İSTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY

HUMAN FACTORS IN AIRCRAFT MAINTENANCE

M.Sc. Thesis by
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Programme: **Aeronautical and Aerospace Engineering**

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<u>İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ</u>

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PREFACE

I would like to thank to all the owners of all the resources that I have used in the preparation of this document. I believe that this study will bear the property of being a general summary document for all civil and military aircraft maintenance organizations.

Just as the founder of our country, Turkish Republic, the mighty leader Ataturk has said:

“Turkish Woman should be the world's most enlightened, moral and influential woman”.

“The torch that Turkish Nation holds in his hand and in his mind in walking the way of advancement and civilization is positive sciences. It is for this reason that our national ideal is always and by all means, feeding to improve the high character of our nation, that is hardworking and never tiring, intelligent at birth, committed to science, loving fine arts and a strong sense of national unity”.

I would like to thank to my advisor Prof.Dr.Mehmet Serif Kavsaoglu and his wife, my mother, my son, my husband and my sister for their valuable support during my study. And finally I am very happy that I was able to satisfy the last will of my beloved late grandfather whom I believe is still with us spiritually and always feel his existence with me in our memories.

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ABBREVIATIONS

AAIB	: Air Accidents Investigation Branch, retrived July 3, 2007 from (www.aaib.dtlr.gov.uk)
A/C	: Aircraft
AD	: Airworthiness Directive
ADD	: Acceptable Deferred Defects
AFML	: Aircraft Flight and Maintenance Logbook
AFMR	: Aircraft Flight and Maintenance Report
ASRS	: Aviation Safety Reporting System
CAA	: Civil Aviation Authority
CAP	: Civil Aviation Publication (British CAA Publications)
CDR	: Cabin Defect Report
CRS	: Certificate of Release to Service
CVR	: Cockpit Voice Recorder
DGCA	: Directorate General of Civil Aviation
EASA	: European Civil Aviation Agency
FAA	: Federal Aviation Administration (USA)
HF	: Human Factor
HFAMI	: Human factors in aviation maintenance and inspection
HFIM	: Human Factors in Maintenance
HFSKYWAY	: FAA HFAMI web site, retrived July 3, 2007 from (www.hfskyway.faa.gov)
HIL	: Hold Item List
IATA	: International Air Transportation Association
ICAO	: International Civil Aviation Organization
JAA	: Joint Aviation Authorities
JAR	: Joint Aviation Regulation
M	: Maintenance
MEDA	: Maintenance Error Decision Aid
MEL	: Minimum Equipment List
MMEL	: Master Minimum Equipment List
MOE	: Maintenance Organization Exposition
MRM	: Maintenance Resource Management
NASA	: National Aeronautics and Space Administration
NTSB	: U.S. National Transportation Safety Board
OPS	: Operation Procedures and Specifications
SB	: Service Bulletin

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HUMAN FACTORS IN AIRCRAFT MAINTENANCE

SUMMARY

In this thesis, an investigation is done on human factor errors in aircraft maintenance, the methods of identifiying these errors, studies done on the subject up to date including the results that have been obtained and the applications for future use of aircraft maintenance facilities to protect them from human factor errors. Finally a real life example is analyzed using six sigma approach and the improvements obtained are demonstrated. We will also look at the statistics of human errors in aircraft maintenance and explore the current HF programs adopted by several organizations and try to understand why HF error occur, and how comprehensive, the solutions currently adopted.

Aircraft maintenance is an essential component of the aviation system which supports the global aviation industry. As air traffic grows and the stringent requirements of commercial schedules impose increased demands upon aircraft utilization, the pressures on maintenance operations for on-time performance will also continue to escalate. This will open further windows of opportunity for human error and subsequent breakdowns in the system's safety net. It is also beyond question that unless the aviation industry learns from these occurrences, maintenance-related safety breakdowns will continue to occur. From a Human Factors perspective, important truths have been uncovered during the investigation of these occurrences [17].

Keywords: aircraft, aviation, error, human factor, maintenance, six sigma

Science Code: 618.01.05

HAVA ARACI BAKIMINDA İNSAN FAKTÖRLERİ

ÖZET

Bu tezde havaaracı bakımında yer alan personelin sebep olduğu hataların kaynaklarının neler olabileceği, bu hataların ortaya çıkarılma metodları, günümüze kadar olan zaman içerisinde konu ile ilgili yapılan araştırmaların neler olduğu ve ne gibi sonuçların çıkarıldığı, ileri tarihlerde hangi uygulamalarla havaaracı bakım işletmelerinin insan faktöründen kaynaklanan hatalardan korunabileceği hususlarında çalışmalar araştırılmış ve bir örnek üzerinde Six Sigma yaklaşımı yapılarak analiz yapılmıştır. Ayrıca bazı organizasyonlarda uygulanan İnsan Faktörleri programlarının istatisksel verilerle analizleri yapılmak sureti ile nasıl gerçekçi çözümler oluşrulabileceği, ve bu çözümlerin uygulanmasının nasıl olabileceği üzerinde çalışma yapılmıştır.

Uçak bakımı küresel havacılık sektöründe çok önemli bir süreçtir. Hava trafiği arttıkça ve uçakların uçuş sayılarına bağlı olarak ticari anlamda gelişmeler sağlandıkça, hava aracı bakım sürecinde oluşabilecek baskı artış gösterebilecektir. Bu durum insan faktörü konusunda yeni penceler açılmasına fırsatlar çıkarabilecektir. Bu durumların karşılaştırılmasındaki en önemli etkenlerden biri olan araştırmalar bu süreçlerde bizlere yardımcı olabilecektir.

Anahtar Kelimeler: Altı sigma, bakım, hata, havacılık, hava aracı, insan faktörü

Bilim Dalı Sayısal Kodu: 618.01.05

1 INTRODUCTION

Aircraft maintenance is an essential component of the aviation system which supports the global aviation industry. As air traffic grows and the stringent requirements of commercial schedules impose increased demands upon aircraft utilization, the pressures on maintenance operations for on-time performance will also continue to escalate. This will open further windows of opportunity for human error and subsequent breakdowns in the system's safety net. It is also beyond question that unless the aviation industry learns from these occurrences, maintenance-related safety breakdowns will continue to occur. From a Human Factors perspective, important truths have been uncovered during the investigation of these occurrences [17].

In this research project we will analyze the top human factor problems in aviation maintenance and evaluate a solution to addressing these problems. We will start with the background and description of the subject and a brief look at the history of HF programs and the changes that have taken place over the years in aviation. We will also look at the statistics of human errors in aircraft maintenance and explore the current HF programs adopted by several organizations and try to understand why HF error occur, and how comprehensive, the solutions currently adopted. Then finally, we will look at a company named as ABC’s quality program and criteria for the human related errors in aircraft maintenance to see if we can formulate a more comprehensive solution to managing HF in maintenance. In essence, we would be looking at a more systemic solution to HF management as HF is more than just about people.

1.1 Background of the problem

There is no question that human error in aircraft maintenance and inspection has been a causal factor in several recent air carrier accidents. Whenever humans are involved in an activity, human error is a certain sequel.

According to one source [9] the number of maintenance concern accidents and incidents to public transport aircraft has increased significantly. This source defines maintenance concern as one which is not necessarily a maintenance error (it may be a design error) but one which is of concern to the maintenance personnel as frontline managers of technical problems in daily operations. The same source states that in the first half of the 1980s, there were 17 maintenance concern-related accidents and incidents, involving aircraft belonging only to Western operators and excluding all “routine” technical failures (engine, landing gear, systems, structure, component separations, ramp accidents, etc). All these accidents and incidents had serious consequences (fatal, serious damage, significant previous occurrences, significant airworthiness implications, etc). In the second half of the 1980s, the same source enumerates 28 accidents of maintenance concern, an increase of 65% over the first half of the decade. In the same period, traffic movements (flight departures, scheduled and non-scheduled) increased by 22%. In the first three years of the 1990s there were 25 accidents involving maintenance concerns. This compares with seven in the first three years of the 1980s [17].

Whether maintenance concern-related occurrences are a “new” phenomenon in aviation or whether they have always existed but have only recently been validated by statistics may be a matter of debate. Indeed, the awareness of the importance of maintenance to aviation safety may be the logical consequence of the gradual acceptance of broader, systemic approaches to aviation safety. Whatever the case may be, the increase in the rate of accidents and incidents involving maintenance concerns appears to be at least statistically significant. In the last ten years, the annual average has increased by more than 100% while the number of flights has increased by less than 55%.

Aircraft have become more automated and more complex. The current generation of Boeing 747-400s and Airbus A340s has duplicated or triplicated flight management systems. This may have reduced the burden on the flight crew but it has placed a greater demand on aircraft maintenance technicians, many of whom acquired their basic training in mechanical rather than computerized control systems. This suggests a mismatch of the Liveware- Hardware (L-H) and Liveware-Software (L-S) components of the SHEL model. This model will be explained in this thesis section 2.10.4.

The increasing significance of human error is not unique to aircraft engineering. Hollnagel [12] conducted a survey of the Human Factors literature to identify the extent of the human error problem. In the 1960s, when the problem first began to attract serious attention, the estimated contribution of human error to accidents was around 20%. In the 1990s, this figure has increased fourfold to 80%. There are many possible reasons for this dramatic increase, but there are three which relate to aircraft engineering (Figure 1.1).

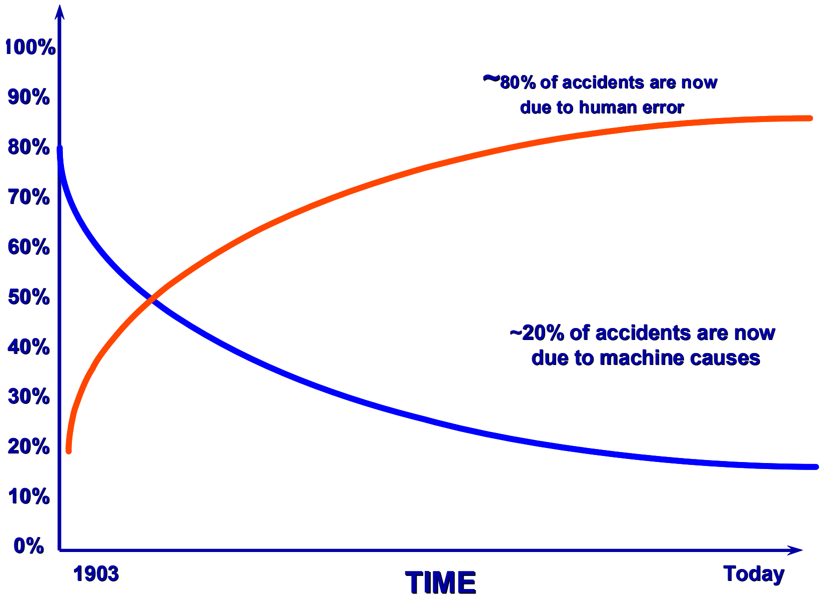


Figure 1.1: The role played by human performance in civil aircraft accidents [14]

The reliability of mechanical and electronic components has increased markedly over the past thirty years. People have stayed the same.

Increased aviation system complexity creates the potential for organizational accidents in which latent procedural and technical failures combine with operational personnel errors and violations to penetrate or circumvent defences as the Reason model suggests. In short, complexity acts to shift the errors to other people.

Traditionally, Human Factors endeavors have been directed towards flight crew performance and, to a lesser extent, towards the performance of air traffic controllers. Until recently, available literature showed little consideration of the Human Factors issues which could affect aircraft maintenance personnel who inspect and repair aircraft. This has been a serious oversight, since it is quite clear that human error in aircraft maintenance has indeed had as dramatic an effect upon the safety of flight operation as the errors of pilots and air traffic controllers.

Aircraft maintenance and inspection uty can be very complex and varied in an environment where possibilities for error is abound. Maintenance personnel — at least in the most developed aviation systems — frequently work under considerable time pressures. Personnel at the maintenance base and at the flight line stations realize the importance of meeting scheduled departure times. Operators have increased aircraft utilization in order to counteract the economic problems that plague the industry. Aircraft maintenance technicians are also maintaining a fleet that is increasing in age. It is not uncommon to find 20 to 25 year old aircraft in many airline fleets, including those of major operators. In addition, many operators intend to keep some of these aircraft in service in the foreseeable future, perhaps beyond the turn of the century [17]. Engine hush kits will make some older narrow-body aircraft economically and environmentally viable. However, these aircraft are maintenance-intensive. The old airframes require careful inspection for signs of fatigue, corrosion and general deterioration. This places an increased burden on the maintenance workforce. It creates stressful work situations, particularly for those engaged in inspection tasks, because additional maintenance is required and because the consequences may be serious if the signs of aging, which are frequently subtle, remain undetected.

While maintenance of these aging aircraft is ongoing, new technology aircraft are entering the fleets of many of the world's airlines, thus increasing the demands on aircraft maintenance. These new aircraft embody advanced technology such as composite material structures, “glass cockpits”, highly automated systems and built-in diagnostic and test equipment. The need to simultaneously maintain new and old fleets requires aircraft maintenance technicians to be more knowledgeable and adept in their work than they may have been previously. The task of simultaneously maintaining these diverse air carrier fleets will require a highly skilled workforce with proper educational background.

There is at present a growing awareness of the importance of Human Factors issues in aircraft maintenance and inspection. The safety and effectiveness of airline operations are also becoming more directly related to the performance of the people who inspect and service the aircraft fleets. One of the objectives of this digest is to bring to light Human Factors issues which are of significant importance to aviation safety [17].

1.2 Motivation

The purpose of the work where this document states, to describe clearly and to evaluate how to control and eliminate the errors those have been caused by human during the maintenance of the aircraft.

The human factor error data in aircraft maintenance that has been used in this document has been evaluated and compared statistically with the other error factors. The data collection has been done by reviewing the other documents those have been issued on this subject and evaluation of the incidents and accidents in one of the private aircraft maintenance company in Turkiye.

