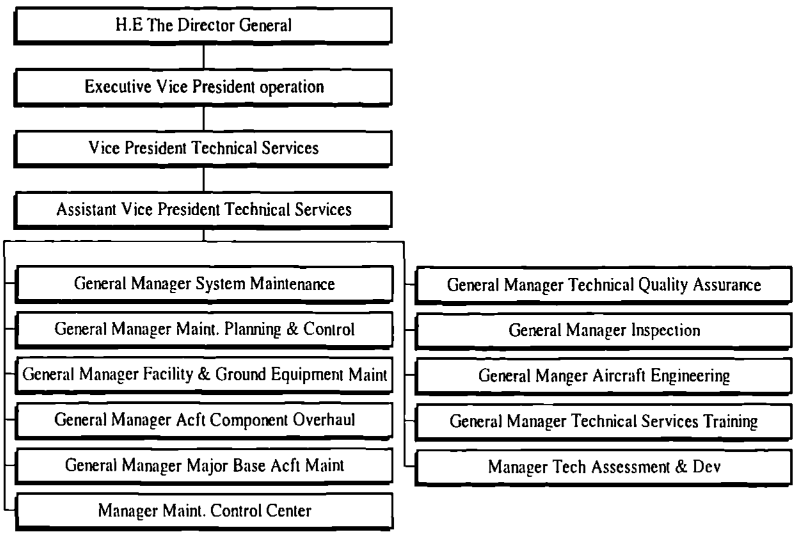
Friend (1992) indicates that the implementation of this type of maintenance sharing has generated significant savings in Hangar and Shop construction, since major aircraft checks requires certain types of test equipment and hangar space as well as the special equipment needed for each check. The same standard applies to engine maintenance and overhaul, as each engine overhaul requires certain test cell equipment. To avoid the problem of moving aircraft parts between different bases, the partner groups have selected the major cities that conduct the maintenance activities to be close to each other, i.e. less than 1000 km apart if possible. Nevertheless the scheduled maintenance intervals between checks are fairly lengthy which allows enough time to move parts when needed. Friend (1992) notes that this type of maintenance sharing has been successful in Europe, but not in other countries. The author lists the reasons why they were not successful in other countries:

1. Anti-trust legislation.
2. Exchange rate fluctuation combined with economic instability.
3. Cross-border problems and customs clearance.
4. Long geographical distances could separate partners.
5. Different skills of partners.

2.3 SAUDI AIRLINE MAINTENANCE DEPARTMENT ORGANISATION STRUCTURE

Maintenance has changed over the past fifteen years due to the large increase in the number and variety of physical assets such as plant, equipment and buildings (Moubray, 1991). The growing concern is that failure in a component or a system could cause effects in the safety of the operation. Furthermore, the maintenance industry is subject to changes in technology and environment which provide a test of the management's ability to adapt to these changes and be able to provide a service which is safe, efficient and reliable. The Shop, Line and Hangar in the maintenance department differ in the maintenance tasks carried out in each department or units, in their environments and in the available resources (tools, test equipment) they use. This could play an important role in identifying the characteristics of each unit Figure 2.4 shows the units in Saudi Airlines Maintenance Department.

Figure 2.4 Technical Services Organisation Structure



Source: Maintenance Technical Report, Dec, 1998b.

2.4 AIRLINE MAINTENANCE OBJECTIVES

Maximising the performance of equipment is one of the purposes of maintenance and it is done to ensure that such equipment performs normally and efficiently to prevent breakdowns or failures (Wild, 1995). Moreover, increasing system reliability is one of the objectives of maintenance function. To ensure such objectives are met, the following steps must be observed:

1. Improvement in the layout of equipment to facilitate maintenance work (providing enough space around the equipment).
2. Establishment of repair facility, to speed up replacement of broken parts, to minimise equipment downtime.
3. Improvement in the design of equipment to ease replacement of failed items.
4. Improving equipment quality through improved manufacturing standards.

Wells (1989) states that the fundamental intent of the airline maintenance organisation is to provide the highest levels of safety of the company's aircraft and to maintain them in an airworthy condition. In order for an airline maintenance department to achieve these goals it must continuously be trying to implement a number of maintenance efficiency goals *minimising aircraft out of service time, use up all the time allowable on aircraft and parts between overhaul, seek optimum utilisation of personnel and finally maximise the use of facilities.* Furthermore, safety will never be compromised just to meet a schedule, as it is critical in airline maintenance.

1. *Minimising out of service time* - An airline maintenance department must give great attention to planning scheduled maintenance and exert every effort to use up all the allowable time before scheduling the aircraft for service, but without compromising safety. Since the profitability of an aircraft is greatly reliant on its daily utilisation or on its availability for service, the carrier must arrange for a reliable high standard maintenance system that achieves the minimum out of service time (Wells, 1989).
2. *Minimising ground time* - The author considers this factor as an important element that will have a great affect on the efficiency of the airline maintenance department. It can be well managed through various inspection programmes, which are designed and implemented by carriers in accordance with flight safety regulations and manufacturer specifications as well as government bodies. This is to ensure a high standard of airworthiness and the availability of aircraft, yet minimising aircraft ground time (Wells, 1989).
3. *Personnel utilisation* - Almost all technical personnel in the airline maintenance department must be qualified technicians in order to carry out any repair, inspection, engineering work or modification on the aircraft. Skilled professionals cost the airline millions of dollars each year; and therefore, it is important to keep their cost under control. Planning the work in advance will allow the management to allocate the right number and mix of specialisation to carry out the maintenance activities.

Consequently, since the nature of the work that is been carried out in the maintenance department requires highly skilled personnel, then they must be utilised efficiently as they are not easily available in the open market (Wells, 1989).

Esler (2000) states that Air Canada's experience in providing third party maintenance service was a success as it turned its maintenance facility into a profit generator for the corporation. The idea was started several years ago to keep an idle workforce busy, while taking advantage of excess capacity in its hangars and shops in the off-season. It is expected that that third party contracts will generate $230 million (Canadian) in year 2000, which is expected to rise to $500 (Canadian) million in five years. Air Canada has taken several steps to be able to provide a maintenance service for other carriers. The airline have spent $23 million (Canadian) on the modernisation of its maintenance facility for the purpose of slashing turn-time for major overhaul by 20%. To achieve this goals especially custom designed work stand to be quickly configured to accommodate different types of aircraft were in place, this programme was called "Hangar-Focused Maintenance Concept".

4. *Facility utilisation* - Maximum utilisation of the company's facilities such as the Hangar, Shop, and ground equipment are required to achieve the company's objectives (Wells, 1989).

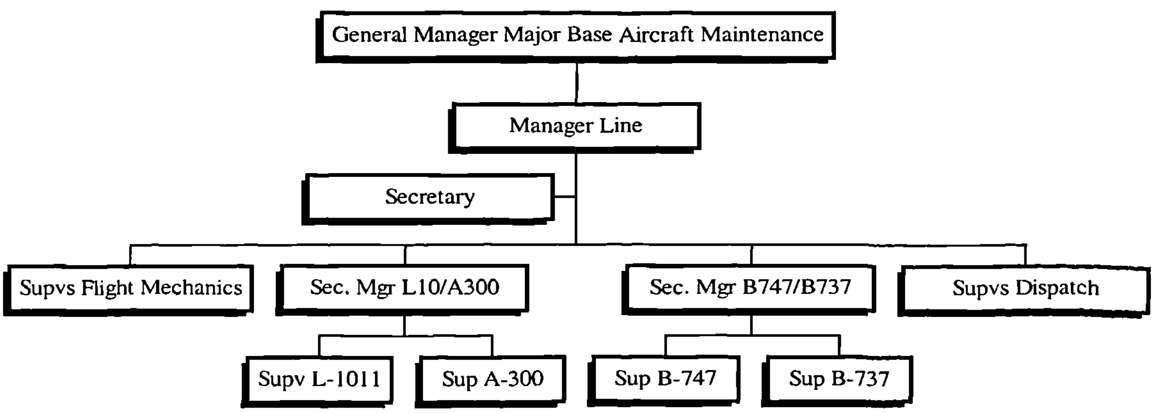
2.5 LINE MAINTENANCE

Kenneth Morin, the UPS division Line Manager describes the nature of the Line maintenance at UPS as "fast moving, and it takes people who are quick on their feet and conscious of their surroundings. You have got to be careful. There is lots of activity and lots of moving vehicles" (Ott, 1999). During the aircraft on ground period, UPS line maintenance mechanics conduct arrival service inspections, logbooks are checked for flight crew-noted maintenance items and the aircraft are fuelled. Pilots can relay maintenance information to ground bases, and maintenance problems are discussed and planned before the aircraft arrives. Yet there is always something unexpected, e.g. if an aircraft picks up Foreign Object Damage (FOD) on landing. According to Ott Line maintenance deals with the day-to-day basis. Exceptions are handled between maintenance visits, such as assessing in engine change and other light modifications (Ott, 1999).

Friend (1992) defines line maintenance as "The maintenance organisation immediately responsible for the maintenance and preparation of use of the complete systems or requirement". First line maintenance undertakes depth-A maintenance, yet it may be authorised to undertake depth-B maintenance. The author defines depth A as "That maintenance which is directly concerned with preparing end items for use, and keeping them in day-to-day order, it may include operations such as functional testing, replacement, servicing, re-arming, role changing, minor modification, fault diagnosis and corrective maintenance by replacement adjustment or minor repair". The line maintenance technicians may be required to carry out several tasks see Figure 2.5 for Saudi Airlines Line Maintenance, these may include:

A. Providing technical assistance for minor repairs and some major repairs in some cases.
B. The handling of routine visual checks during turn around time at each station.
C. Acting as a first point of contact with the crew as soon as the aircraft arrives to handle any problems.
D. Ensuring the aircraft logbook (which includes aircraft records) and pilot report is taken care of before the next flight is due to take off.
E. Conducting minor routine overnight checks, to ensure the readiness of the aircraft for the next morning trip.
F. Running general ramp activities i.e. (refuelling, checking for leaks etc.) .
G. Maintaining the Minimum Equipment List (MEL) for each aircraft. MEL are the list of items missing or inoperative on a certain aircraft, yet they do not affect the safety and the airworthiness of the flight (Saudi Airlines, 1997).

Figure 2.5 Saudi Airlines Line Maintenance Organisation Structure Organised by Aircraft Types



Source: Maintenance Technical Report, Dec, 1998b.

Measures of the effectiveness of line maintenance include *percentage on time performance*, *number of delays*, and *number of technical log entries by pilots* (Saudi Airlines, 1997b). The purpose of these to set an alert level to the Line maintenance management on how well maintenance is achieving its intended goals. The following is a description of measures of effectiveness used in the line:

1. *On-time-performance* - Is time scheduled for the aircraft to leave the gate
   The equation used for on-time-performance is one minus the number of technical delays divided by the total scheduled departures.
2. *Technical Delays* - Is defined as the number of chargeable technical delays. Technical delays will be considered if they are only greater than fifteen minutes, as shorter times could be recovered during the flight.
3. *Number of technical log entries* - Is defined as the total number of pilot reports of a fault in the system or a malfunction, e.g. a cabin door locking mechanism that is not working properly.

The purpose of the preventative maintenance is to even out the pressure of the work conducted in the maintenance units. The nature of the work in the line can be described as stressful during peak periods, as any technical fault will cause a great disturbance in the system. The flow of the work may well be disrupted, as in some cases more than one technician is needed to carry out a quick repair for a late departing aircraft. In addition, technicians may have to deal with more than one type of aircraft in a shift. Table 2.3 shows weekly movements during the month of May-1997 to illustrate how busy line staff are. Given the time of the year this table shows how busy the technicians in the Line could be.

Table 2.3 Weekly Movements (May-1 to 24-Jun 97)

DAY	B-747	L1011	A300	B-737	Total
Mon	40	52	40	115	247
Tus	44	58	42	120	264
Wed	42	70	51	127	290
Thu	43	60	37	113	253
Fri	47	62	56	128	293
Sat	45	62	33	111	251
Sun	35	47	39	99	220
Total	**292**	**411**	**298**	**813**	**1818**
Average	*42.3*	*58.7*	*42.6*	*116.1*	*259.7*

Source: Saudia Airline, TSV, Maintenance Technical Report: Aug 1997e.

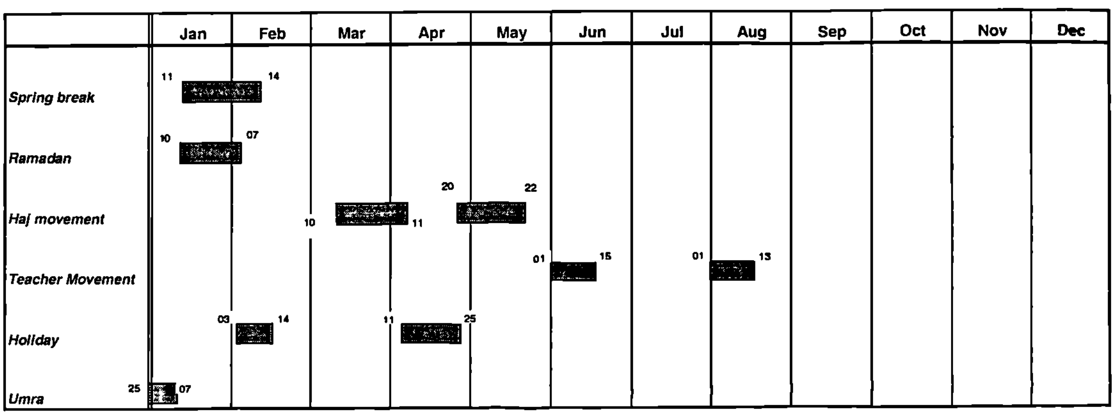
Horn (1985) states that management should first draw an upper limit for the alert level in any of the measures of effectiveness used, and therefore, must decide what the alert level should be based on. Is it based on previous trends? Or industry average?. The most normally applied method is to base it on a measure of past experience.

In general management in the Line continuously monitor these measures of effectiveness to ensure they remain below upper limits, which have been set based on the industry average over time. If any measure reaches the upper limit, management will initiate an investigation of the possible causes which can be identified as one of the following (Horn 1985).

1. Fault in the design.
2. Accidental or deliberate damage.
3. Faulty batch of system components.
4. Incorrect maintenance practice performed.
5. Incorrect use by flight crew.

One method used by the airline maintenance departments to cope with the problem of idle time is to transfer personnel with a low workload from Hangar to Line. The reason for doing this is because. Hangar personnel may not have any aircraft to work on, yet the Line personnel are short of manpower (De Vaal, 1970). The author states that if the situation persists for a period of time, then there has obviously been a miscalculation in manpower planning. However, this need arises because of occasional peaks in workload, and temporary manpower transfer is necessary instead of allowing the personnel to remain idle. See table 2.4 for the yearly significant period.

Table 2.4 Yearly Significant Period



Source: Saudi Airlines, Engineering Monthly Report, Sep, 1997f.

Horn (1985) states that it is difficult sometimes to achieve higher levels of success with transferring technicians from one unit to another simply because of the required skill and expertise needed in doing the work. Personnel may resist the new environment since they are not used to working there. Since technical problems require high knowledge and skill to perform the required maintenance tasks, then it is difficult sometimes to transfer technicians between the Hangars and workshop for example.

The scheduling of workforce in a small office tends to be easy if it involves daily routine operations and they are well known, and there is only one shift. However, the nature of the operation will determine the workers that will be assigned to a specific shift to do a specific maintenance task. Therefore, the total staffing plan identifies the required levels of workforce for each planning period (Noori and Radfors, 1995). Yet it gets more complicated when the demand pattern differs from day to day or when there are demands and peaks during different periods, such as the maintenance work accomplished in the line maintenance. One way to overcome this problem is to assign workers to low-priority work before demand increases.

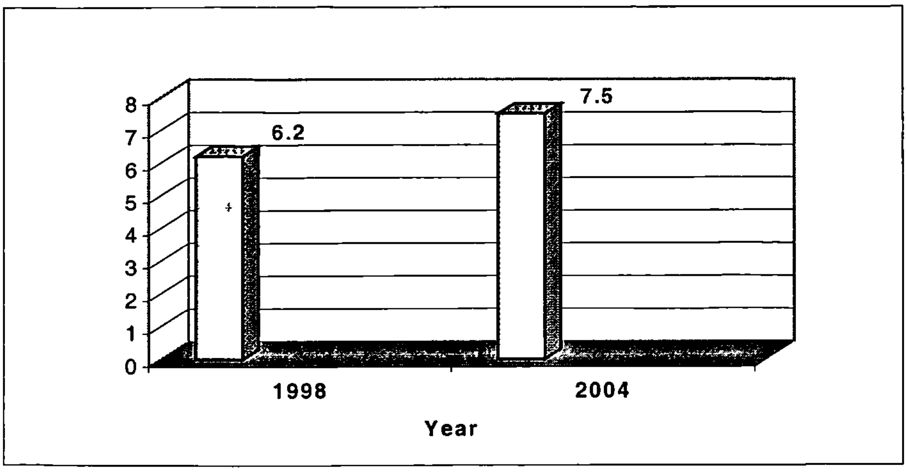
The authors state that management is faced with some constraints when trying to satisfy daily workforce requirements. If the set maximum hours per week are exceeded then overtime must be paid; if workers are not given two consecutive days off, overtime payments could be excessive. In the case that more than one shift is generally scheduled per day, the firm must allow the managers to rotate from one shift to the next during the period, and are given sufficient time between shift rotation to adjust. Therefore, an effective forecasting method for demand becomes vital. Long waiting queues lines puts pressure on personnel and may lead to unsatisfactory output. Therefore, queuing theory is often employed to determine the amount of needed capacity to prevent idle time for workers and to keep waiting line to a reasonable size (Noori and Radfors, 1995).

2.6 SHOP MAINTENANCE

Aircraft components which are repaired and overhauled in the Shop comprise $6.2 billion of the total commercial MRO market, and this is expected to reach a level of $7.5 billion by 2004. See Figure 2.6 for component market growth, according to The Canaan

Group (Palmgren, 1999). In the current market more than half of the component (Aircraft parts) servicing market is outsourced by the airline. This is because of a big change in new aircraft component technology, which is characterised by highly improved reliability, yet requires a significant investment for repair capability. Airline operators are always reassessing their business models and choosing not to invest in in-house capabilities, Figure 2.6 shows the change from 1998 to that projected for 2004.for components MRO market.

<u>Figure 2.6</u> Component Maintenance Repair And Overhaul (MRO) Market



Source: O&M, April, 1999:32.

With improved component reliability, component self-test capabilities and large capital requirements, the number of aircraft required to justify in-house repair capability is increasing. Test equipment for modern digital avionics has become so expensive that only a few operators can justify total in-house capability. Many airlines have accepted as a rule of thumb that a fleet of 50 aircraft is necessary to justify the investment needed for in-house capability.

Friend (1992) defines shop maintenance as "The maintenance organisation responsible for providing maintenance support to specified first line organisations. Second line organisations normally undertake Depth-B maintenance, yet may be authorised to undertake Depth-C maintenance". The author defines Depth-B as "The maintenance which is required on items and assemblies which are in an unacceptable condition or which require preventive maintenance. This may include schedule maintenance, embodiment of prescribed modifications, bay maintenance of assemblies, and corrective maintenance beyond Depth-A but within generally provisioned resources"

There are different workshops to support the maintenance tasks which include the sheet metal shop, welding shop, paint shop, landing gear shop, avionics shop, electrical shop, wheel and brake shop, hydraulic shop. The purpose of these shops is to support first line requirements for components or testing and troubleshooting. Some aircraft components are not overhauled at the shop; they are sent to a third party for overhaul and inspection.

Fulfilling promised due dates is one of the main objectives of the job shop managers, as well as making the best of people, equipment and materials; to meet the expectations regarding equality, working conditions and responsiveness to unanticipated needs (Markland *et al.*, 1995). Managers use various performance measures. The first measure of shop performance is, *Work-in-process* (WIP) which is an open order that has been issued, yet has not been (closed) completed. WIP is considered to be undesirable and therefore, should be reduced for several reasons:

1. In a situation where there are many orders that are still open, either managers have allowed more orders than normal or have consistently understated the lead time. Therefore, WIP is an indication of either long flow time or cycle times.

2. WIP inventory contributes to shop congestion in trying to move unfinished goods from one place to another; people misplace orders or damage material.

Throughput is another important measure of shop performance. Markland *et al.*, (1995:604) defines throughput as "Total volume of output from a process". This can be measured by how many inspected parts are completed per shift or per hour. Another traditional measure of shop performance is *utilisation* or the percentage of time a resource is being used productively. While higher personnel utilisation is desirable and generally advisable, it often inspires managers to make a decision that may be counterproductive in the long term. The major sub-functions of shop-floor control are:

1. Assessing priority to each shop order.
2. Maintaining WIP quantity information.
3. Conveying shop order status information to the office.
4. Providing actual output data for capacity control purposes

5. Providing measurement of efficiency, utilisation and productivity of the workforce.

Another measure of shop performance used by Saudi Airlines is the number of components received compared to the number of units produced for one month (Saudi Airlines, 1998a).

Markland *et al.*, (1995) stated that in some instances shop managers have to deal with a job which they may never have dealt with before. The manager would have to provide a list of the necessary materials, equipment, and skilled personnel to carry out such a task. For example, aircraft manufacturers issue service bulletins of a new mandatory modification to the design of a specific aircraft system, such as the re-routing of electrical wires that passed through the fuel tank in the 747 type aircraft as a result of the fatal crash of the TWA flight 800 just after take off on July 17,1996 (Anonymous, 2000, http://www.abcnews.go.com/sections/us/DailyNews/twa_threeyears990717.html).

In an airline operating this type of aircraft, the maintenance department may have never accomplished such a task before. Managers must determine the sequence of operation, depending on the availability of the resources, taking into account the heavy workload that is already experienced by some work centres and trying to avoid them or work around them if possible. Once the sequence of the job is established, maintenance managers must work out the time required and determine the delivery date of the aircraft needed to accomplish the maintenance task to meet the scheduled requirement.

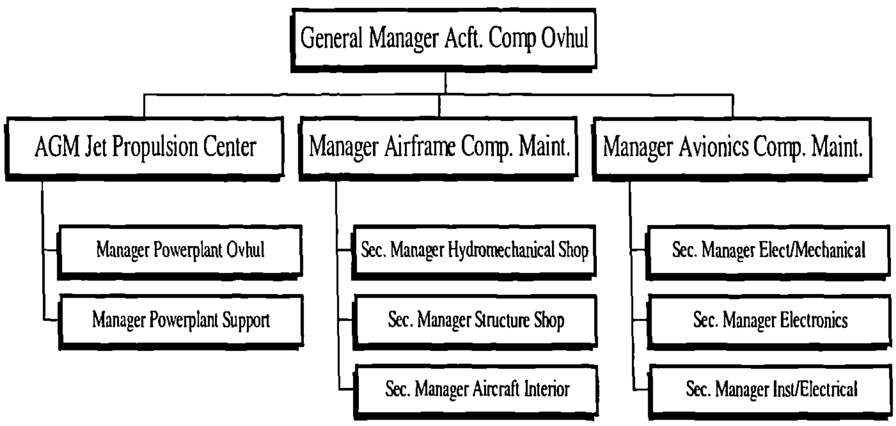
A sample of the day-to-day loading activities in the shop are listed below, generated from Saudi Airlines, Shop Production Planning and Control (SPPC), see Figure 2.7 for Saudi Airlines Shop Organisation Structure (Saudi Airlines, 1996c).

- Set priority for the Shop production. Planner/Controller should take a MEMIS print out to set up and clear the Shop priorities. This should be complied with on a daily basis. This transaction should contain the following information:

    A. In-house capability critical items and should be reviewed and updated on a monthly basis.

- Monitor daily production versus daily Shop loading.
- Investigate/prepare units to be sent to third party repair. Follow up on all Aircraft On Ground (AOG) and Minimum Equipment List (MEL) situations with the respective Shops.
- Check each Shop order for Outstanding Engineering Orders (EO's). Update Shop order properly. Place priorities on Hangar and Flight Line components.
- Research and update all stock deficient (SD) piece parts in the Technical Information System (TIS).
- Schedule repair of other carrier components.
- Monitor and record all no-fault found (NFF) repairable components.
- Perform system update and all intershop routing of repairable components.
- Schedule and follow up on local fabrication of items. Complete all purchase orders in accordance with the applicable procedures.
- Co-ordinate and follow-up with all pending in-house repair components forms.

Figure 2.7 Saudi Airline Shop Organisation Structure



Source: Maintenance Technical Report, Dec, 1998b.

2.7 HANGAR MAINTENANCE

Friend (1992:94) defines Hangar maintenance as "The maintenance organisation within the services but excluding the organisations within first and second line. Third line organisation, normally undertake Depth C and D maintenance". The author defines

Depth C as "that maintenance which is the repair, partial reconditioning and modification requiring special skills, special equipment or relatively infrequently used capability which is not economic to provide generally, but which is short of complete strip, reconditioning and re-assembly". Depth D is defined as "that maintenance which is full reconditioning, major conversion or such major repair that involves work of this depth". Table 2.5 provides an example of a major overhaul carried out in the Hangar for an ageing aircraft modification carried out at Britannia Airways (Newton *et al.*, 1993).

Table 2.5 Overhaul And Ageing Aircraft Modification

Work Description	Material Cost (£000)	Labour Hours	Labour Cost
Basic Check (Including external component repair)	507	39,206	400
Service Bulletins	26	2,896	29
Britannia Modifications	---	53	1
Corrosion Rectification	24	9,683	99
External Paintwork	---	2,442	25
Welding Rectification	---	4	---
Main door Maintenance	10	1,465	15
Fibreglass Material	---	2	---
Workshop Rectification	32	3,942	40
Additional Work	3	2,207	23
Total	**602**	**61,900**	**632**

Source: Newton, Britannia Airways, 1993.

The market for major and minor modification and conversion of commercial aircraft should reach $4.8 billion by 2004 (Proulx, 1999). All modifications are conducted in the Hangar and can be subdivided into seven different categories: passenger-to-freighter conversions, interiors and in-flight entertainment (IFE), structural enhancements, avionics upgrades, VIP interiors, service modifications and fleet integration.

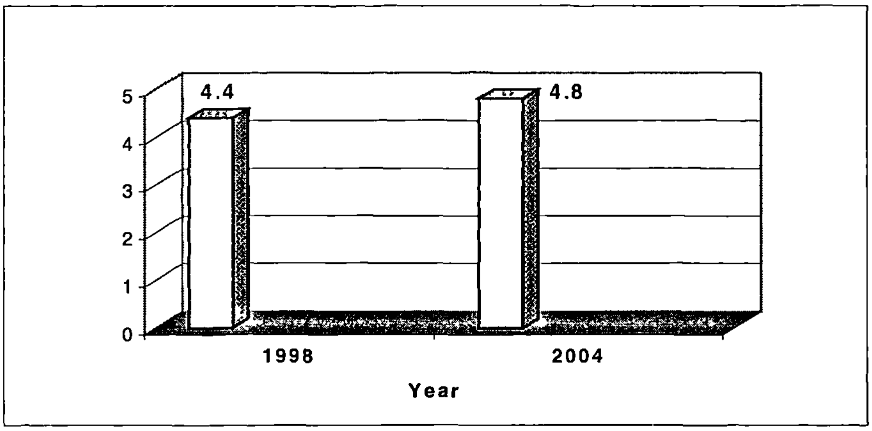
1. *Passenger-to Freighter Conversions* - is considered to be one of the most complicated activities to be conducted in the Hangar, as it costs million of dollars and

could put the aircraft out of service up to nine months. The need for aircraft conversion from passenger to cargo is driven by the following factors: the demand for and growth in air cargo, the lower cost of converting older airframes versus a purchase of a new freighter. According to (Proulx, 1999) during recessions, the basic airframes become cheap, thus a B-747 would cost $20 million without the engines, and it would be necessary to spend $5 million to $10 million to convert it, compared to $150 million for a new B-747 freighter.

2. *The Interior and In-flight Entertainment Upgrades* market averages about $1.1 billion annually, according to The Canaan Group. Several airlines have undertaken interior modifications over the past few years to enhance their image, or to cope with customer demand in particular markets. For example, Delta Air Lines' "Business Elite" conversion, combines first and business classes into a single category on transcontinental flights.
3. *The Structural Enhancement* sector is mainly driven by the Overhaul & Engineering Maintenance (OEM) and or the CAA, FAA authority. The Canaan Group conservatively estimates this market at a steady $350 million per year. It is very hard to predict market growth for this segment, since it is hard to predict what the CAA, FAA will discover over the life service of the fleet.
4. *The Avionics Upgrades* market, according to The Canaan Group, tends to stay at a steady $480 million a year. Several factors could drive this market such as FANS (Future Area Navigation System) and TAWS (Terrain Awareness Warning Systems), also know as EGPWS (Enhanced Ground Proximity Warning System), as well as TCAS II, the second generation of (Traffic Collision Avoidance Systems). The degree of complexity of these systems varies from major engineering & rewiring work to just a simple swap of an older display with a newer one. These types of activities are scheduled during heavy maintenance.
5. *The VIP Conversions Market* stands at $185 million and is divided into three segments: security-sensitive VIP, which includes some heads of state, high-end VIP which includes royalty and finally corporate and executive conversion, passengers who seek comfortable, tasteful business aircraft.
6. *Service Modifications* include aircraft ageing modifications. This market is growing at about 4.8% per year, according to The Canaan Group.
7. *Fleet Integration* is where planes are modified to reflect new purchasers. Major carriers tend to take delivery of a new aircraft and sell their old one in the market.

Furthermore, the high growth of aircraft leasing is pushing this market ahead, as well as mergers and acquisitions. For example, American Airlines is converting the 28 aircraft it acquired in its Reno Air purchase, see Figure 2.8 for modifications expenditure (Proulx, 1999). The researcher's experience is that whenever the airline decides to buy new aircraft, it is always that the best technicians get to move to the new aircraft. This action could have an impact on the fleet that they used to service.

Figure 2.8 Modifications Expenditure



Source: Proulx, April, 1999:35.

The Hangar is faced with two major issues. These include *shortages of labour force* and *Broader Service offering.*

Shortages of Labour Force - The maintenance activities carried out in the Hangar can be characterised as labour intensive activities. Approximately 70% of the costs of a heavy check are labor (Chrisman, 1999). The availability of qualified mechanics is becoming a growing concern for both the airlines that perform their own work internally and the suppliers to the airlines that outsource. One reason for this shortage is that because of the increase in aircraft production rate over the past few years, aircraft manufacturers have attracted many qualified mechanics away from maintenance organisations. The result of this has translated into a 10% increase in labour rate billed to the airlines (Chrisman, 1999).

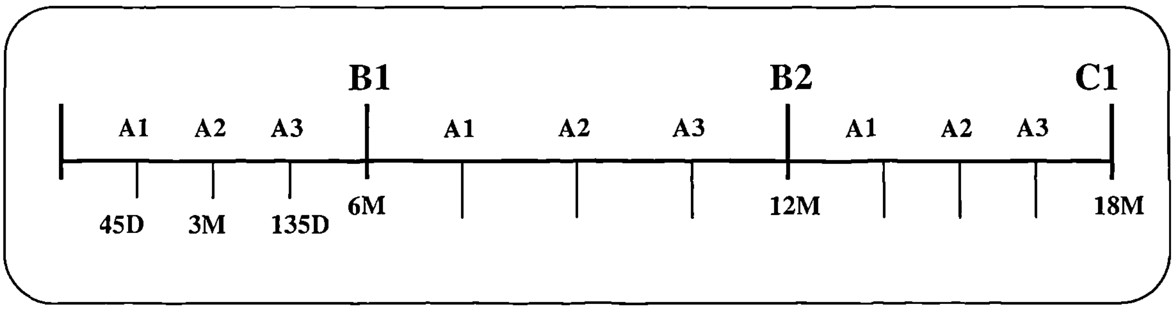
Europe and North America have suffered from this problem; yet Asia has not. There are two reasons for that, first, there is no shortage of available personnel in the region.

Second, most of the maintenance providers in the region have established technical training programmes to assure an adequate supply of qualified mechanics.

Broader Service Offering - European airlines and maintenance suppliers have long embraced the concept of full service (which includes all scheduled maintenance designed by the manufacturer). This concept was passed to North America which resulted in a major change in the maintenance provided by third party maintenance facilities. The result is that airlines in Europe are no longer dealing with smaller contractors, instead focusing on long-term relationships with their broader service suppliers. Furthermore, many airlines in Europe have come to realise that significant reductions in indirect costs can be achieved by contracting with fewer suppliers to perform more activities. This has caused contractors to move towards offering a broader service.

Planned maintenance schedules for the fleet are carried out in the hangar at detailed intervals, Figure 2.9 illustrates the maintenance schedule for the A-300 (Airbus). The type of work carried out in the hangar will also include non-routine work that arises from the detail inspections. In addition, major modification to comply with the manufacturer and the local regulatory agency, such as the Presidency of Civil Aviation (PCA) in Saudi Arabia, is implemented in the hangar (Saudi Airlines, 1998c).

Figure 2.9 A300 Maintenance Philosophy

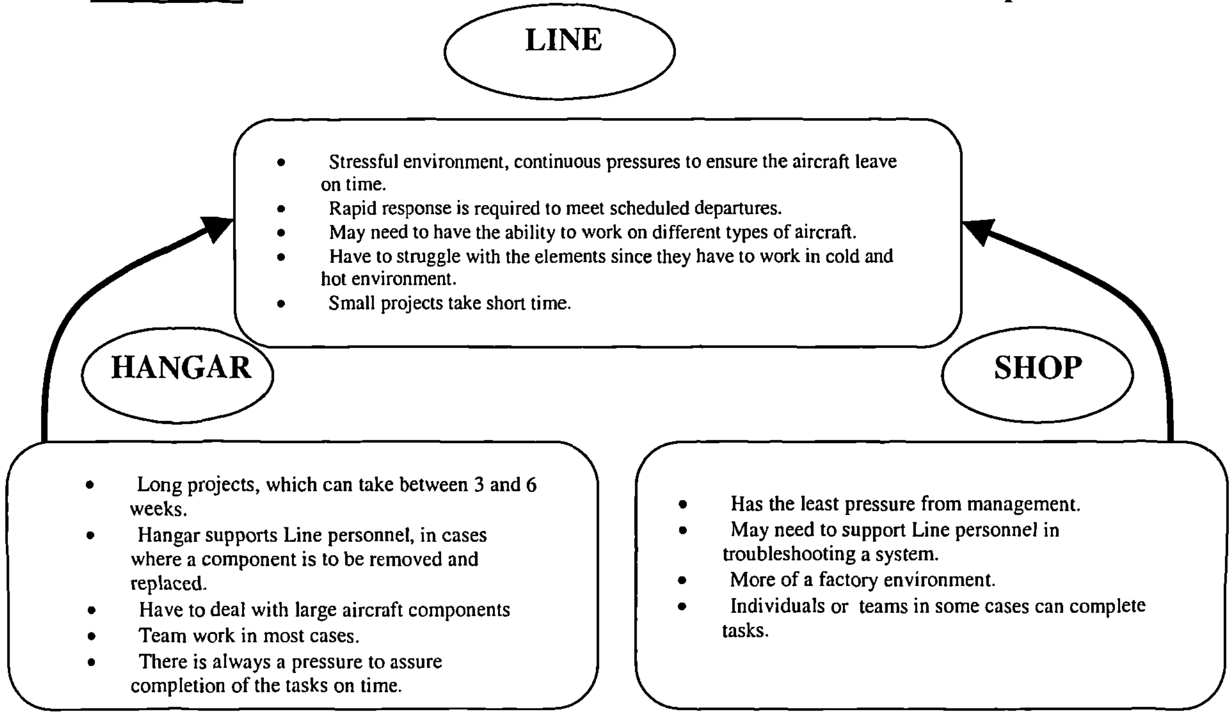


Source: Saudi Airlines, Technical Service Information Report, May, 1998c.

'A' Check = 45 days, 'B' Check = 6 Month, 'C' Check = 18 Month, Mid-Check = 4 Years, 'D' Check = 8 Years

There are different maintenance tasks to be carried out in each maintenance department Shop, Hangar and Line. To illustrate these difference the characteristics of each maintenance department is highlighted in Figure 2.10 which shows the main differences between the three different units in the technical department. In addition, it is also seen in Figure 2.10 that both maintenance department Shop and Hangar are supporting the maintenance function in the Line as Line maintenance technicians under certain situations would require the assistance of either the Shop and/or the Hangar technicians. These are requested in cases where an aircraft part needs to be replaced or troubleshooting needs to be carried out by a specialised technician. In this case assistance could be provided.

Figure 2.10 The Three Different Cultures Within The Technical Department



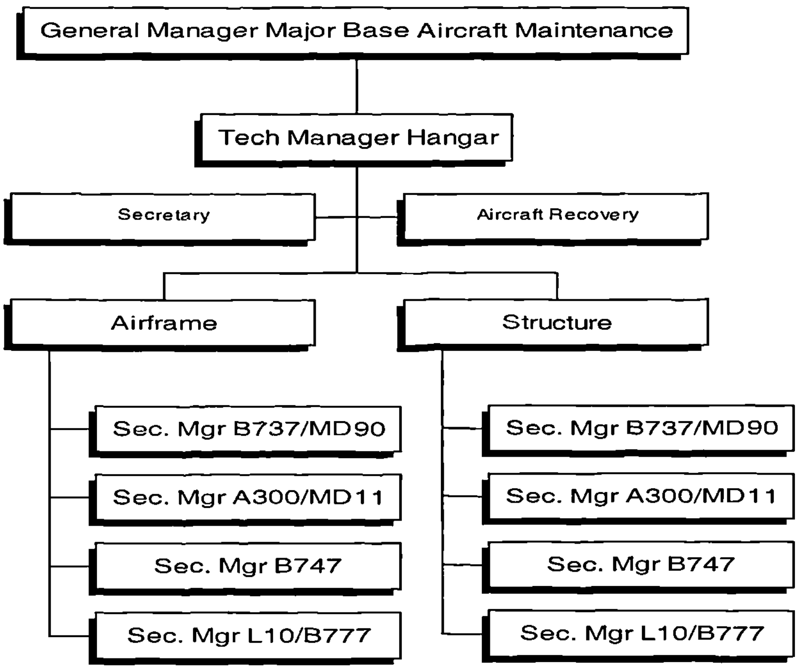
De Vaal (1970) states that major maintenance carried out in the Hangar involves the following fundamental activities to a greater or lesser extent:

1. The pre-check preparation involves the removal of all panels in areas concerned.
2. Visual inspection for any abnormality in the aircraft airframe structure, or leakage.
3. Operational check for flight control, instruments and components.
4. Change of faulty components or components that are time expired.
5. Carrying out a special check to discover irregularities.
6. Modifications.
7. Rectification of defects.

Aircraft manufacturers, however, are subject to the local aviation authority's recommended maintenance intervals, inspections and procedures (De Vaal, 1970). Different airline operators around the world utilise their fleet in different ways, thus aircraft have different working environments, yet all airline operators have to comply with the "life-span" for which the aircraft was designed. For example, the early Boeing 707 had a life span of about twenty four thousand flying hours and the present 747 have a life span of about thirty six thousand, the new design increases this time to fifty thousand hours and more.

Saudi Airlines has four different Hangars to carry out major repairs and modifications to its fleet. The first Hangar is for the B-747 and B-777 wide body type aircraft, the second is for the A-300 medium body type aircraft, the third is for the MD-90 and the B-737 narrow body type of aircraft, the fourth is for the L-1011, which was phased out in January-1999. See Figure 2.11 for Saudi Airlines' Hangar organisation structure.

<u>Figure 2.11</u> Saudi Airlines' Hangar Organisation Structure



Source: Maintenance Technical Report, Dec, 1998b.

2.8 THE NEED TO STUDY AIRLINE MAINTENANCE PRODUCTIVITY AND PERFORMANCE

Fierce competition among airline operators has pressured airlines around the world to pursue productivity improvement techniques to minimise "non-essential" maintenance practices (Taylor and Christensen, 1998). These authors also state that from 1978 into the mid-1990's, there was a nearly constant rate of aviation accidents. However, accident studies indicated that a reduction in accident rate could be achieved through improvements in communication. Chapter Five of the thesis, the survey analysis, will discuss this issue in more detail.

Taylor and Christensen, (1998) further state that airline maintenance needs to have a balance between technical skills and social skills, this would be defined in improved workplace communication. That information exchange will make a big different in the safety and efficiency of a mechanic's work. Moreover, communication in the workplace will improve the quality, quantity and cost of the work. This can involve better co-ordination and better teamwork in the flight line, overhaul hangar, and in the repair shop too. The complexity of the work in airline maintenance has grown beyond the scope of one individual working alone, as one person cannot comprehend the whole job or co-ordinate all parts alone. Therefore, a special team-based system of maintenance is needed. Allowing technicians to learn the technology of modern workplace communication and sharing responsibility for co-ordination will help improve the efficiency and productivity of the work. Frequent group meetings for reviewing the work at hand are of great benefit; however, most aircraft maintenance departments do not think highly of this style of communication.

The aviation maintenance requirement for workers entering this occupation is the certificate for an aircraft maintenance technician. With that a person can be a mechanic, lead mechanic, crew chief, inspector, etc. However, higher grade jobs require technical skill plus company service and seniority. Thus, further upgrading requires administrative ability. Consequently, the technicians' job is clearly defined by technical requirements. However, issues like communication, co-ordination and teamwork are given little or no attention at all. Table 2.6 shows the requirement given by the Federal Administration Aviation (FAA) careers pamphlet.

An example is given by (Taylor and Christensen, 1998) to illustrate poor communication and its negative effect on shift change of safety. In December-1992 a shift turnover problem at the Continental Express Houston maintenance base resulted in an aircraft taking off with a missing screw that had been removed during an overnight shift. The pilot returned to Houston aircraft after severe vibration was felt in the left side panel. According to the National Transportation Safety Board (NTSB) investigator twelve out of the fifty-one screws were missing, and according to an NTSB board member, many of the shift turnover processes used by Continental Express are used by most airlines in North America.

Table 2.6 Entry-Level Requirement for an Aviation Maintenance Career, (1984)

- Understanding the physical principles involved in the operation of the aircraft and its systems
- An understanding of English language
- A willingness to continue technical education
- An above average mechanical ability
- A desire to work with one's hands
- An interest in aviation
- An appreciation of the importance of doing a job carefully and thoroughly

Source: FAA careers pamphlet, (Taylor and Christensen, 1998:12).

Another highly important issue in airline maintenance is written communication. Taylor and Christensen, (1998) state that without clear information and direction from management, technicians will tend to blame each other for doing the job wrong, rather than focusing on the important issue which is achieving the highest safety levels in doing the job. To ensure that safety is given great attention, written information must be clear. If written information is not clear, this can increase the cost and risk of error. Therefore, written communication needs to reflect the company's core purpose, and serve as an official record for all forms of work-related communication. Therefore, developing employee competence in providing clear information on maintenance tasks conducted by them should be the main objective of airline maintenance management.

Exchanging information between management and employee is a highly recommended technique to improve the work efficiency and productivity (Potter, 1980). In addition, the author further states that, if the feedback information regarding the work performance was used to punish employee, then this action is considered to be counterproductive, can greatly weaken communication and therefore should be avoided.

Task allocation and workload effects on the operator are considered to be a serious issue. Task allocation decisions define the "load" to be imposed on the operators; therefore, the workload needs to be matched to the operators' capability to conduct the task (Beevis, 1988). This issue reflects the importance of considering human factors at the early stages of any system design. Furthermore, the author states that at this stage the task should be modelled and refined so that it can match the human ability to carry out the task with the right amount of workload. However, human performance specialists point out that there are some factors that determine workload, such as boredom, emotional stress and motivation as well as time stress (Beevis, 1988).
The main purposes of studying airline maintenance productivity and performance are for management to be able to highlight areas of great concern (poor performance) and be able to control the cost of operations in the Shop, Hangar and Line. Moreover, to allow management to measure the degree by which objectives are being achieved or not. Individuals in airline maintenance still receive little feedback about their performance in spite of the availability of computerised information systems (Luthans, 1995). This author states that continuous communication between management and personnel could enhance individual performance, as people in general have the desire to know how they are doing, particularly if they have some degree of achievement motivation. Allowing employees to generate ideas and set goals would eventually have a powerful effect on their performance.

One area of concern to airline maintenance management is the shift system, and how it affects the flow, safety and productivity of the work. The main purpose of the shift work in airline maintenance is to reduce elapsed time, increase facility utilisation and to meet the required demand for maintenance (De Vaal, 1970). This author lists some of the characteristics of shift work:

1. Shift work is generally unpopular, this is particularly evident on the night shift.
2. More staff at higher levels as inspectors, supervisors and even an engineer are needed such to cover the different activities during the night shift.

The work environment can play a significant role in the efficiency of workers and, therefore, the effectiveness with which work is carried out is governed by the nature of environment that surrounds the workplace (Muhlemann *et al.*, 1992). As a consequence, equipment in general use should be designed to be utilised by the majority of persons likely to use it. These authors lists four environmental elements that are important to work performance:

1. *Lighting* - Allows personnel to move easily and safely, yet it assists in the efficient performance of the work conducted.
2. *Glare and contrast* - The effectiveness of the lighting system does not only depend on its intensity, even more important is the glare and contrast generated.
3. *Climate* - Air temperature, air movement, air pollution and the relative humidity of the air affect the "climate" of the work.
4. *Noise* - Described as any unwanted sound, may also affect efficiency by inducing stress and may mask communication.

2.9 TYPES OF MAINTENANCE ACTIVITIES IN THE AIRLINE INDUSTRY

Maintenance is defined as "any action, which retains non-failed units in a reliabilitywise and safetywise satisfactory, operational condition; if they have failed, restores them to a reliabilitywise and safetywise operational condition" (Kececioglu, 1995). This author states that maintenance activities involve fixing a system preferably without interrupting system operation.

Two main different types of maintenance activities are carried out in maintenance departments *scheduled maintenance* and *unscheduled maintenance* (Kececioglu, 1995). *Scheduled maintenance* is performed on operational units or systems at regular intervals. It includes, but is not limited to, the following actions:

1. Periodical servicing such as adjusting and aligning, checking electrical contacts and making routine checks.
2. Inspecting, checking out components and repairing or replacing failed redundant units.
3. Replacing units before they reach the end of their prescribed life period.
4. Overhauling in a minor way aged and worn out units.

The author states that the main objective of scheduled maintenance is to increase a unit's reliability, and therefore, to decrease the number of failures, minimising the time that the system is not operable and non-productive, and to decrease usage of spare parts.

Before scheduled maintenance can be carried out, management has to decide first who will perform the maintenance tasks. Whether they will be performed in-house or contracted out to third party can subsequently lead to the following:

1. Availability of maintenance skills.
2. Number of personnel to carry out the job.
3. Training requirements.
4. Operational conditions to perform the maintenance action.
5. Maintenance safety procedures.
6. Facilities.
7. Time and cost factors.

It is important for maintenance department managers to identify the desired benefits, which can be achieved by the process of scheduled maintenance. A failure to do so leads to unjustifiable tasks being carried during the scheduled maintenance (Stewart, 1963). The author lists some of the primary and secondary benefits of the scheduled maintenance. The *primary benefits include*:

1. One of the primary objectives of the scheduled maintenance is that jobs are started on a due date, which demands the execution of work at the predetermined time.
2. Carrying the task of scheduled maintenance increases the duration of operation of equipment, which would allow for higher operating efficiencies, and in some instances reduces the production of scrap materials.

3. Over time the frequency of scheduled maintenance will increase the amount of work done by each worker to some extent, which will eventually improve labour performance.
4. Quality of supervision exercised over workers will improve over time and would also allocate the labour force more effectively.

The *secondary benefits* of scheduled maintenance includes the following:

1. Inefficiencies are revealed and, therefore, rectified in the following scheduled maintenance.
2. The use of job cards with allowed or target times can be monitored for method study and to identify areas of high labour costs.
3. The scheduled jobs, which are implemented by job cards carrying predefined times for accomplishing the job, often reveal the use of inferior equipment and tools that have been in use for many years.
4. It is essential to support any scheduled maintenance design with a thorough overhaul of the store-keeping procedures, as lack of material can be most frustrating to maintenance personnel, and it becomes intolerable when workers are trying to put most of their effort into meeting a schedule.

When carrying out a maintenance task, it is not easy to calculate the actual time taken for the work involved without the use of a strict data collection methods, especially in a large plant were various complex maintenance work is carried out (Muhlemann *et al.*, 1992). Therefore, a logical policy needs to be based on data and the magnitude of data collection and analysis will be reflected in the degree of maintenance reliability. In addition, decisions by maintenance staff must be made as to whether to repair or replace items, components or parts and when to carry out a scheduled maintenance, therefore, reliability data are a useful tool.

There are four maintenance programs approved by the manufacturer and the regulatory agency (Anonymous, 1996). These are:

1. *A-Check* - This is considered to be a primary visual inspection, aimed to inspecting general and some specific components for condition and security, estimated labour hours for this particular check is about 60 hours.

2. *B-Check* - It is an intermediate check. At this stage inspection and servicing are required for the aircraft in determining its original condition for the purpose of insuring continues airworthiness, this check requires between 200 and 500 labour hours.
3. *C*-Chec*k* - Depending on the maintenance philosophy for the airline, this check is done at several intervals as they vary from one aircraft to another. This check requires a thorough visual inspection of the aircraft and would require between 3,000 and 12,000 labor hours, A-checks and B-checks are often included.
4. *D-Check* - This is aimed at returning the aircraft to its original condition, as far as is possible. The duration for this check is normally 30 days, and would require upwards of 20,000 labour hours, depending on the type of aircraft. However, the variation in conducting these four checks varies between the old and the new generation aircrafts. Table 2.7 illustrates the intervals of checks for both generations.

According to Baker (1995b) each aircraft would receive approximately from 12-14 hours of maintenance for every hour it flies. However, this depends on several factors such as the age, type of aircraft and the type of operation the aircraft accomplishes.

Table 2.7 Intervals Between Maintenance Checks Of The Old And The New Generation Aircraft

Check	Old Generation*	Mid Generation**	New Generation***
A	150-170	200 to 450	350 to 600
B	500 to 625	800 to 1,700	N/A
C	2,000 to 3,200	3,500 to 4,500	3,500
D	17,000 to 20,000	20,000 to 26,000	N/A

*(707/DC-8/727/737/DC-9)
**(737-300/A-300/DC-10/747)
***(757/767/777/A320/A310/A330/A340)

Unscheduled maintenance is performed on malfunctioning or failed units or systems. This type of maintenance is conducted at unpredictable intervals, since the time of any failure cannot be established in advance (Kececioglu, 1995). The main objectives of unscheduled maintenance are to restore equipment to satisfactory and safe operational functioning in the shortest possible time.

Depending on the type of maintenance work and its level, airline maintenance management usually divides the work into different levels. Wells (1989) lists four different types of maintenance activities conducted by air carriers these include: En route service, Terminating Pre-flight, Service checks and a Maintenance check.

1. *En route service* - The type of maintenance conducted for this type of service includes a routine exterior visual check of the aircraft, especially for fuel or oil leaks. Other defects include worn or flat tires, low shock struts or external fuselage or wing damage. Sometimes this service includes interior and exterior cleaning, depending upon the need and the available ground time assigned for the aircraft to stay at the station (Wells, 1989).
2. T*erminating pre-flight* - This is the second type of maintenance activity conducted and it is carried out at least every twenty-four hours, when a flight terminates at either a major service or Class-1 station. The type of work conducted on the aircraft includes the same work done as in the En route service plus some additional elements such as checking engine oil supply; checking engine inlet and exhaust areas for sign of deterioration; checking exterior lighting; checking the oxygen system and auxiliary power units, as well as checking some other defects noted in the aircraft log book (Wells, 1989).
3. *Service Check* - At a predetermined frequency the aircraft has to have a scheduled service check according to the manufacturer's specified time. This check can be carried out at either a major station or at designated Class-1 stations. In any case the local civil aviation authority must approve the station that is conducting the service check. A service check contains those items involved in the "Terminating pre-flight checks" and "En route service check" plus a significant volume of extra intensive maintenance activities. These will include inspection of Engine accessories, Control components, High-lift components, Hydraulic units, Cockpit equipment and so forth. It may also include examination of certain structural members as well as special maintenance, which may be of extreme importance to the airworthiness of the aircraft. The author notes that this type of service check may take as much as thirty-five to sixty man-hours (Wells, 1989).
4. *Maintenance check* - The only stations capable of conducting this type of maintenance check are the major stations, because they are well prepared and equipped to execute such big maintenance tasks. The time between each maintenance check varies from one aircraft to another and relies on the different aircraft manufacturers' specification for each type of aircraft, e.g. the maximum time

between maintenance check might be as high as 875 flight hours for a B-727 or 500 flight hours for a B-737. To ensure that the workload is the same in each maintenance check, the maintenance activities are well planned in advance. The major base will issue a complete form of all types of work which needs to be conducted on the aircraft while it is having the maintenance check. The first form will provide the maintenance personnel with the number of the job to be assigned to each specialisation, such as airframe, interior, engine, inspectors, and technician as required. Then for each job, a job card is produced; this will cover a specific job assignment and sign off information. Certain modifications and repairs assigned by engineering department are planned for in advance to be accomplished during specific maintenance checks depending on the available time.

5. *Major overhaul of airframe and engines* - This type of overhaul requires a plan document to be prepared and formulated by the engineering department to the specification of the carrier for maintaining the structural integrity of the fleet (Wells, 1989). When the local aviation authority approves this plan it becomes a vital part of the maintenance operations specifications; compliance then becomes mandatory. A planned work report will be issued to cover the entire structure, landing gear and all control surfaces. This work report will identify the type of inspection and the time intervals to be inspected. The Engineering Maintenance and Control (EMAC) manual is the document that controls the operational checking of the aircraft systems, removals and replacement of time-controlled units.

The EMAC is designed to assemble, disseminate and control all the essential information for the proper maintenance of components and systems. It also determines which work is planned into overhaul. Wells (1989) states that in some cases the overhaul will consume around 15,000 hours. These are divided as follows: ten per cent is directed towards inspection, forty per cent involves component change and system check out, twenty per cent goes on modifications and thirty per cent is devoted to non-routine work generated by the overhaul inspection. The same procedure is used to overhaul an engine and its accessories. A large part of engine overhaul is made up of repair and reconditioning operations, which are approved to manufacturer specifications. Very often the planner schedules an engine change so as to minimise shipping costs and transit time.

2.10 SUMMARY OF CHAPTER

Airline maintenance activities are complex, they require the co-operation and co-ordination of several departments. Due to the immense investment in airline fixed assets such as aircraft, materials and equipment airline maintenance operators are always seeking to improve performance of the maintenance department, to ensure continuous operation of their fleet with the minimum ground time for servicing. However, the application of performance measurement techniques must consider the strategic objectives of the airline concerned. Since airline operators around the world vary in their operational activities and depending on the size of the airline maintenance operational activities, this suggests that a performance measurement system that could work for one airline may not work for another. In addition, the differences between the Shop, Hangar and Line were illustrated in detail as they differ in terms of the maintenance activities carried out.

CHAPTER THREE

LITERATURE REVIEW

CHAPTER THREE

LITERATURE REVIEW

3.0 INTRODUCTION

The preceding chapter discussed some of the key elements of airline maintenance practices. In this chapter a literature review of the issue of productivity and performance follows. Due to the relatively small amount of literature on airline maintenance productivity, and an even smaller amount on aircraft maintenance productivity, the chapter will be divided into five major sections representing major themes in airline maintenance productivity and productivity measurement in general.

The major issues that will be discussed include the issue of productivity and reliability measurement in the airline maintenance industry, information resources and their effects on productivity, productivity improvement techniques, performance and efficiency measurement systems and finally measurement of work.

3.1 GENERAL PRODUCTIVITY MEASURES

This section will consider the definition of productivity, as it has been defined differently by many authors. The term productivity will be explored and defined as well as a further illustration of the break down of productivity elements. Different types of productivity will be introduced and discussed.

3.1.1 Productivity Definitions

The word "Productivity" has become widely used. The first time the word was referred to was in an article by Quesnay in 1766 (Sumanth, 1984:3). In 1833, Litter defines productivity as the "Faculty to produce." That is, the desire to produce. The term later gained a more definite meaning as a link between output and input (Sumanth, 1984:3). The organisation for European Economic Cooperation (OEEC) in 1950 presented an additional formal definition of productivity:

"Productivity is the quotient obtained by dividing output by one of the factors of production. In this way it is possible to speak of the productivity of capital, investment, or raw materials according to whether output is being considered in relation to capital, investment or raw materials, etc." (Sumanth, 1984:3).

Moreover, Sumanth (1984) provided two different definitions of productivity. These are "productivity engineering" and "productivity management". He noted that the term "productivity" was becoming a major interest of both managers and engineers; it was clear that the two disciplines were evolving together (Sumanth, 1984). While industrial engineers design, develop, and install integrated systems of people, machines, and material, productivity engineers are interested in the design, installation and maintenance of productivity measurement, productivity evaluation, planning, and productivity improvement systems. Therefore, Sumanth believes that productivity engineering is actually a subset of industrial engineering. In 1955 the Institute of Industrial Engineering adopted a formal definition of productivity engineering.
"Productivity engineering is concerned with the design, development and maintenance of productivity measurement, evaluation, planning and improvement system in manufacturing and service organisations" (Sumanth, 1984:49) and defined industrial engineering as being "C*oncerned with the design, improvement and installation of integrated systems of men, materials and equipment. It draws upon specialised knowledge and skill in the mathematical, physical, and social sciences together with the*

principles and methods of engineering analysis and design to specify, predict, and evaluate the results to be obtained from such systems" (Sumanth, 1984:49).

Sumanth (1984), stated that it had recently been thought that the term productivity management' had taken on a formal meaning, although organisational management had been employing the management of productivity and had been doing so, for the most part, as an informal technique. Consequently, both manufacturing companies and service organisations spotted the benefits of assigning the responsibility of productivity measurement and improvement to the "director of productivity". A formal definition of productivity management is presented by the American Productivity Management Association as "A *formal management process involving all levels of management and employees, with the ultimate objective of reducing the cost of the manufacturing, distributing, and selling of a product or a service through an integration of the four phases of the productivity cycle, namely, productive measurement, evaluation, planning and improvement*" (Sumanth, 1984:51).

Sumanth (1984) commented on the formal definition by recognising five keywords in the definition which are: formal, management, employees, cost and integration. It implies that the management of any organisation should set up a formal structure to monitor and control productivity levels and growth rate. This duty can be achieved by genuinely including managers which was an important element to test management's ability to reduce cost.

Fabricant (1969) identifies productivity as the comparison between the quantity of the produced goods and quantity of resources used to produce goods or services. If the quantity used to produce goods or services increased and the level of resources is still the same then it can definitely be said that productivity has increased.

Vonderembse and White (1991) break down productivity into two main elements; these are effectiveness and efficiency. A system is effective if it achieves its intended goals, and a system is efficient if it uses a "reasonable" amount of inputs to produce the appropriate outputs. Furthermore, the authors state that these two elements are fundamental to any business system.

Sumanth (1984) suggested that the term "Productivity" is often confused with the term "Production." This confusion misleads people into thinking that the greater the production, the greater the productivity, which is not necessarily true. To further clarify this point, Sumanth defines both terms: *Production* is involved with the activity of producing goods and/or services; while *Productivity* is concerned with the efficient utilisation of resources inputs in producing goods and/or services output (Sumanth, 1984). He goes even further in explaining the terms productivity, efficiency and effectiveness as they are very closely related to each other. *Efficiency* is the ratio of actual output gained to standard output expected. *Effectiveness* is the degree of accomplishment of goals. Therefore, *productivity* is a union of both efficiency and effectiveness, since effectiveness is linked to performance while efficiency is linked to a resource utilisation.

Both authors Lawlor (1985:36) Neely *et al.*, (1995:80) stated that an organisation that is producing a product must give attention to the conservation of resources. They described productivity as, 'How efficiently inputs are converted into outputs'. Behind this simple way of measuring productivity lie different beliefs about the best way of measuring conversion efficiency. Lawlor examines five main factors he believes to be essential to any system intended to measure productivity (Lawlor, 1985).

1. *Objectives* – Maximising profit is the objective of many accountants, business executives and economists, but when interpreting the meaning of this they have different views as to whether the organisational objectives have been achieved. Commercial organisations consider profit to be very important, but there are other things that should be taken into consideration such as paying employees adequately, paying bills and establishing a fund for future investment. Lawlor cites Adam Smith (1776) as stating that the intention of any organisation is to provide a decent living for everyone involved and to maintain its fixed and circulating capital (Lawlor, 1985).

   Profit margin can be reduced significantly in the airline business especially when other competitive carriers serve the same route and tend to set a lower air fare on that competitive route, starting a price war between the carriers. Since profit is considered one of the main objectives for the airline operators they therefore have to achieve economies of scale in order to survive (Friend, 1992). Furthermore, an effective use of cost control techniques is considered vital to profit survival. According to Lam (1995) maintenance costs account for about 10% of an airline's total costs, this is approximately as much as fuel and travel agents. In addition, Lam

(1995) states that maintenance labour cost varies from one department to another. In the *Line maintenance* 90% of the cost is attributed to labour, in *Shop maintenance* it is about 40% and in the *Hangar* it amounts to 65%.

Friend (1992) states that the airline business nowadays functions by allowing each unit or department such as Workshops, Hangars or Servicing Centres to generate profits. Accordingly, since maximising profit is one of the main objectives, one way to achieve this is to lower aircraft maintenance cost, since this ranges from ten to twenty per cent of the total aircraft operating cost (Friend, 1992). Another way to lower maintenance cost is for the airline to acquire new aircraft. Contracting out maintenance to larger airlines is another technique used to control the cost of maintenance (Friend, 1992).

2. *Efficiency* – How available resources are being used to utilise a meaningful output. Lawlor (1985) stated that there are two main benefits that could be generated from efficiency measurement in an organisation. The first is establishing the relationship between outputs and inputs. The second is concerned with the utilisation of resources (Lawlor, 1985).

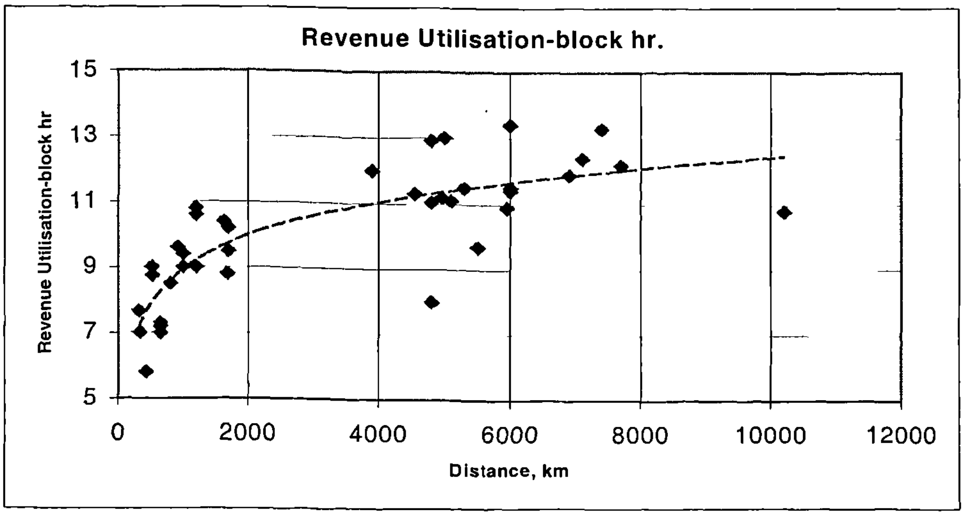
   In order to utilise the available resources in the airline industry, an airline operator must achieve a high level of flying hours with the maximum allowable loads. Utilisation of the aircraft is measured in flying hours per year or per day; an average value of four thousand hours per year or twelve hours per day is considered to be good on intercontinental operations. In addition, Friend (1992) stated that the higher the annual aircraft utilisation, the lower the hourly charges for depreciation which make it easier for the airline operator to earn a profit or to cut fares (Friend, 1992).

Taneja (1981) states that the steady increase in airlines' load factor has led to improved efficiency of airline operations by reducing cost per passenger or at least preventing air fares from increasing. Doganis (1991:5) states that load factor is obtained by expressing the passengers carried as a percentage of the seats available for sale. On a network of routes, the seat factor is obtained by expressing the total passenger-km as a percentage of the total seat-km available.

Greater efficiency can come about through technical changes, such as introducing faster machines; managerial changes, such as better planning, scheduling, and control activities; or through behavioural changes in workers, such as working more efficient (Ruch, 1992).

Although most carriers seek to have optimum utilisation of their fleet, aircraft utilisation is governed by factors such as the ratio of aircraft loading and unloading time on the ground to flying time. Also, local airport restrictions on night flights impose further restrictions (Friend, 1992). Furthermore, the author stated that it is not possible with most operations to fly the regular schedule at the peak time without interruption and therefore, efficiency is harmed. Figure 3.1 provides an example of a measure of efficiency in the airline industry given by distance flown. In addition, it also illustrates in general that the utilisation rate is low on the short range flight, while the highest utilisation is with the mid-range which is about 6,000-7,000 km as given in the chart.

Figure 3.1 Aircraft Utilisation By Range



Source: Friend, 1992:30

3. *Effectiveness* – The comparison of how resources could have best been managed with how they were managed. There are two main areas of focus when trying to achieve effectiveness, 'How much better could we do?' and 'What else should we be doing?' (Lawlor, 1985).

Effectiveness is defined as "the degree to which the purpose of an organisation is achieved". For example, if the firm is in the transportation industry then the more people it moves, the more effective it is (Ruch, 1992). And in order to achieve greater levels of effectiveness, organisations must try to eliminate needless.

To achieve more effective use of the available resources, airline operators set a planned scheduled programme to maintain the airworthiness of their fleet (Friend, 1992). Additionally, this author states that what airline maintenance management should be doing is to implement a more focused and intensive maintenance programme such as an "*ageing aircraft program*". The ageing aircraft program will provide extra effort to check areas where fatigue problems may occur and possible areas of corrosion effects, which may not have been looked for before. Friend (1992) states that the cost of maintenance will keep rising until it is cheaper to buy a new aircraft, which may not require the same stringent maintenance checks for some time.

Friend (1992) states that in order to increase the effectiveness of the maintenance programme, aircraft operators invest in sophisticated technologies which can be placed on the aircraft, to provide a continuous monitoring of aircraft system and component while the aircraft is in the air. The introduction of these systems has helped to achieve greater effectiveness in airline maintenance activities (Friend, 1992).

4. *Comparability* – The productivity ratio on its own is not useful without a direct comparison with competitors. Lawlor gives an example of two retail shops, one which increases its sales from £20,000 to £30,000 in a month using ten staff, the other which makes £50,000 a month with only nine staff. This simple comparison allows the manager to think more about how higher standards of improvement might be achieved. Therefore, comparisons between similar organisations allows better target setting. Remaining competitive is a consequence of frequent comparisons with other similar businesses (Lawlor, 1985).

   Friend (1992) provides a simple comparison which allows airline maintenance managers to evaluate their current position relative to other carriers close to their size. In the maintenance and overhaul department, they accounted for typically between fourteen per cent to twenty four per cent of the total employees according to the IATA Report for 1989.

Furthermore, comparison with different international carriers could help managers to set forecast issues and help to set them up for the future to achieve better results and stay competitive. Table 3.1 shows passenger traffic development.

Table 3.1 Passengers Traffic Development ICAO World And Region (Billion Revenue Passenger Kilometres (RPK))

Year	1978	1988	1998	2008
Europe (excl. USSR	262	419	683	1031
North America	425	753	1158	1709
Latin America	49	82	153	258
Africa	28	43	69	110
Middle East	28	48	82	136
Asia/Pacific	130	315	712	1367
Total World	***922***	***1660***	***2857***	***4611***
Annual Growth Rate				5.5%

Source: Friend, 1992:167.

The process of comparability is defined as setting a competitive benchmark (Noori and Radfors, 1995). In order for a firm to be sure that the goals and objectives that have been set are realistic and whether the firm would like to identify how much of an improvement is needed to catch up with others, then competitive benchmarking can help answer the question. The author defines benchmarking as "a standard or point of reference by which something can be measured or judged". In addition, Noori and Radfors stated that by inspecting the best, a firm can hope to find out how this performance can be achieved. Moreover, as the sole purpose of benchmarking is to discover ways to improve performance, it is not used to punish those responsible for any weakness. A final note that the author makes with regard to implementing benchmarking, is that before a firm compares its operations to any other firm, it must carefully analyse the intended areas for improvement in great detail. The internal analysis should take into account quantifiable measures such as throughput, product quality, customer satisfaction, equipment set-up times and availability and the number of workers classifications.

5. *Trends* – Looking at product trends over time is an important tool for the measurement of performance. Lawlor (1985) states that when assessing growth improvement, last month's performance could be compared with that of the previous

month's or year's. Two major problems that Lawlor cautions against here are price increases (along with inflation) and the need to consider the differing mixes of inputs and outputs (Lawlor, 1985).

Friend (1992) provides a typical example in monitoring trend analysis in the maintenance department. Implementing modern technical approaches to turbine engine monitoring can help maintenance personnel to predict problems, which may occur in the aircraft engine. The primary objective of the maintenance manger is to accomplish high levels of on-time service to passengers, as well as controlling the engine operating cost, and that is done by minimising engine unscheduled maintenance. Trend analysis will help in assessing aircraft engines' reliability, reflect the effectiveness of the maintenance activities being accomplished, and provide the operator with significant data on which possible improvements can be based.

3.1.2 Why Productivity Is Measured

There are many reasons for measuring productivity for the purposes of its enhancement. Brinkerhoff and Dressler, (1990) identify six of the more frequent reasons which include:

1. Identifying any declines in productivity - one of the immediate benefits of implementing productivity measurement is the capability to identify productivity declines at an early stage. This will prove to be useful for Saudi Airline maintenance management in order to be able to identify reasons for decline in productivity. This will be explored further in Chapters Six and Eight.

2. Management should have the ability to compare productivity measurement across individuals, work teams, organisation and competitors in similar industries. The parameters that are being measured should be important to the goals and mission of the organisation. Furthermore, the authors state that the main threat of measuring and improving aspects of operations which can be classified as not very important to the overall organisation productivity is the threat of "sub-optimisation", trying to optimise the performance of secondary, or even irrelevant, aspects of operations. In the case where a unit manager's considerations grow larger than the company wider considerations, the threat of sub-optimisation grows even larger. Furthermore, an

individual working for an organisation may think that a single element of their job is more important than other job elements.

3. The applications of productivity measurement on a wider scale where productivity teams are formed of all levels of company managers will unite labour and management in pursuing real productivity gains. Employees should be involved, and should feel positive about their involvement. Then the likelihood of the employees actually using the measures would increase. To achieve this employees should be involved in the productivity measurement planning process from the very start. Their involvement can yield a number of advantages which include:

    A. Jobholders themselves are most knowledgeable and are thus the most able personnel to conduct the appropriate analyses and to identify critical work dimensions and measures.
    B. Employees are more likely to support a system which they themselves have helped to build, and are less likely to sabotage it.
    C. An important element of involving employees is achieving the necessary awareness and understanding needed for productivity measurement purposes.

4. Productivity measurement can make a significant contribution to determining how bonuses are structured. Tying bonuses to productivity gains by the individual, the work unit, or even the entire organisation can bring objectivity to the productivity measurement process. The rewards and incentives attached to productivity measures can be salary increases and/or bonuses or recognition and public praise. Yet, whatever the rewards or incentives are, they must be perceived as important to those whose performance is being measured.

Werther *et al.*, (1986) identify three main reasons for measuring productivity: first it is done for *evaluation*, and therefore, to answer the question, "How well did we do?". That evaluation is done for control reasons, to show the effects of trade-offs and allocation decisions made in the past. Second, productivity measures are done for *planning* purposes, to answer the question "What should we do now?". This is mainly dependent on management having accurate information on the feedback on current productivity. The analysis of the results of past productivity efforts establishes the need for change in the current system. The third reason for measuring productivity is to create awareness, the fact that something is being measured leads people to work up to the measure.

3.1.3 Factors Affecting Airline Maintenance Productivity

Scoles (1994) defines some of the human aspects that contribute to low productivity in aircraft maintenance. One of the areas that the author discussed was continuous updating of technician's knowledge which would lead to confidence, confidence leads to professionalism and professionalism leads to safety. In addition, the author lists some of the problems in Table 3.2 that face airline maintenance technicians and how maintenance managers should deal with them in order not to affect productivity.

Table 3.2 Management Approach To Common Problems

Human Factor Deficiency	Suggested Antidotes
Stress of time pressure/the hurry-up syndrome	Re-evaluate unrealistic schedules
Physical stress of poor working conditions heat, noise and shift change	Identify and improve the condition
Personal stress	Develop employee assistance program
Fatigue and lack of situational awareness	Watch for signals and discuss with employee
Lack of knowledge	Set up realistic recurrent training programs

The author emphases the "hurry-up syndrome" or time pressure as these account for most of the maintenance errors. Safety should always be the primary emphasis, and the term hurry-up may cause the technician to fail to use the appropriate knowledge, tools, advice and information available in carrying the maintenance tasks. In the end this would be to the maintenance department's disadvantage.

Gorsuch (1999) states that a number of job-related injuries among airline maintenance workers is on the rise, and these directly affect work productivity and performance. According to the U.S. Department of Labour (DOL) statistics, from 1992 through to 1997 the number of injuries in the workplace have risen from a rate of 12.6 cases per

10,000 full-time employees to 18.9 cases per 10,000 employees. The statistics shows that inappropriate hand tools were the main contributing factors to these injuries. Cumulative trauma disorder (CTD) is caused by continuous use of vibration power tools and is mainly responsible for the growing number of technicians' complaints. Vibration from these hand tools is transmitted to the hands, wrist and arms causing serious muscle, joint and bone disorders.

Hobbs (1995) states that some of the factors that affect the productivity and performance of the maintenance work include:

A. Technicians striving to work with the elements. They may be required to perch high above the ground, perhaps in rain and darkness, sometimes they have to communicate by hand signals through deafening noise.
B. Many maintenance tasks are too large to be completed in a single shift, and the resulting handover is a significant challenge to job quality. Although, paperwork generally ensures a seamless continuity of work tasks however, cross-shift misunderstandings can still occur.
C. Shift work changes and fatigue associated with the type of work carried out can cause poor performance.

Under current aviation management, technicians must obtain expertise rapidly and continuously on the job without improper delays to their work (Schaaf and Walters, 1998). One of the important issues that face technicians in the airline maintenance industry is that while formal training on aircraft systems is provided, little consideration has been given to the many specific tasks performed in the day-to-day operating environment. Schaaf and Walters, (1998) claim that the basic "how-to" steps for many tasks are not written out in such a way that new or less experienced technicians feel comfortable performing the tasks unassisted. Eventually, this lack of unwritten guidelines could create a system where errors may be made, and this will cause the technicians unnecessary concern in performing their jobs.

The lack of availability of written how-to was viewed by many technicians as affecting their daily work performance, allowing significant steps to be left out and mistakes to be perpetuated, which eventually could lead to greater safety concerns (Schaaf and Walters, 1998). In addition, the absence of written guidelines can lead to a situation where the work lacks consistency from one technician to another and from one shift to another.

Moreover, short cuts develop more rapidly due to the lack of understanding as to why things are done in a specific fashion.

According to Schaaf and Walters, (1998), more than ninety per cent of the critical skills that a technician uses are obtained through on-job-training (OJT). They claim that most technicians depend on the knowledge obtained from an existing technician while on the OJT because "that's the way it's always been". They provide an example of Northwest Airlines, where management in the technical operations department has adopted a new technique which involves trainers and trainees in using step-by-step "how-to" procedures. The purpose is to guide each training session so that all trainees learn the same correct procedure. Northwest management claims this method makes the technicians carry out tasks exactly the same way at every gate, and on every shift. To ensure that the required competency is being achieved, performance standards are made and communicated clearly to both the trainers and the trainees. The training technique implemented here, which aims to improve overall performance by setting clear performance standards, has achieved the following:

A. Established written, agreed-upon performance standards that are measurable and observable.
B. Trained technicians verified to be working to established standards.
C. A plan to continue using the system with an internal facilitator.
D. The building of teams, improved communications and decision-making skills as well as boosting morale.

Many factors can affect productivity in the airline industry (Friend, 1992). This author classifies these factors into two categories: internal and external factors. The internal factors are the equipment and staff of the company, while the external factors are the airports, air traffic control, airworthiness regulation systems, and state of the economy. Furthermore, the author notes that the internal factors, in theory, should be known to the airline management and under its control, while the external factors can be revealed through market research or by consulting representatives of the airline maintenance organisations (Friend, 1992).

Friend further explains some of the internal factors:

Engineering - The plan made by the airline engineering departments for support for flying, will be dictated by the number and different types of aircraft available for operations.

Ground operations - Depending on the type of agreement signed between the airport authority and the airlines, some airports provide ground services to operators, but most operators support their own airport ground services.

Aircrew - Duty time is limited by legislation, but the airline may have other agreements with unions on the allowable time for crew usage and this may place even further restrictions on it. In industrialised countries *Shift work* requires an extra payments as well as intensive negotiation with staff unions to plan the shift arrangements. Friend further states that the safety issue is considered an important element in aircraft maintenance activities. Employees are more efficient in delivering high quality work when the proper stand equipment (used to reach areas on the aircraft like the wing) are used. If the workers feels unsafe or in danger of falling or being fallen on, then the reliability as well as the productivity of the work will be affected tremendously.