I believe this document will be helpful for the aircraft maintenance companies in civil aviation in the world.

1.3 Scope of the work

Information about the six sigma methodolgy is provided in the third section of this thesis. In the Fourth section, findings recorded for four years between 2003 and 2006 during internal and external audits in the database of the quality department of an industry approved aircraft maintenance facility, are evaluated. In this evaluation, using six sigma methodolgy, the problem is defined, its importance is determined, the sources for this problem are identified and how these sources can be deleted or be taken under control using statistical apporach, are studied.

1.4 Description of the thesis

China Eastern flight 5210 (CES5210, MU5210) was a flight from Baotou, Inner Mongolia, China to Shanghai Hongqiao Airport Shanghai, China. On November 21, 2004 it crashed into a park shortly after take off, killing all 53 passengers on board and two more people on the ground.

The aircraft took off at 08.20'/8.20am local time (00.20/12.20am UTC/19.20/7.20pm ET). In less than a minute, it was out of control and crashed into a lake inside Nanhai Park, two kilometres from the airport. Eye witnesses reported seeing smoke near the plane shortly after take off, followed by shaking of the plane and then its eventual crash. The CVR recording contains the captain calling "What's wrong?"

and passengers crying at the time of the crash. The aircraft departed 15 minutes ahead of schedule.

Aircraft

Model: Bombardier CRJ-200LR

Registration: B-3072

Serial Number: 7697

Engine: General Electric CF34-3B1

Year of Delivery: 2002

Weather

Weather at the time of crash was fine, although the temperature was below zero degrees Celsius. There was a rumor stating that the fuel was "frozen", causing the disaster. This was immediately proved to be impossible.

Accident report

On May 26, 2005, at the Flight Safety Conference of China Eastern Region, Yang Yuanyuan, president of CAAC declared the disaster was caused by human error: The crew did not perform the de-icing procedure and the preflight inspection, the snow and ice on the control surface and fuselage seriously degraded the lift, which caused the immediate crash after becoming airborne.

According to the airport security log, the crew arrived at the airport late at 08:00CST, just 20 minutes before the scheduled departure time, which was insufficient for a complete preflight inspection. Normally the crew should arrive at least 90 minutes before departure. The report has yet to be formally released to the public [28].

The above accident can give us an idea what this thesis is related with. This thesis shows that human factors in aircraft maintenance are a very critical element to consider in reducing maintenance errors. What is shown here is that the old school approach of “fire the technician who did the error” is not the right way to resolve the problem? The more effective way is to evaluate the reasons, namely the “why”s of that human factor in the error and reduce or eliminate the reasons underlying such that this error or similar errors will not occur whoever the person conducting the maintenance action is. To do this, a systematic approach works the best, also to reduce the variation in analyzing the problem from case to case. For this reason, it is shown that six sigma methodoly is not only effective for manufacturing environment problems but also very useful for human factor analysis in aircraft maintenance.

2 HUMAN FACTORS IN AIRCRAFT MAINTENANCE

2.1 Human Factors

The term “human factors” is used in many different ways in the aviation industry. The term is, perhaps, best known in the context of aircraft cockpit design and Crew Resource Management (CRM). However, those activities constitute only a small percentage of aviation-related human factors, as broadly speaking it concerns any consideration of human involvement in aviation [18].

The use of the term “human factors” in the context of aviation maintenance is relatively new. Aircraft accidents such as that to the Aloha aircraft in the USA in 1988 and the BAC 1-11 windscreen accident in the UK in June 1990 brought the need to address human factors issues in this environment into sharp focus. This does not imply that human factors issues were not present before these dates nor that human error did not contribute to other incidents; merely that it took an accident to draw attention to human factors problems and potential solutions.

"Human factors" refers to the study of human capabilities and limitations in the workplace. Human factors researchers study system performance. That is, they study the interaction of maintenance personnel, the equipment they use, the written and verbal procedures and rules they follow, and the environmental conditions of any system. The aim of human factors is to optimise the relationship between maintenance personnel and systems with a view to improving safety, efficiency and “well-being”.

Before discussing how these accidents were related to human factors, a definition of human factors is required. There are many definitions available. Some authors refer to the subject as ‘human factors’ and some as ‘ergonomics’. Some see “human factors” as a scientific discipline and others regard it as a more general part of the human contribution to system safety.

The description of “Human Factors” has been documented in many ways by different agencies within a same manner. The followings are the different definitions of this subject:

By Elwyn Edwards [19]: Human Factors is concerned to optimize the relationship between people and their activities, by the systematic application of human sciences, integrated within the framework of systems engineering.

By UK CAA [20]: Human Factors as a term has to be clearly defined because when these words are used in the vernacular they are often applied to any factor related to human. The human element is the most flexible, adaptable and valuable part of the aviation system, but it is also the most vulnerable to influences which can adversely affect its performance. Throughout the years, some three out of four accidents have resulted from less than optimum human performance. This has commonly been classified as human error. The term “human error” can be misleading when referring to human factors in accident prevention, because although it may indicate WHERE in the system a breakdown occurs, it provides no guidance as to WHY it occurs. An error attributed to humans in the system may have been design-induced or stimulated by inadequate training, badly designed procedures or the poor concept or layout of manuals. Further, the term “human error” allows concealment of the underlying factors which must be brought to the fore if accidents are to be prevented. In fact, contemporary safetythinking argues that human error should be the starting point rather than the stop-rule in accident investigation and prevention. An understanding of the predictable human capabilities and limitations and the application of this understanding are the primary concerns of Human Factors. Human Factors has been progressively developed, refined and institutionalised for many decades, and is now backed by a vast store of knowledge which can be used by those concerned with enhancing the safety of the complex system which is today’s civil aviation.

By FAA [21]: Within the FAA, human factors entails a multidisciplinary effort to generate and compile information about human capabilities and limitations and apply that information to equipment, systems, facilities, procedures, jobs, environments, training, staffing, and personnel management for safe, comfortable, and effective human performance.

By FAA [22]: Human Factors refers to the study of human capabilities and limitations in the workplace. Human Factors include, but are not limited to, such attributes as human physiology, psychology, work place design, environmental conditions, humanmachine interface, and more. Human Factors researchers study system performance. That is, they study the interaction of humans, the equipment they use, the written and verbal procedures and rules they follow, and the environmental conditions of any system.

By dictionary [23]: "Human factors" is an umbrella term for several areas of research that include human performance, technology, design, and human-computer interaction. It is a profession that focuses on how people interact with products, tools, procedures, and any processes likely to be encountered in the modern world.

By Jensen, R. [13]: “Human Factors” and ergonoics and engineering psychology are roughly equivalent terms used for the field of science concerned with the optimization of the relationship between people and the machines they operate through the systematic application of human sciences integrated within the framework of systems engineering. Human Factors has been more widely used in the USA, ergonomics has been more widely used outside of the USA, and engineering psychology has been more widely used in academia.

By Sanders, M.S. and McCormick, J. [1]: Human Factors focuses on human beings and their interaction with products, equipment, facilities, procedures, and environments used in work and every-day living. The emphasis is on human beings (as opposed to engineering, where the emphasis is more on strictly technical engineering considerations) and how the design of things influences people. Human Factors, then, seeks to change the things people use and the environments in which they use these things to better match the capabilities, limitations, and needs of people.

ICAO Definitions Relating to Human Factors

Human Factors Principles: Principles which apply to aeronautical design, certification, training, operations and maintenance and which seek safe interface between the human and other system components by proper consideration to human performance [24].

Human performance: Human capabilities and limitations which have an impact on the safety and efficiency of aeronautical operations [24].

Human Factors is about people: it is about people in their working and living environments and it is about their relationship with equipment, procedures and the environment. Just as importantly, it is about their relationships with other people. Human Factors involves the overall performance of human beings within the aviation system; it seeks to optimize people's performance through the systematic application of the human sciences, often integrated within the framework of system engineering. Its two objectives can be seen as safety and efficiency [25].

Human factors are essentially a multi-disciplinary field, including but not limited to: psychology, engineering, physiology, sociology and anthropometry [25].

Human Factors has come to be concerned with diverse elements of the aviation system. These include human behavior and performance; decision-making and other cognitive processes; the design of controls and displays; flight deck and cabin layout; communication and software aspects of computers; maps, charts and documentation; and the refinement of training. Each of these aspects demands skilled and effective human performance [25].

Aviation Human factors are primarily oriented towards solving practical problems in the real world. As a concept, its relationship to the human sciences might well be likened to that of engineering to the physical sciences. And, just as technology links the physical sciences to various engineering applications, there are a growing number of integrated Human Factors techniques or methods; these varied and developing techniques can be applied to problems as diverse as accident investigation and the optimization of pilot training [25].

Briefly human factors means; In information operations, the psychological, cultural, behavioral, and other human attributes that influence decision making, the flow of information, and the interpretation of information by individuals or groups at any level in a state or organization.

2.2 Errors, Violations and Non-compliance with Procedures

As we may recall, maintenance and inspection errors are implicated in 12% of major air accidents. However, maintenance error costs not just lives, but money too. This is a short list of some of the major cost factors associates with maintenance error.

1- The average cost of an inflight engine shutdown is $500,000.

2- The average cost of a flight cancellation is $50,000.

3- The average cost of a return to gate is $15,000.

4- The Airline Transportation estimates that ground damage costs $850 million/year

5- The average ground damage incident costs $70,000.

6- One airline estimated between $75-$100 million/year is wasted on error.

A Hangar example:

The following example illustrates how a simple mistake made by an AMT affects an entire organization. A 747 was brought into the hangar for heavy maintenance. It was backed too far and collided with the aft work stands, causing the stands to fall through the rear wall of the hangar. Fortunately, no one was hurt. Take a second and consider how much this accident ended up costing the airline (See Figure 2.1).

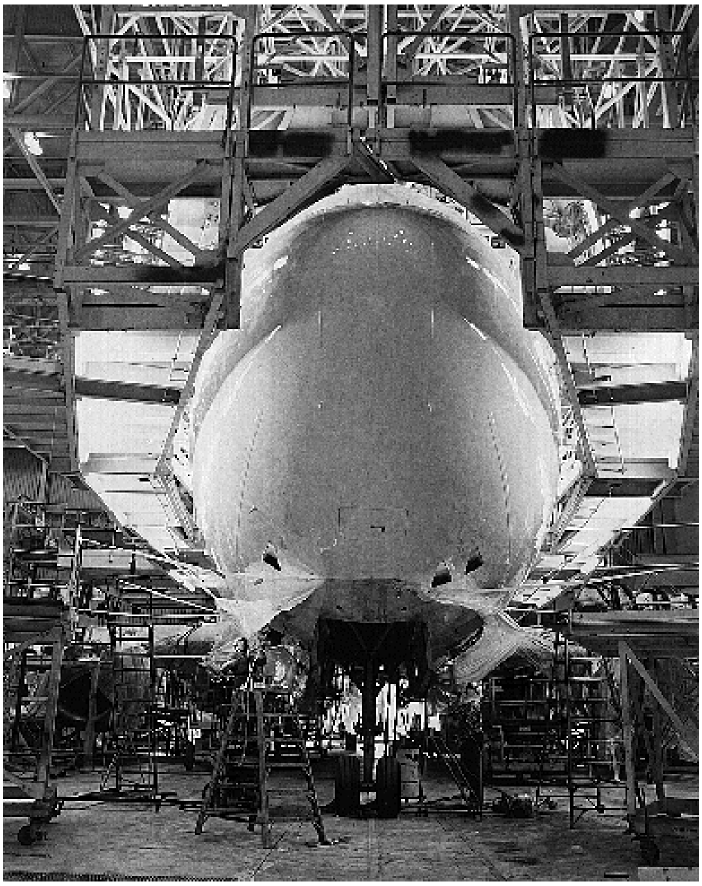


Figure 2.1 : The picture of the aircraft

As a result, all of the following equipment was damaged;

1- Left-hand horizontal stabilizer

2- Rudder

3- Rear dock stands

4- Hangar wall

Here is a list of the cost factors associated with this one example;

1- material

2- regular and overtime labor

3- repair to dock stands and hangar wall

4- loss of bay during extra repair duration

5- delayed or third party maintenance for other aircraft

6- operational complications due to aircraft unavailability

7- investigation and remediation

Estimated total cost = $900,000!

When we begin to consider the cost implications of this one maintenance error in terms of the entire organization, we will see that this one slip consumed ½ day's total profit for the whole airline! Put another way, 60.000 airline personnel using 700 aircraft and associated equipment can work for 8-12 hours merely to repay two serious maintenance errors. Obviously, the impact would be worse on a smaller airline.

1- Annual airline revenue = $ 12,000,000,000

2- Revenue/day = $33,000,000

3- Estimated profit margin = 5%

4- Profit per day = $1,650,000

5- Total repair/associated costs = $900,000

6- Summary : Error consumed ½ day of total profit

Boeing analyzed the most common errors behind 746 inflight shutdowns. In all, almost 70% of inflight shutdowns were traced back to installation problems.

1- Incomplete installation (48%)

2- Damage on installation (14.5%)

3- Improper installation (11%)

4- Equipment not installed or missing (11%)

5- Foreign object damage (6.5%)

6- Improper troubleshooting, inspection and test (5%)

7- Equipment not activated or deactivated (4%)

Researchers studied the most frequently occurring maintenance problems. The top 8 are listed in order of occurrence [16].

1- Incorrect installation of components

2- The fitting of wrong parts

3- Electrical wiring discrepancies (including cross-connection)

4- Loose objects (tools, etc.) left in aircraft

5- Inadequate lubrication

6- Cowlings, access panels, and fairings not secured

7- Landing gear and refuel not secured

An other study performed by Pratt& Whitney (US Engine Manufacturer) of 120 inflight shut downs revealed similar results. Problems with installation were, by far, the most frequent made (120 IFSDs on 747s in 1991. Causes ranked by frequency – Pratt & Whitney) [16];

1- Missing parts

2- Incorrect parts

3- Worn out parts

4- Careless installation of O-rings

5- B-nuts not safely wired

6- B-nuts wired backwards

7- Nuts not torqued

8- Over torquing

9- Not loosening both ends of connection

10- Replacing tube assembly without breaking connections

A working definition of “human error” (including violations) is “those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failures cannot be attributed to the intervention of some chance agency” [2].

We could have an idea about the portion of the Human Error in aircraft maintenance [3].

Human error rather than technical failures has the greatest potential to adversely affect contemporary aviation safety. The Boeing recently analyzed 220 documented accidents and found the top three causal factors to be:

- Flight crews not adhering to procedures (70/220)
- Maintenance and inspection errors (34/220)
- Design defects (33/220)

The following quotation illustrates this point:

“Because civil aircraft are designed to fly safely for unlimited time provided defects are detected and repaired, safety becomes a matter of detection and repair rather than one of aircraft structure failure. In an ideal system, all defects which could affect flight safety will have been predicted in advance, located positively before they become dangerous, and eliminated by effective repair. In one sense, then, we have changed the safety system from one of physical defects in aircraft into one of errors in complex human-centered systems.” [13].

2.3 Aviation Safety Culture

The safety culture is very important in aviation. This subject is a phrase like “Safety comes first”.

“For the need of a nail the shoe was lost.

For the need of a shoe the horse was lost.

For the need of a horse the messenger was lost,

For the need of a messenger the battle was lost.

For the need of a battle the country was lost.

And all for the need for care about a horseshoe nail.” as Benjamin Franklin said.

The air safety has been defined in the dictionary [23] as: Air safety is a broad term encompassing the theory, investigation and categorization of flight failures, and the prevention of such failures through appropriate regulation, as well as through education and training. It can also be applied in the context of campaigns that inform the public as to the safety of air travel. No matter the speed and economy of any mode of transportation, if it is not perceived and demonstrated as safe, it will find few customers and, with few customers, unless it can still be priced to make a profit, the transportation mode will fail and fade from the scene. The dirigibles of the 1920s and '30s provide a good example of this principle.

An organization with a good safety culture is one which has managed to successfully institutionalize safety as a fundamental value of the organization, with personnel at every level in the organization sharing a commitment to safety [20].

One of the key elements is effective support from the top levels of the organization, for safety. It is necessary for senior management to demonstrate their commitment to safety in practical terms, not just verbally or only as long as safety is a no-cost item.

It is all very well for an organization to commit to putting in place, say, a safety reporting and investigation scheme but if such a scheme is not resourced properly or if safety recommendations are not acted upon, it will be ineffective. It is also important that such commitment to safety is long-term, and that safety initiatives are not the first items to be cut in terms of financial support when the organization is looking for cost savings. Safety management within an organization should be addressed with as much commitment as financial management tends to be. CAP 712 [29] describes the elements of a Safety Management System which should, if implemented properly and supported, lead to a good safety culture.

Table 2.1 : Key Elements Contributing Towards a Good Safety Culture [16]

• Support from the top management • A formal safety policy statement • Awareness of the safety policy statements and organization • Practical support to enable the workforce to do planning, resources, workable procedures, etc. • A just culture and open reporting • A learning culture and willingness to change when • Corporate and personal integrity in supporting potentially conflicting commercial demands

The Benefits of a Safety Management System are to improve on existing levels of aviation safety in the light of the continuing growth of the industry, additional measures are needed. One such measure is to encourage individual operators to introduce their own Safety Management System. Such a system is as important to business survival as a financial management system and the implementation of a Safety Management System should lead to achievement of one of civil aviation's key business goals: enhanced safety performance aiming at best practice and moving beyond mere compliance with regulatory requirements.

A good safety culture needs to be nurtured, and is not something which can be put in place overnight, or with a training course alone. It can be improved in the short term by putting staff through a training course dealing with the elements of safety culture. However, the improvement will only be sustained if the types of behaviours conducive to safety are rewarded and poor safety behaviour is not condoned, or even punished (in the extreme cases). This relies on staff at all levels within the organisation, especially middle management and supervisory levels,

(i) Recognizing what good and bad safety behavior is,

(ii) Good safety behavior being encouraged and poor safety behavior being discouraged. Sometimes the opposite is true in that staff are rewarded for cutting corners in order to meet commercial deadlines and, in a few cases, punished for complying with procedures (e.g. refusing to sign off work which they have not had the opportunity to check) [26].

(iii) A good safety culture is based on what actually goes on within an organisation on a day-to-day basis, and not on rhetoric or superficial, short term safety initiatives.

It is possible to measure the safety culture of the organisation by using a safety culture survey. Care should be taken with the timing of such a survey, in that it may be positively or negatively affected by specific recent events such as industrial action, training courses, etc. It is important to be sure that measuring behaviour, attitudes and fundamental beliefs, rather than morale [16].

2.4 Maintenance Organization Safety Policy

A certified (in accordance with the JAA regulations) maintenance company should establish a safety policy. This should be part of the Maintenance Organisation Exposition (MOE), and signed by the Accountable Manager. The safety policy should define the senior management's intentions in terms of commitment to ensuring that aircraft are returned to service after maintenance in a safe condition [27].

An example of safety policy can be as following;

The Quality and Safety Policy of ABC TECHNIC is always to keep quantity of customers` aircraft and aircraft components which are ready to release to service in maximum level by complying with the DGCA requirements and by taking into account safety and quality standards as :

- Recognize safety as a prime consideration at all times
- Apply Human factors principles
- Encourage personnel to report maintenance related errors/incidents
- Recognize that compliance with procedures, quality standards, safety standards and regulations is the duty of all personnel
- Recognize the need for all personnel to cooperate with the Quality Auditors

2.5 What is the meaning of Aircraft Maintenance and recordings?

In the nature of things, nothing man-made is indestructible, but performing repairs at intervals by an activity known as maintenance can extend useful life. Maintenance can be defined as those activities required to keep a facility in "as-built" condition and therefore continuing to have its original productive capacity [8].

Maintenance is usually categorized into the following three types [8]:

(1) preventive maintenance – all actions carried out on a planned, periodic, and specific schedule to keep an item/equipment in stated working condition through the process of checking and reconditioning;

(2) corrective maintenance – unscheduled maintenance or repair to return items/equipment to a defined state, carried out because maintenance persons or users perceived deficiencies or failures; and

(3) predictive maintenance – the use of modern measurement and signal-processing methods to accurately diagnose items/equipment condition during operation.

Aircraft maintenance checks [23] are periodic checks that have to be done on all aircraft after a certain amount of time or usage. Airlines casually refer to these checks as one of the following: A check, B check, C check, or D check. A and B checks are lighter checks, while C and D are considered heavier checks.

A Check - This is performed approximately every month. This check is usually done overnight at an airport gate. The actual occurrence of this check varies by aircraft type, the cycle count (takeoff and landing is considered an aircraft "cycle"), or the number of hours flown since the last check. The occurrence can be delayed by the airline if certain predetermined conditions are met.

B Check - This is performed approximately every 3 months. This check is also usually done overnight at an airport gate. A similar occurrence schedule applies to the B check as to the A check.

C Check - This is performed approximately every 12-18 months. This maintenance check puts the aircraft out of service and requires plenty of space - usually at a hangar at a maintenance base. The schedule of occurrence has many factors and components as has been described, and thus varies by aircraft category and type.

D Check - This is the heaviest check for the airplane. This check occurs approximately every 4-5 years. This is the check that, more or less, takes the entire airplane apart for inspection. This requires even more space and time than all other checks, and must be performed at a maintenance base.

Company produced task cards are based on procedures taken from related manufacturer manuals or written instructions such as telexes, faxes from manufacturer and the DGCA/EASA/FAA instructions. They are issued for periodic and scheduled maintenance. All task cards including repair details are certified by appropriately qualified personnel and covered in the work package which is cross referred to the certificate of release to service to be issued after scheduled maintenance.

Aircraft Log Book

The Aircraft Log System is a system for recording defects and malfunctions discovered during customer aircraft operation, details of all maintenance carried out on the particular aircraft while it is operating between scheduled visits to the Main Maintenance Base. It also contains information for each flight as Journey Log. It is used for recording operating information relevant to flight, flight safety and contains maintenance data that the operating crew needs to know.

Description of Log System

According to JAR OPS 1 Subpart M customer aircraft technical log may consist of two main reports as Aircraft Flight and Maintenance Report (AFMR) and Cabin Defect Report (CDR). It may also cover deferred items list as Hold Item List (HIL), Non-performance Acceptable Deferred Defects (ADD), and Cabin Acceptable

Deferred Defects. The customer may use equivalent forms, but the content of the forms must comply with JAR OPS 1 Subpart M. AFMR or equivalent customer form contain following information for each flight according to JAR OPS 1 Subpart M:

- Aircraft type and registration
- Date
- Crew members name including duty assignment
- Place of departure in three letters code
- Place of arrival in three letters code
- Time of departure (off-block time)
- Time of arrival (off-block time)
- Hours of flight
- Number of landings
- Delay time and reasons in codes -if any
- Passenger data
- Incident and observation -if any.
- Reference loading for load sheet
- Information for the quantity of fuel available at the beginning and at the end of the flight, and quantities of fuel and oil added before departure,
- Provision for Certifying Staff and Pilot in Command to sign for Transit and Daily Check performance and acceptance respectively,
- Provision for a Certificate of Release to Service following a scheduled maintenance check.
- Details of any defect to the Aircraft Airworthiness and Flight Safety including emergency systems by flight crew or maintenance crew

- Details of work performed including component changes.
- Provision for a Certificate of Release to Service following rectification of a defect
- Cross reference to HIL

Minimum Equipment List (MEL) Application

The MEL is intended to permit operation with inoperative items of equipment for a period of time until repairs can be accomplished. The aircraft operator (airline) must establish and provide to the maintenance company a Minimum Equipment List for each type of Aircraft within its fleet, approved by the National Authority, based on, but not less restrictive than the relevant MMEL (Master Minimum Equipment List). The maintenance company does not operate an Aircraft other than in accordance with the approved MEL unless permitted by the National Authority. Any such permission does not permit operation outside the constraints of the MMEL.

When an item is discovered to be inoperative, it is reported by making an entry in the customer technical log according to the related customer procedure. It is then repaired or may be deferred per the MEL.

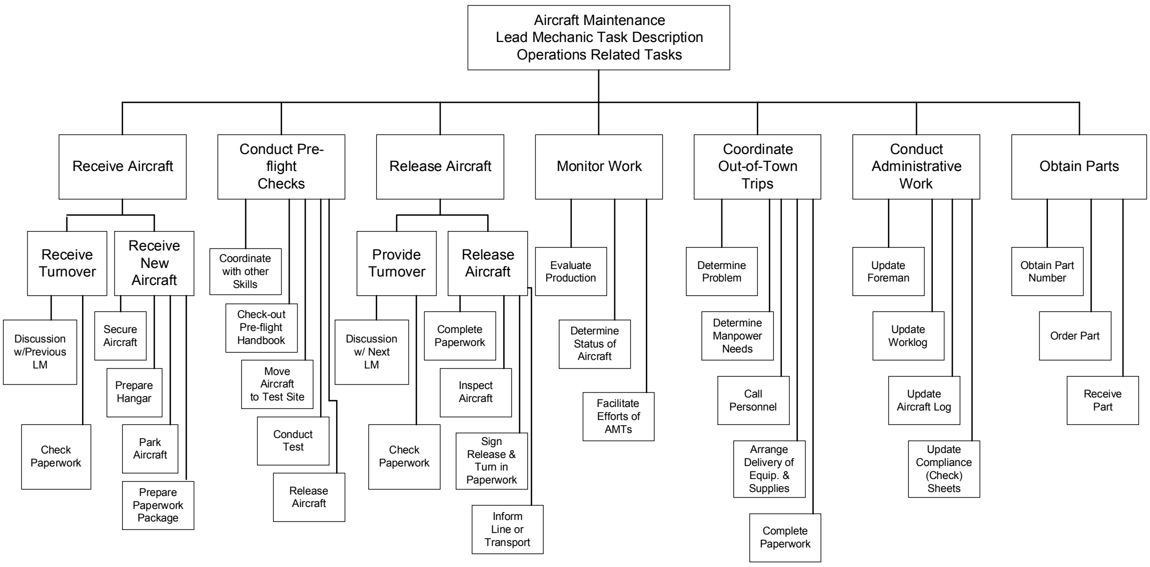


Figure 2.2 : Basic task description schemes

Figure 2.2 shows an example of the basic task description scheme in a Maintenance Repair Organization.

2.6 Human Factors in Aviation History

2.6.1 History of human factors

In the late 1970s, Cockpit Resource Management (CRM) featured prominently in pilot training. The term was used to apply to the process of training flight crews to reduce pilot error by making better use of the resources on the flight deck. A change in name was made from Cockpit to Crew Resource Management (CRM) to change the emphasis of training to focus on cockpit group dynamics. Some airline programs dealt with specific topics such as team building, briefing strategies, situational awareness and stress management [4]. In the early 1990s, CRM training began to reflect the many factors, such as organizational culture, within the aviation system in which the crew must function which can determine safety. Similarly, but much later, it was not until in the 90s that Maintenance Resource Management (MRM) was made available to maintenance personnel. After years of accidents, many caused by HF errors, nothing significant was really done to determine the HF root causes. Unlike CRM, MRM was very new to the aviation maintainers and it was not until June 10, 1990 when a cockpit window blew out at 16,000 feet, and a pilot almost went with it, that an in depth look at the contributing factors to a maintenance error were examined. David King, from the United Kingdom is one of the first to look at HF in the same light it is looked at today [5].