Some of the external factors listed by Friend (1992) include:

1. *Delays along route* - This can occur on long-range operations, which requires the sequencing of several flights by one aircraft, the assumption of flight delays at one stop can be made at this stage.
2. *Weather effects* - Can cause a disruption in flight scheduling due to flight cancellation or postponement. Usually under these circumstances airline operators usually try to minimise the disruption to flight arrivals by diverting planes to the nearest airports.
3. *Public holidays* - Are also considered as an external factor. At these times the public demand is at a peak which sometimes can last for a long period. A problem which may occur during peak times is that airline operators are susceptible to sudden constraints outside their control, such as air traffic control industrial disputes. This kind of circumstance can make it difficult for the airline to meet demand and the routine servicing requirements of aircraft in some cases, especially if they do not return to base at the expected time. Irrgang (1995) states that if the aircraft is diverted to an alternate airport, this could mean an extra cost for the airline. Potentially it could take longer to

recover the aircraft by maintenance. Due to various maintenance problems on average 0.1% to 0.2% of a typical airline's flight will be interrupted.

4. *Skill and labour shortages* - Is another external factor, and according to Friend (1992) most western industrialised nations are concerned about the reduction in entries to the labour market. The author credits this to two factors, the decline in the proportion of young people in the population, and a decline in those taking science and technical subjects at school. There is a strong possibility that airline maintenance work will go to other countries with cheap labour and with high levels of performance (Friend, 1992).

Sumanth (1984) lists some factors which are believed to have an affect on productivity in the U.S. The author states that different economists have studied productivity problems, but their findings vary for several reasons. This is because of the differences of time in conducting the study, the different hypotheses that are built into the model, the differences in economic views and the different questions asked by the researchers:

1. Strong correlation between investment and productivity improvement.
2. Capacity utilisation - The per cent of time plant is in operations and labour productivity are closely related.
3. Cleaner environment and safe work place - These and other regulations have to provide a balance between industrial progress and desirable social goals.
4. Workers' fear of losing their jobs.
5. Management can affect performance because of poor planning, poor scheduling of work, lack of co-ordination of material flow and unavailability of needed tools.

Vonderembse and White, (1991) list two main factors which influence productivity and product cost. First, *product design*: as the product gets more complicated and sophisticated it tends to cost more. Therefore, an effective product design with less complexity can increase productivity. A second factor, which influences productivity, is *facility layout*: in order to eliminate wasted movement in production, an efficient layout is useful. Along with the previously mentioned list of factors that affect productivity.

Heap (1992) focuses attention on two main factors, which if they are given some attention by management can very much improve performance and productivity. The first is *the influence of technology*. It is important to use the most up-to-date technology, but it is important not to just use high technology, but to stay aware of current technological advances and to be able to make logical decisions. The second factor is *organisation structure.* This is important as it provides the basis for high productivity. The following section gives a detailed discussion of the two factors:

1. The Influence Of Technology

Heap (1992) focuses attention on technological changes and their affects on organisational productivity. He suggests that technological changes should be investigated more with a long-term commitment towards productivity improvement. Heap identifies two elements of technology which all organisations must operate through these are systems and people. In addition, the author suggests that in order to be more productive the selection of technology must be cost effective e.g. high-powered, full-featured computers are not necessarily needed to execute routine word processing. Furthermore, Heap (1992) suggests that there should be a system of technological scanning, since a technological change has implications for productivity review and improvement. The focus here is directed towards the resource inputs; to establish whether technological developments will allow the product to be more cost effective. The author lists three elements of technological scanning systems which, if conducted effectively, will provide a service to the overall productivity improvement programme. These are:

1. Continuous environmental monitoring for signs of relevant technological changes.
2. Frequently assessing potential consequences of new technology.
3. Presenting the output of the scanning process in a timely and appropriate manner to decision makers.

2. The Influence Of Organisation Structure

The structures of a range of organisations in the UK in different industries and commercial sectors were almost the same (Heap, 1992). Furthermore, the author states that these structures are the same as those organisations had 20, 30, or 40 years ago. The two main issues that the author discusses are: first, would changes be beneficial in term of producing higher productivity; second, how can the structure provide a catalyst for change and improved productivity. An effective productivity measurement and improvement programme relies on the availability of sound data to be used for measurement, monitoring and control.

Shani and Stjernberg (1998) states that the pressure for organisational transformation in order to meet changing business environments set in motion a wave of change programmes labelled as BPR. The first wave concentrated on operational improvements by bringing cost structures in line with changes demanded by the market place. The second wave concentrated on business growth and strategy objectives along with core competencies.
The third wave relied on theory developed through empirical studies and was linked to other theories of change. This meant that there was a deeper understanding of many aspects of BPR such as its applicability in different contexts, and the relationships between BPR and other approaches to change.

Galloway (1998) linking BPR to Total Quality Management (TQM), states that the aim of TQM is to achieve perfection in dealing with customers. This not only includes assuring that the product meets the customer's satisfaction, it should also go beyond that to such things as avoiding late delivery, sending incorrect quantities or just failing to understand the customer. The author states that quality should be defined as what the customer wants, instead of what the supplying organisation sees as appropriate, since the whole intention of TQM is to achieve competitive advantage. The implementation of TQM has to be carefully monitored, since it is "people" based rather than a technique and therefore, cannot be partially introduced. This means introducing TQM only for selected products or customers is doomed to failure, since prosperity requires a continuous attitude of quality first. Consequently, TQM involves the whole organisation, and since it is based upon the idea of continuous improvement, it never ends.

Everett *et al.*, (1981) state that other factors affecting individual attitudes result from a combination of company policy and the effects of the informal organisation. One of the factors, peer relationships, is considered organisational but is determined by the informal organisation rather than by company policy. If the task design is inefficient, the worker may show less effort than he would in a better designed task. Task design may also interact with peer relationships as in some cases on an assembly line. In that context, peer relationships tend to cause workers to become interdependent socially, and thus have an extremely strong affect on actual productivity. Task design can also interact with supervision. Poorly designed tasks or tasks that allow the individual freedom of choice may require closer supervision. Another influence on productivity is that if unions are granted more power under the law, they may well effectively block changes which they feel are not in the best interest of their workers. Moreover, labour can exert their influence on productivity through organisation and collective bargaining. Each group has the ability to influence productivity, yet some clearly have a stronger and more direct impact than others. The author states that it is the government's responsibility to maintain that balance of power, so that productivity increases can be shared equally by each group.

Employee job performance has an effect on productivity, therefore, satisfactory performance levels are needed for proper operation of machinery and equipment. The author identifies two important elements that can contribute to lower productivity. These are: ability and motivation. The link between these two factors is explained as follows: If an employee has no motivation, he could be capable, and therefore and there would be no connection between his ability and his performance. However, if the person has no ability, but is well motivated, there would be no connection between motivation and performance. Both motivation and ability are necessary for good performance (Sutermeister, 1963). In addition, Brayfield and Crockett (1963) stated that there is a link between productivity and employee satisfaction. If employee dissatisfaction exists, it is more likely that low productivity may serve as a form of aggression reflecting worker hostility towards management.

3.1.4 Productivity And Quality

Very often, scholars and practitioners refer to "productivity" and "quality" as if they were two separate performance measures. Eventually, an important part of any productivity equation is quality. Increased output becomes worthless if the increase is offset by a downgrade in quality. There are different definitions of quality, Everett *et al.*, (1981) stated that it should be able to permit measurement and reporting of data in specific applications, yet the definition should be general enough to apply to a wide variety of products and services. The definition offered by these authors state that "quality is the degree to which a product or service conforms to a set of predetermined standards related to the characteristics that determine its value in the market place and its performance of the function for which it was designed." (Everett *et al.*, 1981:17). In *manufacturing*, product quality is either measured by attributes or by variables. The attribute measurements include those characteristics of the product that make it either "good" or "bad". Variable measurement assumes that product characteristics being measurable on an interval or ratio scale, examples are temperature, length and density. In *services*, the measurement of quality could be for the total organisation or for the service function within an organisation. Quality is often measured mostly by consumer complaints, the attitudes of consumers, observation or the subjective assessment of the producer.

McLaughlin and Coffey (1990) state that productivity has always been measured on the basis of meeting a specified level of quality. However, in the manufacturing sector it is more likely to be easy to measure the tolerance of the end product, thus, in the service sector consumers view the quality differently.

3.2 TRADITIONAL PRODUCTIVITY AND RELIABILITY MEASUREMENT IN THE AIRLINE MAINTENANCE INDUSTRY

The first measure of the effectiveness of the maintenance programme is the *Statistical Control Chart and Alerting System.* The second is *Engineering Analysis of Data* (Friend, 1992).

1. *Statistical Control Chart and Alerting System* - This system provides the procedures for the development and revision of the control limits used to determine the acceptability of aircraft system and component actual performance as measured by the reliability performance parameters. It uses control charts, which automatically revise and provide alerts in the event of deteriorating trends. The statistical control charts serve the following purposes:
   - A. To define the goal or standard for the process.
   - B. As an instrument to obtain that goal
   - C. As a mean of judging whether the goal is being achieved.
   - D. To demonstrate clearly past and current performance.
   - E. To enable the establishment of realistic goals.
   - F. To acknowledge performance improvement.

Different performance parameters are used: for *aircraft*, mechanical delays, cancellations and pilot reports, for *engines*, in-flight shut-downs, and for *components*, the number of unscheduled removals. Alerting systems are employed to provide automatic alerts in the event of a deteriorating trend, and are designed to provide the following:

A. Timely alerts for all deteriorating trends.
B. Advanced warning before deteriorating trends become severe.

2. *Engineering Data Analysis*. This method is used where statistical control charts and alerting are not feasible or practicable, these are:

   A. Aircraft structure integrity programme.
   B. Engine condition-monitoring programme.

The world's airlines spent nearly $17.8 billion on aircraft overhaul and maintenance in the fiscal year 1996, according to the most recent statistics compiled and released by the International Civil Aviation Organisation (ICAO) (Canaday, 1998). The statistics show that the U.S. and Canadian carriers spent a combined $9.8 billion on overhaul and maintenance in that year 1996. Europe, excluding Air France, Alitalia and Lufthansa, but including British Airways, Finnair, Iberia, KLM, LOT Polish Airlines, SAS and TAP Air Portugal, among others, accounted for $3.5 billion in spending. Asia/Pacific carriers spent $3.9 billion; more than half of that amount was spent by Japanese airlines.

These figures can be controlled or reduced by the proper implementation of efficiency and productivity techniques (Canaday, 1998). Canaday states that the cost of maintenance per unit of capacity (available tonne-miles or available seat mile equivalents) is a reflection of fleet type, fleet mixture, age and aircraft utilisation. The statistics show that flag carriers like KLM, SAS, and Finnair have relatively high maintenance costs. Iberia, British Airways and Virgin Atlantic do better in terms of cost of maintenance. The following Table 3.3 shows some of the selected carriers.

Table 3.3 Overhaul And Maintenance Spending Fiscal Year 1996

Country	Carrier	$Million	Cents/ATM*	Cents/ASM**
Japan	JAL	859.3	7.6	0.8
Singapore	SIA	468.5	5.1	0.5
Finland	Finnair	137.6	9.5	1.0
Netherlands	KLM	699.1	8.6	0.9
Poland	LOT	28.9	4.6	0.5
Portugal	TAP	127.7	10.6	1.1
Scandinavian	SAS	402.8	14.4	1.4
Spain	Iberia	275.2	7.8	0.8
UK	British Airways	1,009.9	7.8	0.8
UK	British Midland	61.5	15.5	1.5
UK	British Regional	11.3	18.5	1.9
UK	Virgin Atlantic	139.6	6.1	0.6
Canada	Air Canada	257.6	5.3	0.5
US	Continental	557.8	8.3	0.8
US	American	1388.6	5.9	0.6
US	United	1815.5	7.8	0.8

Source: (Canaday, Overhaul & Maintenance, March-April 1998:32).
* ATM: Available Tonne Miles, a measure of production covering passengers, cargo and mail products.
**ASM: Available Seat Miles, a measure of actual business performed, in term of seat sold.

The magnitude of capital invested in the airline industry is immense, therefore, airline operators spend a lot of time and effort in deciding on which is the most appropriate fleet mix before considering buying it (Baker 1995b). The author states that at any given time there are wide ranges of aircraft available for different flight operations. For the purpose of selecting the right aircraft a range of experienced personnel from maintenance, engineering, marketing, scheduling, planning and finance are involved in the decision on which aircraft to buy. Options are analysed on interior configuration, customer appeal and fuel consumption rate etc. Finally all technical input along with the financial issues are gathered for a final decision on which aircraft the company should acquire.

3.2.1 Military Aircraft Maintenance Overview

The aim of the Royal Air Force (RAF) maintenance organisation is to support the operational task by providing engineering support, which requires special facilities and skills. This task, which is carried out mainly within the RAF support command involves the repair and overhaul of most fixed-wing fighter aircraft and their associated equipments for all services (Friend, 1992).

Maintenance problems associated with military aircraft operations are different from those of civil aircraft. As the utilisation tends to be higher in civilian aircraft, the maintenance hours required by the RAF are lower than those for airlines. On the other hand, military aircraft are subjected to greater levels of stress. Furthermore, the operational activities can be carried out from different sites, such as conventional airfields or overseas stations.

In the RAF, shorter maintenance is carried out by first line maintenance about every 75 hours at the operating unit/squadron. Major maintenance is carried out by the second line organisation, which can provide the necessary equipment and skills needed. Third line maintenance in the RAF exists for major overhauls, yet there are few stations that can carry out this type of activity and such work may be contracted to the manufacturer. First line maintenance may have to be done outdoors, even in bad weather. Second and third line maintenance work requires the aircraft to be in the Hangar (Friend, 1992). There are some differences between civilian aircraft and military aircraft maintenance in the practices, procedure and policy of conducting the work (Friend, 1992). The author lists five major distinctions in the RAF. These are:

1. *The aircraft flying rate* – When comparing civil aircraft utilisation to military aircraft it is found that military combat aircraft are being utilised for a few hundred flying hours per year, compared to four thousand flying hours per aircraft per year for the aircraft used for commercial services.
2. *Structural stress* – The RAF experience with military aircraft is that the nature of the mission carried out by fighter pilots, such as low-level flying practice, eventually causes great structural stress on the aircraft. These types of mission can cause fatigue-related modifications that are needed after a few years service with some military aircraft types. Furthermore, low-level techniques coupled with the high speed can cause the risk of ingestion of Foreign Objects Damage (FOD), or erosion, while civil aircraft cruise at higher altitude where turbulence is less than at low levels.
3. *Size of aircraft* – Many military combat aircraft are small in size. They maybe single-seater or two-seater. The result of this is that there will be limited access for technicians during maintenance or inspections. Therefore, it becomes more difficult to carry out an intensive maintenance programme at the same time.

4. *Age of aircraft* – Some old military aircraft still remain in service much longer than would be considered economic to maintain by a civil operation. This is due to changes in plans forced by circumstances, such as the cancellation of the Nimrod project, or where a more cost-effective alternative to the in-service aircraft cannot be readily obtained.
5. *Unusual skills required of personnel* – These include the capability to carry out emergency battle-damage repairs, or use special protective clothing and the possibility of being deployed to remote sites when necessary.

3.2.2 Overhaul Maintenance Process Of Military Aircraft

A major overhaul for the Tornado fighter aircraft for example could take about 13,400 man-hours and which is scheduled for seventy-two days of shift working. Some of the maintenance to be carried out on the aircraft could involve the removal of most components and stripping down to the primary aircraft structure, to allow a detailed inspection to be carried out (Friend, 1992).

The maintenance of mechanical components in RAF aircraft such as electrical and avionics components is done at RAF Sealand. Repairs and overhauls are not carried out by RAF units; instead manufacturers and independent maintenance organisations are considered for this type of work on a contract basis. Friend lists three reasons for performing maintenance work in-house:

A. Quicker turnaround time for parts, thus reducing spare holdings and aircraft un-serviceability.
B. Lower cost of repair in some cases.
C. Better utilisation of facilities and specialist personnel.

3.2.3 RAF Handling Of Maintenance Data

In 1969 the RAF established the Maintenance Data Center (MDC). Its main duties were to collect, store and analyse maintenance information for the RAF. In 1984 the system was improved to support on-line access. The upgrade to the old system allowed a change from routine report production to interactive analysis of the database on request from users. In 1990 the system was merged with the Supply Control Center at RAF

Stanbridge to form the RAF Logistic Establishment becoming the Maintenance Analysis and Computing Division (MACD). The usefulness of the MACD was seen in the outputs generated such as developing graphical presentation of results. Friend (1992) states that the systems have the capability of generating trends by any measures of age (airframe hours, calendar time, landings, etc.). In addition, regular management reports are produced and circulated to user units and engineering authorities. The central database is useful for staff planning, thus, it is less useful for first line operating units seeking information about technical problems.

3.2.4 Civil Aircraft Maintenance Productivity Measures

In a seminar at the Royal Aeronautical Society, Cumming (1987) gave an overview of airline maintenance productivity and efficiency measures, focusing the issue on British Airways' experience in measuring the efficiency and productivity of their maintenance units. Aircraft maintenance practice is involved with a wide range of specialities of aircraft maintenance requiring consistent conformity with legal regulatory. With this in mind, the effectiveness of civil aircraft maintenance lies in the hands of skilled technicians who execute the maintenance tasks.

The opportunity for improvement lies in the often-misunderstood word "productivity". In the late 1970's, this word was often associated with wage bargaining "productivity deals" (Cumming, 1987). The author further states that this was a cause of management apprehension. Consequently, the phrase *productivity* was viewed by many as a tool to illustrate the case for paying more, regardless of the condition of the delivered work. By 1987, there was a better understanding of the term productivity. It meant, "producing additional work output for a given headcount" Cumming (1987). The author noted that there was a disturbing temptation among aircraft maintenance management for productivity to be viewed as "working harder and faster". This concept, as the author stated, is considered to be very dangerous especially in the airline maintenance function where safety issues are very important. The forces which might cause the worker to perform the maintenance below standards include:

1. The parts needed to perform the job may not be available.
2. Not thinking about the job sequence sufficiently before attempting to start it.

3. The unavailability of proper tools to conduct the job.
4. The lack of training and constraints on performing high quality work.
5. The absence of technical support when needed.

British Airways (BA) had reintroduced a system of measuring time consumed for work done in its maintenance units. In order to identify any cause of disruption, supervisors were held accountable for every component of time being spent. This was done to permit a maximum use of time and staff in the most effective way. BA management concluded the following Cumming (1987).

1. Avionics and mechanics will start doing the work of others if they are capable.
2. Staff should alternate for others at different skill levels if time allows and it is within their experience.

The author listed some of the benefits that BA had gained:

A. They had to lay off workers, and achieved higher productivity. In contrast to the Japanese who have shown that productivity will be freely given, only if workers had a sense of job security. In the U.K. and the U.S. this principle does not exist.

B. They cashed in on some of the productivity improvement by building a substantial third party business whose aim was to perform aircraft, maintenance work for other airlines. A turnover of more that £35 million was achieved in two years.

One of the general and most frequently used measures of the productive performance of a firm is *output per employee*. Table 3.4 provides an example for some information on revenue tonne-kilometres (RTK) per employee for selected years. Furthermore, the authors noted that managers should not pay much attention when doing a comparison of this partial productivity. This is because of the differences in time when fixed assets are acquired, which can have a strong impact on the numbers. Another reason is because of differences in the way the service is conducted; for example, one airline may choose to perform maintenance services to its fleet, while another airline may choose to contract them out (Gillen *et al.*, 1985).

Table 3.4 RTK per Employee (Thousands)

YEAR	Air Canada	CP Air	PWA	Quebecair
1965	54.0	69.8	44.5	20.5
1971	79.90	87.7	81.8	47.9
1978	115.0	137.7	85.9	125.3
1981	115.6	134.2	69.1	44.2

Source: Gillen *et al.*, 1985 page: 68.

The table shows that C.P. Air generally had the highest labour productivity, followed by Air Canada. Usually a surge in traffic can significantly contribute to higher RTK per employee if the number of employees was stable during that period of time (Gillen *et al.*, 1985). The authors state that some airline operators are unwilling to use RTK because a tonne-kilometre of a scheduled service, is equivalent to a tonne-kilometre of freight or charter services. They object because freight and charter services require less resources, such as reservations personnel, when compared to scheduled services. In general terms, when comparing the quality of the services being provided between the two there will be a big difference. This will vary from one carrier to another depending on the amount of investment in each type of service (Gillen *et al.*, 1985).

Another frequently used productivity measure in the airline industry is the amount of output per unit of only one type of input (Gillen *et al.*, 1985). The input measures that are used include fuel, materials, flight equipment, ground property and other equipment. The authors provide a simple productivity measure using RTK per gallon of fuel and RTK per constant dollar expenditure on other inputs (materials). These measures are illustrated in Table 3.5 and Table 3.6.

Table 3.5 RTK per Gallon of Fuel

	Air Canada	CP Air	PWA	Quebecair
1965	.85	.81	.98	.68
1971	.94	1.04	.96	.66
1978	1.57	1.44	1.01	1.09
1981	1.36	1.56	.95	.62

Source: Gillen *et al.*, 1985 page: 69.

Table 3.6 RTK per Constant Dollar Expenditure on Other Inputs (Materials)

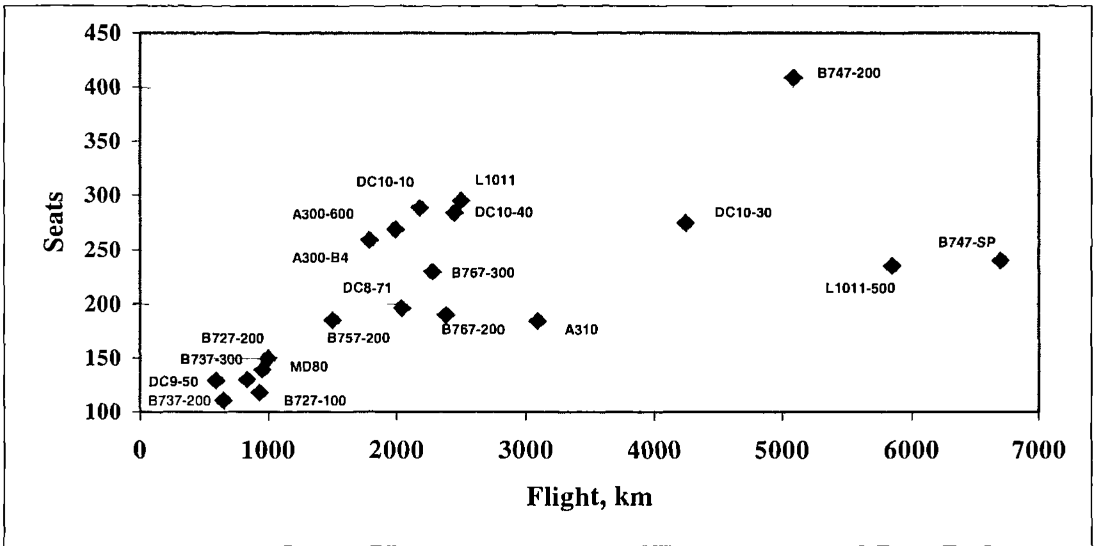
	Air Canada	CP Air	PWA	Quebecair
1965	5.44	4.58	4.18	3.56
1971	7.74	7.76	5.76	4.65
1978	8.99	10.59	9.05	6.82
1981	8.96	10.17	5.97	2.87

Source: Gillen *et al.*, 1985 page: 69.

Investment in a new maintenance facility or acquiring a major computer data acquisition can cause a change in the figures (Gillen *et al.*, 1985).

In the airline industry some general productive measures are employed in order to get a picture of productivity (Friend, 1992). This author provides *Aircraft output,* which is measured in capacity tonne-km per hour (CTK/hr). This measure provides the maximum productivity that could be obtained by any aircraft depending on its range. Therefore, airline operators try to acquire the aircraft that best suits their route network. In general, aircraft production can be measured in *capacity tonne-km per hour* (CTK/hr) and this is considered as an operational measure rather than a technical one (Friend, 1992).
In order to achieve the best range for maximum productivity, airline operators are always trying to acquire and use the aircraft which most match their route structure. Actual seat capacity and route length are being analysed by major US operators for large aircraft Figure 3.2 illustrates these two elements for year 1988-89.

Figure 3.2 Seats And Ranges Of Civil Aircraft In Use



Source: Friend, 1992:29.

Another productivity measure used in the airline industry is *Available Seat-Kilometres* (ASK) the author notes that this measure is obtained by multiplying the numbers of seats offered for sale for each flight by the distance flown (Friend, 1992). *Available-Seat-Kilometres* (A.S.K), is also another important element in airline operational productivity, which is closely linked to availability of the aircraft. The aircraft out of service time has a great effect on A.S.K, since A.S.K is the result of multiplying the seats offered for sale on each flight by distance flown.

A further operational productivity measure employed by airline operators is *aircraft daily utilisation.* There are several important factors that affect aircraft daily utilisation, i.e. the ratio of aircraft loading and unloading time on the ground to flying time. Local airport limitations on night flying, frequency and time of the year can all affect this ratio. Friend (1992) identifies other reliability measures that are frequently used by the maintenance department as follows:

1. Pilot reports on technical problems.
2. Engineering reports on technical problems.
3. Average level of deferred defects carried.
4. Time off service for technical repair.
5. Maintenance man-hours per flying hour.
6. Maintenance cost per flying hour.

Quite often airline operators give a great deal of effort to meeting scheduled reliability, since it closely conforms to the performance offered to the public, while pilot reports are given a high degree of importance by company's management as an indication of maintenance department efficiency in reducing the number of pilot reports (Friend, 1992). Moreover, maintenance man-hours per flying hour are also used by company management for measuring the quality of work accomplished. Airline operators as a measure of maintenance diagnostic accuracy also use component defect rates to measure the efficiency of the maintenance unit. Furthermore, in order to measure the effect of the original maintenance process applied airline maintenance operators tend to use defect/removal/failure rate trends. This is done by checking the rate of occurrence of incidents such as delays or turnback (Friend, 1992). The author states that with the advancements in computer technology computer-based recording and analysing may be used for storing pre-specified data. This tool can allow airline maintenance operators to gather data for performance measurement level, which helps in assessing the need for corrective action.

3.3 INFORMATION RESOURCES AND THEIR EFFECT ON PRODUCTIVITY

When computers were first used in the airline maintenance units they were limited to the standard business function of payroll, purchasing inventory and accounting systems. Not until the 1960's, did larger airlines start to use computer systems in the specialised field of aircraft maintenance function. One type of use was to apply computer technology to keep track of components on the aircraft. The availability of statistical analysis was a by-product of using the computer for recording data, e.g. number of cycles an engine operates (Friend, 1992). This author provides some examples of this use in airline maintenance units. British Airways have applied computer technology in the process of maintenance. One notable application is the *aircraft technical log entry database.* In order to analyse aircraft defects and repairs, the system holds all the information that was logged in the aircraft log for every flight. This includes the pilot's report and the ground engineer's response. The hangar and the technical offices are equipped with online access to these data (Friend, 1992).

Accurate and timely information are greatly needed in aircraft maintenance, thus, better communication is needed for this moment for one reason and that is work itself is becoming more complex, lives have been lost due to maintenance errors, and the reason is a lack of communication. Technicians in most cases have no time to plan, they are required to act promptly in having to make a complex decision. This issue causes a great deal of stress for employees (Taylor and Christensen, 1998).

Two types of information are needed for productivity measurement (Lawlor, 1985). The first deals with the basic information necessary to calculate productivity measurements. The second is the resulting measurements. There are five major areas of information that Lawlor considers when measuring productivity.

1. *Information* – Defined as something published on a regular basis. Lawlor argues that the effort required to collect information on productivity should be justified. A simple test for this would be, 'Is it put to practical use?' If the answer is 'No' then it is questionable whether the firm should continue gathering the data. The author argues that

a steady flow of information on the forces affecting business both on the internal and external levels is required (Lawlor, 1985).

Taylor and Christensen (1998) stated that the nature of the airline maintenance requires a group of people, technicians, lead team and a supervisor to co-ordinate with each other from different units. Despite the distance between them and the time constraints that always apply to them, they have to communicate with each other effectively, and most importantly to exchange information so that the whole team doing the job are aware of the latest situation. This ensures high performance of the team, as one member may have unique or vital information which could be important to the work of the group as a whole. It is worth mentioning here that the analysis of the questionnaire in Chapter Five discusses the issue of time constraints on the technician as most the jobs being carried out in the Hangar and the Line have to be completed in a limited time frame which adds to the pressure being applied to technicians.

2. *Difficulties* – The biggest one in measuring productivity is obtaining a regular supply of information. Lawlor provides guidance on useful ways to overcome this. The first is 'Will' where a manager has to go on resolutely in spite of difficulties in order to get the necessary information and to continue getting it. The second is to maintain high levels of accuracy when obtaining essential information. The third is to put the collected information to better use (Lawlor, 1985).

Computer systems have been used by most airlines as a part of their aircraft maintenance activities for many years (Friend, 1992). This author states that major carriers in the 1960's started to use computer systems to itemise aircraft maintenance objectives. A number of problems faced aircraft management when implementing aircraft maintenance inventory-control systems. The author lists some of these problems:

A. The need for accurate data.
B. The need for agreement on the basic data and the way that it will be presented collected and reported.
C. Users of the specialised maintenance system frequently found it hard to locate information in printouts.

3. *Frequency* – Some information may need to be gathered on a daily basis or even more frequently. Other information may only be needed monthly, for example. Therefore, the decision to be made by maintenance managers on how frequently an item should be

observed is significant to the effectiveness of the measurement system. In the airline maintenance industry a manager may want to monitor the number of times an aircraft engine uses most of its oil to initiate the necessary action if needed. In order to do that information needs to be reported more frequently (Lawlor, 1985).

Management must pay considerable attention to when the feedback of the requested information should be available for analysis (Richards and Greenlaw, 1972). They stated that a different managerial system varies in two important elements depending on the nature of the work. First, the duration of the time period included in the feedback report. Second, the proximity with which data is fed into the system after the performance has occurred. In some systems, performance could be measured every second, e.g. through the use of artificial intelligence in collecting and sending data about the status of the aircraft engines. One important element of data feedback the authors states is cost, as the more frequently data are collected for performance measurement to be assessed by managers, the more time and cost will be involved.
Maskell (1991) lists three important benefits of fast feedback:

A. It eliminates the cause of waste in the production process.
B. It seeks to discover production deviation.
C. It minimises the need for rework and scrap.

4. *Providers and Recipient* – Once the information needed has been agreed upon, the frequency with which information is required must also be agreed. For a large firm there could be a number of people involved in the whole process; those who will gather and analyse the information and those who will use this performance measurement information (Lawlor, 1985).

5. *Control* – The final major factor in information gathering and its importance to productivity measurement. One of the basic requirements of an effective information system is that it should lead in the end to modifications in the system which it measures. Every two to three months productivity information should be inspected using the four following questions. This is to guarantee that information meets the standard (Lawlor, 1985).

1. When was last time the information was used?
2. When was last time the information was produced?

3. Are there any changes needed in any way?
4. Is new information now necessary? Who will produce it?

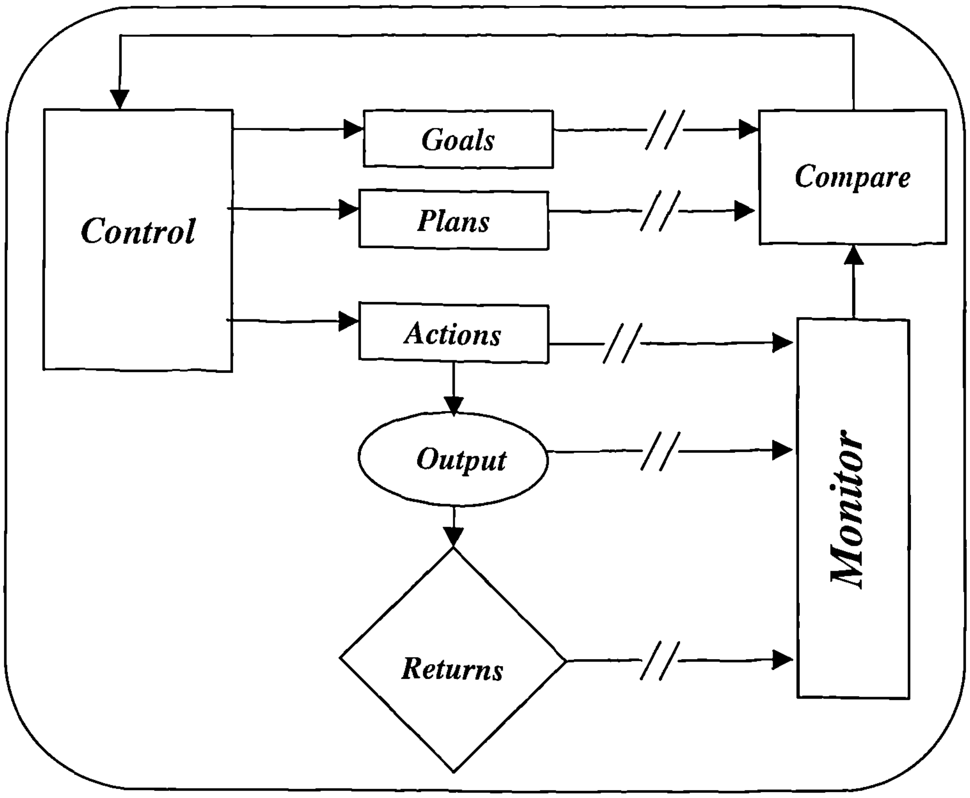
Dent and Ezzamel (1995) state that great significance is attached to information flow in an organisation, since it leads to effective control by management. This is needed as organisations carry out a variety of activities and information flows help to support and provide co-ordination among the different managerial levels. Walton (1997) provides an example in the aviation business, which relates to the use and the speed of information. *Hunting Aviation*, which is located at the East Midlands International Airport, specialises in aircraft maintenance. It is a business where the maintenance of high-quality standards is essential, and in this respect the need for an efficient information system to track all types of operations becomes more evident.

The company had experienced some problems with the old system, which was based on recording maintenance information on paper as well as the recording of time and attendance of employee, and the time spent on each work with the activities conducted. The drawback was the time needed to process the data. This was clear when an aircraft arrived for minor repair and had to be released before its costing data was available.

To be able to track performance and able to provide quick and accurate information regarding the maintenance activities conducted, Hunting Aviation adopted an automated shop floor data collection system to evaluate current performance. For this purpose maintenance data are fed every hour to management to assess the efficiency of the work accomplished. The information system allowed management to enhance planning.

The concept of control plays an important role in monitoring a system which has been designed to carry out a certain procedure (Meredith, 1992) and (Burbidge, 1962). In addition, a control system monitors and takes action when a plan or a design goes wrong. This author provides the general managerial process, which is illustrated in Figure 3.3. First, management will set goals, and plans are developed.

Figure 3.3 The Control Process



Source: Meredith, 1992:620.

Subsequently, several activities will be carried out, and according to the plan put forward, a series of procedures will be undertaken which will lead to a logical return (such as money) to the organisation. Accordingly, data are compared against the intended goals, plans and predetermined standards. Then, if required, an adjustment to the goals, and plans are made. This simple operation is called a feedback control system. The actual performance of the system is monitored and measured against an adopted standard in the feedback system. Then decision makers receive the status, check for deviations from a plan, and if they exist an adjustment action control will be initiated to put the system back on course. Feedback control systems are known as dynamic systems since the monitoring and feedback process is continuous. The feedback control system is designed in the "plans" stage, as it is the standard by which performance is measured and the policies are chosen to take any corrective action. Epstein and Henderson (1989) noted that the diagnosis in the feedback control systems requires an awareness of the conditions and the different events that are going on in the system. Moreover, the authors state that one important source of feedback is performance measurement, therefore, DEA method clearly has the potential as a powerful instrument to provide the management with control needed to efficiently run the systems that they desire.

3.4 PRODUCTIVITY IMPROVEMENT TECHNIQUES

Sumanth (1984) provided brief implicit guidelines for the implementation of productivity improvement programme in an organisation, which cover the structure, the planning aspects, the human aspects, and common problems which can be encountered when setting up the productivity improvement programme.

The *planning aspects* of the productivity improvement programme are determined by the organisational level at which the programme is to be set. At the *corporate level* top management will first appoint a productivity manager and publish the importance of the productivity programme in all divisions of the company by illustrating its economic benefits, as well as its benefits to the employees. At the *division level* in order to eliminate overlapping work activities, the general manager needs to merge existing industrial engineering functions with production co-ordination. Ideally, a plan must be formulated to redraft the process of collecting the maintenance data and the way to process it (Sumanth, 1984).

A. Lastly Sumanth (1984) list some of the *common problems* of productivity programmes and ways to counter them. *Resistance to change* - the author states that the best way to overcome this is to involve the employees in the programme and at the same time try to win them over by offering the changes which they have been looking for. Besides, at this stage both financial and non-financial motivations are important to get the employees to support the productivity programme.

Broderick (1998) illustrates an example of empowerment in the airline maintenance industry. At Delta Air Lines, top management at the maintenance department are emphatic about the importance of controlling costs at every turn. The management has taken this one step further, empowering employees to help trim costs through a simple yet innovative programme, which places front-line workers in charge of improving the bottom line. The basic argument that Delta management uses is: "empower the most responsible for Delta's productivity, the ones who do the day-in, day-out work that keeps the airline going, to come up with ways to make their work, and therefore, their company, more cost effective". Delta's management claims that since its launch in 1995, the Continuous Improvement Team (CIT) has avoided $62.4 million in maintenance costs. The programme has also led to 170 safety improvements and 1,246 process improvements. The employees and technical operations department state that the company philosophy behind empowering its employees become apparent in that they are doing their work as completely and as cost-effectively as possible, as this become an inherent goal. Adding to this the extra challenge of coming up with new and better procedures. The result of this philosophy has inspired technicians to become more innovative in doing their daily work. Brainstorming and re-evaluation are two ongoing processes. Ideas are assessed to ensure the final solution is indeed the best choice.

One of the great benefits that such a system would bring to Saudi Airlines is that the technicians will be able to accomplish the maintenance tasks in the most efficient way without any harm to safety standards. Once management put their trust in their employees and give them the freedom to express their ideas for the purpose of improving the work process, the maintenance department will experience a high rate of efficiency and productivity. Technicians would feel that they are doing maintenance work in the way that they always wanted and possibly would save the airline a great amount of maintenance expenses. In addition, the technicians would be highly motivated as they feel that the management is valuing them. This will benefit the technicians in the Hangar, Shop and the Line. For example, the technicians in the Hangar suggest that specially designed stands are necessary to carry out the maintenance work a lot faster and much safer for them.

1. Internal and External Communication

Mundel (1983), states that internal communication as well as external communication can help management to improve productivity.

Schroeder (1993) gives an example of using internal communication in Northwest Airlines (NWA). The NWA engine and aircraft overhaul facility began a defined productivity improvement effort in 1987. These were a result of the considerable time that was given to obtaining useful suggestions from employees in the productivity enhancement process. In addition, cross-functional employee teams were formed and trained in solving problems and in communication skills. These were put to immediate use in helping to solve crucial difficulties. External communication was achieved through the union which was encouraged to play a major role in the improvement process (Schroeder, 1993). In the end the results were impressive:

1. Reducing wasteful inputs.

2. Output in terms of engines overhauled increased by forty six per cent in one year, with only a 2.9 per cent increase in the number of managers.
3. Final test rejects dropped from nearly one-third to under one-eighth over three years.
4. In addition, employee safety was significantly improved.

3.4.1 Types Of Productivity Improvement Techniques In Organisations

Sumanth (1984) provides a list of *Employee-based* basic productivity improvement techniques.

1. Employee-based techniques:

The author presents some employee-based productivity improvement techniques from the point of view of human productivity and total productivity. These are as follows:

Job rotation – The author states that the advantages generated by this technique are that it relieves boredom by providing flexibility in the assignment of jobs. In the long term, giving workers opportunities to master a task that they were not initially hired for can provide "all-rounders" in the company. In addition, the author differentiates between job rotation and retraining. Retraining mainly arises out of the need to displace an employee from an existing job, whereas job rotation is an on-going effort to move workers to a different task at regular intervals. Accordingly, job rotation can be controlled formally by the supervisor in association with the operator to decide on the interchange schedule.

Communication - In order to achieve a common agreement between employees and management, and to help set the conditions that will motivate the employee to improve productivity, effective communication must be in force. Moreover, a certain amount of loyalty will be developed if consistent, open communication is in place. Consequently, says Sumanth, the mistake that management will quite often make is that they will be open about revealing the company's financial state, until productivity starts rising, when management tends to draw back fearing that the employees will start to demand higher pay.

Pieter *et al.*, (1993) state that top management are sometimes not aware of the missing link in quality management, that is they are inadequately aware of issues relating to daily practice in their organisation.

Avoiding working conditions - This technique involves a detailed audit of the working conditions, installing and maintaining improvements in the working conditions and designing improved conditions of work. Sumanth lists some factors that must be audited to improve working conditions. These are as follows:

1. Temperature, light and humidity
2. Noise
3. Colours of surroundings
4. The extent of handling hazardous material, or parts
5. The extent of manual handling of heavy items

As was mentioned in Chapter Two the Hangar varies from the shop and the line. The factors listed above are considered to be of great interest to Saudi Airlines' maintenance managers, as they are of significance to technicians' performance. This issue will be discussed further in Chapter Five.

Sumanth (1984) suggests that these five factors can very much affect the level of safety in the work place.

Training - To improve total productivity, training must be an on-going activity. This author indicates that the need for training becomes greater when new technology emerges. Initially training may cause total productivity to decrease (because of the increase in other inputs) without contributing to an instant increase in output. But the long-term effect of training on total productivity is favourable.

3.4.1.1 Artificial Intelligence In Improving Airline Maintenance Efficiency And Productivity

Yates (1995) states that one of the significant factors influencing airline maintenance productivity improvements was due to the tremendous technological advances in this field. They have brought about an improved reliability, lower airfares and most importantly, improved safety. Improvement in human productivity was seen in the new generation of aircraft, which only requires a pilot and a co-pilot, as opposed to the old generation, which require three officers to fly the aircraft. In the airline maintenance filed, maintenance productivity has improved with the use of technology. This is evident in the engine inspections, as nowadays greater proportion of the maintenance is done while the engine is on the wing. This is resulted in less engine removals to strip down for inspection, which also means less workforce is needed to bring the engine down. Some of the techniques used which allow "on wing" monitoring are:

1. Vibration monitoring.
2. Range of engine parameters monitoring.
3. Oil analysis by electron microscope.
4. Boroscope inspection to monitor cracking and erosion.
5. X-ray and gamma Ray inspection to monitor cracking.

Most aircraft maintenance activities especially failure-detection, testing, diagnosis and repair are characterised as knowledge intensive and experienced-based tasks (Grigoriu, 1991). Furthermore, Grigoriu states that it has been thought that aircraft maintenance problems such as the planning/scheduling of maintenance activities and many more are too complicated to be resolved satisfyingly with the use of computer systems. Besides many people in the airline industry agree that the airline maintenance business has been "data rich" for many years, yet not fully capable of utilising that knowledge and experience through computerisation. In addition, the author describes how expert systems can enhance human expertise in order to be more efficient in an environment like aircraft maintenance. Grigoriu (1991) defines expert systems (E.S.) as "intelligent computer programs that use knowledge and heuristics to solve complex problems", moreover, E.S. emulate the reasoning process of the human expert as well. The author provides a list of E.S. applications in aircraft maintenance:

1. Planning and scheduling of activities.
2. The interpretation of non-destructive testing results.
3. Condition monitoring
4. Fault diagnosis
5. Computer-based training (CBT) by utilising real data/information.
6. Intelligent help facilities.

Expert systems are designed to handle data, information, expertise and reasoning used for decision-making in aircraft maintenance (Docker, 1991). This author states that expert systems can provide aircraft maintenance management with a level of flexibility which is not being delivered by any traditional programming technique. This is because those expert systems separate out data, information, expertise and reasoning in an explicit way. Furthermore, traditional computing has improved efficiency by handling and storing data and information faster and more accurately than people can manage. Consequently, this level of efficiency can be improved even further by co-ordinating expert systems with traditional data processing computer systems such as databases and condition monitoring systems.

Docker (1991) notes that integrating both traditional systems and expert systems together has the ability to increase the efficiency and productivity of these applications as well as improving the quality of the generated solutions. Advanced expert systems constitute an "integrating vehicle" between these important functional areas.

A. Workload definition:

This element can be sub-divided into Fault diagnosis/isolation and predictive maintenance that includes condition monitoring (CM).

1. *Fault diagnosis/isolation* – Advances in aircraft manufacturing have resulted in the introduction of more complex systems incorporating highly advanced technologies into today's aircraft. These technological advances have in turn led to improvements in identifying a fault and the tools to diagnose it. This phenomenon has led to the introduction of a new perspective on maintainability improvements, which is integrated into the aircraft design, to minimise the maintenance component of aircraft life cycle costs. This improvement in fault diagnosis has helped in improving maintenance efficiency and has improved the balance between time expended on determining what the actual problem is and solution implementation and control.

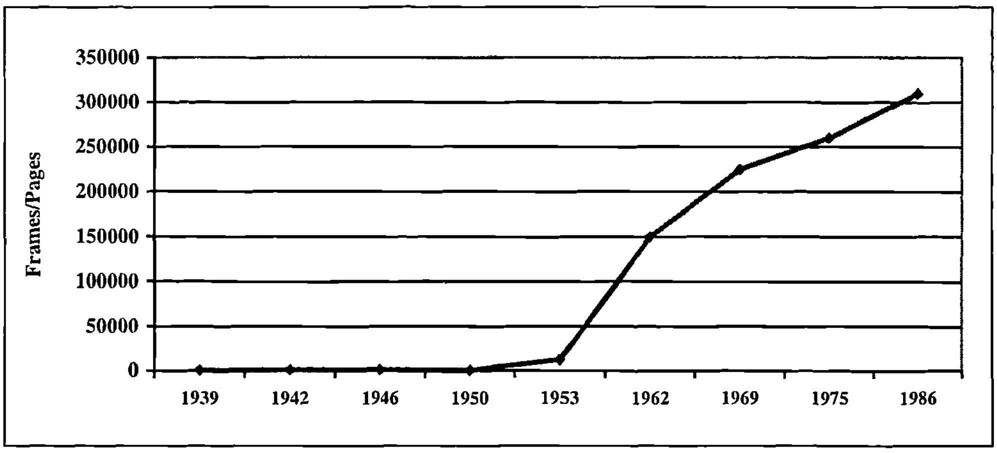
2. *Predictive maintenance or Condition monitoring (CM)* – In order to improve the efficiency of aircraft maintenance, monitoring systems are integrated into the aircraft. One example of which is a predictive maintenance technique to monitor wear in aircraft engines through oil debris analysis and vibration analysis of the high power rotation. Such a system allows maintenance engineers to continuously monitor an aircraft engine (which is an expensive part of the aircraft) in flight conditions under actual load, which may not be reproducible on the ground by airline operators. A further improvement to aircraft maintenance is an on-board monitoring system which

transmits requested data to a ground control station computer at the main base. This can be done while the aircraft is still airborne in order to minimise ground testing time and avoid any delays. These highly advanced condition monitoring systems in some cases may take action automatically without ground control taking any necessary action such as an automated adjustment of avionics.

B. Technical Documentation:

The number of technical manuals continues to rise as aircraft require more and more sophistication in their maintenance operation procedures (Docker, 1991). This increase makes it more difficult to update the manuals and takes up a lot of time, Figure 3.4 shows the growth in technical manuals used by the U.S. Naval Air System. In order to improve productivity and efficiency of aircraft maintenance operations, hypermedia software is being used, which enables maintenance personnel to retrieve information as quickly and as accurately as possible.

Figure 3.4 Technical Manual Growth Rate within the Naval Air Systems Command



Source: Grigoriu, 199:1.7.

Grigoriu (1991) list four reasons for using expert systems in aircraft maintenance:

1. Since aircraft maintenance requires personnel with high skill and expertise, it is difficult to have them available at all times. This is more evident during the night shift, which can affect the quality and productivity of the work during that turn time. Using expert systems (E.S.), will make it easier to obtain the knowledge needed to get the job done in the most efficient way, e.g. an engine trouble shooting problem, which must be tackled on the spot and as fast as possible.

2. In order to maintain the same levels of efficiency an expert system can "Capture" the expertise required to do the job in case the most experienced person leaves the company or retires.
3. The different types of engines and the advancement in the technology require that the expert must keep up with all the changes, modifications and new engines. In addition, it becomes harder for one person to be knowledgeable on all aspects of an aircraft engine. Therefore, in order to minimise the time of analysing the problem ES can provide advice, which is based on knowledge to improve maintenance performance and reduce downtime.
4. Efficiency of the work can be affected by overload or crisis situations, while ES are not affected by these circumstances as they provide consistent results at all time regardless of the workload.

3.4.2 Benefits Of Productivity Measurement

Productivity improvement is essential for an organisation to survive in today's competitive environment (Werther *et al.*, 1986) and can originate from many human and non-human sources. Improvement through technology for example can often allow an in-depth search into product design and manufacturing processes. The better design of facilities and equipment can bring about improved productivity in both manufacturing and service sectors, especially if careful attention is given to the science of efficient human machine interfacing. Furthermore, employees' attitudes and morale can be increased through improvements in facilities and equipment design, which in the end may lead to improvements in productivity beyond those achieved through economies of scale. Moreover, the improvement in work methods and procedures, especially in work design and layout, may also contribute to productivity improvement.

Productivity measurement illustrates the direction for comparisons within the organisation and inside the industry (Sumanth, 1984). Therefore, in order for an organisation to identify a target, it should determine the level of productivity, at which it is operating at. The following benefits can be achieved through the application of productivity measurement:

1. The efficiency of conversion of the organisation's resources can be assessed, so that more services can be produced for a given amount of resources.

2. Through the use of productivity measurement, short and long term resource planning can be attained.
3. The opportunity to organise the economic and non-economic objectives of the organisation in the light of a sound productivity measurement system.
4. By employing current measurement levels of productivity, managers are able to plan productivity level targets for the future.
5. The gap between the planned level and the measured level of productivity can be used as a base to determine strategies for improving productivity.
6. Productivity measurement is useful in comparing the levels of productivity between organisations within a particular category, either at the industry or national level.
7. Planning the profit levels in an organisation can be achieved through the use of productivity values produced as a result of measurement.
8. Once productivity measurement estimates are available, collective bargaining can be accomplished more rationally.

These previously mentioned benefits could also be of interest to Saudi Airline maintenance managers. As the airline is set for privatisation, resources becomes an important issue for the maintenance manager's success in achieving the corporate goals of being a highly reliable airline.

Schroeder (1993) states that since World War I, the availability of land, labour and capital have risen rapidly, which has contributed to productivity improvement. Another benefit from improved productivity is an increase in the industry's ability to compete in the world market. In addition, it will help to ease the negative affects of inflation as well as helping to maintain wage stability.

3.5 PERFORMANCE AND EFFICIENCY MEASUREMENT SYSTEMS

Jorm *et al.*, (1996) state that the enormous spread of new technologies, coupled with world-wide economic pressures and social and political changes, has had its effect on both private and public sector ways of work. As a result of these changes organisations have been forced into cutting costs and becoming more productive. In this environment, which is characterised by constant change, management are placing more emphasis on employing more precise performance measurement techniques. Furthermore, private and public sector organisations have started a major performance programme. Such frameworks are focused on the alignment of functional and management activities in order to accomplish the best possible results. The authors state that a performance management system impacts on all aspects of the organisation and combines the following.

1. Corporate and strategic planning to define the long and short-term objectives of the organisation.
2. Translation of these into operational plans for the organisation, divisions and individuals.
3. Assessment of training to identify priorities;
4. Development of appropriate measures of performance at organisational, divisional and individual level.
5. Continuous review, adjustment and feedback

There are several factors that drive managers to improve business performance. According to Lawson (1995) one of these is the profit motive that makes them constantly search for ways to improve the efficiency and the effectiveness of their organisation. Individual units within the organisation may not have the same priorities if each individual manager seeks to optimise the performance of their own unit without having to make reference to the organisation as a whole (Lawson, 1995).

Action learning programmes have confirmed that managerial performance is closely linked to information about what is being managed. These programme were pioneered by Professor Reg Revans and generally consist of a group of managers who work on solving actual problems in their organisations. The activities of these groups of managers has revealed some common problems that combine the following factors:

1. Ignorance of the key information that should be available the "What do I need?" problem.
2. Confusion about how to select and use information which is available the "How do I use it?" problem.

It was this recurring problem that led to the development of what is called Performance Improvement Programmes (PIP). The first experimental programme was started in 1978, which included eight small to medium manufacturers in the West Midlands region of England. A (PIP) establishes an efficient productivity measurement programme then links it to the human part of improving the system, Figure 3.5 illustrates its four main stages (Lawlor, 1985).

Ghobadian and Ashworth (1994) stated that performance measurement is considered to be important for the following reasons:

1. The quality of the managerial decisions and resource allocations are improved.
2. It provides a solid base for planning, monitoring and control.
3. It makes responsibilities definite by enhancing accountability as well as being able to give an indication of success or failure.
4. It sets the ground work for staff appraisal and motivation.

Figure 3.5 The Four Main Stages Of A PIP

1	Where are you now? How do you compare with others?	Productivity audits Primary & Secondary levels
2	Reveal main problems	Analysis audits
3	Decide where do you want to be	Agree action plans
4	Action program	Internal and external action learning groups

Source: Lawlor, 1985: P.101.

The broad aim of a (PIP) is to allow the organisation to effectively improve its performance through continuous performance improvement. The more specific objective is to set up an effective productivity information system, to establish performance standards, to allow an in-house productivity programme to be established and to allow for external learning by joining other groups who are adopting the same system (Lawlor, 1985). Productivity audit is part of the performance improvement programme and is designed as a useful low-cost method of building awareness of the needs for of such a system. At the same time, managers can earn by the active involvement of employees in the kind of information that they need and, of equal importance of productivity audit, is how to use it to improve the performance of their organisations. The success of this measurement system will largely depend on the availability of information which can be acquired with minimum time and cost.

Primary audits take place for the following reasons (Lawlor, 1985)

1. To provoke the initial question, 'Where are you now?'
2. To reach a common understanding on the type of information needed and to find a way of assessing this information.
3. To show that the importance of performance and productivity should be clear to management and provide them with rapid information at a time when they need it most.
4. To mark areas of improvement.

Armstrong (1997) stated that it is the organisation's responsibility to create the right environment for its workers in which such a continuous learning process can take place. The analysis of employee knowledge, skill and competencies will indicate not only the areas that need some attention as it will also identify the level of knowledge, skill and competence that they need.

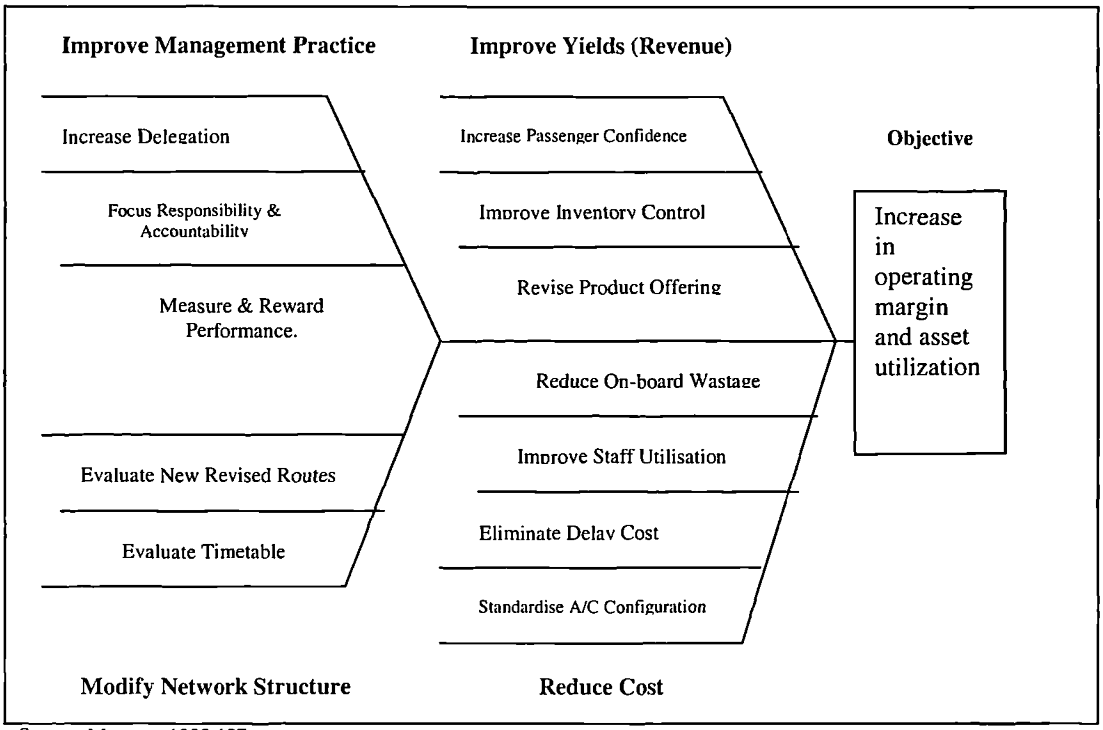
Walters (1995) states that in many organisations workers are asked to perform their job task against a predefined standard of formal goals and measures. Yet the terminology may vary from one organisation to another: these can be named as, strategic measures, critical success factors, performance indicators and key indices, thus the main aim is generally similar. Eventually, systematic measures are the main way to underpin all work activities, and allow the organisation to evaluate how effectively they are performing and how their performance can be improved.

In that example, one of the important elements that caused a decline in return was determined to be the poor punctuality record. This caused the costs of operation to increase in terms of overtime, crew-out-of-hours, extra meals, hotels and transportation, and transferring passengers to another airline. Moreover, business class passengers did not want to risk flying with an airline with a poor on-time-performance record.

Through these measures management can have a multidimensional picture of their organisations performance to identify areas of high performance, as well as identifying areas of the organisation, which have a scope for improvement.

Morrow (1992) states that in each and every operational and functional area of the business, management must ensure that there is a continuous improvement. This concept is widespread in Japanese companies, using methods such as fishbone analysis. Figure 3.6 shows Fishbone Analysis applied to an airline.

Figure 3.6 Application of Fishbone Analysis To An Airline



Source: Morrow, 1992:137.

In this example, on of the important elements that caused a decline in return was the poor punctuality record. This caused the cost of the operation to increase in terms of overtime, crew-out of hours, extra meals, hotels and transportation, and transferring passengers to another airline.

When performance measurement was implemented in the organisation it was confronted with resistance in many different sectors, such as health and education, where it was treated with scepticism, because it was linked to individual appraisal and pay. The author identifies the reasons behind this resistance. In many cases there is a concern about a "hidden agenda" which may emphasise more systematic measures. Furthermore, the employees can see performance measurement as posing a threat for introducing privatisation which will involve cost cutting or staff reduction (Walters, 1995). Since Saudi Airlines is about to be privatised the maintenance managers may face the same problem. The author states that it may be difficult to develop the same measures for the whole workforce as in an organisation. Therefore, managers may wish to search for different types of performance measures for work teams. Accordingly, both the diversity and the linkages between the different work-groups, departments and functions operating in the organisation must be recognised. In each one there is a need to identify performance measures, which indicate the different role and purpose of each working group. More importantly, is to ensure that all measures support the achievement of the company's strategic objectives. Management needs to identify the level of performance needed, in order to achieve a specific organisational goal. For example, if the organisation focus is to be on new product development, then there may be a need to evaluate if the organisational culture and structure are suitable to support innovation. Therefore, there is a need to decide whether the organisation has the required level of skills, both in technical and management innovation. Also, there may be a need to assess the organisation's competence in identifying market needs. In doing so, the organisation should be able to identify its performance priorities.

A major initial purpose of audit is to gain this early acknowledgement that current performance could be better. This step can be achieved in three ways. First, a reminder of the more common ways of judging performance which this can include levels of activity like sales turnover, obvious changes in stocks and the amount of incoming work. All these are day-to-day events, which lead managers and workers to feel if things seem better or worse. Second, to involve the person in charge in carrying out an audit of their existing information systems. Third, the previous quick audit used will achieve the recognition needed to show that there is room for improvement (Lawlor, 1985). *Performance management* is defined by Walters (1995) as, 'Directing and supporting employees to work as effectively and efficiently as possible in line with the needs of the organisation'. The author identifies various levels of performance management, e.g. strategic planning, identifying appropriate performance goals and measures for the organisation.

Lawson (1995) identified two approaches to develop superior performance, process-focused techniques and people-focused techniques. He states that the *process approach* deals with the maximum performance that can only be achieved by analysing the work accomplished. Designing the most efficient work processes is part of this approach.

Quite often management focuses on improving their organisation's performance yet stress one dimension of performance at the expense of another. For example, quality at any price, or improving on-time delivery by allowing the inventory to rise. Therefore, the objective of any department or function must be to manage business processes, which improves quality and delivery whilst at the same time reducing cycle time and waste. Consequently, these performance measures are either internal such as cycle time or waste, and are therefore invisible to customers, or external, such as quality and delivery, where they are visible and important to customers. The author states that these performance measures are frequently conducted simultaneously. Thus, the main focus of attention relies on a number of factors, for example, the difference between the company's performance and the performance of the company's competition. Therefore, in competitive markets, significant amendment arises from managing key performance indicators, which will lead the management to compare its rate of improvement with that of its most competitive rivals (Lawson, 1995).

In terms of process measurement, Gammie (1995) stated that one should start by measuring the delivered result at the end of each process, then work backwards in order to highlight what has been done. As an example we can illustrate this idea in the airline maintenance domain by analysing a simple maintenance process - the change of landing gear on a particular aircraft. After the work has been accomplished we can set the stage for process analysis by identifying the steps in the work that was carried out. We can measure, for example, the on-time delivery of parts, personnel injury, evidence of oil leakage on the part that has been mended, the need for a rework work measured against standard time and the general quality of the job. The end result of the job that has been accomplished can then be assessed. If a fault occurred during the process, we can retrace the steps to identify the actual cause and fix it immediately. By so doing we can identify areas which need attention.

3.5.1 Individual Performance Measurement

Jorm *et al.*, (1996) state that many management systems include a highly subjective assessment of personnel characteristics. In some cases, employees are not told the result of assessments which does not allow them the opportunity to improve weak areas or to be motivated by a positive assessment.

The lack of effective measurement of individual employees, and not being clear about organisational needs and objectives, can lead to complaints from employees. These may include for example, "I don't know what the organisation wants from me, as we should improve quality, but then it won't let me fill half the jobs in my department because of cost constraints" (Walters, 1995:15). The author states that in some cases, even if the organisation succeeds in identifying its corporate objectives, it still has the difficulty of turning those into a useful measure. Therefore, in order to achieve effective measures of individual performance, a balance between a number of dissimilar and potentially even contradictory, requirements is needed. Moreover, management needs to ensure the measures, and their intentions are clear to the managers. According to Walters (1995)

1. Employees should know all the measures applied to them.
2. Employees should know the different weighting used for each measure.
3. Employees should be aware of any special performance targets or benchmark levels that have been set.
4. On a constant basis employees should be aware of their performance compared to the measures.

Gammie (1995) differentiates between accountability and responsibility, in terms of individual performance. The author identifies *Accountability* as, 'Implying that we have been charged with delivering a specified outcome, regardless of whether we have direct control over the various process elements that contribute to the outcome' (p.54). While *Responsibility* is defined as, 'Those areas in which we have direct control over the delivery of a specified output' (p.54). The author considers these two definitions to be a critical aspect of performance management as both cut across the conventional concept of power in the workplace.

The added advantage of an organisation focusing on outputs is that they are easy to measure, whereas responsibilities or job profiles are far less so. Thus, problems may arise if management only focuses on improper output measures. While individual input measures are evident in vocational training and qualifications they are also clear in recruitment which is more input-focused; put in another way, the organisation is trying to measure what the person can bring into the workplace (Gammie, 1995). In addition, Gammie identifies two levels at which individual performance can be measured. The first is concerned with the boundaries of the job. The second is concerned with the amount of contribution that a person may make towards the organisation. Examples of these are team working, collaboration and innovation. This means that besides the direct output measures, the organisation is also looking for precise performance standards in terms of these three facts. Since it is much harder to prescribe quantitative measures of output, management will be searching for a stronger indications of appropriate behaviour. The author suggests that in order to agree on appropriate individual performance measures, firstly an individual perspective on the job must be obtained; secondly, any individual measure must be related to the organisational context, in other words, identifying what the organisation wishes to acquire from this individual contribution and over what time scale. The purpose of measuring individual performance is necessary to analyse each individual contribution towards organisational needs and objectives. After collecting such information, with the aim of improving performance, organisations tend to use the collected information for two main reasons. Firstly, as a basis for pay, using the assumption that relating high performance to pay will maintain or may improve overall performance. Secondly, because it can reveal the need for extra training programs in some weak areas.

There are four different techniques to measure individual performance (Gammie, 1995). These are as follows:

1. *Business-focused* - This takes into consideration the business goals and values, which are then translated down through the organisation. The author states that this approach can fail due to bureaucracy.
2. *Activity-focused* - Various activities delivered by an individual are measured day by day. This method describes jobs according to what responsibilities the individual holds.
3. *Customer-focused* - The first need is to identify what each individual is expected to deliver to the customer, and, must therefore identify their customer. Gammie states that the customer-based focus is the most appropriate approach that provides a precise and tangible basis for assessing performance. Yet, its disadvantage is that it is not directed towards a more strategic understanding of the organisation's needs and goals.
4. *Person-focused* - This method depends on the ability to evaluate the skills, knowledge and behaviour of someone in his job situation. For example, some organisations have developed competence profiles for specific jobs.

3.5.2 Handling Poor Performance

Different organisations use various techniques to assess their employee to be able to spot poor performance. These techniques may take the form of systems designed to highlight areas of known problems, or they may consist of training the employee to analyse their performance in a better way (Stewart and Stewart, 1982). The authors categorise the methods which organisations provide to their employee into two groups: checks against existing standards and outside/long views.

Checks against standards - Individual people or departments are reviewed on a continuous basis against a set of job-related standards, which are set by the organisation. These may include analysis of customer complaints and quality control checks. These analyses will reveal areas of poor performance, e.g. scrap rates and returned goods. Managers can use historical data as a guideline to be sure of getting the full picture of poor performance. This can be done by reviewing customer complaints into different categories. For example, British Rail's, letter of complaint were designed for different settings e.g. "late running train", "train cleanliness" and so on. Thus, if the operator wanted to track individual poor performance, then they might have wanted to capture data such as the helpfulness of the guard on a late-running train. Trends of poor performance can be checked to assess their importance. However, care must be taken in allocating blame, as one person with a high scrap rate could be classified as a poor performer, but if their whole section has a high rate, then the fault may be from the manager or the system design.

Outside/long views - This includes any feedback about standards or performance, which comes from an informed outsider source. This method may point out areas where performance levels should be explored even further. In the case of an outside consultants' report, many firms will attempt to find the performance of their organisation through surveys which are addressed to a special closed question. Consequently, the outside consultants' report can be especially valuable in helping to set performance standards in areas where the existing management teams are less experienced, and in addressing performance problems at senior levels.

3.5.3 Determinates Of Poor Performance

Stress and emotional problems - Stress can cause poor performance as motivation boosts the standard of performance, also, low levels of motivation can cause performance standards to be low (Stewart and Stewart, 1982). In a stressful situation people feel threatened, therefore, the authors define stress as what happens to a normal person when placed into abnormal environments. Consequently, managers need to understand that any job has some basic level of stress. The appropriate way of managing this situation is to change the pace of one's work; having a sense of a prospect that enables one to put small occurrences in their place.

Work group - The author states that when one starts work it means joining a group of strangers, the people with whom most of the person's time is spent. Therefore, getting along with the group requires some effort especially for the first job, as the new worker would work with others who might have a wider background of age and experience. Under these circumstances, poor group stress probably becomes the single best method of getting someone to change his attitude. The implication of this for understanding poor performance is that, there are two common causes of poor performance linked to the work group (Stewart and Stewart, 1982).

This point is highly important for Saudi Airline maintenance managers as they would have to provide a special training programme that is aimed at preparing the new technicians for their new job. This is to better prepare them and allow them to understand the new work environment much better, and at the same time reduce the possibility of early failure of the new technicians.

Norms and output limitation; where people who are all working at the same task output tends to remain fairly constant between workers. For example, the phenomenon of "self-compensation absenteeism" is seen in some heavy manual industries; there seems to be an unwritten accord between workers, that especially hard shifts merit some time off at later date.

The Organisation - Managers sometimes hold back from taking any corrective action when they see someone performing poorly. It may be too much trouble, or the person may be coming up for retirement and therefore not seem worth the effort. Excuses such as these are used by individual managers for not taking strong action against poor performance. Stewart and Stewart, (1982) claims that it is rare to find an organisation ready to train mangers to deal with poor performance. The consequence is that as long as people see poor performance standards being accepted, they see no reasons to try to improve them. Eventually, the poor standards become normal; and therefore, the good worker who is doing well or wants to do well will ultimately suffer (Stewart and Stewart, 1982).

In an old organisation, often a special pattern of poor performance exists. Several factors contribute to this continuous pattern. One factor is the average length of service of employees, which makes it difficult for them to react to change and creates resistance to attempts to change them. Another factor is the average length of stay in the same job. Furthermore, in some old organisations there is the tendency to find people who have been doing the job for ten years, having been taught it by someone who has been doing the same job the same way for fifteen years. And therefore, the result is a tradition of people adapting old ideas before they become aware of having had them. In some organisations, training becomes a cause of poor performance. The basic way in which this can happen is by having the employee trained to a different standard from the one used in the organisation. The most serious way in which an organisation can originate poor performance amongst the trainee, is to not support their training after they have completed it.

Therefore, it is very important for Saudi Airline maintenance training managers to highlight the importance of work standards, and provide the trainee with the exact performance standard used in the environment that they will work in.

Working conditions - Most people find temperatures above 80 degrees difficult to work in, especially if the humidity is high. The same principles apply to noise in the work place, as it interferes with performance in a variety of ways, and may disrupt employee concentration. Consequently, poorly designed Hangars can effect employee's performance (Stewart and Stewart, 1982).

3.5.4 Performance Measures In The Public Sector

The public sectors of European, North America, Scandinavian and Australian countries at the present time are working towards greater efficiency. It is now the time to control public expenditure growth, which characterised the 30 year period from 1950 to 1980.

The aim was to achieve a reduction in tax rates and public sector borrowing (Jackson, 1990). The public sector image was of a unresponsive, bureaucratic giant, inert. Because of the absence of competition it was inefficient in its use of resources. With all this in mind, the public sectors of major industrialised countries have become more positive in responding to change. Today, there is more interest in questioning whether certain activities should be produced directly in the public sector. The result has been the privatisation of many activities, through asset sales or contracting out i.e. airlines. By giving managers the freedom and flexibility to manage their environment more efficiently, and to be held accountable for their actions, it has generated a demand for a more precise performance measurement. These changes in the ways of doing the work were mainly intended to improve the performance of the public sector. Consequently, managers required a number of precise internal performance indicators, which will reflect whether or not the company is heading into the right direction of making a profit (Jackson, 1990).

Public sector managers who are interested in improving value added are faced with a number of problems, as the bottom line of any organisation's performance has to be assessed in terms of consumer and client satisfaction. However, there are many different types of consumers and clients, each of which has different choices and evaluations of the services, and therefore each group will assign a different evaluation to the end result (Jackson, 1990).

3.5.5 Performance Measurement Indicators

Performance monitoring should be a strategic and integral part of the organisation's aims. Therefore, for an organisation to implement performance measurement in order to secure improvement in performance, requires a strong commitment as well as a strong lead from top management. For an organisation to succeed to achieve its optimum goals of monitoring performance measurement, they would require a high quality of work force as well the need to acquire a new skill in monitoring it. This will eventually result in a specially organised training programme to handle the demand for well-trained and skilled personnel (Jackman, 1999).

Jackson (1988) and Fortuin (1988) state that performance indicators work as a tool for alerting management to consider the issue that they are investigating further. However, both authors state that performance measurement and indicators are signified in terms of differences from objectives set by management. The gap between actual and target objectives for a given department over time is given great importance by management.

Whitaker (1991) states that reviews of performance measurement indicators are done frequently at a managerial level and will often be presented in a monthly, weekly, or daily reports. In this context the continuity of communicating performance measurement indicators is considered to be important as they will be used to initiate corrective action if needed as well as being used for a review by employees and managers to monitor progress.

This can be resolved by each department manager to allocate a performance indicator, one that achieves his department goal and at the same time coincides with the organisation's main objectives. As a result the group of managers who are aware of the problems, are involved in using performance indicators. This, managers using performance indicators have to be aware that it might have a hard impact upon individuals behaviour, since their information content impacts upon the organisation's incentive structure, yet, this only true if it is done for that purpose (Jackman, 1999).
Another problem that faces managers is that of "short-termism". This again is an incentive-related issue, as there is an emphasis by managers on achieving short-term gains for the organisation. If promotion relies upon performance levels achieved, then individual managers will attempt to secure short run efficiency improvement, and allow their successors to look after the long run achievement of effectiveness. This eventually means that no one looks after effectiveness. Having set up a management information system to measure performance, some organisations regard this as the end of the story. This means that they are not actually willing to use it to manage improvements in performance (Jackman, 1999). Something which was also mentioned in this chapter about the PIP programme.

3.6 MEASUREMENT OF WORK

Stewart (1963) states that every job has to have a standard time or a specified standard in which it has to be completed, regardless of who does it and at what speed. The standard is used to assess the relative value of the actual rating of the work being done to pre-defined standard levels accepted by management for the purpose of meeting the benchmark standard.

The main objective of work measurement is the establishment of standard times for jobs, which are being set at standard level of performance or as "target" times for the purpose of planning, manning, costing, remuneration, and general control (Whitmore, 1975). A formal definition approved by the British Standards Institution for *work measurement* is "the application of techniques designed to establish the time for a qualified worker to carry out a specified job at a defined level of performance." Standard times for a job can offer the basis for planning and allocation of work-load, manning jobs, measuring operator and department effectiveness etc.

For the purpose of achieving high productivity or improving productivity in existing work, work study is considered to be a relatively low-cost way of improving current work methods and reducing ineffective or wasted time. The design or improvements are assessed within the capabilities of existing resources and equipment (Wild, 1995).

For Saudi Airlines this may prove to be useful in areas about which technicians complain the most such as conducting maintenance tasks which involve replacing an electrical unit of the aircraft in which the method used to replace that part requires the technicians to carry out the replacement process alone, and would have to go to the tool room to bring out the necessary tools, and bring the appropriate stands if needed. All these waste time from the technician's point of view. Using method study would suggest for example, the technicians should be treated as a professional worker and therefore, all the necessary support equipment needed to carry out the maintenance task should be easily provided. In addition, the technician for example, should have the appropriate stands brought up by ground support equipment personnel, and the only task that the technicians need to do is carry out exactly what the maintenance cards says (replacing a specific unit and putting a new one in).

Under any circumstances, the technique used should deliver maximum returns. Whether these economic returns are an increase in throughput, reduction in waste, improved safety, reduction in training time, or better use of equipment or labour, they should at the end outweigh the cost of the detailed investigation. In order to ensure that this happen, the following should be considered:

A. The anticipated life of the task
B. Whether manual work is considered to be an important part of the job.
C. Utilisation of equipment machines, tools, etc, the cost of this equipment, and whether the utilisation is dependent on the work method.
D. The importance of the job to the company.

When using human labour as part of the productivity operation, it is essential to know the productivity of the workers for capacity planning, process design and scheduling considerations. Accordingly, there becomes a need to establish work measurement standards for output rates (Meredith, 1992).

Managers have different methods of work measurement available for them to choose from. The choice frequently depends on the intention for using these data. For example, if management is looking for a high degree of precision when comparing actual work method results to standards. In this case, a stopwatch study might be required. Alternatively, for a manager to estimate the percentage time that an employee is idle while waiting for materials, then a method such as work sampling is required. Consequently, a manager may choose to use more than one approach to acquire the needed work measurement information (Krajewski and Ritzman, 1993).

Work measurement and its resulting work standards have been contentious since Taylor's time (Chase and Aquilano, 1995). The authors state that much of the comment has come from unions, who always claim that management is often setting standards that cannot be achieved on a regular basis. The degree of accuracy in conducting work measurement is largely a question of economics and is conditioned by the intention for which the work measurement is needed. If the objectives of work measurement are to compare alternative methods of working, then the level of accuracy required can be very high indeed. This is because there is a need to answer every question of work measurement to a fine detail.

Allard *et al.*, (1971) and Currie (1972) agree that any programme aimed at improving productivity needs to have a soundly based work measurement. However, the scale of success to be achieved would heavily rely on the way the information available is handled. The objectives of the work measurement are as follows:

1. Establishing the right staffing level.
2. Controlling cost.
3. Determining true cost for handling different types of works.
4. Planning further manpower need.
5. Establishing management control information.

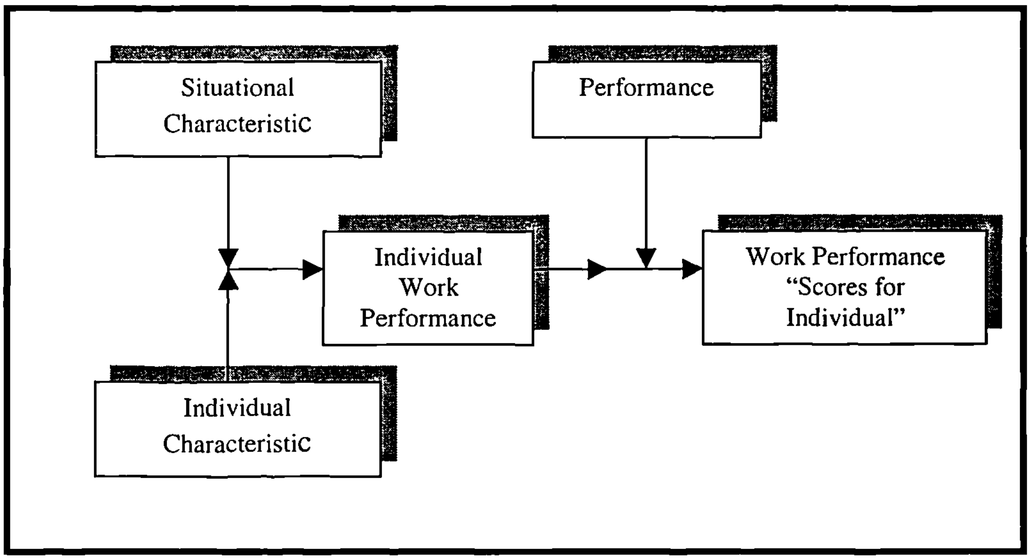
3.6.1 General Measurement Issues

Work measurement can only be applied to the work place when the observer is absolutely sure that the working method of measurement is the best and can be achieved smoothly (Whitmore, 1975). Therefore, a properly trained operator who is suited to be familiar with the task should be used to set performance targets based on work measurement. The proper application and introduction of work measurement contributes to the following.

1. Better use of manpower resources through,
   - A. Balanced work-loading.
   - B. Improved manpower-planning.
   - C. Labour-cost control.
   - D. Through rationally based incentives and bonus schemes, manpower performance can be improved.
2. Better use of capital assets through,
   - A. A strong based production-planning.
   - B. Improved materials-forecasting.
   - C. Implementing standards for plant and machine operation.

Work performance measurement procedures are based on the actuality of individual differences. Most of the theoretical and applied work in the area of measurement is interested in inter-individual differences in behaviour. In work performance measurement this is also true, especially in the application of work measurement in employee development. Landy and Farr (1983) stated that work performance is influenced by a group of factors that are illustrated in Figure 3.7 which affect the characteristics of the individual to measure the work performance of the individual.

Figure 3.7 Factors Influencing The Measurement Of Work Performance



Source: Landy and Farr, 1983:8.

Whitmore defines *situational characteristics* as all aspects of the work setting other than the single individual whose performance is considered. These characteristics may include the supervisor, peer, work design, reward system, organisational structure and policies, etc. While *individual characteristics* include ability, motivation, and role perceptions. A significant point in the model is the difference between the work performance of the individual and the work performance "score" of the individual as acquired by the use of a performance measurement procedure.

3.7 SUMMARY OF CHAPTER

The chapter started by defining the term productivity, and then explored the factors that contribute to low productivity. In addition, different productivity measurement techniques were discussed.

Productivity and efficiency measurement techniques vary from one department to another based on management strategic objectives. Therefore, a sound productivity and efficiency measurement system should be able to reflect actual operational activities, in order to enable management to assess their actual performance against the predefined measures.

As a consequence of work experience and literature research to date, the following research issues have been developed which the research is aiming to test. These issues help in developing the operational definition of the findings of the main methods. The research issues are:

1. How to utilise the current performance indicator system in setting the DEA model for the airline maintenance unit.
2. How to define and select the most appropriate variables which have a strong relationship to the performance of the investigated unit.
3. How to measure the effect of poor training and the availability of material as well other factors that affect efficiency and performance.

A summary of the set of research questions that emerges from the chapter includes:

1. The logical question that emerges from the first point is how much better could we do, as was asked by Lawlor (1985).
2. How trends could be useful for maintenance managers in helping them to understand the characteristics of the airline maintenance industry and its impacts on efficiency
3. How the idea of improving the work environment for the technicians through empowerment, better communications and providing the most appropriate environment to conduct the maintenance tasks could prove to be significant to performance and productivity levels.
4. How management can choose the most appropriate variables among many different ones, for the purpose of analysing the business under consideration.
5. How can management can learn from other airlines' experience in improving their maintenance work environment

CHAPTER FOUR

SURVEY DATA COLLECTION

CHAPTER FOUR

SURVEY DATA COLLECTION

4.0 INTRODUCTION

To obtain a better grasp of the topic under consideration, Saudi Airlines maintenance managers and employees were focused upon in order to identify areas of efficiency, performance and productivity in the workplace. The purpose was to investigate potential problems contributing to poor performance, as well as attempting to identify maintenance managers' and employees' perceptions of relevant issues relating to performance and efficiency. Both Oppenheim (1992) and Parasuraman (1991) state that the term 'questionnaires' covers postal questionnaires, group-or self-administrated questionnaire and structured interview schedules, and it is a tool that is used by many research projects.

Two forms of questionnaires were used in this research. First, a set of questions was addressed to the employees in the maintenance department. As seen in chapter two this covers three main departments Hangar, Line and Shop. The second set was directed towards the managers of these three departments. The purpose of having two sets was to identify the perceptions of both technicians and management and to be able to compare their views.

Oppenheim (1992) noted that a pilot study should be able to highlight the need for additional refinement. Therefore, questionnaires need to be tested and developed in advance, to ensure that they achieve their intended purposes. He identifies some of the benefits of retrying the questionnaires before final distribution as:

1. Getting help with wording.
2. And the design of the letter of introduction.
3. Checking the most appropriate order of question sequence.
4. Reduction of non-response rate.

Accordingly a group of five managers and five employees was selected to review the set of questionnaires at an early stage in August 1998, for the purpose of gathering comment checking readability and ease of understanding of the questionnaires (De Vaus, 1991) states that in order to provide the most realistic simulation of the administration of the survey, the interviewers need to examine different experience of those involved in answering the questionnaire.

This pilot study actually achieved its goals of providing an early feedback on whether to add further questions or not; or whether slight modifications were needed to the questionnaires. In the managers' pre-test feedback, they suggested adding three extra variables to question fourteen, which asked the managers to rank the factors which they believed to have an effect on managers' productivity. These additions were *Shortages of manpower*, *Shortages of ground support equipment* and *Inappropriate ground support equipments.* These three variables were added to both manager and employee questionnaires. Furthermore, the purpose of conducting the questionnaires was also explained to both the managers and the employees during the implementation of the pilot test. Consequently, in light of the feedback from the pilot test, minor changes were carried out.

Furthermore, some minor changes were made to the manager questionnaires relating to the open-ended questions, in relation to their sequence in the questionnaire. The managers thought that they were better moved to the end of the questionnaire, because this would help increase the response rate. Moreover, the managers wished to add ideas about the following: whether shift changes and their effect on the employees and what was their preference with regards to shift change, the pattern of shift change, preference of permanent shift and finally the time variation to the next shift change. Therefore, they suggested adding five extra questions to answer these issues. The final version of the questionnaires is presented in Appendix.A.

4.1 DATA COLLECTION

In collecting the data, the researcher then made an effort to contact each designated department and unit manager for the purpose of explaining the main objective of the questionnaires; to further co-ordinate with them to arrange a time for distributing the questionnaires; to agree on a person in each unit or departments to act as a point of contact; and to further assess with any problems that might arise. Consequently, each department manager gave special attention whenever possible to orchestrate the distribution of the questionnaires. This was inline with the recognised author of Oppenheim (1992) who states that self-administrated questionnaires should either be introduced to the respondent directly by the interviewer or by some one with an official position in the organisations. Oppenheim suggested that this method of data collection ensure the following:

1. Ensures a high response rate.
2. Accurate sampling and a minimum of interviewer bias.
3. Provides necessary explanations.
4. Gives the benefit of a degree of personal contact.

The researcher travelled to Saudi Arabia during the first stage of distribution of the questionnaires. In addition, a list of all the names, titles and telephone numbers of the designated department and unit managers was obtained, in order to assist in making necessary contact for follow up and organising the data collection procedures. During the researcher's visit to Saudi Arabia for the purpose of collecting data he met each department's managers and senior supervisors and discussed with them the best way of distributing the questionnaires. Eventually, this involved an organised visit to each department and unit for this particular reason.

At the three locations Shop, Hangar and Line maintenance, the researcher administered the distribution of the questionnaires to the staff of the three departments. This was carried out to assess any problems which the employees might have during the completing of the questionnaires, though there were no major issues raised by the employees other than reassurance as to the purpose of the questionnaires. At this point relevant information were gathered which was thought might be helpful later on in the analysis stage as it might help in interpreting the results. This included maintenance department manuals and how they are being handled. This was helpful in highlighting areas related to the daily standards in the maintenance to explore whether manual usage's are always being implemented in the workplace or not. And to examine the effect of this issue and if it could possibly be one of the causes of poor performance. To further improve his understanding the researcher attempted to analyse all comments made by either the managers or the employee in the questionnaires; they were also discussed further with the managers after conducting the analysis. Nachmias and Nachmias (1996) noted that in collecting the data the practitioner may wish to act as a participant observer. The researcher administered the questionnaires to ensure that proper procedures were followed.

4.2 ACCESSIBILITY OF DATA

This section presents detailed information on how the fieldwork was carried out and the different activities that were performed during the fieldwork. The researcher was granted access to the facilities of Saudi Airlines' Maintenance departments including the locations of the Shop, Hangar and Line in order to carry out the distribution of the questionnaires. In order to gain access for data collection, the researcher first contacted the general manager of Maintenance Planning and Control, for the purpose of arranging the distribution of questionnaire; to further obtain permission to conduct the research questionnaire in the designated departments, which included the Hangar, Shop and Line. This step was necessary for the researcher to gain the support of maintenance management and assistance in distributing the questionnaires. This proved to be helpful later on in the process of distributing and collecting the questionnaires. Moreover, the researcher was handed the different organisation structures for the designated departments, to ease the process of understanding the different managerial levels, and to enable him to contact the appropriate department manager. Since the researcher is a member of the organisation, gaining access to the facilities posed no problems. Nachmias and Nachmias (1996) states that it is beneficial to choose a site, which is easily accessible, where the researcher has an influential contacts or is a member. Once the data collection was completed SPSS for windows 8.0 was utilised as a tool for storing and analysing the questionnaire response.

4.3 DESIGN OF THE QUESTIONNAIRES

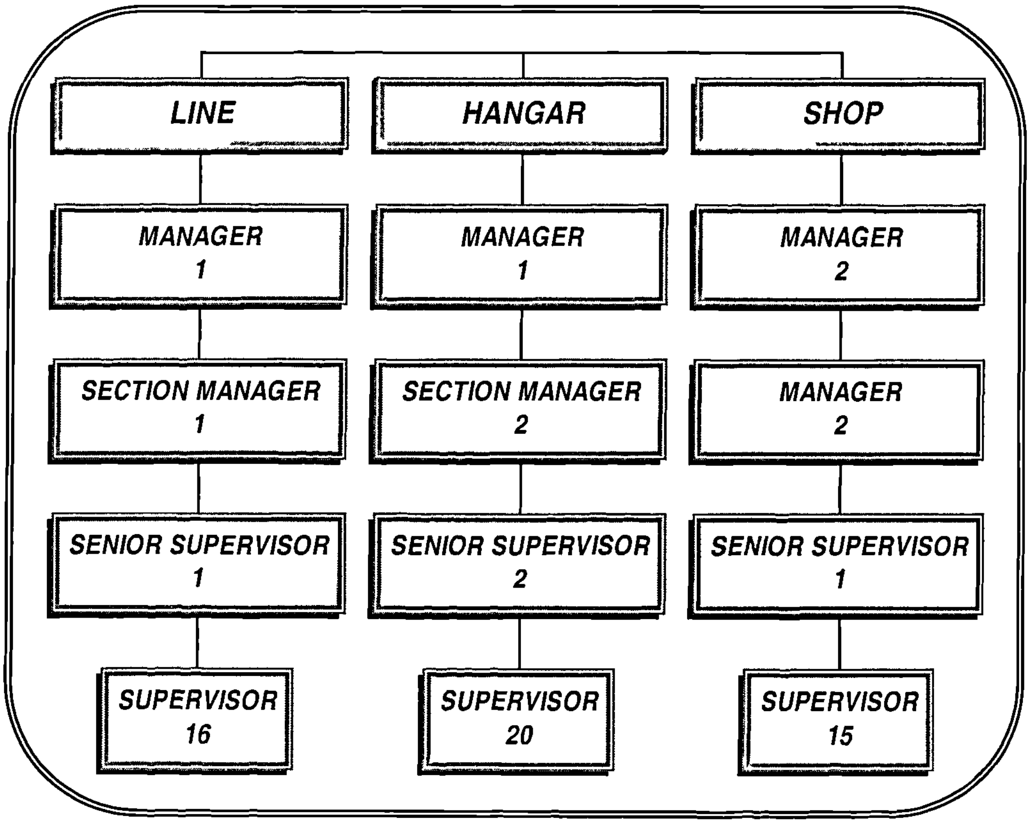
This section will focus on the design of the managers and the employee's questionnaires. Oppenheim (1992) notes that an appropriate research design is needed in order for the analyst to come to an appropriate finding. This can be achieved in term of frequency or about the relationship. However, the author defines research design as the basic plan or strategy for the researcher, and its logic to draw conclusions from it.

4.3.1 Design Of Manager Questionnaires

The manager questionnaires were designed for managers in the Hangar, Shop and Line Figure 4.1 shows the number of managers responded at each level.
The managers' questionnaires carried a clear instruction to the respondent, which enabled the respondent to provide an extra comment, this had been achieved through the designated blocks after a specified questions for extra comment, a five point likert-scale was used for the questions asked. The managers' questionnaires adopted both open and close-ended types of questions. According to Oppenheim (1992) and Nachmias and Nachmias(1996) the main advantages of open-ended questionnaires are that:

They allow the respondent the freedom to answer the questions in their own way. The disadvantages include the fact that using such questionnaires is time-consuming, as coding is considered to be very slow process. Especially with a large number of respondents and therefore, demands more efforts from the researcher.

Figure 4.1 Number At Each Of The Different Managerial Levels That Responded To The Questionnaires In The Three Different Department



As for the closed-ended questions their advantages are that:

1. They require little time.
2. Low cost.
3. And easy to process.

One of the main disadvantages is the loss of the spontaneous response and potential bias in answer categories, due to the order of the questions for example.

Multiple-choice questions were used to allow the managers or the technicians to select the answer that best matched the situation. The manager questionnaires sought to determine manager perceptions with regards to issues such as productivity measurement in the workplace. In addition, the manager questionnaire were also designed in a way to categorise respondent based on the department that they work in, number of years spent in the company, years spent on present job and years spent on similar job.

The broad question areas that was covered in the survey included: communication in the workplace, training related issues, issues that affect employee performance and finally technicians views with regard to performance and efficiency. In addition, both employees and managers were asked to rank the effect of several factors which are believed to have an influence of the performance and productivity of the work, these will be discussed in greater detail in Chapter Five.

The process of coding of open ended question was given a great attention and considerable time was given to insure appropriate coding. This was done to achieve the consistency and reliability needed in the analysis. De Vaus (1991) Nachmias and Nachmias (1996) and Oppenheim (1992) agree that the first step in coding should be examining the sample of responses, and reviewing them to formulate a set of selected answers, which covers the entire set of responses. In addition, code categories can be combined; this step may be needed when dealing with small sub-analyses. This step is called transforming or recoding the variables Parasuraman (1991:624) states that new variables may need to be constructed from the raw variables. He describes recoded variables as "A variable that is created by combining or modifying data on one or more raw variables." (p.264)

4.3.2 Design Of Employee Questionnaires

The employee questionnaire followed a similar format to the manager questionnaire, except that it did not include a separate section for open-ended questions. This was because it was felt to be difficult to require the employees to spend a long time answering the open-ended questions. Instead, enough space was provided for employee's comment with regard to the close questions. Moreover, they also informed that they could use the back of the page if extra spacing was needed if they desired to give them. This act enabled the employees to be able to add their comment, if they felt that it was necessary.

Another difference from the manager questionnaire, was in question twenty, where the employees were asked to rank the three most important factors which were thought by them to have an effect on their performance on the job. This was done to identify the three most important factors, so that managers' attention can be focused on these three factors. The employee questionnaires were also designed to determine employee perceptions with regards to issues such as performance, efficiency and productivity measurement in the workplace.

In addition, managers and employees were divided into two groups according to the years spent in the company, ten years or less and over ten years.

Moreover, the extra spacing provided in the closed-ended questions were gathered, coded and analysed using SPSS for Windows 8.0. The coding process also, included the analysis of the open-ended questions of all managers responded to the questionnaire.

4.4 RESPONSE RATE

Saudi Airlines maintenance departments headquarter for the Hangar and the Shop are located at in Jeddah. Other main stations such as Riyadh, Dhahran and Dammam do not include major overhaul facilities, yet they provide Line support for Saudi Airlines fleet as was mentioned in chapter two. In addition, other stations include small number of ground maintenance staff to support Line activities if needed. Therefore, the decision was made by the researcher to conduct the distribution of questionnaire at Jeddah the headquarters, where all three major departments are available.

Great attention was given by each department manager to ensuring a high response rate for the questionnaires and to ensure that they were completed and returned by the specified time. Every effort is made to have the employee fill in the questionnaires, as the majority of the technicians were busy working on the fleet.

A total of four hundred questionnaires were distributed to the technicians in the Hangar, Shop and Line. Table 4.1 shows the response rate for employees in each department.

Table 4.1 Employees Distribution Sample

DEPARTMENT	NUMBER OF QUESTIONNAIRES DISTRIBUTED	NUMBER OF RETURNED QUESTIONNAIRES	RESPONSE RATE
HANGAR	134	87	64.9%
SHOP	133	111	83.4%
LINE	133	76	57.1%
TOTAL	**400**	**274**	**68.5%**

Fewer responses were received from the employee in the Line because, it was a little difficult to get them to fill in the survey questionnaires, as they were very busy servicing the fleet. The same comment applies to the slightly better response from the employees in the Hangar as they were also working on long major projects. A better response rate was obtained from the technicians in the Shop, as the locations of the Shop are close to each others, and the nature of their job does not requires them to be at different location such as the Line for example. The total employee response rate was 68.5%.

The second questionnaire was distributed to the managers in the three different departments Hangar, Shop and Line. These questionnaires were designed for department managers, section managers, senior supervisors and supervisors. Table 5.2 shows the response rate for the managers in each department.

Table 4.2 Managers Distribution Sample

DEPARTMENT	NUMBER OF QUESTIONNAIRES DISTRIBUTED	NUMBER OF RETURNED QUESTIONNAIRES	RESPONSE RATE
HANGAR	34	25	73.5%
SHOP	33	21	63.6%
LINE	33	19	57.6%
TOTAL	**100**	**65**	**65%**

The total manager response rate was 65%. In both the managers and employees questionnaires, a reminder telephone call was made to ensure completion of questionnaires on time. Due to the nature of the work in the maintenance department an extension of three weeks beyond the six weeks originally allowed was needed to allow enough time for the employees to complete the questionnaires.

CHAPTER FIVE

SURVEY DATA ANALYSIS

CHAPTER FIVE

SURVEY DATA ANALYSIS

5.0 INTRODUCTION

This chapter analyses the results of the employee and manager surveys. As described in Chapter Four (Table 4.1 and 4.2) 274 employee questionnaires and 65 manager's questionnaires were received. The employee questions will be analysed first including the comment that was noted down by them, followed by the manager's questions. Continuing comparisons are then undertaken between the responses to the employee and managers' survey.

The purpose of the survey was to identify issues relating to the efficiency and productivity levels of the work carried out, and to investigate some specific factors which could cause the efficiency and productivity of the Aircraft Maintenance Technicians to decline. The list of the questionnaire were prepared by the researcher, and they were generated from observation and previous work experience in the field. The reason behind asking the technicians some questions relating to efficiency in the workplace, as was mentioned in Chapter Three, that greater efficiency could be brought out by working more efficient. In addition, as was mentioned in Chapter Three that one reason to measure efficiency is to compare our output to other competitors in the same business, in order to highlight areas of concern which needs attention, and to illustrates areas of strength in which management need to maintain. The analysis that was carried out will investigate whether there were significant differences in views between the technicians in each of the three different maintenance department Shop, Hangar and Line and between the technicians and the managers as well. The *Chi-square* test was carried out for the purpose of identifying the significant differences between the managers and the technicians if there are any. A *Factor Analysis* test was carried out to investigate the ten factors, which are believed by managers and technicians to affect performance.

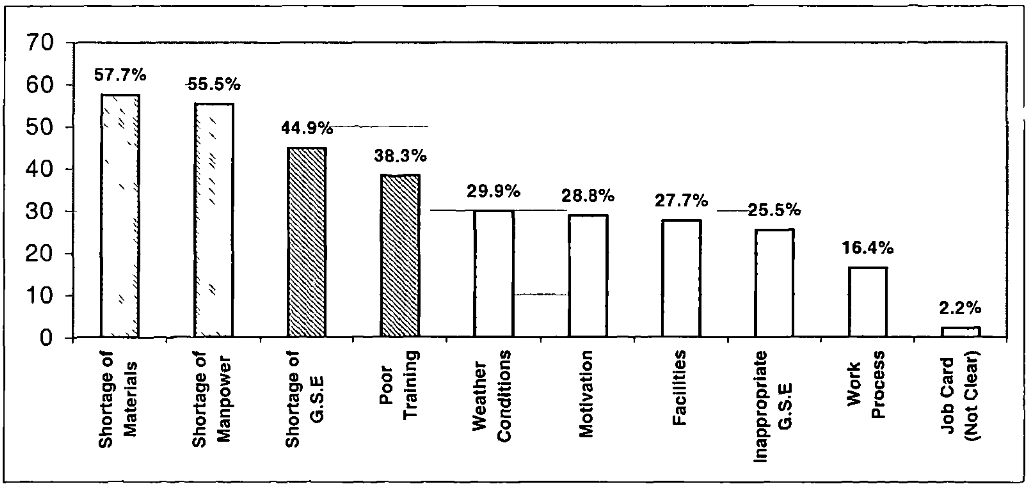
5.1 ANALYSIS OF FACTORS AFFECTING PERFORMANCE

This section examines the effect of ten factors, which were asked by the researcher. In addition, manager's view towards the sixteen different factors is examined.

5.1.1 Analysis Of Factors Effecting Employee Performance

As was mentioned in Chapter Four a list of ten problems that could affect employees' performance was prepared for the employees and they were asked to rank the three problems that could affect their performance the most. Figure 5.1 shows the ten factors examined. The result showed that *shortages of materials* (57.7%) was ranked to be the most important problem affecting employees' performance, followed closely by *shortages of manpower* (55.5%), and then *shortages of ground support equipment (G.S.E)* (44.9%).

Figure 5.1 Observed Percentage Of The Problems That Employees Agreed Affected Their Performance



More detailed analysis of which department suffers the most from these problems will be discussed later in the chapter when discussing the different comments made by the employees. Shortages of Materials and Shortages of Manpower would appear to prevent employees from achieving higher levels of performance. This suggests that if management wishes to improve efficiency and performance levels, they need to pay great attention to these two factors. Furthermore, both of these factors could have an effect on the safety and the effectiveness of the work.

Other factors that the employees ranked as having an indirect effect on performance included shortages of ground support equipment (44.9%), followed by poor training (38.3%). The implication of *poor training* for work performance is that it could affect the reliability of the work conducted by a poorly trained technician, given employees said that poor training contributes to lower performance levels. The direct impact of *shortages of ground support equipment* is, lower quality of the work performed, since lack of ground support equipment can in some cases prevent the technicians from conducting a specific inspection, e.g. if a technician is instructed to inspect the vertical stabiliser of an aircraft, he needs the right set of stands to carry out the task.

The following four factors: weather conditions, motivation, facility and inappropriate ground support equipment, were selected by the researcher conducting the survey to assess their effect on maintenance performance. The observed frequency for *weather conditions* was (29.9%), yet, for this airline it can be a severe problem during the summer time especially in closed areas such as the Hangar and the Shop. Employees can suffer from the hot weather, and for that reason they may not be able to achieve the level of work expected from them. *Motivation* (28.8%) was ranked by employees to have a smaller effect on their performance than other factors in the list.

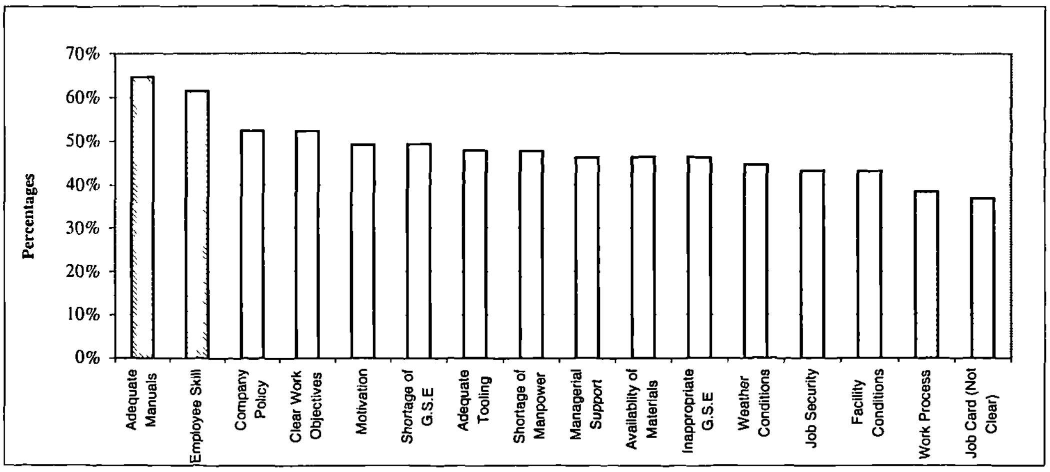
This issue will be discussed further in the employees' comments. *Facility* (27.7%) was ranked as the seventh factor out of ten to effect employees' performance, this factor could be linked to the weather conditions as many employees in their comment mentioned poor ventilation and air-conditioning systems in the facility in which they work. *Inappropriate ground support equipment* was mentioned by (25.5%) of the employees as having an effect on their performance. More detailed analysis will be provided in the section on employees' comments.

5.1.2 Analysis Of Factors Believed By Managers To Affect Performance

A list of the sixteen problems were selected by the researcher were presented to maintenance managers to get their view on productivity and these will be discussed in further details. The sixteen problems were divided into three groups on the basis of visible break points in Figure 5.2. The first group was noted by between 100-60% of the respondents the second group by 55-40% of the respondents, and group three by 0-39% of the respondents. The purpose of this division is to make it easier to discuss these problems in groups according to their importance. The two most important items selected by the majority of the managers as affecting work productivity were *inadequate manuals* 64.60%, followed by *employees' skills* with 61.50%. As was mentioned earlier in Chapter Two the effect of not having an adequate manual could be crucial to the safety of the aircraft, as manufacturers often change manuals in significant ways.

Employee skill was ranked by managers to be the second most important factor affecting work productivity. Skilled personnel who are able to perform the job quickly and safely play an important role in improving the work productivity as viewed by the managers, whether they are in the Line, Shop or Hangar. Also, managers can rely on skilled personnel to achieve high on time performance. A majority of the managers (52.30%) identified *company policy* (which deals with day to day activities) as having an effect on work productivity. 52.30% of the managers noted the effect of *lack of clear work objectives* on work productivity on the level of performance. This suggests that the objectives of a great deal of the work accomplished are not very clear since almost half of the managers agreed on the importance of this issue. Later in the analysis both managers' and technicians' views with regards to the problems believed to effect technician performance are compared and analysed. The next section will examine differences between the three different departments using the Chi-square test.

Figure 5.2 Observed Percentage Of The Problems That Was Agreed By Managers To Effect Work Productivity



5.2 chi-square TEST

This section examine differences in views between the three different groups Line, Shop and Hangar for both the employees and the managers, therefore, only questions, which showed a statistically significant difference on the x^2 test, will be discussed. The interpretation is based on standard residual. The expected values are calculated, the significance of the expected values is to show that the row and the column are independent of each other or that there is no relationship between them, in addition, the significance of the expected values of 5 or less is to determine the discrepancies between the observed frequencies and the one that we expect are due to chance. The expected values are calculated as follows (multiplying the total of the row to which it belongs by the total of the column to which it belongs and then dividing by the grand total for the whole table).

5.2.1 Employee Chi-square Tests

- ***Do you think the workload assigned in each shift is fair?***

There was a highly significant difference (.000) in the views of the personnel in the three different departments with regards to the allocation of workload assigned in each shift, see Table 5.1.

Both personnel in the Line and the Hangar stated that the workload assigned in each shift is unfair or unevenly divided, while the personnel in the Shop were neutral. A possible reason for the employees at the Hangar and the Line stating that the workload assigned in each shift is not fair, is because of the nature of the work in these two departments.

Table 5.1 Do You Think The Workload Assigned In Each Shift Is Fair?

		department			
		LINE	HANGAR	SHOP	Total
VERY UNFAIR	Count	24	28	13	65
	Expected Count	17.9	20.8	26.3	65.0
UNFAIR	Count	21	12	19	52
	Expected Count	14.3	16.6	21.0	52.0
AVERAGE	Count	18	17	37	72
	Expected Count	19.9	23.0	29.1	72.0
FAIR	Count	11	17	25	53
	Expected Count	14.6	17.0	21.4	53.0
VERY FAIR	Count	1	13	16	30
	Expected Count	8.3	9.6	12.1	30.0
Total	Count	75	87	110	272
	Expected Count	75.0	87.0	110.0	272.0

Pearson Chi-Square 0.000
0 Cells (.0%) have expected counts less than 5. The minimum expected count is 8.27

As was described in Chapter Two employees in the Hangar which operates a twenty four hour three shift system, have to deal with large projects that involve a major repair and major check that can sometimes last for two to three weeks, or even longer. As was noted in Chapter Two this could be for the reason of conducting a C-Check. Additionally, employees in the Hangar may also have to undertake extra work that is discovered during inspection, which was not originally scheduled. This could be complying with mandatory manufacturer recommendation, which could be involving a major modification sometimes. In addition, the employees in the Hangar have deadlines to comply with in order to get the aircraft back to service. This means that the personnel in the Hangar are driven by the need for compliance with the planned schedule as well as non-scheduled work. These factors could contribute to the fact that the Hangar personnel thought that workload assigned in each shift is not fair or not evenly distributed. Since many employees in the Hangar said workload is not fairly distributed, this could suggest that unscheduled repairs or modifications are a cause of a significant burden.

One technique used to even out the pressure of the work is *scheduled maintenance*, which is mainly intended to balance the workload assigned in the Hangar over an interval. Since many technicians in the Hangar said the work is not fairly distributed, this could suggest that a significant proportion of their work consists of unscheduled repairs or modifications.

A possible reason that thirty-two percent of the employees in the Line said that the workload assigned in each shift is not fair, is because of the characteristics of the flight schedule during the twenty-four hours. As discussed in Chapter Two, there are three different shifts in the Line to allow a continuous flight service around the clock. Most flights are dispatched during the early morning, and this puts more pressure on the employees working on the morning shift which runs from 07:30 until 15:30 in the afternoon and the mid day shift that runs from at 15:30 in the afternoon until 23:30 at night, while the midnight shift which starts from 23:30 at night until 07:30 in the morning the next day, tends to have less flights. Some international flights arrive at the midnight shift, these may have experienced delays for some reason, and have arrived late. These late arriving international flights are fitted into the schedule for servicing and repairs so that they will be ready for the next morning flight in order not to have the aircraft grounded for longer time. The implication for the Line maintenance technicians is that the workload may not be distributed evenly due to out of schedule arrivals as mentioned above, and therefore these late arrivals may be completed along with other maintenance tasks which may have a higher priority.

Furthermore, the employees in the Line sometimes have less than forty-five minutes turn-around time for some domestic flights, which requires a prompt service in order to release the aircraft to achieve the on-time performance target. In addition, employees in the Line have to carry out routine daily and weekly checks on the aircraft. These usually take place during the midnight shift while the aircraft are on the ground, because these checks require four technicians, two avionics personnel, and an additional six technicians for interior maintenance. If the manpower required to carry out these tests is not fully available, it could affect the quality and the performance of the technicians carrying out the work. As was seen earlier shortages of manpower were ranked as one of the highest problems that contribute to poor performance as mentioned by employees. The relationship to work distribution is that in the process of planning the maintenance task, planner needs to take the two issues workload distribution and the availability of manpower into consideration when planning for a maintenance task.

Many employees in the Shop thought the workload was similar across the two shifts. A possible reason for this is because of the nature of the work being accomplished in the Shop as described in Chapter Two. Aircraft parts, which have been taken off the aircraft for service or overhaul, are usually replaced immediately with other serviceable parts that are either new or overhauled. In most cases, aircraft engine accessories or avionics equipments and other spare parts are available at all times. Most parts on the aircraft whether avionics parts or mechanical parts tend to have a lifetime that can be measured by flight hours or measured by cycles (the number of times the aircraft engine is started). Therefore, aircraft parts are monitored regularly and when necessary they are removed from the aircraft for repair, overhaul and testing or scrapped if they are not repairable. The implication for the Shop manager is that when the cycles of flight hours limits are reached, this means that the Shop manager should be prepared to service these parts in order to have them ready for service the next time they are needed or to scrap them if they cannot be serviced.

To further investigate the differences in views on whether the workload was fair or not, an analysis based on the number of years that the employees spent in the company was carried out. This revealed that there was a significant difference (.033) in the views of the personnel based on the number of years spent in the company, see Table 6.2. The result shows that a higher proportion than expected of employees who spent ten years or less in the company thought that the workload assigned to each shift was very unfair, while a lower proportion than expected of employees who have spent more than ten years in the company said that it was very unfair or fair.

Table 5.2 Do You Think The Workload Assigned In Each Shift Is Fair? Classified by Years Spent In The Company

		YEARS IN COMPANY		
		TEN YEARS OR LESS	OVER TEN YEARS	Total
VERY UNFAIR	Count	36	29	65
	Expected Count	26.8	38.2	65.0
UNFAIR	Count	24	28	52
	Expected Count	21.4	30.6	52.0
AVERAGE	Count	26	46	72
	Expected Count	29.6	42.4	72.0
FAIR	Count	18	35	53
	Expected Count	21.8	31.2	53.0
VERY FAIR	Count	8	22	30
	Expected Count	12.4	17.6	30.0
Total	Count	112	160	272
	Expected Count	112.0	160.0	272.0

Pearson Chi-Square .033
0 cells (.0%) have expected count less than 5. The minimum expected count is 12.35.

Possibles reasons for this result could be:

1. Employees who have spent ten years or less may not be fully familiar with the nature of the work being accomplished in their department, when compared to the other group of more than ten years of experience.
2. Level of expertise is different, as the employees who have spent over ten years tend to take less time in carrying out a certain task, as personnel become expert on the aircraft system over time.
3. The advantages of personal friendship in the work place may allow the employees who have spent over ten years to select certain tasks that require less time and effort. This is to some extent confirmed by the employee's comments which mentioned unfairness between the different staff.

- ***Do you think you can increase your performance through extra manpower?***

There was a highly significant difference (.000) in the views of the personnel in the three different departments with regard to increasing their performance through extra manpower, see Table 5.3.

The analysis shows that a higher proportion of individuals than expected in the Line and the Hangar felt that they could increase their performance with extra manpower, whereas the converse was true for those in the Shop. As was discussed in Chapter Two the characteristics of the work in the three different departments differ. A possible reason for the Line staff complaining about shortages of manpower is that the Line essentially represents a queuing system with a single service team for each major aircraft type. Such systems are notorious for generating schedule-disrupting queues, unless the utilization of the Line team is low which usually means assigning an additional team.

The Hangar staff complained about shortages of manpower, this is because the nature of the maintenance tasks carried out in the Hangar requires that maintenance task should be carried out by groups of technicians as opposed to the Line maintenance task which could be easily in most cases accomplished by one technician.

As for the technicians in the Shop the result shows that a higher proportion of individuals than expected said that they absolutely do not agree that increasing manpower will increases their performance, while a lower proportion than expected of the technicians in the Shop said that they absolutely agree that they can increase their performance through extra manpower.

Table 5.3 Do You Think That You Can Increase Your Performance Through Extra Manpower?

		department			
		LINE	HANGAR	SHOP	Total
ABSOLUTELY UNTRUE	Count	0	8	26	34
	Expected Count	9.4	10.8	13.8	34.0
UNFAIR	Count	3	1	11	15
	Expected Count	4.2	4.8	6.1	15.0
AVERAGE	Count	4	5	16	25
	Expected Count	6.9	7.9	10.1	25.0
FAIR	Count	14	13	22	49
	Expected Count	13.6	15.6	19.9	49.0
ABSOLUTELY TRUE	Count	55	60	36	151
	Expected Count	41.9	47.9	61.2	151.0
Total	Count	76	87	111	274
	Expected Count	76.0	87.0	111.0	274.0

Pearson Chi-Square 0.033
0 Cells (.0%) have expected count less than 5. The minimum expected count is 12.35.

As for the staff in the Shop they had the least percentage complaining about shortages of manpower. The manpower allocation problem is not a major one in the Shop compared to the Line or the Hangar. In addition as explained in Chapter Two, jobs carried out in the Shop do not take a long as those carried out in the Hangar. It may also reflect the fact that the Shop has only two shifts which allows overtime to be worked at peak times unlike the Line or the Hangar which have three shifts.

- ***Do You Think You Can Increase Your Performance Through Job Rotation?***

There was a significant difference (.028) in the views of personnel in the three different departments about the possibility of increasing their performance through job rotation, see Table 5.4. The analysis shows a higher proportion of individuals than expected of the technicians in the Hangar have expressed their views that they do not think that they can increase their performance through job rotation. This is possibly due to the nature of the work carried out in the Hangar, which is based solely on specialisation, and therefore, it is difficult to move from the Hangar to another maintenance unit without having the prior knowledge and experience to assess in any maintenance problems that they could face. Although a technician may have the required specialty on a particular engine, he may not be qualified to work on other types of engines. This is also because of the nature of airline maintenance operations, which requires the technician to be qualified before working on any maintenance task given to him. In order for a technician to be able to work in a different area other than his specialised one then he would be required to go through several training courses and have to pass different examinations in order to be certified to work on a different types of aircraft system. This can be difficult sometimes especially for the employees in the Hangar, since an aircraft system such as the hydraulic system for example, requires a lot of knowledge and experience in order to be fully understood, and to be able to troubleshoot the system in case it fails. In short, a long time is needed for the technician to acquire a good knowledge of other specialised maintenance work. The employees in the Line stated the same thing as the employees in the Hangar, since specialisation in the Line also exists as the airline tends to have different types of aircraft. Of the staff in the Shop there were a higher proportion of technicians than expected who were neutral, this may possibly indicate that the employees in Shop do not think that job rotation could increase their performance, and this could be related to the shift work which only comprises of two shifts.

Table 5.4 Do You Think You Can Increase Your Performance Through Job Rotation?

		department			
		LINE	HANGAR	SHOP	Total
ABSOLUTELY UNTRUE	Count	14	9	19	42
	Expected Count	11.6	13.3	17.0	42.0
UNTRUE	Count	13	10	9	32
	Expected Count	8.9	10.2	13.0	32.0
NEUTRAL	Count	13	14	33	60
	Expected Count	16.6	19.1	24.3	60.0
TRUE	Count	20	20	25	65
	Expected Count	18.0	20.6	26.3	65.0
ABSOLUTELY TRUE	Count	16	34	25	75
	Expected Count	20.8	23.8	30.4	75.0
Total	Count	76	87	111	274
	Expected Count	76.0	87.0	111.0	274.0

Pearson Chi-Square 0.028
0 Cells (.0%) have expected count less than 5. The minimum expected count is 8.88

- *How Do You Rate The Department's Performance?*

There was a highly significant difference (.001) in the views of the personnel in the three different departments in regard to rating their department's performance, see Table 5.5. The results indicate that a higher proportion than expected of the employees in the Line rated their department performance to be very much less than it could be, while the opposite was true for the Hangar and the actual figures for the Shop were close to the expected values. The responses of the Line employees to these questions may possibly reflect that they think that there is room for improvement. The analysis of the employee's comments later on will cast further light on this issue. For the personnel in the Hangar there were a fewer personnel than expected of the technicians in the Hangar rated their department performance to be very much less than it could be. There was a higher proportion of individuals than expected of the personnel in the Shop who thought that their department performance was good. This is possibly because they have fewer complaints about manpower shortages and have no problems with the allocation of workload during the different shifts. This may also be contributed to by the fact that the Shop technicians have only two shifts, which makes them more relaxed in terms of shift change process. Moreover, the environment that the Shop technicians work in is considered to be better in comparison to the Line staff for example.

Table 5.5 Employees' Views On Their Department's Performance

		department			
		LINE	HANGAR	SHOP	Total
VERY MUCH LESS THAN IT COULD BE	Count	26	9	21	56
	Expected Count	15.6	17.8	22.6	56.0
LESS	Count	9	8	12	29
	Expected Count	8.1	9.2	11.7	29.0
NEUTRAL	Count	21	32	26	79
	Expected Count	22.0	25.2	31.8	79.0
GOOD	Count	10	21	40	71
	Expected Count	19.8	22.6	28.6	71.0
AS GOOD AS IT POSSIBLY COULD BE	Count	10	17	11	38
	Expected Count	10.6	12.1	15.3	38.0
Total	Count	76	87	110	273
	Expected Count	76.0	87.0	110.0	273.0

Pearson Chi-Square .001
0 Cells (.0%) have expected count less than 5. The minimum expected count is 8.07.

- ***Was performance level explained or mentioned in any of the training programmes that you had before starting the job?***

There was a highly significant difference (.002) in the views of the personnel in the three different departments on whether performance levels were explained or mentioned in any of the training programme that they had before starting their job, see Table 5.6.

Table 5.6 Was performance level explained or mentioned in any of the training programme that you had before starting the job?

		department			
		LINE	HANGAR	SHOP	Total
YES	Count	20	14	44	78
	Expected Count	21.5	24.4	32.0	78.0
NO	Count	54	70	66	190
	Expected Count	52.5	59.6	78.0	190.0
Total	Count	74	84	110	268
	Expected Count	74.0	84.0	110.0	268.0

Pearson Chi-Square .002
0 Cells (.0%) have expected count less than 5. The minimum expected count is 21.54.

Overall more technicians said no that performance levels were not explained in any of the training programmes that they had before starting their job. The technicians in the Line were in line with the expected number, while in the Hangar there were fewer than expected who said yes. The Shop responses were opposite to the Hangar as there were a high proportion of technicians than expected who said yes.

Management in all three maintenance departments would need to consider reviewing the training policies in order to make a greater emphasis on what levels of performance would be expected from the technicians. In this way the technicians would have an idea on the performance levels that they should achieve.

- ***Do you feel the need to establish a special information for information programme to explain what efficiency and performance are?***

There was a highly significant difference (.000) in the views of personnel in the three different departments on the need to establish a special information programme to explain what efficiency and performance are, see Table 5.7.

Table 5.7 Do You Feel the Need to establish a special information for Information Programme to explain what efficiency and performance are?

		department			
		LINE	HANGAR	SHOP	Total
ABSOLUTELY UNTRUE	Count	37	3	5	45
	Expected Count	12.5	14.3	18.2	45.0
UNTRUE	Count	7	6	3	16
	Expected Count	4.4	5.1	6.5	16.0
NEUTRAL	Count	5	10	7	22
	Expected Count	6.1	7.0	8.9	22.0
TRUE	Count	13	16	26	55
	Expected Count	15.3	17.5	22.2	55.0
ABSOLUTELY TRUE	Count	13	51	68	132
	Expected Count	36.7	42.0	53.3	132.0
Total	Count	75	86	109	270
	Expected Count	75.0	86.0	109.0	270.0

Pearson Chi-Square .000
1 Cell(6.7%) have expected count less than5. The minimum expected count is 4.44.

The analysis shows that a higher proportion of individuals than expected of the employees in the Line said that there is absolutely no need for this kind of programme. This probably could indicate that they might not be interested in such a programme or that they felt that there are more important issues that management should tackle first. The analysis of the employees' comments includes more detail with regard to the issues that concern the employees in the Line the most. The personnel in the Line may seem to be uninterested because they are either know what efficiency and performance are, or they do not think it would make a great difference in improving their job, as there might be more important issues that should be addressed first by management other than introducing the efficiency and performance information programme.

As for the employees in the Hangar and the Shop there was a low proportion of individuals who said that there was absolutely no need for this kind of programme. This might indicate that they think that there is still some room for improvement and one way to achieve this could be through this kind of information programme about efficiency and performance in the work place.

- ***Do you expect Management to accept your suggestions?***

There was a highly significant difference (.001) in the views of personnel in the three different departments in regard to expecting management to accept their suggestions, see Table 5.8.

Overall, more technicians said no than yes. However, there is a lower proportion of individuals than expected in the Line who said yes that they expect management to accept their suggestions. This suggests that a large majority of the technicians in the Line (80.8%) did not think that management would accept their suggestions.

As for the Hangar there was less than expected number of individuals in the Hangar who said yes to the same statement. Both the Line and the Hangar technicians felt that management does not accept their suggestions, this may be due to the stress levels at these two department generated by the nature of their work.

A high proportion of the technicians in the Shop thought that management would accept their suggestions, compared to the Line and the Hangar. This suggests that there may be a better level of communication between the managers and technicians in the Shop, perhaps due to the nature of the jobs carried out in the Shop. For example, the technicians in the Shop only work a two shift system unlike the Hangar and the Line technicians have to work a three-shift system. The implication of this system is that the technicians in the Shop experience less stress than both the Hangar and the Line technicians, all these combined have a direct relationship to stress levels in the job.

Since the majority of the personnel in the three different departments stated that they do not expect management to accept their suggestions, this suggests that communication between management and personnel in the three different departments could be improved. Lack of communication is likely to lead to poor performance by technicians as they may think that management does not like to share ideas with them on how to carry out the job particularly in respect of introducing new productivity measurement systems.

Table 5.8 Employees Views On Whether Management Accepts Their Suggestions

		department			Total
		LINE	HANGAR	SHOP	
YES	Count	14	23	47	84
	Expected Count	22.8	27.2	34.0	84.0
NO	Count	59	64	62	185
	Expected Count	50.2	59.8	75.0	185.0
Total	Count	73	87	109	269
	Expected Count	73.0	87.0	109.0	269.0

Pearson Chi-Square .001
0 Cells (.0%) have expected count less than 5. The minimum expected count is 22.80.

The implication of such result like that may render any performance measurement system to fail, as there is a poor communication level between technicians and management. As was mentioned in Chapter Three there are certain factors that cause the staff to perform their job in a way, which is not the natural sequence of the job. In addition, any performance measurement programme that needs to be introduced into the maintenance department should have the technicians as a main part of it. So that technicians could provide their own views on the new proposed measurement system and could possibly suggest how management could better introduce such a system to the maintenance department. Communication between management and technicians is considered to be an important element of management success in implementing any performance measurement systems.

- ***Do you think the term performance was defined in any training courses that you had before starting your job?***

There was a highly significant difference (.005) in the views of the personnel in the three different departments on whether the term performance was defined in any training courses that they had before starting the job, see Table 5.9.

Table 5.9 Do You Think The Term Performance Was Defined In Any Training Courses That You Had Before Starting Your Job?

		department			
		LINE	HANGAR	SHOP	Total
YES	Count	21	20	48	89
	Expected Count	25.0	28.2	35.8	89.0
NO	Count	55	66	61	182
	Expected Count	51.0	57.8	73.2	182.0
Total	Count	76	86	109	271
	Expected Count	76.0	86.0	109.0	271.0

Pearson Chi-Square .005

0 Cells (.0%) have expected count less than 5. The minimum expected count is 24.96.

The overall result shows that the majority of the personnel in the three different departments said no. However, there was a lower proportion than expected in the individuals in both the Line and the Hangar who said yes. This suggests that the technicians in both the Line and Hangar think that there is still a room for improvements with regards to that issue.

For the employees in the Shop there is a higher proportion of individuals than expected of the employees in the Shop who said yes. This may possibly suggest that there are variations in the effort that is exerted by the different department managers as well as the training department in making personnel aware of the term performance and therefore, could have provided them with the necessary information with regards to what performance means to the maintenance department.

Generally speaking this also may imply that awareness about performance is not given great attention at early stages when preparing the employees for the job, i.e. pure technical issues such as technical know how are more focused upon than any other issues like performance levels.

- ***Do you think the term efficiency was defined in any training courses that you had before starting your job?***

There was a highly significant difference (.002) in the views of the personnel in the three different department on whether the term efficiency was defined in any training courses that they had before starting the job, see Table 5.10.

Table 5.10 Do You Think The Term Efficiency Was Defined In Any Training Courses That You Had Before Starting Your Job?

		department			
		LINE	HANGAR	SHOP	Total
YES	Count	17	18	45	80
	Expected Count	22.1	25.7	32.2	80.0
NO	Count	57	68	63	188
	Expected Count	51.9	60.3	75.8	188.0
Total	Count	74	86	108	268
	Expected Count	74.0	86.0	108.0	268.0

Pearson Chi-Square .002
0 Cells (.0%) have expected count less than 5. The minimum expected count is 22.09.

The result suggests that overall the technicians said no. In the Hangar and the Line there was a lower proportion of individuals than expected in both departments who said yes. This suggests that the Line and Hangar technicians agree that management should make them more aware of what is meant by efficiency in the workplace. In addition, this suggests that managers should put more effort to teach the technicians on issues related to performance and efficiency. As this would bring more benefits to the overall maintenance department's performance and efficiency and in the end this effort would help managers to improve the overall picture of the maintenance department.

In the Shop there were higher proportions of individuals than expected of technicians in the Shop who said yes. This may suggest that awareness about efficiency in the Shop exist more than the Line and the Hanger. This possibly be due to management policy in the Shop which requires Shop management to emphasis issues related to efficiency.

- ***Do you think the term productivity was defined in any training courses that you had before starting your job?***

There was a highly significant difference (.003) in the views of the personnel on whether the term productivity was defined in any training courses that they had before starting their job, see Table 5.11.

Table 5.11 Do You Think The Term Productivity Was Defined In Any Training Courses That You Had Before Starting Your Job?

		department			
		LINE	HANGAR	SHOP	Total
YES	Count	23	20	50	93
	Expected Count	25.8	29.6	37.5	93.0
NO	Count	52	66	59	177
	Expected Count	49.2	56.4	71.5	177.0
Total	Count	75	86	109	270
	Expected Count	75.0	86.0	109.0	270.0

Pearson Chi-Square .003
0 Cells (.0%) have expected count less than 5. The minimum expected count is 25.83.

The evidence makes it clear that the majority of personnel in the three different department were not instructed or provided with any necessary information with regard to efficiency, performance and productivity during any training courses that they had before they started their work. This may affect the performance and productivity as personnel may well adopt bad techniques in carrying out their job, which are used by their co-workers with more experience than them in the job and this eventually could harm the performance and the productivity of the job.

The result for both the Line and Hangar maintenance department shows that a lower proportion of employees than expected said yes, while a higher proportion than expected of technicians in the Shop said yes. In general, the result suggests that productivity related issues in the Shop seem to be known to the technicians in the Shop when compared to the Line and the Hangar. Consequently, this suggests that maintenance management need to build awareness among the technicians with issues related to productivity, efficiency and performance.

- ***Do you think that if you know your department objectives you would achieve better performance levels?***

There was a significant difference (.030) in the views of the personnel in the three different department on whether they thought that if they know their department's objectives they could achieve better performance, see Table 5.12.

Table 5.12 Do You Think That If You Know You Department Objectives You Would Achieve Better Performance Levels?

		department			
		LINE	HANGAR	SHOP	Total
ABSOLUTELY UNTRUE/ UNTRUE	Count	10	3	4	17
	Expected Count	4.8	5.4	6.8	17.0
NEUTRAL	Count	8	16	13	37
	Expected Count	10.4	11.7	14.9	37.0
ABSOLUTELY TRUE/ TRUE	Count	58	67	92	217
	Expected Count	60.9	68.9	87.3	217.0
Total	Count	76	86	109	271
	Expected Count	76.0	86.0	109.0	271.0

Pearson Chi-Square .030
1 cell (11.1%) have expected count less than 5. The minimum expected count is 4.77.

The result shows that the majority of the employees in the three different departments agreed that their department's objective should be made known in order for them to achieve better performance. This may suggest that communication between management and staff is necessary to achieve higher performance levels. Furthermore, personnel could probably achieve greater performance because they want to reach the targeted objectives of achieving maintenance tasks within the planned time, which were set by their department managers.

In the Line the result shows that a high proportion of individual than expected of the technicians in the Line said absolutely do not agree. In the Hangar the result shows that there is a high proportion than expected of individuals in the Hangar who were neutral, while in the Shop the result shows that a lower proportion than expected of the technicians in the Shop said they absolutely disagree with that statement. Which indicates that Shop technicians agree that knowing the objectives of their department would eventually help them to achieve better performance. In general, the findings suggest that management communicating with technicians is considered to highly favorable, as it would bring about an improvement in the maintenance department.

- ***Did the subject you studied in technical school cover the term efficiency, performance and productivity?***

There was a highly significant difference (.006) in the views of the personnel in the three different departments on whether the subjects that they had studied in technical school covered the terms efficiency performance and productivity or not, see Table 5.13.
Overall the result show that the majority said no. However, the result for the Line and Hangar shows a lower proportion of individuals than expected for the technicians in the Line and Hangar said yes. The result suggests that both Line and Hangar personnel agrees that technical school did not mention issues relating to performance, efficiency and productivity. The result for the Shop suggests that there is a high proportion than expected of the technicians in the Shop said yes. This possibly suggest that the Shop personnel may have had information about performance, efficiency and productivity as part of their on-job training that they had when joining. In general, the findings suggest that management would need to provide a special training programme that would remind technicians particularly those in the Line and Hangar.

Table 5.13 Did The Subject You Studied In Technical School Cover The Term Efficiency, Performance And Productivity?

		department			Total
		LINE	HANGAR	SHOP	
YES	Count	23	21	50	94
	Expected Count	26.5	29.6	37.9	94.0
NO	Count	53	64	59	176
	Expected Count	49.5	55.4	71.1	176.0
Total	Count	76	85	109	270
	Expected Count	76.0	85.0	109.0	270.0

Pearson Chi-Sqaure .006

0 cells (.0%) have expected count less than 5. The minimum expected count is 26.46.

- ***Do you think shift work can affect your performance levels negatively?***

There was a highly significant difference (.000) in the views of the personnel in the three different departments on whether shift work could have a negative affect on personnel performance, see Table 5.14.

Overall Technicians in all three maintenance departments said yes. However, the result for both the Line and Hangar were similar. The result shows that a lower proportion of individuals than expected in the Line and Hangar said no. The findings suggest that technicians in the Line and Hangar thought that their performance would decline with the change between shift, as was mentioned in Chapter Three to be one of the main factors that could contribute to lower productivity levels. In the Shop the result shows that a higher proportion of individuals than expected said no. This result suggests that technicians in the Shop considered themselves to be less affected by the shift change when compared to the Line or hangar personnel. This is again due to the nature of the shift pattern in the Shop, which requires only two shifts, compared to the Line and Hangar who operates a three shifts system. This issue is less of a problem in the Shop when compared to the Line department. In addition, this possibly implies that technicians in both the Line and the Hangar are seeking to have a permanent shift rather than having to switch every two or three weeks as they do at present.

<u>Table 5.14</u> Do You Think Shift Work Can Affect Your Performance Levels Negatively?

		department			Total
		LINE	HANGAR	SHOP	
YES	Count	68	63	62	193
	Expected Count	54.5	61.0	77.5	193.0
NO	Count	8	22	46	76
	Expected Count	21.5	24.0	30.5	76.0
Total	Count	76	85	108	269
	Expected Count	76.0	85.0	108.0	269.0

Pearson Chi-Sqaure .000
0 cells (.0%) have expected count less than 5. The minimum expected count is 21.47.

- ***Do you think job rotation can decrease your performance levels?***

There was a highly significant difference (.002) in the views of the two groups of employees based on the number of years spent in company, with regard to whether job rotation decreases performance, see Table 5.15.

The result shows a lower proportion of individuals than expected of technicians who spent ten years or less in the company said yes, while the result shows that a higher proportion of individuals than expected of the personnel who spent over ten years in the company.

Table 5.15 Do You Think Job Rotation Can Decrease Your Performance Levels?

		YEARS IN THE COMPANY		
		TEN YEARS OR LESS	OVER TEN YEARS	Total
YES	Count	40	90	130
	Expected Count	52.9	77.1	130.0
NO	Count	71	72	143
	Expected Count	58.1	84.9	143.0
Total	Count	111	162	273
	Expected Count	111.0	162.0	273.0

Pearson Chi-Sqaure .001
0 cells (.0%) have expected count less than5. The minimum count is 52.86.

The result shows that employees who had spent ten years or less in the company are more likely to think that job rotation does not decrease their performance levels. Employees who had spent over ten years did think that job rotation could decrease their performance levels for several reasons:

A. Perhaps because they have spent long time to master the full understanding of the system that they are working on.
B. This analysis may possibly also indicate that the employees with ten years or less are more enthusiastic and would like to try out different areas of the work, and therefore, they did not think that job rotation could affect their performance negatively, while the employees who spent over ten years in the company are less willing to rotate on the job.
C. Or this could be because of the level of specialisation required on the job. Since there are different types of aircraft and if the employees are to rotate on

the job, then they might have to acquire a special qualification in order to be qualified to do the job.

D. The group with over ten years of experience thinks that they have mastered a specific aircraft system and they are very good in troubleshooting, with less time and effort compared to those who spent less than ten years. Therefore, if they do rotate or change areas, they may have to learn the new system from scratch, and then they may think that their performance had decreased.

The analysis could possibly suggest that there are few incentives for the employees to rotate on the job. As each additional qualification on a different aircraft would mean extra pay for the technicians. However, if the airline is not willing to pay more for extra qualifications this causes the employee not be motivated to get a new qualification.

- ***On day to day work, is there any performance standard you have to meet?***

There was a significant difference (.034) in the views of the personnel in the three different departments on whether in day to day work, there is any performance standard that they have to meet, see Table 5.16.

Table 5.16 Employees' Views On Whether In Day To Day Work, That There Is Any Performance Standard In Which They Have To Meet

		department			Total
		LINE	HANGAR	SHOP	
THERE IS NO STANDARD	Count	32	36	30	98
	Expected Count	27.4	31.8	38.8	98.0
THERE IS A STANDARD LEVEL BUT NOT WRITTEN	Count	27	41	48	116
	Expected Count	32.4	37.6	46.0	116.0
THERE IS A WRITTEN STANDARD	Count	15	9	27	51
	Expected Count	14.2	16.6	20.2	51.0
Total	Count	74	86	105	265
	Expected Count	74.0	86.0	105.0	265.0

Pearson Chi-Sqaure .034
0 cells (.0%) have expected count less than 5. The minimum expected count is 14.24.

The result shows that a higher proportion of individuals than expected of the personnel who works in the Line to say there is no standard, while a similar value of standard if residual shows that a lower proportion of individual than expected of the employees in the Line said that there is a standard but not written. In general, the result for the Line suggests that Line managers need to emphasis the level of standard required from the technicians. In the Hangar the result shows that a lower proportion of individuals than expected said that there are written standard, while in the Shop the result shows that a higher proportion than expected of individuals in the Shop who said that there is a written standard. Overall, the Shop personnel were the only department who could confirm that there are written performance standards for technicians to meet. The findings suggest that the establishment of a defined performance standard for maintenance work could help the management to set up work measurement techniques and enable daily performance measurement. This could be an important tool for management to be able to identify areas of weak performance more easily.

- ***Does your supervisor or head of department prepare a performance evaluation for each employee?***

There was a highly significant difference (.007) in the views of personnel in the three different departments on whether their supervisor or head of department prepares a performance evaluation, see Table 5.17. The result shows a higher proportion of individuals than expected of personnel in the Line said they were uncertain. This suggest that the personnel in the Line either that they are not aware of such an evaluation procedure or that they are aware of it thus, they do not give it much attention since there are no incentives or rewards for high performer technicians. The result could possibly suggest that personnel may think that more frequent performance evaluation could help them improve their performance, as it makes them aware of their current performance levels and what they need to do in order to improve their overall performance. The result further shows that a lower proportion of individuals than expected of the personnel in the Hangar said uncertain. This result suggests that performance evaluations are in place however, the technicians may not be aware of it. The result shows a higher proportion of individuals than expected in the Shop said that performance evaluation are being done every year.

Table 5.17 Does Your Supervisor Or Head Of Department Prepare A Performance Evaluation For Each Employee?

		department			
		LINE	HANGAR	SHOP	Total
EVERY YEAR	Count	21	36	48	105
	Expected Count	29.1	33.3	42.5	105.0
WHEN NEEDED	Count	22	36	40	98
	Expected Count	27.2	31.1	39.7	98.0
NEVER	Count	13	7	9	29
	Expected Count	8.0	9.2	11.7	29.0
UNCERTAIN	Count	20	8	14	42
	Expected Count	11.6	13.3	17.0	42.0
Total	Count	76	87	111	274
	Expected Count	76.0	87.0	111.0	274.0

Pearson Chi-Sqaure .007
0 cells (.0%) have expected count less than 5. The minimum expected count is 8.04.

- ***Are you able to look at your evaluation form to discuss it further with your supervisor?***

There was a highly significant difference (.000) in the views of personnel in the three different departments on whether that they can discuss their performance evaluation with their supervisor, see Table 5.18.

Table 5.18 Are You Able To Look At Your Evaluation Form To Discuss It Further With Your Supervisor?

		department			
		LINE	HANGAR	SHOP	Total
YES	Count	8	30	66	104
	Expected Count	26.4	33.1	44.5	104.0
NO	Count	46	27	19	92
	Expected Count	23.4	29.3	39.3	92.0
SOMETIMES	Count	9	22	21	52
	Expected Count	13.2	16.6	22.2	52.0
Total	Count	63	79	106	248
	Expected Count	63.0	79.0	106.0	248.0

Pearson Chi-Sqaure .000
0 cells (.0%) have expected count less than 5. The minimum expected count is 13.21.

The result shows that a higher proportion of individual than expected of personnel in the Line said no. This suggests that technicians in the Line are aware of their current performance level and therefore, they feel that there is no need to discuss it with their supervisor. Or this may suggest that managers in the Line do not have a policy as yet to discuss technicians' performance evaluation.

The result further shows a higher proportion of individuals than expected of the technicians in the Hangar said sometimes. This suggests that the case is different in the Hangar as sometimes the technicians could further discuss their performance evaluation with their supervisor.

Finally, the result shows the standard of residual have an even split in the technician response with regard to the same question. However, the first split shows a higher proportion of individuals than expected of the technicians in the Shop said yes that they could discuss their performance evaluation with their supervisor. The second split shows a lower proportion of individuals than expected said no.

Generally speaking maintenance management should make it clear to the technicians if they can review their performance evaluation with them or not. This issue is considered to be highly important in terms of performance measurement application in the maintenance department. And this suggests that if a sound performance measurement system exists, then it would evidently allow the technicians in all three maintenance departments to be able to know their current level of performance, so that they can improve it if needed under the supervision of their immediate supervisor. In addition, a proper performance measurement system would eventually allow the technicians to view their performance evaluation in order to be able to examine their past performance and how to better improve it if needed. As was mentioned in Chapter Three by Schroeder (1993) communication between technicians and management played a positive role in improving North West airlines (NWA) maintenance performance.

- ***Which best describes your skill levels?***

There was a significant difference (.011) in the views of personnel in the three different departments on which statement best described their work skill, see Table 5.19. The majority of the employees in the Line and the Shop said that their skill level is very high, while the majority of the employees in the Hangar side that they are fairly skilled.

The result shows that a lower proportion of individuals than expected of the technicians in the Line said that their skill level is considered to be fairly skilled. This suggest that either the type and the nature of maintenance work conducted in the Line requires this level of skill or that they think that there is still room for improvement. This may be achieved through extra training programmes to boost their skill levels.

As for the Hangar the result shows that a higher proportion of individuals than expected of technicians in the Hangar said fairly skilled. The result suggests that working in the Hangar does not require a high level of skill, or that there is room for improvement through a more focused training programme.

Finally, the result shows that a higher proportion of individuals than expected in the Shop said highly skilled. This indicates that the level of the skill of the technicians in the Shop is considered to be high. This is due to the nature of the maintenance job that they accomplish, as it requires a technician with high level of skill to troubleshoot, repair and overhaul an aircraft component.

Table 5.19 Which Best Describes Your Skill Levels?

		department			Total
		LINE	HANGAR	SHOP	
HIGHLY SKILLED	Count	42	30	65	137
	Expected Count	37.9	43.5	55.6	137.0
FAIRLY SKILLED	Count	28	50	40	113
	Expected Count	32.7	37.4	47.9	118.0
SEMI SKILLED/ NO SKILL	Count	5	6	5	16
	Expected Count	4.4	5.1	6.5	16.0
Total	Count	75	86	110	271
	Expected Count	75.0	86.0	110.0	271.0

Pearson chi-Sqaure .011
1 cell (11.1%) have expected count less than 5. The minimum expected count is 4.43.

5.2.2 Manager Chi-square Test

The previous section discussed the differences in views from the employee point of view. However, this section examines differences in views between the managers in the three different departments Line, Shop and Hangar. The discussion covers only questions, which showed statistically significant difference.

- ***How do you rate the effect of work process on productivity?***

There was a significant difference (.033) in the views of managers in the three different departments on the effect of work process on work productivity, see Table 5.20.

Table 6.20 How Do You Rate The Effect Of Work Process On Productivity?

		DEPARTMENT WHERE EMPLOYEE WORK			
		LINE	HANGAR	SHOP	Total
VERY LOW/ LOW	Count	10	5	5	20
	Expected Count	5.7	7.9	6.3	20.0
NEUTRAL	Count	6	6	6	18
	Expected Count	5.1	7.1	5.7	18.0
HIGH/ VERY HIGH	Count	2	14	9	25
	Expected Count	7.1	9.9	7.9	25.0
Total	Count	18	25	20	63
	Expected Count	18.0	25.0	20.0	63.0

Pearson Chi-Sqaure .033
0 cells (.0%) have expected count less than 5. The minimum expected count is 5.14.

The result shows that a lower proportion of individuals than expected of the managers in the Line said that the effect of work process on productivity is high. This indicates that the managers in the Line are more concerned with achieving on-time-performance and dispatching the aircraft on time with no delays as a top priority. This is linked to the employees' comment when they said that there are no standards for carrying out the work. The type of work that is being carried out in the Line may not require the technicians to follow a long procedure compared to the Hangar personnel for example. The Line personnel job is mainly concentrated on servicing the aircraft and making sure that the aircraft systems are working properly. When an aircraft system fails before departure, Line staff should be able to assist the pilot and if they do not succeed, then a specialist from the Hangar or Shop will be called upon in order to assess in the problem that they have.

In the Hangar the result shows that a higher proportion of individuals than expected of the managers in the Hangar said that the effect of work process is considered to be high. The reason for this could be because of the type of work that is carried out in the Hangar which requires the technicians to follow a certain procedure in the manual such as troubleshooting the system in order to find out the possible cause of the fault. They may thus try several tests in an orderly fashion in order to quickly diagnose the problem. Again, most scheduled maintenance and reconditioning tasks require adherence to processes specified in the appropriate manual. However, there is a sample of a written guideline from the technical manual presented in Chapter Two. In addition as mentioned in Chapter Three, the absence of written guidelines could lead to a work that lacks consistency.

In the Shop the result shows that a lower proportion of individual than expected of the managers in the Shop said that the effect of work process is low. The majority of the managers in the Shop agreed that the work process in examining the aircraft component for faults is considered to be very important. Avionics technicians would need to follow the proper work process when examining faulty equipment according to the test manual in order to save time and to properly diagnose the problem and be able to make a decision on how to start fixing the aircraft component.

- ***Is a regular check kept on the relationship between material consumption and the number of cycles?***

There was a significant difference (.046) in the views of managers in the three different departments, with regard to whether a regular check is kept on the relationship between material consumption and the number of cycles produced (each engine starts is considered as one cycle), see Table 5.21.

The result shows that a higher proportion of individuals than expected of the managers in the Line who said that there is absolutely no relation is drawn. This indicates that the managers in the Line are the least concerned about the relationship between material consumption and the number of cycles that the aircraft accomplishes. This is probably due to the fact that the nature of their work in the Line does not require the Line managers to monitor the cycles of each component that they fit into the aircraft, as this is being monitored by the planning department. In general, the Line managers are required to carry out minor maintenance as was mentioned in Chapter Two, and further analysis concerned with the comparison of material consumption and cycles is not part of their daily routine.

For the managers in the Hangar the result shows that a higher proportion of individuals than expected of the managers in the Hangar were neutral. However, the same consideration applies to the managers in the Hangar, as they also need to monitor the relationship between material consumption and number of cycles accomplished. As engine changes are carried out in the Hangar, they may need to follow up on the work that they have performed. Again if more aircraft engines being returned to the Hangar after being serviced, this may trigger a concern for the managers in the Hangar as to whether there is an inaccuracy in the procedure of removing and installing engines.

Finally, the result shows that a lower proportion of individuals in the Shop than expected of the managers said that there is absolutely no relationship is drawn. This result may suggest that the managers in the Shop are more concerned with the relationship between material consumption and the number of cycles accomplished. This may be useful to check on the reliability of their testing and overhauling procedures that are being conducted in the shop, which may allow the managers to track the performance of their staff as well as the reliability of the fleet. For example, managers in the Shop, would monitor the components that fail before the designated life time (cycle), as this might indicate a fault in the overhauling or testing procedures, which may require prompt action.

Table 5.21 Is A Regular Check Kept On The Relationship Between Material Consumption And The Number Of Cycles?

		DEPARTMENT WHERE EMPLOYEE WORK			Total
		LINE	HANGAR	SHOP	
ABSOLUTELY UNTRUE/ UNTRUE	Count	11	8	3	22
	Expected Count	6.4	8.5	7.1	22.0
NEUTRAL	Count	3	10	8	21
	Expected Count	6.1	8.1	6.8	21.0
ABSOLUTELY TRUE/ TRUE	Count	5	7	10	22
	Expected Count	6.4	8.5	7.1	22.0
Total	Count	19	25	21	65
	Expected Count	19.0	25.0	21.0	65.0

Pearson Chi-Sqaure .046
0 cells (.0%) have expected count less than 5. The minimum expected count is 6.14.

- ***Do you have complete information on effectiveness?***

There was a significant difference (.030) in the views of managers on whether a complete information on effectiveness is available or not, see Table 5.22.

The result shows that a lower proportion of individuals than expected of the managers in the Line said that they always have had good information on effectiveness.

The analysis suggests that managers in the Line are less aware of the effectiveness of their department. This could be for several reasons:

A. The managers in the Line may not be willing to measure the effectiveness of their department because top management does not require it, although they have the tools to carry out this process.

B. They may not have the required information to carry out such a process. They lack the knowledge to measure the effectiveness of their department. It may not be on their priority list.

Table 5.22 Do You Have A Complete Information On Effectiveness?

		DEPARTMENT WHERE EMPLOYEE WORK			
		LINE	HANGAR	SHOP	Total
ABSOLUTELY UNTRUE/ UNTRUE	Count	8	8	4	20
	Expected Count	5.8	7.7	6.5	20.0
NEUTRAL	Count	8	3	5	16
	Expected Count	4.7	6.2	5.2	16.0
TRUE/ ABSOLUTELY TRUE	Count	3	14	12	29
	Expected Count	8.5	11.2	9.4	29.0
Total	Count	19	25	21	65
	Expected Count	19.0	25.0	21.0	65.0

Pearson Chi-Square .030
1 cells (11.1%) have expected count less than5. The minimum expected count is 4.68.

As for the managers in the Hangar the result shows a lower proportion of individual than expected of the managers in the Hangar who were not sure. The result indicates that they are well aware of the effectiveness of their department in carrying out the scheduled work. The managers in the Hangar have a whole year pre-planned schedule for the number of aircraft to be serviced and the type of the work, which needs to be carried out during a specified period of time. This may help them determine if they were effective in conducting a certain project on time given the resources available to them.

Finally, the result for the managers in the Line shows that a lower proportion of individuals than expected in the Line said that they never have a complete information on effectiveness. The result suggests that the managers in the Line do not have clear information on the level of effectiveness, this is possibly due to the lack of information.

5.3 FACTOR ANALYSIS

The purpose of the factor analysis was to identify the dimensions supposed to underline maintenance performance. Factor analysis is considered to be a method of data reduction, it seeks the underlying dimensions, which account for patterns of variation among the observed variables (Tabachnick and Fidell, 1996). In addition, the authors states that Factor analysis is often employed by researchers to understand the underlying structure of the variables. Marriott (1974) and Parasuraman (1991) stated that Factor analysis is the oldest of the main multivariate techniques and is essentially a data and variable reduction technique that attempts to partition a given set of variables into groups of maximally correlated variables.

A total of ten items which were believed to affect employees performance, were listed and employees were asked to rank the top three items, which they believed affected their performance the most. These are *Shortages of Material*, *Shortages of Manpower*, *Shortages of Ground Support Equipment*, *Poor Training*, *Weather Condition*, *Motivation*, *Facility*, *Inappropriate Ground Support Equipment*, *Work Process* and *Job Card.*

5.3.1 Employee Factor Analysis

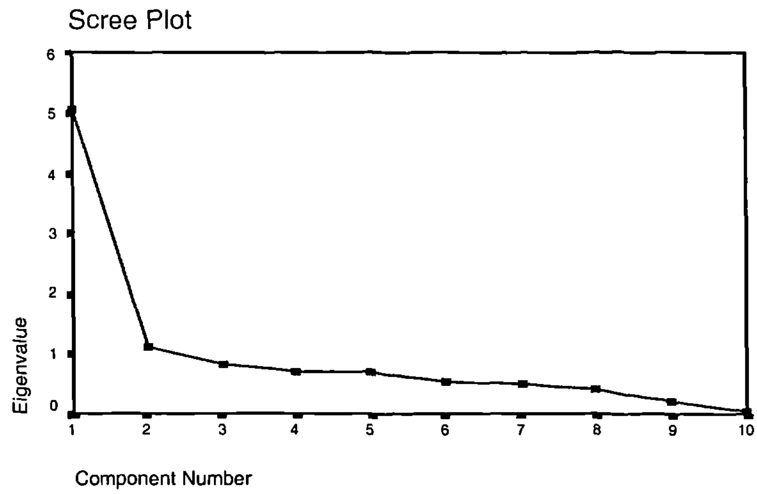
Kinnear and Gray (1999) states that in Factor analysis the greater the value of the loading on one factor, the more important is that factor in justifying for the correlations between that test and others in the set.

A goodness of fit test (Bartlett's Test of Sphericity) was conducted to measure the significance of correlation as an indication of the reliability of relationships between pairs of variables. The test show a significance level of 0.000, provide strong evidence of interrelationships amongst the variables.

The result for Kaiser-Meyer-Olkin test of sampling adequacy was 0.709, which provided an indication of reliability of relationship between pairs of variables, as a good fit it should be a value of 0.6 and above according to De Vaus (1991).

By examining the Scree Plot in Figure 5.3 it became evident that only one component should be retained which explains 50.6% of the variation from the initial principal component analysis. Tabachnick and Fidell (1996) states that the Scree plot is used with Factor analysis to find the number of factors to be retained.

Figure 5.3 Scree plot



Tabachnick and Field (1996) stated that as a rule of thumb, only variables with loadings of (.32) and above should be used in interpreting a factor and that, the greater the loading, the more the variable is a pure measure of factor. They stated that a loading in excess of (.71) (50% overlapping variance) is considered to be excellent, (.63) (40% overlapping variance) are considered to be very good, (.55) (30% overlapping variance) are considered to be good, (.32) (10% overlapping variance) are considered to be poor. See Table 5.23 for the rotated component matrix. For example, the retained factor has a correlation of .846 with *Job Cards*. For the purpose of factor naming a cut off at (0.55) was used.

There are two items that are generally related to the only retained factor in terms of importance. The first one is *job cards* which loads highly (0.987) with the only retained factor. The second one is *work process*; this item is the second in importance to correlate highly (.917) with the retained factor. These are generally associated with factors affecting employees' work performance in terms of the process of the work, therefore, the factor that was retained was named *process of doing the work.*

Kim and Mueller (1978,) and Parasuraman (1991) stated that users of factor analysis choose a label on the basis of common thread running the original variables that have high loading on it. Yet, it becomes more difficult when variable loadings on it have little in common for the researcher to draw a meaningful name.

Table 5.23 The Rotated Component Matrix

	Component
	Process of Doing the Work
Shortages of manpower	
Shortages of materials	.679
Shortages of G.S.E	
Inappropriate G.S.E	.678
Work process	.807
Job cards	**.846**
Facilities	
Poor training	.606
Weather condition	.738
Motivation	.761
% of var	***50.59***
Cum %	***50.59***

EXTRACTION METHOD: Principal Component Analysis
Rotation Method: Varimax with Kaiser Normalization.
[a] Rotation converged in 3 iteration.