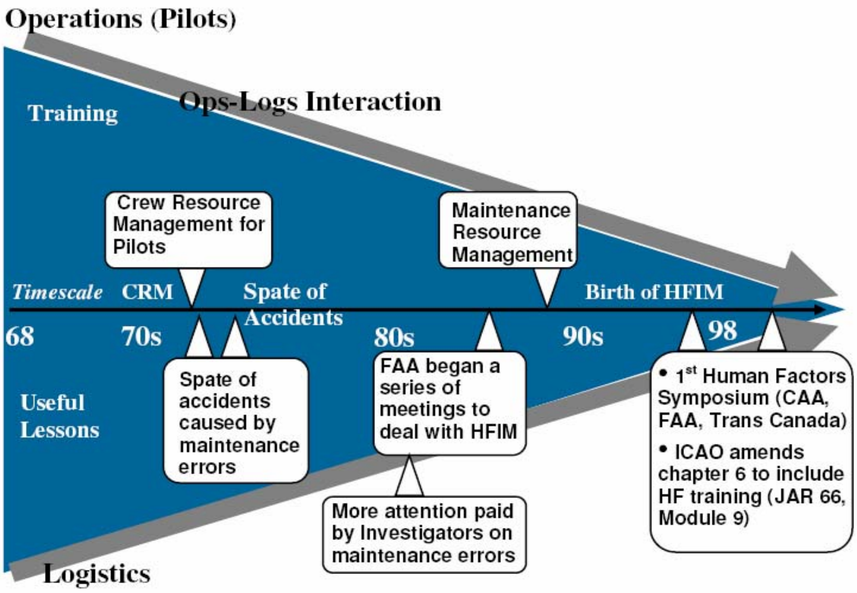


Figure 2.3 : Human Factors History [8].

The need for a change in approach to human errors and their reporting was reinforced during the CAA sponsored 12th Symposium on Human Factors in Aviation Maintenance that was held in Gatwick Airport, England, on 10-12 March 1998. It was the first of the international symposiums involving the CAA, FAA and Transport Canada. The foundation of Human Factors training as a modern aviation tool was probably initiated in the United States at a workshop sponsored by the National Aeronautics and Space Administration (NASA) in 1979. This workshop was the development of NASA research into the causes of air transport accidents. The International Civil Aviation Organization, (ICAO) now requires organizations to include HFIM training. HF training which helps our fellow maintenance personnel to avoid an error he/she never intends to make had finally arrived (See Figure 2.3 and Figure 2.4) [8].

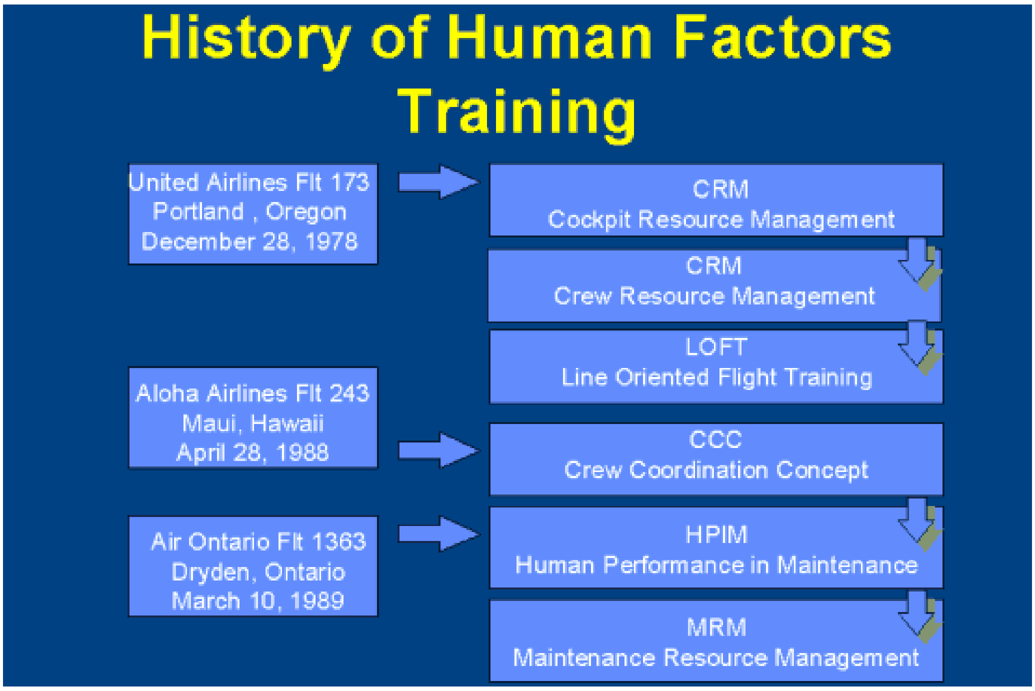


Figure 2.4 : History of human factors training

2.6.2 Literature review

A comprehensive review of the published literature during the period 1981-2003 is presented on Figure 2.5.

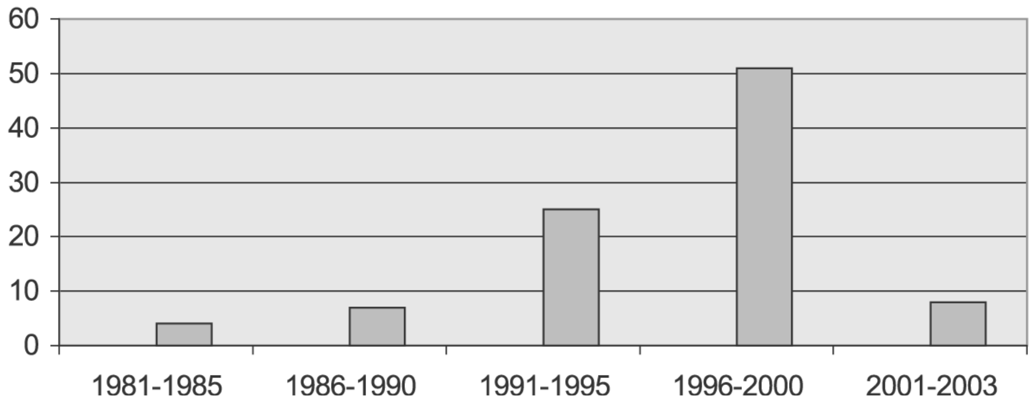


Figure 2.5 : Presents a histogram of publications on human error in maintenance for the period 1981-2003 [8].

An aviation maintenance and inspection task is a complex undertaking in which individuals perform varied tasks in an environment with time pressures, minimal feedback, and sometimes difficult ambient conditions. These situational characteristics, in combination with generic human erring tendencies, result in varied forms of errors [10].

Latorell and Prabhu (2000) reviewed current approaches to identifying, reporting, and managing human error in aviation maintenance and inspection. They focused on both reactive and proactive methods of error detection and intervention strategies for controlling human error in aviation maintenance.

Graeber and Marx's (1993) article was focused on aircraft safety, and showed that maintenance error has significant economic implications.

Maintenance resource management (MRM) was the theme of Taylor's (2000a) article. In this article, he discussed systems thinking and culture change as current subjects in aviation human factors. In another paper, Taylor (2000b) described the test of the effectiveness of the MRM/TOQ (Maintenance Resource Management/Technical Operation Questionnaire) for its intended purpose as an evaluative measure.

Allen and Rankin (1995) in their article discussed the Maintenance Error Decision Aid (MEDA) Tool and field test evaluation.

In another article, Hibit and Marx (1994) anticipated that, by improving the analysis of individual events through tools such as MEDA, people can begin to better understand those factors underlying human error in maintenance so that future system performance can be methodically improved in better safety, greater maintenance system reliability, and economic efficiencies gained through error reduction.

Nelson et al. (1998) presented structured methods of human error analysis developed and applied at Idaho National Engineering and Environmental Laboratory (INEEL) to identify potential human errors, assess their effect on system performance, and develop strategies to prevent the occurrences of errors or mitigate their consequences. Maintenance is considered an essential component of the air transportation system and an accident factor contributing to the loss of human lives.

Masson and Koning (2001) in their publication tried to capture the philosophy and method behind JAR66 (Joint Aviation Requirements) and presented an overview of the error management concepts.

Kania (1997) conducted research into the causal factors that result in human error and additional maintenance paperwork.

Ford (1997) discussed three different aspects of aerospace safety – accidents, regulation and human factors – in airline maintenance, and what is required to lessen the safety inadequacies in each of these two aspects.

Manwaring et al.'s (1998) study showed that by adhering to existing regulations and manufacturer recommendations, and by implementing improved training and frequent maintenance, helicopter external load operations become safer.

Shepherd (1997) presented a discussion of factors such as evaluation of simplified English, technician teaming and advanced technology, which influence the performance of inspectors and maintainers.

Rankin et al. (2000) evaluated the development and implementation of an airline industry process (MEDA) for determining the factors that contribute to maintenance errors and making corrective actions to eliminate the occurrence of similar errors in future.

Fotos (1991) in his paper presented a cockpit resource management (CRM) technique that is widely used by major US airlines to encourage teamwork and effective problem solving by maintenance personnel or pilots.

Manwaring et al. (1998) presented a descriptive analysis of National Transportation Safety Board (NTSB) "accident briefs" indicating that mechanical failure, pilot error, and maintenance errors are the most common probable causes of accidents.

Koli et al. (1998) discussed two human factor audits – inspection audit and maintenance audit – which can provide aircraft maintenance and inspection personnel with rapid means of locating the human-system mismatches that can lead to errors.

McGrath (1999) discussed aviation maintenance management imperatives in the hope of enhancing the professionalism of the field personnel's culture with regard to airworthiness and safety.

Ivaturi et al. (1995) reviewed task analysis of aircraft inspection/maintenance operations, which is the first effort to examine team training and effort within the aircraft inspection/maintenance environment.

In Ciavarelli's (1997) article, the purpose of his study was to develop, validate, and apply a questionnaire survey methodology for assessing the effectiveness of naval units in managing risks associated with flight operations.

Allen and Marx (1999) discussed the leading causes of major aircraft accidents and maintenance error analysis with the MEDA tool.

Bacchi et al. (1997) reviewed major systems used in the aviation maintenance field for accident analysis and safety assessment.

Walter (2000) discussed major elements of a model that includes needs identification, outlining targeted jobs, writing and verifying training procedures, and evaluating and establishing a maintenance/audit plan.

Hobbs and Williamson (1995) conducted research in cooperation with an air carrier in the Asia-Pacific region with the aim of identifying the types of errors made by aircraft maintenance technicians.

Endsley and Robertson (2000) presented recommendations for developing a training program to improve situation awareness in aircraft maintenance at the individual and team levels.

Wenner and Drury (2000) developed a methodology that allows analysis of reports of human error.

Reason (1997) argued that maintenance-related errors rather than fallibility on the flight deck constitute the largest single human factors problem facing modern aircraft systems. In another paper (Reason, 1997), he discussed safety culture and its important four elements:

(1) reporting culture;

(2) just culture;

(3) flexible culture; and

(4) learning culture.

O'Connor and Bacchi (1997) described an error taxonomy with respect to providing a structured framework for identifying and classifying human error in maintenance and dispatch operations.

Reason (2000) discussed a cognitive engineering perspective on maintenance errors and an activity-oriented approach to identify the human performance problem in aviation.

Wanders (1985), in his case study, described the difficulties experienced in connection with the production control system, its adaptation, and the related organizational changes at a major overhaul facility.

Hobbs (1995) identified the types of errors made by aircraft maintenance technicians and the systemic or organisational failures that set the conditions for such errors.

Shepherd and Johnson's (1995) paper discussed some examples of research efforts that are currently promoting safety and efficiency in maintenance worldwide.

Shepherd and Kraus (1997) presented recent efforts that have been made to develop pre-training job aids and training programs that address human factors issues.

Shepherd (1991) described activities concerning aircraft maintenance and inspection human factors.

Amalberti and Wioland (1997) discussed the complex relationship between errors and accidents and the systemic and organisational safety approach followed for large socio-technical systems.

Havard (1995) presented British Airways' current initiatives with respect to human factors.

Nunn and Witts (1997) discussed how human factors impact aircraft maintenance in Air UK Engineering.

Hobbs and Robertson (1995) discussed an aircraft maintenance workshop report and its objectives.

O'Leary and Chappell (1996) discussed the aviation safety reporting system (ASRS) and its role in incident reporting.

Marksteiner (1999) concluded that some current maintenance practices and philosophies might be causing more problems than they are preventing.

Braithwaite (1997) examined cultural issues and the reasons behind Australia's apparently good record for airline safety.

Strauch and Sandler's (1984) article discussed the role of the aviation maintenance technician (AMT) in the safe operation of an aviation system.

Drury (1991) presented a taxonomy and ways and means of controlling maintenance errors.

2.7 The Industry Need for Human Factors

2.7.1 Overview

Admiral Donald Engen, the former Administrator of the United States Federal Aviation Administration has been quoted as saying (1986): "We spent over fifty years on the hardware, which is now pretty reliable. Now it's time to work with people". This declaration somehow sets the foundation upon which the industry need for Human Factors can be assessed. Curiously enough, we retain a lawyer for advice about a legal problem, or hire an architect to build a house, or consult a physician when trying to establish the diagnosis of a medical problem, but when it comes to solving Human Factors problems, we have adopted an intuitive and in many cases perfunctory approach, even though many lives may depend on the outcome. A background of many years of industry experience or thousands of flying hours may have little or no significance when looking for the resolution of problems which only a thorough understanding of Human Factors can provide.

This is of special significance because, as already mentioned, it has long been known that some three out of four accidents result from performance errors made by healthy and properly certificated individuals. The sources of some of these errors may be traced to poor equipment or procedure design or to inadequate training or operating instructions. But whatever the origin, the question of human performance capabilities and limitations and human behavior is central to the technology of Human Factors. The cost, both in human and financial terms, of less than optimum human performance has become so great that a makeshift or intuitive approach to Human Factors is no longer appropriate. Safety being the ultimate objective of all those involved in aviation, its logical follow up is to ensure a proper level of Human Factors knowledge throughout the industry.