After conducting the factor analysis, a factor score was saved and a One-Way ANOVA test was carried out with the purpose of comparing mean values of the factor between the three departments Shop, Hangar and Line and to determine if they were the same or different with regard to the variable examined. The ANOVA Post Hoc Scheffe test showed a highly significant differences of (0.000) between the mean employee perceptions in the Line and the Hangar.

In addition, there was a significant (0.016) difference in mean perception between the employee in the Hangar and the Shop with respect to the variable examined from the factor analysis (*Process of doing the work*), thus, the mean for the employee in the Shop was 0.4047 less than for the employees in the Hangar.

There was no significant difference between the employee perception in the Line and the Shop, Tables 5.24 illustrates the result of the multiple comparison.

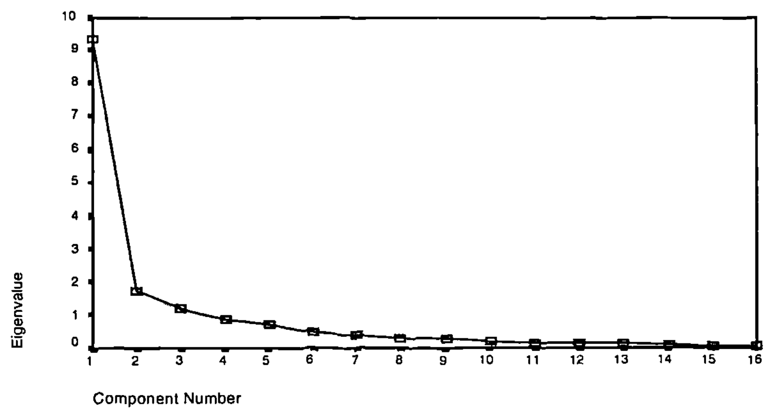
Table 5.24 Multiple Comparison

		Mean Difference	Std Err	Sig.
Line	Line			
	Hangar	-0.6296	0.154	0.000
	Shop	-0.2248	0.146	0.307
Hangar	Line	0.6296	0.154	0.000
	Hangar			
	Shop	0.4047	0.139	0.016
Shop	Line	0.2248	0.146	0.307
	Hangar	-0.4047	0.139	0.016
	Shop			

5.3.2 Manager Factor Analysis

The sixteen items which managers believed to have an effect on work productivity were factor analyzed. The Kaiser-Meyer-Olkin statistic result of 0.868 was very satisfactory, with a significance level of (.000). The next step is to illustrate the eigenvalue of the sixteen factors on a scree plot. This is useful to determine how many components to retain. From Figure 5.4 it was judged that there were only two components that should be retained. Factors that accounted for less than one were eliminated. The loadings for the two rotated factors are shown in Table 5.25.

Figure 5.4 Scree Plot For The Three Retained Component



An initial Principal Component analysis was carried out. From the scree plot Figure 5.4 it was judged that there only two factors should be retained accounting for 68.85% of the total variance. The loadings for the two rotated factors are shown in Table 5.25.

In the rotated matrix again a cut off was determined at (0.55). On the basis of the factor loadings, the first factor was labelled *Work environment* and the second factor that was selected was called *Management support.*

Table 5.25 The Rotated Component Matrix

	Component	
	Work Environment	**Management Support**
Company Policy		.785
Managerial Support		.849
Job Security		.765
Employee Skill		.772
Motivation		.667
Clear Work Objectives		.718
Inadequate Tooling	.697	.581
Adequate Manuals		.606
Availability of Materials	.845	
Shortage of Manpower	.890	
Shortage of Ground Support Equipment (G.S.E)	.865	
Weather Conditions	.811	
Work Process	.658	
Job Cards		
Facility Conditions	.744	
Inappropriate G.S.E	.816	
% of var	***37.63***	***31.22***
Cum %	***37.63***	***68.85***

EXTRACTION METHOD: Principal Component Analysis
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 6 iteration.

Again One-Way ANOVA was carried out. The results suggests that there was a significant difference of (0.045) with an F-value of 3.27 in respect to factor one (*Work Environment*) between the managers in the Line and the Hangar. The result strongly suggests that the managers in both the Line and Hangar valued the effect of the work environment differently, thus, the managers in the Line evaluated the effect of the *work environment* less highly than did the managers in the Hangar and the Shop.

5.4 COMMENT ANALYSIS

This section aims to analyse the employee's qualitative comments that were made during the answering of the survey questionnaires. A further purpose is to identify the significant differences among the different employees in the three departments. This section provides more details on problems encountered by the employees in the three different departments on a daily basis and they have made a note of them in the space that was provided for them.

5.4.1 Employee Comment Analysis

5.4.1.1 Background

To provide a brief background to the discussion, the employees comment were analysed by means of x^2-test:

5.4.1.2 Analysis Of Employee Comments

- ***Do you think you can increase your performance through process change?***

Personnel in the Line said that they want to work on a single type of aircraft rather than having to work on more than one type. Personnel in the Hangar, also made the same point as the employees in the Line, see Table 5.26.

The employees in the Shop expressed the views that they wanted to cancel the double shift. The second most important comment to be made by the employees in the Line, was with regard to providing immediate authority to supervisor. As for the Hangar, the second most important comment that was made, was with regard to cancelling the night shift as many managers in the Hangar thought that this could increase their performance if this were to be implemented. The second most important comment made by the employees in the Shop was related to management courses, as some employees thought that there was a need for them, in order to improve performance.

Table 5.26 Employees' Comments On Increasing Their Performance Through Process Change

		department			
		LINE	HANGAR	SHOP	Total
BACK TO FLEET TYPE AS BEFORE (GOOD PLANNING)	% within department	66.7%	46.7%	14.3%	44.7%
STOP ROBBING PARTS FROM OTHER A/C, REVIEW ORDERING PROCESS	% within department	5.6%	6.7%	21.4%	10.6%
CANCEL NIGHT SHIFT	% within department	5.6%	20 0%		8.5%
PROVIDE IMMEDIATE AUTHORITY TO SUPERVISOR	% within department	16.7%		7.1%	8.5%
CHANGE THE WAY PAPER WORK IS BEING HANDLED	% within department	5.6%	6.7%	7.1%	6.4%
WE NEED MGT COURSES TO ORGANISE THE WORKLOAD	% within department		13.3%	14.3%	8.5%
CANCEL DOUBLE SHIFT	% within department		6.7%	28.6%	10.6%
AVIONICS AND A&P SHOULD BE TOGETHER IN LINE DISPATCH	% within department			7.1%	2.1%
Total	% within department	100.0%	100 0%	100.0%	100.0%

- ***Do you think you can increase your performance through better use of tools?***

Most employees in the three different departments commented that proper tools that could make the job easier are needed. As for the personnel in the Line the second most important comment that they made was that they have very old tools, which are not very useful in carrying out their tasks, as was mentioned in Chapter Three that inappropriate tools could cause technicians to have a lower productive levels. Thus, the second most important comment that the staff in the Hangar and the Shop made was with regard to missing or inadequate tools. Some employees stated that twenty to thirty minutes are lost sometimes, just looking for tools, see Table 5.27.

Table 5.27 Employees' Comments On Increasing Their Performance Through Better Use Of Tools And Equipment

		department			
		LINE	HANGAR	SHOP	Total
PROPER TOOLS TO MAKE JOB EASIER(VEHICLE,STANDS,GLOVES,RU	% within department	56.7%	53.8%	31.8%	46.8%
HAVING THE CORRECT TEST STAND FOR THE RIGHT COMPONENT	% within department	13.3%	13.5%	13.6%	13.5%
WE HAVE VERY OLD TOOLS	% within department	20.0%	9.6%	9.1%	11.9%
SOME TOOLS MISSING(SPECIAL TOOL)NOT AVAILAB(SHORTAGE OF	% within department	3.3%	19.2%	29.5%	19.0%
EXTRA HOT BONDING MACHINE	% within department			2.3%	.8%
CONSIDERABLE TIME WASTED FIXING OR LOOKING FOR TOOLS	% within department	6.7%		4.5%	3.2%
WORK AREA NOT PROPERLY EQUIPED WITH ELEC PLUG. AIR HOSE FITT	% within department		3.8%		1.6%
INTRODUCE (COMPUTERS)TO ORGANIZE ASSIGNEMENT	% within department			9.1%	3.2%
Total	% within department	100 0%	100.0%	100.0%	100.0%

- ***Do you think you can increase your performance with better working conditions?***

The analysis shows that employee in the Hangar and the Shop complained about the lack of availability of air-conditioning the most, while the employees in the Line have also ranked the availability of air-conditioning as an important factor. The Line staff also said more reliable equipment and introducing reward for outstanding performance are necessary, see Table 5.28.

Table 5.28 Employees' Response To Increase Their Performance Under Better Working Conditions

		department			
		LINE	HANGAR	SHOP	Total
AIR-CONDITIONING	% within department	31.0%	83.7%	43.6%	55.9%
TREATING EMPLOYEES THE SAME	% within department			7.7%	2.7%
NEED MORE RELIABLE EQUIPMENT (NEW CARS &TRUCKS)	% within department	31.0%	7.0%	12.8%	15.3%
GER AND CLEAN AND CLEAR AREA	% within department	3.4%		15.4%	6.3%
GOOD VENTILATION	% within department	3.4%	4.7%	10.3%	6.3%
NEED TO INTRODUCE (PAY) REWARDS FOR OUTSTANDING EMPLOYEES	% within department	31.0%	4.7%	10.3%	13.5%
Total	% within department	100.0%	100.0%	100.0%	100.0%

- ***Do you share ideas with your supervisor that would boost performance?***

Employees in the Hangar and Shop said that they do share ideas with their supervisor with respect to setting priority list staff utilisation and schedule set-up. As for the employees in the Line they complained about having the technician to go to the tool room to order parts and bringing necessary stand and test equipment in order to carry out their job. They believe that they should only concentrate on their main jobs of servicing the aircraft and troubleshooting. Some notes indicated that twenty minutes or more could be lost looking for stands or going to the tool room to order parts. They think that assistants should be available to carry out these tasks and that technicians should only perform the work on the aircraft.

Table 5.29 Employees Comments With Regard To Sharing Ideas With Their Supervisor

		department			Total
		LINE	HANGAR	SHOP	
SHARE MANY IDEAS	% within department	20.8%	26.7%	26.3%	24.1%
BETTER WORKING AREAS	% within department		13.3%		3.4%
IMPROVING IN-HOUSE TROUBLESHOOTING	% within department	4.2%		10.5%	5.2%
THAT WE SHOULD BE EVALUATED ON A DAILY BASIS	% within department	4.2%		5.3%	3.4%
IDEAS ARE SHARED, BUT ARE NOT BEING IMPLEMENTED	% within department	8.3%			3.4%
STAFF UTLISATION/SPECIALITY,SCHEDU	% within department	20.8%	60.0%	52.6%	5
TECHNICANS SHOULD NOT GO TO TOOL ROOM TO ORDER	% within department	41.7%			17.2%
TO MOTIVATE HARDWORKERS, AND PUSH OTHERS TO IMPROVE	% within department			5.3%	1.7%
Total	% within department	100.0%	100.0%	100.0%	100.0%

5.4.2 Manager Comment Analysis

5.4.2.1 Background

This section analyses managers' comments relating to work performance in the Line, Hangar and Shop. An additional aim is to identify any significant differences between managers' views in the three departments that may help to identify differences in techniques and methods used by the managers in the three different departments.

Thus, this analysis will help to provide an example of why the employees were not happy with certain aspects of their work situation, for example complaining about the workload not being fair.

5.4.2.2 Analysis Of Managers' Comments

The top three managerial levels' responses to the different questions will be examined in more detail; in particular, the managers' responses will be discussed in greater depth, in order to better understand their views on the various problems present in their departments. Figure 5.3 shows the different levels that were included in the survey as well as the number of respondents in each different department. Table 5.30 shows the total number at the different managerial levels. In addition, cross tabulation classified by managerial levels and department was carried out.

Table 5.30 Distribution Sample in General by Job Title

	FREQUENCY	PERCENT
Supervisor	51	78.5
Senior Supervisor	4	6.2
Section Manager	5	7.7
Manager	4	6.2
Engineer	1	1.5
TOTAL	**65**	**100.0**

This purpose of this analysis is only to look at differences in views between the managers. However, managers' comments are classified by job title and department, therefore, only managers' comments that were found to be significant by the Chi-square test will be discussed in terms of their differences.

- ***Defining Productivity***

The question asked how do you define productivity? There was a significant difference (.050) in the views of the managers in the three different department, in defining the term productivity according to the nature of the job that is being carried out in their unit. See Table 5.31 for the different definitions that were selected.

The analysis further shows that 30% of the supervisors are more concerned with units produced per specified time. This may suggest that supervisors in the Shop for example, are more influenced by the number of units overhauled and tested by the technicians, as this directly reflects the technicians' performance.

However, (66.7%) of senior supervisors defined productivity as output per man-hours. This is very similar to the supervisor definition, as again they are more interested with the number of units produced per man-hours. This may suggest that senior supervisors are attempting to use this technique of measurement for forecasting purposes so that they can identify the need for manpower if they have a large stock of units which needs to be tested.

Section managers were evenly divided between *meeting targeted quantity*, *comparing workload to manpower*, *units produced per specified time*, and *output per man-hours* in defining productivity. Generally, the section managers have a broader viewpoint in defining productivity, however, these definitions all come to one conclusion, which is to meet schedule for delivering the part or the units overhauled. As for the managers

(66.7%) defined the same term as output to input ratio, in this respect the managers are focusing on evaluating resources needed to produce a given number of outputs.

Table 5.31 Definition Of Productivity Classified By Manager Type

		JOB TITLE EMPLOYEE HOLDS				
		SUPERVISOR	SENIOR SUPERVISOR	SECTION MANAGER	MANAGER	Total
MEET TARGETED QUANTITIY	% within JOB TITLE	25.0%		25.0%		20.0%
COMPARING WORKLOAD TO	% within JOB TITLE	15.0%		25.0%		13.3%
UNITS PRODUCED PER SPECIFIED TIME	% within JOB TITLE	30.0%	33.3%	25.0%	33.3%	30.0%
OUTPUT PER MANHOURS	% within JOB TITLE	20.0%	66.7%	25.0%		23.3%
OUTPUT TO QUALITY	% within JOB TITLE	10.0%				6.7%
OUTPUT TO INPUT RATIO	% within JOB TITLE				66.7%	6.7%
Total	% within JOB TITLE	100.0%	100.0%	100.0%	100.0%	100.0%

- ***Defining Efficiency***

The question asked how do you define efficiency? There was a significant difference (.040) in the views of the managers in the three different departments, in defining the term efficiency according to the nature of the job that is being carried out in their unit. See Table 5.32 for the different definitions that were selected.

The analysis shows that the managers in the Line defined efficiency as minimum use of manpower. In this regard it appears that the managers in the line are looking to minimising the use of the manpower as much as possible, to allow more free manpower to be available to provide line maintenance services as was mentioned in Chapter Two with regards to the queue system in the Line. However, this could also suggest that, the managers in the line are more concerned with having the technician to spend the minimum time in providing line maintenance service, so that they can achieve the minimum possible cost.

In the Hangar (71.4%) of the majority of the managers defined efficiency as achieving work objectives with minimum cost. This result suggests that Hangar managers are trying to minimise waste, by achieving work objectives with minimum cost. The work carried out in the Hangar (this was discussed in detail in Chapter Two) which tends to last from one week to five weeks, and this will involves a heavy use of both manpower and material. Therefore, it is the Hangar manager's duty to achieve maintenance objectives with minimum cost as well as delivering the aircraft on time with the highest levels of quality.

Managers in the Shop (40%) defined the term efficiency from their point of view as maximum units produced in the shortest time. This suggests that manager in the Shop are aware of the maintenance department's need to have serviceable parts ready at all times. Therefore, efficiency from their work perspective is defined as producing the maximum number of units, in the shortest possible time. This also may suggest that managers want to keep the cost of testing, inspection and overhaul at a minimum.

Table 5.32 Managers Definitions of Efficiency Classified By Department

		DEPARTMENT WHERE EMPLOYEE WORK			Total
		LINE	HANGAR	SHOP	
MINIMUM TIME OF MANPOWER USAGE	% within DEPARTMENT WHERE EMPLOYEE WORK	100.0%	28.6%		28.6%
ACHIEVE WORK OBJECTIVES WITH MINIMUM COST	% within DEPARTMENT WHERE EMPLOYEE WORK		71.4%		35.7%
ACHIEVING WORK WITH HIGH QUALITY	% within DEPARTMENT WHERE EMPLOYEE WORK			20.0%	7.1%
MAXIMUM UNITS IN SHORTAST TIME	% within DEPARTMENT WHERE EMPLOYEE WORK			40.0%	14.3%
SELECTING TH EMOST BENIFICAIL ALTERNATIVE FOR BEST RESULT	% within DEPARTMENT WHERE EMPLOYEE WORK			20.0%	7.1%
USING THE MINIMUM RESOURCE TO ACHIEVE DESIRED OBJECTIVES	% within DEPARTMENT WHERE EMPLOYEE WORK			20.0%	7.1%
Total	% within DEPARTMENT WHERE EMPLOYEE WORK	100.0%	100.0%	100.0%	100.0%

- *Defining Effectiveness*

The question asked how do you define effectiveness. There was a significant difference (.004) in the views of the managers in the three different department, see Table 5.33 for the different definitions that were selected.

The analysis shows that the managers in the Hangar defined effectiveness as achieving desired goals with minimum time and cost, while the managers in the Shop were evenly divided between saying that effectiveness means to them the following: *time*, *quality* and *quantity*, and saying that effectiveness is locating the right technician in the right place to achieve maintenance objectives.

Table 5.33 Definition Of Effectiveness Classified By Departments

		DEPARTMENT WHERE EMPLOYEE WORK		Total
		HANGAR	SHOP	
ACHIEVING DESIRED GOALS WITH MINIMUM TIME AND COST	% within DEPARTMENT WHERE EMPLOYEE WORK	100.0%		63.6%
TIME, QUALITY AND QUANTITY	% within DEPARTMENT WHERE EMPLOYEE WORK		50.0%	18.2%
THE RIGHT TECHNICIANS IN RIGHT PLACE,TO ACHIEVE OBJECTIVES	% within DEPARTMENT WHERE EMPLOYEE WORK		50.0%	18.2%
Total	% within DEPARTMENT WHERE EMPLOYEE WORK	100.0%	100.0%	100.0%

- ***Assessing The Need For Process Improvement***

The question asked how often do you review the need for process improvement? There was a significant difference 0.031 in the views of the managers in the three different departments, see Table 5.34. The supervisors (38.9%) and section managers (50%) both stated that review for process improvement is done on a monthly basis. However, the senior supervisors indicated that it is done continuously. Managers in the maintenance department were evenly divided as they either said it is done when needed, or that it is done quarterly. The analysis suggests that the review of process improvement is very similar on the first three managerial levels starting from the supervisor. Consequently, the managers said that its is done every quarter or when needed, this may reflect the actual assessment of how often it is necessary to review work process at the first three levels.

Table 5.34 Managers' Views About The Frequency Of Assessing The Need For Process Improvement

		JOB TITLE EMPLOYEE HOLDS				Total
		SUPERVISOR	SENIOR SUPERVISOR	SECTION MANAGER	MANAGER	
DAILY	% within JOB TITLE EMPLOYEE HOLDS	5.6%		25.0%		7.7%
MONTHELY	% within JOB TITLE EMPLOYEE HOLDS	38.9%		50.0%		34.6%
SEMI-ANNUALY	% within JOB TITLE EMPLOYEE HOLDS	11.1%				7.7%
WHEN NEEDED	% within JOB TITLE EMPLOYEE HOLDS	27.8%			50.0%	23.1%
CONTINUOUSLY	% within JOB TITLE EMPLOYEE HOLDS	5.6%	100.0%	25.0%		15.4%
YEARLY	% within JOB TITLE EMPLOYEE HOLDS	11.1%				7.7%
QUARTERLY	% within JOB TITLE EMPLOYEE HOLDS				50.0%	3.8%
Total	% within JOB TITLE EMPLOYEE HOLDS	100.0%	100.0%	100.0%	100.0%	100.0%

5.5 COMPARISON OF MANAGERS AND EMPLOYEES

Of the sixteen factors that were asked to the managers to, and of the set of ten factors that were asked to the employee by the researcher, there are nine factors that appear in both questionnaires. This set of nine factors is: *Shortages of manpower, Availability of materials, Shortages of ground support equipments, Inappropriate ground support equipments, Work process, Job cards, Facility condition, Weather conditions* and *Motivation.*

The Chi-square test was used, the purpose of this analysis is to compare and find the differences in view between the managers and the employee with regards to the nine factors listed earlier, only statistically highly significant questions will be discussed.

Out of the nine common factors there were only six factors which showed highly significant differences these are: *Shortages of manpower, Availability of material, Shortages of ground support equipment, Work process, Job cards* and *Motivation,* theses factors are discussed in more details.

The process of recoding these factors was done by reducing the scale on the managers' questions from a scale of five to two in order to match the one for the employees.

- ***Shortages of manpower***

There was a highly significant difference (0.000) between the managers and the employees with regards to shortages of manpower see Table 5.35.

While 52.3% of the managers said that the effect of shortages of manpower is high, there were more employees (74.8%) who said that the effect of the shortages of manpower is high. Thus a bare majority of managers view the issue of manpower shortages as important whereas the bulk of the employees do. Employees in general think that there is a need to increase manpower.

Table 5.35 Managers' And Managers' Views About Shortages Of Manpower

		JOB TITLE		Total
		MANAGER	EMPLOYEE	
VERY HIGH	Count	34	205	239
	Expected Count	45 8	193.2	239.0
	% within Q14-J	14.2%	85.8%	100.0%
	% within JOB TITLE	52.3%	74.8%	70.5%
	Std. Residual	-1.7	.9	
VERY LOW	Count	31	69	100
	Expected Count	19.2	80.8	100.0
	% within Q14-J	31.0%	69.0%	100.0%
	% within JOB TITLE	47.7%	25.2%	29.5%
	Std. Residual	2.7	-1.3	
Total	Count	65	274	339
	Expected Count	65.0	274.0	339.0
	% within Q14-J	19.2%	80.8%	100.0%
	% within JOB TITLE	100.0%	100.0%	100.0%
	Std. Residual			

- ***Availability of materials***

There was a highly significant difference (0.005) between the managers' and employees' views with regards to the effect of availability of materials on work productivity see Table 5.36. This suggests that employees value the effect of availability of material more highly than the managers do.

Table 5.36 Managers' And Employees' Views About Lack Of Availability Of Materials

		JOB TITLE		Total
		MANAGER	EMPLOYEE	
VERY HIGH	Count	34	194	228
	Expected Count	43.3	184.7	228.0
	% within Q14-I	14.9%	85.1%	100.0%
	%within JOB TITLE	53.1%	71.1%	67.7%
	Std. Residual	-1.4	.7	
VERY LOW	Count	30	79	109
	Expected Count	20 7	88 3	109.0
	% within Q14-I	27.5%	72.5%	100.0%
	%within JOB TITLE	46.9%	28 9%	32.3%
	Std. Residual	2.0	-1.0	
Total	Count	64	273	337
	Expected Count	64.0	273.0	337.0
	% within Q14-I	19.0%	81.0%	100 0%
	%within JOB TITLE	100.0%	100 0%	100.0%
	Std. Residual			

- ***Shortages of G.S.E***

There was a highly significant difference (0.003) between the managers' and the employees views, with respect to shortages of G.S.E, see Table 5.37. In general, the employees are the ones who are involved with the actual work. Therefore, they are assessing the effect of these issues from their daily experience. However, managers do agree with the employee on the importance of these issues

Table 5.37 Managers' And Managers' Views About Shortages Of G.S.E

		JOB TITLE		
		MANAGER	EMPLOYEE	Total
VERY HIGH	Count	33	191	224
	Expected Count	42.9	181.1	224.0
	% within Q14-K	14.7%	85.3%	100.0%
	% within JOB TITLE	50.8%	69.7%	66.1%
	Std. Residual	-1.5	.7	
VERY LOW	Count	32	83	115
	Expected Count	22.1	92.9	115.0
	% within Q14-K	27.8%	72.2%	100.0%
	% within JOB TITLE	49.2%	30.3%	33.9%
	Std. Residual	2.1	-1.0	
Total	Count	65	274	339
	Expected Count	65.0	274.0	339.0
	% within Q14-K	19.2%	80.8%	100.0%
	% within JOB TITLE	100.0%	100.0%	100.0%
	Std. Residual			

- ***Work process***

There was a highly significant difference (0.001) between the managers and the employees with regard to the work process, see Table 5.38. 68.3% of the managers saw the effect of work process as very high against 45.1% of the employees. This suggests that the managers are more concerned about the issue of following the work process according to the maintenance manual than the employees. Moreover, this may suggest that managers put more emphasis on following the guidelines given by the manufacturer's maintenance manual.

Table 5.38 Managers' And Employees' Views Towards Work Process

		JOB TITLE		
		MANAGER	EMPLOYEE	Total
VERY HIGH	Count	43	123	166
	Expected Count	31.1	134.9	166.0
	% within Q14-M	25.9%	74.1%	100.0%
	% within JOB TITLE	68.3%	45.1%	49.4%
	Std. Residual	2.1	-1 0	
VFRY LOW	Count	20	150	170
	Expected Count	31.9	138.1	170 0
	% within Q14-M	11.8%	88.2%	100.0%
	% within JOB TITLE	31.7%	54.9%	50.6%
	Std. Residual	-2.1	1 0	
Total	Count	63	273	336
	Expected Count	63.0	273 0	336.0
	% within Q14-M	18.8%	81.3%	100.0%
	% within JOB TITLE	100.0%	100.0%	100.0%
	Std. Residual			

- ***Job Cards***

There was a highly significant difference (0.000) between the managers' and managers' views with regard to job cards, see Table 5.39. The majority of the managers (71.9%) thought that the effect of the job cards not being clear is high, while only 40.7% of the employees said the same. The management emphasis on the issue of job cards not being clear is presumably because if the instructions are not clear, employee may not be able to perform the job adequately. Moreover, it is the employee's responsibility to complete the requested information regarding the job conducted in the job cards. This includes the part number of the new installed part, or the time that was taken to complete a maintenance task. This information is used for assessing the work performance in terms of the number of technicians needed and the time necessary to complete the maintenance task.

Table 5.39 Managers' And Employees' Views Towards Job Cards

		JOB TITLE		
		MANAGER	EMPLOYEE	Total
VERY HIGH	Count	46	111	157
	Expected Count	29.8	127.2	157.0
	% withins Q14-N	29.3%	70.7%	100.0%
	% within JOB TITLE	71.9%	40.7%	46.6%
	Std. Residual	3.0	-1.4	
VERY LOW	Count	18	162	180
	Expected Count	34.2	145.8	180.0
	% withins Q14-N	10.0%	90.0%	100.0%
	% within JOB TITLE	28.1%	59.3%	53.4%
	Std. Residual	-2.8	1.3	
Total	Count	64	273	337
	Expected Count	64.0	273.0	337.0
	% withins Q14-N	19.0%	81.0%	100.0%
	% within JOB TITLE	100.0%	100.0%	100.0%
	Std. Residual			

- *Motivation*

There was a significant difference (0.000) between the managers and the employee view with regards to motivation, see Table 5.40. The result suggest that a substantial majority of the managers (75.4%) view the effects of motivation on work productivity as high whereas only 51.8% of the employees said the same. The result may mean that the employccs are self motivated, or that the employee do not rank importance of motivation to be high when compared to other issues such as shortages of manpower.

Table 5.40 Managers' And Employees' Views Towards Motivation

		JOB TITLE		
		MANAGER	EMPLOYEE	Total
VERY HIGH	Count	49	142	191
	Expected Count	36.6	154.4	191.0
	% within JOB TITLE	75.4%	51.8%	56.3%
	Std. Residual	2.0	-1 0	
VERY LOW	Count	16	132	148
	Expected Count	28.4	119.6	148.0
	% within JOB TITLE	24.6%	48.2%	43.7%
	Std. Residual	-2.3	1.1	
Total	Count	65	274	339
	Expected Count	65.0	274.0	339.0
	% within JOB TITLE	100.0%	100.0%	100.0%
	Std. Residual			

5.6 SUMMARY OF CHAPTER

The survey analysis was useful in highlighting areas in which maintenance management need to give a great attention. The technicians in all the three departments were asked to answer questions, which relate to performance, efficiency and productivity. The survey analysis suggested that the majority of the technicians lack a required knowledge about the issue relating to performance, efficiency and productivity. This suggests that in order for the maintenance management to implement a successful performance measurement programme, then they would need to make the technicians aware of the issues. This could be achieved through a well-planned for and an organised training programme. This would be beneficial from several dimensions:

A. Once technicians gain the necessary knowledge about efficiency and performance related issues, they could contribute to their department.
B. Improve communication between maintenance management and technicians.
C. Allow technicians to be more motivated as they feel that they are contributing to their department, at the same time make them feel that maintenance management are listening to them.
D. Allow technicians to share ideas with their maintenance management.

Further findings of the survey suggest that management need to give more attention to several areas to bring about an improvement in overall performance:

A. Improve workplace environment.
B. Provide the technicians with the appropriate tools that would help them carry out the maintenance task with less time and effort.
C. Provide the necessary manpower to conduct the maintenance task.
D. Build technicians' awareness of the performance standards required from them.
E. Make the technicians aware of their department objectives.

CHAPTER SIX

DEA METHODOLOGY

CHAPTER SIX

DEA METHODOLOGY

6.0 INTRODUCTION

The chapter is aimed at explaining the basis of the Data Envelopment Analysis DEA method before applying it to Saudi Airlines' maintenance department. Thus, it will be discussed in further detail in Chapter Eight.

An improvement in the productivity of airline maintenance is highly desirable since productivity gains can be converted into an increase in operational performance. Since airline maintenance handles an enormous number of equipments, facilities, manpower, therefore, the outputs of such a huge operation are of great importance to operational management. A positive outcome could be expected from the application of productivity improvement techniques as was seen in Chapter Three. As seen in Chapter Three this means that a measurement system designed for measuring and monitoring airline maintenance activities must be in place to bring about an improvement in the overall performance of the maintenance activities.

Data Envelopment Analysis (DEA) handles multiple inputs and multiple outputs, that characterise airline maintenance as seen in Chapter Three and Chapter Two of the different variables available for analysis. And therefore the use of DEA analysis to provide such a system will be explored in this thesis.

Data Envelopment Analysis will be used to assess the impact of the airline maintenance operating strategy on the relative efficiency of its fleet. This analysis is useful for maintenance management to enhance their competitive position and to improve their operational performance, with the objective of improving overall productivity, reducing maintenance man-hours, and minimising maintenance cost in order to increase efficiency and productivity for the airline maintenance. Chapter Two listed different outputs and inputs used in the airline maintenance industry for the purpose of measuring efficiency and productivity. However, the variables used for the DEA analysis model will be discussed in Chapter Eight in more detail.

Management in the airline maintenance division always seeks to obtain current information on the activities being accomplished on the maintenance floor. This information helps management to identify the performance levels of the job being worked on. From the researcher's previous work experience information on current maintenance usually takes a long time to reach decision-makers. However, as up-to-date information is crucial to decision-makers in this industry, a systematic method for gathering and analysing data should be implemented.

Through the application of continuous improvement, e.g. by a performance-monitoring programme, managers can actually identify below average performance and therefore they can initiate the necessary corrective actions. Performance monitoring should provide accurate measures of performance for minimising cost and improving overall performance as well as being able to trace areas of inefficiency pre-defined by management. Among the advantages of continuous monitoring systems are that it helps to improve maintenance efficiency which as shown in Chapter Three should increase fleet utilisation reducing ground time and leads to fewer flight delays or cancellations.

As was seen in Chapter Three there are two reasons for the interest in measuring efficiency and productivity and the DEA is the way of achieving it. First, they form successful indicators, performance measures, by which production units are assessed. Second, the sources of efficiency and productivity differentials can be explored, with the aim of highlighting the sources of inefficiency. Consequently, management ability to quantify efficiency and productivity provides them with a control mechanism with which to monitor the performance of various production units under their control (Fried *et al.*, 1993).

Airline carriers are always seeking to run their operational activities as cost effectively, reliably and rapidly in order to stay profitable (Schefczyk, 1993). Cost efficiency, reliability and timeliness are used as measure of performance by performance measurement analysts for the purposes of identifying areas for improvement and providing an appropriate aid to strategic decision making. Such an aid is highly desirable as it is in line with the management's aim to improve efficiency. However, Schefczyk argued that measurements of efficiency need to be consistent with corporate objectives, as an airline may focus on load factors as a basis for performance measurement, while corporate strategy are aiming at an aggressive growth strategy, as was referred to in chapter regarding "sub-optimisation". In addition, Schefczyk (1993) noted that when analysing airline operations, management has to have a model that essentially relates the set of services to the resources consumed in order to provide a final product or service.

As was mentioned in Chapter Three, government and businesses pay a great deal of effort in measuring and comparing their performance to other competitors. The purpose of this comparison is to depict deviation from one period to another. This will allow management to conclude if they are performing as they should be or whether corrective measures should be taken. In addition, since profit motive in most public sectors is not the main objective when compared to the private sector, it is essential for public sector management to outline outcome measures, and these measures become a useful tool in evaluating performance (Norman and Stoker, 1991). However, the improvements in the productivity of the maintenance department are highly desirable, since the gains in productivity are converted into increased operational capabilities and a possible profit gain (Clarke, 1992).

Norman and Stoker, (1991) provides an example on using the DEA method to develop a system in each department with the main idea that all management levels could have a clear view of their objectives and at the same time be able to assess their performance, and if possible measure outputs relating to those objectives. One way to carry out this procedure was to identify activities and relate them to the resources being utilised. The example given in this respect is of an administrative nature:

- Staff utilisation, this will include the ratio of actual number compared to work measurement assessed numbers.
- Productivity, this can be measured by average of output per person.

- Accuracy, number of errors as a proportion of work dealt with.
- Customer satisfaction, this is usually given in a form of the number of customer complaints received.

An important concept, which is related to productivity measurement, is that of "effective" production and "efficient" production (Brinkerhoff and Dressler, 1990). The authors identify *Effective production* as the process that produces the desired results. An example from the airline industry is if an avionics shop were able to effectively increase the number of units inspected by 10% on a monthly basis. However, the 10% increase in effectiveness (output) may have been achieved by a higher cost of the level of input. This may have come at a price of 20% increase in capital and 12% in labour cost. This may indicate that while effective production has increased the organisation overall productivity has gone down. This is mainly due to the rise in the input needed to produce the output, in another words output has risen more quickly than the effective production. *Efficient production* would reflect achieving desired outputs with a minimum of inputs.

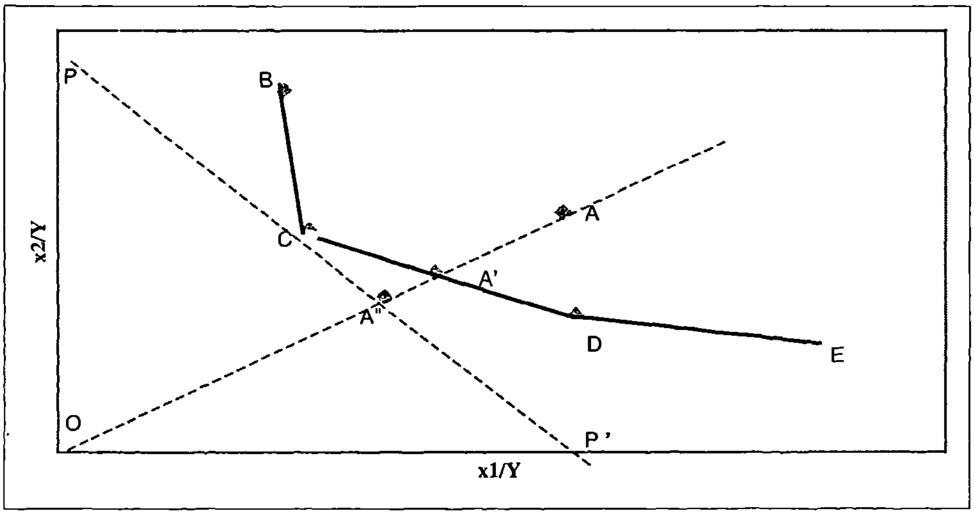
6.1 FARRELL'S EFFICIENCY MEASUREMENT

This section starts by defining the production function, the technical relationship between inputs and outputs. Athanassopoulos (1994) notes that efficiency is described in economic terms as "the outcome of comparing the actual output of a productive unit against a theoretically defined maximum output given the resources used" (p.4) . The maximum outputs that can be obtained from a given vector of inputs are defined by the production function. The term "Productive efficiency" has been used by economists such as Schmidt (1985) to describe how well an organisation is performing in terms of utilising its resources in order to produce meaningful outputs (Norman and Stoker, 1991). The *productive efficiency* has two components. The first one is called *technical* or *physical*, this component attributes to management capability for avoiding waste by producing as much outputs as inputs usage allows, or using as little inputs as outputs production allows. The second component is allocative, this component refers to management's ability to combine inputs and outputs in optimal production in the light of current prices (Fried *et al.*, 1993).

Farrell 1957 who drew upon the work of Debreu (1951) and Koopmans (1951) to define a simple measure of firm efficiency, demonstrated that the terms "Overall Efficiency" can be divided into two different measures; these are "Allocative efficiency" and "Technical efficiency" Figure 4.1 illustrates these measures. *Technical efficiency* reflects the firm's ability to generate maximum output from a given set of inputs. Accordingly, Fried *et al.*, (1993) technical efficiency is defined as: a procedure is technically efficient (or Pareto optimal) if an increase in output requires a reduction in at least one other output or an increase in at least one input. *Allocative efficiency* reflects the firm's ability to use the inputs in optimal operations, given the respective price and the production technology (Coelli *et al.*, 1998).

A simplified example is provided in Figure 6.1 of a single output, two input model which is rarely applicable in reality where multiple inputs multiple outputs are typical. This is because other important inputs are not accounted for.

Figure 6.1 Efficiency Measurement



Source: Sueyoshi, 1992:142.

However, the simplification allows simplicity of discussion of the production economic concepts. This in turns helps introduce the application of *Data Envelopment Analysis* (DEA) which is capable of handling multiple inputs and multiple outputs. Five DMUs are considered in Figure 6.1 and these are denoted by A, B, C, D and E. A *Decision-Making Unit* (DMU) is defined as the name given to any unit to be assessed for its relative efficiency using the DEA analysis. Since point A is located outside the efficiency frontier it is considered to be inefficient. However, point (A′) falls between the line C and D and therefore, uses less input quantities than the point A in order to give the same output levels. The proportion of its efficiency is identified as "*Technical efficiency*" (TE) this is measured by OA′/OA. *Technical efficiency* is defined as the input saving or the output augmentation or a combination of both. The degree of (1-OA′/OA) gives the technical inefficiency and thus, measures the proportion by which the inputs to point A could be changed while still maintaining the same quantity of output.

The line PP′ has a slope equal to the ratio of the two inputs. Point C corresponds to the cost minimisation point. Since the cost at the point A″ is the same as the cost at point C, then, A″ can substitute the point C in terms of cost and the ratio will be given as (OA″/OA′). This ratio indicates the measure "Allocative efficiency" and therefore, the ratio (1-OA″ /OA′) points out the *allocative inefficiency*, i.e. the possible reduction in cost from using the appropriate input mix. By combining both Technical Efficiency and Allocative Efficiency, Farrell derived a measure referred to as "Overall Efficiency" (OE) this is defined as OA″ /OA, while (1-OA″ /OA) is the overall inefficiency and denotes the possible reduction in cost due to a change from the point A (observed input quantities) to the point C (cost minimising input quantities) (Sueyoshi,1992).

It must be noted here that a performance measurement analyst using DEA is aiming to measure the relative productive efficiency of a set of comparable producing units, called *Decision-Making units* (DMUs). Since the Data Envelopment Analysis technique evolved in the public sector, the term "decision making unit" or *DMUs* is used to the operational unit under consideration. For example, the DMUs are defined as being a set of bank branches, hospital, schools, universities and police departments etc. Each DMU uses a number of different inputs to produce a variety of different outputs.

Farrell's work opened up an analytical procedure for both measuring efficiency and estimating production frontiers, it is widely accepted that the efficiency measurement was actually initiated with the research work of Farrell (Sueyoshi, 1992). Farrell's three efficiency measurements will be discussed in some detail. The two inputs and the single output are assumed to be all positive.

It is assumed in this example that two inputs ($x1$ and $x2$) and a single output (y) are used, under the assumption of Constant Returns to Scale (CRS), this assumption allows the technology to be represented using the unit isoquant.

Efficiency frontier is defined as the set of DMUs which scored 100% relative efficiency, these will be discussed further in Chapter Eight in more detail. The efficiency frontier derived from the set of the five points is given by the points B, C, D and E. In addition, the efficiency frontier is used to identify:

A. The set of efficient units.
B. The gap between the efficient units and the inefficient units.
C. Target setting.
D. Peer units.

In general the DEA analysis attempts to explore the performance of a system which utilises input factors to produce outputs. The nature of the performance measurement is highly affected by the set of inputs and outputs used in the DEA analysis.

On the basis of Farrell's 1957 paper, the CCR Data Envelopment Analysis model was developed by Charnes, Cooper and Rhodes in 1978. In 1985 Charnes and Cooper gave their formal definition of efficiency as (Norman and Stoker, 1991):

A) None of the outputs can be measured without either (i) increasing one or more of the inputs, or (ii) decreasing some of the other outputs;
B) None of its inputs can be decreased without either (i) decreasing some of the outputs, or (ii) increasing some of the other inputs.

In their 1978 paper CCR gave the definition of efficiency as "100% relative efficiency is attained by any unit only when comparison with other relevant units does not provide evidence of *inefficiency* in the use of any input or output". In the same paper CCR introduced the term "Decision Making Unit" (DMU). This is used to describe the set of firms, departments, divisions or units which have a common sets of inputs and outputs and are being assessed for efficiency (Norman and Stoker, 1991).

6.2 COST EFFICIENCY MODEL USING TWO FACTORS

As a preliminary to the discussion of the full DEA model, this section examines the use of a simple two factor DEA model to measure efficiency in an airline maintenance department using *flight hours* and *Maintenance cost*. One can claim that if a given month could have done better in terms of efficiency, this must be as a result of either (Norman and Stoker, 1991).

A. Achieving the same flight hours at a reduced cost through more efficient use of resources, or
B. Achieving greater flight hours through increased flight length (Stage) without incurring more than a directly proportional increase in cost.

Ruch (1992) states that any productivity ratio can be increased in four basic ways:

1. *Producing more outputs from the same inputs.* This can be accomplished by, reducing waste in any of the resources, or finding productive uses for by-products. This method could be termed "Working Smarter".
2. *Producing the same outputs from fewer inputs.* The way to achieve this is by using better technology, improved communications, reduced paper work, and streamlined methods allowing fewer inputs to be used.
3. *Increasing outputs more than inputs are increasing.* When the firm is in a stage of "controlled growth" getting bigger but also getting better, the firm can use highly skilled workers, better raw material, adding more advanced equipment to increase output by more than the increase in inputs.
4. *Reducing inputs more than outputs are reduced.* This can be achieved by selling unproductive divisions, combining product lines at one facility and other ways of downsizing.

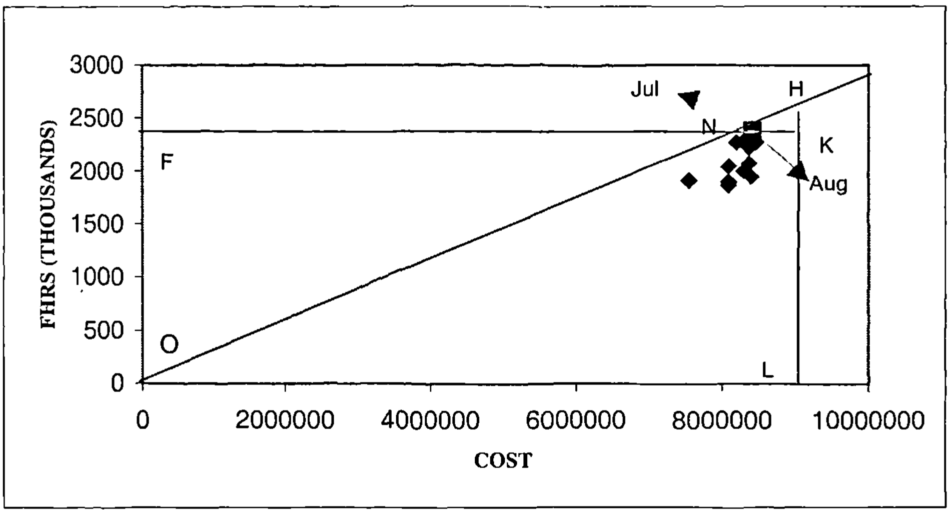
The question that needs to be asked is for a given level of flight hours achieved what level of cost should have been incurred? This is referred to as cost efficiency model. A simple example is illustrated utilising the Airbus (A-300) data for both cost and flight hours for the year of 1994. The cost efficiency Table 6.1 shows the efficiency for each month of 1994, the result in Table 6.1 shows that the month of July was ranked to be 100% scale efficient.

Table 6.1 Efficiency: Flight hours versus Cost

YEAR	COST	FHRS	FHRS/COST	EFFICIENCY	RANK
Jul-94	841548.2	2384	2.833	1.00	1
May-94	835598	2334	2.793	0.986	2
Sep-94	819511.6	2279	2.781	0.982	3
Aug-94	846598	2283	2.697	0.952	4
Mar-94	836445.4	2233	2.670	0.942	5
Apr-94	809562.6	2054	2.537	0.896	6
Feb-94	755591.7	1913	2.532	0.894	7
Jan-94	836548	2081	2.488	0.878	8
Dec-94	829497.6	2009	2.422	0.855	9
Nov-94	809555.5	1904	2.352	0.830	10
Oct-94	839532.3	1956	2.330	0.822	11
Jun-94	809562.6	1871	2.311	0.816	12

This efficiency model that was illustrated in Table 6.1, can be analysed graphically as shown in Figure 6.2.

Figure 6.2 Efficiency: Flight hours versus Cost



All twelve months flight hours are plotted against cost. The straight line on through the month of July and the origin indicates that all months on that line are equal in efficiency, therefore, this line is considered to be as an efficiency frontier. Since all other months fall below the efficiency frontier line therefore, they have a lower flight hours/cost ratio and hence lower efficiency. Since all other months fall below the efficiency frontier line this confirms that the month of July is the most efficient month. The efficiency score given earlier in Table 6.1 can be determined from Figure 6.2. For example, the efficiency of the month of August (0.952) is given by either of the ratios LK/LH or FN/FK, each of these ratios are also equal to ON/OH and both ratios are equal. The ratio of LK/LH is considered to be significant because it expresses the flight hours achieved by the month of August as a proportion of what it would achieved at the same levels of cost if it were efficient. Similarly, the ratio of FN/FK is the cost at which August could achieve given its current flight hours if it were efficient, this is given as a proportion of the cost at which it actually achieves it.

Moreover, the point H, represents the preferred performance level for August if it was targeted to achieve the best flight hours, given its current levels of cost. Additionally, the point N describes the appropriate performance of August if it was decided by management to operate at the lowest cost at which its current level of flight hours could be achieved.

It is necessary to mention here that this analysis assumes constant return to scale. This implies that an increase in cost is reflected in a proportionate increase in flight hours irrespective of the value of cost from which the increase occurs. The rest of the DEA analysis in this thesis will assume the constant returns to the scale input orientation model, avoiding the additional complications of the variable returns to the scale model. The input orientation model is used, because of the belief that management here have greater control over input quantities relative to output quantities. *Input-orientation* is the term used to point out that an inefficient unit could be transferred to become an efficient by reducing the proportions of its inputs, thus, keeping the output proportions constant (Hussain and Brightman, 2000:3)

The problem with the simple cost efficiency measurement in assessing performance is that it is not a reliable measure for performance if we have more than one input and one output. Moreover, it does not give an indication in itself of whether lower flight hours for a given month are due to other factors or due to inefficient use of resources.

The DEA technique adopted in Chapter Eight does not require the assumption of a mathematical form, while regression methods require the performance measurement analyst to assume the mathematical form for the relationship derived (Norman and Stoker, 1991). These authors states that choosing regression in preference to DEA is ascribed to the grounds that regression is easily understood, and also this can be attributed to the fact that the DEA is comparatively new technique. Both techniques are similar in terms of complexity in that:

A. The calculation of a surface is considered in both techniques.
B. Complex mathematics is required for both techniques to calculate the surface.
C. Graphical illustrations are needed to understand the underlying concept.

This simple example shows how efficiency can be analysed using DEA, thus, with a larger number of variables to be assessed this two-factor model is no longer feasible. Therefore, in this thesis four different DEA models are examined in Chapter Eight to determine the usefulness of the DEA methodology in identifying fleet efficiency as a measure of resource utilisation as in Chen (1997). The four different DEA models that would be developed in Chapter Eight represent a totally different picture of relative performance for the airline maintenance department. These differences look at different aspects of performance, for example, the use of resources to achieve the desired levels of efficiency. Or looking at the rate of average aircraft daily utilisation as an important aspect of performance measurement for maintenance management.

The approach used to build the four DEA models contains the answer for different issues of a great deal of importance to airline maintenance management. In doing so maintenance management objectives were looked at through the four different DEA models to achieve the highest levels of performance. These DEA model are overall fleet performance, fleet performance, utilisation model and reliability model. These four DEA models helps management to answer the question on how well they are doing in terms of aircraft utilisation for example at any given period.

In order to manage the organisation complexity, management would need to have a tool that would assess them in making the most appropriate decision, the one that is based on a scientific approach. This tool needs a reliable source of information, and a large part of this information relates to the judgement of people in making the right choice about selecting the right information to be used in the DEA analysis (Norman and Stoker, 1991). Therefore, a complex instrument to manage both strategic and the day-to–day levels must be in place.

6.3 THE CONCEPT OF DEA

DEA has received significant attention by many authors such as: Charnes *et al.*, (1994); Dogramaci and Fare (1988); Fare *et al.*, (1985); Sengupta (1995); Coelli *et al.*, (1998); Fried *et al.*, (1993); Liu and Sharp (1999); Rumsey (1987); Roll *et al.*, (1989); Bowlin (1987); Chan and Sueyoshi (1991); Clarke (1992); Peck *et al.*, (1998); Beasley (1995); Schefczyk (1993); Sueyoshi (1992); Thanassoulis and Dyson, (1987); Charnes *et al.*, (1991); Boussofiane *et al.*, (1991); Seiford and Thrall (1990), Peck *et al.*, (1998).
The approach to frontier estimation, proposed by Farrell (1957), was considered later by two authors. Boles (1966) and Afriat (1972) suggested a mathematical programming method, which could achieve the task of frontier estimation. However, their method did not receive great attention until the paper by Charnes, Cooper and Rhodes (1978) in which the term *Data Envelopment Analysis* was first used (Coelli *et al.*, 1998).

Data Envelopment Analysis was first proposed by Charnes *et al.*, (1978) for evaluating the relative efficiency of organisations. The relative efficiency score can range from 0 to 100%. The value 100% being the most efficient (Charnes and Cooper, 1985). The definition of efficiency is given in terms of ratio of output to input measure, and, the efficient frontier is made up of a piecewise linear combination of efficient DMUs. Thus, DEA can distinguish between efficient and inefficient DMUs depending on whether or not they are on the frontier line. DEA is designed to identify the sources of inefficiencies and to estimate the amount of inefficiencies that can be present in the different output and input.
The level of inefficiency is established by comparing the inefficient DMUs to a single referent DMU or a convex combination of other referent DMUs placed on the efficiency frontier, by which they utilise the same level of inputs and generate the same or a higher levels of outputs (Charnes *et al.*, 1994). Moreover, these authors state that there are two features of the DEA method that makes it of great interest to the analyst:

1. Each DMU is described by a single summary relative efficiency score;

2. When a specific DMU is projected for improvements, these improvements are based on an observed referent set, which reveal best-practice DMU.

6.3.1 Envelopment Surface

The production function is depicted to form the basis for a description of the set of input and output relationships in an organisation. This production function comprises a frontier for the production set. The set of DMUs in the observed data set will determine and at the same time will form the production function or the envelopment surface. This envelopment surface is referred to as the *empirical production function* or the *efficiency frontier*. There are two basic types of envelopment surfaces in DEA, these are referred to as *constant returns to scale* (CRS) and variable *returns to scale* (VRS) (Fried *et al.*, 1993). For the purpose of this thesis the CRS form will be discussed. Since the envelopment area is defined as the set of all possible input-output combinations, the two dimensional case, as seen in the simple example of section 6.2, involves the envelopment being drawn in a way that it will pass through at least one data point other than the origin, this leads to prescribing the area under the envelopment as a production possibility set (Macmillan, 1987).

The justification for using the CRS is that the DEA analysis in this thesis involves similar months, with common workload, therefore, similar cost and man-hours levels should be used. However, if maintenance management wants to allow maintenance schedule to be accomplished during the peak period, then they would expect to use twice as many resources; consequently, scaling up the quantity of aircraft to be maintained. Eventually this would result in a doubling of inputs. Since maintenance policies allow maintenance management to increase the maintenance work when needed, and since there is no reason to believe that the act of increased maintenance activities has a scale effect on the productivity of the inputs, VRS did not seem to be justified. Moreover, the CRS-I (input orientation) has a strong appeal when applied to maintenance activities (Charnes *et al*, 1994).

The input orientation model help to answer the question given the level of output, could the input be reduced? The model can be effectively used not only to observe changes in the utilisation of resources and to identify which input might be reduced, thus, to assess management to determine why maintenance practice varies from one month to another.

Good *et al.*, (1995) stated that the DEA over the last fifteen years, with the original formula of CCR with its constant returns to scale assumption, is consistent with the vast majority of the airline literature and therefore, it will be used in this thesis. Schefczyk (1993) states that the CRS is assumed because the airlines are unlike, for example, municipal subway system, can influence their own scale over time, by engaging in mergers for example. Since airlines are less limited to a special operating region due to regulation, therefore, airlines should not be credited for deviations from the optimal scale. This is better formulated through a CRS model. In addition, there is great interest in the airline industry to study the input-orientation model, this is because the output of an airline is regarded as a target value, which is specified by management. Airline operational management then would have to meet those targets with minimum use of resources.

6.3.1.1 Constant Returns to Scale

In the CRS model all supporting hyperlines for the CRS envelopment pass through the origin. A DMUi is efficient if it lies on a facet-defining hyperline of the envelopment surface. The CCR model of Charnes, Cooper and Rhodes (1978) is considered as the starting point for the DEA. The basic formula used to define efficiency is, Efficiency = $\frac{Output}{Input}$, in this section the focus is given to CRS, which means that the procedures are able to linearly scale the inputs and the outputs without increasing or decreasing efficiency (Class Notes, Ch.2, 1999).

The term *efficient reference* is defined as the reference set of an inefficient unit, to which the inefficient unit has been most directly compared when the efficiency rating is being calculated. These reference sets usually have similar input/output orientation to the inefficient unit under consideration. And therefore, it should provide an example of a good operating practice for the inefficient unit to adopt. As was mentioned in Chapter Three by Lawlor (1985) that reference comparison is very useful as it provides a direct comparison with competitors.

DEA calculates a maximal performance measure for each DMU relative to all other DMUs in the population. The topic of comparing DEA and regression analysis has been the focus of different authors such as Bardhan *et al.*, (1998); Thanassoulis (1993); Sengupta and Sefir (1988); Bowlin *et al.*, (1985); and Charnes *et al.*, (1985). The DEA model optimises on each observation instead of optimising across all observations as done in regression. This results in a better understanding of each DMU instead of depicting an "average" DMU. Moreover, DEA is capable of producing specific estimates for changes in inputs and/or outputs to project those DMUs located below the efficiency frontier onto the efficiency frontier.

The primary strength of DEA is that it can simultaneously deal with multiple (output) and multiple (input) measures and thus, give a single measure of the relative effectiveness of units without requiring specification of any *priori* weight. Moreover, DEA expands to the analysis of output efficiencies as well as input efficiencies (Chan and Sueyoshi, 1991).

6.4 DATA ENVELOPMENT ANALYSIS PROPERTIES

Orientation – Throughout this thesis relative efficiency measurements are assessed by using an input minimisation programme, as the output maximisation procedure is inappropriate at this stage. This is for two reasons, first, the organisation under investigation is concerned more with the issue of minimising input levels rather than maximising the output, as this orientation coincides with the strategic focus of the organisation. At this stage as Saudi Airlines is being prepared for privatisation, therefore, management attention is mainly focused on the possibilities of reducing input levels at this stage. Second, management can have more control over input levels, while there is difficulty in controlling output. For these reasons the input minimisation approach was preferred. In addition, efficiency studies have emphasised the input dimension of efficiency in education for example, that there are large measurement errors in the output cited (Ganley, 1989).

In an input-oriented projection the analysis seeks to maximise the proportional decrease in input variables, while staying within the envelopment space. Consequently, the maximal proportional decrease is accomplished in the first-stage problem, while the

resulting point is applied in the second-stage programme in the CRS or the VRS in order to obtain the projected point (Fried *et al.*, 1993).
Ali *et al.*, (1995) state that the implied objective of a DMU being assessed under the input orientation programme, is to achieve efficiency by reducing excess inputs used, while continuing operation with its present mix of technology. Similarly, Seiford and Thrall (1990) viewed the input orientation as producing the observed outputs with minimum resource levels.

Target – for a DMU, which is positioned below the efficiency frontier, it is important to note that DEA results are aimed to direct managerial actions in which the calculated improvements either in the input or the output are considered to be indicative of potential performance increase in the concerned DMU. More importantly, management attention can be directed towards the DEA result in acquiring a better understanding as to why some DMUs are located on the efficiency frontier, while others are considered to be relatively inefficient (Charnes *et al.*, 1994). The significance of the DEA analysis helps management to establish definable reasons for inefficiency. This will lead management to identify what organisational performance changes need to be implemented in the inefficient DMU to bring about improvement and how to implement these changes. In terms of Total Quality Management (TQM) attention is always directed towards benchmarking and therefore, best practice process of a DMU are located on the frontier (Charnes *et al.*, 1994). Using benchmarking as a tool to evaluate corporate strategy is considered to be an important issue in the search for competitive advantage (Watson, 1992). The author states that it is necessary to gain knowledge in areas that represent the core competence for the organisation, as this will be achieved through the use of a goal-oriented planning process with the aim of boosting performance with or beyond the competitors' level. Therefore, gaining a good knowledge of a unit's relative position, especially in the key business processes and core competence, which is essential aspect of strategic planning process, is greatly needed.

In DEA analysis the dual variable produces a hypothetical DMU for each inefficient DMU, this hypothetical DMU is perfectly (100%) efficient and is a linear combination of the DMUs included in the efficient reference set. Therefore, the reference set can be realised as a set of role models for the inefficient DMU to imitate. In an input-orientation model for an inefficient DMU to become efficient it is required to reduce all its inputs and maintain its output (Silkman 986:26). However, Boussofiane *et al* (1991) state that the input oriented target should be based on the maximum practical pro rata reduction in the controllable input levels. Besides, the reduction in the controllable inputs, an increase of the output levels needs to be considered for efficiency. Setting target levels is useful for management, as it provides them with an idea about any possible potential improvements in the unit under consideration. However, this potential improvement must be practical, in other words, it must be a realistic target, which could be achieved if changes in managerial policies took place. This means that if the management felt that they have extra capacity for extra production then the suggested targets by the DEA analysis could be taken as a guideline for the projected improvements. Management experience in the business under consideration is very useful in making the judgement about the usefulness of the target setting, and how they can manoeuvre the business in order to come close to or achieve the targets that were set by the DEA analysis. Thanassoulis and Dyson (1992) stated that the setting of targets can prove to be useful to management as they can help to identify the extent needed to bring about an improvement in efficiency. Therefore, it is desirable to take account of both the controllability of inputs and outputs as identifying priorities when setting targets.

In recent years best practice has become a valuable performance measurement technique. Its main purpose is to seek an enhanced competitive advantage by learning from relative performance at different levels: strategic, operational or business management level. Dence (1995) states that comparisons are ideally established on the basis of time, cost and quality, however, these are considered from different viewpoints either functional or from a business perspective. The improvement of competitive business performance is considered to be the most critical challenge of a strategic nature for many organisations. Much of the incentive received by an organisation attempting to implement the best practice technique are given in cost reduction programmes as a key analytical tools in identifying performance targets (Dence, 1995).

Weights in DEA – Weights can be applied to the variables in DEA analysis to provide more control by the person conducting the analysis; they are also applied if management wants to emphasise certain variables. The application of weights in DEA requires the set of DMUs under investigation to have the same set of outputs and inputs (Ganley, 1989).

Weights restriction is defined as the set of weight to be applied into the DEA model which are calculated to determine the efficiency of a unit. DEA allow each DMU to select any weights for each input and output, provided that they fulfil two considerations. First, no weight can be negative. Second, the weights must be universal, this means that any DMU should be able to use the same set of weights to evaluate its own ratio of weighted outputs to weighted inputs, and that the outcome of the ratio does not exceed one. Therefore, each DMU in the DEA analysis is expected to select the weights that maximise its own efficiency score. This means that each input and output will be evaluated in such a way that it would maximise the ratio of its own weighted output to its own weighted input (Sexton, 1986).

Roll *et al.*, (1991) state that there is no single "correct" procedure in applying the values for weights. Therefore, there are three characteristics of DEA that should be presented:

1. The virtual weights depend on the units, in which factors are measured. This means that a change in the unit of movement would cause a change in the weights.
2. The different weights are considered to be meaningful only in a relative sense.
3. Setting high bounds on one subset of weight will have an effect on the range of other DMUs.

In addition, Roll *et al.*, state that there are several techniques by which weight restriction could be applied to the DEA model. First, the analyst can run a DEA model without imposing any weights restrictions. Then sets of weight matrices are developed for each input and output. There are various methods of assigning the weights. For example, the analyst may use his/her own judgement, or the method proposed by Roll *et al.,* can be used. This determines a ratio variation for each weight is then set. Then the weights are set at this ratio as an example (1:2), this technique allow the analyst to use his judgement as to the relative importance of the different factors. The final method for setting weights is that the analyst can start using a known practicable set of weights, and then allow changes in weights by a fixed percentage. However, this method depends greatly on managerial attitudes towards an acceptable variation in the weights.

Roll *et al.*, (1991) state that the process of setting bounds in the DEA model is considered to be case-dependent, therefore, different approaches can be implemented, and thus, different factor weights could be imposed on the model, depending on the application.

In the analysis of weight restriction, if the constraints on the weights are too loose then there is little effect on the DEA model, while very tight restrictions will allow little or no scope for flexibility, and therefore, the resulting model may be unfeasible (Ball *et al.*, 1999). In terms of input the maximum weight specified is 100%, according to Ball *et al.*, (1999) it is apparently not possible for that factor to achieve a virtual weight of 100%, because of the constraints applied to the remaining factors. In terms of the output, the authors believe that each output should be able to contribute equally to the efficiency scores, however in practice some output may contribute more than others to the efficiency scores for each DMU. The technique of implementing weights in the DEA should also reflect the importance of the different variables, this is viewed by management as a tool to control efficiency scores, in order to reflect the most acceptable efficiency scores.

Roll *et al.*, (1991) state that one of the advantages of setting weight restriction is to show the hidden deficiencies in performance relative to other DMUs. However, the magnitude of weight variation can vary from one case to another and therefore, a general guideline for reasoning may be difficult in some cases.

Dyson and Thanassoulis, (1988) state that by recognising that the weights point to a value or a cost that is associated with an input or an output, then the assessment can provide justifiable restrictions on weights. And the constraint of weights in this way will naturally enhance the discriminatory power of the DEA.

Wong and Beasley (1990) state that when deciding to implement weight restriction, the proper way to arrive to this process is by seeking agreement of experts familiar with current situation. However, the way to implement weights could be determined by answering the following questions (although, in these two questions the authors use an output approach, thus, the same principle could be applied to input orientation model):

- 'Do you think that the significance of output measure i in assessing DMUs could be as low (as high) as z%? or

- 'Should as a matter of policy, the importance of output measure i in assessing DMUs be allowed to be as low (as high) as z%?

Peer selection – When a specific inefficient DMU is being compared to other DMUs in the set, what it actually mean for the reference DMU from a policy view is the setting up of peer units, which helps in observing inefficient DMU (Sengupta, 1995). Thanassoulis and Dyson, (1987) stated that an inefficient DMU should be able to compare itself with its peer units, this is done to imitate better performance levels than its actual levels.
As was mentioned in Chapter Three benchmarking is defined as the process used to measure the company's method, process, procedure, product and service performance compared to other companies identified in the same category. This strategic view takes a wider perspective in comparing the company's performance to other competitors, as this helps in understanding relative competitive advantage (Watson, 1992).

For each inefficient DMU the DEA analysis determines a set of efficient units this set of efficient units forms the peer group for an inefficient unit. This set of efficient units will have similar input and output orientation, in order to draw up the relationship between the inefficient units and the peer group, the DEA assessment is done by comparison with other units for the purpose of improving inefficient units' performance. The usefulness of the comparison is to help scale input/output vectors of peer units for the purpose of ease of comparison with the inefficient units. Target setting and the introduction of the best practice are two of the useful elements of the peer units. However, not all peer groups are of the same importance to the inefficient unit. Therefore, a percentage must be calculated for each input/output, this computation will discover the scope to which any peer units dominate the set of the peer units. Then the dominant peer will act as the most favourable peer for comparison (Boussofiane *et al.*, 1991).

Efficient units in DEA – To investigate the reasons that allow a unit to be efficient, it must be noted that the DEA analysis allows units to freely choose the most appropriate weight mix for inputs and outputs, that make it look most efficient. In the case that a unit needs to ignore a set of inputs and/or outputs in order to appear efficient, then it sets a very small weight to those unwanted inputs and outputs, as they will be diminished, and the DEA analysis would keep the mix of input/output that will make it looks efficient.

Another important element in setting the efficiency level for the efficient units is to look at the 'virtual' inputs and outputs (Boussofiane *et al.*, 1991).

Thanassoulis and Dyson, (1987) state that the set of virtual inputs and outputs allocated to each input and output indicate how the efficiency rating is obtained. In Chapter Eight, the DEA analysis illustrates the virtual input and output assigned to each input and output in the set. This is useful in telling the analyst which of the input mix or output mix has contributed to the unit's efficiency. This will lead the discussion to a further investigation of the efficient unit, which will focus on whether the identified 'virtual' input and output are evenly distributed among the mix of the input and output variables, or are focused only on one single variable. Boussofiane *et al.*, (1991) note that for any efficient unit the sum of its virtual outputs illustrates the contribution to the rating by each output. However, in the case of the virtual input, they sum to a pre-set constant, normally 100, and thus, the virtual input illustrates the magnitude to which a specific input appears in the comparison between units.

Thanassoulis and Dyson, (1987) suggest that if a unit is identified to be efficient and the virtual input and output is shown to be uniformly distributed among all inputs and outputs mix, then it can be strongly said that the unit shows a well rounded performance, as all aspects of performance have been taken into account.

A final remark is necessary on the efficient units and their potential for improvement. Thanassoulis states that potential improvement for efficient units should not be ignored, since DEA assessment is based on relative efficiency. However, the potential improvement for a unit is more likely to be achieved in a unit that does not have a well-rounded performance, which means that if much weight allocated to a specific input or output mix, and little or no weights being allocated for other variables, the unit that does not have a well rounded performance will attempt to improve its operating practice by focusing on its areas of weakness.

Inefficient units in DEA – DEA analysis has the ability to identify both efficient and inefficient DMUs. The purpose of the reference set of efficient DMUs is to provide a guideline within which perfect targets can be set for the inefficient DMUs; to allow them to improve their efficiency (Thanassoulis and Dyson, 1987). They pointed out that one of the advantages of comparison between an efficient and an inefficient unit is to demonstrate the weak performance of the inefficient unit. This analysis is even more useful as it will actually illustrate the magnitude of deficiency and highlight the problem areas. Consequently, this comparison provides management with valuable information on the units concerned, in which, proper actions are needed in order to meet performance targets which is high maintenance performance and low cost. If management takes the initiative to attempt to implement the pre set targets from the DEA analysis, it must be understood that some of these targets may not be achievable in practice. This is because some of the inputs and outputs used may not be fully under the unit's control. As a general guideline, the proposed adjustments for the inefficient units are more applicable if inputs are controlled. Where inputs and outputs are controllable by management, then the new achieved targets can be accomplished over a period of time. Rowley (1977) states that a firm under investigation for inefficiency will be under pressure to reduce inefficiency, and therefore, management responsible for improving efficiency will introduce measures to eliminate non-functional activities, and seek out higher productivity opportunities which in the past went unrecognised. Therefore, though inefficiency will not disappear entirely, competitive pressure will minimise the level of inefficiency. Ware (1977) states that one of the reasons for the existence of labour inefficiency is that, conflict of motivation between employee in the same department will eventually result in an output, which tends to be low.

The efficiency of a DMU could be assessed for a particular time period. As was noted in Charnes *et al.*, (1994) which discussed the notion of *Window analysis* to assess performance over a period of time. Chapter Eight and Nine of the thesis attempt to discuss the relative efficiency of the maintenance department over a 60-month period. Efficiency chart would be presented to clarify the time period of good performance and others with low performance. In addition, the implication for Saudi Airline maintenance managers in using the relative efficiency chart in using it as a tool for managerial learning about past performance behaviour will be discussed.

Efficiency change over time – The reason for change in efficiency over time could be attributed to the variation in staff and/or operational policies or to the effect of seasonal factors as was mentioned in Chapter Three. The effect of seasonal factors can have a different consequence on different units for each period of time. However, the efficiencies obtained from the DEA analysis will provide strong evidence if variability in efficiency does actually exists. Rowley (1977) states that monitoring the growth in efficiency seems to be appropriate to identify efficiency change. This will also help management to understand that any shift in the relative efficiency will also reflect any output quality changes or any shift in the demand, which impacts on the level of efficiency.

Through the application of the DEA analysis, any fleet manager will be able to have an insight into the direction and the rate of improvement of their fleet maintenance performance over time. The design of the four DEA models would allow maintenance management to answer questions such as, are we getting better at the things that are considered to be most important to our operating strategy? What is the rate of our fleet improvement? Where do we focus our attention the most? The design of the DEA methodology was intended to answer management questions with regard to "Overall fleet performance", "Fleet performance", "Fleet utilisation" and "Fleet reliability". The DEA analysis involves several steps, these include, the selection of the different inputs and outputs that represent the organisation under consideration, forming the DEA model, initial run up of the model, assessing the selected variables and finally interpreting the outcomes of the DEA analysis. Chapter Seven will deal with these issues in more detail. Bowlin *et al.*, (1985) note the utility of implementing both techniques DEA and Multiple Regression for comparing the two methodologies to compare the accomplishment relative to knowledge of the underlying model, and what could be detected by employing these two techniques. However, the multiple regression lacks the ability to accommodate multiple inputs and outputs. One key element in this comparison is that the multiple regression lacks the ability to identify the source of efficiency and its level in the various inputs. Unlike the DEA as it is a straight forward issue, that is not all, thus, as one of its great feature that the DEA adequately identify the source and the level of inefficiency.

6.5 SUMMARY OF CHAPTER

The continuous pressure by management to enhance efficiency and performance has led to the increase in using different managerial tools to assess the process of measuring performance and productivity. The application of the Data Envelopment Analysis is as one of the tools used to assess the relative efficiency of organisation units. The DEA can give the principles for a framework for assessing organisation efficiency using inputs and outputs to identify the levels of the relative efficiency, identify targets, peers and reference set.

Due to the importance of the topic of performance measurement the interest in the DEA methodology has grown further in the last twenty years since the original model was given by Charnes *et al.*, (1978). Management can now use the DEA to draw the link between resource allocation and performance and/or assessing the impact of operational activities on the level of performance, as will be seen in Chapter Eight.

Data Envelopment Analysis technique has the ability to handle both multiple inputs and multiple outputs. Due to the different variables available for analysis, the DEA analysis model allows the analyst to design a model with a set of input and output which if analysed will calculate the relative efficiency of the business under investigation. In addition, DEA can be designed to have input or an output orientation. DEA also has the ability to identify peers, set targets and compare the least efficient DMUs with best practice.

CHAPTER SEVEN

DEA DATA COLLECTION

CHAPTER SEVEN

DEA DATA COLLECTION

7.0 INTRODUCTION

This chapter describes the procedure for collecting the data for the DEA models and how was it carried out. In addition it will discuss the availability of the data and a brief description of the variables used in this research.

7.1 ACCESSIBILITY OF DATA

In this research the data were gathered from both the Aircraft Reliability Programme department (ARP) and the Technical Information System department (TIS). In each of these department the ARP and the TIS data were always made available through Miniframe computer data base. Apart from the availability of data, the accuracy and reliability of the data are an important elements, which can determine the success of a DEA analysis. The researcher had spent a considerable time at both the ARP and the TIS departments in collecting the data needed for the DEA analysis. Therefore, in terms of reliability of the data, they are considered to be highly reliable, and therefore, the DEA assessment would be able to reveal actual activities carried out.

Since the maintenance facility of Saudi Airlines is the main focus of the research. Top maintenance management have suggested that the Aircraft Reliability Program department (ARP) and the Technical Information Services (TIS) department in the Saudi Airlines Technical Services to be the mean of collecting the data requested. Saudi Airline officials granted full access to the operational data for period from 1994 to 1998 necessary for the thesis. An *HP 3000 Mini frame* is used to store airline's operational data. This was used to extract selected variables that will fit each fleet, in this respect the TIS unit provided valuable assistance in gathering the data needed. Each department manager is requested to submit data related to the maintenance activities conducted in their department. For example, the Hangar manager will submit the data to the ARP and TIS department such as the total man hours used to accomplish a C-check. The data are then stored in order if management wishes to verify a certain maintenance check, or they decided to launch an investigation then they can refer to these data for further analysis.

7.2 CHOOSING THE SET OF INPUTS AND OUTPUTS

Defining the objectives or the goals of the maintenance department was considered to be a key element in determining the accomplishment of the DEA analysis, as was mentioned in Chapter Three. In the airline maintenance department goals are defined in terms of achieving the highest aircraft utilisation, maximum aircraft reliability and lower maintenance cost and man-hours. These goals or objectives are not only the maintenance department objectives, they are the objectives of the organisation as a whole. According to Harper (1984) the definition of the goals of a unit under investigation, must also have a relationship to overall goals where appropriate.

At this stage defining the unit under consideration was considered to be a key element in the success of the DEA analysis. The maintenance department was to be the focus of the study, therefore, the decision was made to explore efficiency measurement in the maintenance department rather than evaluating the whole of the Technical Services (TSV). This is important as the input and output mix will only focus on the activities of the maintenance department, especially the outputs, which reflect the kind of service delivered from the different fleet. All four DEA models of the different fleet maintenance process are shown in Table 7.1.

Table 7.1 All Four DEA Model Input and Output Variables

	INPUT	OUTPUT
MODEL. 1	Cost, Man-hours	Flight Hours, Cycles, Departure, Utilisation, Flight hours/Cycles, Technical on-time Performance
MODEL. 2	Cost, Man-hours	Flight hours, Cycles, Departure
MODEL. 3	Cost, Man-hours	Utilisation, Flight hours
MODEL. 4	Cost, Man-hours	Flight hours, Cycles, On-time performance

Great attention was given at this stage to co-ordinate efforts with maintenance management to come at a shared understanding of the significance of inputs and outputs to management, since the selection of inputs and outputs in the DEA analysis has great implications for the results obtained. In addition, these inputs and outputs needed to be practically useful to maintenance management. However, for the purpose of this study management was mainly concerned with minimising input variables. As this was discussed earlier in Chapter One, the airline under investigation was due to be privatised, and at this stage input minimisation was the prime focus of top maintenance management.
In this respect there were only two input variables of main concern to management (Cost and Man-hours) and these were used in the DEA analysis.

To ensure maximum advantage from the DEA analysis, management accepted these inputs and outputs measures, as they represent real operational activities. The DMUs used for the DEA analysis represent the months, over a five years period. The implications of the fact that demand for air travel varies with the time of the year, will be explored further in Chapter Eight.

7.3 DATA COLLECTION ORGANISATION

For the purpose of collecting the data, the maintenance departments were visited and formal communication between the Line, Hangar and Shop departments were established. This was useful to arrange how the data were going to be collected, and where they were going to be collected from. In addition, several other departments were visited for the same purpose, such as the maintenance planning and control. However, it was finally found that the ARP and the TIS department could actually assist in the gathering of the data requested which includes: *Cost, Man hours, Flight hours, Cycles, Departure, Utilisation, On-time performance* and the ratio of *flight hours to cycles.* During the gathering of the data key maintenance managers provided assistance to make this process as accurate as possible. These data were specially collected for the purpose of this thesis.

7.4 THE PROCESS IN COLLECTING THE DATA

As mentioned in Chapter Two, the airline maintenance industry is a complex one, which involves a large amount of capital equipment. Part of this investment is allocated to the Technical Information Services (TIS). For the purpose of collecting the data needed to form the DEA models, two technical departments Aircraft Reliability Programme (ARP) and Technical Information systems (TIS) were heavily involved in the process of collecting the data and these were done in conjunction with the ARP and the TIS departments.

Due to the large scale of the operation the assistance of these two department was needed to carry out the data collection. Several choices were available for collecting the data. Technical reports, are printed on a monthly basis for several departments, such as Engineering and Maintenance. However, these printed reports do not include all the variables requested. In addition, a few of these printed reports were not available, which would have caused a problem in collecting the data. Since it was thought it would take more effort going through the printed monthly reports to

extract the data from the monthly reports for a five years period, it was decided to collect the data from the ARP and the TIS computer systems.
The next step was to identify all the variables, that reflected the actual business activities. A large number of possible variables were narrowed down, only to those that were considered to be the direct responsibility of the maintenance department and at the same time fulfil the requirement of the study.

According to the TIS department it was possible to go back five years only in collecting the maintenance data. There were two advantages of choosing this time frame. From management's point of view, it was preferable to start in 1994, because during and after the Gulf War there were several interruptions to flight schedules, which did not only affect Saudi Airlines alone, but were world-wide circumstance. However, management's view was that two years after the Gulf War was considered sufficient to ensure that there would be no major effect that would disturb the data.

The decision to choose the end of the study period as 1998 was because, the airline was due to receive the new fleet, which was supposed to enter the service at the fourth quarter of 1998. However, most of the new fleet was in service at the end of 1998, and those planes were not included in the study. Another reason was that two types of aircraft were due to be phased out, the B-737 and the L-1011. In this respects the time frame that was selected to conduct the DEA analysis is considered to be the right time just before the phasing out of the old fleet, and before the new fleet was in full service.

Given the previous experience of the researcher, the decision was made to focus the analysis on the four types of aircraft in the fleet classified on a monthly basis, in addition, to focus the attention on the various variables that were needed to set up the DEA model and those variables that were relevant to the maintenance department. The main point in selecting the variables was to focus on the services that were being delivered and in return identify the different output variables generated by the daily operations.
Using all the operational variables generated from the daily maintenance operation would have been an impossible task. Furthermore, attempting to include all these variables in one model would not have been be feasible. As was mentioned in

chapter four, if the DEA model has too many inputs and outputs, the chances are that the DEA analysis will show most of the months investigated, will turn out to be efficient. Therefore, concentrating on the core business meaning the actual daily operational activities, was the first priority, and to focus on those variables that were going to be used in the DEA analysis so that they reflect a great deal of importance to maintenance management. And at the same time they do reflect the business in a greater respect.

To ensure that these variables are of great importance to management, the monthly technical reports have two main areas. These include reliability (*on-time performance*) and aircraft utilisation. However, there are other key variables that reflect general performance of the fleet these includes *number of pilot reports* for example. However, with this in mind, the variables that were directly responsible for reflecting the two main issues were requested and collected for the DEA analysis. Further revisions of these variables were made to identify the set of input and output factors that constitute the DEA model.

In determining the size of the DMUs to be included in the DEA analysis, one must keep in mind that a very small number of DMUs with a large number of input and outputs will make the DEA infeasible. According to Golany and Roll (1989) the larger the population, the higher the probability of identifying high performance units, those are the one that could determine the efficiency frontier. In addition, a large set of units allows more accurate identification of typical relations between input and output in the set. According to Ali *et al.*, (1988) the number of units should be at least twice the number of the inputs and outputs in the DEA analysis.

CHAPTER EIGHT

DEA MODELS AND MAINTENANCE PERFORMANCE AUDIIT

CHAPTER EIGHT

DEA MODELS AND MAINTENANCE PERFORMANCE AUDIT

8.0 INTRODUCTION

In this section the four different models (Overall efficiency, Fleet performance, Utilisation and Reliability) will be explained in detail. This will include a justification of each model and what exactly each model reflects. Information is given as to why the selected variables were used and finally a discussion of what each model is expected to deliver. The nature of the data available allows that fleet efficiency to be evaluated over time. This evaluation of the four different fleets studied the A-300, B-747, B-737 and only model one for the L-1011 which are explored over a time period of five years, are expected to provide a general picture of the relative efficiency for these fleets. After discussing the different DEA models for each fleet, the weight restriction will be considered for the A-300 fleet, and finally, the application of the DEA analysis and how the DEA analysis could be used by management will be discussed.

Consequently, the aim of the DEA analysis are to identify best practice, set targets for inefficient months, identify peer months for the inefficient months, the extent that each month can be identified as efficient or not efficient, and how this information would help management in practice. Generally, the main purpose of this chapter is to explore the feasibility of applying the DEA analysis to the airline maintenance department.

According to Charnes *et al.*, (1994) individual units may have different technologies in place at any given point in time, and therefore, lower technology units may appear less efficient. Furthermore, Thanassoulis and Dyson (1992) considered the usefulness of DEA assessment in examining the available resources to be important to management.

8.1 MODEL SET-UP

Before discussing the different DEA models that were used to examine the efficiency of the maintenance department, a more general discussion will be provided of potential inputs and outputs. Various variables were presented in Chapter Two, which is generally used by all airline maintenance departments as a mean of assessing their efficiency and productivity. However, as was mentioned in Chapter Two the importance given to these variables varies from one maintenance department to another based on the operational activities conducted and the frequency by which these variables are being gathered also varies. As an example, of the set of variables being gathered include on time-performance and number of technical delays etc. The following will discuss the specific four DEA models along with the inputs and outputs that were used for analysing the maintenance department efficiency. The DEA analysis was carried out by Banxia *Frontier Analyst* software.

Model One is aimed at providing top maintenance managers with a complete and thorough analysis of all the relevant and significant variables, which are generated as a result of the airline maintenance daily operations. As seen Chapter Two and Chapter Three top maintenance management are always interested in having a good knowledge about the overall picture of the maintenance departments. The selected in this model is being selected in order to provide top maintenance managers with the significant information on how well their maintenance objectives are being met. Consequently, the DEA model one will play that role by targeting the concerns of top maintenance managers. According to the result obtained from model one, top maintenance management could appropriately use the DEA analysis result of the relative efficiency and target setting information as guidelines for changes if current result deviate from their planned objectives. Moreover, the analysis of model one would also be of great use to top maintenance management in order to help them understand and verify some or most of technicians issues which has been discussed in Chapter Six, such as manpower shortages problem etc. The selection of the variables is designed so that they can provide a meaningful measurement of the efficiency of airline maintenance operations as a whole. Model one includes eight different variables; these are divided into two inputs and six outputs. For model one the variables that were used for the *inputs* are cost and man-hours. For each fleet a monthly *cost* figure in Dollars is given as the total cost of maintenance activities that were carried out on that fleet during a specified month. *Man-hours* are the second input variable, which is used to reflect the total number of man-hours used to perform the maintenance tasks on that fleet. The reason behind the selection of the these two input variables is to try to control the different input variables. The reason that they were selected as input because of the belief that they can be controlled by maintenance management, and because of the maintenance process to be completed both cost and man-hours are needed to generate the intended output. The variables used for the *output* in model one are flight-hours, number of cycles, number of departures, aircraft daily utilisation, flight-hours divided by cycles and technical on time-performance.

The total *flight-hours* for the month is used as an output measure of fleet performance. This measure is used because it is assumed that the flight hours an aircraft is able to achieve is measured by maintenance. Another output measure used is the number of *engine cycles* performed, which refers to the number of times the aircraft engines are switched on and off again during the month. This variable is considered to be a significant one, from the technical engineering point of view, in terms of reliability, as some parts which are installed on the aircraft engine have a lifetime that are measured by the number of engine cycles. Again engine cycles were used as an output because it is assumed that the engine cycles an engine is able to achieve is measured by maintenance. There could be a problem with using engine cycles as an output variables, as engine cycles may include cycles which did not contribute to flying hours, as in the case if the engine is being tested, it would be started several times by the engineers testing the engine in order to ensure that it is serviceable. A further output variable used in the analysis is the *number of departures*. This output variable is defined as the number of take-offs of all normal operated flight legs during the reporting period. This measure is used because it determines the number of departure performed by a specific fleet at a given time, and it is an indication of the airworthiness of the aircraft. Again the same situation applies here as in the number of cycles. As a normal procedure each aircraft would be flown by a test pilot after each major D-check to ensure that it is safe to fly; moreover, an aircraft could be used for training new pilots, in this case several take offs and landing could be accomplished in one day. A further output used in this model is *aircraft utilisation*, i.e. the average daily flying hours of one aircraft in service. This measure is used because again it is assumed that maintenance influence utilisation. Another output measure is Fhrs/Cycles since airline operators are always seeking to maximise the ratio of flight-hours to cycles. It is considered to be a maintenance output, as it is the resultant of dividing flight hours by the number of engine cycles; therefore, maintenance managers attempt to maximise this ratio. If this ratio is low it will mean that the utilisation rate is low as well or it will mean that the aircraft is flying for short haul only. The usefulness of this input variable is to highlight to top maintenance managers if the right aircraft size is used for a specific sector. For example, if the ratio of flight hours to cycles is small and the type of aircraft being used is a wide-body aircraft, then a narrow-body aircraft should be used instead. Finally, technical on time-performance (Tech O.T.P) is an output measure used to measure the extent of fleet reliability in despatching a particular aircraft on time. The reason for selecting this variable is to highlight an important issue, which is the on time-performance, achieved by a certain fleet.

Model Two is aimed at the Hangar and Shop middle maintenance managers in order to provide them with clear picture of their fleet performance. The model includes both the input variables used in Model One, but the output variables are focused upon fleet related performance measures. These *outputs* are: flight-hours, number of cycles and number of departures. The purpose of selecting these three output measures is to center the attention on variables, which reflect fleet performance. This model is expected to identify the most efficient month in terms of fleet performance. As was mentioned in Chapter Three in order to overcome the sub-optimisation issues discussed earlier, these variables identified for model two are used to meet the concerns of middle maintenance managers in the Hangar and Shop.

Model Three is aimed at middle maintenance managers in the Hangar in order to help them to assess fleet utilisation efficiency and how far their operational practices are effective in maximising the fleet average daily utilisation. This model again utilises the two inputs: cost and man-hours. The outputs include only two measures, which are flight-hours and the average daily utilisation. The reason for selecting these outputs is to illustrate how effectively a particular fleet is being utilised in terms of daily flying hours in a given month at the same time the model is also useful in reflecting Hangar efficiency in carrying out maintenance tasks. This model will identify those periods where a particular fleet is being utilised the most as well as highlighting those months with low utilisation rate.

Model Four is aimed at middle maintenance managers in the Line by measuring the reliability of each fleet; this is accomplished by using the same two inputs i.e. are cost and man-hours and three outputs these are: flight-hours, number of engine cycles and technical on time-performance. The focus of this model is based on technical on time-performance as a measure of fleet reliability. As can be seen from the description of the four DEA models to be used in assessing the relative efficiency of the maintenance department, that the maximum number of inputs used in the DEA models is two, and the maximum number of outputs used is six. This should help the DEA analysis to have a strong discriminating power.

By using the four DEA models described to measure technical operational efficiency, it is possible to link the different variables in each model to a designated maintenance department as was mentioned earlier in this chapter. The number of engine cycles is directly related to both the Shop and the Hangar as was mentioned earlier in Chapter Two from the nature of work carried out in each maintenance department. The technical on time-performance is mainly the responsibility of the Line department, which is responsible for dispatching the aircraft on time, provided there is no mechanical fault due to part failure. The number of departures is directly linked to the Line department, so if there are any technical delays caused by Line maintenance personnel they can be directly associated with Line department. Pilot reports and average daily utilisations are variables, which can be linked to the Hangar. It must be noted that in some cases when a delay is looked into there can be some controversy over who or which department is mainly responsible for that delay. Usually, it is not known until an investigation into the matter is carried out. For example, if a line AMT request an avionics technician to troubleshoot an electrical component on the aircraft before departure, and the avionics technicians arrived late, this will cause the aircraft to be delayed. This delay may well be argued to be mainly the responsibility of the line, whereas the line technician may have initiated the call well before departure, and it is the fault of the avionics technician who arrived late.

8.2 THE DEA METHOD USED TO ANALYSE THE OUTPUTS

One of the problems of the DEA analysis is that it produces an enormous amount of output. The end result is that for each aircraft type a DEA model was developed to explore the DEA's ability as a method of efficiency and productivity measurement in assessing airline maintenance units, as was mentioned in Chapter One. For this purpose each DEA model examined the different fleets in service to produce the following: relative efficiency graphs, target setting, best practice, reference set, input and output contribution and finally the total potential improvement. Each one of these different analyses will be discussed in depth, in order to highlight areas of inefficiency and suggesting possible improvement through target setting. In analysing the inefficient months, the least efficient month from each model is discussed in detail, to identify the reason for its inefficiency. In addition, consideration will be given to what should have been done in terms of operations, in order to improve the operational efficiency of the least efficient operating month. Moreover, each inefficient month is discussed in light of its location in terms of the significant periods of operation. The significant periods have been discussed in Chapter Two, and therefore, in this chapter each inefficient month is discussed from that point of view to determine whether or not the significant periods were the reason for the poor efficiency. In addition, weight restriction were implemented for the A-300 fleet, and the non-significant period analysis were also carried out in order to examine the differences in setting the target when compared to the all sixty month model.

8.3 A-300 FLEET ANALYSIS

The A-300 is considered to be mid-range type of aircraft, it carries about 258 passengers, and was received in Jun-84 (Saudia Airlines, 1997: P 41-42).

8.3.1 A-300 Overall Fleet Efficiency Analysis Model (One)

In analysing the data using model one "Overall fleet efficiency" the comparative efficiency score in Table 8.1 shows that DEA assessment yielded ten efficient months and their distribution of efficiency is from 79.2% at the minimum to 100% at the maximum, while the average efficiency score was 91%. The efficient months examined have an optimal solution $\theta^* = 1$ and all slack $S_i^*, S_r^* = 0$ values zero, as required by in Charnes *et al.*, (1978) and Banker (1984). Five of these efficient months were in 1997, four in 1998 and only one in 1994. This suggests that the overall maintenance performance for the A-300 has increased in the last two years of the period under study. The set of the efficient months provides the basis for drawing out the best achiever among the efficient months. In other words, the efficient months provide a target for the inefficient months in terms of better utilisation of the input variables.

Efficient Month Analysis

The efficient months shown in the Table 8.1 below are considered to be different from each other in terms of which represent the best practice. A reference set analysis is needed to identify how many times an efficient month appears in the reference set for the inefficient month.

Table 8.1 Comparative Efficiency Analysis

100% Jan-97	96.64% Sep-94	92.16% Jul-94	84.94% Jan-95
100% Feb-97	96.34% Nov-98	91.88% Mar-94	83.87% Jul-96
100% Apr-97	95.96% Sep-95	91.46% Feb-95	83.47% Dec-95
100% Jul-97	95.66% Apr-98	91.04% Jun-94	83.29% Apr-96
100% Aug-97	95.26% Dec-98	90.66% Feb-94	83.27% May-96
100% Jan-98	95.25% Apr-95	89.89% Oct-97	83.18% Sep-96
100% Feb-98	94.37% Apr-94	89.71% Aug-96	82.96% Nov-94
100% Aug-98	94.3% Jun-98	88.55% Aug-95	82.48% Dec-94
100% Sep-98	94.15% Oct-98	87.97% Feb-96	82.33% Oct-94
100% May-94	93.88% Mar-97	87.78% Oct-95	81.37% Jan-96
99.68% Nov-97	93.75% May-97	87.75% Jun-95	81.33% Mar-96
98.18% Dec-97	93.68% Jul-98	87.44% May-95	80.84% Dec-96
98.1% Sep-97	93.53% Mar-95	86.79% Jul-95	80.22% Jun-96
97.42% Jun-97	92.46% May-98	86.38% Nov-95	80.06% Nov-96
96.73% Mar-98	92.41% Aug-94	85.57% Jan-94	79.19% Oct-96

Figure 8.1 A-300 Overall Efficiency Model Relative Efficiency Scores

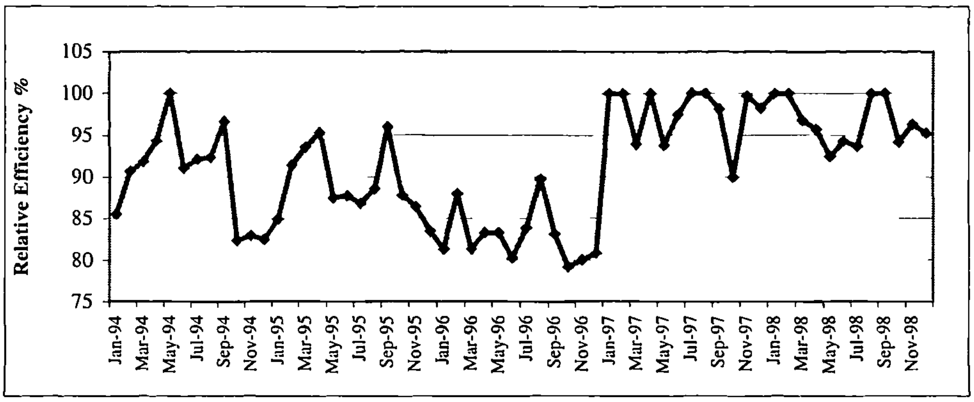


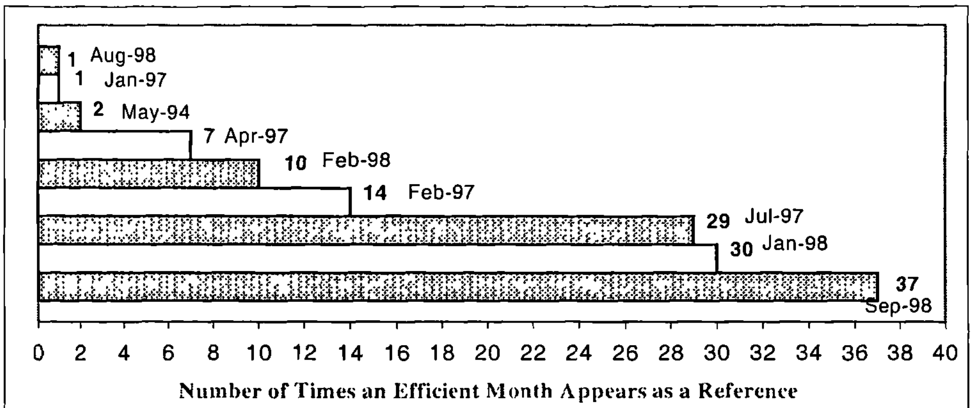
Figure 8.1 illustrates the time series graph for the relative efficiency scores obtained from the DEA model one a five year period. The efficiency scores in Figure 8.1 shows that there was decline in the relative efficiency scores from May-94 until November-96. After that the relative efficiency score for the A-300 started to rise sharply starting January-97 as it reached the levels of 100%. A possible reason for that big jump in the relative efficiency is that as was discussed in Chapter Two that each fleet type has a planned scheduled maintenance and these given as (A-check etc..), and since a D-check would be conducted every 8 years, it is suspected that the A-300 was due for its D-check.

The overwhelming evidence of an improvement in the overall performance of the A-300 fleet specifically in the last two years of the period could be related further to various factors. First, it could be related to a major policy change. For example, it might be a data artefact, because of a change in the definition of input variables such as cost, where part of the maintenance cost figures have been allocated to a different maintenance center from January-97, and for this reason the relative efficiency scores were higher than previously. Second, it might represent a genuine improvement in that management may have decided to outsource specific maintenance tasks, which they had previously been carried out in house. Finally, a genuine improvement could be because of technological change, as the maintenance department may have acquired new equipment, which helped improve the work process.

Efficient Month Analysis

Figure 8.2 below shows that an efficient month September-98 constitutes a "best practice" month for model one, as it appears 37 times in the reference frequency set. Therefore, September-98 can be determined as the best performing month in this sense. Months in the efficient reference set are relatively efficient and they are termed "Good-practice" months, this indicates that in the sample reported in Figure 8.1, the DEA analysis did not identify other months that were more efficient than these set.

Figure 8.2 Overall Fleet Efficiency Model, Reference Set Frequency For The Efficient Months



The result for all the efficient units analysing and the list of all the inputs and outputs which contributed to the efficient months are listed in Table 8.2 below. Looking at January-98, September-98 and August-98 for example, shows that the main contributing factor to these months' efficiency was their high ratio of flight hours to the number of cycles performed, this strongly suggest a change in routes flown.

Table 8.2 Input and Output Contribution Of The Efficient Months

	I/Os	Level %		I/Os	Level %		I/Os	Level %		I/Os	Level %
Sep-98	Cost	96	Feb-98	Cost		Jul-97	Cost	100	Aug-97	Cost	80
	Man-hours	4		Man-hours	100		Man-hours			Man-hours	20
	Fhrs			Fhrs			Fhrs			Fhrs	100
	Cycles			Cycles			Cycles	38		Cycles	
	Deprt	33		Deprt			Deprt			Deprt	
	UTZ			UTZ			UTZ			UTZ	
	Fhrs/Cycles	67		Fhrs/Cycles			Fhrs/Cycles			Fhrs/Cycles	
	O.T.P			O.T.P	100		O.T.P	62		O.T.P	
Jan-98	Cost	93	Apr-97	Cost	84	Jan-97	Cost	95	Aug-98	Cost	97
	Man-hours	7		Man-hours	16		Man-hours	5		Man-hours	3
	Fhrs			Fhrs			Fhrs	48		Fhrs	
	Cycles			Cycles	83		Cycles			Cycles	
	Deprt			Deprt			Deprt			Deprt	34
	UTZ			UTZ			UTZ			UTZ	
	Fhrs/Cycles	100		Fhrs/Cycles			Fhrs/Cycles			Fhrs/Cycles	66
	O.T.P			O.T.P	17		O.T.P	52		O.T.P	
Feb-97	Cost	93	May-94	Cost							
	Man-hours	7		Man-hours	100						
	Fhrs	46		Fhrs							
	Cycles			Cycles	100						
	Deprt			Deprt							
	UTZ			UTZ							
	Fhrs/Cycles			Fhrs/Cycles							
	O.T.P	54		O.T.P							

Furthermore, this suggests that the A-300 fleet was utilised for longer than usual flight hours compared to the number of cycles accomplished in that month. Since the A-300 fleet is considered to be a mid range type of aircraft, it is desirable to increase this ratio of flight hours to number of cycles. This means that the A-300 should be used for a longer haul than its current mission, as management always aims to boost this ratio. Moreover, the month of January-98 falls in the busy period, which demands more flight hours than any other time of the year. Consequently, this type of analysis for efficiency reflects the proper utilisation of the fleet when demand for air travel is high. Another interesting observation in the set of the efficient months is August-97. This month was ranked to be efficient and the analysis of the inputs and outputs that contributed to its efficiency shows that August-97 was deemed to be efficient due to its high flight hours. Again this can be interpreted as for January-98, as both of the months fall during the peak period and still the performance was superior. They only differ in the output variables, which contribute to their efficiency. This raises the issue of the application of weight restrictions, which will be discussed later in this chapter.

Moreover, the input and output contribution of the efficient month shows that on time-performance was weighted heavily in February-98, February-97, January-97 and July-97. This analysis suggests that during the peak period especially early in the year on time-performance is an important factor in determining efficiency. July-97 was also identified as being efficient based on its on time-performance and it was considered to be within the significant period.

The last two efficient months to be discussed are May-94 and April-97. These were efficient due to the high number of engine cycles performed during these months. This suggests that during April-97 and May-97 the A-300 have accumulated a large number of engine cycles. This may be because it was been used for a shorter haul during those months. The implication of this result is that the A-300 mission varies during the year; as this type of aircraft may be generating more flight hours on long hauls at busy times of the year, while when there is less demand it is used for shorter hauls. This is clear from the months, which had the largest number of engine cycles; these are the time for the Haj season, and the aircraft would have flown to Europe and Africa during these months.

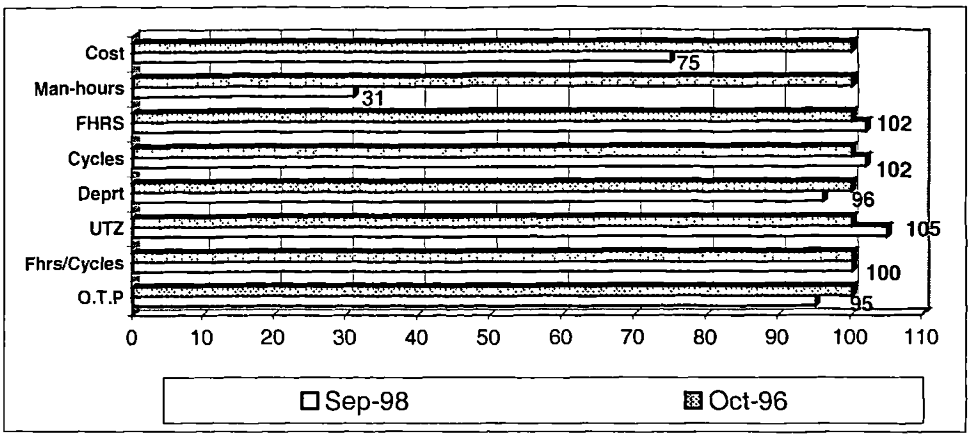
Inefficient Month Analysis:
The meaning of the inefficient rating derived from the DEA analysis can be grasped by inspecting the result for the month of October-96 which was identified as being the least efficient month in terms of overall fleet efficiency. The DEA analysis presents the input and output adjustments that would have made an inefficient month become relatively efficient. However, it is up to the management to select the most proper operating changes that will bring about the best results, in the future. To better understand the main reasons for the poor efficiency of October-96 the sources of inefficiency and its level had to be identified. Therefore, actual performance was compared with targeted performance to identify the sources of the poor performance. The possible potential improvements for the least efficient month are illustrated in Table 8.3 below. The results of the target setting convey information about the overall extent to which individual input or output could be improved Banker *et al.*, (1984). Furthermore, these authors state that such information would prove particularly valuable as a first guide towards improving efficiency. The result for the target for October-96 suggests that there was room for reducing man-hours. Thanassoulis and Dyson (1992) state that the target table is useful in cases where management do not have a well developed set of preferences over the mix of input and outputs that ought to improve the relative efficiency of a DMU.

Table 8.3 Potential Improvement

Oct-96		ACTUAL	TARGET	POTENTIAL IMPROVEMENT
Inputs	COST	8285496	6561285.1	-20.81
	MAN-HOURS	21494	6977.5	-67.54
Outputs	FHRS	1851	1973.58	6.62
	CYCLES	1380	1482.8	7.45
	DEPRT	1348	1352.27	0.32
	UTZ	5.4	5.95	10.22
	FHRS/CYCLES	1.3	1.36	4.42
	O.T.P	98.7	98.7	0

A reference comparison between the most efficient month September-98 and the least efficient month October-96 was carried out. The comparison of inefficient DMUs to best-practice DMUs has been analysed by several authors e.g. Bowlin (1986); Thanassoulis and Dyson, (1987); Charnes *et al.*, (1978) who have shown that a comparison of inefficient DMUs with the best-practice are useful. This is viewed as the inefficient DMU can learn from the best practice and be able to transfer the managerial practice from the efficient DMU in an attempt to improve the current performance practice. Data Envelopment Analysis is used here as a diagnostic tool to tell managers that a month performed poorly for various reasons, and therefore managers can agree with this result or not. Moreover, managers may imply that they are aware of the poor efficiency during that month, yet, they do not have detailed information on the size and the magnitude of inefficiency. Figure 8.3 shows that September-98 utilised only 75% of the cost of the least efficient month October-96 and used only 31% of the man-hours utilised for the least efficient month. In addition, September-98 produced more outputs in terms of the number of cycles, number of departures and aircraft daily utilisation rate. This analysis shows that an efficient month was able to produce higher levels of outputs with less consumption of inputs. This suggests that the greatest weakness in the least efficient month was the excessive consumption of man-hours. This type of comparison is considered to be of a great benefit as it can compare two similar months with regard to the significant period which differ in terms of efficiency, as one is highly efficient and the other is inefficient. Generally, this analysis confirms that October-96 is inefficient, and therefore, needed to reduce its operating cost as well as its man-hours logged for completing maintenance tasks. Planned maintenance can be spread out throughout the year, especially, during the low season when demand for air travels decreases, this discussion refers to sub-optimisation which was discussed in Chapter Three. Therefore, maintenance tasks could be scheduled round the year to avoid having higher workload at different time of the year, which was mentioned in the previous chapter in the survey analysis by the employees to affect their work performance. In addition, an assessment of maintenance cost associated with carrying out the maintenance tasks should be carried out to evaluate the in-house maintenance compared to conducting maintenance with a third party. For example, outsourcing the heavy maintenance and then compare the cost of maintenance including all resources used in this type of maintenance.

Figure 8.3 Reference Comparison



An examination was conducted to assess the correlation between different inputs and outputs spread and the efficiencies the result suggest that for the inefficient month October-96, the result shows that a negative correlation of (-0.72) existed between *cost* and the levels of efficiency. This indicates that an increase in operational cost would always cause a decrease in the efficiency levels. Moreover, a negative correlation of (-0.56) exists between *man-hours* and the level of efficiency. The same conclusion can be drawn in this case as to cost and efficiency levels. This type of analysis is helpful for management in identifying the levels at which efficiency will start to decline with an increase in either cost or man-hours. Therefore, with the given levels of operations management can identify the upper limit required for both cost and man-hours.

As a final remark on the total potential improvements for the whole model that can be achieved by the different input and output for model one are illustrated in Table 8.4. The purpose of this analysis is to provide the managers with a quick insight into where the greatest efficiency gains can be made. If the numbers are large then this highlights an area for managers to investigate, while if the numbers are small then there is little improvement that can be made. The results in the table below suggest that reducing man-hours by 31.97% could have brought about the greatest improvement in efficiency. Therefore, it is worth investigating the probable causes for the high usage of man-hours.

Table 8.4 Total Potential Improvement

INPUT	COST	-17.30%
	MAN-HOURS	-31.97%
OUTPUT	FHRS	13.34%
	CYCLES	5.08%
	DEPRT	2.85%
	UTZ	14.82%
	FHRS/CYCLES	12.20%
	O.T.P	2.44%

8.3.2 A-300 Fleet Performance Analysis Model (Two)

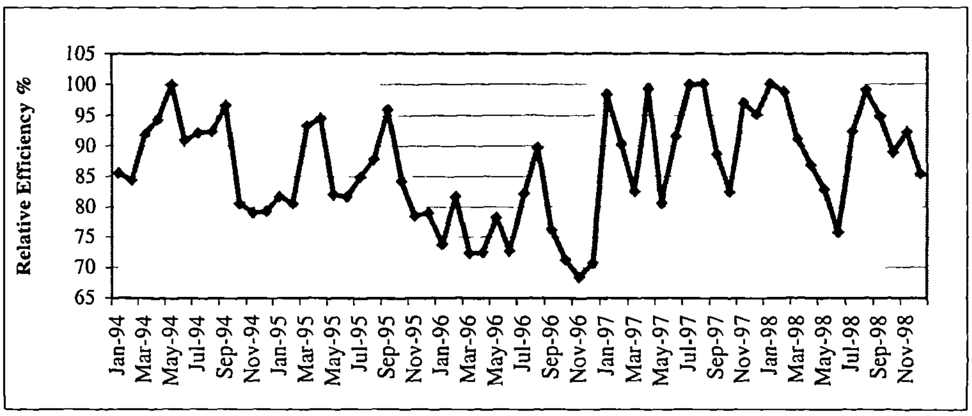
Model two "Fleet performance" relative efficiency scores are listed in Table 8.5. This shows that there were only four efficient months, these are July-97, January-98, August-97 and May-94. As before the set of the efficient months forms the basis for identifying the best practice as a reference set for the set of inefficient months. The average efficiency level was 86%, while the minimum efficiency calculated by the DEA analysis was 68% in November-96.

Table 8.5 Comparative Efficiency Analysis

100% Jun-97	93.3% Mar-95	85.54% Jan-94	80.56% May-97
100% Aug-97	92.41% Aug-94	85.4% Dec-98	79.34% Dec-94
100% Jan-98	92.36% Jul-98	84.87% Jul-95	79.12% Nov-94
100% May-94	92.19% Nov-98	84.44% Feb-94	79.01% Dec-95
99.27% Apr-97	92.16% Jul-94	84.24% Oct-95	78.57% Nov-95
99.05% Aug-98	91.88% Mar-94	82.83% May-98	78.27% May-96
98.81% Feb-98	91.63% Jun-97	82.53% Mar-97	76.14% Sep-96
98.38% Jan-97	91.16% Mar-98	82.47% Oct-97	75.74% Jun-98
96.98% Nov-97	91.04% Jun-94	82.22% Jul-96	73.74% Jan-96
96.64% Sep-94	90.32% Feb-97	81.98% May-95	72.7% Jun-96
95.96 Sep-95	89.71% Aug-96	81.72% Jan-95	72.44% Apr-96
95.13% Dec-97	88.92% Oct-98	81.68% Jun-95	72.36% Mar-96
94.74% Sep-98	88.68% Sep-97	81.66% Feb-96	71.24% Oct-96
94.53% Apr-95	87.82% Aug-95	80.61% Oct-94	70.73% Dec-96
94.37% Apr-94	86.76% Apr-98	80.59% Feb-95	68.42% Nov-96

Figure 8.4 shows the time series chart for a five years period for the A-300 fleet-performance model. The result suggests a similar result to model one in that there was a downward trend in the relative efficiency which picked up again starting January-1997 however, it is different in scale. In model one, the efficiency rating started to improve by January-97 and it maintained a high efficiency rating afterward. However, in model two the efficiency result pre-and post-January-97 were similar to a certain extent. As after the sudden improvement in January-97 the efficiency rating still fluctuated between 100 at the maximum and 75% at the minimum.

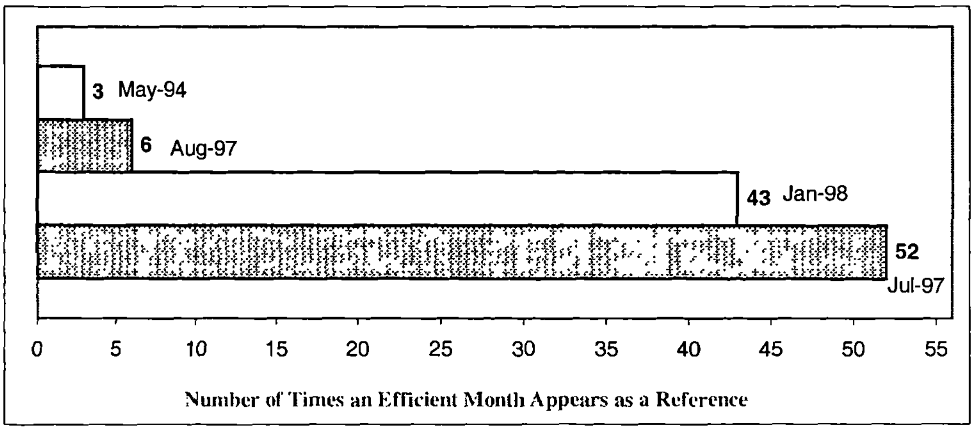
Figure 8.4 A-300 Fleet Performance Model Relative Efficiency Scores



This finding suggests that the A-300 fleet performance has improved, yet there is still quite a large fluctuation in the efficiency rating. Moreover, this suggests that at this point in time there may have been a change in management policy, or a new managerial change is taking effect in terms of maintenance planning procedures to improve maintenance performance.

Figure 8.5 below shows that July-97 is the best performing month as it appears in the reference set fifty two times. Table 8.6 below lists the contributing factors in terms of inputs and outputs. Looking closely at the efficient months in Table 8.6 shows that the number of cycles performed was the greatest contributing factor in terms of the output variables.

<u>Figure 8.5</u> Fleet Performance Model Reference Set Frequency For The Efficient Months



This may reasonably be justified as the month of July-97 falls in the high demand period, and therefore, the demand for flight hours is especially great; these have been for short haul only. This result is drawn from the table of input and output contributions as it shows that the month July-97 achieved a high level of cycles. This result coincides with the actual operations as it reflects actual increase in demand for flying during the different time of the year. On the other hand August-97 was efficient largely due to its high flight hours performed.

Table 8.6 Input and Output Contribution Of The Efficient Months

	I/Os	Level %		I/Os	Level %
May-94	Cost		Jan-98	Cost	91
	Man-hours	100		Man-hours	9
	Fhrs			Fhrs	
	Cycles	100		Cycles	
	Deprt			Deprt	100
Aug-97	Cost	93	Jul-97	Cost	74
	Man-hours	7		Man-hours	26
	Fhrs	100		Fhrs	
	Cycles			Cycles	100
	Deprt			Deprt	

Inefficient Month Analysis:

November-96 was identified as being the least efficient month in Model Two "Fleet performance". A detailed analysis of November-96 was carried out to find out the reasons, which caused it to be inefficient, and what possible improvements could have been achieved. From Table 8.7, the analysis shows that given the level of operation during that period of time, the month of November-96 should have decreased its inputs levels by 41.39% for man-hours and 31.58% for operational costs. It is obvious that this month suffered in efficiency, due to the high man-hours. Therefore, a thorough investigation needs to be carried out by the management to assess whether extra man-hours really were needed to accomplish the maintenance tasks in that month. Since most of the scheduled maintenance tasks are assigned during the low season, this may have contributed to the lower efficiency as discussed in the previous section.

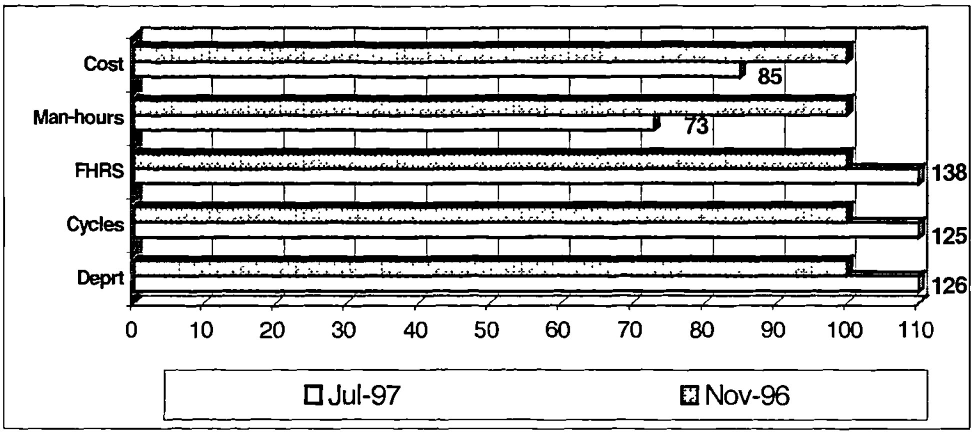
Table 8.7 Potential Improvement

Nov-96		ACTUAL	TARGET	POTENTIAL IMPROVEMENT
Inputs	COST	8199580	5610453	-31.58
	MAN-HOURS	13299	7794.08	-41.39
Output	FHRS	1820	2010.63	10.47
	CYCLES	1489	1489	0
	DEPRT	1263	1281.31	1.45

To further investigate the actual weakness of November-96 a comparison between the best performing month and the least efficient month was carried out. This analysis is useful as it shows the relative performance of the inefficient month November-96 compared to its close-

-st peer (its reference month) when assessing its performance. Figure 8.6 shows that July-97, which is the closest peer and acts as a reference month for November-96, had only 85% of the operational costs of November-96. Also, the efficient month used only 73% of the man-hours, which were incurred by November-96. Although the efficient month used less input resources, it produced higher levels of output. For example, the efficient month produced 38% extra flight hours. This type of analysis is useful as it highlights the area of weakness for the inefficient month, and therefore helps management to make decisions about how to improve efficiency levels.

Figure 8.6 Reference Comparison



In terms of the input variables when compared to the efficiency levels achieved the results suggest a negative correlation of (-0.42) between *cost* and efficiency and a negative correlation of (-0.69) between *man-hours* and *efficiency.* This suggests that any increase in either man-hours or cost for a given month will always cause efficiency levels to decline. However, the effect of an increased man-hour on *efficiency* is greater than the increase in maintenance cost levels.

Table 8.8 shows the total potential improvement that can be achieved from this model. The result in the table below highlights where the greatest efficiency gains can be made. The result shows that man-hours should have been reduced by 38.26%, while cost levels should have been reduced by 29.97%. However, the greatest potential efficiency gains can be obtained through the investigation by management into the ways to decrease either man-hours or cost.

Table 8.8 Total Potential Improvement

INPUT	COST	-29.97%
	MAN-HOURS	-38.26%
OUTPUT	FHRS	19.69%
	CYCLES	7.91%
	DEPRT	4.16%

8.3.3 A-300 Fleet Utilisation Model (Three)

The analysis of Model Three "Fleet utilisation" is listed in Table 8.9. This shows that there were only five efficient months. Consideration of the efficiency scores of this model and the previous model suggests that the year of 1997 should be considered to have the best efficiency score as it has the most efficient months. This may suggest that either a change in management style or policy took place, since the overall efficiency of A-300 maintenance picked up in 1997 but improvement was not sustained.

Table 8.9 Comparative Efficiency Analysis

100% Jul-97	86.42% Dec-97	79.66% Apr-94	72.21% Oct-97
100% Aug-97	86.41% Jun-97	79.49% Aug-94	71.87% Oct-98
100% Jan-98	86.34% Mar-98	78.9% Sep-96	70.68% Nov-94
100% Feb-97	86.17% Feb-96	78.75% Mar-97	70.23% Dec-94
100% May-94	85.25% Sep-97	78.09% Aug-95	70.16% Oct-95
99.7% Feb-98	84.99% Jul-98	77.98% Nov-98	70.06% Dec-95
98.38% Jan-97	84.59% Feb-95	77.91% May-97	68.39% Jun-95
97.93% Apr-97	83.76% Jul-94	77.14% May-96	67.67% Dec-98
92.51% Aug-98	83.44% Mar-94	76.49% Jun-98	67.53% Nov-95
90.49% Sep-95	82.99% Sep-98	74.91% Jan-94	67.51% Dec-96
89.61 Nov-97	82.44% Feb-94	74.86% Jun-94	66.51% Oct-94
88.42% Sep-98	82.32% Jul-96	74.63% Apr-96	66.04% Jun-96
87.8% Apr-98	80.36% Jul-95	74.14% Jan-96	63.66% Nov-96
87.53% Apr-95	80.23% Mar-95	73.28% May-98	62.34% Oct-96
87.16% Aug-96	80.12% May-95	72.85% Jan-95	62.3% Mar-96

Figure 8.7 shows the time series graph for the A-300 model three for the five years. The result shows that utilisation efficiency for the A-300 is having a somewhat negative trend. However, there was an improvement starting January-97 but the improvement was not sustained. This suggests that later on in the period the A-300 was used for flying a shorter route structure than it used to be.

Figure 8.7 A-300 Fleet Utilisation Model Relative Efficiency Scores

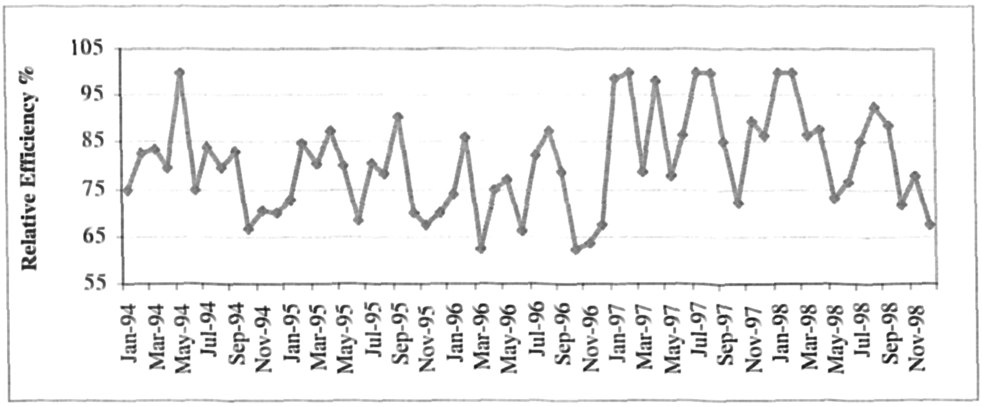
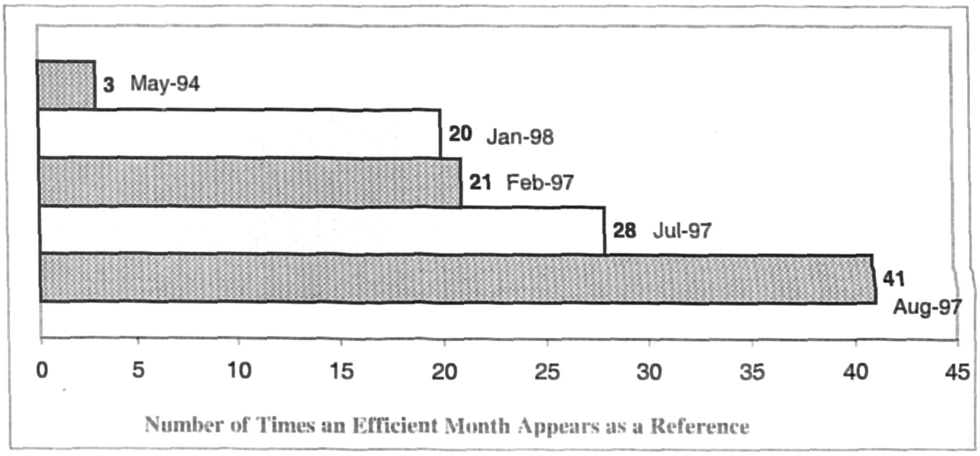


Figure 8.8 below compares the five efficient months to each others in terms of input and output contributions and shows how many times an efficient month appears as a reference month for the inefficient months. The result suggests that August-97 should be regarded the 'best practice' month as it appears forty one times as a reference month.

Figure 8.8 Fleet Utilisation Model Reference Set Frequency For The Efficient Months



In order to investigate the reasons behind the efficiency of the five efficient months, one needs to explore the inputs and outputs contributing to their efficiency. Table 8.10 shows that utilisation was the main determinant of August-97 and July-97 efficiency, this is due to the fact that these two months considered to be in the high season according to the significant period table discussed in Chapter Two. As for the group of efficient months February-97, January-98 and May-94, these months were identified as being efficient mainly due to the number of flight hours accomplished during the month. In each of the three efficient months flight hours was given a weight of 100, which means that these months were efficient solely because of their high number of flight hours. However, these months differ from the other two efficient months, in that August-97 and July-97 had a higher average aircraft daily utilisation, which means that the A-300 flew more distance than in January-98, February-97 and May-94. This suggests that it could be a management policy to use the A-300 fleet to fly to longer haul destinations during the summer time, and shorter haul destinations in other time of the year.

This type of analysis shows the pattern of operation that the management follows in operating the A-300 fleet. This pattern is designed to work based on the increase in the demand for air travel during season period, and tends to shift to a shorter flight when the demand for air travel become less.

Table 8.10 Input and Output Contribution of the Efficient Months

	I/Os	Level %		I/Os	Level %
May-94	Cost		Jan-98	Cost	87
	Man-hours	100		Man-hours	13
	Fhrs	100		Fhrs	100
	UTZ			UTZ	
Aug-97	Cost	92	Feb-97	Cost	93
	Man-hours	8		Man-hours	7
	Fhrs	7		Fhrs	100
	UTZ	93		UTZ	
Jul-97	Cost	88			
	Man-hours	12			
	Fhrs	7			
	UTZ	93			

Inefficient Month Analysis:

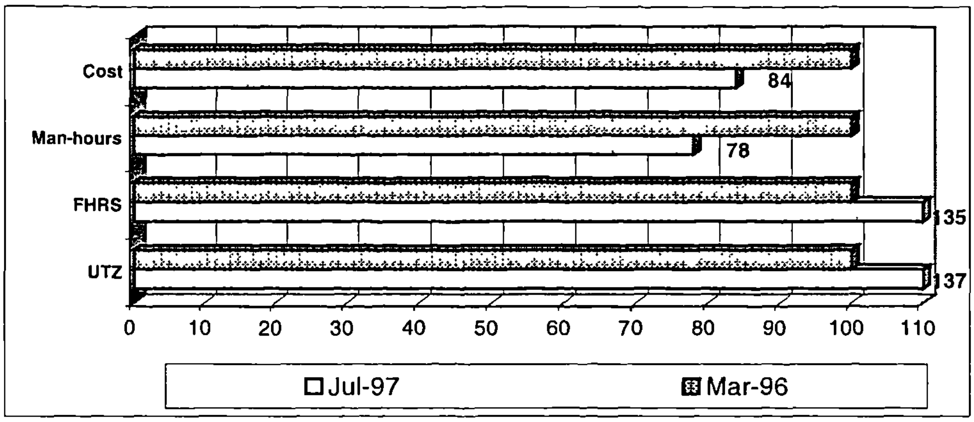
The month of March-96, which had a 62.3% efficiency level, was considered to be the least efficient month in Model Three. Therefore, target levels for March-96 were calculated for further analysis. Table 8.11 shows that man-hours for March-96 needed to be reduced by 42.26% and the cost of maintenance operation by 37% to make it efficient.

Table 8.11 Potential Improvement

Mar-96		ACTUAL	TARGET	POTENTIAL IMPROVEMENT
Inputs	COST	8289910	5165023.9	-37.7
	MAN-HOURS	12426	7175.29	-42.26
	UTZ	5.4	5.44	0.78
Output	FHRS	1851	1851	0

Figure 8.9 shows that July-97, which is considered to be an efficient month, used 84% of the cost that the least efficient month used. Moreover, the efficient month used 78% of the inefficient month's man-hours. Through this analysis it is clear that the efficient month utilised fewer inputs levels in order to produce higher levels of outputs when compared to the least efficient month. For example, the efficient month achieved 35% more flight hours than the inefficient month and 37% more in aircraft daily utilisation when compared to the inefficient month.

Figure 8.9 Reference Comparison



When analysing the efficiency for March-96, there was a negative correlation of (-0.46) between *cost* and *efficiency*, and a negative correlation between *man-hours* and *efficiency*. These results suggest that either an increase in cost or man-hours would always lead to a decrease in efficiency levels. While, there was a positive correlation of (0.71) between *aircraft daily utilisation rate* and *efficiency*. Therefore, this result indicates that an increase in aircraft daily utilisation would improve efficiency levels. Table 8.12 illustrates the total potential improvement for this model from reducing man-hours by 52.29% and cost by 44.13. Management can use this important information to identify the areas that need improvement.

Table 8.12 Total Potential Improvement

INPUT	COST	-44.13%
	MAN-HOURS	-52.29%
OUTPUT	UTZ	0.14%
	FHRS	3.43%

8.3.4 A-300 Fleet Reliability Model (Four)

Using the data available from Model Four a comparative efficiency score table is presented in Table 8.13. In carrying out the DEA analysis input minimisation under CRS for the A-300 Fleet Reliability model, only nine months out of sixty months proved to be 100% efficient. Therefore, this set of efficient months forms a basis for deriving best performing months in terms of fleet reliability. In addition, the nine months that scored 100% efficiency level reflect the best use or allocation of the company's resources in terms of cost required for operation and man-hours assigned for the maintenance tasks.

Table 8.13 Comparative Efficiency Analysis

100% May-94	95.25% Apr-95	90.49% Feb-94	83.87% Jul-96
100% Aug-97	94.93% Mar-98	89.71% Aug-96	83.78% Jan-95
100% Feb-98	94.77% Sep-95	89.68% Apr-94	82.91% May-96
100% Jan-98	94.47% Apr-98	89.62% Jun-98	82.88% Apr-96
100% Sep-98	94.15% Oct-98	87.93% Oct-97	82.86% Nov-94
100% Feb-97	93.93% Sep-97	87.8% Feb-96	82.67% Sep-96
100% Jan-97	93.53% Mar-95	87.87% Oct-95	82.11% Dec-95
100% Apr-97	93.07% Dec-97	87.75% Jun-95	81.91% Dec-94
100% Jul-97	92.7% Jul-98	87.47% Jun-94	81.33% Jan-96
97.42% Jun-97	92.46% May-98	87.33% May-95	81.33% Mar-96
96.64% Sep-94	91.98% May-97	87.2% Aug-95	81.14% Oct-94
96.18% Nov-98	91.88% Mar-94	86.66% Aug-94	80.06% Nov-96
95.53% Nov-97	91.61% Mar-97	86.48% Jul-95	79.96% Jun-96
95.29% Aug-98	91.27% Feb-95	86.38% Nov-95	79.19% Oct-96
95.26% Dec-98	90.88% Jul-94	85.58% Jan-94	78.69% Dec-96

From observation of the efficient months, the results show that five of the efficient months were in 1997, while three efficient months were in 1998, and only one in 1994. This suggests that 1997 be considered the best year in terms of the reliability of the A-300 fleet, followed by 1998. This indicates that there is a positive trend in the reliability of the A-300. This might be because the AMTs have developed a good understanding of the various A-300 aircraft systems in terms of troubleshooting and carrying out maintenance tasks; or because of management emphasis on improving the A-300 fleet reliability by providing the necessary training to master the different aspects of achieving a higher level of aircraft reliability.

The efficiency result show that the average efficiency score calculated was 90%, while the minimum efficiency score achieved was 78% in December-96.

Figure 8.10 shows that relative efficiency for the reliability model. The results for the fleet reliability model were similar to model one, as there was a decline in the relative efficiency from the start of the period under study, however, it picked up again in January-97. The relative efficiency result in terms of model four fleet reliability model suggest that the reliability were highly fluctuating, thus this suggests that different operational activities at different time of the year have an effect on the fleet reliability.

Figure 8.10 A-300 Fleet Reliability Model efficiency scores

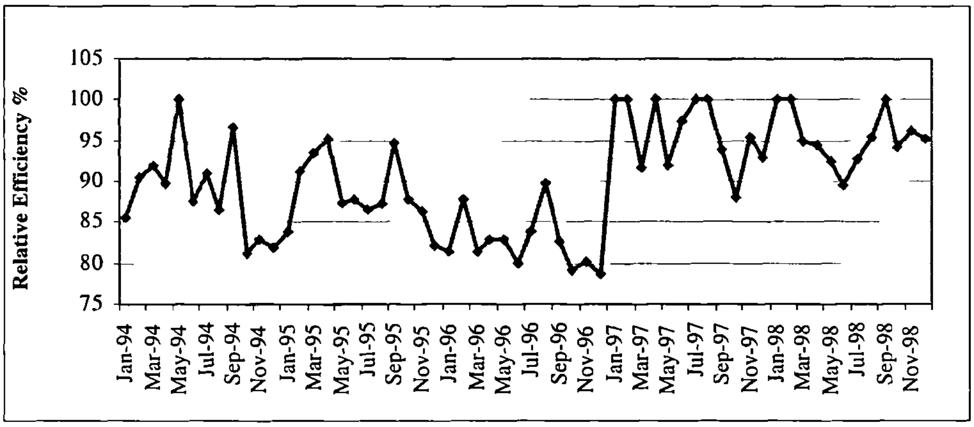
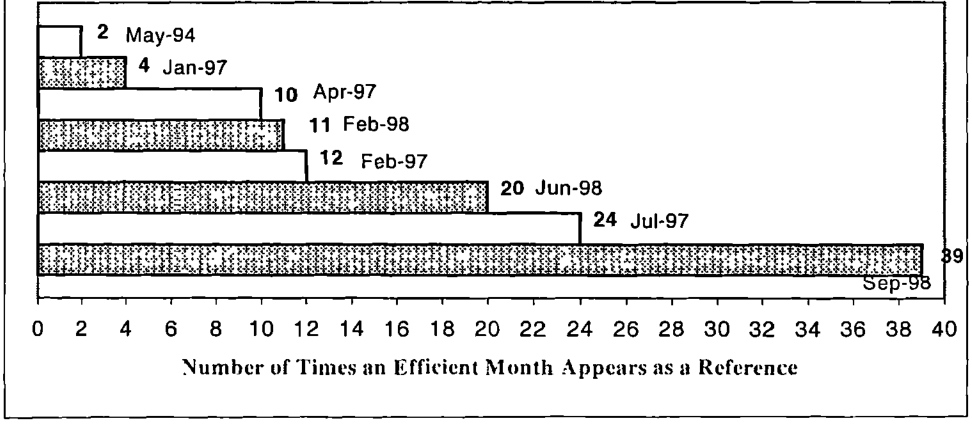


Figure 8.11 shows that September-98 was considered to be the best performing month, due to the number of times it appears in the reference set for inefficient months. Since the month of September is considered to be in the low season travel, there is a little pressure on the AMTs in terms of the number of the aircraft that they handle in each shift, and therefore, the available man-hours during that time of the year is sufficient to despatch the aircraft on time and achieve higher on time-performance. The increase in Line maintenance manpower in peak months is done for queuing reasons.

Figure 8.11 Fleet Reliability Model Reference Set Frequency For The Efficient Months



To further analyse the efficient months, a list of the factors contributing to their efficiency levels is illustrated in Table 8.14. The result suggests that in the month of January-98, July-97, September-98 and February-98, the efficiency was mainly due to a single output, which is technical on time-performance. Therefore, it becomes clearer that technical on time-performance has been used as an indication in determining that month's performance in term of reliability. Moreover, these efficient months all fall in the high season period except September-98, which means that on time-performance is weighted heavily during this time of the year.

The analysis for the input/output contribution for the efficient months suggest that January-97, February-97 and April-97 made efficient based on the on time-performance as well but also had a high weight on the number of the flight hours accomplished during these months. The month of May-94 and August-97 were efficient based on the high number of engine cycles accomplished during these two months.

Table 8.14 Input And Output Contribution Of The Efficient Months

	I/Os	Level %		I/Os	Level %		I/Os	Level %
	Cost	85		Cost	93		Cost	95
	Man-hours	15		Man-hours	7		Man-hours	5
Sep-98	Fhrs		Feb-97	Fhrs	46	Jan-97	Fhrs	48
	Cycles	31		Cycles			Cycles	
	O.T.P	69		O.T.P	54		O.T.P	52
	Cost	100		Cost	90		Cost	
	Man-hours			Man-hours	10		Man-hours	100
Jul-97	Fhrs		Feb-98	Fhrs	4	May-94	Fhrs	
	Cycles	38		Cycles			Cycles	100
	O.T.P	62		O.T.P	96		O.T.P	
	Cost	90		Cost	94		Cost	93
	Man-hours	10		Man-hours	6		Man-hours	7
Jan-98	Fhrs	5	Apr-97	Fhrs	41	Aug-97	Fhrs	100
	Cycles			Cycles	5		Cycles	
	O.T.P	95		O.T.P	53		O.T.P	

Inefficient Month Analysis:

The inefficient month analysis Table 8.15 starts by analysing the potential improvement in the least efficient month. This suggests that the month of December-96 which was the least efficient month needed to reduce its man-hours by 64.61%, and reduce its operating cost by 21.31% in order to become efficient. However, the result further suggests that the month of December-96 achieved its maximum output levels and therefore its output levels will stay the same and will not be able to improve further.

Further analysis suggests that, in the light of the significant period, December-96 was in the relatively low season, at least for the first two weeks. Management may be able to justify the high number of man-hours used because major overhauls and repairs for the fleet take place after a long usage of intensive usage of the fleet. In other words, this analysis suggests that previous operations have an impact on the fleet, as more aircraft parts will be required for inspection or replacement after a period of high usage. Therefore, the heavy use of the fleet in the end creates a need for major maintenance inspection to insure safety. This will be discussed further in the Non-significant period analysis.

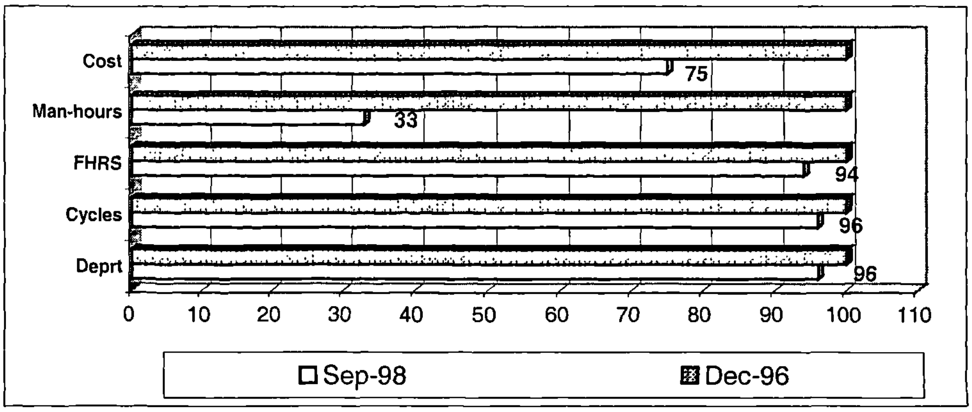
Table 8.15 Potential Improvement

Dec-96		ACTUAL	TARGET	POTENTIAL IMPROVEMENT
Inputs	COST	8295316	6527969.5	-21.31
	MAN-HOURS	20107	7116.85	-64.61
Output	FHRS	2000	2000	0
	CYCLES	1477	1477	0
	O.T.P	97.84	97.84	0

The analysis of the potential improvement for the month of December-96 suggests that man-hours needed to be reduced by 64.61%. Management can establish a goal for the month of December by setting a percentage, which they believe best, fits their operational requirements. The extra use of man-hours may be due to achieving a maintenance schedule assigned for that fleet. It may be during the month of December-96 management allocated more man-hours in order to achieve their operational goals, which are to keep the fleet in a safe and usable conditions and therefore, management can justify the use of more man-hours.

In order to provide management with a more detailed analysis for the least efficient month December-96 and identify its weaknesses, a reference comparison was carried out, see Figure 8.12. September-98, which is the reference month for December-96 with 100% efficiency score, was selected for comparison with December-96 (78.69%) efficiency score. When comparing the man-hours utilised in the month of September-98 compared to December-96 it was found that September-98 used fewer man-hours to produce a higher level of output compared with December-96. The same was true when comparing the cost as only 75% of the cost required in December-96 was incurred in September-98.

Figure 8.12 Reference Comparison



When calculating the efficiency for the inefficient month December-96, a negative correlation of (-0.61) exists between *man-hours* and *efficiency* level. This strongly suggests that an increase in man-hours assigned for a maintenance task will cause the efficiency rating to decrease. The same result is true for cost versus efficiency level for the month of December-96 as a correlation of (-0.72) was found between *cost* and *efficiency*. The analysis suggests that increase in either man-hours or cost will generate a lower efficiency rating.

Finally, Table 8.16, illustrates the total potential improvement that can be achieved in the different input and output. The larger the figure for one of the inputs, the larger the room for improvement. For example, man-hours had the largest reduction needed (-51.24%). This means that man-hours have greater room for improvement by attempting to reduce it. Moreover, such a variable would require more attention from management to improve tham. In addition, the excess use of man-hours confirms a weakness in utilising man-power and this needs be avoided for a similar month and therefore, the analysis for total potential improvement suggests that more attention needs to be given in allocating manpower.

Table 8.16 Total Potential Improvement

INPUT	COST	-28.90%
	MAN-HOURS	-51.24%
OUTPUT	FHRS	14.33%
	CYCLES	4.01%
	O.T.P	1.53%

8.3.5 A-300 Summary Of 60-Month Results

The general result suggest that the A-300 had a relatively good maintenance record starting 1997, and this may be due to new management policy or a change in the management structure. However, the efficiency was lowest in 1996.

Weight Restriction

Various authors cited in Chapter Six have mentioned that the application of weight restriction is good. Therefore, for the purpose of this thesis only the A-300 fleet model one will be examined in section 8.5. The restriction of weights on the A-300 will be implemented to compare the result of the unrestricted weight to the one with weights. The reason for implementing weights only for the A-300 was because this is the only fleet that did not experience any changes in terms of adding new aircraft or phasing out part of its fleet, unlike the B-747, which had a new B-747-400 join the service, and the B-737, where most of the fleet was phased out, and replaced by the new MD-90. Therefore, it made more sense to run the weight model for the A-300, as the number of the aircraft in the fleet did not change.

Brief Overview of the L-1011 60-Month Model Last Year Only

The next section will explore the L-1011 fleet efficiency, by only looking at the last twelve months for model one only. This is done because the maintenance management decided to phase out this fleet. The results are presented in the following section.

8.4 L-1011 OVERALL FLEET EFFICIENCY ANALYSIS MODEL ONE

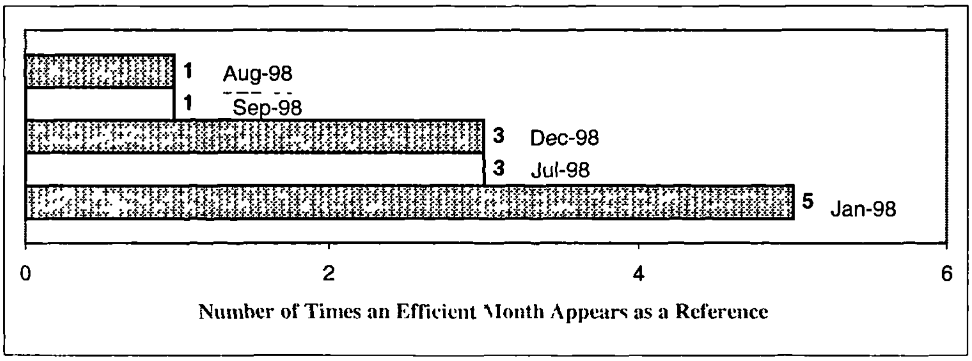
The analysis of efficiency levels for model one "Overall fleet Efficiency" are listed in Table 8.17. For this type of fleet only the last 12 months were analyzed. The result shows that there were seven efficient months. The efficiency scores are between 100% at the maximum and 91.32% at the minimum, with an average relative efficiency score of 98.48%.

Table 8.17 Comparative Efficiency Analysis

Dec-98	100	May-98	100	Apr-98	99.03
Sep-98	100	Nov-98	100	Oct-98	98.86
Aug-98	100	Jul-98	100	Mar-98	92.57
Jan-98	100	Jun-98	99.98	Feb-98	91.32

Figure 8.13 shows that January-98 is considered to be the best efficient month. This is because it appears five time as a referent month.

Figurs 8.13 Overall Fleet Efficiency Model Reference Set Frequency For The Efficient Units



Examining the list of inputs and outputs that contributed to the efficiency of the list of the efficient months Table 8.18 shows that both December-98 and July-98 were identified as being efficient due mainly to the high levels of on-time performance achieved. As for the months of May-98, August-98 and September-98 they were found to be efficient due to the high cycles achieved during these months. The month of January-98 was identified as being efficient because of the high levels of departures achieved, and finally, the month of November was also identified as being efficient due to the high ratio of flight hours to cycles.

Table 8.18 Input And Output Contribution Of The Efficient Months

	I/Os	Level %		I/Os	Level %		I/Os	Level %
	Cost	100		Cost	69		Cost	88
	Man-hours			Man-hours	31		Man-hours	12
	Fhrs			Fhrs			Fhrs	
Jan-98	Cycles		May-98	Cycles	100	Jul-98	Cycles	
	Deprt	100		Deprt			Deprt	
	UTZ			UTZ			UTZ	13
	Fhrs/Cycles			Fhrs/Cycles			Fhrs/Cycles	
	O.T.P			O.T.P			O.T.P	87
	Cost	100		Cost	100		Cost	100
	Man-hours			Man-hours			Man-hours	
	Fhrs			Fhrs			Fhrs	
Aug-98	Cycles	61	Sep-98	Cycles	57	Nov-98	Cycles	
	Deprt			Deprt			Deprt	
	UTZ			UTZ			UTZ	
	Fhrs/Cycles			Fhrs/Cycles			Fhrs/Cycles	100
	O.T.P	39		O.T.P	43		O.T.P	
	Cost	100						
	Man-hours							
	Fhrs							
Dec-98	Cycles							
	Deprt							
	UTZ							
	Fhrs/Cycles							
	O.T.P	100						

Inefficient Month Analysis

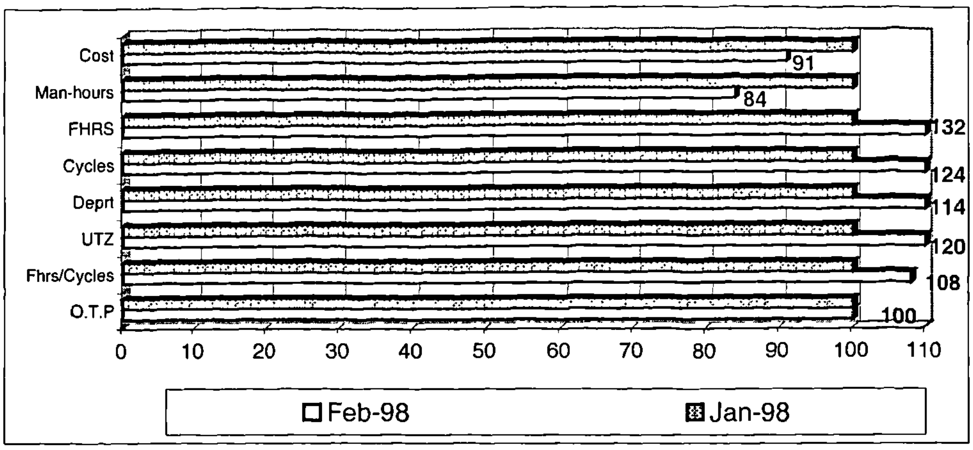
The analysis of the least efficient month February-98, is shown in Table 8.19. The analysis identifies the source of inefficiencies and their levels. Man hours needed to be reduced by 15.91%, while cost of maintenance needed to be reduced by 8.68%. in terms of the outputs the analysis shows that the outputs level should have been increased i.e. flight hours should have been increased by 32.28%.

Table 8.19 Potential Improvement

Feb-98		ACTUAL	TARGET	POTENTIAL IMPROVEMENT
Inputs	COST	11456852	10462526	-8.68
	MAN-HOURS	15142	12732.83	-15.91
Output	FHRS	1649	2181.35	32.28
	CYCLES	1365	1687.76	23.65
	DEPRT	1277	1455.89	14.01
	UTZ	3.5	4.18	19.42
	FHRS/CYCLYS	1.2	1.29	7.81
	O.T.P	94.21	94.21	0

Further analysis of the least efficient month February-98 can be generated by comparing its technical operational performance to the most efficient month January-98, see Figure 8.14. The analysis shows that the efficient month January-98 have consumed less inputs levels compared to the least efficient month, and at the same time the most efficient month has achieved higher levels of outputs.

Figure 8.14 Reference Comparison



Total potential improvement for the L-1011 is illustrated in Table 8.20. The analysis suggest that the cost and man hours for the L-1011 should be reduced by 6.33% and 8.84% respectively. In terms of the outputs variables they also show an increase in there input is needed for example flight hours should be increased by 24.89%.

Table 8.20 Total Potential Improvement

INPUT	COST	-6.33%
	MAN-HOURS	-8.84%
OUTPUT	FHRS	24.89%
	CYCLES	14.92%
	DEPRT	9.25%
	UTZ	23.21%
	FHRS/CYCLES	12.55%
	O.T.P	0.00%

8.5 WEIGHT RESTRICTIONS

This section will focus on setting weight on different variables. The previous DEA analysis permitted zero weights. However, in some situation where management want to emphasise one variable more than the other, it may be useful to management to allocate different weight to different variables as was discussed in Chapter Six. However, for the purpose of this thesis weight restriction is explored for the A-300 fleet model one only, as an example of the strengths of this type of DEA analysis.

8.5.1 A-300 And Weight Restriction

The sets of virtual inputs and outputs are considered to be the most important element in restricting weights in the DEA analysis. Ordinary DEA analysis identifies a set of weights, these are attached to each input and output and these are different for each DMU. In this section the issue of imposing bounds on factor weights is examined. In the earlier DEA analysis there were no bounds imposed on these models, and that gave the DMU the freedom to select the set of weights that would make the unit efficient. However, in the case that management are concerned with a specific issue, then the implementation of weights are considered to be more useful. The weighting facility in the DEA analysis allows management to control efficiency scores, by not allowing for example, to put less than a certain percentage on a particular variable. The A-300 fleet utilisation model was selected because of management's great interest in enhancing this fleet's average daily utilisation.

In the A-300 fleet utilisation model, the input used are, cost and man-hours, while the output are aircraft average daily utilisation and the number of aircraft flight hours accomplished, these were explained in chapter seven. However, from the previous analysis of the free weights, the result showed that cost level and man-hours were very high, especially the cost of doing maintenance work. For this reason a set of weight was applied to the model using the technique provided by Roll *et al.*, (1991) which was stated earlier in Chapter Six.

<u>Table 8.21</u> Result Of Relative Efficiencies With The Different Models

Month	*Zero Weight*	*With Weight*	Month	*Zero Weight*	*With Weight*	Month	*Zero Weight*	*With Weight*
Jan-94	74.91	74.15	Sep-95	90.49	88.48	May-97	77.91	74.77
Feb-94	82.44	78.68	Oct-95	70.16	69.56	Jun-97	86.41	83.03
Mar-94	83.44	83.07	Nov-95	67.53	66	Jul-97	100	95.61
Apr-94	79.66	77.85	Dec-95	70.06	67.91	Aug-97	100	100
May-94	100	91.8	Jan-96	74.14	71.51	Sep-97	85.25	78.38
Jun-94	74.86	73.03	Feb-96	86.17	83.06	Oct-97	72.21	68.22
Jul-94	83.76	83.21	Mar-96	62.3	58.21	Nov-97	89.61	88.09
Aug-94	79.49	79.05	Apr-96	74.63	67.95	Dec-97	86.42	83.04
Sep-94	82.99	81.5	May-96	77.14	76.89	Jan-98	100	100
Oct-94	66.51	65.34	Jun-96	66.04	56.06	Feb-98	99.7	91.63
Nov-94	70.68	69.27	Jul-96	82.32	70.33	Mar-98	86.34	86.28
Dec-94	70.23	69.87	Aug-96	87.16	86.02	Apr-98	87.8	85.66
Jan-95	72.85	72.04	Sep-96	78.9	63.72	May-98	73.28	69.51
Feb-95	84.59	79.75	Oct-96	62.34	49.25	Jun-98	76.49	58.93
Mar-95	80.23	77.95	Nov-96	63.66	57.91	Jul-98	84.99	84.1
Apr-95	87.53	83.07	Dec-96	67.51	54.82	Aug-98	92.51	91.56
May-95	80.12	79.02	Jan-97	98.38	97.55	Sep-98	88.42	86.13
Jun-95	68.39	67.5	Feb-97	100	94.21	Oct-98	71.87	71.37
Jul-95	80.36	78.76	Mar-97	78.75	76.44	Nov-98	77.98	76.42
Aug-95	78.09	76.13	Apr-97	97.93	96.52	Dec-98	67.67	67.22

The set of virtual input and outputs were examined in an attempt to define the limit to impose the lower and upper bounds. The set of weights imposed on the fleet utilisation model were focused upon cost and utilisation, however, man-hours and flight hours had a wider range of weight restriction. The decision to impose these sets of weight were considered after a close examination of the set of virtual input and output as indicated earlier. In addition, the general focus of maintenance managers was also considered as it leans towards increasing the number of average aircraft daily utilisation. The results of the DEA weighted model are shown in Table 8.21.

For the purpose of comparison, the results of the relative efficiency for the free weight model are also included. The result of relative efficiency for the bounded model are, of course, always equal to or less than those obtained by the free weight approach, (Roll *et al.*, 1991).

By imposing weight restrictions on the model set, the relative efficiencies with the weight restriction were reduced in most of the months. The largest differences appear in Jun-98, September-96, October-96, December-96 and July-96. The actual differences for these five months were 17.56%, 15.18, 13.09, 12.69 and 11.99 respectively. Two of the five months listed Jun-98 and July-96 are considered to be within the significant period. However, the other months that experienced the largest difference in relative efficiencies when compared to the unbounded relative efficiency result, were characterised as having a lower demand for air travel when compared to Jun-98 and July-96.

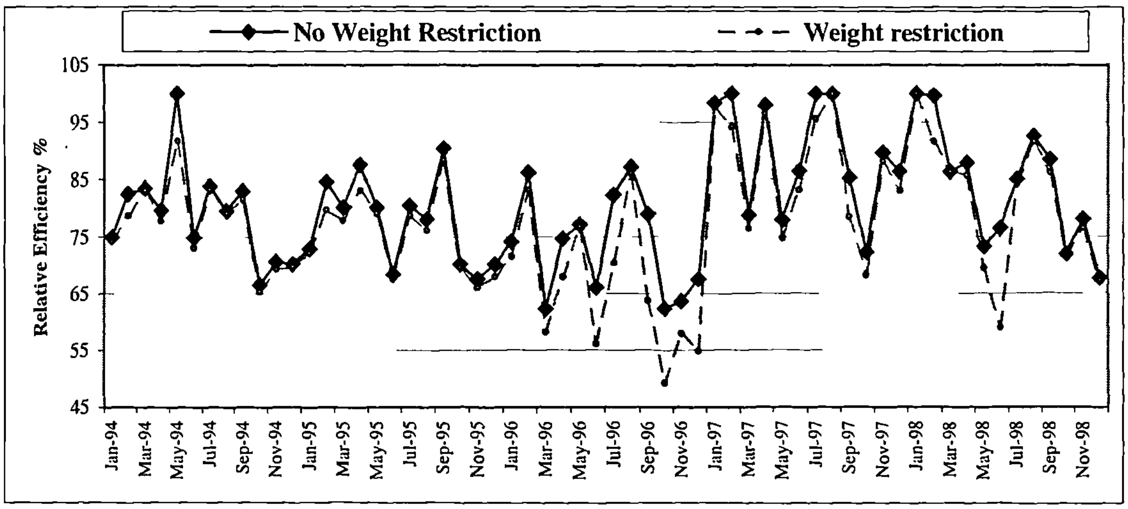
It can be seen that imposing weight restriction on the model reduces the apparent relative efficiency in fifty-eight months out of sixty months in the set. There were only two months August-97 and January-98 which did not experience any reduction in their relative efficiency scores in both approaches the unbounded and the bounded model, as they have achieved 100% efficiency level. Moreover, there were forty eight months which had a reduction in relative efficiency below five percent, the five percent level is selected as an arbitrary percentage just to determine the number of months which had a lower relative efficiency below this level. This is useful in identifying that a large number of the months did not have a great difference between the unbounded and the bounded model, this is just to confirm that the model does not have a very high differences in only one month, as this might indicates that the set of weights imposed on the model might not be feasible. However, the variation of the relative efficiencies compared with the unbounded model shows a good overall rounded performance, which indicates that the process carried out in implementing the weights restriction was successful, Figure 8.15 shows the variation of weights between the approaches. Table 8.22 provides an overall summary of the main differences between the unbounded and the bounded model.