2.7.2 Incidents/ Accidents Where Maintenance Error was a Factor

The best way to illustrate the effect on safety of a lack of proper application of Human Factors is through the example of accidents. A few accidents in which aspects of Human Factors are relevant are described here as examples.

There have been several high profile accidents and incidents which have involved maintenance human factors problems. The “www.hfskyway.faa.gov” website lists 24 NTSB accident reports of accidents where maintenance human factors problems have been the cause or a major contributory factor. In the UK, there have been three major incidents, details of which can be found on the AAIB (Air Accidents Investigation Branch) web site (www.aaib.gov.uk). Several of the major incidents and accidents where maintenance Human Factors has been a significant factor are summarized below [20]:

2.7.2.1 NTSB/AAR-84/04. Eastern Airlines, L-1011, N334EA, Miami, May 1983

During maintenance, technicians failed to fit O-ring seals on the master chip detector assemblies. This led to loss of oil and engine failure. The aircraft landed safely with one engine. Technicians had been used to receiving the master chip detectors with O-ring seals already fitted and informal procedures were in use regarding fitment of the chip detectors. This problem has occurred before, but no appropriate action had been carried out to prevent a re-occurrence.

2.7.2.2 NTSB/AAR-89/03. Aloha Airlines, B737-200, N73711, Hawaii, April 1988

The Aloha accident involved 18 feet of the upper cabin structure suddenly being ripped away, in flight, due to structural failure (See Figure 2.6). The Boeing737 involved in this accident had been examined, as required by US regulations, by two of the engineering inspectors. One inspector had 22 years experience and the other, the chief inspector, had 33 years experience. Neither found any cracks in their inspection. Post-accident analysis determined there were over 240 cracks in the skin of this aircraft at the time of the inspection. The ensuing investigation identified many human-factors-related problems leading to the failed inspections.

Figure 2.6 : Aloha Accident Picture; just after the landing.

Joseph T. Nall, Member (June 14, 1989), filed the following concurring/dissenting statement:

“While I concur with most of the majority's findings, I disagree with the probable cause and certain conclusions.

Industry's best engineers reviewed the carrier's records, knew of its high-cycle operations, and even inspected some of Aloha's 737 fleet.

No one--not Boeing, Aloha nor the FAA principal maintenance inspectors--recognized or predicted the critical nature of the multi-site cracking or that the aircraft hull was about to rupture. If a "failure" occurred, it was a system failure. Could those who designed, inspected or maintained the aircraft, given their knowledge at the time of the accident, have reasonably foreseen this accident was about to happen? I think not. I would have preferred to cite simply "the presence of undetected disbonding and fatigue cracking" as the probable cause. I agree with the majority that contributing to the failure to detect the hull defects were systems, programs or decisions of all the participants.

But I emphasize these are simply contributing factors, not the probable cause of the accident.

The majority's probable cause is too narrow and I therefore cannot agree that Aloha's maintenance program was the probable cause of the accident. I would have supported the following probable cause:

The National Transportation Safety Board determines that the probable cause of this accident was the presence of undetected disbonding and fatigue cracking which led to the failure of the fuselage lap joint at S-10L.

Contributing to the accident were: the failure of Aloha Airlines management to supervise its maintenance force properly; the failure of the Federal Aviation Administration to assess the quality and effectiveness of the Aloha Airlines maintenance program; the failure of FAA Airworthiness Directive 87-21-08 to require inspection of all the lap joints as proposed by Boeing Alert Service Bulletin 737-53A1039; and the lack of a complete terminating action (neither generated by Boeing nor required by the FAA) after the discovery of difficulties in the early production B-737 cold bond lap joint.

2.7.2.2 AAIB/AAR 1/92, British Airways BAC1-11, G-BJRT, Didcot, June 1990

In 1990, in the UK, a BAC1-11 was climbing through 17,300 feet on departure from Birmingham International Airport when the left windscreen, which had been replaced prior to flight, was blown out under the effects of cabin pressure when it overcame the retention of the securing bolts, 84 of which, out of a total of 90, were smaller than the specified diameter. The commander was sucked halfway out of the windscreen aperture and was restrained by cabin crew whilst the co-pilot flew the aircraft to a safe landing at Southampton Airport.

The Shift Maintenance Manager (SMM), short-handed on a night shift, had decided to carry out the windscreen replacement himself. He consulted the Maintenance Manual (MM) and concluded that it was a straightforward job. He decided to replace the old bolts and, taking one of the bolts with him (a7D), he looked for replacements. The store man advised him that the job required 8Ds, but since there were not enough 8Ds, the SMM decided that 7Ds would do (since these had been in place previously). However, he used sight and touch to match the bolts and, erroneously, selected 8Cs instead, which were longer but thinner. He failed to notice that the countersink was lower than it should be, once the bolts were in position. He completed the job himself and signed it off, the procedures not requiring a pressure check or duplicated check.

There were several human factors issues contributing to this incident, including perceptual errors made by the SMM when identifying the replacement bolts, poor lighting in the stores area, failure to wear spectacles, circadian effects, working practices, and possible organizational and design factors. The full text of the investigation can be found in AAIB report 1/92 and in the AAIB website, and an in depth discussion of the human factors aspects of this accident can be found in the book "Beyond Aviation Human Factors" by Maurino et al.

2.7.2.3 NTSB/AAR-92/04. Britt Airways, (d/b/a Continental Express), EMB-120, N33701, Eagle Lake, September 1991

The EMB-120 suffered in-flight structural break up and crashed with no survivors. The accident occurred because the attaching screws on the top of the left side leading edge of the horizontal stabilizer had been removed during maintenance, leaving the leading edge/de-ice boot assembly secured to the horizontal stabilizer by only the bottom attachment screws.

The report of this accident is of particular interest to human factors because, although the wording of the accident report placed the blame upon the individual technician(s) who failed to refit the horizontal stabilizer de-ice boots correctly, there was a dissenting statement by John Lauber (then of the NTSB) which referred to corporate culture being partially to blame, in addition to the many contributory factors leading to the incorrect re-fitment.

2.7.2.4 AAIB/ AAR 2/95, Excalibur Airways, A320-212, G-KMAM, Gatwick, August 1993

Another incident in August 1993 involved an Airbus 320 which, during its first flight after a flap change, exhibited an undemanded roll to the right after takeoff. The aircraft returned to Gatwick and landed safely. The investigation discovered that during maintenance, in order to replace the right outboard flap, the spoilers had been placed in maintenance mode and moved using an incomplete procedure; specifically the collars and flags were not fitted. The purpose of the collars and the way in which the spoilers functioned was not fully understood by the technicians. This misunderstanding was due, in part, to familiarity of the technicians with other aircraft (mainly 757) and contributed to a lack of adequate briefing on the status of the spoilers during the shift handover. The locked spoiler was not detected during standard pilot functional checks.

The full text of the investigation can be found in AAIB report 2/95) and a synopsis can be found in the AAIB website.

2.7.2.6 NTSB/SIR-94/02. Northwest Airlines, B747, N637US, Narita, March 1994

On March 1st, 1994, a B747 landed at Narita Airport, Japan, with the front of the No.1 engine touching the ground. A fire developed but was quickly extinguished and there were no casualties. During maintenance, the No.1 pylon aft diagonal brace primary retainer had been removed but not re-installed. The NTSB special investigation report findings included:

a) “Maintenance and inspection personnel who worked on the airplane were not adequately trained and qualified to perform the required maintenance and inspection functions. Critical functions had been taught by on-the-job training and were not standardized or formalized in an initial or recurrent training program”.

b) “The ‘OK to close’ inspection of the pylon area was hampered

c) “The CITEXT used by [the airline] was inadequate”.

d) “The work environment for the heavy maintenance of the airplane was inadequate and contributed to an error-producing situation for the workers”.

2.7.2.7 AAIB/ AAR 3/96, British Midland, B737-400, G-OBMM, Daventry, February 1995

In February1995, a Boeing 737-400 suffered a loss of oil pressure on both engines. The aircraft diverted and landed safely at Luton Airport. The investigation discovered that the aircraft had been subject to borescope inspections on both engines during the preceding night and the high pressure (HP) rotor drive covers had not been refitted, resulting in the loss of almost all the oil from both engines during flight.

The line engineer was originally going to carry out the task, but, for various reasons, he swapped jobs with the base maintenance controller. The base maintenance controller did not have the appropriate paperwork with him. The base maintenance controller and a fitter carried out the task, despite many interruptions, but failed to refit the rotor drive covers. No ground idle engine runs (which would have revealed the oil leak) were carried out. The job was signed off as complete.

The full text of the investigation can be found in AAIB report 3/96 and in the AAIB website [15]. A detailed discussion of the incident can be found in Professor James Reason's book "Managing the Risks of Organizational Accidents".

2.7.2.8 AAIB Bulletin 5/97, British Airways, B747, GBDXK, Gatwick, November 1996

The 4L door handle moved to the 'open' position during the climb. The Captain elected to jettison fuel and return to Gatwick. An investigation revealed that the door torque tube had been incorrectly drilled/fitted. The Maintenance Manual required a drill jig to be used when fitting the new undrilled torque tube, but no jig was available. The LAE and Flight Technical Liaison Engineer (FTLE) elected to drill the tube in the workshop without a jig, due to time constraints and the operational requirement for the aircraft. The problem with the door arose as a result of incorrectly positioned drill holes.

2.7.2.9 AIB Bulletin 7/2000. Airbus A320; G-VCED; 20/1/2000

As the A320 rotated for take-off, both fan cowl doors detatched from the No 1 engine and struck the aircraft. It is likely that the doors had been closed following maintenance but not latched. There are no conspicuous cues to indicate an unlatched condition, and no flight deck indication. Similar incident have occurred on at least 7 other occasions.

2.7.2.10 Lufthansa A320 incident, 20 March 2001

During maintenance, two pairs of pins inside one of the elevator/aileron computers were cross connected. This changed the polarity of the Captain's side stick and the respective control channels, bypassing the control unit which might have sensed the error and would have triggered a warning. Functional checks post maintenance failed to detect the crossed connection because the technician used the first officer's side stick, not the pilot's. The pilots' pre-flight checks also failed to detect the fault. The problem became evident after take-off when the aircraft ended up in a 21° left bank and came very close to the ground, until the co-pilot switched his sidestick to priority and recovered the aircraft.

2.8 Human Factor Errors in Aircraft Maintenance Statistics [8]

It is only since Second World War that there have been profound advances in engineering and scientific technology that have highlighted the need for more attention to be paid to maintenance of engineering systems. Each year over $300 billion is spent on plant maintenance and operation by US industry, and about 80 percent of this is spent to correct the chronic failures of machines, systems, and people.

Humans play an important role during the design, installation, production, and maintenance phases of a product. Human error may be defined as the failure to perform a specified task (or the performance of a forbidden action) that could lead to disruption of scheduled operations or result in damage to property and equipment. While human error has existed since the beginning of mankind, only in the last 50 years has it been the subject of scientific inquiry. There are various reasons for the occurrence of human errors, including inadequate lighting in the work area, inadequate training or skill of the manpower involved, poor equipment design, high noise levels, an inadequate work layout, improper tools, and poorly written equipment maintenance and operating procedures. Human error may be classified into six categories:

1. operating errors;
2. assembly errors;
3. design errors;
4. inspection errors;
5 installation errors; and
6 maintenance errors [8].

Maintenance error occurs due to incorrect repair or preventive actions. Two typical examples are the incorrect calibration of equipment and application of the wrong grease at appropriate points of the equipment. The occurrence of maintenance errors increases due to the increase in maintenance frequency as the equipment becomes older [8].

A. J. Xavier performed a study on this subject as following [8];

In the United Kingdom (UK) between 1982 and 1991, there were 1,270 Mandatory Occurrence Reports (MOR) which involved maintenance errors submitted to the CAA Safety Data Department (CAA, 1992). Of these, only 230 resulted in an unexpected or undesirable occurrence that interrupts normal operating procedures that may cause an accident or incident. The CAA concluded that there was no significant risk to the public.

In the period 1992-1994, however, there were 230 MORs and in 1995 to 1996 there were 534. The number of reported errors was occurring at a greater frequency. Similarly a study by Boeing in 1993 of 122 occurrences between 1989 and 1991 revealed that 56% of human factors errors resulted in omissions with a further 30% resulting in incorrect installations.

In a field test by Boeing in 1994 to 1995 with nine maintenance organizations, the main types, causes and results of errors are summarized on Table 2.2 (Boeing, 1996).

Table 2.2 : Boeing field test with MEDA

1. **Operational Events**	**2.** **Maintenance Error Types**	**3.** **Contributing Factors**
3 Top Items :		
Flight Delay **(30%)**	**Improper Installation** **(35%)**	**Information** **(50%)**
Aircraft Damage **(23%)**	**Improper testing** **(15%)**	**Communication** **(42%)**
Air Turn Back **(15%)**	**Improper servicing** **(12%)**	**Job/Task/Environment** **(40%)**

In 1998, the Australian Transport Safety Bureau (Hobbs & Williamson, 1998) surveyed close to 1400 Licensed Aircraft Maintenance Engineers (LAMEs).

The most common outcomes for airline related maintenance occurrences were:

1. Systems operated unsafely during maintenance
2. Towing events
3. Incomplete installation

The most common outcomes of non-airline occurrences were:

1. Incorrect assembly or orientation
2. Incomplete installation
3. Persons contacting hazards

The most common causes to these unsafe acts are summarized on Table 2.3.