Table 8.22 Summary Of Differences Between The Unbounded and the Bounded Models

	Unbounded Model	Bounded Model
Minimum Efficiency	0.623	0.492
Average Efficiency	0.807	0.772
Number of Efficient DMUs	5	2

The result shows that the minimum efficiency obtained under the free weight (0.623) was higher than the one obtained under the weight restriction (0.492). However, the difference between the average efficiency in the two approaches was not large, thus, the unrestricted model identified five months that have a 100% relative efficiency, these were reduced to two in the weight restricted model.

Figure 8.15 Observing Relative Efficiency Scores Between The Unrestricted And The Restricted Model



8.6 Application Of Multiple Regression Analysis

To further analyse the operational performance of the airline maintenance stepwise regression analysis was carried out to explore a wider view of the efficiency measurements. Once again the A-300 model is used to run the stepwise multiple regression analysis for the reason explained previously. The previous DEA analysis treated the non-significant period months unfairly when they are being compared with the months in the significant period because of the different operational activities over the year, and therefore, the stepwise regression is done to explore this issue further.

8.6.1 Measurement Of Airline Maintenance Operational Performance

This section describes the process carried out to analyse the A-300 fleet operational performance using stepwise regression. Maintenance may not yield effects on performance in the same time period, i.e. there may be a lag effect. To explore this the regressor (independent) variables *cost* and *man-hours* lagged by up to twelve months. The regression analysis was used to determine the relationship between flight hours and lagged values of cost and man-hours, and the relationship between aircraft utilisation and lagged values of cost and man-hours, the dependent variable used in the analysis, were *flight hours* and *utilisation*. The multiple regression models estimates were as follows:

$$\text{Flight Hours}_t = c + \beta_1 \text{Cost}_t + \beta_2 \text{Cost}_{t-1} + \ldots + \beta_{13} \text{Cost}_{t-12} + \beta_{14} \text{Mhrs}_t + \beta_{15} \text{Mhrs}_{t-1} \ldots \beta_{26} \text{Mhrs}_{t-12}$$

While: Flight Hours = the factor output to be predicted

c = the constant

Cost_1 = is the input variables used

β = Coefficient of determination

The challenge as well as the contribution of this type of the analysis is to outline an improved depiction of technical operational performance which will help in judging the effectiveness of such a maintenance system in delivering the highest levels of outputs with the minimum consumption of resources.

Flight hours and Lagged Cost and Man-hours

As was mentioned earlier that the result of any maintenance tasks is not felt immediately the next month, thus, it will be felt afterward. Therefore, the stepwise regression analysis was carried out to see if maintenance cost and man-hours could be controlled. Before running the analysis the values for the independent variables *cost* and *man-hours* were deseasonalized, because it gave a better result. The first dependent variable used for the analysis was flight hours, and the two independent variables used were the lagged cost and lagged man-hours. The results of the regression model are illustrated in Table 8.23.

Table 8.23 Flight Hours And The Lagged Cost And Man-hours

Dependent Variable	Independent Variables	Std. Coeff.	t-value	P
Flight hours	Deseasonalized Cost $_{t-12}$	0.374	2.86	0.006
	Deseasonalized Man-hours $_{t-9}$	0.291	2.23	0.031

DW = 1.79, F-statistic = 8.78, R^2 = 0.281

The result shows that the relative magnitude of the coefficient of cost is higher than man-hours. The relationship between cost and man-hours and the output were examined. This can be determined from the coefficient of determination R^2. The stepwise multiple regression model thus identified this variable, which could be used predict the level of the output, flight hours. The R^2 coefficient of determination was 0.281, and the Durbin-Watson was 1.79. R^2 here is the coefficient of determination a commonly used measure of the goodness of fit. The higher the value of R^2 the better the fit for example R^2 is 97.6% it means that 97.6% of the variation in efficiency can be explained by the combined variation in flight hours and cycles; it is useful to tell the maintenance managers how the different variables are correlated. As for Durbin-Watson statistic is a test for sequential correlation, a small value of DW indicate positive correlation and large values indicate negative correlation.

Flight hours and Lagged Cost and Man-hours

The second multiple regression involves the use of utilisation variable as the dependent variable rather than using flight hours as has been done in the first model. Again both lagged independent variables cost and man-hours were included in the test in order to investigate whether there is a relationship between the lagged independent variable *cost* and the lagged *man-hours* and the dependent variable *utilisation*. By inspecting the coefficient of determination R^2 it shows a value of 0.284, and the Durbin-Watson test shows a value of 1.781, both result are acceptable, however, the R^2 a little better than in the previous test. The values for the F statistic were 8.930, see Table 8.24.

An interesting finding is that both stepwise regression test have identified similar predictors, $cost_{t-12}$ and $man\text{-}hours_{t-9}$

Table 8.24 Aircraft Utilisation And The Lagged Cost And Man-hours

Dependent Variable	Independent Variables	Std. Coeff.	*t*-value	*P*
Aircraft utilisation	Deseasonalized Cost $_{t-12}$	.388	2.97	0.005
	Deseasonalized Man-hours $_{t-9}$	279	2.14	0.038

DW = 1.78, F-statistic = 8.93, R^2 = 0.284

DEA and Multiple Regression Analysis

These findings suggest that both lagged cost and man-hours, are strong predictors not only for flight hours, but also for aircraft utilisation.

Using the predictors identified from the multiple regression analysis, and two output variables examined to run the fleet utilisation model using DEA. The following inputs and outputs were used in the DEA analysis:

- **Input:**
  1. Deseasonalized Cost t-12
  2. Deseasonalized Man-hourst-9
- **Output:**
  1. Flight Hours
  2. Utilisation

The DEA model was run using the two input and two outputs, however, the DMUs (months) used started at January-95, which means that now there are forty-eight months, compared to sixty months before, the 1994 data were dropped to accommodate the variable $cost_{t-12}$. The first observation on the result is that there are more efficient months than in the previous fleet utilisation model with free weights. Furthermore, the relative efficiencies recorded are uniformly high; Table 8.25 provides the relative efficiency scores obtained form the DEA analysis.

There were twelve efficient months, the relative efficiency of twenty months was between 91-99.99%, while the relative efficiency of the poorest sixteen months was between 81-90%. Thus, the average relative efficiency were 94.17%. In general, this comparison confirms that the relative efficiency for the months is now higher. Further investigation of this high efficiency shows it is related to two reasons. First there is a smaller number of degree of freedom involved when using four variables compared to the original fleet utilisation model. In addition, the number of DMUs were less in this model as it included only forty eight months compared to sixty in the original model. These two factors have contributed to the higher relative efficiency. The findings for the relative efficiency after adding the new variables reflect the findings of Nunamaker (1985) as the relative efficiency increased after adding the new variables. This author stated that the addition of a perfectly positively correlated variable could only increase the relative efficiency or leave it unchanged. Therefore, the more variables considered the greater chance that an inefficient DMU will dominate based on the newly added dimension, and thus will become efficient.

Table 8.25 Relative Efficiency Scores

Jan-95	81.9	Jan-96	86.44	Jan-97	95.54	Jan-98	100
Feb-95	87.33	Feb-96	92.27	Feb-97	90.53	Feb-98	100
Mar-95	98.36	Mar-96	92.73	Mar-97	95.06	Mar-98	100
Apr-95	93.68	Apr-96	99.95	Apr-97	94.72	Apr-98	98.92
May-95	100	May-96	98.28	May-97	89.15	May-98	84.21
Jun-95	100	Jun-96	97.96	Jun-97	97.35	Jun-98	100
Jul-95	90.49	Jul-96	94.61	Jul-97	100	Jul-98	90.78
Aug-95	81.24	Aug-96	89.99	Aug-97	100	Aug-98	96.22
Sep-95	99.98	Sep-96	100	Sep-97	81.42	Sep-98	86.95
Oct-95	99.92	Oct-96	100	Oct-97	89.99	Oct-98	100
Nov-95	83.77	Nov-96	87.51	Nov-97	99.92	Nov-98	99.87
Dec-95	94.59	Dec-96	91.87	Dec-97	100	Dec-98	86.85

8.7 NON-SIGNIFICANT PERIOD ANALYSIS

The previous DEA analysis was done for the A-300 fleet the analysis was carried out to compare the most efficient month to the least efficient month. In this respect the months in the non-significant period mentioned in Chapter Two, September, October, November and December were treated unfairly together with other months in the significant period. This made the months in the non- significant period look extremely inefficient; moreover, the output targets set for these months in the non-significant period were above actual levels and the input targets way below actual levels. The main reason for this gap was the differences in operational activities carried out during the year.

Maintenance management plans to conduct the major maintenance activities during the non-significant period, as the demand for air travel decreases during these months. This affects the efficiencies of those months in the non-significant period. Therefore, the comparison that was made earlier is considered to be unfair for the non-significant months. For the reason explained in the previous section regression was not considered a practical approach to this problem. As an alternative the next DEA analysis will attempt to examine only those months in the non-significant period in each of the years 1994-98 only to make the analysis fairer. It is expected for example, that the resulting target setting will be less demanding than in the previous DEA analysis. For this purpose three fleets were included in the DEA non-significant period analysis these were: A-300 aircraft, B-747 and the B-737. All four DEA models were examined for all three.

8.7.1 A-300 Overall Fleet Efficiency Analysis Model One For The Non-Significant Period

The comparative efficiency scores in Table 8.26 show that the DEA assessment for the non-significant period yielded six efficient months. The efficiency distribution is from 100% at the maximum to 79.2% at the minimum. The average relative efficiency score was 92.3%. In general the average relative efficiency scores were higher than the original DEA model when the non-significant months were included with the significant months. This is because the non-significant months' comparison analysis does not compare non-significant months with significant months.

Table 8.26 Comparative Efficiency Analysis

Month	Efficiency	Month	Efficiency	Month	Efficiency	Month	Efficiency
Oct-95	100	Sep-94	100	Sep-96	91.64	Dec-94	85.42
Nov-97	100	Nov-98	99.53	Oct-97	90.41	Dec-95	84.5
Sep-98	100	Sep-97	99.09	Nov-95	88.15	Dec-96	81.57
Sep-95	100	Dec-98	98.59	Nov-94	85.67	Nov-96	80.28
Dec-97	100	Oct-98	96.78	Oct-94	85.54	Oct-96	79.19

The analysis of the set of the efficient month's shows that the month of September-98 is considered to be "best practice" month as it appears as a reference month 14 times. Table 8.27 shows the input and output variables that contributed to the high efficiency for the set of efficient months.

Table 8.27 Input and Output Contribution Of The Efficient Months

	I/Os	Level %		I/Os	Level %		I/Os	Level %
	Cost	100		Cost			Cost	53
	Man-hours			Man-hours	100		Man-hours	47
	Fhrs			Fhrs			Fhrs	
Sep-94	Cycles	86	Nov-97	Cycles		Sep-98	Cycles	
	Deprt			Deprt			Deprt	
	UTZ			UTZ			UTZ	
	Fhrs/Cycles			Fhrs/Cycles	100		Fhrs/Cycles	
	O.T.P	14		O.T.P			O.T.P	100
	Cost	86		Cost	100			
	Man-hours	14		Man-hours				
	Fhrs			Fhrs				
Sep-95	Cycles	77	Dec-97	Cycles				
	Deprt			Deprt	100			
	UTZ			UTZ				
	Fhrs/Cycles	23		Fhrs/Cycles				
	O.T.P			O.T.P				

Both September-94 and September -95 were classified as being efficient mainly due to the high numbers of cycles achieved during these two months. This suggests that the A-300 fleet was mainly used for a short haul operation in these particular months. As for the month of September 98 the efficiency was mainly due to the high level of on-time performance achieved during that month. In November-97 the case was different as the high efficiency was attributed to the high ratio of flight hours to cycles achieved. Finally, the month of December-97 was considered to be highly efficient due to the high number of departure achieved.

Inefficient Month Analysis

By examining the result of the month of October-96 Table 8.28, which is considered to be the least efficient month in the list of the months in the non-significant period, a better understanding of the DEA analysis can be grasped. The target levels identified by the DEA analysis for this particular month coincide with the result of the original DEA model, which included all sixty months, the reason being that the best practice month in both cases was September-98. The reference set comparison between the least efficient month and the best practice month will be the same, therefore, the illustration of the reference comparison is not presented as it has been discussed earlier.

Table 8.28 Potential Improvement

Oct-96		60 Month Model %	Non-Significant Period %
Inputs	COST	-20.81	-20.81
	MAN-HOURS	-67.54	-67.54
Output	FHRS	6.62	6.62
	CYCLES	7.45	7.45
	DEPRT	0.32	0.32
	UTZ	10.22	10.22
	FHRS/CYCLYS	4.42	4.42
	O.T.P	0	0

8.7.2 A-300 Fleet Performance Efficiency Analysis Model Two For The Non-Significant Period

The analysis of the relative efficiency shows that there were five efficient months among the set of the months in the non-significant period. The minimum relative efficiency score is 76.0% for the month of October-96, see Table 8.29. This result is higher than the result obtained when same month was included along with the significant months. The month of September-98 in this analysis scored 100% relative efficiency score, while when this month was included in along with the significant period months it only scored 94.74%.

Table 8.29 Comparative Efficiency Analysis

Month	Efficiency	Month	Efficiency	Month	Efficiency	Month	Efficiency
Sep-98	100	Sep-97	98.45	Sep-96	88.75	Nov-94	82.92
Nov-97	100	Nov-98	95.34	Oct-97	87.98	Nov-95	81.94
Dec-97	100	Oct-98	93.11	Oct-94	85.54	Dec-96	79.49
Sep-95	100	Oct-95	92.7	Dec-94	84.04	Nov-96	78.02
Sep-94	100	Dec-98	88.91	Dec-95	83.62	Oct-96	76

The reference set comparison analysis suggests that the month of December-97 should be considered the best practice month as it appears eleven times as a referent month. When the same DEA model was analyzed with the full sixty month set July-97 was the best practice month. This is an indication that the non-significant months analysis result has achieved the intended goal, which is to allow the months that appeared to be poor performers in the earlier DEA analysis to show their actual operational strength when compared on a common basis. In other words, the set of months that operate at similar levels given their activity levels, needs to be analyzed separately from other months that have different levels of operations.

The analysis of the inputs and outputs that determined the efficient months was carried out in Table 8.30. As for September-95, September-94 and September-98 the high efficiency rating was mainly due to the number of cycles achieved during these months. Due to the decrease in demand for air travel during these months, the A-300 fleet was used for short haul flights; therefore, the number of cycles was high. As for November-97 and December-97 the high efficiency was due to the high number of departures achieved.

Table 8.30 Input and Output Contribution Of The Efficient Months

	I/Os	Level %		I/Os	Level %		I/Os	Level %
	Cost	100		Cost	91		Cost	92
	Man-hours			Man-hours	9		Man-hours	8
	Fhrs			Fhrs			Fhrs	43
Sep-94	Cycles	62	Nov-97	Cycles		Sep-98	Cycles	57
	Deprt	38		Deprt	100		Deprt	
	Cost	94		Cost	87			
	Man-hours	6		Man-hours	13			
	Fhrs	42		Fhrs				
Sep-95	Cycles	58	Dec-97	Cycles				
	Deprt			Deprt	100			

Inefficient Month Analysis

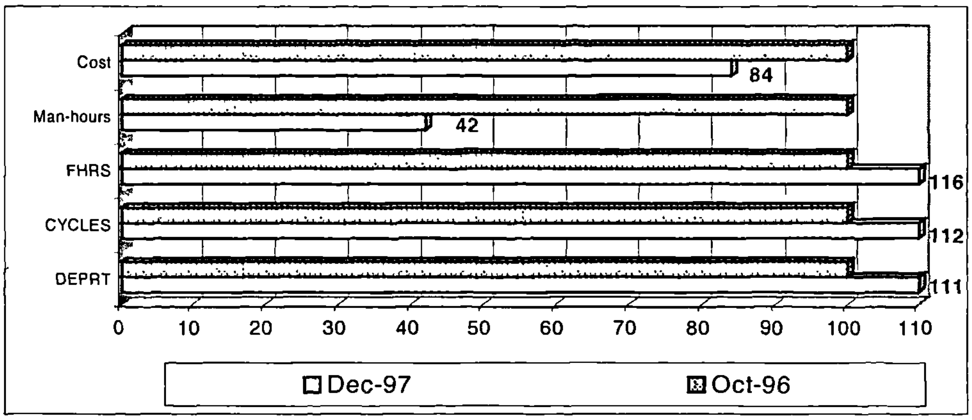
The analysis for the potential improvement for the month of October-96 shows that the target for the output was much less when compared to the previous DEA model which included all sixty months, see Table 8.31. For example, the target for the Flight-hours in the earlier model was 14.28 compared to 4.62 in the non-significant period analysis. This analysis shows that this DEA analysis sets more realistic figures for targets. It is necessary to mention here that since the month of October-96 falls in the non-significant period, it might not have been able to achieve the high target given by the earlier DEA analysis, as there was little scope to achieve this target.

Table 8.31 Potential Improvement

Oct-96		60 Month Model %	Non-Significant Period %
Inputs	COST	-28.76	-24
	MAN-HOURS	-61.85	-62.25
Output	FHRS	14.28	4.62
	CYCLES	13.51	0.67
	DEPRT	0	0

The reference comparison analysis shows that the best-performing month December-97 consumed less inputs, while it achieved better results compared to October-96. The same month October-96 when analyzed in the reference comparison showed that the gap between the two months are great, while in Figure 8.16 the output achieved by the best-practice month are relatively lower.

Figure 8.16 Reference Comparison



8.7.3 A-300 Fleet Utilization Model Three For The Non-Significant Period

The relative efficiency analysis in Table 8.32 shows that there were only four efficient months. The distribution of efficiency was between 100% at the maximum and 72.7% at the minimum. The average efficiency rating was 86.12%. This is the minimum average efficiency among the four different DEA models for the A-300. This result suggests that the A-300 utilization rate was low during the non-significant months. From observation of the relative efficiency scores the least efficient month is October-96 which achieved 72.7% efficiency rating. For the same month in the 60 month model the efficiency was lower at 62.34%. Again the non-significant period analysis appears to have allowed the months in the non-significant period to have a higher level of relative efficiency compared to the previous DEA model analysis, which included all sixty months.

Table 8.32 Comparative Efficiency Analysis

Month	Efficiency	Month	Efficiency	Month	Efficiency	Month	Efficiency
Sep-95	100	Sep-94	93.39	Oct-98	83.31	Dec-98	78.13
Nov-97	100	Sep-96	91.64	Dec-94	81.39	Oct-94	77.35
Sep-98	100	Nov-98	87.69	Dec-95	81	Nov-95	76.2
Dec-97	100	Oct-97	84.14	Nov-94	79.5	Nov-96	73.94
Sep-97	99.09	Oct-95	83.86	Dec-96	79.02	Oct-96	72.7

The analysis for the reference set showed that the month of September-98 to be the best-practice month. Table 8.33 gives the input and output contribution analysis was carried out. Both months September-98 and November-97 were made efficient mainly due to the high levels of aircraft utilization. As for the months of December-97 and September-95 the high levels of efficiency were due to the high levels of flight hours achieved during these two months.

Table 8.33 Input and Output Contribution Of The Efficient Months

	I/Os	Level %		I/Os	Level %
Sep-98	Cost	100	Dec-97	Cost	100
	Man-hours			Man-hours	
	Fhrs	35		Fhrs	100
	UTZ	65		UTZ	
Nov-97	Cost	87	Sep-95	Cost	
	Man-hours	13		Man-hours	100
	Fhrs			Fhrs	100
	UTZ	100		UTZ	

Inefficient Month Analysis

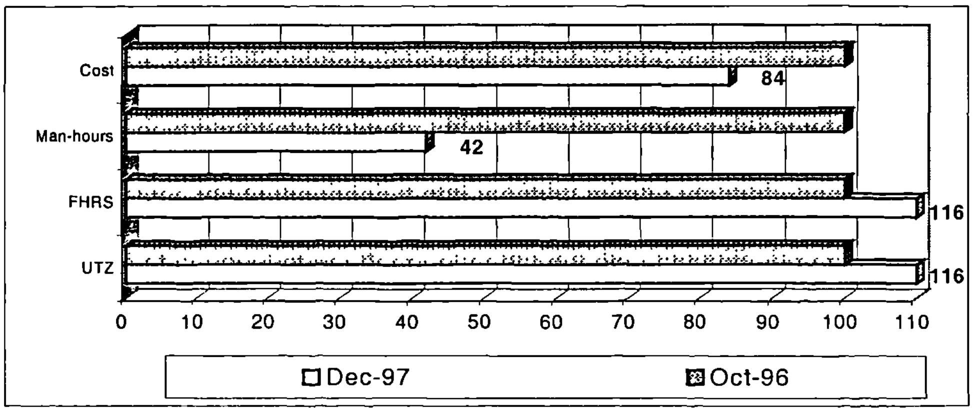
The analysis for the potential improvement suggests that the month of October-96 needs to reduce the level of input, however, no improvement is required in the output variables, see Table 8.34. This suggests that the month of October-96 reached its optimum operating level and therefore, there was very little room for improvement unless the market condition changes and the demand for air travel increases.

Table 8.34 Potential Improvement

Oct-96		60 Month Model %	Non-Significant Period %
Inputs	COST	-37.66	-27.3
	MAN-HOURS	-66.62	-64.1
	UTZ	0.78	0
Output	FHRS	0	0

The analysis for the reference comparison in Figure 8.17, shows a moderate increase in the output variables achieved by the best-practice month when the significant period months were eliminated from the analysis. December-97 has achieved an extra 16% in terms of the output variables, while it consumed less input variables.

Figure 8.17 Reference Comparison



8.7.4 A-300 Fleet Reliability Model Four For The Non-Significant Period

The analysis of the relative efficiency in Table 8.35 shows a distribution of relative efficiency between 100% at the maximum and 79.2% at the minimum, with an average relative efficiency rating of 91.78%. From observation of the relative efficiency scores the month of October-95 was ranked to be 100% efficient, compared to 87.78% in the previous analysis when all sixty months were included in the analysis.

Table 8.35 Comparative Efficiency Analysis

Month	Efficiency	Month	Efficiency	Month	Efficiency	Month	Efficiency
Oct-95	100	Sep-94	100	Sep-96	88.75	Oct-94	84.49
Nov-97	100	Nov-98	99.53	Nov-95	88.15	Dec-95	82.47
Sep-95	100	Dec-98	98.59	Oct-97	87.93	Nov-96	80.28
Sep-98	100	Sep-97	98.45	Nov-94	85.67	Dec-96	79.83
Dec-97	100	Oct-98	96.78	Dec-94	85.42	Oct-96	79.19

The analysis of the input and output contribution in Table 8.36, shows that both months November-97 and September-98 were made efficient by the high levels of on-time performance achieved. As for the months of September-94 and September-95 the high efficiency ratings were mainly due to the high levels of cycles achieved in these two months. Finally, the month December-97 was efficient due to the high levels of flight hours achieved during that month.

Table 8.36 Input and Output Contribution Of The Efficient Months

	I/Os	Level %		I/Os	Level %		I/Os	Level %
Sep-98	Cost	100	Sep-94	Cost	100	Sep-95	Cost	86
	Man-hours			Man-hours			Man-hours	14
	Fhrs			Fhrs			Fhrs	
	Cycles			Cycles	86		Cycles	77
	T.O.P	100		T.O.P	14		T.O.P	23
Nov-97	Cost	58	Dec-97	Cost	100			
	Man-hours	42		Man-hours				
	Fhrs			Fhrs	100			
	Cycles			Cycles				
	T.O.P	100		T.O.P				

Inefficient Month Analysis

The analysis for the inefficient month shows that the month of October-96 could have improved its output by 6.62% in terms of flight hours. However, the interesting observation is that the input variables need to be reduced tremendously. This is apparent in the level of man-hours used during that particular month. Since major maintenance activities and scheduled maintenance are accomplished during this time of the year, the high levels of man-hours are understandable, see Table 8.37.

Table 8.37 Potential Improvement

Oct-96		60 Month Model %	Non-Significant Period %
Inputs	COST	-20.81	-20.81
	MAN-HOURS	-67.54	-67.54
Output	FHRS	6.62	6.62
	CYCLES	7.45	7.45
	O.T.P	0	0

8.7.5 A-300 Non-Significant Period Analysis Summary

In general the non-significant period result were successful in comparing those months in the non-significant period, in that they were able to set more acceptable targets levels for the inefficient month. (The target levels for non-significant month set by the 60 month DEA analysis were in general impossible). In addition, the reference set comparison for the least efficient month showed a smaller gap between the "best-practice" and the inefficient month.

8.8 DEA EXTENSION MEAN EFFICIENCY ANALYSIS FOR ALL FLEETS

The analysis in the previous sections discussed both efficient and inefficient months. Moreover it also highlighted the problem areas in each model, which contributed to inefficiency levels. To find out which was the best performing fleet in any of the main four models discussed, the mean efficiency of each model was calculated. These highlight for management, which fleet, has performed well for which model, see Table 8.38.

Table 8.38 Mean Efficiency For The Different Fleets

Aircraft Type		Model (1)	Model (2)	Model (3)	Model (4)
A-300	Mean	91.26	**86.59**	80.69	90.26
B-747	Mean	**91.38**	83.86	**83.41**	88.26
B-737	Mean	91.19	85.1	82.36	**90.27**

The result in the table above shows that the best performing fleet in Model One "Overall fleet efficiency" was the B-747 as it has a mean score of 91.38%, this was followed by the A-300 with 91.26%. However, the overall mean efficiencies were high and they are quite similar. Which means that there is very little obvious difference noted between the different fleets.

Moving on to model two, which is "Fleet performance", the result suggests that the best fleet performance was the A-300 with a mean efficiency of 86.59%. Again the result suggests that other fleets had a very similar mean efficiency.

Model three "Fleet utilisation" the best performing fleet was found to be the B-747. Since the B-747 is considered to be a long-range type of aircraft it should have highest average aircraft daily utilisation, and that is what was concluded from this analysis. Other fleet efficiencies were very close to the B-747.

Finally, Model Four, the fleet reliability model, suggests that the B-737 had the highest mean efficiency in terms of fleet reliability. This analysis helps management identify which fleet is performing the best along each of the dimensions identified by the four models. Furthermore, this analysis is useful in highlighting the weakness in a particular fleet compared to other fleets.

A-300 Mean Efficiency Analysis

This section examine the mean efficiency for each fleet based on the five years studied. This analysis will help in highlighting whether a certain fleet mean efficiency has increased or decreased over the period of the five years studied.

The mean efficiency for the *A-300*, shows that the highest mean efficiency for all four models was achieved in 1997, see Table 8.39. The results for the A-300 fleet in all four models, suggests that the mean efficiency started high at the beginning of 1994, then declined for the next two years 1995 and 1996 for all four models. By 1997 all four model mean efficiencies had increased and reached the highest levels of efficiency for the five year period studied, and then started to decline once more. The highest increase achieved in the A-300 was in model two as it increased by 16.36% from 1996 to 1997.

Table 8.39 All Four Model Mean Efficiency Scores By Years

	Model	1994	1995	1996	1997	1998
A-300	Model (1)	90.21	89.11	82.86	**97.58**	96.55
	Model (2)	88.96	85.36	75.80	**92.16**	90.66
	Model (3)	79.08	77.53	73.53	**89.41**	83.92
	Model (4)	88.77	88.64	82.53	**95.96**	95.42
B-747	Model (1)	95.38	**98.54**	95.44	83.26	84.31
	Model (2)	88.57	**93.04**	90.06	74.53	73.10
	Model (3)	88.11	**93.50**	89.90	73.79	71.75
	Model (4)	92.79	**96.45**	92.81	78.41	80.83
B-737	Model (1)	89.76	92.11	86.83	**96.55**	90.69
	Model (2)	85.82	85.53	84.31	**93.41**	76.42
	Model (3)	81.71	82.66	81.97	**90.98**	74.48
	Model (4)	88.78	91.51	85.62	**95.33**	90.10

A-737 Mean Efficiency Analysis

An interesting aspect of the efficiency distribution is brought out in the analysis of the B-737 mean efficiency. The best mean efficiency was also achieved in 1997. Table 8.39 shows that the mean efficiency scores for the B-737 for 1998 were below the 1997 mean score. This was due to the phasing out of a large portion of the B-737. Analysis of the result in Table 8.39 suggest that model one *Overall fleet efficiency*, model three *Fleet utilisation* and model four "Fleet reliability" all exhibited similar patters. The mean efficiency for all three models increased in 1995, then dropped again in 1996. As for model two *Fleet performance* it experienced a decline from 1994 to 1996; in 1997 it reached its maximum efficiency then started to decline again, because of the phase out of a large number of this fleet as well as the introduction of a newer type of aircraft to replace it.

B-747 Mean Efficiency Analysis

The *B-747* had the best mean efficiency in 1995, for all four models. However, the mean efficiency score started to deteriorate after that. The lowest efficiency was achieved in 1998 for models two and three. This is because of the introduction of the B-777 in service in 1998, which caused the mean efficiency for model three "Fleet utilisation" to be the lowest in all five years studied. Sengupta (1995) states that the fluctuation of efficiency over time raises an important policy issue. The author notes that technological changes can have an effect on efficiency levels. In this respect management decision with regards to changes in maintenance strategy definitely have an impact on maintenance efficiency.

Comparing Efficient And Inefficient Months

The final discussion of the efficiency of the four models for the four different fleets illustrates the difference between the efficient and inefficient month means for the input variables. The results in Table 8.40, suggest that the efficient months for all fleets utilised fewer input resources compared to the inefficient months. For example, the input variables utilised for the B-747 model were (16,380,274) for the cost and the cost of the inefficient month was higher (17,768,050), these finding are consistent with Peck *et al.*, (1998)

Table 8.40 Mean Values For Input For The Efficient And Inefficient Months

		Efficient Month		Inefficient Month	
	Model	Cost	Man-Hours	Cost	Man-Hours
A-300	*M1*	7,035,784.00	7,015.44	7,731,321.10	9,090.38
	M2	7,352,212.25	5,622.75	7,634,197.25	8,784.98
	M3	7,237,759.20	6,304.20	7,649,729.07	8,780.53
	M4	7,049,940.78	5,902.22	7,649,729.07	8,780.53
B-747	*M1*	16,380,274.27	14,844.73	17,768,050.64	18,679.64
	M2	17,025,770.83	13,914.83	17,561,922.39	18,608.57
	M3	16,015,881.83	14,257.17	17,674,132.28	18,570.54
	M4	16,424,671.20	14,864.80	17,606,819.60	1,8430.00
B-737	*M1*	3,386,123.50	7,796.00	3,676,638.14	14,925.11
	M2	3,589,609.90	9,643.90	3,670,802.62	15,411.02
	M3	3,401,394.50	7,774.50	3,666,093.81	14,680.02
	M4	3,459,136.33	12,323.33	3,667,698.61	14,561.75

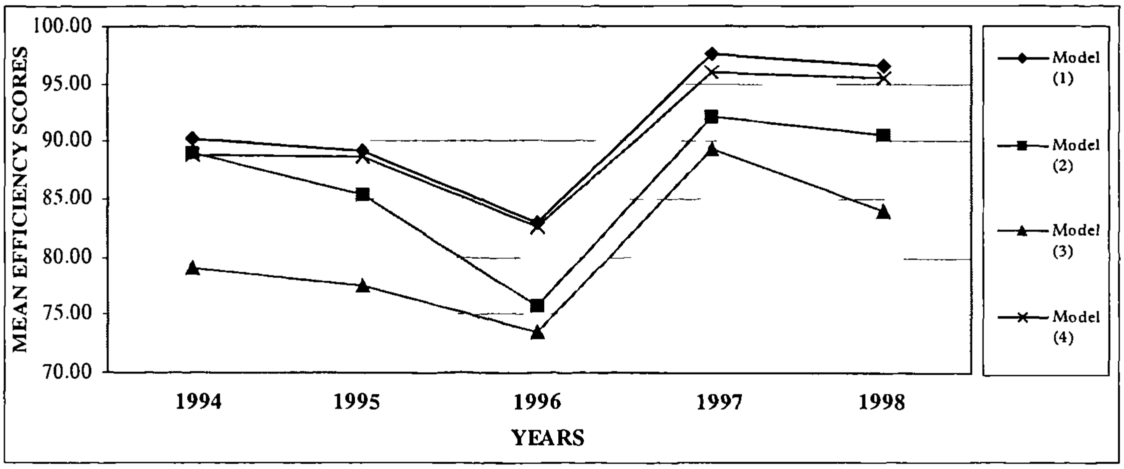
8.9 SUMMARY OF CHAPTER

This chapter audited the maintenance department, to explore the performance of the maintenance in achieving their task. The four fleets A-300, B-747, B-737 and the L-1011 were examined using different DEA models. Moreover, targets values were also explored so that maintenance management can identify if there is a room for improvement or not.

Management can learn a great deal from the mean efficiency analysis carried out in Chapter Eight. For example, how their decisions in regard to maintenance activities affect their fleet efficiency. Therefore, management can review their future strategic planning based on the information given by the DEA analysis. In addition, management can benefit from the mean efficiency analysis by focusing their attention on those fleets that have a lower mean efficiency, and set long-term strategic goals to increase the mean efficiency. Moreover, the mean efficiency analysis provides management with good information on whether available resources need to be increased in order to achieve higher levels of efficiency. Therefore, the mean efficiency analysis can be used as a powerful tool to tell management how well their goals are being met, and what are the areas to focus upon to bring about higher efficiency levels.

In Figure 8.18 below the A-300 model one "Overall fleet efficiency" results were applied to better investigate how a certain fleet is behaving for the past five years. Managers can enquire about the way the data behaved. For example, they can ask what are the causes behind the decline? What was the current situation that could have affected this mean efficiency? Or what are the action that were taken along with current situation at that time that could have caused the mean efficiency to rise sharply?. Looking at Figure 8.18 the result suggests that model one "Overall fleet efficiency" and model four "Fleet reliability" were very close to each other. Similarly but not as close as the previous two models, the "Fleet performance model" and "Fleet utilisation" model were somewhat similar to each other starting 1996.

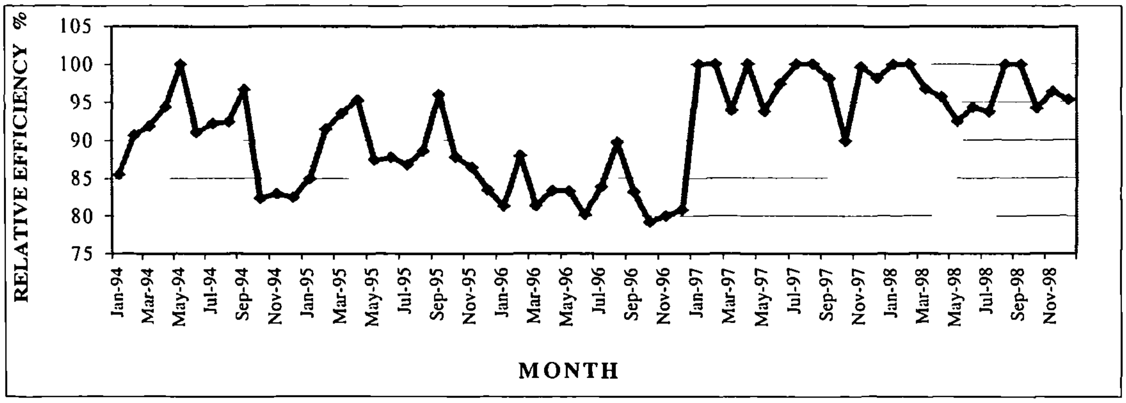
Figure 8.18 All Four Model Mean Efficiency Scores By Years



Moreover, maintenance managers could learn from previous mistakes that have caused poor efficiency, or learn from a good practice, which caused the mean relative efficiency to rise.

The next useful output generated by the DEA analysis relative efficiency scores is the graph of the relative efficiency over a period of time for a specific fleet. Figure 8.19 illustrates the time series graph for the A-300 aircraft model one over the five years period 1994-98. Since the previous mean efficiency graphs gives the mean efficiency over the five years period which is rather general information, the data present in Figure 8.19 are more detailed than in the previous one. This graph provide detailed indicator to maintenance managers on how effectively their decisions are meeting their goals of improving maintenance efficiency. Maintenance managers could use this type of information to learn from previous maintenance practice, and therefore, can avoid action that harms efficiency. Over a period of time maintenance managers will develop a good grip on the maintenance department and would be able to make the right decision to bring about overall improvement into the maintenance department. This could be in terms of reduced maintenance cost, less ground time and higher productivity.

Figure 8.19 A-300 Model One Five Years Period Relative Efficiency Scores 1994-98



Finally, maintenance managers could effectively analyses the data generated from the DEA analysis and identify the monthly (DMUs) that are identified by the DEA analysis as low performers. Once these DMUs are identified as was done in Chapter Eight for the non-significant period analysis. They can be analysed separately so that they can be judged fairly among each other. This is useful in allowing the maintenance managers to set targets setting that could possibly be achieved.

CHAPTER NINE

DEA AND CONTROL OF MAINTENANCE PERFORMANCE

CHAPTER NINE

DEA AND CONTROL OF MAINTENANCE PERFORMANCE

9.0 INTRODUCTION

This chapter discusses how maintenance management could make use of the DEA productivity based measurement system that was discussed in Chapter Eight in some detail. In addition, this chapter will discuss how maintenance managers should use the different outputs that are generated by the DEA analysis. It will also make a great deal of use of the information provided in Chapter Two that discusses the significant period of operations in the year and in Chapter Three on the characteristics of effective productivity measurement systems. Moreover, this chapter will also comment on how maintenance managers can make use of the efficiency analysis to better enhance the result of the DEA based productivity measurement system approach.

A sound efficiency and productivity measurement system could be of great benefit to the carrier if the top maintenance management decided that airline would start providing major maintenance activities for other airlines that would like to outsource their maintenance activities. To do this, maintenance managers would require a tool that would allow them to be able to identify areas that could obstruct their mission of providing major maintenance service for other carriers. Once the maintenance management can effectively identify the barriers that hinder the launching of this kind of ambitious program, then it can start working on other areas such as capacity availability, manpower needed and more importantly the cost of the maintenance to be carried out, as this must be competitive with other major maintenance providers in the market. As was discussed in Chapter Three, the airline business nowadays functions by allowing the different maintenance units such as the Workshop and the Hangar to generate profits by carrying out major maintenance tasks for other carriers. This process of outsourcing acts as a profit generation mechanism for the maintenance department and the airline as a whole.

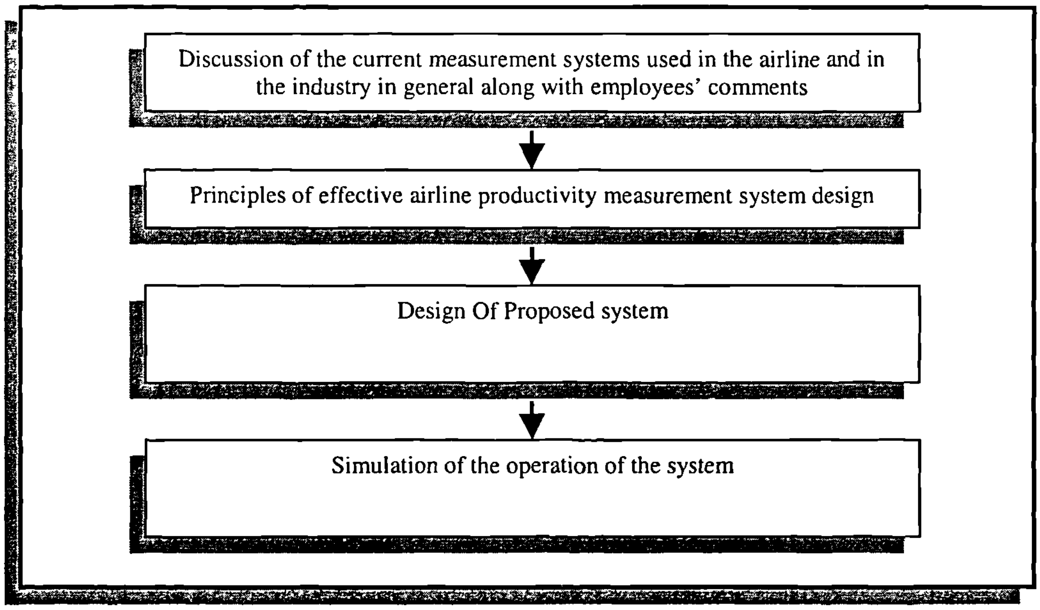
As referred to in Chapter Six, the advantage of using DEA in the airline maintenance is that it has the ability to handle multiple inputs and multiple outputs and these are exactly the characteristics of airline maintenance operations.

DEA analysis has various properties that could be useful to decision-makers in the airline maintenance industry. Chapter Six discussed the target setting feature of the DEA and its application was illustrated in Chapter Eight. This characteristic of DEA enables maintenance managers to be able to set a strategic plan to meet the target values provided by the DEA analysis. However, this depends on the maintenance managers being able to evaluate the target values given by the DEA analysis, to determine if they are achievable or not and to identify, the possible ways to achieve the given target or a specific percentage of it.

9.1 DEVELOPING A DEA BASED PRODUCTIVITY SYSTEM

In this section the A-300 type of aircraft will be used to illustrate the outcome of the previous DEA analysis and what maintenance management could actually learn from it. This section is aimed at identifying how management can utilise DEA analysis as a powerful tool to assist decision makers in the maintenance department to bring about improvements in the maintenance department in general. There are four main stages that will be discussed in the process of developing a DEA based productivity system in the airline maintenance. These are illustrated in Figure 9.1.

Figure 9.1 The Four Main Stages In Developing A DEA Based Measurement System



9.2 Current Productivity And Efficiency Measurement Systems In The Airline Industry

In the airline maintenance industry there are different types of performance measurement indicators that are monitored by the maintenance managers as a means of measuring efficiency and productivity, as was mentioned in Chapter Three. However, these measures of efficiency differ from one airline to another depending on the size of the operational activities undertaken in the maintenance department and the size of the fleet.

Due to the complexity of airline maintenance operations, there tend to be many different outputs that can be generated from normal daily operations. With this in mind maintenance management, aircraft engineers and planners decide on what are the output variables that need to be monitored to answer their questions on how well they are doing on efficiency and performance. In other words, maintenance managers generate a list of variables that help them achieve their goals. If for example, they are concerned with high reliability then, *technical on-time performance* is a suitable indicator, which reflect how the Line maintenance is doing.

As was suggested in Chapter Two there is a need for a more rigorous productivity measurement system than the one in place at the moment because of the fierce competition among airline operators and the rising cost of maintenance. This competition is forcing top airline management to request that maintenance managers should be able to control or minimise their maintenance costs of operation, in order to provide a service that is characterised as being efficient and affordable to a wider range of the public. Chapter Three mentioned that greater efficiency can come about through technical changes, such as introducing faster machines; or by managerial changes that will achieve better planning, scheduling and control of the maintenance activities carried out. Chapter Three also suggested that greater efficiency could be obtained through changes in workers' behaviour such as working smarter and by listening to them.

Communication barriers between maintenance managers and technicians could possibly act as strong barriers to achieving higher levels of efficiency and productivity. As was seen in Chapter Five, regarding the technicians' comments that they require better tools to carry out the maintenance tasks and better information about what productivity and efficiency is in the workplace. Points like these, if ignored, do not help maintenance management to accomplish their goal of running an effective airline maintenance unit. In this respect both maintenance managers and the technicians can work together on achieving the same objective of providing an effective maintenance service.

In general, there is no sound efficiency measurement system in place in Saudi Airlines at the moment as was mentioned in Chapter Two; a system that will attempt to fully answer managerial concerns on the exact sources and levels of inefficiency; a system that will also allow managers to learn from previous operations. This kind of tool is considered to be a key success factor for maintenance managers in achieving two significant aims. The first is to accomplish their company's overall goals through achieving customer expectations, which could be, for example, being the most "Reliable Airline" in order to increase passenger confidence. The second is to achieve the departmental targets of high on-time performance to complement the overall picture of the carrier by improving the on-time performance.

9.3 Characteristics Of Effective Airline Productivity Measurement Systems

In order for airline maintenance managers to be able to use any productivity measurement system, the system should have several characteristics:

1. Any productivity measurement system should be functional i.e. it should be easy to operate. This will allow the maintenance managers to easily interact with the system in order to obtain any necessary data they need to know about the different maintenance departments. In other word, the proposed system should not be complicated to run, and should use minimum manpower to run the system as well.

2. Another characteristic that the productivity measurement should have is that it should have high validity. For an effective productivity system to be highly supported by the different maintenance managers, it should have validity in terms of the outputs it produces. This means that the system should reflect actual operational activities carried out in the maintenance department, and should be perceived by maintenance managers as truly reflecting their actual operational activities. In this respect all maintenance managers should agree with the outputs generated from the productivity measurement system in place.

3. Moreover, for any productivity measurement system to be valid, it must be working in line with the strategic aims of the airline. It must therefore, provide maintenance managers with information that tells them if they are aligned with the strategic aims of the airline, or if they have deviated from them, and therefore, some necessary action should be taken to correct for the deviations that have occurred. It is very important for airline maintenance managers to have a reliable tool, that informs them of any problem that may occur, as with the size of the operation being conducted it become difficult for the maintenance manager to quickly recover from a poor operating month, as the action that might be initiated to correct any deviation may not take effect immediately.

4. In addition, one of the principles for an effective productivity measurement for airline maintenance is that it should not be over reactive. The productivity measurement

system should gradually indicate the right direction. It is important that maintenance managers do not react too quickly and initiate unnecessary action. The nature of the business that they are operating with, should be understood by the maintenance managers, and therefore, that some periods of operation can have lower efficiency than others in terms of efficiency because of the nature of the operation. For this reason maintenance managers should not over react because of a sudden decline in efficiency.

5. The proposed system should make use only of the data that is available and that is being collected in a continuous basis, in order to avoid any interruption in running the system later on. As was mentioned in Chapter Three, an effective productivity measurement system should rely on sound data that will be used for measurement, monitoring and control purposes.

6. The proposed productivity measurement system should be set up so that it can be run once all the month's data have been stored and then produce a monthly reports based on the data entered into the system. However, as mentioned in Chapter Three, there is a need for agreement among all the top maintenance management on the basic data to be used and the way that it will be presented, collected and reported.

7. Finally, the productivity measurement system must not change past measurements, e.g. the July-00 value is fixed at end of July-00 and does not change thereafter, as this will cause confusion.

9.4 Design Of The Proposed System

There are several steps that need to be taken in translating the principles of section 9.3 into a DEA system for performance monitoring. The following steps are illustrated to highlight the process followed in designing the DEA system.

1. List all variables that could possibly be used in the DEA analysis, for which sufficient data is available.
2. Separate these variables into two categories input and output variables.
3. Decide on form of DEA model to be used.
4. Decide on the model orientation i.e. input or output orientation.
5. An optional step for maintenance managers is to divide the data into groups that are examined separately as was done in Chapter Eight for the non-significant period analysis.
6. DEA will calculate the efficiency and add one more month at a time, therefore, there is a need to set up a software package to generate the performance measurement needed for assessing efficiency of maintenance.

Designing A performance Monitoring System For The A-300

This section will provide a brief information of how the 6 step process listed above can be followed in designing a performance measurement system for the A-300. Another important issue is that once maintenance managers have identified the type of inputs and outputs, how the system will operate which model to use, and which model to use for which department, then they need to identify the set of control limits which maintenance manager will use to determine when to take action to correct for deviations in the efficiency of maintenance. Moreover, maintenance managers need to identify how often they will run these models in order to assess the efficiency of maintenance department.

Step one and two as was discussed in Chapter Eight, applying these design steps to Saudi Airlines using the set of inputs used for model one include the following: cost and man-hours. The outputs variables used for model one were: flight-hours, cycles, departure, utilisation, flight hours to cycles and technical on-time performance.

Step three identifying which model to be used and for which maintenance departments. As was stated in Chapter Eight, DEA model one for example, will generally be used by top maintenance management. This allows top maintenance management to get an overall picture of how well they are achieving their goals. The second DEA model is aimed at identifying the efficiency and performance for the Hangar and the Shop. This DEA model would be utilised by middle maintenance managers in these two departments. The third DEA model is particularly aimed at middle maintenance managers in the Hangar, with the main focus on fleet utilisation efficiency. Finally, the DEA model four is aimed at middle maintenance managers in the Line only. It is designed to reflect their department efficiency in terms of fleet reliability.

Step four depending on the current situation of the airline, maintenance management may have different objectives. For example, since Saudi Airlines is being prepared for privatisation, it is more important for maintenance management at this important stage to focus on minimising input variables such as maintenance cost, and the man-hours associated with completing the maintenance tasks.

Step five maintenance management now need to examine the different operational activities over a year time, and try to identify the months with high demand for air travel. In addition, after successfully identifying the significant months by using data from the maintenance department, then maintenance management would need to explore the degree of differences in efficiency between the high season and low season months. Based on these findings, then airline maintenance management could divide the data into two groups to be examined separately only if they found that there is a big difference in the level of efficiency as was done in Chapter Eight.

Step six what management really need in the process of designing a DEA based performance measurement system, is to set up a software package that will keep measurement data, and at the same time generate a report to the maintenance management responsible for monitoring efficiency measurement. Based on the information generated by the system, management can use it to initiate necessary action if required. Need to mention here that the time taken to generate the report is important, as this will help maintenance management to tackle the problem before efficiency get worse.

9.5 Simulation Of The Operation Of Such A System

The usefulness of the simulation of the system is as follows. Firstly, simulation analysis is useful to airline maintenance managers, as it will show them how the system will work in practice and what decisions would be taken on the basis of the information it provides. The second purpose of the simulation is to show how effective a DEA based measurement system would be in picking up different patterns of efficiency in operational activities. A third potential use for simulation is to be used as a training tool for maintenance managers who would be using such a system.

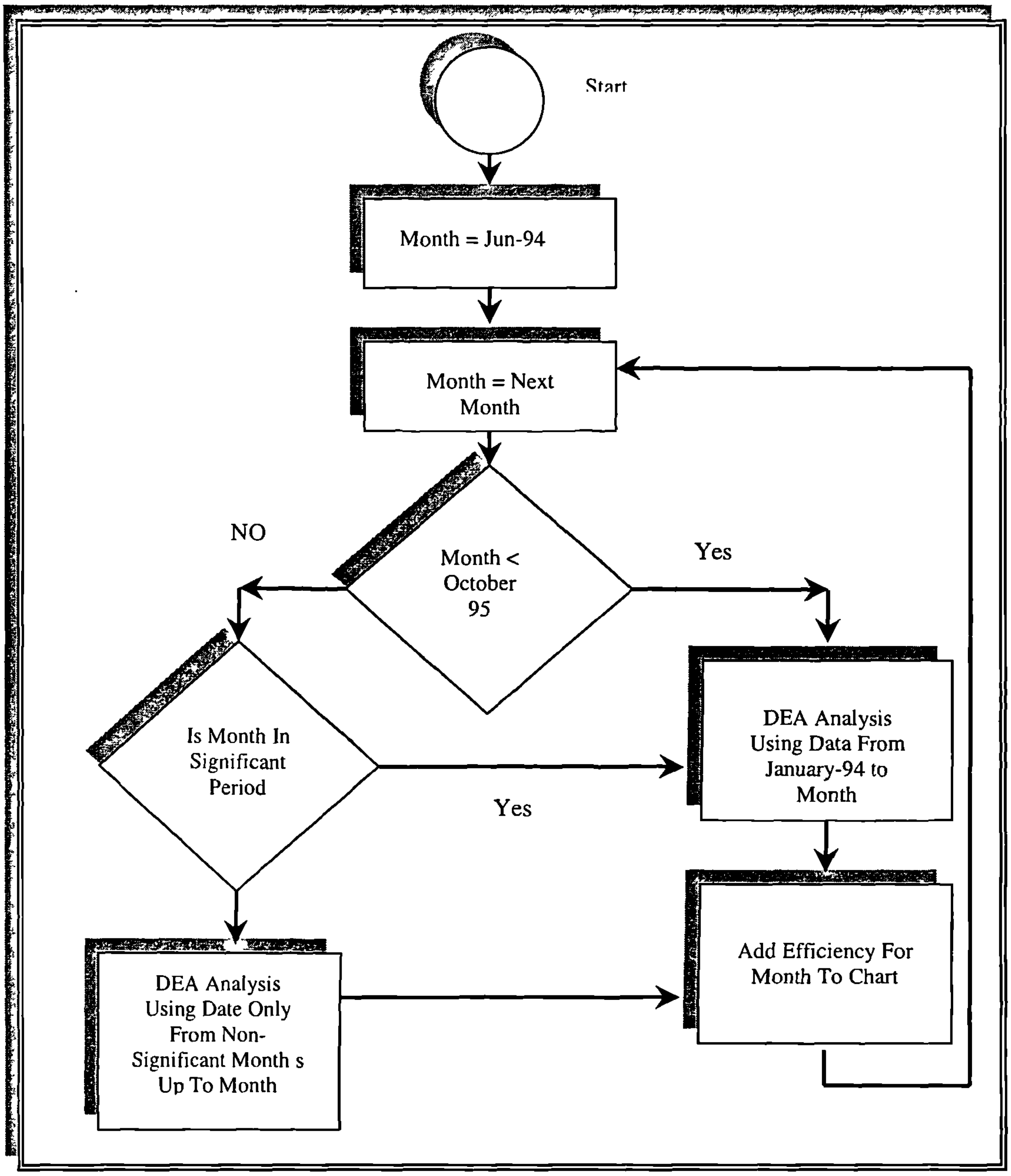
9.5.1 An Example Simulation

As an illustration, the A-300 model one was simulated from the beginning of 1994 to end 1998, with significant and non-significant months treated separately where possible. The first thing that needs to be mentioned here is that if a decision had been made by the maintenance managers to implement the system in January-1994, then the first time a sensible result could have been obtained was July-94, the reason being is that the system would need 7 months of data to start, as was mentioned in Chapter Six that the fewer the DMU examined the higher the tendency that they would be 100% efficient. That means that the first month for which results are available is July, and similarly that non-significant months cannot be treated separately until October-95.

Unlike the DEA analysis carried out in Chapter Eight the simulation would operate as follows: each month the efficiency of the latest month would be calculated (depending on point in simulation) and added into the chart (Shown in Appendix.C). This means that once calculated the figure remains unchanged in later charts. Airline maintenance management would then use the latest month figures and those for the preceding two or three months for decision-making. In the next section more detail will be provided of how in reality airline maintenance managers might make use of the charts.

In order to illustrate how the simulation procedure could be carried out in an automated system, a simplified flow chart in Figure 9.2 summarises how the simulation works.

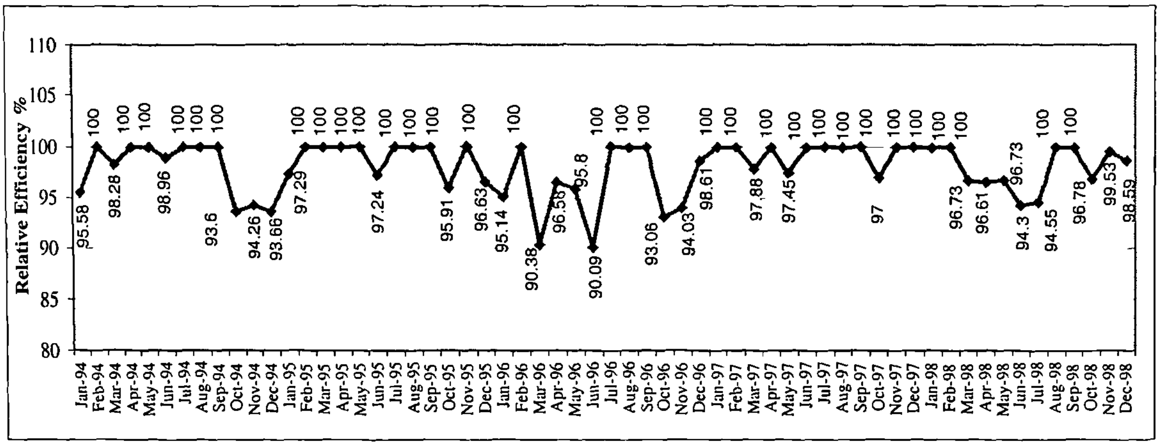
Figure 9.2 The Simulation Procedure Flow Chart



9.5.2 Using The DEA Performance Monitoring System

This section takes a close look at what airline maintenance management would do with the data generated in the charts in Appendix.C. Because the full simulation generates 54 charts it is convenient for the purpose of discussion to summarise the information in the 54 charts of Appendix.C into Figure 9.3.

Figure 9.3 A-300 Simulation Analysis



It should be noted that, in practice, maintenance managers would use the charts in Appendix.C. This means that in interpreting Figure 9.3 only points to the left of any particular point in time would be visible to maintenance managers, e.g. the end of month of March-96 shows only the points from January-94 to March-96 which would be visible to maintenance managers.

The possible reactions of maintenance managers to each new efficiency measurement will now be discussed. For example starting at July-94, the efficiency is 100%, the next month data arrives is calculated again 100%, and likewise in August-94, so far there is no concern about efficiency. On receiving the October-94 result the maintenance management have two choices, either they let the system continue on its normal operation without any interference since the system is new and they may let it work for a while to see how it will behave, or they can take an immediate action. Looking at the November-94 result it is slightly better than the previous month. In December-94 the efficiency drops back slightly to what it was in November-94 and this would likely cause maintenance management to initiate further corrective action. Afterwards efficiency starts to pick up again. Now management can look back and try to draw causes of the poor efficiency occurred in the last three months of 1994. Through this discussion airline maintenance management could possibly reach a common understanding on the possible causes of the decline in efficiency, so that they could be avoided or minimised.

Having illustrated the ways in which the 1994 results might have been used by maintenance management Table 9.1 shows likely managerial responses for each month from July-94 to December-98.

Table 9.1 Simulation Results And Likely Action To Be Taken By Maintenance Managers

MONTH	EFFICIENCY	LIKELY ACTION BASED ON DATA UP TO THIS MONTH
July-94	100%	Do nothing
August-94	100%	Do nothing
September-94	100%	Do nothing
October-94	93.6%	Maintenance management have two choices, either they let the system continue its normal operation without any interference since the system is new and they may let it work for a while to see how it will behave, or they can take an immediate action.
November-94	94.26%	Results are slightly better than the previous month, this may indicate that the system is correcting it self now.
December-94	93.66%	Efficiency drops back slightly to what it was in October-94, and this would likely cause maintenance management to initiate further corrective action.
January-95	97.29%	Clearly efficiency is heading in the right direction, maintenance management can now see the effect of their decision, and measure its effectiveness by how much efficiency has improved from previous month.
February-95	100%	Do nothing, however, maintenance management can look back and try to identify some causes of poor efficiency that occurred in the last three months.
March-95	100%	Do nothing
April-95	100%	Do nothing
May-95	100%	Do nothing
Jun-95	97.24%	The result were close to January-95, maintenance management can effectively use the same decision that was taken in that month.
July-95	100%	It appears now that the series of action that was taken was effective in improving the level of efficiency.
August-95	100%	Do nothing
September-95	100%	Do nothing
October-95	95.91%	The result is considered to be better than the one from last year, this may indicate that maintenance management may have learned from the problem which may have occurred last year, and therefore, the decline in efficiency in this month is better than the one from the last year.
November-95	100%	Do nothing, moreover, the result are better than the one from last year.
December-95	96.63%	Maintenance management may now have noticed that efficiency tends to decline in the last three months of the year, and therefore, some corrective actions may have been taken, as the result has improved from last year.
January-96	95.14%	Clearly efficiency is declining, and maintenance management need to be worried as to how to bring efficiency back to its normal levels.
February-96	100%	Do nothing
March-96	90.38%	Last year's result showed that the next two months including this one should be 100%, however, up to date this efficiency level is considered to be the greatest drop in efficiency since starting the system. Obviously, this will cause the great concern to management, and therefore, immediate action needs to be taken to correct the drop in efficiency.
April-96	96.58%	Maintenance management can now see a big improvement from the last drop in efficiency.
May-96	95.8%	Managers could continue to use similar actions to the one used in earlier month.

Table 9.1 Continued

Jun-96	90.09%	Maintenance management should now start to lunch an investigation into assignable causes of the decline. Clearly there must be a problem and it seems that management are struggling to solve these problem however, with little success.
July-96	100%	Do nothing
August-96	100%	Do nothing
September-96	100%	Do nothing
October-96	93.06%	Quite a similar result to the one from October-94, But lower than October-95. There is need for mangers to go back and considering lunching an investigation.
November-96	94.03	Slight improvement, however, efficiency is lower than the one from last year same month.
December-96	98.61%	It appears that efficiency is heading into the right direction
January-97	100%	Do nothing
February-97	100%	Do nothing
March-97	97.88%	Small drop in efficiency from the one compared to March-95, some action need to be taken
April-97	100%	Do nothing
May-97	97.45%	The level of efficiency that it drops to, is similar to the efficiency of March-97. Therefore, maintenance managers may need to assess their previous decision as it seems that efficiency is not holding steady.
Jun-97	100%	Do nothing
Jul-97	100%	Do nothing
August-97	100%	Do nothing
September-97	100%	Do nothing
October-97	97%	It seems that management now have managed to understand how to deal with efficiency. As this is considered to be the highest efficiency score achieved, when compared to same month from the previous years since the system started in 1994.
November-97	100%	Do nothing
December-97	100%	Do nothing
January-98	100%	Do nothing
February-98	100%	Do nothing
March-98	96.73%	There is some drop in the level of efficiency, maintenance management need to be worried, since this month is not considered to be among the one that are characterised to be in the non-significant period.
April-98	96.61%	The drop in efficiency almost similar but slightly lower to the previous month. This may suggest that action that was taken earlier was not sustained.
May-98	96.73%	Maintenance managers need to be worried by now, as the summer season is very close and efficiency is still low.
Jun-98	94.3%	Now maintenance management need to identify the causes behind the continuous decline in efficiency levels.
July-98	94.55%	Management can probably reach an agreement that the introduction of the new fleet may have caused the decline inefficiency. However, this may be temporary until all the new aircraft in the new fleet arrive.
August-98	100%	Do nothing
September-98	100%	Do nothing
October-98	96.78%	It is very much like previous October-97, by now maintenance management should be able to fix the problem.
November-98	99.53%	Acceptable level of efficiency, and efficiency levels seems to hold up reasonably well.
December-98	98.59%	At this stage maintenance management can ignore this result as long as it is inline with last year result.

To sum up the information listed in Table 9.1, it points out to the following:

1. The system behaved reasonably in that in around half the months the indication was 'Do nothing'.
2. The system would have detected points of concern to maintenance management, e.g. 1998 performance, that were revealed by the analysis of the full 5 year period discussed in Chapter Eight.
3. There is still a need for managerial judgement, e.g. about seasonal effects and the simulation could be used as a training tool to develop this by feeding trainees the 54 charts in Appendix.C one at a time and asking what decision they would take.
4. The information listed in Table 9.1 provided maintenance management with an overall picture of how a typical maintenance operation would behave at different time in the year, and therefore, the DEA based measurement system could possibly be used as a tool for other airlines seeking to develop their efficiency measurement techniques in the maintenance department.

9.6 SUMMARY OF CHAPTER

There are four stages to the adoption of a productivity measurement system : discussion of the current efficiency measurement systems used in the airline industry, identifying the principles of effective airline productivity measurement system design, the design of the proposed system and simulation of the operation of the system. The four stages were illustrated by applying them to the A-300. In this chapter therefore, a systematic way by which a DEA system could be developed to monitor airline maintenance efficiency was explored. The characteristics, design and simulation of the system were examined.

The operation of a DEA performance monitoring system was simulated and showed that this would have caused maintenance managers to carry out some useful investigations of the causes of declines in efficiency e.g. by identifying the effect of introducing a new fleet on the efficiency and performance of an existing one. The simulation could have a role in training maintenance managers in the use of the productivity measurement system and, more broadly, in how to manage maintenance efficiency.

CHAPTER TEN

FINDINGS AND FUTURE RESEARCH

CHAPTER TEN

FINDINGS AND FUTURE RESEARCH

10.0 INTRODUCTION

Airline maintenance productivity and efficiency measurements were the main focus of the thesis, as the maintenance department of Saudi Airline was the center of attention. The aim of this chapter is to provide a comprehensive overview of the work that was carried out in the thesis. This will cover the findings of the survey questionnaires and the findings of the *Data Envelopment Analysis* techniques used to assess the relative efficiencies for the various fleets studied. Proper efficiency measurements in airline maintenance are unquestionably a very important element of maintenance management success. These performance measurement mechanisms are basically required for three key reasons, to help reduce the burden of high cost associated with accomplishing the maintenance tasks, to ensure achieving the optimum safety levels and to prepare the airline for privatisation.

Airline maintenance operation can be characterised as a highly complex business as shown in Chapter Two, due to the variety of capital assets involved in this industry. Therefore, a highly reliable tool for measuring performance and efficiency measurement in the airline maintenance that can handle multiple inputs and multiple outputs is needed. This thesis was initiated due to the apparent lack of distinct and reliable productivity and efficiency measurement in the maintenance department.

In order to explore the development of a sound performance measurement system, two different approaches were utilised in this thesis. *First*, a survey was carried out; to examine the factors that affected performance the most; to examine what is meant by the performance of airline maintenance; to examine communications between the employees and managers and, to consider general issues related to the maintenance tasks. The *second*, was to design DEA models to fit the various element of airline maintenance management; these different models were found to be effective in highlighting the source of poor efficiency.

The performance measurement approach developed in this thesis, used the survey to focus the attention on general productivity and efficiency measurement practices in the airline maintenance by assessing both employee and management views on these issues, while the DEA analysis focused on examining the feasibility of using DEA as a technique for assessing the performance of the airline maintenance department. Through these two approaches a not-for-profit entity was examined for the application of performance measurement techniques. In addition, the relationship between the efficiency of the airline maintenance department and the performance of Saudi Airlines was assessed. A set of practical DEA models has been proposed to relate maintenance management decisions to performance measurement. This means that a DEA model was developed to focus on *aircraft utilisation* for example. In this chapter, the aim is to summarise the consequences of these models. The organisation of the summary of the findings will start first with the survey outcomes and, then consider the outcome of the DEA analysis. Problems associated with applying DEA in airline maintenance are discussed, then this will be followed by a managerial perspective on the practicability of applying DEA in airline maintenance and finally further research possibilities will be discussed.

10.1 SURVEY SUMMARY FINDINGS

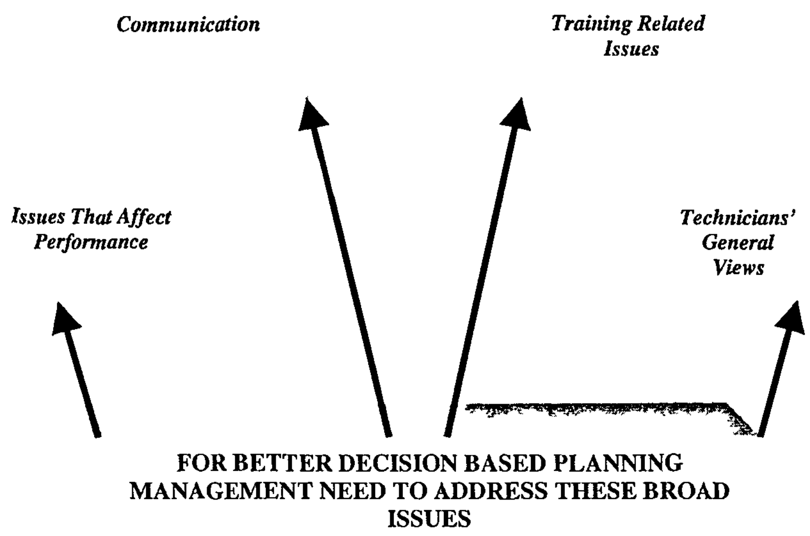
The design of the survey allowed the employees and the managers to provide their views with regards to issues relating to airline maintenance and productivity measurement. Both sets of questionnaires covered a sensitive area, i.e. the factors that are believed to affect the performance and the productivity of the work. However, the survey also covered other important issues that were explored in some detail. This section which is designed to summarise the findings of the survey, will start by summarising the employee findings and then followed by the summary of the manager findings.

10.1.1 Summary Of Employee Survey

The survey was conducted in a way so that it covered all the maintenance department directly related to the maintenance function; these are the Shop, Hangar and the Line. Technicians in all three departments were asked to rank the effect of ten issues, which were believed to have an effect on their efficiency from achieving a high quality of maintenance work. Consequently, the findings of the ten issues suggested that there were three issues, which were believed by the technicians to have a major effect on their performance. These were illustrated in Chapter Five Figure 5.1, and are as follows, *Shortages of material* (57.7%), *Shortages of manpower* (55.5%), *Shortages of ground support equipments* (44.9%). The summary findings of the manager's survey with regards to these issues were compared with the findings of the technician survey.
Technicians expressed a strong view that there are real problems with these three issues. However, these were discussed in more detail in the analysis of technician comments noted during the process of answering the questions, thus, only a summary of the comment analysis will be discussed later in the section.
Chi-squared tests were carried to examine the differences among the three different groups Shop, Hangar and Line. A variety of topics were explored to assess technician views with regards to these issues. For example, the survey analysis suggested that the majority of the technicians lack knowledge about performance, efficiency and productivity in the workplace. A further major finding of the survey suggests that maintenance management need to give more attention to issues like improving the workplace environment, providing technicians with the appropriate tools and providing the necessary manpower.

There were four main major issues of concern to technicians'. For the purpose of this chapter these can be classified into four different categories. Figure 10.1 illustrates these four classifications *training related issues*, *communication*, *issues that affect performance* and *technician views*. These four classification are considered to be highly useful to help maintenance management achieve better decision support for planning purposes. One of the thesis' objectives was to identify what is meant by the performance of airline maintenance units. The following discussion will attempt to answer this question. Figure 10.1 includes the four main themes extracted from the survey.

Figure 10.1 Major Issues In The Technician Survey



Training related issues - This category was divided into five different subjects, the main theme of this category is to discuss the technician survey findings for the three groups Shop, Hangar and Line. A detailed summary of the differences (in percentage) in views was given in Chapter Five, however, for the purpose of this chapter a generalised summary will be provided, a summary table is illustrated in Table 10.1a.

Table 10.1a Training Related Issues Given By Department

Training related issues	SHOP	HANGAR	LINE
Were performance and training explained	No 60%	No 83.3%	No 73%
Performance and training courses were defined	No 56%	No 76.7%	No 72.4%
Efficiency and training courses were defined	No 58.3%	No 79.1%	No 77%
Productivity and training courses were defined	No 54.1%	No 76.7%	No 69.3%
Knowledge taught at technical school	No 54.1%	No 75.3%	No 69.7%

These will be illustrated in terms of the answers that were given by the technicians rather than giving the percentage differences between the groups since these were discussed in detail in Chapter Five. A general overview of the training related issues suggested that performance training related issue is an area, which requires some attention from management. Technicians in all three departments expressed the view that performance efficiency and productivity were neither discussed nor explained during any training course that they had before starting the job. In addition, performance, efficiency and productivity related to the maintenance work were not discussed during the time technicians were in technical school.

Communication - There are four different sub categories related to communication between technicians and management, see Table 10.1b. Technicians in the three departments Shop, Hangar and Line thought that management would not accept their suggestions, though there were some differences between the Shop, Hangar and Line.

Table 10.1b Communication Related Issues Given By Department

Communication	SHOP	HANGAR	LINE
Management to accept technicians suggestions	Yes 56%	Yes 27.4%	No 16.7%
Knowing your department objective boost performance levels	Absolutely True 42.2%	Absolutely True 30.9%	Absolutely True 26.7%
Expected performance to be evaluated	There is no standard Level 30.6%	There is standard Level But not written 35.3%	There is no standard 29.4%
Can you review performance evaluation	Yes 63.5%	Yes 28.8%	No 50%

Technicians in the Shop and Hangar said that they could review their performance evaluation, however, the technicians in the Line said they could not. With regard to the expected performance standard required from the technicians, Shop and Hangar technicians stated that there is a performance standard but it is not written, while the technicians in the Line stated that there are no standards. All the technicians in the three departments indicated that if they knew their department's objectives they could achieve better performance; however, the differences were in the weights given by each department.

Issues that affect performance - Is the third category shown in Table 10.1c. Technicians in the Hangar and the Shop agreed that the workload is not being distributed evenly, however, the Shop technicians were neutral. The increase in performance through extra manpower was supported highly by the technicians in the Hangar and the Line, while very few Shop technicians agreed with the same statement. The implication for maintenance management is that they may need to revise the design of shifts, e.g. by looking at more than three main shifts.

The next issue is job rotation and whether it increases performance. The technicians in the Line agreed strongly with this statement, while Shop technicians agreed less highly and Hangar technicians were neutral. With the regards to the effect of the shift change of performance, the Line technicians supported this statements highly, while less supported it in the Hangar followed by the Shop which had the least who agreed with this statement. The implication for maintenance managers is that Line technicians favour job rotation, and that they thought that it would increase their performance.

Table 10.1c Issues That affect Performance Given By Department

Issues to effect performance	SHOP	HANGAR	LINE
Workload effect	Average 51.4%	Very Unfair 43.1%	Very Unfair 36.9%
Need for extra manpower	Highly Required 23.8%	Highly Required 39.7%	Highly Required 36.4%
Increasing performance through job rotation	True 38.5%	Neutral 23.3%	Absolutely True 21.3%
Shift change effect and negative performance	Yes 32.1%	Yes 32.6%	Yes 35.2%
Job rotation and the decrease in performance*	Ten Years Or Less		Over Ten Years
	No 49.7%		Yes 69.2%

* This Question was significant based on the number of years spent in the company.

For the question concerned with job rotation and whether it decreases performance, the chi-squared test showed a highly significant difference between age groups rather than departmental groups. The difference is that the technicians who had spent ten years or less in the company said that job rotation does not decrease performance, while technicians who had spent over than ten years did not agree. The possible managerial implication for this is that when the airline is privatised it is useful to develop the young technicians who thought that job rotation does not decrease performance, at the same time maintenance management need to consider the issue of age discrimination between the two groups, and therefore, maintenance management need to mention to the older group that they have mentioned in the survey that job rotation decrease performance.

Technician's views are the last of the four main categories shown in Table 10.1d. In rating department performance, the views were different, as the technicians in the Shop said that it is good, Technicians in the Hangar were neutral and the technicians in the Line said that it is very much less than it could be.

<u>Table 10.1d</u> Technicians' General Views Given By Department

Technicians views	SHOP	HANGAR	LINE
Rating department performance	Good 56.3%	Neutral 40.5%	Very Much Less Than It Should Be 46.4%
The need for information program	Absolutely True 51.5%	Absolutely True 38.6%	Absolutely No Need 82.2%
When performance evaluation are being done	Every Year 45.7%	When Needed 36.7%	When Needed 47.6%
Skill level	Highly Skilled 47.4%	Fairly Skilled 42.4%	Highly Skilled 30.7%

Technicians accepted the need for an information program about efficiency and productivity, however, with a different weight given by each department. The views of technicians in the three departments were different about when their supervisor conducts a performance evaluation, the differences were in the weight given by each department's technicians. Finally, technicians in the three different departments described their skill levels differently. Both Shop and Line technicians described their skill levels as being highly skilled, while technicians in the Hangar stated that they are fairly skilled.

With regards to the employees' comments, there were four different issues that concerned the employees. These are *process change*, *increasing performance through better tools*, *increasing performance under better working conditions* and *management and employee communications*. For each one of these issues detailed analysis was provided in Chapter Five, however, the general view of the managers, was that providing the working environment coupled with changes in the process of doing the work, helps employees to increase their performance. The communication issue was discussed earlier; thus, employees emphasised the importance of establishing better and more direct communication channels in order to improve efficiency and performance. One point for the DEA, is that there was little reference in technicians' comments to the impact of maintenance performance on airline performance.

Factor analysis

The Factor Analysis technique was used to identify which factor shows the biggest variation in opinion. The analysis revealed that there is only one factor that was identified which is the *process of doing the work.*

10.1.2 Manager Survey Summary Findings

The manager survey was conducted in a way that allowed more room for the managers to write extra comments if desired, since managers had a little more time to respond than the technicians. An interesting finding is that only three significant questions were revealed by the chi-squared test. This suggests that on the whole the managers have similar views towards the different issues in the survey although employees did not. These differences were: managers' rating of the effect of *work process on job productivity*, managers' views on *keeping regular check on the relationship between material consumption and number of cycles achieved*, and managers' views on having *complete information on effectiveness.*

There was a highly significant difference between the managers in the three different department. A lower proportion of individuals than expected in the Line said that the effect of work process is high, while a higher proportion than expected in the Hangar said it is high. In the Shop a lower proportion of individuals than expected of the managers in the Shop said it is low.