Table 2.3 : 1997 Survey by Australian Transportation Safety Bureau

Occurrence Causes and Contributory factors	Airline	Non-airline
Pressure	**21%**	**23%**
Fatigue	**13%**	**14%**
Coordination	**10%**	**11%**
Training	**10%**	**16%**
Supervision	**9%**	**10%**
Lack of Equipment	**8%**	**3%**
Environment	**5%**	**1%**
Poor Documentation	**5%**	**4%**
Poor procedure	**4%**	**4%**

A ground crew attitude survey in the military in Asia (classified source) revealed similar findings to that of the Australian Transport and Safety Board. The surveys were conducted bi-annually from 1999 to 2003 on approximately 2500 aviation technicians. In the survey conducted in 1999, the top three violations were:

1. Servicing without a checklist
2. Speeding
3. Omitting job steps

Approximately 20% of those surveyed disclosed that they would violate rules daily or once a week. The top three reasons for these violations were:

1. Too much work, too little time
2. Insufficient manpower
3. Time pressure to complete duties

In 2003, when the survey was conducted again, several key initiatives had been implemented to address HFIM such as:

1. Implementing a Human Factor training program initiated by Mr. Gordon Dupont, Chief Executive Officer (CEO), System Safety Services in 1999.

2. Training 100% of the licensed aircraft engineers in Human Factors Management.

3. Implementing a MEDA type Human Error Analysis Tool (HEAT).

4. Embracing a local version of the Malcom Baldridge Performance Excellence Framework for the military over six years from 1998.

5. Embracing additional performance excellence measurement tools such as the Balanced Score Card and Enhanced Value Organization principles.

The survey results comparison between 1999 and 2003 revealed the following significant improvements as shown on Table 2.4.

Table 2.4 : Asian Study survey comparison between 1999 and 2003.

Survey Coverage	**Results**	
Safety Culture (new)	√	99% agreed that the organization placed strong emphasis on safety and quality. Personnel also agreed that management (96.43%), supervisors (97.30%) and personnel (94.38%) showed strong emphasis and take safety / quality seriously.
Reasons for Violations	χ	Top 4 reasons remain unchanged. "Easy way out (taking short cuts)", which registered an increase of 11% (13% to 24%), has emerged as the 5th reason. "Lack of proper tools", the 6th reason, registered a significant increase of 14% (7% to 21%).
Types of Violations	√	Overall reduction of 4% (14% to 10%) was noted for the 6 common types of violations observed everyday and once a week.
Frequency of Violations	√	Improvement of 22% (21% to 43%) that violations observed were "very infrequent."
Calling Timeout	√	Reduction by 11% (50% to 39%) in holding back to call timeout.
Overtime Management	√	Reduction by 11% (50% to 39%) in holding back to timeout.
Open Reporting Culture	√	Improvement of 16% (66% to 82%) that open reporting is being practiced widely in the organization.
Safety / Quality Information Dissemination	√	98% (an improvement of 8%) agreed that Safety/Quality information are readily available. Management are also conducting briefings and dissemating safety/quality information more frequently, matching closely to that desired in the previous survey.

Several UK maintenance organizations have pooled their Maintenance Error Management System (MEMS) data, using a common MEDA taxonomy. The initial results were presented at a MEMS-MEDA seminar in the UK in May 2003, a selection of which is listed on Table 2.5

Table 2.5 : Several UK Maintenance Error Management System (MEMS) data

1. Improper Installation	**2. Improper Fault Isolation**	**3. Improper Servicing**
3 Top Items :-		
Incomplete Installation	**System not Re/Deactivated**	**Service not performed**
Wrong Orientation	**Not properly tested**	**System not Re/Deactivated**
System not Re/Deactivated	**Not properly inspected**	**Insufficient fluid**
3 Top Factors :-		
Individual performance factors	**Individual performance factors**	**Information**
Information	**Information**	**Communications**
Technical knowledge/Skills	**Communications**	**Individual performance factors**

The maintenance error trends in US, Australia, Asia and United Kingdom from 1982 to 2003 are alarmingly similar and they continue to plague the aviation industry and in some areas of aviation such as in the military. The trends in maintenance human factor errors have continued to increase. A closer look at the statistics indicates that these trends are due mainly to lapses in the organizational operational culture and business processes.

Time pressure seems to be the main factor due to lack of manpower and excess workload.

In recent years, HF training has focused on these lapses in rules and the detrimental consequences of such actions. There is still an uptrend of these maintenance errors and violations in the aviation maintenance field.

2.9 Human Performance and Limitations [18]

Just as certain mechanical components used in aircraft maintenance engineering have limitations, engineers themselves have certain capabilities and limitations that must be considered when looking at the maintenance engineering 'system'. For instance, rivets used to attach aluminum skin to a fuselage can withstand forces that act to pull them apart. It is clear that that these rivets will eventually fail if enough force is applied to them. While the precise range of human capabilities and limitations might not be as well-defined as the performance range of mechanical or electrical components, the same principles apply in that human performance is likely to degrade and eventually 'fail' under certain conditions (e.g. stress).

Mechanical components in aircraft can, on occasion, suffer catastrophic failures. Man, can also fail to function properly in certain situations. Physically, humans become fatigued, are affected by the cold, can break bones in workplace accidents, etc. Mentally, humans can make errors, have limited perceptual powers, can exhibit poor judgement due to lack of skills and knowledge, etc. In addition, unlike mechanical components, human performance is also affected by social and emotional factors. Therefore failure by aircraft maintenance engineers can also be to the detriment of aircraft safety.

The aircraft engineer is the central part of the aircraft maintenance system. It is therefore very useful to have an understanding of how various parts of his body and mental processes function and how performance limitations can influence his effectiveness at work.

2.9.1 Vision Performance Issues

Being able to see clearly is vital in aircraft maintenance and inspection.

- Vision requirements are task based
- Illumination requirements are task based

- Technicians must recognize their individual visual limitations and capabilities

2.9.1.2 The Basic Function of the Eye

In order to understand vision, it is useful first to know a little about the anatomy of the eye (see Figure 2.7). The basic structure of the eye is similar to a simple camera with an aperture (the **iris**), a **lens**, and a light sensitive surface (the **retina**). Light enters the eye through the **cornea**, then passes through the iris and the lens and falls on the retina. Here the light stimulates the light-sensitive cells on the retina (**rods** and **cones**) and these pass small electrical impulses by way of the **optic nerve** to the **visual cortex** in the brain. Here, the electrical impulses are interpreted and an image is perceived.

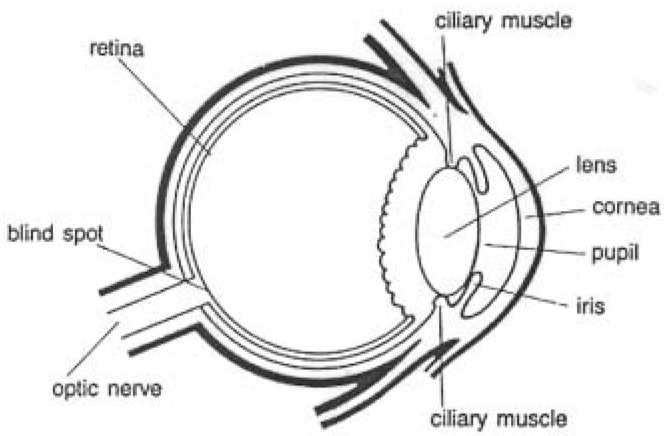


Figure 2.7 : The human eye

2.9.1.2 The Cornea

The cornea is a clear 'window' at the very front of the eye. The cornea acts as a fixed focusing device. The focusing is achieved by the shape of the cornea bending the incoming light rays. The cornea is responsible for between 70% and 80% of the total focusing ability (refraction) of the eye.

2.9.1.3 The Iris and Pupil

The iris (the colored part of the eye) controls the amount of light that is allowed to enter the eye. It does this by varying the size of the pupil (the dark area in the center of the iris). The size of the pupil can be changed very rapidly to cater for changing light levels. The amount of light can be adjusted by a factor of 5:1.

2.9.1.4 The Lens

After passing through the pupil, the light passes through the lens. Its shape is changed by the muscles (cillary muscles) surrounding it which results in the final focusing adjustment to place a sharp image onto the retina. The change of shape of the lens is called accommodation. In order to focus clearly on a near object, the lens is thickened. To focus on a distant point, the lens is flattened. The degree of accommodation can be affected by factors such as fatigue or the ageing process.

When a person is tired accommodation is reduced, resulting in less sharp vision (sharpness of vision is known as **visual acuity**).

2.9.1.5 The Retina

The retina is located on the rear wall of the eyeball. It is made up of a complex layer of nerve cells connected to the optic nerve. Two types of light sensitive cells are found in the retina - rods and cones. The central area of the retina is known as the fovea and the receptors in this area are all cones. It is here that the visual image is typically focused. Moving outwards, the cones become less dense and are progressively replaced by rods, so that in the periphery of the retina, there are only rods.

Cones function in good light and are capable of detecting fine detail and are color sensitive. This means the human eye can distinguish about 1000 different shades of color. Rods cannot detect color. They are poor at distinguishing fine detail, but good at detecting movement in the edge of the visual field (peripheral vision). They are much more sensitive at lower light levels. As light decreases, the sensing task is passed from the cones to the rods. This means in poor light levels we see only in black and white and shades of grey.

2.9.1.6 Factors Affecting Clarity of Sight

The eye is very sensitive in the right conditions (e.g. clear air, good light, etc.). In fact, the eye has approximately 1.2 million nerve cells leading from the retinas to the area of the brain responsible for vision, while there are only about 50,000 from the inner ears - making the eye about 24 times more sensitive than the ear.

Before considering factors that can influence and limit the performance of the eye, it is necessary to describe visual acuity.

Visual acuity is the ability of the eye to discriminate sharp detail at varying distances.

An individual with an acuity of 20/20 vision should be able to see at 20 feet that which the so-called ‘normal’ person is capable of seeing at this range. It may be expressed in metres as 6/6 vision. The figures 20/40 mean that the observer can read at 20 feet what a ‘normal’ person can read at 40 feet.

Various factors can affect and limit the visual acuity of the eye. These include:

• Physical factors such as:

• physical imperfections in one or both eyes (short sightedness, long sightedness),

• age.

• The influence of ingested foreign substances such as:

• drugs,

• medication,

• alcohol,

• cigarettes.

• Environmental factors such as:

• amount of light available,

• clarity of the air (e.g. dust, mist, rain, etc.).

• Factors associated with object being viewed such as:

• size and contours of the object,

• contrast of the object with its surroundings,

• relative motion of the object,

• distance of the object from the viewer,

• the angle of the object from the viewer.

Each of these factors will now be examined in some detail.

2.9.1.7 Physical Factors

Long sight - known as Hypermetropia - is caused by a shorter than normal eyeball which means that the image is formed behind the retina (Figure 2.8). If the cornea and the lens cannot use their combined focusing ability to compensate for this, blurred vision will result when looking at close objects.

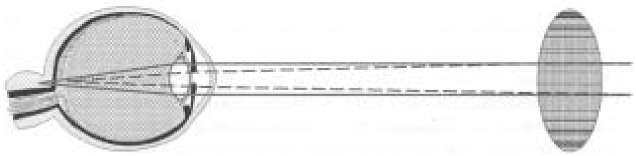


Figure 2.8 : A convex lenses will overcome long sightedness by bending light inwards before it reaches the cornea.

Short sight - known as Myopia - is where the eyeball is longer than normal, causing the image to be formed in front of the retina (Figure 7). If the accommodation of the lens cannot counteract this then distant objects are blurred.

2.9.1.8 Other visual problems include:

• cataracts - clouding of the lens usually associated with ageing;

• astigmatism - a misshapen cornea causing objects to appear irregularly shaped;

• glaucoma - a build up in pressure of the fluid within the eye which can cause damage to the optic nerve and even blindness;

• migraine - severe headaches that can cause visual disturbances.

2.9.1.9 Finally

As a person grows older, the lens becomes less flexible meaning that it is unable to accommodate sufficiently. This is known as presbyopia and is a form of long sightedness. Consequently, after the age of 40, spectacles may be required for near vision, especially in poor light conditions. Fatigue can also temporarily affect accommodation, causing blurred vision for close work.

2.9.1.10 Foreign Substances

Vision can be adversely affected by the use of certain drugs and medications, alcohol, and smoking cigarettes. With smoking, carbon monoxide which builds up in the bloodstream allows less oxygen to be carried in the blood to the eyes. This is known as hypoxia and can impair rapidly the sensitivity of the rods. Alcohol can have similar effects, even hours after the last drink.

2.9.1.11 Environmental Factors

Vision can be improved by increasing the lighting level, but only up to a point, as the law of diminishing returns operates. Also, increased illumination could result in increased glare. Older people are more affected by the glare of reflected light than younger people. Moving from an extremely bright environment to a dimmer one has the effect of vision being severely reduced until the eyes get used to less light being available. This is because the eyes have become light adapted. If an engineer works in a very dark environment for a long time, his eyes gradually become dark adapted allowing better visual acuity. This can take about 7 minutes for the cones and 30 minutes for the rods. As a consequence, moving between a bright hanger (or the inside of an aircraft) to a dark apron area at night can mean that the maintenance engineer must wait for his eyes to adjust (adapt). In low light conditions, it is easier to focus if you look slightly to one side of an object. This allows the image to fall outside the fovea and onto the part of the retina which has many rods.

Any airborne particles such as dust, rain or mist can interfere with the transmission of light through the air, distorting what is seen. This can be even worse when spectacles are worn, as they are susceptible to getting dirty, wet, misted up or scratched. Engineers who wear contact lenses (especially hard or gas-permeable types) should take into account the advice from their optician associated with the maximum wear time - usually 8 to 12 hours - and consider the effects which extended wear may have on the eyes, such as drying out and irritation. This is particularly important if they are working in an environment which is excessively dry or dusty, as airborne particles may also affect contact lens wear. Goggles should be worn where necessary.

2.9.1.12 The Nature of the Object Being Viewed

Many factors associated with the object being viewed can also influence vision. We use information from the objects we are looking at to help distinguish what we are seeing. These are known as **visual cues.** Visual cues often refer to the comparison of objects of known size to unknown objects. An example of this is that we associate small objects with being further away. Similarly, if an object does not stand out well from its background (i.e. it has poor contrast with its surroundings), it is harder to distinguish its edges and hence its shape. Movement and relative motion of an object, as well as distance and angle of the object from the viewer, can all increase visual demands.

2.9.1.13 Color Vision

Although not directly affecting visual acuity, inability to see particular colors can be a problem for the aircraft maintenance engineer. Amongst other things, good color vision for maintenance engineers is important for:

- Recognizing components;
- Distinguishing between wires;
- Using various diagnostic tools;
- Recognizing various lights on the airfield (e.g. warning lights).

Color defective vision is usually hereditary, although may also occur as a temporary condition after a serious illness.

Color-defective vision (normally referred to incorrectly as color blindness) affects about 8% of men but only 0.5% of women. The most common type is difficulty in distinguishing between red and green. More rarely, it is possible to confuse blues and yellows.

There are degrees of color defective vision, some people suffering more than others. Individuals may be able to distinguish between red and green in a well-lit situation but not in low light conditions. Color defective people typically see the colors they have problems with as shades of neutral grey.

Ageing also causes changes in color vision. This is a result of progressive yellowing of the lens, resulting in a reduction in color discrimination in the blue-yellow range.

Color defective vision and its implications can be a complex area and care should be taken not to stop an engineer from performing certain tasks merely because he suffers from some degree of color deficient vision. It may be that the type and degree of color deficiency is not relevant in their particular job. However, if absolutely accurate color discrimination is critical for a job, it is important that appropriate testing and screening be put in place.

Vision and the Aircraft Maintenance Engineer

It is important for an engineer, particularly one who is involved in inspection tasks, to have adequate vision to meet the task requirements. As discussed previously, age and problems developing in the eye itself can gradually affect vision. Without regular vision testing, aircraft maintenance engineers may not notice that their vision is deteriorating.

In the UK, the CAA has produced guidance which states:

“A reasonable standard of eyesight is needed for any aircraft engineer to perform his duties to an acceptable degree. Many maintenance tasks require a combination of both distance and near vision. In particular, such consideration must be made where there is a need for the close visual inspection of structures or work related to small or miniature components. The use of glasses or contact lenses to correct any vision problems is perfectly acceptable and indeed they must be worn as prescribed. Frequent checks should be made to ensure the continued adequacy of any glasses or contact lenses. In addition, color discrimination may be necessary for an individual to drive in areas where aircraft maneuver or where color coding is used, e.g. in aircraft wiring.

Organizations should identify any specific eyesight requirement and put in place suitable procedures to address these issues.”

Often, airline companies or airports will set the eyesight standards for reasons other than aircraft maintenance safety, e.g. for insurance purposes, or for driving on the airfield.

Ultimately, what is important is for the individual to recognize when his vision is adversely affected, either temporarily or permanently and to consider carefully the possible consequences should they continue to work if the task requires good vision.

2.9.2 Hearing

2.9.2.1 The Basic Function of the Ear

The ear performs two quite different functions. It is used to detect sounds by receiving vibrations in the air, and secondly, it is responsible for balance and sensing acceleration. Of these two, the hearing aspect is more pertinent to the maintenance engineer, and thus it is necessary to have a basic appreciation of how the ear works.

As can be seen on Figure 2.9, the ear has three divisions: **outer ear, middle ear** and **inner ear.** These act to receive vibrations from the air and turn these signals into nerve impulses that the brain can recognize as sounds.

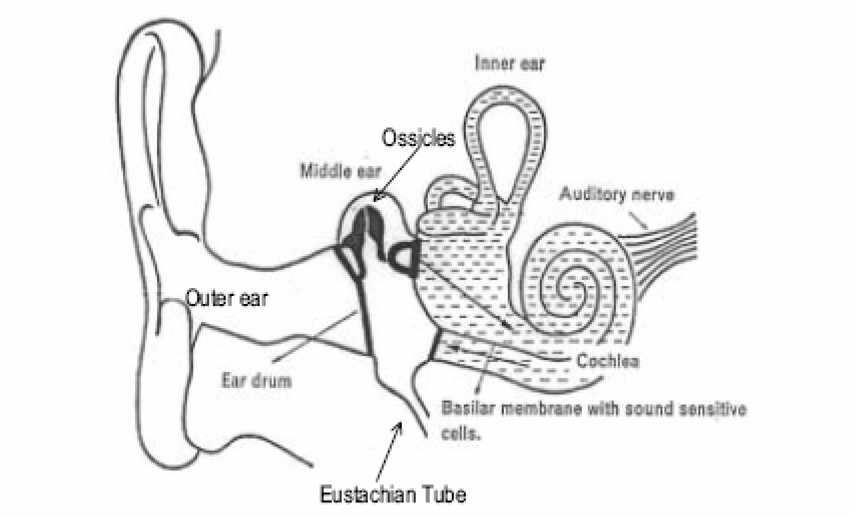


Figure 2.9 : The human ear

2.9.2.2 Outer Ear

The outer part of the ear directs sounds down the **auditory canal**, and on to the **eardrum**. The sound waves will cause the eardrum to vibrate.

2.9.2.3 Middle Ear

Beyond the eardrum is the middle ear which transmits vibrations from the eardrum by way of three small bones known as the **ossicles**, to the fluid of the inner ear. The middle ear also contains two muscles which help to protect the ear from sounds above 80 dB by means of the **acoustic** or **aural reflex**, reducing the noise level by up to 20 dB. However, this protection can only be provided for a maximum of about 15 minutes, and does not provide protection against sudden impulse noise such as gunfire. It does explain why a person is temporarily 'deafened' for a few seconds after a sudden loud noise. The middle ear is usually filled with air which is refreshed by way of the **eustachian tube** which connects this part of the ear with the back of the nose and mouth. However, this tube can allow mucus to travel to the middle ear which can build up, interfering with normal hearing.

2.9.2.4 Inner Ear

Unlike the middle ear, the inner ear is filled with fluid. The last of the ossicles in the middle ear is connected to the **cochlea**. This contains a fine membrane (the **basilar membrane**) covered in hair-like cells which are sensitive to movement in the fluid. Any vibrations they detect cause neural impulses to be transmitted to the brain via the **auditory nerve.**

2.9.2.5 Performance and Limitations of the Ear

The performance of the ear is associated with the range of sounds that can be heard - both in terms of the pitch (frequency) and the volume of the sound.

Volume (or intensity) of sound is measured in decibels (dB). Table 2.6 shows intensity levels for various sounds and activities.

Table 2.6 : Typical sound levels for various activities

Activity	Approximate Intensity level (Decibels)
Rustling of leaves / Whisper	20
Conversation at 2m	50
Typewriter at 1m	65
Car at 15m	70
Lorry at 15m	75
Power Mower at 2m	90
Propellor aircraft at 300m	100
Jet aircraft at 300m	110
Standing near a propellor aircraft	120
Threshold of pain	140
Immediate hearing damage results	150

2.9.2.6 Impact of Noise on Performance

Noise can have various negative effects in the workplace. It can:

• be annoying (e.g. sudden sounds, constant loud sound, etc.);

• interfere with verbal communication between individuals in the workplace;

• cause accidents by masking warning signals or messages;

• be fatiguing and affect concentration, decision making, etc.;

• damage workers' hearing (either temporarily or permanently).

The amount of vibration detected in the cochlea depends on the volume and pitch of the original sound.

The audible frequency range that a young person can hear is typically between 20 and 20,000 cycles per second (or Hertz), with greatest sensitivity at about 3000 Hz.

Intermittent and sudden noise are generally considered to be more disruptive than continuous noise at the same level. In addition, high frequency noise generally has a more adverse affect on performance than lower frequency. Noise tends to increase errors and variability, rather than directly affect work rate.

2.9.2.7 Hearing Impairment

Hearing loss can result from exposure to even relatively short duration noise. The degree of impairment is influenced mainly by the intensity of the noise. Such damage is known as **Noise Induced Hearing Loss (NIHL).** The hearing loss can be temporary - lasting from a few seconds to a few days - or permanent. Temporary hearing loss may be caused by relatively short exposure to very loud sound, as the hair-like cells on the basilar membrane take time to 'recover'. With additional exposure, the amount or recovery gradually decreases and hearing loss becomes permanent. Thus, regular exposure to high levels of noise over a long period may permanently damage the hairlike cells in the cochlea, leading to irreversible hearing impairment.

The UK 'Noise at Work' regulations1 (1989) impose requirements upon employers. They stipulate three levels of noise at which an employer must act:

a) 85 decibels (if normal speech cannot be heard clearly at 2 metres), employer must;

- assess the risk to employees' hearing,
- tell the employees about the risks and what precautions are proposed,

• provide their employees with personal ear protectors and explain their use.

b) 90 decibels (if normal speech cannot be heard clearly at 1 metre) employer must;

• do all that is possible to reduce exposure to the noise by means other than

by providing hearing protection,

• mark zones where noise reaches the second level and provide recognized signs to restrict entry.

c) 140 decibels (noise causes pain).

The combination of duration and intensity of noise can be described as **noise dose**.

Exposure to any sound over 80 dB constitutes a noise dose, and can be measured over the day as an 8 hour Time Weighted Average sound level (TWA).

For example, a person subjected to 95 decibels for 3.5 hours, then 105 decibels for 0.5 hours, then 85 decibels for 4 hours, results in a TWA of 93.5 which exceed the recommended maximum TWA of 90 decibels.

Permanent hearing loss may occur if the TWA is above the recommended maximum.

It is normally accepted that a TWA noise level exceeding 85 dB for 8 hours is hazardous and potentially damaging to the inner ear. Exposure to noise in excess of 115 decibels without ear protection, even for a short duration, is not recommended.

2.9.2.8 Hearing Protection

Hearing protection is available, to a certain extent, by using ear plugs or ear defenders.

It is good practice to reduce noise levels at source, or move noise away from workers.

Often this is not a practical option in the aviation maintenance environment. Hearing protection should always be used for noise, of any duration, above 115 dB. Referring again to Table 1, this means that the aviation maintenance engineer will almost always need to use some form of hearing protection when in reasonably close proximity (about 200 - 300m) to aircraft whose engines are running.

2.9.2.9 Hearing and the Aircraft Maintenance Engineer

The UK, CAA makes the following recommendations regarding hearing:

“The ability to hear an average conversational voice in a quiet room at a distance of 2 metres (6 feet) from the examiner is recommended as a routine test. Failure of this test would require an audiogram to be carried out to provide an objective assessment. If necessary, a hearing aid may be worn but consideration should be given to the practicalities of wearing the aid during routine tasks demanded of the individual.”

It is very important that the aircraft maintenance engineer understands the limited ability of the ears to protect themselves from damage due to excessive noise. Even though engineers should be given appropriate hearing protection and trained in its use, it is up to individuals to ensure that they actually put this to good use. It is a misconception that the ears get used to constant noise: if this noise is too loud, it will damage the ears gradually and insidiously.

2.9.3 Information Processing

The previous sections have described the basic functions and limitations of two of the senses used by aircraft maintenance engineers in the course of their work. This section examines the way the information gathered by the senses is processed by the brain. The limitations of the human information processing system are also considered.

Information processing is the process of receiving information through the senses, analyzing it and making it meaningful.

2.9.3.1 An Information Processing Model

Information processing can be represented as a **model.** This captures the main elements of the process, from receipt of information via the senses, to outputs such as decision making and actions. One such model is shown in Figure 2.10.

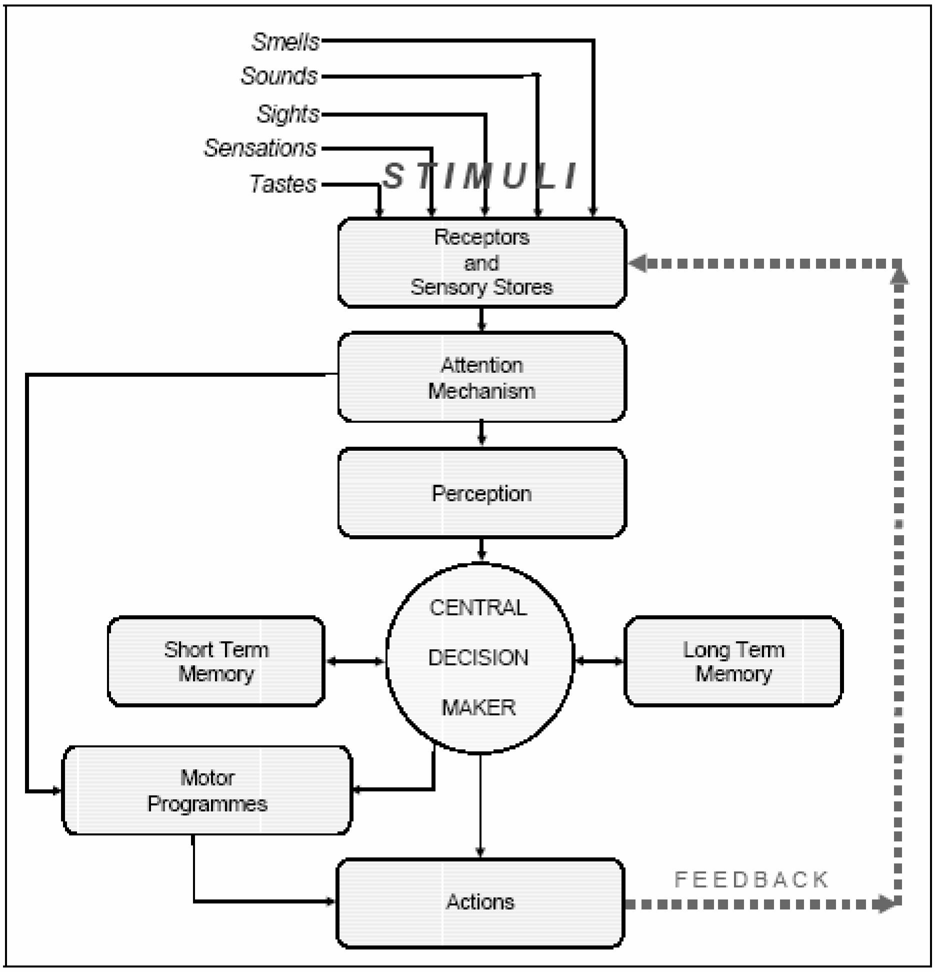


Figure 2.10 : A functional model of human information processing

2.9.3.2 Sensory Receptors and Sensory Stores

Physical stimuli are received via the sensory receptors (eyes, ears, etc.) and stored for a very brief period of time in sensory stores (sensory memory). Visual information is stored for up to half a second in iconic memory and sounds are stored for slightly longer (up to 2 seconds) in echoic memory. This enables us to remember a sentence as a sentence, rather than merely as an unconnected string of isolated words, or a film as a film, rather than as a series of disjointed images.