There were differences between managers with regards to the need for keeping regular check on the relationship between material consumption and number of cycles, Shop managers indicated that they do agree with the statement, while Hangar managers answer was neutral and Line managers indicated that they do not need to keep such information. In terms of policy implications for maintenance managers, this means that a clear policy should be in place, one that identifies the requirements that need to be fulfilled by each department manger.

Shop and Hangar managers agreed that they do have a complete information on effectiveness, while the Line managers were evenly divided between neutral and having the necessary information on effectiveness. In addition, there were differences in views between the managers with regards to the comment analysis. These differences were based on the maintenance task that is being accomplished in each department. Therefore, Line managers' views towards issue of assessing cost of delays were different as they indicated that they do not get involved in assessing cost of delays, while the Shop managers for example claimed that they do get involved in assessing cost of delays. In terms of policy implications top maintenance managers need to highlight issues related to the assessment of cost. Top maintenance management also need to emphasis the issue of effectiveness, and how maintenance managers in the three departments should be able to measure effectiveness in their department based on the maintenance task accomplished in their department.

10.2 SUMMARY OUTCOME OF THE DEA

The second part of the thesis sought to assess the feasibility of applying Data Envelopment Analysis to the airline's maintenance department (cost centre). This section is designed to discuss the findings of the DEA analysis in this thesis. It will focus on providing maintenance management with a perspective on the different DEA models developed for assessing airline maintenance performance.

10.2.1 DEA Models And Maintenance Performance Audits Chapter 8

The DEA models focused the attention on four main areas of importance to airline maintenance. Each of the fleets in operation was analysed according to the four DEA models, over a five-year period. The feasibility of assessing the airline maintenance department was examined through the four fleets studied.

The DEA analysis was useful in evaluating the relative efficiency for the different four models over the period 1994-98. In addition, several advantages of the DEA assessment were explored in the airline maintenance application. First, the DEA analysis was able to successfully identify retrospective targets for inefficient months for both the 60 month model and the non-significant period analysis, in order to bring the efficient months to the efficiency frontier. As explained in Chapter Eight, the target setting provides maintenance management with a mechanism for identifying improvements in maintenance policies.

Other finding of the DEA analysis was that a best practice month was identified, which other months were compared to. The best practice assessment proved to be useful in allowing management to compare the best practice month to any inefficient month. This analysis was found to be highly significant in highlighting the weak areas of the inefficient DMUs.

One of the important advantages of the DEA analysis is that it allowed assessment of relative efficiency over the five year period, which highlighted the changes in relative efficiency, and whether improvement in relative efficiency for the fleet were taking place or not.

A major finding was that DEA is a good way of diagnosing problems of interest to airline maintenance management e.g the dramatic decrease in L-1011 maintenance efficiency in 1998 and the A-300 improvement. With the DEA's flexibility to handle multiple inputs and multiple outputs, DEA analysis was used to consider issues like Overall fleet performance, Fleet performance, Utilisation and Reliability. These parameters are being monitored by maintenance management as was mentioned in Chapter Three, however, the DEA approach provides maintenance management with more important information, as the current performance measurement lacks the ability to provide maintenance managers with the information that they need in terms of what levels of input should have been used in order to improve the efficiency levels. This differs from the data being followed by most airline maintenance management. The Current measurement system only provides maintenance management with one side of the picture, and therefore, it is considered inadequate as no information is included in the method used by management, which includes the levels of input that were consumed to generate the output. The DEA analysis however includes both inputs and outputs in the model studied and provides relative efficiency measurement on the basis of the variables defined by the analyst as either inputs or outputs.

Another major finding of the thesis is that the DEA analysis helped to assess the effect of operational performance at different times of the year on the relative efficiency obtained. The effect of operational activities at different time of the year could heavily impact the relative efficiency such as the planned maintenance schedule or the significant period.

The relationship between the relative efficiency of the maintenance department and the performance of the airline in terms of reliability was successfully assessed through the DEA analysis. The reliability of an airline is a key element of the airline's success in attracting passengers. The effect of not recognising the impact of reliability on the airline could be substantial.

Following the analysis of the four different models, the weight restriction techniques were explored. The findings of the weight restriction indicated that the relative efficiency for the studied fleet increased. However, the findings of DEA weight restriction showed that the result of the relative efficiency for the weight restriction model are equal or less than those obtained by the free weight approach, this is to satisfy the additional constraint when implementing weight according to Roll *et al.*, (1991). Second observation of the DEA weight analysis is that by imposing weights on the model, the relative efficiencies with the weight restriction were reduced in most of the months. The largest differences appeared in five months, the maximum reduction in relative efficiency being 17.56%. The conclusion is that the weight restriction does not add much to the system and is probably not worth looking at.

An attempt was made to look at the lagged effects of inputs for the A-300, however, this type of analysis is complicated. The results obtained from this analysis gave some negative coefficients and therefore could not easily be translated into a data envelopment analysis.

As an alternative approach to the problem that this month measurement affects performance for several months in the future, the non-significant months were also explored separately, as it was felt that they were being treated unfairly when included with the significant months. The result for the non-significant period analysis showed a little improvement in the target setting.

10.2.2 DEA And Control Of Maintenance Performance Chapter.9

Chapter Nine discussed the issues involved in the design of a DEA based maintenance system. In Chapter Nine four stages to the adoption of a productivity measurement system were identified. They included: discussion of the current efficiency measurement applied in the airline industry, identifying the principles of effective airline productivity measurement system design, the design of the proposed system and finally, the simulation analysis for the A-300.

An example simulation was provided in Chapter Nine as the operation of such a system for the A-300 over the period 1994-98 was simulated and shown to give acceptable results. The system would operate as follows: each month the efficiency of the latest month would be calculated and added into the chart (shown in Appendix.C) a procedure flow chart was provided in Chapter Nine. In addition, a table of the likely action to be taken by maintenance managers was prepared. Using the information in Chapter Nine Table 9.1 provided some advantages to maintenance management. The simulation analysis carried out for the A-300 showed that the system behaved reasonably in that in around half the months the indication was 'Do nothing'. Moreover, the system was able to detect months of concern to maintenance management. Additionally, the simulation analysis pointed out to an important point, which is the usefulness of the simulation as a training tool for maintenance management by feeding in the 54 charts in Appendix.C one at a time to see what kind of decision that they would take. Finally, the information listed in Table 9.1 provided maintenance management with an overall picture of how a typical airline maintenance activities would perform at different time of the year.

10.3 Limitations Of The Thesis

It was not possible to conduct a DEA analysis using different airlines. This was for several reasons. First, most airlines do not collect and publish maintenance data; second, there is no standard procedure being used to produce a report that includes all the maintenance-related outputs. Some airlines produce more information than others, as determined by their maintenance management. Moreover, airline operators have different policies regarding doing maintenance in-house or outsourcing maintenance and this is a key element in comparing different airlines. Another important issue is that an airline may have initially decided to outsource its maintenance facility at some point in time, and after several years it may have decided to establish its own maintenance facility, however, the scale of operation could be very small at the start. Another major issue, is that not all maintenance departments invest a lot in people, equipment and time to collect data that may not be used for analysis. And, if management decides to spend the time and the effort to collect the data, they may differ in format from one airline to another depending on the type and the size of operation being conducted and more importantly the aims of collecting these data.

Furthermore, the cost figures for the maintenance department was given as a total of the maintenance tasks accomplished. Therefore, it was not possible to add additional input variables for the different DEA models used. The availability of such data could have helped to highlight further areas of concerns to maintenance management.

10.4 Managerial Perspective On DEA

The results of Chapter Eight were sent to the maintenance managers for their comments. The analysis of the DEA proved to be useful to the maintenance management on different levels. First, top management were interested in getting an idea on the overall picture of the efficiency in carrying out the maintenance duties that it is responsible for. Therefore, the overall fleet efficiency model was useful from that perspective. In addition, the idea of the DEA model one "*Overall fleet performance*" became more useful to top maintenance management at a time were talks are being carried on, as mentioned in Chapter Two, about privatising the national carrier. However, one of the comments made with regards to the variables used in the DEA model one was about the input variables. This was focused on the possibility of using additional input variables by giving the breakdown of maintenance costs. At this time the breakdown of maintenance cost are not available; therefore, the current study only used overall maintenance cost and the number of man-hours utilised to conduct the maintenance tasks.

The other DEA models were discussed further in terms of their ability to achieve their goal of informing maintenance managers in the Shop, Hangar and the Line of their department's efficiency. The feedback was positive, as managers agreed to the list of the output variables used in the DEA analysis. However, the main question that was raised was whether the different DEA models could be modified to incorporate different input variables. Maintenance management were interested in going further and allowing more breakdown of the input variables to dig deeper into the analysis and better understand where the inefficiencies are coming from. Maintenance management agrees so far with the findings of the current DEA model on the actual causes of inefficiency; as was pointed out in Chapter Eight, that the source of the inefficiency is either being generated from the high cost of accomplishing the maintenance tasks or the number of man-hours used in a particular month.

This analysis has triggered another discussion about the usefulness of the four DEA models, in that the efficiency result obtained from each model could be used to evaluate the option of conducting maintenance tasks in-house or to outsource them to a third party. The interest of the maintenance management was also focused on the potential of the DEA results for making decisions on outsourcing or making major changes in the planned maintenance schedule.

On a different perspective the maintenance management saw a great deal of importance in analysing maintenance schedules by incorporating input and output variables, rather than only evaluating the output levels being generated from the daily operation as is done at the moment. The maintenance management were also interested in the DEA analysis as it provided a strong tool to evaluate a specific level of input compared to the output that is being generated. And they saw an opportunity to actually learn from previous operational practice of similar month in the year that have similar characteristics, and eventually, help better improve the planning aspect of the maintenance activities to bring about higher levels of efficiency.

Concluding on the feasibility of introducing DEA based system to Saudi Airlines, is that it seems that on the basis of this result, Saudi Airlines could perhaps after modification to the inputs and outputs they can use a DEA based performance measurement system successfully. The main usefulness of such a system is that it will highlight areas of weakness, by identifying the sources and levels of inefficiency. And this is what the maintenance management in Saudi Airlines needs at this time, when they are getting ready for the privatisation of the carrier.

10.5 SIGNIFICANCE OF THE STUDY

This thesis comes at a time when the government of Saudi Arabia has launched an ambitious program to improve the efficiency and performance of State Owned Enterprises (SOE). Saudi Arabian Airlines was chosen for this research because of its great importance in being the only national carrier and because of the large number of staff working in the airline, (approximately 24,000 employees). Saudi Airline's annual revenue is about 2 billion dollars and it has around 113 aircraft. A contract worth 6 billion dollars has been signed with the aircraft manufacturers to provide another 60 new aircraft and to put thirty old aircraft out of service (Davis, 1995b). This huge government investment was made to improve the current position of the airline and to strengthen it for the next century enabling it to compete with other international carriers.

The significance of this thesis lies in the following:

1. Previous research has applied Data Envelopment Analysis to airforce maintenance units, but not to airline carriers' maintenance department. The thesis attempts to fill the gap in this respect.

2. One of the most important Saudi public sector companies is Saudi Airlines (which currently has a monopoly in Saudi Arabia). The study is the first research to use Data Envelopment Analysis to assess efficiency in the Saudi public sector.

3. This thesis comes at a time when Saudi Airline managers are seeking new ways to assess corporate efficiency and performance in order to boost productivity and finally achieve profit to meet the new challenges of the global market. The maintenance department of Saudi Airlines is considered to be important as it has more than 4000 employees who care for the fleet.

4. This thesis offers a contribution to the literature on applying Data Envelopment Analysis in developing countries.

5. The thesis has demonstrated research into the acceptability of DEA methods and the problems of implementing them.

10.6 FUTURE RESEARCH

Data Envelopment Analysis as indicated in Chapter Six has wide application. The establishment of efficiency measurements in the airline maintenance could offer a number of benefits. The availability of a standard monthly maintenance report from all the airline carriers, would allow the assessment of airline maintenance performance through comparison of maintenance units of several airlines. Possible agreement among certain airlines to publish a continuous monthly standard maintenance reports, would permit further assessment of airline maintenance. With the advances in data collection procedures through bar coding, all technicians carrying out the maintenance tasks could generate data, by sliding their identification card before and after the maintenance task. At the end of the shift data could be fed into the main computer system to process the information. In this case maintenance management would become more aware of the different tasks that had been achieved during the last shift. With more and more airline maintenance implementing digitised data collection mechanisms in the Line, Shop and Hangar, it has become more easier to obtain data quickly. A possible future research topic is to aim to study a group of different airline maintenance departments for the purpose of assessing their efficiency and productivity. This would need airlines around the world to publish reports which cover information on their maintenance activities accomplished. One important element would be that these reports are all written in the same format and more importantly collecting similar variables

Since Saudi Airlines is being considered to be privatised in the near future, one could explore the possibility of assessing maintenance performance before and after privatisation and more generally of using DEA to assess the effectiveness of the privatisation programme.

In addition, two further research areas that could be explored which are linked to the airline maintenance are: first, how to assess productivity where the effects of input activity on outputs are lagged as here. Clearly the lag effect applies to operations other than airline maintenance, however, a successful analysis needs to overcome problem of the negative coefficient that may occur. Second how to deal with the effects of seasonality on DEA performance measurement and monitoring systems. One way of dealing with the seasonality problem, is to deseasonalize the data before doing the DEA analysis. Another would be to take the charts in Appendix.B and deseasonalize them using standard forecasting methods.

- - END OF THESIS - -

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APPENDIX

APPX.A CHAPTER 6

COVERING LETTER

This survey questionnaire is conducted as a part of a Ph.D. research requirement. The purpose of the survey is to learn more about how the employees and the managers in the maintenance department of Saudi Airlines feel about certain aspects relating to performance, efficiency and productivity in the workplace.

A research student at the Canterbury Business School carries out this questionnaire and you have been selected at random to participate in the survey, because your opinion is important.

The questionnaire will require less than thirteen minutes to complete. It is hoped that you will take the time to complete it and return it to the designated department supervisor. The information you provide will contribute to an important study which may be used to influence future policies and procedures in the maintenance departments. As you are aware, on-time performance and productivity-related issues are quite important in the airline maintenance filed. There is no question that a well-defined maintenance programme is needed, and through this questionnaire an attempt will be made to identify employees and managers opinions on the issues of efficiency, performance and productivity, for possible deficiencies in the current system.

Your willingness to help in completing this questionnaire is highly appreciated. Thank you for your co-operation.

Yours sincerely,

Abdulatef H. Halawani

Research Associate
University of Kent
Canterbury Business School

EMPLOYEE QUESTIONNAIRE

This section is for the *Employee* who works in the hangar, shop and line maintenance, please answer the following questions:

1. Do you think the workload being assigned in each shift is fair?

    2. Very Unfair ☐
    3. Unfair ☐
    4. Neutral ☐
    5. Fair ☐
    6. Very Fair ☐

2. Do you think you can increase your performance through training courses?

    1. Absolutely Disagree ☐
    2. Disagree ☐
    3. Neutral ☐
    4. Agree ☐
    5. Absolutely Agree ☐

3. Do you think you can increase your performance through process change, if so, which process?

    1. Absolutely Disagree ☐
    2. Disagree ☐
    3. Neutral ☐
    4. Agree ☐
    5. Absolutely Agree ☐

____

____

4. Do you think you can increase your performance through better use of tools and equipment? If so, give examples?

    1. Absolutely Disagree ☐
    2. Disagree ☐
    3. Neutral ☐
    4. Agree ☐
    5. Absolutely Agree ☐

____

____

5. Do you think you can increase your performance through extra manpower? If so, give examples?

   1. Absolutely Disagree ☐
   2. Disagree ☐
   3. Neutral ☐
   4. Agree ☐
   5. Absolutely Agree ☐

____

____

____

6. Do you think you can increase your performance under better working conditions? Please give examples.

   1. Absolutely Disagree ☐
   2. Disagree ☐
   3. Neutral ☐
   4. Agree ☐
   5. Absolutely Agree ☐

____

____

____

7. Do you think you can increase your performance through feedback between employee and supervisor?

   1. Absolutely Disagree ☐
   2. Disagree ☐
   3. Neutral ☐
   4. Agree ☐
   5. Absolutely Agree ☐

____

____

8. Do you think you can increase your performance through job rotation?

   1. Absolutely Disagree ☐
   2. Disagree ☐
   3. Neutral ☐
   4. Agree ☐
   5. Absolutely Agree ☐

9. Do you think you can increase your performance through better incentives?

   1. Absolutely Disagree ☐
   2. Disagree ☐
   3. Neutral ☐
   4. Agree ☐
   5. Absolutely Agree ☐

10. How do you rate your overall performance?

    1. Very low compared with other similar workers ☐
    2. Low ☐
    3. Neutral ☐
    4. High ☐
    5. Very high compared with other similar workers ☐

11. How do you rate the department's performance?

    1. Very much less than it could be ☐
    2. Less ☐
    3. Neutral ☐
    4. Good ☐
    5. As good as it possibly could be ☐

12. Was performance level explained or mentioned in any of the training program that you had before starting the job?

    Yes ☐ No ☐ Not sure ☐

13. Do you feel you should know your overall performance?

    Untrue ☐1 ☐2 ☐3 ☐4 ☐5 Absolutely true

14. Do you feel the need to establish a special information programme on how to boost individual performance?

    1. Absolutely no need to establish an information program ☐
    2. No Need ☐
    3. Neutral ☐
    4. There is a need ☐
    5. High need for this program ☐

15. Do you wish to attend future training courses to gain the necessary knowledge of performance and efficiency?

    Yes ☐ No ☐

16. Do you feel the need to establish a special information programme to explain what efficiency and performance are?

    1. Absolutely no need for this program ☐
    2. No Need ☐
    3. Neutral ☐
    4. There is a need ☐
    5. High need for this program ☐

17. Do you share ideas with your supervisor that would boost performance, if so, what are these?

    1. Don't share any idea ☐
    2. Some times I do not share ideas ☐
    3. Neutral ☐
    4. Some times I share ideas ☐
    5. I share ideas all the time ☐

____

____

18. Do you expect management to accept your suggestions?

Yes ☐ No ☐ Uncertain ☐

19. How do you rate the level of satisfaction of your work?

Very low ☐1 ☐2 ☐3 ☐4 ☐5 Very high

20. Rank the 3 most important factors that can reduce your performance in decreasing order of these impact on performance:

☐ Shortage of manpower

☐ Shortage of materials

☐ Shortage of (G.S.E) equipment

☐ Inappropriate (G.S.E) equipment

☐ Work process

☐ Job Card (not clear)

☐ Facilities

☐ Poor training

☐ Weather condition

☐ Motivation

Any other factors in the list that reduces your performance significantly

____

____

21. Do you think the term *performance* was defined in any training courses you had before starting your job?

Yes ☐ No ☐ Not sure ☐

22. Do you think the term *efficiency* was defined in any training courses you had before starting your job?

Yes ☐ No ☐ Not sure ☐

23. Do you think the term *productivity* was defined in any training courses you had before starting your job?

Yes ☐ No ☐ Not sure ☐

24. Do you think if the term performance, efficiency, and productivity had been defined, you could perform better?

Yes ☐ No ☐ Uncertain ☐

25. Do you think that if you know your department's objectives you would achieve better performance levels?

1. Absolutely Untrue ☐
2. Untrue ☐
3. Neutral ☐
4. True ☐
5. Absolutely True ☐

26. Did the subjects you studied in technical school cover the term efficiency, performance and productivity?

Yes ☐ No ☐ Uncertain ☐

27. Do you think shift change can affect your performance levels negatively?

Yes ☐ No ☐ Uncertain ☐

28. Do you think job rotation can decrease your performance levels?

Yes ☐ No ☐ Uncertain ☐

29. Do you think job rotation can increase your performance levels?

Yes ☐ No ☐ Uncertain ☐

30. Do you think the job is boring?

Yes ☐ No ☐ Sometimes ☐

31. Are you satisfied with your job?

Yes ☐ No ☐ Sometimes ☐

32. On a day to day work, is there any performance standard you have to meet

☐ There is no standard

☐ There is a standard level but not written

☐ There is a written standard level

33. Does your supervisor or head of department prepare a performance evaluation for each employee?

☐ Every year

☐ When needed

☐ Never

34. If yes, are you able to look at it to discuss it even further with him?

Yes ☐ No ☐ Sometimes ☐

35. Which best describes your skill level

- ☐ Highly skilled
- ☐ Fairly skilled
- ☐ Semi skilled
- ☐ No skill required

36. How ☐Y 2 Weeks ☐ 4 Weeks ☐ 6 Weeks ☐ 8 Weeks

37. In your opinion, which shift are you more productive?

☐ Day ☐ TWI ☐ GRV

38. Which pattern of shift change would you like?

☐ DAY☞TWI☞GRV ☐ DAY☞GRV☞TWI

☐ Others________________________________(Specify)

39. Do you prefer to work in permanent shift?

☐ No

☐ Yes, Which Shift? ☐ DAY ☐ TWI ☐ GRV

Thank you for completing the following information, ***THIS INFORMATION WILL NOT BE REVIEWED BY ANYONE OTHER THAN THE PERSON CONDUCTING THE RESEARCH***:

- Job title: ______________________________
- Unit: ______________________________
- Years with company: ______________________________
- Years in present job: ______________________________
- Years in similar job: ______________________________
- Are you willing to be interviewed again: ______________________________
- Education qualifications:

  ____

  ____
- Training certificate held (training qualifications):

  ____

  ____
- Licenses held (if applicable):

  ____

  ____

  ____
- Number of personnel you are responsible for in your unit

  ____

  ____

MANGERS QUESTIONNAIRES

1. The knowledge of efficiency that the employees have at the shop floor level is high

   1. Information on efficiency is very low ☐
   2. Low ☐
   3. Neutral ☐
   4. High ☐
   5. Information on efficiency is very high ☐

2. The knowledge of performance that the employees have at the shop floor level is high

   1. Information on performance is very low ☐
   2. Low ☐
   3. Neutral ☐
   4. High ☐
   5. Information on performance is very high ☐

3. The employees have knowledge of what level of efficiency is expected from them?

   1. Absolutely Untrue ☐
   2. Untrue ☐
   3. Neutral ☐
   4. True ☐
   5. Absolutely True ☐

4. The employees have knowledge of what level of performance is expected from them?

   1. Absolutely Untrue ☐
   2. Untrue ☐
   3. Neutral ☐
   4. True ☐
   5. Absolutely True ☐

5. Should employees at the shop be aware of the shop's performance in the previous month?

   1. Strongly Disagree ☐
   2. Disagree ☐
   3. Neutral ☐
   4. Agree ☐
   5. Strongly Agree ☐

6. Should employees at the hangar be aware of their monthly performance?

   1. Strongly Disagree ☐
   2. Disagree ☐
   3. Neutral ☐
   4. Agree ☐
   5. Strongly Agree ☐

7. The knowledge of performance standard that the employees in the hangar have is high

   1. Absolutely Untrue ☐
   2. Untrue ☐
   3. Neutral ☐
   4. True ☐
   5. Absolutely True ☐

8. The knowledge of performance standards that the employees in the line have is high

   1. Absolutely Untrue ☐
   2. Untrue ☐
   3. Neutral ☐
   4. True ☐
   5. Absolutely True ☐

9. The knowledge of performance standards that the employees in the shop have is high

   1. Absolutely Untrue ☐
   2. Untrue ☐
   3. Neutral ☐
   4. True ☐
   5. Absolutely True ☐

10. Should employee at the line be aware of their monthly performance?

   1. Absolutely Untrue ☐
   2. Untrue ☐
   3. Neutral ☐
   4. True ☐
   5. Absolutely True ☐

11. Do you think the training department should have explained the meaning of performance, efficiency and productivity during the training period?

   1. Strongly Disagree ☐
   2. Disagree ☐
   3. Neutral ☐
   4. Agree ☐
   5. Strongly Agree ☐

12. How do you rate the level of co-ordination and co-operation between training and maintenance departments to improve personnel skills?

   1. Very low ☐
   2. Low ☐
   3. Neutral ☐
   4. High ☐
   5. Very high ☐

13. Do you have written guidelines for maintenance personnel by which they can identify their levels of efficiency and performance?

Yes ☐ No ☐

14. If there are written guidelines do they clearly describe the level required to do a certain job?

Yes ☐ No ☐

15. How do you rate the affect of the following factors in your point of view on work productivity?

A. Company policy	Very low ☐1	☐2	☐3	☐4	☐5 Very high
B. Managerial support	Very low ☐1	☐2	☐3	☐4	☐5Very high
C. Job security	Very low ☐1	☐2	☐3	☐4	☐5Very high
D. Employee skills	Very low ☐1	☐2	☐3	☐4	☐5Very high
E. Motivation	Very low ☐1	☐2	☐3	☐4	☐5Very high
F. Clear work objectives	Very low ☐1	☐2	☐3	☐4	☐5Very high
G. Adequate tooling	Very low ☐1	☐2	☐3	☐4	☐5Very high
H. Adequate manuals	Very low ☐1	☐2	☐3	☐4	☐5Very high
I. Availability of materials	Very low ☐1	☐2	☐3	☐4	☐5Very high
J. Shortage of manpower	Very low ☐1	☐2	☐3	☐4	☐5Very high
K. Shortage of (G.S.E) equipment	Very low ☐1	☐2	☐3	☐4	☐5Very high
L. Weather conditions	Very low ☐1	☐2	☐3	☐4	☐5Very high
M. Work process	Very low ☐1	☐2	☐3	☐4	☐5Very high
N. Job cards (not clear)	Very low ☐1	☐2	☐3	☐4	☐5Very high
O. Facility conditions	Very low ☐1	☐2	☐3	☐4	☐5Very high
P. Inappropriate (G.S.E) equipment	Very low ☐1	☐2	☐3	☐4	☐5Very high

16. Do you compare actual historical performance data with current performance data to assess improvement?

Yes ☐ No ☐

17. How often do you evaluate the workload associated with shift change, when assessing efficiency?

- ☐ Weekly
- ☐ Monthly
- ☐ Quarterly
- ☐ Not considered

18. What do you consider is the current level of productivity (Last six month)?

- ☐ Very high
- ☐ High
- ☐ Medium
- ☐ Low
- ☐ Very low

Assess each statement and give a score based on degree of truth ranking from completely untrue at 1 to absolutely true at 5. Please tick the score that best fits your responses:

19. Information on material and component costs are well known.

1. Absolutely Untrue ☐
2. Untrue ☐
3. Neutral ☐
4. True ☐
5. Absolutely True ☐

20. A monthly report gives the rate of stock usage.

1. Absolutely Untrue ☐
2. Untrue ☐
3. Neutral ☐
4. True ☐
5. Absolutely True ☐

21. Efficiency and performance levels are affected by availability of materials and components.

1. Strongly Disagree ☐
2. Disagree ☐
3. Neutral ☐
4. Agree ☐
5. Strongly Agree ☐

22. Most materials are ordered on the basis of Aircraft on Ground.

1. Strongly Disagree ☐
2. Disagree ☐
3. Neutral ☐
4. Agree ☐
5. Strongly Agree ☐

23. We treat high usage components differently to low usage ones.

1. They are always treated the same ☐
2. Some times are ☐
3. Neutral ☐
4. Not all the time ☐
5. They are always treated differently ☐

24. We do not maintain stocks of high usage parts and materials.

1. A stock record has never been maintained ☐
2. Some time it is not maintained ☐
3. Neutral ☐
4. Some times it is maintained ☐
5. A stock record has always been maintained ☐

25. Previous historical information on material consumption is taken into account when ordering material.

1. Past material usage has never been accounted for ☐
2. Some times it is not accounted for ☐
3. Neutral ☐
4. Some times it is accounted for ☐
5. Past material usage has always been accounted for ☐

26. A regular check is kept on the relationship between material consumption and the number of cycles (or flights hours).

1. There is absolutely no relation is kept ☐
2. Some times the relation is not accounted for ☐
3. Neutral ☐
4. Some times it is accounted for ☐
5. There relation has always been taken into account ☐

Please read each statement below and give a score based on degree of truth ranking from completely untrue at 1 to absolutely true at 5. Please tick the score that best fits your responses:

27. We have complete information on productivity.

1. We never had ☐
2. Some times we do not have ☐
3. Neutral ☐
4. Some times we do ☐
5. We always had good information ☐

28. We have complete information on efficiency.

1. We never had ☐
2. Some times we do not have ☐
3. Neutral ☐
4. Some times we do ☐
5. We always had good information ☐

29. We have complete information on effectiveness.

1. We never had ☐
2. Some times we do not have ☐
3. Neutral ☐
4. Some times we do ☐
5. We always had good information ☐

30. We regularly measure our performance.

1. That is never been done ☐
2. Some times it is not done ☐
3. Neutral ☐
4. Some times it is done ☐
5. This has always been maintained regularly ☐

31. We maintain regular information on other airlines' performance.

1. That is never been done ☐
2. Some times it is not done ☐
3. Neutral ☐
4. Some times it is done ☐
5. This has always been maintained regularly ☐

32. We know the factors that affect our performance.

1. We never did ☐
2. We do not know ☐
3. Neutral ☐
4. Some time we know these factors ☐
5. They are well known ☐

33. We keep a continuous measure of staff productivity.

1. That is never been done ☐
2. Some times it is not done ☐
3. Neutral ☐
4. Some times it is done ☐
5. This has always been maintained regularly ☐

34. We continuously monitor productivity movement for improvement.

1. That is never been done ☐
2. Some times it is not done ☐
3. Neutral ☐
4. Some times it is done ☐
5. This has always been maintained regularly ☐

35. How often do you monitor productivity movements?

- ☐ Weekly
- ☐ Monthly
- ☐ Quarterly
- ☐ Biannually
- ☐ Annually
- ☐ Not Considered

The following will be used as an open-ended question:

35. How do you define productivity?

____

____

____

36. How do you define efficiency?

____

____

____

____

37. How do you define effectiveness?

38. What are the key dimensions of your unit's performance?

39. What are the main factors that affect your unit's performance?

40. What are the main factors that affect your unit's efficiency?

41. What are the main factors that affect your unit's productivity?

42. What are the main factors that affect your unit's effectiveness?

43. How do you measure the performance of the shop, the hangar the line and how often?

____

____

44. How do you assess the need for training?

____

____

45. How often do you assess the need for training? What are the key process?

____

____

46. How do you review the need for process improvement?

____

____

47. How often do you review the need for process improvement?

____

____

48. Do you assess the costs of delays caused by your department?

____

____

49. If yes, how do you assess the costs of delays?

____

____

50. How often do you assess the costs of delays caused by your department?

____

____

51. How do you measure the performance of individual employees in your departments?

____

____

Thank you for completing the following information, ***THIS INFORMATION WILL NOT BE REVIEWED BY ANYONE OTHER THAN THE PERSON CONDUCTING THE RESEARCH***:

- Job title: ______________________________
- Unit: ______________________________
- Years with company: ______________________________
- Years in present job: ______________________________
- Years in similar job: ______________________________
- Are you willing to be interviewed again: ______________________________
- Education qualifications:

  ____

  ____

- Training certificates held (training qualifications):

  ____

  ____

- Licenses held (if applicable):
- ______________________________

  ____

- Number of personnel you are responsible for in your unit

  ____

APPENDIX.B CHAPTER EIGHT

Table APP.8.1 B-747 Comparative Efficiency Analysis Model (One)

100% Jan-95	98.40% Aug-96	93.89% Mar-94	84.32% Apr-98
100% Feb-95	97.81% Sep-94	93.12% Nov-96	83.99% Feb-98
100% Apr-95	97.38% May-94	93.00% Jun-96	83.20% Sep-97
100% Jul-95	97.18% Jan-96	92.65% Nov-94	83.17% Jun-98
100% Aug-95	97.17% May-95	91.73% Jun-94	82.77% Nov-98
100% Sep-95	97.10% Sep-96	91.01% Oct-96	82.43% Jul-98
100% Dec-95	96.94% May-96	90.79% Mar-96	80.72% Aug-98
100% Feb-96	95.92% Nov-95	89.48% Oct-94	80.42% Oct-98
100% Mar-98	95.36% Jan-94	89.46% Aug-97	79.33% Nov-97
100% Jun-95	95.25% Mar-95	87.32% Dec-97	78.59% Oct-97
100% Jul-97	94.92% Jul-94	86.60% Jan-98	78.25% Mar-97
99.39% Apr-94	94.86% Dec-96	86.57% Apr-97	78.05% Jan-97
98.97% Dec-94	94.37% Aug-94	85.30% Dec-98	77.78% Jun-97
98.63% Jul-96	94.19% Apr-96	84.93% Sep-98	77.05% May-98
98.55% Feb-94	94.10% Oct-95	84.85% Feb-97	75.77% May-97

Figure APP.8.1 B-747 Model One Overall Fleet Efficiency Model One Relative Efficiency Score

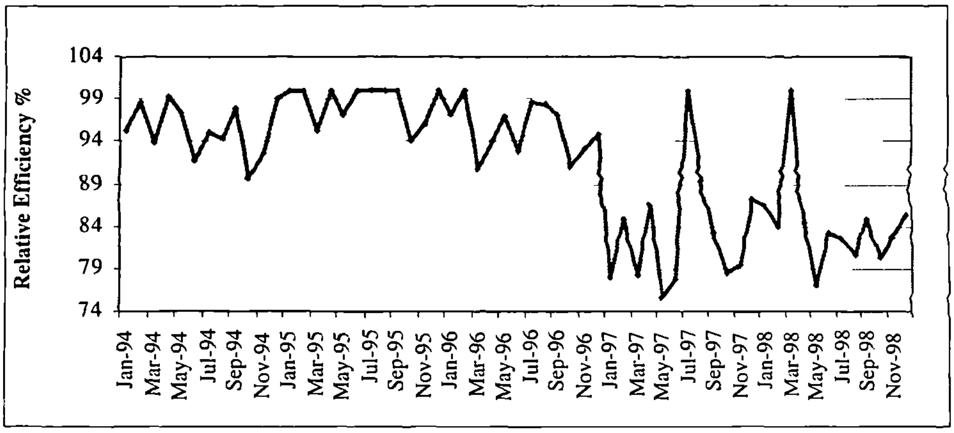


Figure APP.8.2 B-747 Overall Fleet Efficiency Model One Reference Set Frequency For The Efficient Months

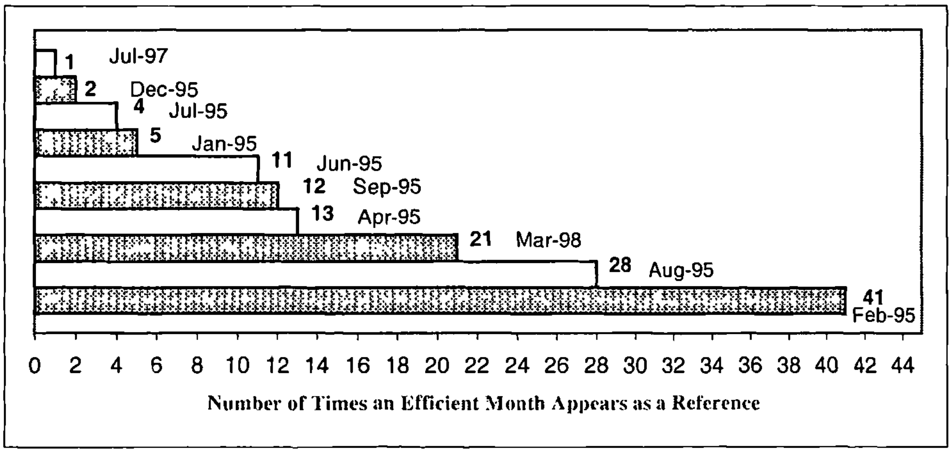


Table APP.8.2 B-747 Model One Input and Output Contribution Of The Efficient Months

	I/Os	Level %		I/Os	Level %		I/Os	Level %		I/Os	Level %
Jan-95	Cost	31	Jul-95	Cost	100	Mar-98	Cost	83	Aug-95	Cost	70
	Man-hours	69		Man-hours			Man-hours	17		Man-hours	30
	Fhrs	100		Fhrs			Fhrs			Fhrs	
	Cycles			Cycles	91		Cycles			Cycles	
	Deprt			Deprt	9		Deprt			Deprt	25
	UTZ			UTZ			UTZ			UTZ	
	Fhrs/Cycles			Fhrs/Cycles			Fhrs/Cycles	100		Fhrs/Cycles	75
	O.T.P			O.T.P			O.T.P			O.T.P	
Jul-97	Cost	47	Feb-96	Cost	73	Apr-95	Cost	100	Jun-95	Cost	91
	Man-hours	53		Man-hours	27		Man-hours			Man-hours	9
	Fhrs			Fhrs	39		Fhrs	43		Fhrs	
	Cycles			Cycles			Cycles			Cycles	
	Deprt	78		Deprt			Deprt	5		Deprt	22
	UTZ			UTZ	61		UTZ			UTZ	
	Fhrs/Cycles	22		Fhrs/Cycles			Fhrs/Cycles	52		Fhrs/Cycles	73
	O.T.P			O.T.P			O.T.P			O.T.P	5
Sep-95	Cost	100	Feb-95	Cost	58	Dec-95	Cost	71			
	Man-hours			Man-hours	42		Man-hours	29			
	Fhrs			Fhrs			Fhrs	7			
	Cycles	100		Cycles			Cycles				
	Deprt			Deprt			Deprt	18			
	UTZ			UTZ			UTZ				
	Fhrs/Cycles			Fhrs/Cycles			Fhrs/Cycles	75			
	O.T.P			O.T.P	100		O.T.P				

Table APP.8.3 B-747 Model One Potential Improvement

May-97		ACTUAL	TARGET	POTENTIAL IMPROVEMENT
Inputs	COST	19681555	14913077	-24.23
	MAN-HOURS	22058	16633.38	-24.59
Output	FHRS	4566	4773.9	4.55
	CYCLES	1348	1359.06	0.82
	DEPRT	1112	1112	0
	UTZ	7.8	8.49	8.88
	FHRS/CYCLYS	3.4	3.4	0
	O.T.P	94.42	94.42	0

Figure APP.8.3 B-747 Model One Reference Comparison

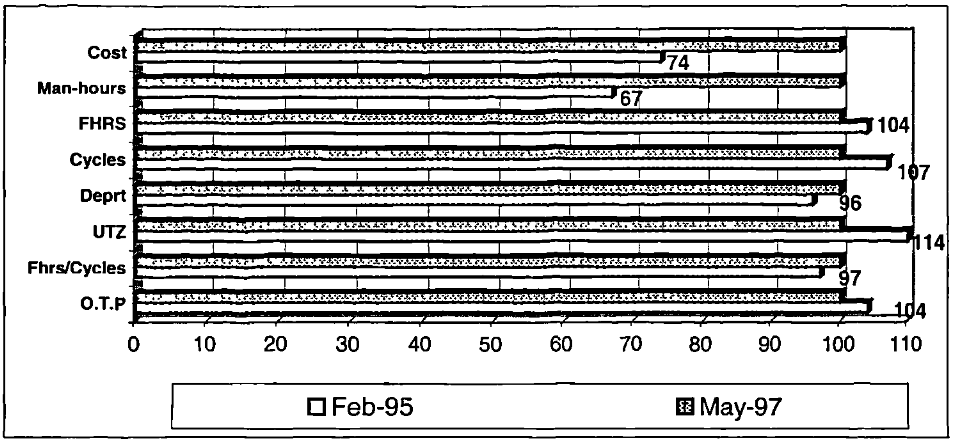


Table APP.8.4 Total Potential Improvement

INPUT	COST		-18.39%
	MAN-HOURS		-32.92%
OUTPUT	FHRS		11.43%
	CYCLES		10.24%
	DEPRT		4.69%
	UTZ		16.77%
	FHRS/CYCLES		1.51%
	O.T.P		4.04%

B-747 Fleet Performance Analysis Model (Two)

Table APP.8.5 B-747 Model Two Comparative Efficiency Analysis

100% Jan-95	94.34% Feb-95	82.95% Apr-97	73.39% Dec-97
100% Jul-95	93.83% Dec-94	82.22% Mar-96	72.87% Sep-97
100% Aug-95	93.79% Sep-94	81.90% Jun-95	71.64% Oct-94
100% Sep-95	93.78% Jul-94	81.77% Jun-94	69.66% Jan-98
100% Jul-97	92.71% Mar-94	80.84% Apr-94	69.46% Feb-97
100% Mar-98	92.48% Aug-94	80.66% Oct-95	68.15% Mar-97
98.14% Jul-96	92.27% Apr-96	80.16% Oct-96	67.87% Nov-98
98.10% Dec-95	91.39% Jan-94	79.94% Jun-96	67.61% Oct-98
97.91% Aug-96	90.05% Apr-95	79.60% Nov-96	67.37% May-97
97.32% May-94	89.70% Feb-94	79.57% Dec-98	67.23% Oct-97
97.12% Feb-96	89.44% Mar-95	77.36% Aug-98	67.14% Sep-98
97.10% Sep-96	88.41% Aug-97	76.28% Apr-98	67.02% Jun-97
96.17% May-95	86.22% Dec-96	76.26% Jul-98	63.07% Nov-97
95.21% Jan-96	85.80% Nov-95	75.00% Jun-98	62.20% May-98
94.83% May-96	83.57% Nov-94	74.45% Jan-97	58.24% Feb-98

Figure APP.8.4 B-747 Fleet Performance Model Relative Efficiency Score

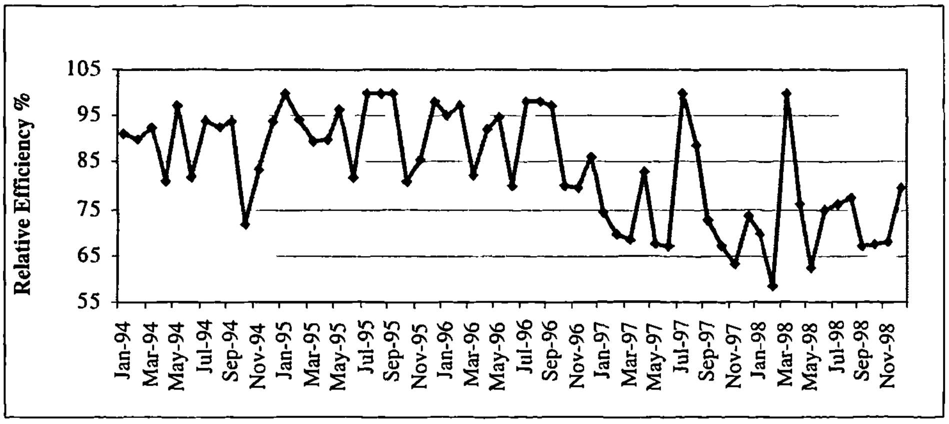


Figure APP.8.5 B-747 Fleet Performance Model Reference Set Frequency For The Efficient Months

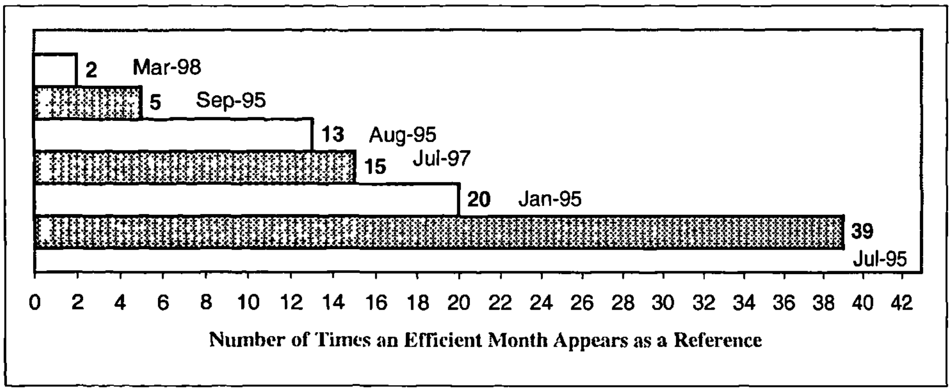


Table APP.8.6 B-747 Model Two Input and Output Contribution Of The Efficient Months

	I/Os	Level %		I/Os	Level %		I/Os	Level %
Mar-98	Cost		Aug-95	Cost	36	Sep-95	Cost	100
	Man-hours	100		Man-hours	64		Man-hours	
	Fhrs	100		Fhrs			Fhrs	
	Cycles			Cycles			Cycles	100
	Deprt			Deprt	100		Deprt	
Jul-97	Cost	42	Jan-95	Cost	35	Jul-95	Cost	100
	Man-hours	58		Man-hours	65		Man-hours	
	Fhrs			Fhrs	74		Fhrs	100
	Cycles	76		Cycles			Cycles	
	Deprt	24		Deprt	26		Deprt	

Table APP.8.7 B-747 Model Two Potential Improvement

Feb-98		ACTUAL	TARGET	POTENTIAL IMPROVEMENT
Inputs	COST	19019365	11076957	-41.76
	MAN-HOURS	16800	9784.39	-41.76
Output	FHRS	3582	3582	0
	CYCLES	1035	1064.61	2.86
	DEPRT	932	932	0

Figure APP.8.6 B-747 Model Two Reference Comparison

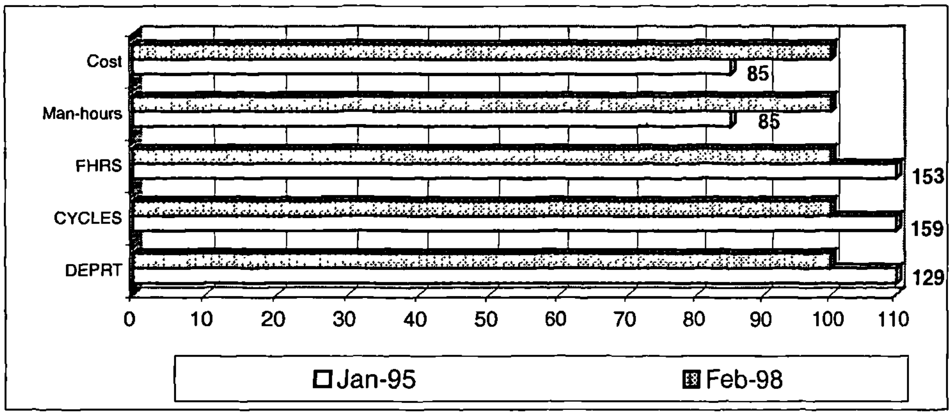


Table APP.8.8 B-747 Model Two Total Potential Improvement

INPUT	COST	-32.90%
	MAN-HOURS	-48.66%
OUTPUT	FHRS	1.62%
	CYCLES	7.40%
	DEPRT	9.42%

B-747 Fleet Utilisation Model (Three)

Table APP.8.9 B-747 Model Three Comparative Efficiency Analysis

100% Jan-95	94.83% May-96	82.65% Apr-97	71.93% Dec-97
100% Sep-95	93.78% Jul-94	82.47% Aug-97	71.56% Oct-94
100% Feb-96	93.15% Sep-96	82.22% Jun-94	71.35% Apr-98
100% Jul-95	92.90% Sep-94	81.54% Apr-94	71.20% Jul-98
100% Feb-95	92.82% Dec-94	80.72% Jun-96	70.71% Jun-98
100% Mar-98	92.79% Apr-96	80.71% Oct-95	68.15% Mar-97
99.66% Aug-95	91.39% Jan-94	80.52% Mar-96	67.41% May-97
98.14% Jul-96	90.51% Apr-95	80.00% Nov-96	67.39% Jun-97
97.91% Aug-96	89.44% Mar-95	79.34% Oct-96	66.61% Oct-97
96.56% Dec-95	89.24% Aug-94	79.31% Dec-98	66.45% Sep-98
96.17% May-95	87.91% Mar-94	74.48% Jan-97	66.26% Nov-98
95.53% Jul-97	86.24% Nov-95	74.05% Feb-97	65.08% Feb-98
95.21% Jan-96	86.22% Dec-96	72.93% Jan-98	64.32% Oct-98
95.05% Feb-94	84.09% Nov-94	72.36% Sep-97	62.49% Nov-97
94.83% May-94	82.73% Jun-95	72.29% Aug-98	61.13% May-98

Figure APP.8.7 B-747 Fleet Utilisation Model Relative Efficiency Scores

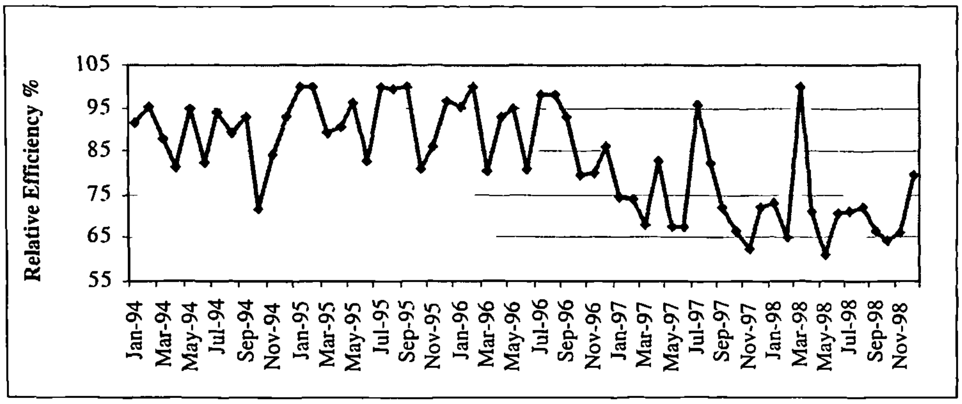


Figure APP.8.8 B-747 Fleet Utilisation Model Reference Set Frequency For The Efficient Months

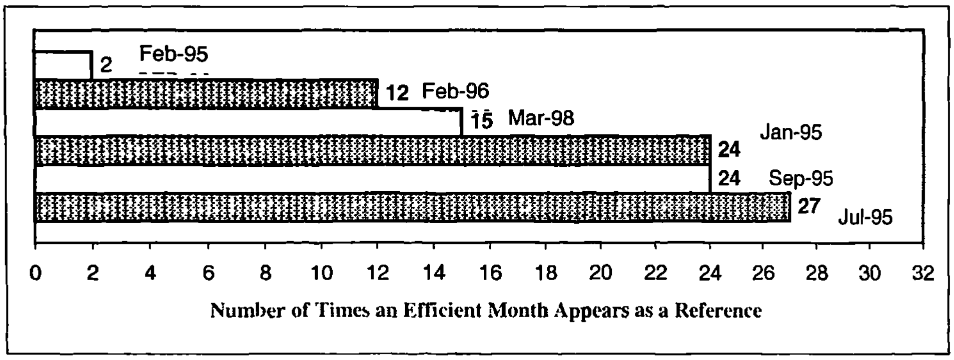


Table APP.8.10 B-747 Model Three Input and Output Contribution Of The Efficient Months

	I/Os	Level %		I/Os	Level %		I/Os	Level %
Mar-98	Cost	54	Feb-95	Cost	100	Sep-95	Cost	84
	Man-hours	46		Man-hours			Man-hours	16
	Fhrs			Fhrs			Fhrs	80
	UTZ	100		UTZ	100		UTZ	20
Jan-95	Cost	39	Feb-96	Cost	73	Jul-95	Cost	85
	Man-hours	61		Man-hours	27		Man-hours	15
	Fhrs			Fhrs	39		Fhrs	100
	UTZ	100		UTZ	61		UTZ	

Table APP.8.11 B-747 Model Three Potential Improvement

May-98		ACTUAL	TARGET	POTENTIAL IMPROVEMENT
Inputs	COST	19251519	11768905	-38.87
	MAN-HOURS	18857	11527.73	-38.87
	UTZ	7.1	7.1	0
Output	FHRS	3954	3954	0

Figure APP.8.9 B-747 Model Three Reference Comparison

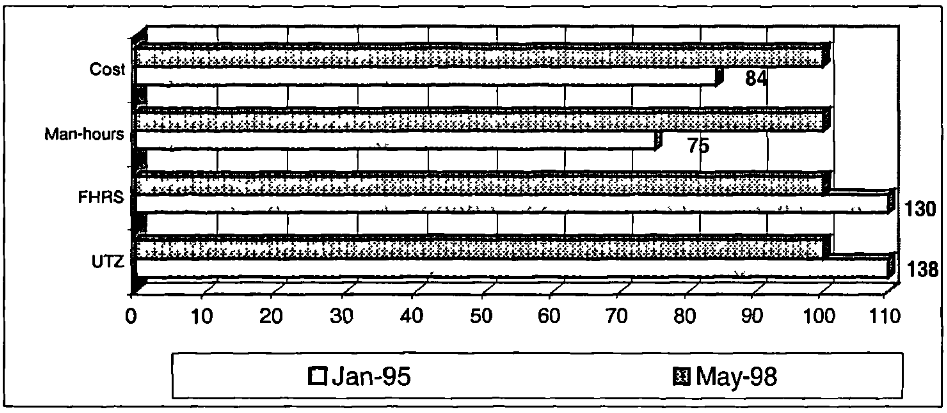


Table APP.8.12 B-747 Model Three Total Potential Improvement

INPUT	COST	-39.71%
	MAN-HOURS	-58.14%
OUTPUT	UTZ	1.61%
	FHRS	0.54%

B-747 Fleet Reliability Model (Four)

Table APP.8.13 B-747 Model Four Comparative Efficiency Analysis

100% Jan-95	95.49% Jan-96	89.59% Oct-95	79.48% Aug-98
100% Feb-95	95.33% May-96	89.25% Oct-94	77.53% Feb-98
100% Sep-96	94.66% Sep-94	88.40% Jun-94	77.46% Sep-98
100% Mar-98	94.48% Apr-95	88.04% Jun-96	77.42% Jul-98
100% Jul-95	94.30% Jul-94	87.93% Mar-96	77.28% Feb-97
99.92% Jul-97	94.19% Apr-96	87.76% Dec-96	76.87% Jan-98
99.73% Aug-95	93.98% Mar-94	86.74% Oct-96	76.73% Sep-97
99.03% Feb-96	93.89% Dec-94	86.57% Apr-97	76.42% Jan-97
98.69% Dec-95	93.01% Jan-94	86.11% Nov-96	75.40% Dec-97
98.14% Jul-96	92.77% Mar-95	85.31% Aug-97	75.31% Jun-97
97.91% Apr-96	92.67% Nov-95	84.32% Apr-98	74.51% May-98
97.38% May-94	92.46% Jun-95	81.65% Nov-98	73.29% Nov-97
97.10% Sep-96	91.58% Aug-94	81.04% Jun-98	73.06% Mar-97
96.96% May-95	90.78% Nov-94	79.87% Dec-98	71.42% May-97
95.86% Feb-94	90.42% Apr-94	79.80% Oct-98	70.16% Oct-97

Figure APP.8.10 B-747 Fleet Reliability Model Relative Efficiency Scores

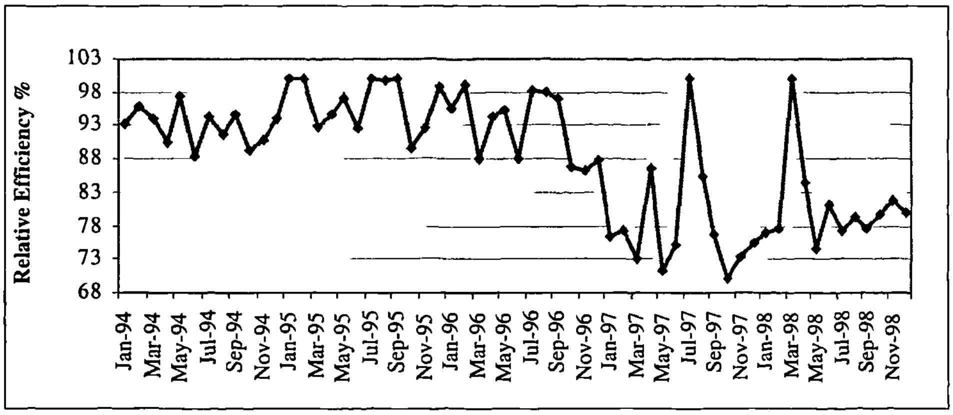


Figure APP.8.11 B-747 Fleet Reliability Model Reference Set Frequency For The Efficient Months

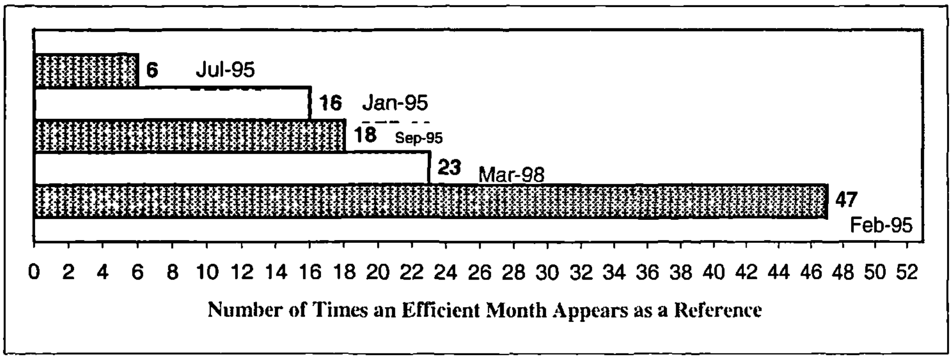


Table APP.8.14 B-747 Model Four Input and Output Contribution Of The Efficient Months

	I/Os	Level %		I/Os	Level %		I/Os	Level %
Mar-98	Cost	74	Jul-95	Cost	85	Sep-95	Cost	91
	Man-hours	26		Man-hours	15		Man-hours	9
	Fhrs			Fhrs	100		Fhrs	75
	Cycles			Cycles			Cycles	
	O.T.P	100		O.T.P			O.T.P	25
Feb-95	Cost	54	Jan-95	Cost	58			
	Man-hours	46		Man-hours	42			
	Fhrs	33		Fhrs	37			
	Cycles			Cycles				
	O.T.P	67		O.T. P	63			

Table APP.8.15 B-747 Model Four Potential Improvement

Oct-97		ACTUAL	TARGET	POTENTIAL IMPROVEMENT
Inputs	COST	19690198	13813927	-29.84
	MAN-HOURS	19449	13644.71	-29.84
Output	FHRS	4510	4510	0
	CYCLES	1345	1368.13	1.72
	O.T.P	91.16	91.16	0

Figure APP.8.12 B-747 Model Four Reference Comparison

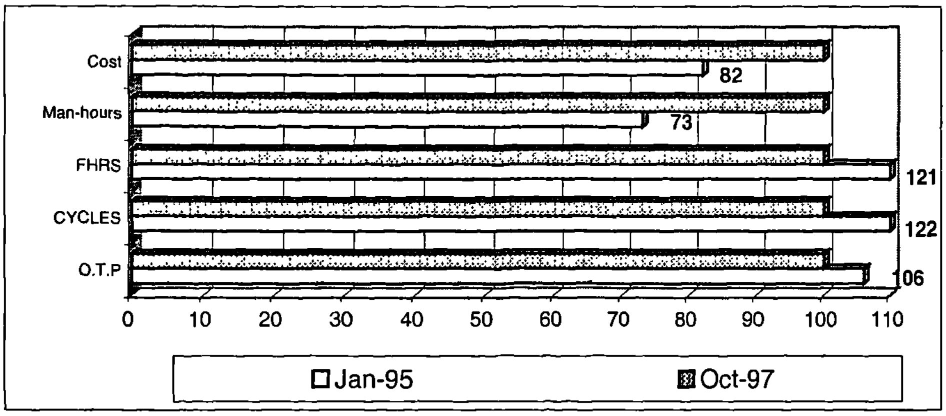


Table APP.8.16 B-747 Model Four Total Potential Improvement

INPUT	COST	-28.97%
	MAN-HOURS	-48.07%
OUTPUT	FHRS	8.37%
	CYCLES	13.57%
	O.T.P	1.02%

B-747 Overall Fleet Efficiency Analysis Model One For The Non-Significant Period

Table APP.8.17 B-747 Model One Comparative Efficiency Analysis Non-Significant Period Only

Month	Efficiency	Month	Efficiency	Month	Efficiency	Month	Efficiency
Dec-98	100	Dec-96	100	Oct-94	97.77	Dec-97	92.66
Sep-95	100	Nov-94	99.77	Sep-96	97.1	Oct-98	92.31
Dec-94	100	Oct-95	98.85	Nov-98	96.3	Nov-97	84.98
Nov-95	100	Nov-96	98.6	Sep-98	96.14	Sep-97	84.56
Dec-95	100	Sep-94	98.39	Oct-96	94.13	Oct-97	81.52

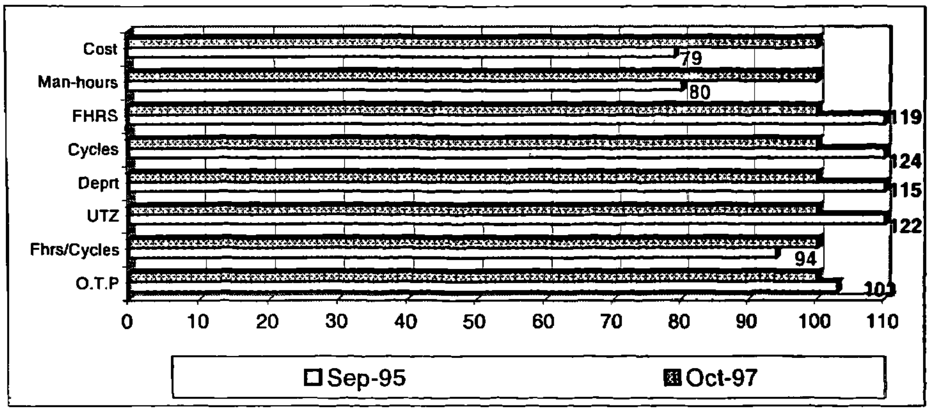
Table APP.8.18 B-747 Model One Input and Output Contribution For The Efficient Months Non-significant Months Only

	I/Os	Level %		I/Os	Level %		I/Os	Level %
Dec-95	Cost	98	Nov-95	Cost	96	Dec-98	Cost	
	Man-hours	2		Man-hours	4		Man-hours	100
	Fhrs			Fhrs			Fhrs	
	Cycles			Cycles			Cycles	
	Deprt	11		Deprt	11		Deprt	
	UTZ			UTZ			UTZ	
	Fhrs/Cycles	71		Fhrs/Cycles	71		Fhrs/Cycles	94
	O.T.P	18		O.T.P	19		O.T.P	6
Sep-95	Cost	100	Dec-96	Cost	96			
	Man-hours			Man-hours	4			
	Fhrs			Fhrs				
	Cycles	100		Cycles				
	Deprt			Deprt	9			
	UTZ			UTZ				
	Fhrs/Cycles			Fhrs/Cycles	74			
	O.T.P			O.T.P	16			

Table APP.8.19 B-747 Model One Potential Improvement No-significant Months Only

Oct-97		60 Month Model %	Non-Significant Period %
Inputs	COST	-21.41	-18.48
	MAN-HOURS	-21.41	-18.48
Output	FHRS	12.62	13.07
	CYCLES	13.48	10.1
	DEPRT	0	0
	UTZ	139.91	13.37
	FHRS/CYCLYS	0	0
	O.T.P	9.62	2.62

Figure APP.8.13 B-747 Model One Reference Comparison Non-significant Months Only



B-747 Fleet Performance Model Two For The Non-Significant Period

Table APP.8.20 B-747 Model Two Comparative Efficiency Analysis No-significant Months Only

Month	Efficiency	Month	Efficiency	Month	Efficiency	Month	Efficiency
Dec-95	100	Dec-98	87.36	Oct-95	81.9	Dec-97	76.63
Sep-95	100	Dec-96	86.7	Nov-96	80.05	Sep-98	74.56
Sep-96	97.1	Nov-95	86.28	Oct-98	77.88	Oct-94	72.57
Dec-94	96.37	Nov-94	84.43	Sep-97	77.47	Oct-97	69.26
Sep-94	96.19	Oct-96	82.23	Nov-98	77.34	Nov-97	64.69

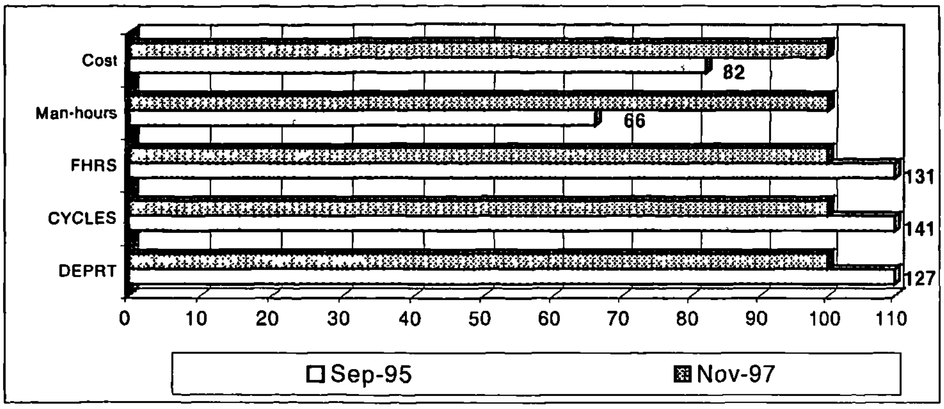
Table APP.8.21 B-747 Model Two Input and Output Contribution For The Efficient Months Non-significant Months Only

	I/Os	Level %		I/Os	Level %
Sep-95	Cost	51	Dec-95	Cost	
	Man-hours	49		Man-hours	100
	Fhrs	100		Fhrs	100
	Cycles			Cycles	
	Deprt			Deprt	

Table APP.8.22 B-747 Model Two Potential Improvement No-significant Months Only

Nov-97		60 Month Model %	Non-Significant Period %
Inputs	COST	-36.93	-35.31
	MAN-HOURS	-48.89	.47.56
Output	FHRS	1.4	3.41
	CYCLES	8.35	11.38
	DEPRT	0	0

Figure APP.8.14 B-747 Model Two Reference Comparison Non-significant Months Only



B-747 Fleet Utilization Model Three For The Non-Significant Period

Table APP.8.23 B-747 Model Three Comparative Efficiency Analysis Non-significant Months Only

Month	Efficiency	Month	Efficiency	Month	Efficiency	Month	Efficiency
Dec-95	100	Dec-98	87.36	Nov-96	80.05	Oct-94	72.57
Sep-95	100	Dec-96	86.7	Oct-96	79.78	Sep-98	72.44
Dec-94	96.37	Nov-95	86.28	Dec-97	75.55	Oct-98	70.2
Sep-96	93.22	Nov-94	84.47	Sep-97	74.58	Oct-97	67.08
Sep-94	93.03	Oct-95	81.11	Nov-98	73.35	Nov-97	62.55

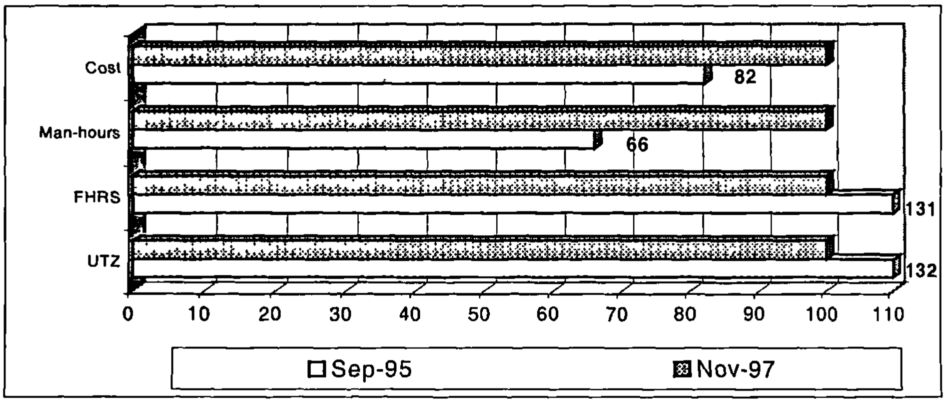
Table APP.8.24 B-747 Model Three Input and Output Contribution For The Efficient Months Non-significant Months Only

	I/Os	Level %		I/Os	Level %
Sep-95	Cost	51	Dec-95	Cost	
	Man-hours	49		Man-hours	100
	Fhrs	100		Fhrs	100
	UTZ			UTZ	

Table APP.8.25 B-747 Model Three Potential Improvement Non-significant Months Only

Nov-97		60 Month Model %	Non-Significant Period %
Inputs	COST	-37.51	-37.45
	MAN-HOURS	-49.35	.49.29
Output	UTZ	0	0.5
	FHRS	0	0

Figure APP.8.15 B-747 Model Three Reference Comparison Non-significant Months Only



B-747 Fleet Reliability Model Four For The Non-Significant Period

Table APP.8.26 B-747 Model Four Comparative Efficiency Analysis Non-significant Months Only

Month	Efficiency	Month	Efficiency	Month	Efficiency	Month	Efficiency
Sep-95	100	Sep-94	97.74	Oct-96	93.62	Sep-98	88.57
Dec-95	100	Sep-96	97.1	Nov-96	93.06	Sep-97	81.9
Nov-95	100	Oct-95	96.95	Oct-98	92.31	Dec-97	79.45
Nov-94	99.77	Dec-94	96.37	Dec-98	91.51	Nov-97	79.17
Oct-94	97.77	Nov-98	95.55	Dec-96	89.45	Oct-97	76.61

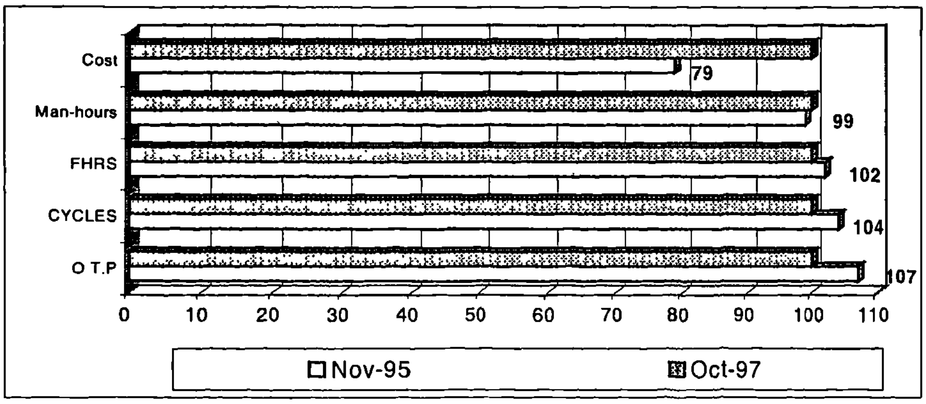
Table APP.8.27 B-747 Model Four Input and Output Contribution For The Efficient Months Non-significant Months Only

	I/Os	Level %		I/Os	Level %		I/Os	Level %
Dec-95	Cost	89	Nov-95	Cost	85	Sep-95	Cost	51
	Man-hours	11		Man-hours	15		Man-hours	49
	Fhrs			Fhrs			Fhrs	100
	Cycles			Cycles			Cycles	
	T.O.P	100		T.O.P	100		T.O.P	

Table APP.8.28 B-747 Model Four Potential Improvement Non-significant Months Only

Oct-97		60 Month Model %	Non-Significant Period %
Inputs	COST	-29.84	-23.39
	MAN-HOURS	-29.84	-23.39
Output	FHRS	0	3.87
	CYCLES	1.72	2.7
	O.T.P	0	0

Figure APP.8.16 Reference Comparison



B-737 Overall Fleet Efficiency Analysis Model (One)

Table APP.8.29 B-737 Model One Comparative Efficiency Analysis

100% Feb-97	93.42% Mar-95	90.24% Aug-94	88.67% Oct-98
100% Apr-97	93.11% Aug-95	90.20% Sep-96	88.49% Aug-98
100% Jul-97	93.03% Jul-95	90.03% Jun-94	88.30% Apr-96
100% Jan-98	93.01% Dec-97	89.97% Sep-98	88.03% Dec-94
98.20% Aug-97	92.37% Nov-95	89.91% Nov-98	87.52% Jan-94
98.11% Feb-95	91.97% Jul-98	89.76% Apr-94	87.14% May-94
98.10% May-97	91.87% Jul-94	89.74% Aug-96	86.84% Feb-96
97.44% Jun-97	91.86% May-98	89.52% May-95	86.83% Mar-94
96.20% Sep-97	91.67% Apr-95	89.51% Dec-95	86.67% Jun-96
94.63% Nov-97	91.54% Sep-94	89.41% Oct-94	85.97% Nov-96
93.93% Feb-94	91.41% Dec-98	89.11% Feb-95	85.86% Mar-96
93.82% Jun-97	90.87% Nov-94	89.36% Oct-95	85.37% Dec-96
93.70% Oct-97	90.80% Jun-95	89.16% Mar-98	85.08% May-96
93.65% Sep-95	90.79% Jan-95	89.09% Feb-98	84.18% Oct-96
93.53% Mar-97	90.39% Jul-96	88.88% Jun-98	83.33% Jan-96

Figure APP.8.17 B-737 Overall Efficiency Model Relative Efficiency Scores

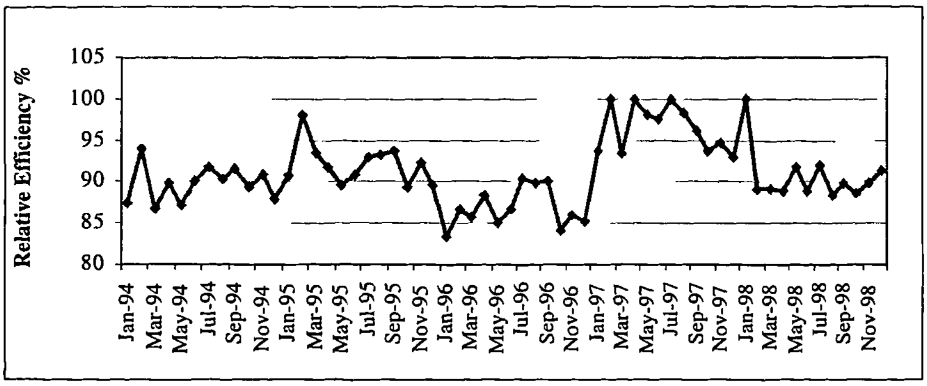


Figure APP.8.18 B-737 Overall Fleet Efficiency Model Reference Set Frequency For The Efficient Months

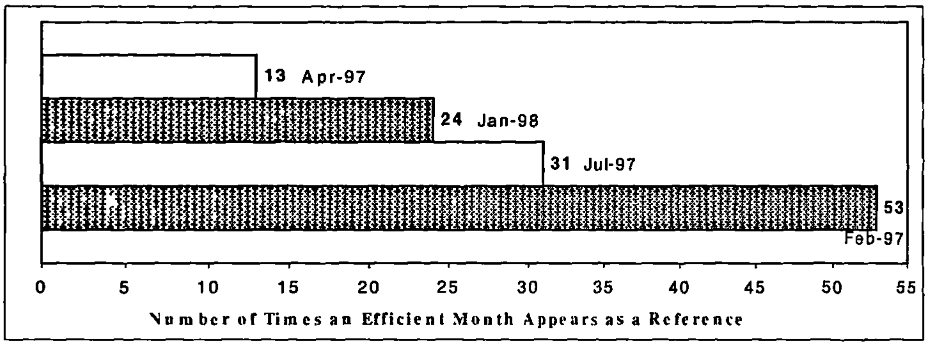


Table APP.8.30 B-737 Model One Input and Output Contribution Of The Efficient Months

	I/Os	Level %		I/Os	Level %
	Cost			Cost	100
	Man-hours	100		Man-hours	
	Fhrs			Fhrs	
Feb-97	Cycles	100	Jan-98	Cycles	32
	Deprt			Deprt	21
	UTZ			UTZ	
	Fhrs/Cycles			Fhrs/Cycles	48
	O.T.P			O.T.P	
	Cost	100		Cost	97
	Man-hours			Man-hours	3
	Fhrs			Fhrs	
Apr-97	Cycles	100	Jul-97	Cycles	
	Deprt			Deprt	55
	UTZ			UTZ	
	Fhrs/Cycles			Fhrs/Cycles	
	O.T.P			O.T.P	45

Table APP.8.31 B-737 Model One Potential Improvement

Jan-96		ACTUAL	TARGET	POTENTIAL IMPROVEMENT
Inputs	COST	3977812	3314780	-16.67
	MAN-HOURS	12947	8758.22	-32.35
Output	FHRS	3628	3779.11	4.16
	CYCLES	3529	3718.41	5.37
	DEPRT	3425	3425	0
	UTZ	6.2	6.55	5.63
	FHRS/CYCLYS	1	1.01	1.28
	O.T.P	98.83	98.83	0

Figure APP.8.19 B-737 Model One Reference Comparison

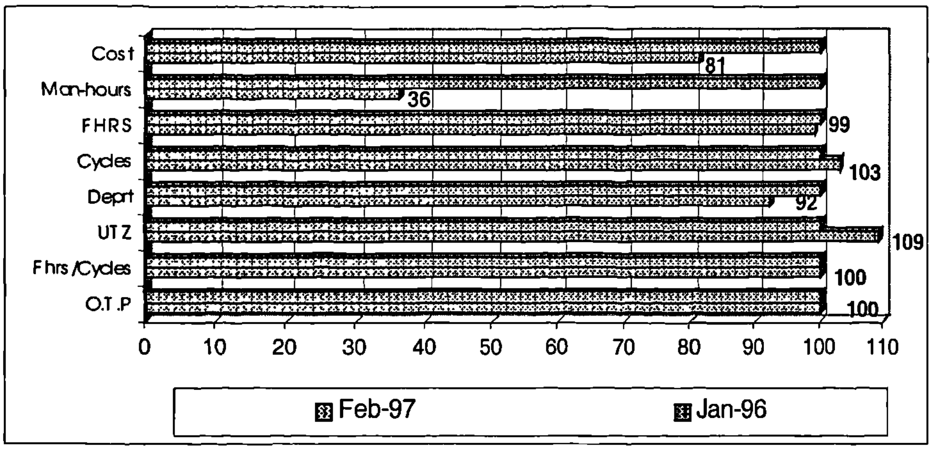


Table APP.8.32 B-737 Model One Total Potential Improvement

INPUT	COST	-11.40%
	MAN-HOURS	-52.53%
OUTPUT	FHRS	9.18%
	CYCLES	5.73%
	DEPRT	3.48%
	UTZ	13.36%
	FHRS/CYCLES	3.74%
	O.T.P	0.54%

B-737 Fleet Performance Analysis Model (Two)

Table APP.8.33 B-737 Model Two Comparative Efficiency Analysis

100% Feb-97	88.68% Jan-97	85.08% May-96	82.28% Jun-98
100% Apr-97	88.60% Sep-95	84.47% Dec-95	82.24% Dec-94
100% Jul-97	88.30% Apr-96	84.34% Mar-96	82.20% May-94
97.87% Aug-97	88.20% Aug-94	84.15% Jan-94	81.50% Feb-96
96.10% May-97	88.15% Nov-94	84.06% May-95	80.55% Oct-95
95.08% Jun-97	88.06% Nov-97	83.40% May-98	80.40% Apr-98
94.49% Jan-98	88.00% Oct-94	83.39% Dec-96	80.01% Apr-95
91.56% Mar-95	87.97% Mar-97	83.22% Jul-98	79.49% Oct-96
91.54% Sep-94	87.70% Dec-97	83.03% Mar-94	77.19% Jan-96
90.77% Sep-97	87.70% Nov-96	83.03% Jun-94	75.93% Febl-98
90.61% Aug-95	86.87% Apr-94	82.92% Jun-96	75.18% Aug-98
89.92% Jul-96	86.56% Sep-96	82.88% Nov-95	71.62% Sep-98
89.77% Jul-95	85.62% Jan-95	82.81% Feb-95	68.60% Oct-98
89.77% Jul-94	85.47% Jun-95	82.71% Feb-94	60.19% Nov-98
88.70% Oct-97	85.29% Aug-96	82.34% Mar-98	59.39% Dec-98

Figure APP.8.20 B-737 Fleet Performance Relative Efficiency Scores

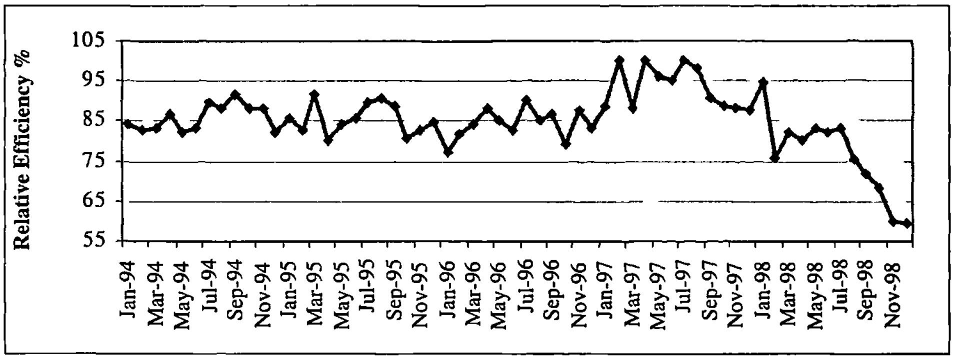


Figure APP.8.21 B-737 Fleet Performance Model Reference Set Frequency For The Efficient Months

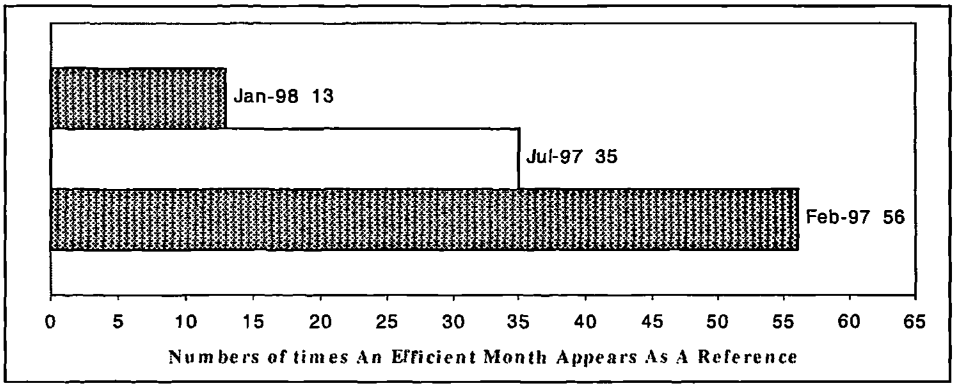


Table APP.8.34 B-737 Model Two Input and Output Contribution Of The Efficient Months

	I/Os	Level %		I/Os	Level %		I/Os	Level %
Feb-97	Cost		Apr-97	Cost	100	Jul-97	Cost	7
	Man-hours	100		Man-hours			Man-hours	23
	Fhrs			Fhrs			Fhrs	
	Cycles			Cycles	89		Cycles	
	Deprt	100		Deprt	11		Deprt	100

Table APP.8.35 B-737 Model Two Potential Improvement

Dec-98

		ACTUAL	TARGET	POTENTIAL IMPROVEMENT
Inputs	COST	3501243	2079306	-40.61
	MAN-HOURS	13089	6026.04	-53.96
Output	FHRS	2336	2546.03	8.99
	CYCLES	2511	2511	0
	DEPRT	2296	2296	0

Figure APP.8.22 B-737 Model Two Reference Comparison

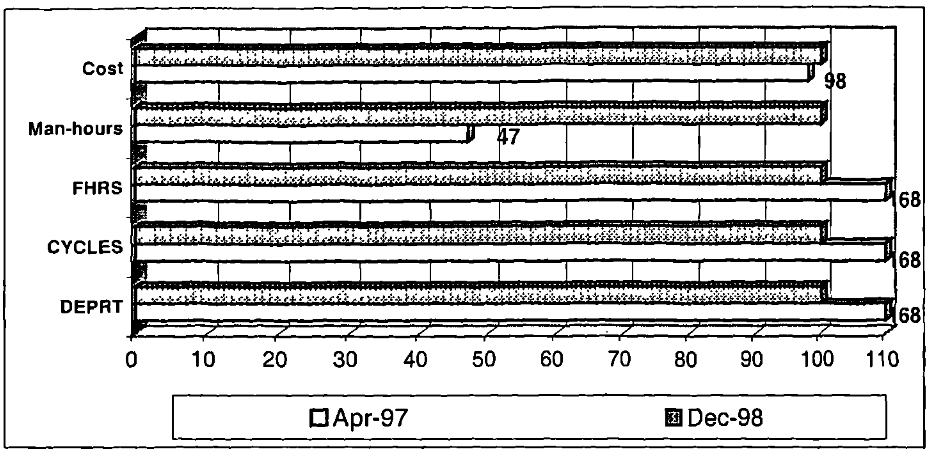


Table APP.8.36 B-737 Model Two Total Potential Improvement

INPUT	COST	-28.49%
	MAN-HOURS	-61.46%
OUTPUT	FHRS	7.65%
	CYCLES	2.14%
	DEPRT	0.25%

B-737 Fleet Utilisation Model (Three)

Table APP.8.37 B-737 Model Three Comparative Efficiency Analysis

100% Feb-97	87.08% Jan-97	82.48% May-96	78.23% May-98
100% Jul-97	87.07% Apr-96	82.44% Apr-98	77.60% Jun-95
99.81% Apr-97	86.59% Nov-97	82.34% Mar-98	76.96% Dec-94
97.58% Aug-97	86.45% Aug-94	81.62% Jun-98	76.94% Apr-95
93.71% Jan-98	85.54% Jul-94	81.56% Nov-96	76.73% Dec-96
92.07% Jun-97	84.85% Jan-95	81.24% Feb-98	76.42% Jun-94
91.31% Jul-95	84.79% Mar-97	81.04% May-95	75.27% Jan-94
90.90% Feb-95	84.30% Aug-95	80.70% Jul-98	74.38% Oct-95
90.12% Sep-96	84.04% Apr-94	80.56% Dec-95	74.25% Jan-96
89.72% Aug-96	83.11% Feb-94	80.33% Nov-94	73.09% Aug-98
89.43% Sep-97	83.07% Oct-97	80.15% Oct-94	72.66% Oct-96
89.19% Sep-94	83.05% Feb-96	80.07% May-94	68.26% Sep-98
88.98% Sep-95	82.96% Mar-94	79.06% Jun-96	60.92% Oct-98
88.51% May-97	82.83% Dec-97	78.92% Mar-96	56.78% Nov-98
87.96% Jul-96	82.80% Mar-95	78.26% Nov-95	54.42% Dec-98

Figure APP.8.23 B-737 Fleet Utilisation Model Relative Efficiency Score

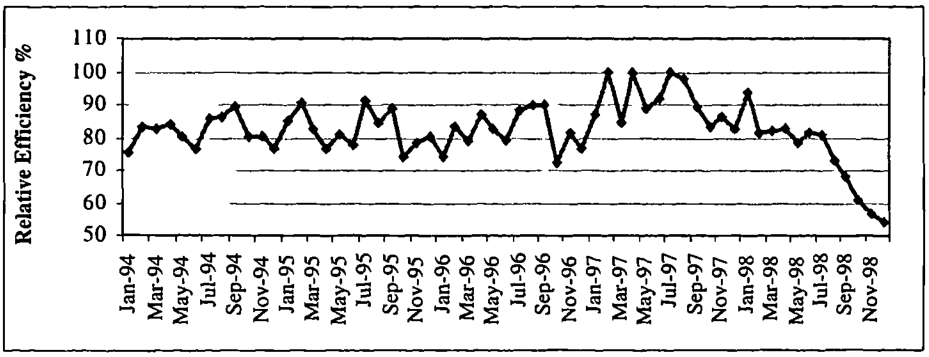


Figure APP.8.24 B-737 Fleet Utilisation Model Reference Set Frequency For The Efficient Months

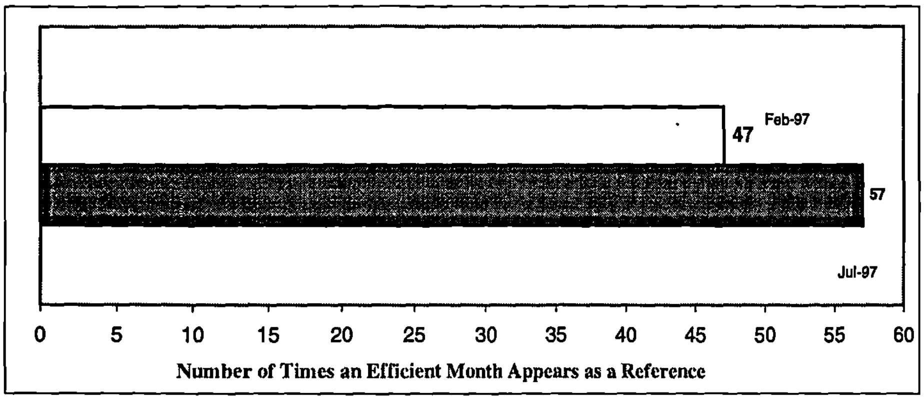


Table APP.8.38 B-737 Model Three Input and Output Contribution Of The Efficient Months

	I/Os	Level %		I/Os	Level %
Feb-97	Cost	100	Jul-97	Cost	100
	Man-hours			Man-hours	
	Fhrs	3		Fhrs	3
	UTZ	97		UTZ	97

Table APP.8.39 B-737 Model Three Potential Improvement

Dec-98		ACTUAL	TARGET	POTENTIAL IMPROVEMENT
Inputs	COST	3501243	1905320	-45.58
	MAN-HOURS	13089	5554.75	-57.56
Output	UTZ	4	4	0
	FHRS	2336	2336	0

Figure APP.8.25 B-737 Model Three Reference Comparison

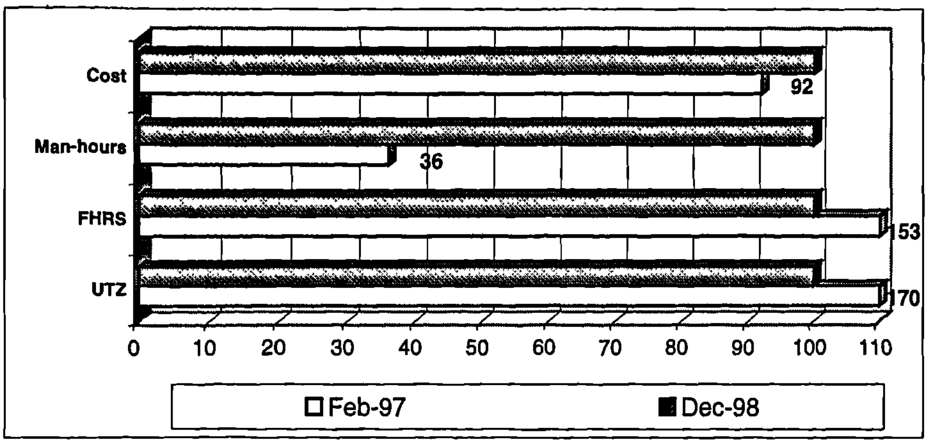


Table APP.8.39 B-737 Model Three Total Potential Improvement

INPUT	COST	-31.95%
	MAN-HOURS	-67.17%
OUTPUT	UTZ	0.88%
	FHRS	0.00%

B-737 Fleet Reliability Model (Four)

Table APP.8.40 B-737 Model Four Comparative Efficiency Analysis

100% Feb-97	92.38% Aug-95	89.92% Jul-96	87.52% Jan-94
100% Apr-97	92.37% Nov-97	89.91% Nov-98	87.21% Aug-96
100% Jul-97	91.71% Nov-95	89.26% Aug-94	87.07% Apr-96
99.78% Jun-98	91.67% Apr-95	89.26% May-95	86.84% Feb-96
97.88% Aug-97	91.41% Dec-98	89.00% Mar-98	86.53% Mar-94
97.63% Feb-95	91.00% Dec-97	88.79% Apr-98	86.52% May-94
96.85% May-97	90.97% Jul-98	88.67% Oct-98	86.46% Aug-98
95.79% Jun-97	90.86% Jul-94	88.56% Oct-94	86.39% Jun-96
94.78% Sep-97	90.67% Sep-94	88.40% Sep-96	85.92% Dec-94
93.93% Feb-94	90.42% May-98	88.37% Oct-95	85.84% Mar-96
93.42% Mar-95	90.29% Jun-95	88.25% Feb-98	84.93% Nov-96
93.06% Jan-97	90.20% Nov-94	87.92% Dec-95	84.51% Dec-96
92.93% Mar-97	90.09% Oct-97	87.85% Jun-94	83.53% May-96
92.82% Sep-95	89.97% Sep-98	87.62% Jun-98	81.54% Jan-96
92.70% Jul-95	89.93% Jan-95	87.53% Apr-94	81.22% Oct-96

Figure APP.8.26 B-737 Fleet Reliability Model Relative Efficiency Scores

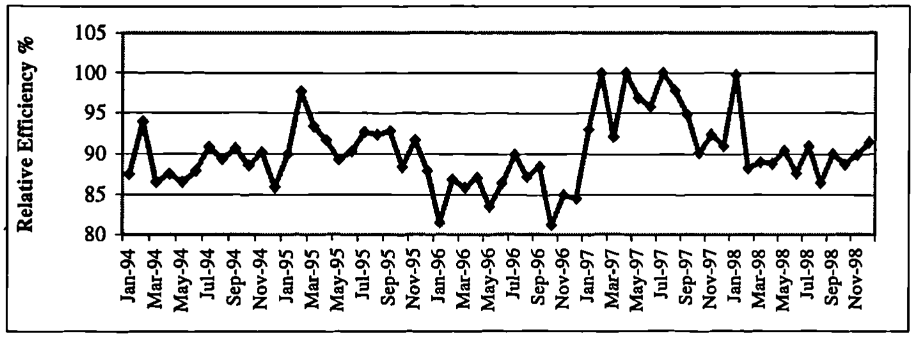


Figure APP.8.27 B-737 Fleet Reliability Model Reference Set Frequency For The Efficient Months

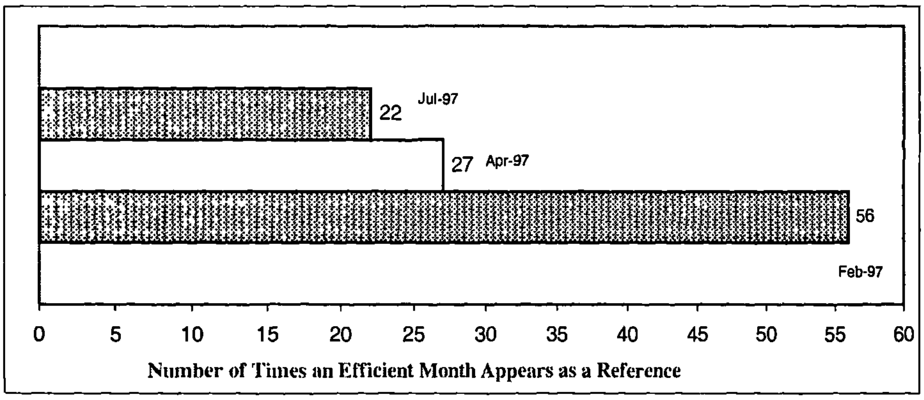


Table APP.8.41 B-737 Model Four Input Output Contribution Of The Efficient Months

	I/Os	Level %		I/Os	Level %		I/Os	Level %
Feb-97	Cost Man-hours Fhrs Cycles O.T.P	100 48 52	Jul-97	Cost Man-hours Fhrs Cycles O.T.P	100 24 36 40	Apr-97	Cost Man-hours Fhrs Cycles O.T.P	100 22 36 42

Table APP.8.42 B-737 Model Four Potential Improvement

Oct-96		ACTUAL	TARGET	POTENTIAL IMPROVEMENT
Inputs	COST	3999842	3248525.7	-18.78
	MAN-HOURS	17997	4911.68	-72.71
Output	FHRS	3582	3620.77	1.08
	CYCLES	3710	3710	0
	O.T.P	98.79	98.79	0

Figure APP.8.28 B-737 Model Four Reference Comparison

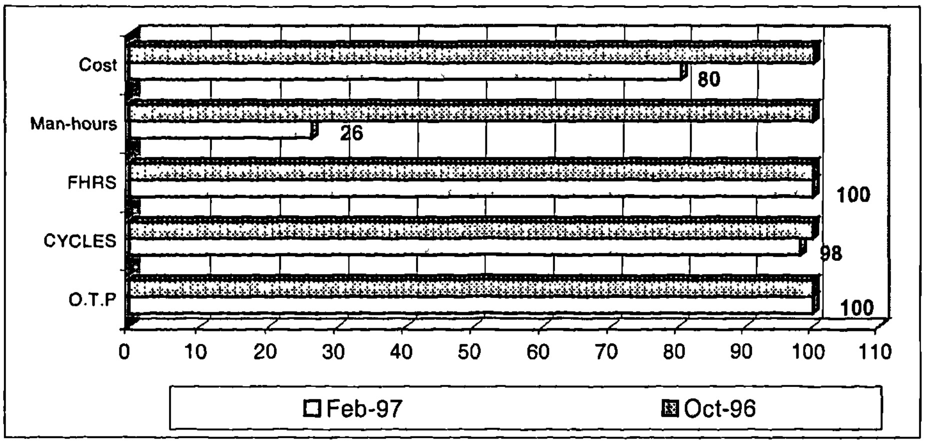


Table APP.8.43 B-737 Model Four Total Potential Improvement

	COST	-14.00%
INPUT	MAN-HOURS	-73.22%
	FHRS	6.91%
	CYCLES	5.77%
OUTPUT	O.T.P	0.10%

B-737 Overall Fleet Efficiency Analysis Model One For The Non-Significant Period

Table 8.82 B-737 Model One Comparative Efficiency Analysis For The Non-Significant Period

Month	Efficiency	Month	Efficiency	Month	Efficiency	Month	Efficiency
Sep-94	100	Nov-97	99.91	Oct-97	98.16	Oct-95	95.88
Sep-97	100	Nov-94	99.74	Sep-98	97.55	Nov-96	95.78
Sep-96	100	Sep-95	99.57	Nov-98	97.51	Dec-94	95.53
Dec-95	100	Dec-98	99.06	Oct-94	97.35	Dec-96	92.8
Nov-95	100	Dec-97	98.73	Oct-98	96.17	Oct-96	87.97

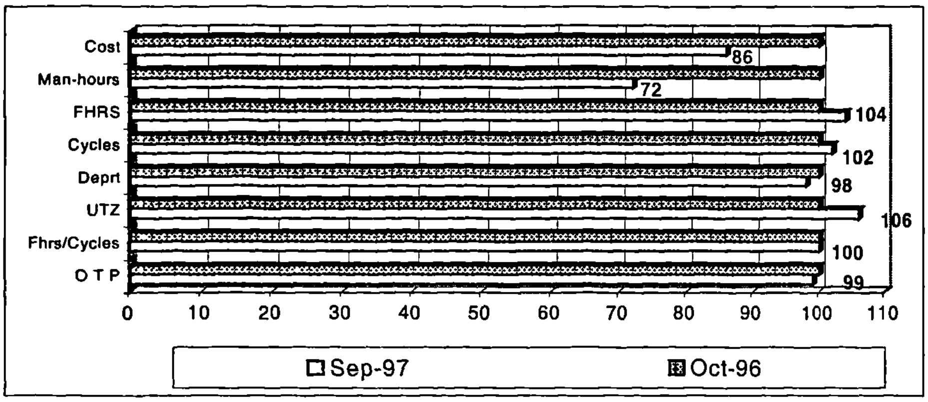
Table 8.83 B-737 Model One Input and Output Contribution For The Efficient Months For The Non-Significant Period

	I/Os	Level %		I/Os	Level %		I/Os	Level %
	Cost	97		Cost	98		Cost	100
	Man-hours	3		Man-hours			Man-hours	
	Fhrs			Fhrs			Fhrs	
Sep-97	Cycles	100	Nov-95	Cycles		Sep-96	Cycles	
	Deprt			Deprt			Deprt	
	UTZ			UTZ			UTZ	92
	Fhrs/Cycles			Fhrs/Cycles			Fhrs/Cycles	8
	O.T.P			O.T.P	100		O.T.P	
	Cost	99		Cost	86			
	Man-hours			Man-hours	14			
	Fhrs			Fhrs				
Sep-94	Cycles		Dec-95	Cycles				
	Deprt			Deprt				
	UTZ	89		UTZ				
	Fhrs/Cycles			Fhrs/Cycles	100			
	O.T.P	11		O.T.P				

Table 8.84 B-737 Model One Potential Improvement For The Non-Significant Period

Oct-96		60 Month Model %	Non-Significant Period %
Inputs	COST	-15.82	-12.03
	MAN-HOURS	-45.9	-26.04
Output	FHRS	8.92	5.89
	CYCLES	2.78	3.88
	DEPRT	0	0
	UTZ	8.88	8.36
	FHRS/CYCLYS	1.37	1.69
	O.T.P	0	0.72

Figure 8.46 B-737 Model One Reference Comparison For The Non-Significant Period



B-737 Fleet Performance Model Two For The Non-Significant Period

Table 8.85 B-737 Model Two Comparative Efficiency Analysis For The Non-Significant Period

Month	Efficiency	Month	Efficiency	Month	Efficiency	Month	Efficiency
Sep-94	100	Nov-94	97.64	Dec-95	94.22	Oct-96	87.97
Sep-97	100	Nov-97	97.45	Dec-94	93.7	Sep-98	79.22
Dec-97	98.17	Oct-94	97.35	Dec-96	92.8	Oct-98	76.22
Oct-97	98.16	Sep-96	96.48	Nov-96	90.65	Nov-98	66.5
Sep-95	97.97	Nov-95	94.32	Oct-95	89.79	Dec-98	65.5

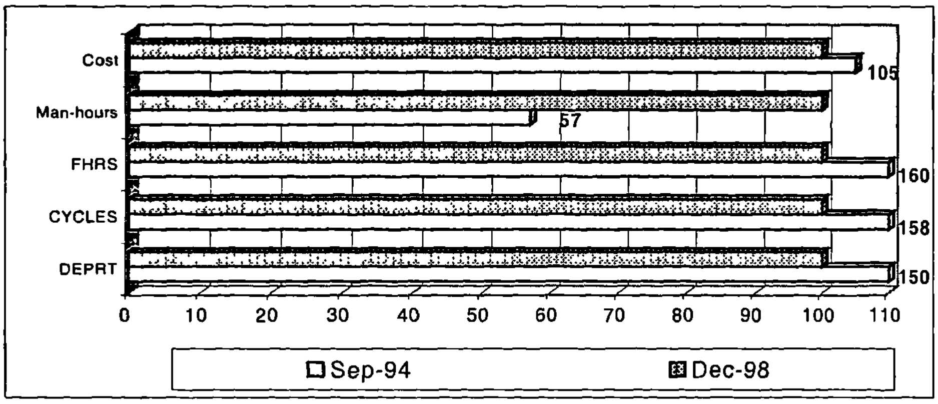
Table 8.86 B-737 Model Two Input and Output Contribution For The Efficient Months For The Non-Significant Period

	I/Os	Level %		I/Os	Level %
Sep-97	Cost	97	Sep-94	Cost	100
	Man-hours	3		Man-hours	
	Fhrs			Fhrs	100
	Cycles	100		Cycles	
	Deprt			Deprt	

Table 8.87 B-737 Model Two Potential Improvement For The Non-Significant Period

Dec-98		60 Month Model %	Non-Significant Period %
Inputs	COST	-40.61	-34.5
	MAN-HOURS	-53.96	-34.5
Output	FHRS	8.99	5.68
	CYCLES	0	0
	DEPRT	0	0.52

Figure 8.47 B-737 Model Two Reference Comparison For The Non-Significant Period



B-737 Fleet Utilization Model Three For The Non-Significant Period

Table 8.88 B-737 Model Three Comparative Efficiency Analysis For The Non-Significant Period

Month	Efficiency	Month	Efficiency	Month	Efficiency	Month	Efficiency
Sep-94	100	Dec-97	95.74	Nov-96	90.89	Oct-96	83.08
Sep-97	100	Oct-97	94.84	Dec-94	90.31	Sep-98	76.26
Sep-96	100	Dec-95	92.86	Dec-96	89.44	Oct-98	70.07
Sep-95	98.83	Nov-94	92.31	Nov-95	89.24	Nov-98	63.37
Nov-97	96.77	Oct-94	91.37	Oct-95	85.21	Dec-98	61.98

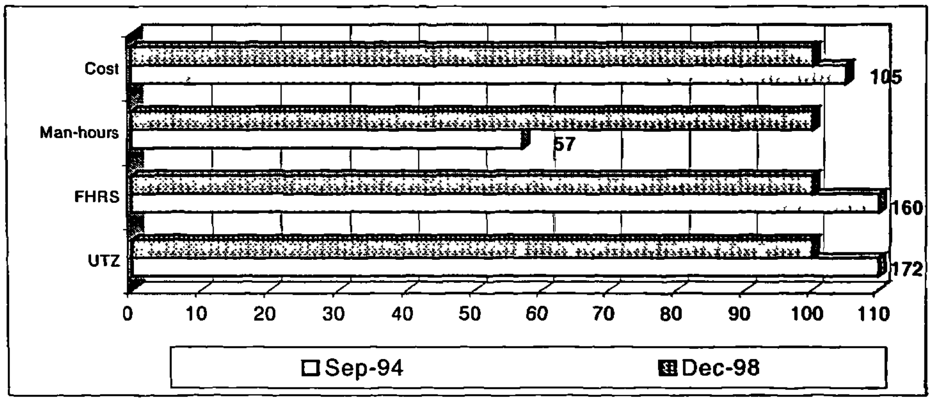
Table 8.89 B-737 Model Three Input and Output Contribution For The Efficient Months For The Non-Significant Period

	I/Os	Level %		I/Os	Level %		I/Os	Level %
Sep-97	Cost	88	Sep-94	Cost		Sep-96	Cost	97
	Man-hours	12		Man-hours	100		Man-hours	3
	Fhrs	100		Fhrs	100		Fhrs	
	UTZ			UTZ			UTZ	100

Table 8.90 B-737 Model Three Potential Improvement For The Non-Significant Period

Dec-98		60 Month Model %	Non-Significant Period %
Inputs	COST	-45.58	-38.02
	MAN-HOURS	-57.56	.38.02
	UTZ	0	1.91
Output	FHRS	0	0

Figure 8.48 B-737 Model Three Reference Comparison For The Non-significant Month Only



B-737 Fleet Reliability Model Four For The Non-Significant Period

Table 8.91 B-737 Model Four Comparative Efficiency Analysis For The Non-Significant Period

Month	Efficiency	Month	Efficiency	Month	Efficiency	Month	Efficiency
Sep-94	100	Nov-97	98.98	Dec-97	97.26	Oct-97	95.76
Sep-97	100	Dec-95	98.88	Oct-94	97.07	Dec-94	94.27
Nov-95	100	Sep-95	98.73	Sep-96	96.48	Nov-96	93.36
Nov-94	99.74	Sep-98	97.55	Oct-98	96.17	Dec-96	92.8
Dec-98	99.06	Nov-98	97.51	Oct-95	95.88	Oct-96	87.34

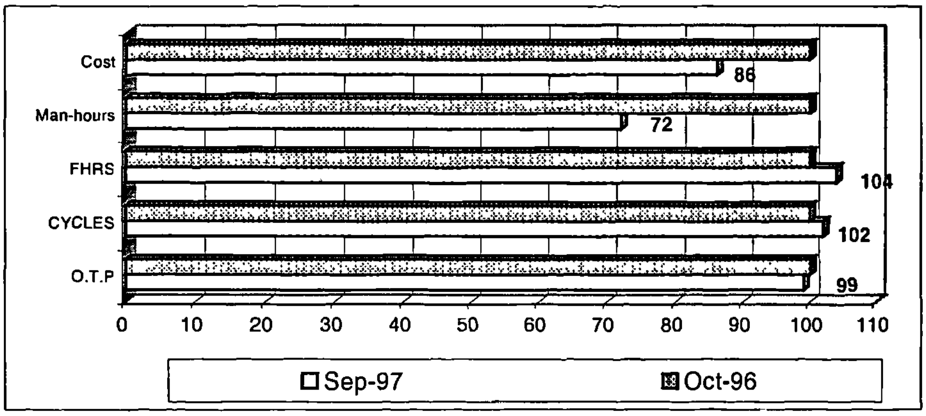
Table 8.92 B-737 Model Four Input and Output Contribution For The Efficient Months For The Non-Significant Period

	I/Os	Level %		I/Os	Level %		I/Os	Level %
Sep-97	Cost	97	Nov-95	Cost	98	Sep-94	Cost	
	Man-hours	3		Man-hours	2		Man-hours	100
	Fhrs			Fhrs			Fhrs	100
	Cycles	100		Cycles			cycles	
	T.O.P			T.O.P	100		T.O.P	

Table 8.93 B-737 Model Four Potential Improvement For The Non-Significant Period

Oct-96		60 Month Model %	Non-Significant Period %
Inputs	COST	-18.78	-12.66
	MAN-HOURS	-72.71	-26.57
Output	FHRS	1.08	5.13
	CYCLES	0	3.14
	O.T.P	0	0

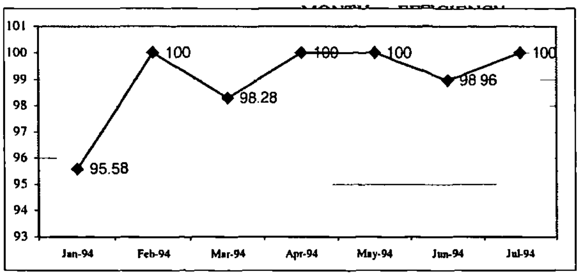
Figure 8.49 B-737 Model Four Reference Comparison For The Non-Significant Period



APPX.C CHAPTER 9

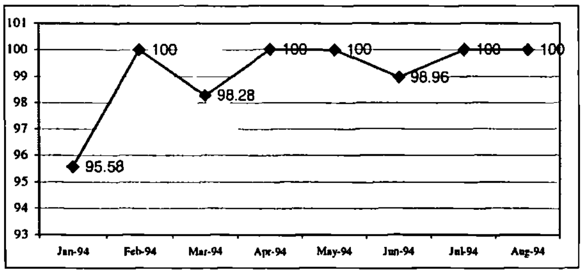
A-300 SIMULATION ANALYSIS MODEL ONE

RUN:1



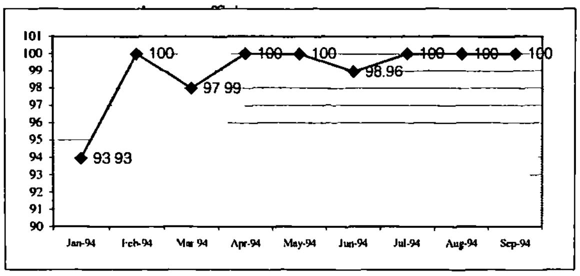
Jan-94		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8365480	7996059 2	-4 42
	MAN-HOURS	6310	6031 35	-4 42
Output	FHRS	2081	2167 59	4 16
	CYCLES	1673	1673	0
	DEPRT	1433	1492 68	4 16
	UTZ	6 1	6 58	7 91
	FHRS/CYCLYS	1 2	1 29	7 48
	O T.P	97 7	97 7	0

RUN:2



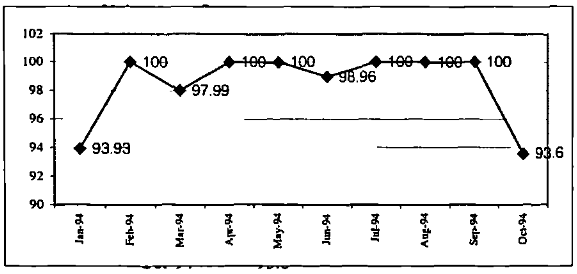
Jan-94		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8365480	7996059 2	-4 42
	MAN-HOURS	6310	6031 35	-4 42
Output	FHRS	2081	2167 59	4 16
	CYCLES	1673	1673	0
	DEPRT	1433	1492 68	4 16
	UTZ	6.1	6 58	7 91
	FHRS/CYCLYS	1 2	1 29	7 48
	O T P	97 7	97 7	0

RUN:3



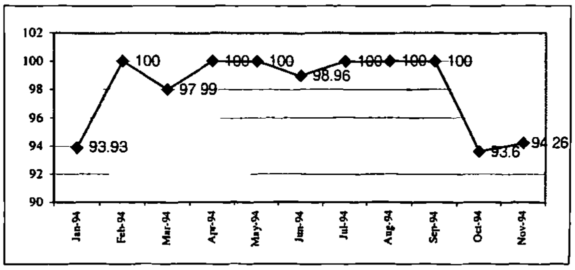
Jan-94		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8365480	7857652 59	-6 07
	MAN-HOURS	6310	5926 95	-6 07
Output	FHRS	2081	2104 86	1 15
	CYCLES	1673	1673	0
	DEPRT	1433	1458 55	1 78
	UTZ	6 1	6 47	6 13
	FHRS/CYCLYS	1 2	1 26	4 94
	O T P	97 7	97 7	0

RUN:4



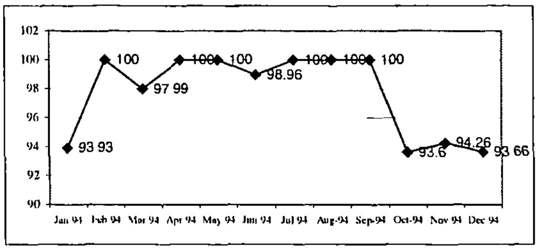
Oct-94		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8395323	7857903 04	-6 4
	MAN-HOURS	8954	6195 11	-30 81
Output	FHRS	1956	2012 91	2 91
	CYCLES	1629	1629	0
	DEPRT	1473	1473	0
	UTZ	5 7	6 26	9 75
	FHRS/CYCLYS	1 2	1 24	3 2
	O T P	98 44	98 44	0

RUN:5



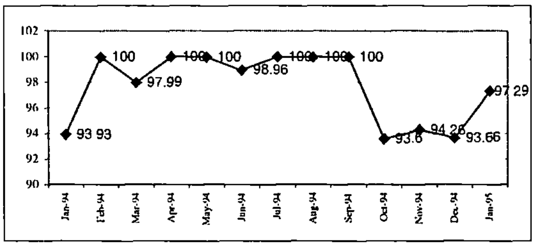
Oct-94		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8395323	7857903 04	-6 4
	MAN-HOURS	8954	6195 11	-30 81
Output	FHRS	1956	2012 91	2 91
	CYCLES	1629	1629	0
	DEPRT	1473	1473	0
	UTZ	5 7	6 26	9 75
	FHRS/CYCLYS	1 2	1 24	3 2
	O T P	98 44	98 44	0

RUN:6



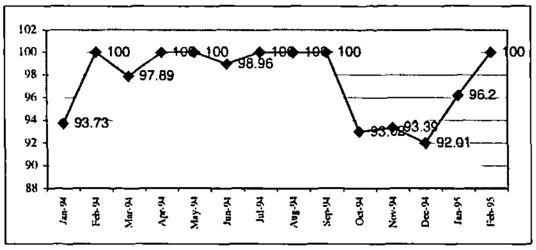
Oct-94		ACTUAL	TARGET	IMPROVEMENT
Inputs	COST	8395323	7857903.04	-6.4
	MAN HOURS	8954	6195.11	-30.81
Output	FHRS	1956	2012.91	2.91
	CYCLES	1629	1629	0
	DEPRT	1473	1473	0
	UTZ	5.7	6.26	9.75
	FHRS/CYCLYS	1.2	1.24	3.2
	O T P	98.44	98.44	0

RUN:7



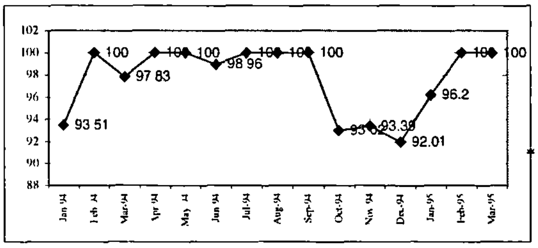
Oct 94		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8395323	7857903.04	-6.4
	MAN-HOURS	8954	6195.11	-30.81
Output	FHRS	1956	2012.91	2.91
	CYCLES	1629	1629	0
	DEPRT	1473	1473	0
	UTZ	5.7	6.26	9.75
	FHRS/CYCLYS	1.2	1.24	3.2
	O T P	98.44	98.44	0

RUN:8



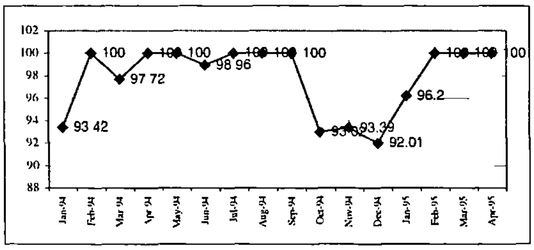
Dec-94		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8294976	7632182.42	-7.99
	MAN-HOURS	7787	7164.8	-7.99
Output	FHRS	2009	2079.95	3.53
	CYCLES	1599	1599	0
	DEPRT	1385	1385	0
	UTZ	5.9	6.54	10.81
	FHRS/CYCLYS	1.3	1.3	0
	O T P	97.83	99.52	1.72

RUN:9



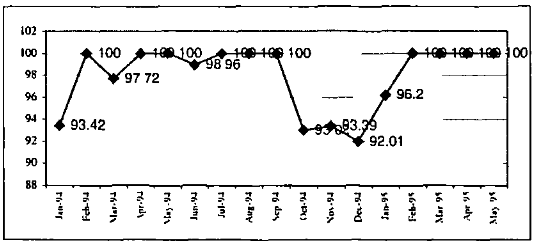
Dec 94		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8294976	7632182.42	-7.99
	MAN-HOURS	7787	7164.8	-7.99
Output	FHRS	2009	2079.95	3.53
	CYCLES	1599	1599	0
	DEPRT	1385	1385	0
	UTZ	5.9	6.54	10.81
	FHRS/CYCLYS	1.3	1.3	0
	O T P	97.83	99.52	1.72

RUN:10



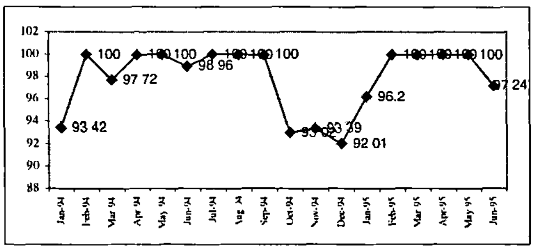
Dec-94		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8294976	7632182.42	-7.99
	MAN-HOURS	7787	7164.8	-7.99
Output	FHRS	2009	2079.95	3.53
	CYCLES	1599	1599	0
	DEPRT	1385	1385	0
	UTZ	5.9	6.54	10.81
	FHRS/CYCLYS	1.3	1.3	0
	O T P	97.83	99.52	1.72

RUN:11



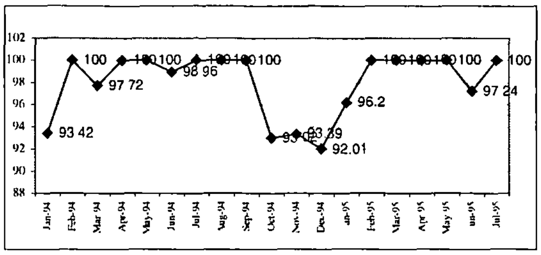
Dec-94		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8294976	7632182.42	-7.99
	MAN-HOURS	7787	7164.8	-7.99
Output	FHRS	2009	2079.95	3.53
	CYCLES	1599	1599	0
	DEPRT	1385	1385	0
	UTZ	5.9	6.54	10.81
	FHRS/CYCLYS	1.3	1.3	0
	O T P	97.83	99.52	1.72

RUN:12



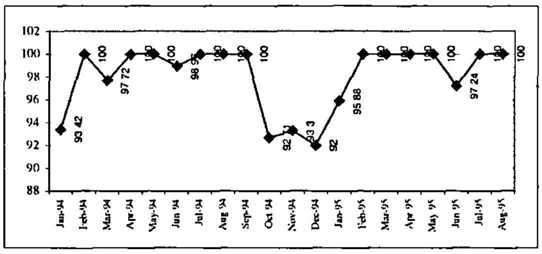
Dec-94		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8294976	7632182.42	-7.99
	MAN-HOURS	7787	7164.8	-7.99
Output	FHRS	2009	2079.95	3.53
	CYCLES	1599	1599	0
	DEPRT	1385	1385	0
	UTZ	5.9	6.54	10.81
	FHRS/CYCLYS	1.3	1.3	0
	O T P	97.83	99.52	1.72

RUN:13



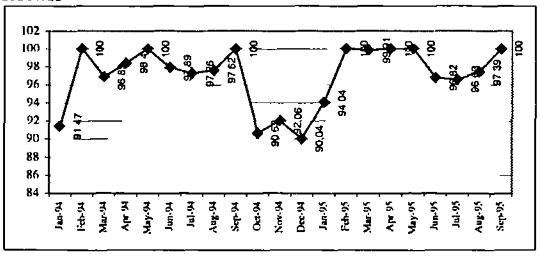
Dec-94		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8294976	7632182.42	[illegible]
	MAN-HOURS	7787	7164.8	7.9
Output	FHRS	2009	207[illegible].95	3.53
	CYCLES	1599	1599	0
	DEPRT	1385	1385	0
	UTZ	5.9	6.54	10.81
	FHRS/CYCLYS	1.3	1.3	0
	O T P	97.83	99.52	1.72

RUN:14



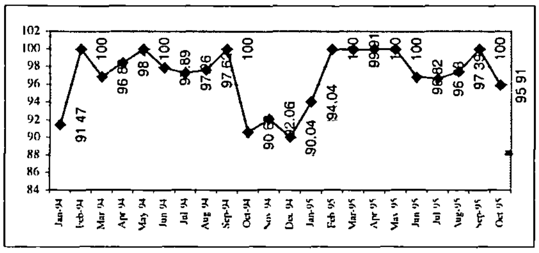
Dec-94		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8294976	7631633.8	-8
	MAN HOURS	7787	7164.28	-8
Output	FHRS	2009	2079.36	3.5
	CYCLES	1599	1599	0
	DEPRT	1385	1385	0
	UTZ	5.9	6.54	10.76
	FHRS/CYCLYS	1.3	1.3	0
	O T P	97.83	99.52	1.73

RUN:15



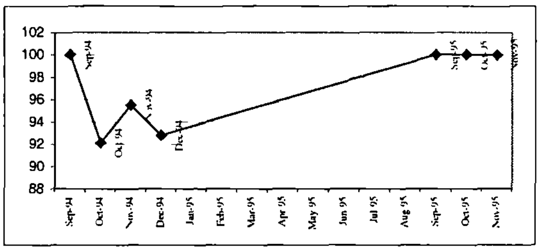
Dec-94		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8294976	7469180.41	-9.96
	MAN-HOURS	7787	6876.16	-11.7
Output	FHRS	2009	2106.24	4.84
	CYCLES	1599	1599	0
	DEPRT	1385	1413.19	2.04
	UTZ	5.9	6.58	11.48
	FHRS/CYCLYS	1.3	1.3	0
	O T P	97.83	98.1	0.27

RUN:16



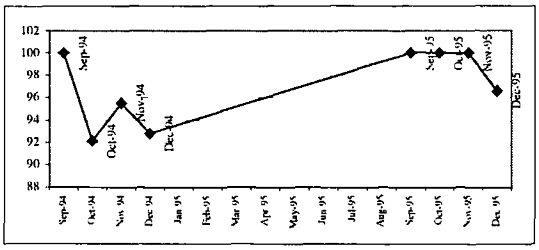
Dec-94		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8294976	7469180.41	-9.96
	MAN-HOURS	7787	6876.16	-11.7
Output	FHRS	2009	2106.24	4.84
	CYCLES	1599	1599	0
	DEPRT	1385	1413.19	2.04
	UTZ	5.9	6.58	11.48
	FHRS/CYCLYS	1.3	1.3	0
	O T P	97.83	98.1	0.27

RUN:17



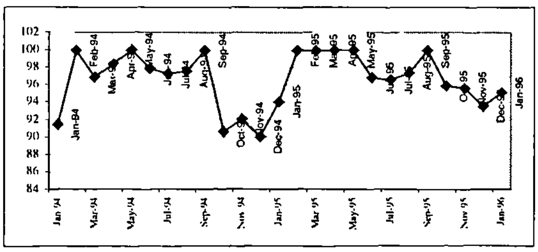
Oct-94		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8395323	7735936.46	-7.85
	MAN-HOURS	8954	6398.05	-28.55
Output	FHRS	1956	2121.11	8.44
	CYCLES	1629	1629	0
	DEPRT	1473	1478.04	0.34
	UTZ	5.7	6.42	12.71
	FHRS/CYCLYS	1.2	1.31	8.87
	O T P	98.44	98.44	0

RUN:18



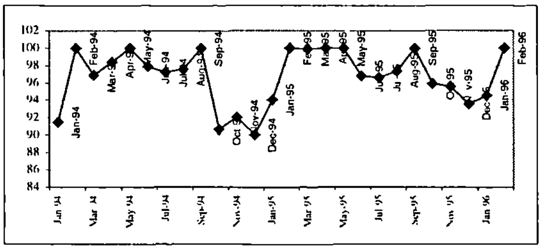
Oct-94		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8395323	7735936.46	-7.85
	MAN HOURS	8954	6398.05	-28.55
Output	FHRS	1956	2121.11	8.44
	CYCLES	1629	1629	0
	DEPRT	1473	1478.04	0.34
	UTZ	5.7	6.42	12.71
	FHRS/CYCLYS	1.2	1.31	8.87
	O T P	98.44	98.44	0

RUN:19



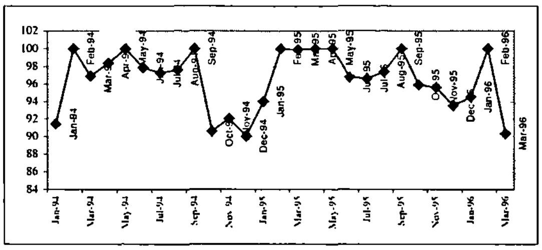
Dec-94		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8294976	7469180.41	-9.96
	MAN HOURS	7787	6876.16	-11.7
Output	FHRS	2009	2106.24	4.84
	CYCLES	1599	1599	0
	DEPRT	1385	1413.19	2.04
	UTZ	5.9	6.58	11.48
	FHRS/CYCLYS	1.3	1.3	0
	O T P	97.83	98.1	0.27

RUN:20



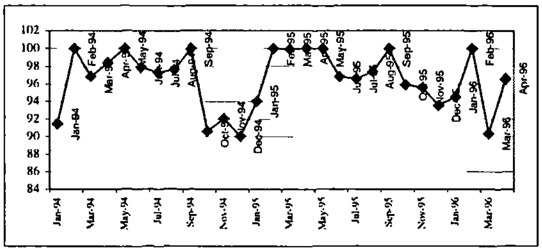
Dec-94		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8294976	7469180.41	-9.96
	MAN-HOURS	7787	6876.16	-11.7
Output	FHRS	2009	2106.24	4.84
	CYCLES	1599	1599	0
	DEPRT	1385	1413.19	2.04
	UTZ	5.9	6.58	11.48
	FHRS/CYCLYS	1.3	1.3	
	O.T.P	97.83	98.1	0.27

RUN:21



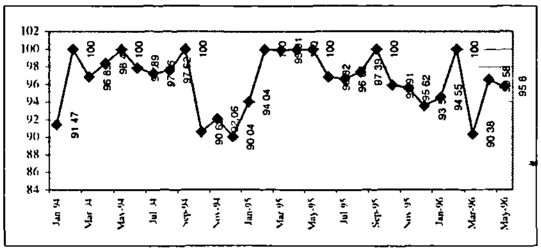
Dec-94		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8294976	7469180.41	-9.96
	MAN-HOURS	7787	6876.16	11.7
Output	FHRS	2009	2106.24	4.84
	CYCLES	1599	1599	0
	DEPRT	1385	1413.19	2.04
	UTZ	5.9	6.58	11.48
	FHRS/CYCLYS	1.3	1.3	0
	O.T.P	97.83	98.1	0.27

RUN:22



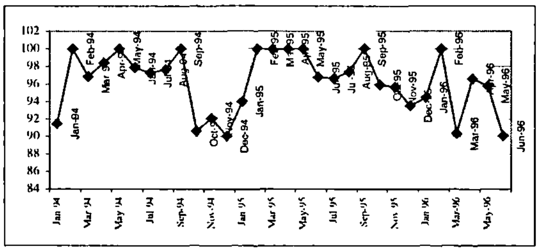
Dec-94		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8294976	7469180.41	-9.96
	MAN-HOURS	7787	6876.16	-11.7
Output	FHRS	2009	2106.24	4.84
	CYCLES	1599	1599	0
	DEPRT	1385	1413.19	2.04
	UTZ	5.9	6.58	11.48
	FHRS/CYCLYS	1.3	1.3	0
	O.T.P	97.83	98.1	0.27

RUN:23



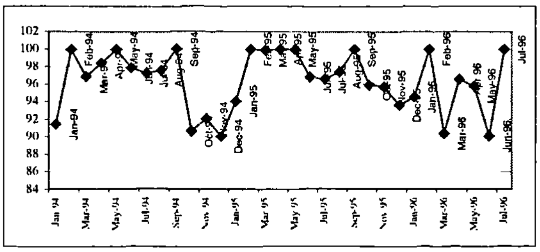
Dec-94		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8294976	7469180.41	-9.96
	MAN-HOURS	7787	6876.16	-11.7
Output	FHRS	2009	2106.24	4.84
	CYCLES	1599	1599	0
	DEPRT	1385	1413.19	2.04
	UTZ	5.9	6.58	11.48
	FHRS/CYCLYS	1.3	1.3	0
	O.T.P	97.83	98.1	0.27

RUN:24



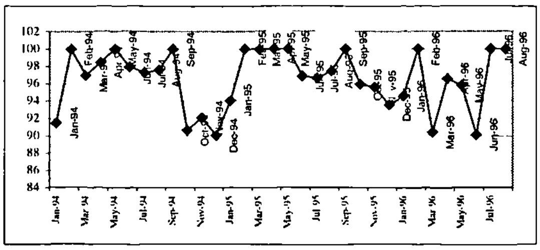
Dec-94		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8294976	7469180.41	-9.96
	MAN-HOURS	7787	6876.16	-11.7
Output	FHRS	2009	2106.24	4.84
	CYCLES	1599	1599	0
	DEPRT	1385	1413.19	2.04
	UTZ	5.9	6.58	11.48
	FHRS/CYCLYS	1.3	1.3	0
	O.T.P	97.83	98.1	0.27

RUN:25



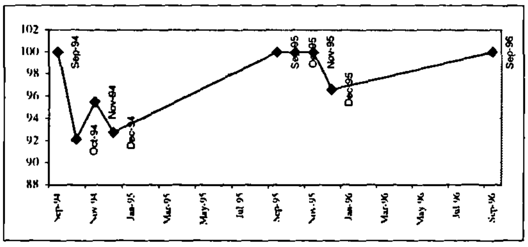
Dec-94		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8294976	7469180.41	-9.96
	MAN-HOURS	7787	6876.16	-11.7
Output	FHRS	2009	2106.24	4.84
	CYCLES	1599	1599	0
	DEPRT	1385	1413.19	2.04
	UTZ	5.9	6.58	11.48
	FHRS/CYCLYS	1.3	1.3	0
	O.T.P	97.83	98.1	0.27

RUN:26



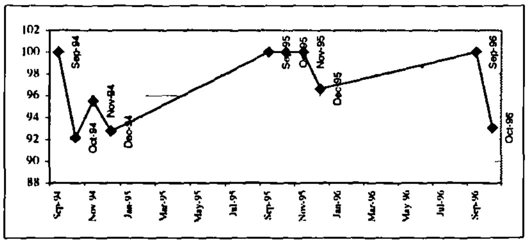
Dec-94		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8294976	7469180.41	-9.96
	MAN-HOURS	7787	6876.16	11.7
Output	FHRS	2009	2106.24	4.84
	CYCLES	1599	1599	0
	DEPRT	1385	1413.19	2.04
	UTZ	5.9	6.58	11.48
	FHRS/CYCLYS	1.3	1.3	0
	O.T.P	97.83	98.1	0.27

RUN:27



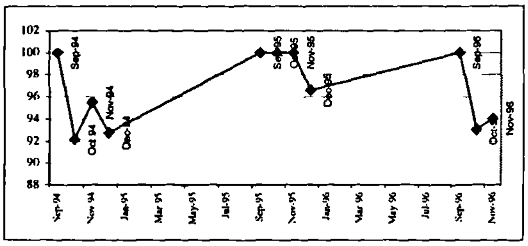
Oct-94		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8395323	7735936 46	-7 85
	MAN-HOURS	8954	6398 05	-28 55
Output	FHRS	1956	2121 11	8 44
	CYCLES	1629	1629	0
	DEPRT	1473	1478 04	0 34
	UTZ	5.7	6 42	12 71
	FHRS/CYCLYS	1 2	1 31	8 87
	O T P	98 44	98 44	0

RUN:28



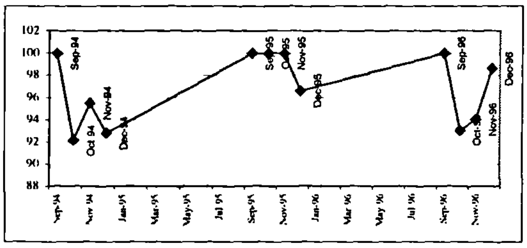
Oct-94		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8395323	7735936 46	-7 85
	MAN HOURS	8954	6398 05	-28 55
Output	FHRS	1956	2121 11	8 44
	CYCLES	1629	1629	0
	DEPRT	1473	1478 04	0 34
	UTZ	5.7	6.42	12 71
	FHRS/CYCLYS	1 2	1 31	8.87
	O T P	98 44	98 44	0

RUN:29



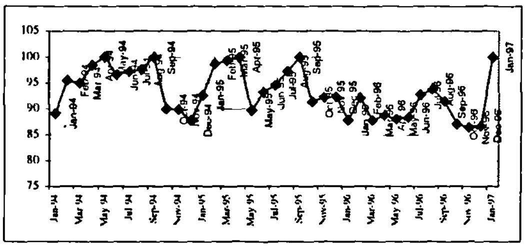
Oct-94		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8395323	7735936.46	-7 85
	MAN-HOURS	8954	6398 05	-28.55
Output	FHRS	1956	2121 11	8 44
	CYCLES	1629	1629	0
	DEPRT	1473	1478 04	0.34
	UTZ	5 7	6 42	12.71
	FHRS/CYCLYS	1 2	1.31	8 87
	O T P	98 44	98 44	0

RUN:30



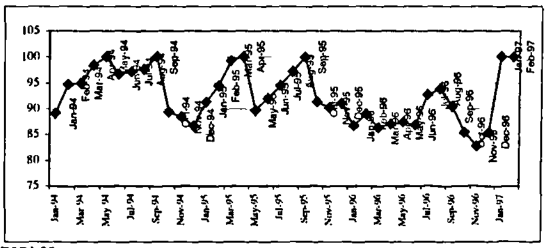
Oct-94		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8395323	7735936 46	-7 85
	MAN HOURS	8954	6398 05	-28 55
Output	FHRS	1956	2121 11	8 44
	CYCLES	1629	1629	0
	DEPRT	1473	1478 04	0.34
	UTZ	5 7	6 42	12 71
	FHRS/CYCLYS	1 2	1.31	8.87
	O T P	98 44	98 44	0

RUN:31



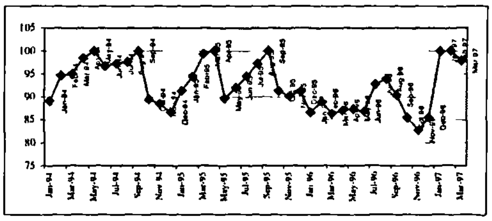
Nov-96		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8199580	7088494 84	-13 55
	MAN-HOURS	13299	5237 29	-60 62
Output	FHRS	1820	2320 96	27 53
	CYCLES	1489	1606 51	7.89
	DEPRT	1263	1303 77	3 21
	UTZ	5 5	6 76	22.93
	FHRS/CYCLYS	1 2	1 41	17 73
	O T P	98 57	98 57	0

RUN:32



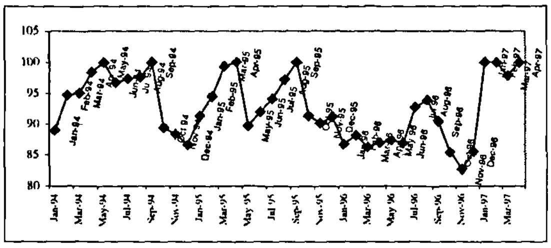
Nov-96		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8199580	6784295 34	-17 26
	MAN-HOURS	13299	7248 01	-45 5
Output	FHRS	1820	2124.1	16 71
	CYCLES	1489	1505.52	1.11
	DEPRT	1263	1263	0
	UTZ	5 5	6.84	24.43
	FHRS/CYCLYS	1 2	1 39	16 01
	O T P	98 57	98 57	0

RUN:33



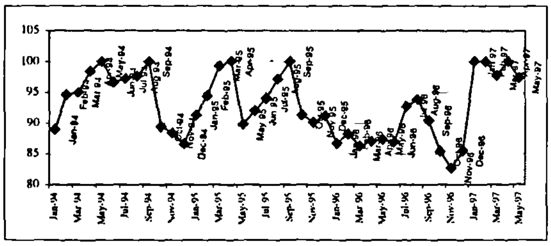
Nov 96		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8199580	6784295 34	-17 26
	MAN HOURS	13299	7248 01	-45 5
Output	FHRS	1820	2124 1	16 71
	CYCLES	1489	1505.52	1 11
	DEPRT	1263	1263	0
	UTZ	5 5	6 84	24 43
	FHRS/CYCLYS	1 2	1 39	16 01
	O T P	98 57	98 57	0

RUN:34



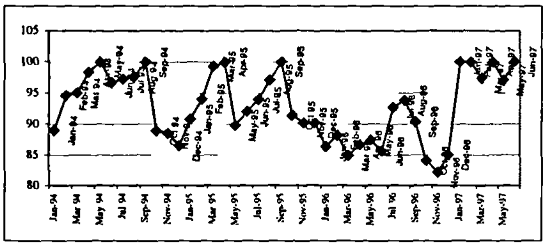
Nov-96		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8199580	6784295.34	-17.26
	MAN-HOURS	13299	7248.01	-45.5
Output	FHRS	1820	2124.1	16.71
	CYCLES	1489	1505.52	1.11
	DEPRT	1263	1263	0
	UTZ	5.5	6.84	24.43
	FHRS/CYCLYS	1.2	1.39	16.01
	O T P	98.57	98.57	0

RUN:35



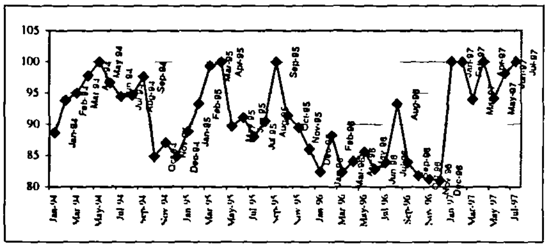
Nov-96		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8199580	6784295.34	-17.26
	MAN-HOURS	13299	7248.01	-45.5
Output	FHRS	1820	2124.1	16.71
	CYCLES	1489	1505.52	1.11
	DEPRT	1263	1263	0
	UTZ	5.5	6.84	24.43
	FHRS/CYCLYS	1.2	1.39	16.01
	O T P	98.57	98.57	0

RUN:36



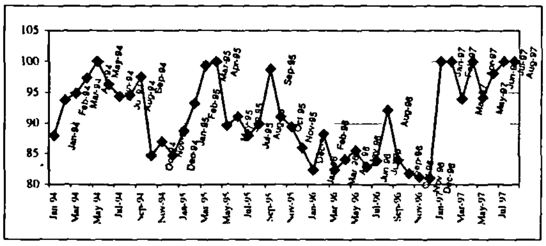
Nov-96		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8199580	6735511.21	-17.86
	MAN-HOURS	13299	7866.11	-40.85
Output	FHRS	1820	2078.38	14.2
	CYCLES	1489	1531.68	2.87
	DEPRT	1263	1263	0
	UTZ	5.5	6.59	19.8
	FHRS/CYCLYS	1.2	1.38	14.61
	O T P	98.57	98.57	0

RUN:37



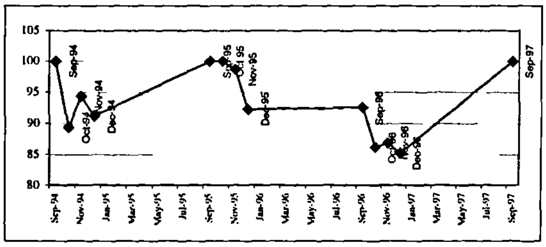
Dec-96		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8295316	6724782.45	-18.93
	MAN-HOURS	20107	8263.02	-58.9
Output	FHRS	2000	2235.72	11.79
	CYCLES	1477	1596.57	8.1
	DEPRT	1340	1340	0
	UTZ	5.9	7.02	18.97
	FHRS/CYCLYS	1.4	1.4	0.2
	O T P	97.84	97.84	0

RUN:38



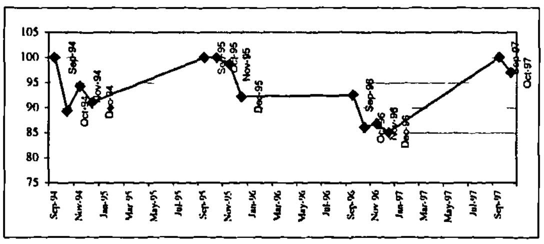
Dec-96		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8295316	6724782.45	-18.93
	MAN-HOURS	20107	8263.02	-58.9
Output	FHRS	2000	2235.72	11.79
	CYCLES	1477	1596.57	8.1
	DEPRT	1340	1340	0
	UTZ	5.9	7.02	18.97
	FHRS/CYCLYS	1.4	1.4	0.2
	O T P	97.84	97.84	0

RUN:39



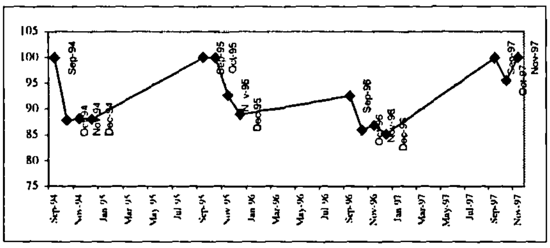
Dec-96		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8295316	7072423.16	-14.74
	MAN-HOURS	20107	11080.13	-44.89
Output	FHRS	2000	2110.7	5.53
	CYCLES	1477	1560.48	5.65
	DEPRT	1340	1432.4	6.9
	UTZ	5.9	6.35	7.67
	FHRS/CYCLYS	1.4	1.43	2.46
	O T P	97.84	97.84	0

RUN:40



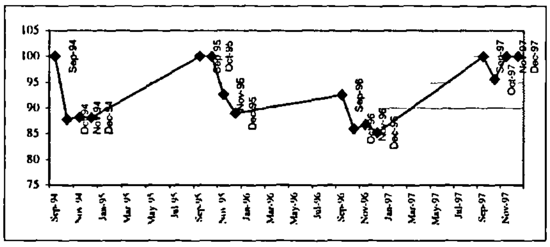
Dec-96		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8295316	7072423.16	-14.74
	MAN-HOURS	20107	11080.13	-44.89
Output	FHRS	2000	2110.7	5.53
	CYCLES	1477	1560.48	5.65
	DEPRT	1340	1432.4	6.9
	UTZ	5.9	6.35	7.67
	FHRS/CYCLYS	1.4	1.43	2.46
	O T P	97.84	97.84	0

RUN:41



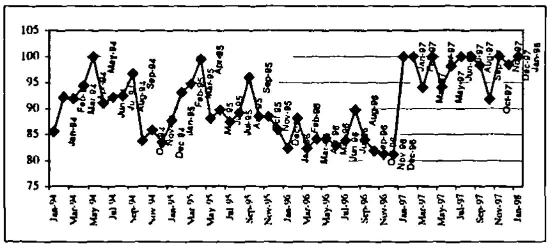
Dec-96		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8295316	7068289.27	-14.79
	MAN-HOURS	20107	6235.96	-68.99
Output	FHRS	2000	2091.96	4.6
	CYCLES	1477	1501.13	1.63
	DEPRT	1340	1449.94	8.2
	UTZ	5.9	6.35	7.6
	FHRS/CYCLYS	1.4	1.43	2.4
	O T P	97.84	97.84	0

RUN:42



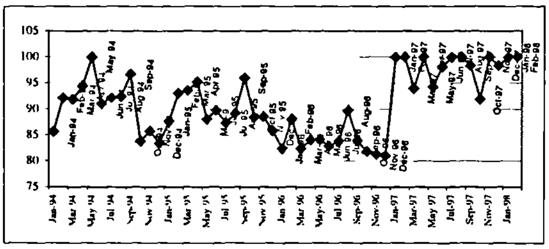
Dec-96		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8295316	7068289.27	-14.79
	MAN-HOURS	20107	6235.96	-68.99
Output	FHRS	2000	2091.96	4.6
	CYCLES	1477	1501.13	1.63
	DEPRT	1340	1449.94	8.2
	UTZ	5.9	6.35	7.6
	FHRS/CYCLYS	1.4	1.43	2.4
	O T P	97.84	97.84	0

RUN:43



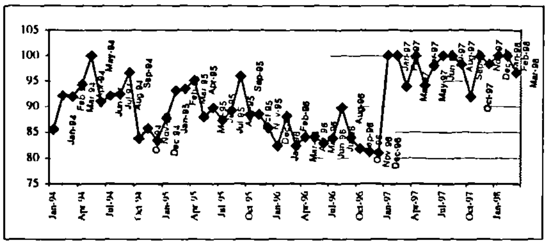
Dec-96		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8295316	6724782.45	-18.93
	MAN-HOURS	20107	8263.02	-58.9
Output	FHRS	2000	2235.72	11.79
	CYCLES	1477	1596.57	8.1
	DEPRT	1340	1340	0
	UTZ	5.9	7.02	18.97
	FHRS/CYCLYS	1.4	1.4	0.2
	O T P	97.84	97.84	0

RUN:44



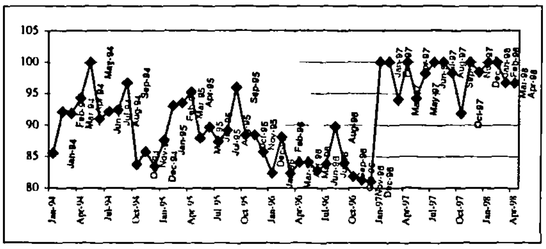
Dec-96		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8295316	6724782.45	-18.93
	MAN HOURS	20107	8263.02	-58.9
Output	FHRS	2000	2235.72	11.79
	CYCLES	1477	1596.57	8.1
	DEPRT	1340	1340	0
	UTZ	5.9	7.02	18.97
	FHRS/CYCLYS	1.4	1.4	0.2
	O T P	97.84	97.84	0

RUN:45



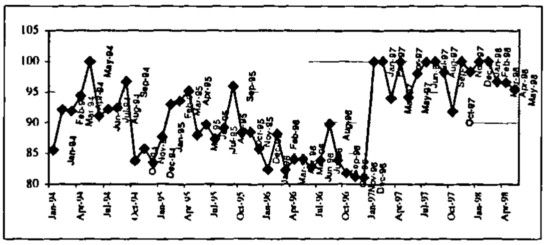
Dec-96		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8295316	6724782.45	-18.93
	MAN-HOURS	20107	8263.02	-58.9
Output	FHRS	2000	2235.72	11.79
	CYCLES	1477	1596.57	8.1
	DEPRT	1340	1340	0
	UTZ	5.9	7.02	18.97
	FHRS/CYCLYS	1.4	1.4	0.2
	O T P	97.84	97.84	0

RUN:46



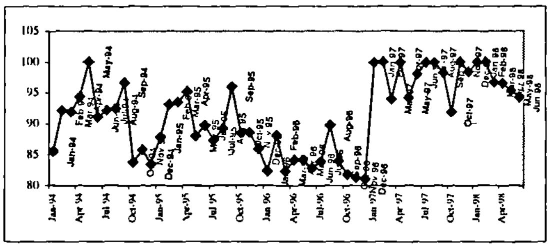
Dec-96		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8295316	6724782.45	-18.93
	MAN-HOURS	20107	8263.02	-58.9
Output	FHRS	2000	2235.72	11.79
	CYCLES	1477	1596.57	8.1
	DEPRT	1340	1340	0
	UTZ	5.9	7.02	18.97
	FHRS/CYCLYS	1.4	1.4	0.2
	O T P	97.84	97.84	0

RUN:47



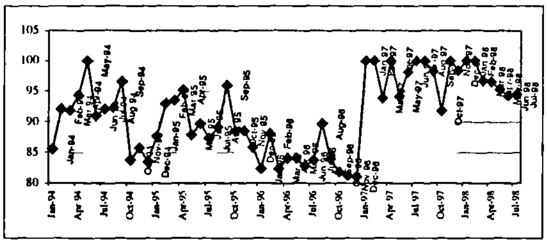
Dec-96		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8295316	6724782.45	-18.93
	MAN-HOURS	20107	8263.02	-58.9
Output	FHRS	2000	2235.72	11.79
	CYCLES	1477	1596.57	8.1
	DEPRT	1340	1340	0
	UTZ	5.9	7.02	18.97
	FHRS/CYCLYS	1.4	1.4	0.2
	O T P	97.84	97.84	0

RUN:48



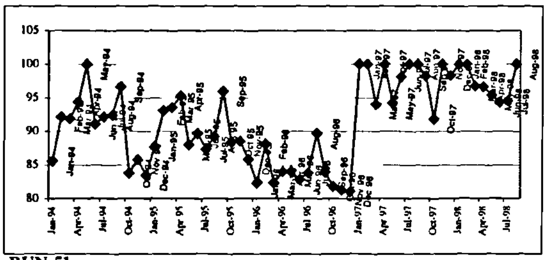
Dec-96		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8295316	6724782 45	-18 93
	MAN-HOURS	20107	8263 02	-58
Output	FHRS	2000	2235 72	11 79
	CYCLES	1477	1596 57	8 1
	DEPRT	1340	1340	0
	UTZ	5 9	7 02	18 97
	FHRS/CYCLYS	1 4	1 4	0 2
	O T P	97 84	97 84	0

RUN:49



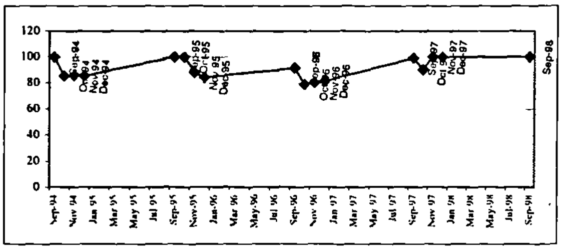
Dec-96		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8295316	6724782.45	-18 93
	MAN-HOURS	20107	8263 02	-58 9
Output	FHRS	2000	2235 72	11 79
	CYCLES	1477	1596.57	8 1
	DEPRT	1340	1340	0
	UTZ	5 9	7.02	18.97
	FHRS/CYCLYS	1 4	1 4	0 2
	O T P	97 84	97 84	0

RUN:50



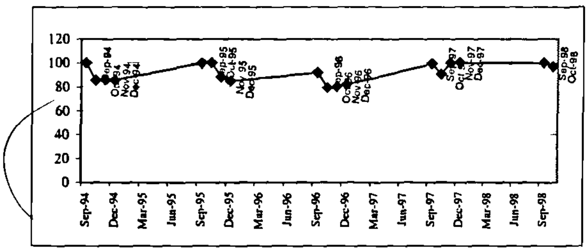
Dec-96		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8295316	6724782.45	-18 93
	MAN-HOURS	20107	8263 02	-58 9
Output	FHRS	2000	2235.72	11 79
	CYCLES	1477	1596.57	8 1
	DEPRT	1340	1340	0
	UTZ	5.9	7.02	18.97
	FHRS/CYCLYS	1 4	1.4	0 2
	O T P	97 84	97 84	0

RUN:51



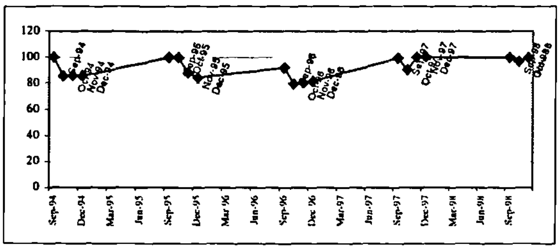
Oct-96		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8285496	6561285.08	-20 81
	MAN-HOURS	21494	6977 5	-67 54
Output	FHRS	1851	1973.58	6 62
	CYCLES	1380	1482 8	7 45
	DEPRT	1348	1352 27	0 32
	UTZ	5 4	5 95	10 22
	FHRS/CYCLYS	1 3	1 36	4 42
	O T P	98 7	98 7	0

RUN:52



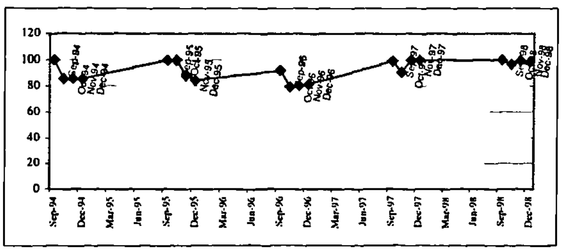
Oct-96		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8285496	6561285 08	-20 81
	MAN-HOURS	21494	6977.5	-67 54
Output	FHRS	1851	1973 58	6 62
	CYCLES	1380	1482 8	7 45
	DEPRT	1348	1352 27	0 32
	UTZ	5 4	5.95	10 22
	FHRS/CYCLYS	1 3	1 36	4.42
	O T P	98 7	98 7	0

RUN:53



Oct-96		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8285496	6561285.08	-20 81
	MAN-HOURS	21494	6977 5	-67 54
Outputs	FHRS	1851	1973.58	6 62
	CYCLES	1380	1482 8	7 45
	DEPRT	1348	1352 27	0 32
	UTZ	5 4	5 95	10 22
	FHRS/CYCLES	1 3	1 36	4 42
	TECH OTP	98 7	98 7	0

RUN:54



Oct-96		ACTUAL	TARGET	IMPROVEMENT %
Inputs	COST	8285496	6561285 08	-20 81
	MAN-HOURS	21494	6977 5	-67 54
Outputs	FHRS	1851	1973 58	6 62
	CYCLES	1380	1482 8	7 45
	DEPRT	1348	1352 27	0 32
	UTZ	5 4	5 95	10 22
	FHRS/CYCLES	1 3	1 36	4 42
	TECH OTP	98 7	98 7	0