2.9.3.3 Memory

Memory is critical to our ability to act consistently and to learn new things Without memory, we could not capture a ‘stream’ of information reaching our senses, or draw on past experience and apply this knowledge when making decisions.

Memory can be considered to be the storage and retention of information, experiences and knowledge, as well as the ability to retrieve this information.

Memory depends on three processes:

• registration - the input of information into memory;

• storage - the retention of information;

• retrieval - the recovery of stored information.

It is possible to distinguish between three forms of memory:

a) ultra short-term memory (or sensory storage);

b) short term memory (often referred to as working memory)

c) long term memory.

Ultra short-term memory has already been described when examining the role of **sensory stores.** It has duration of up to 2 seconds (depending on the sense) and is used as a buffer, giving us time to attend to sensory input.

Short term memory receives a proportion of the information received into sensory stores, and allows us to store information long enough to use it (hence the idea of 'working memory'). It can store only a relatively small amount of information at one time, i.e. 5 to 9 (often referred to as 7 ±2) items of information, for a short duration, typically 10 to 20 seconds. As the following example shows, capacity of short term memory can be enhanced by splitting information in to 'chunks' (a group of related items).

A telephone number, e.g. 01222555234, can be stored as 11 discrete digits, in which case it is unlikely to be remembered. Alternatively, it can be stored in chunks of related information, e.g. in the UK, 01222 may be stored as one chunk, 555 as another, and 234 as another, using only 3 chunks and therefore, more likely to be remembered. In mainland Europe, the same telephone number would probably be stored as 01 22 25 55 23 4, using 6 chunks. The size of the chunk will be determined by the individual's familiarity with the information (based on prior experience and context), thus in this example, a person from the UK might recognize 0208 as the code for London, but a person from mainland Europe might not.

The duration of short term memory can be extended through rehearsal (mental repetition of the information) or encoding the information in some meaningful manner (e.g. associating it with something as in the example above).

The capacity of long-term memory appears to be unlimited. It is used to store information that is not currently being used, including:

• knowledge of the physical world and objects within it and how these

behave;

• personal experiences;

• beliefs about people, social norms, values, etc.;

• motor programmes, problem solving skills and plans for achieving various

activities;

• abilities, such as language comprehension.

Information in long-term memory can be divided into two types:

(i) semantic and

(ii)episodic.

Semantic memory refers to our store of general, factual knowledge about the world, such as concepts, rules, one's own language, etc. It is information that is not tied to where and when the knowledge was originally acquired. Episodic memory refers to memory of specific events, such as our past experiences (including people, events and objects). We can usually place these things within a certain context. It is believed that episodic memory is heavily influenced by a person's expectations of what should have happened, thus two people's recollection of the same event can differ.

Motor Programmes

If a task is performed often enough, it may eventually become automatic and the required skills and actions are stored in long term memory. These are known as motor programmes and are ingrained routines that have been established through practice. The use of a motor programme reduces the load on the central decision maker. An often quoted example is that of driving a car: at first, each individual action such as gear changing is demanding, but eventually the separate actions are combined into a motor programme and can be performed with little or no awareness. These motor programmes allow us to carry out simultaneous activities, such as having a conversation whilst driving.

Situation Awareness

Situation awareness is the synthesis of an accurate and up-to-date 'mental model' of one's environment and state, and the ability to use this to make predictions of possible future states.

An example is an engineer seeing (or perceiving) blue streaks on the fuselage. His comprehension may be that the lavatory fill cap could be missing or the drainline leaking. If his situation awareness is good, he may appreciate that such a leak could allow blue water to freeze, leading to airframe or engine damage.

Situation awareness for the aircraft maintenance engineer can be summarized as:

- the status of the system the engineer is working on;
- the relationship between the reported defect and the intended rectification;
- the possible effect on this work on other systems;
- the effect of this work on that being done by others and the effect of their work on this work.

This suggests that in aircraft maintenance engineering, the entire team needs to have situation awareness - not just of what they are doing individually, but of their colleagues' activities as well.

2.9.3.4 Information Processing Limitations

The basic elements of human information processing have now been explored. It is important to appreciate that these elements have limitations. As a consequence, the aircraft engineer, like other skilled professionals, requires support such as reference to written material (e.g. manuals).

There are many well-known visual 'illusions' which illustrate the limits of human perception. Figure 2.11 shows how the perceptual system can be misled into believing that one line is longer than the other, even though a ruler will confirm that they are exactly the same.

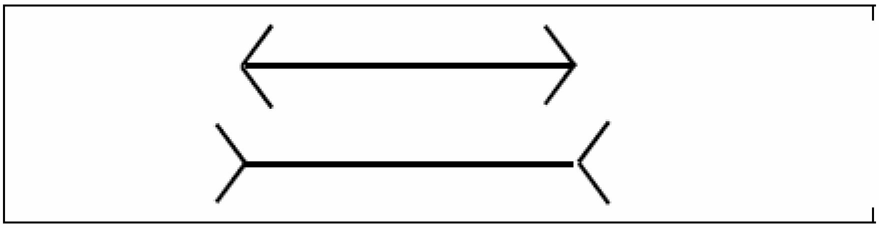


Figure 2.11: The Muller-Lyer Illusion

Figure 2.12 illustrates that we can perceive the same thing quite differently (i.e. the letter “B” or the number “13”). This shows the influence of context on our information processing.

Figure 2.12: The importance of context.

In aviation maintenance it is often necessary to consult documents with which the engineer can become very familiar. It is possible that an engineer can scan a document and fail to notice that subtle changes have been made. He sees only what he expects to see (**expectation**). To illustrate how our eyes can deceive us when quickly scanning a sentence, read quickly the sentence on in Figure 2.13.

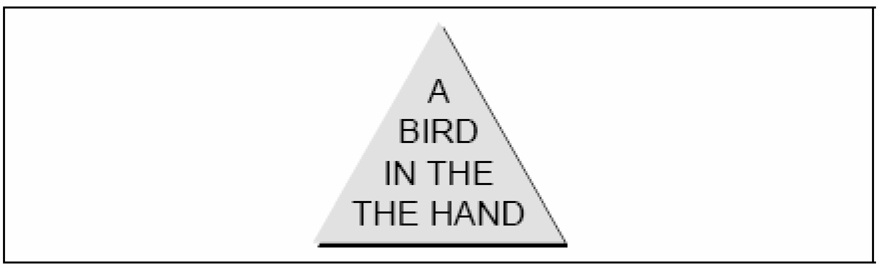


Figure 2.13: The effects of expectation

At first, most people tend to notice nothing wrong with the sentence. Our perceptual system sub-consciously rejects the additional “THE”.

As an illustration of how expectation, can affect our judgement, the same video of a car accident was shown to two groups of subjects. One group was told in advance that they were to be shown a video of a car crash; the other was told that the car had been involved in a ‘bump’. Both groups were asked to judge the speed at which the vehicles had collided. The first group assessed the speed as significantly higher than the second group.

Expectation can also affect our memory of events. The study outlined above was extended such that subjects were asked, a week later, whether they recalled seeing glass on the road after the collision. (There was no glass). The group who had been told that they would see a crash, recalled seeing glass; the other group recalled seeing no glass.

Decision Making, Memory, and Motor Programmes

a) Attention and perception shortcomings can clearly impinge on decision making. Perceiving something incorrectly may mean that an incorrect decision is made, resulting in an inappropriate action. Figure 2.14 also shows the dependence on memory to make decisions. It was explained earlier that sensory and short-term memory have limited capacity, both in terms of capacity and duration. It is also important to bear in mind that human memory is fallible, so that information:

• may not be stored;

• may be stored incorrectly;

• may be difficult to retrieve.

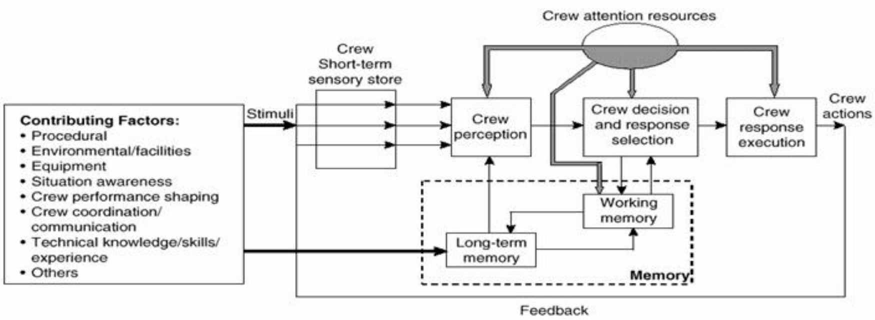


Figure 2.14: A model of human information processing [7]

All these may be referred to as forgetting, which occurs when information is unavailable (not stored in the first place) or inaccessible (cannot be retrieved).

Information in short-term memory is particularly susceptible to interference, an example of which would be trying to remember a part number whilst trying to recall a telephone number.

It is generally better to use manuals and temporary aides-memoires rather than to rely upon memory, even in circumstances where the information to be remembered or recalled is relatively simple. For instance, an aircraft maintenance engineer may think that he will remember a torque setting without writing it down, but between consulting the manual and walking to the aircraft (possibly stopping to talk to someone on the way), he may forget the setting or confuse it (possibly with a different torque setting appropriate to a similar task with which he is more familiar). Additionally, if unsure of the accuracy of memorised information, an aircraft maintenance engineer should seek to check it, even if this means going elsewhere to do so. Noting something down temporarily can avoid the risk of forgetting or confusing information. However, the use of a personal note book to capture such information on a permanent basis can be dangerous, as the information in it may become out-of-date.

In the B737 double engine oil loss incident, the AAIB report stated:

“Once the Controller and fitter had got to T2 and found that this supportive material [Task Cards and AMM extracts] was not available in the workpack, they would have had to return to Base Engineering or to have gone over to the Line Maintenance office to get it. It would be, in some measure, understandable for them to have a reluctance to recross the exposed apron area on a winter’s night to obtain a description of what they were fairly confident they knew anyway. However, during the course of the night, both of them had occasion to return to the Base Maintenance hangar a number of times before the task had been completed. Either could, therefore, have referred to or even drawn the task descriptive papers before the job was signed off. The question that should be addressed, therefore, is whether there might be any factors other than overconfidence in their memories, bad judgement or idleness which would dispose them to pass up these opportunities to refresh their memories on the proper and complete procedures.”

2.9.4 Claustrophobia, Physical Access and Fear of Heights

Although not peculiar to aircraft maintenance engineering, working in restricted space and at heights is a feature of this trade. Problems associated with physical access are not uncommon. Maintenance engineers and technicians often have to access, and work in, very small spaces (e.g. in fuel tanks), cramped conditions (such as beneath flight instrument panels, around rudder pedals), elevated locations (on cherry-pickers or staging), sometimes in uncomfortable climatic or environmental conditions (heat, cold, wind, rain, noise). This can be aggravated by aspects such as poor lighting or having to wear breathing apparatus.

2.9.4.1 Physical Access and Claustrophobia

There are many circumstances where people may experience various levels of physical or psychological discomfort when in an enclosed or small space, which is generally considered to be quite normal. When this discomfort becomes extreme, it is known as **claustrophobia**.

2.9.4.2 Fear of Heights

Working at significant heights (See Figure 2.15) can also be a problem for some aircraft maintenance engineers, especially when doing ‘crown’ inspections (top of fuselage, etc.). Some engineers may be quite at ease in situations like these whereas others may be so uncomfortable that they are far more concerned about the height, and holding on to the access equipment, than they are about the job in hand. In such situations, it is very important that appropriate use is made of harnesses and safety ropes. These will not necessarily remove the fear of heights, but will certainly help to reassure the engineer and allow him to concentrate on the task in hand. The FAA’s hfskyway website provides practical guidance to access equipment when working at height.

Shortly before the Aloha accident, during maintenance, the inspector needed ropes attached to the rafters of the hangar to prevent falling from the aircraft when it was necessary to inspect rivet lines on top of the fuselage. Although unavoidable, this would not have been conducive to ensuring that the inspection was carried out meticulously (nor was it, as the subsequent accident investigation revealed). The NTSB investigation report stated:

“Inspection of the rivets required inspectors to climb on scaffolding and move along the upper fuselage carrying a bright light with them; in the case of an eddy current inspection, the inspectors needed a probe, a meter, and a light. At times, the inspector needed ropes attached to the rafters of the hangar to prevent falling from the airplane when it was necessary to inspect rivet lines on top of the fuselage. Even if the temperatures were comfortable and the lighting was good, the task of examining the area around one rivet after another for signs of minute cracks while standing on scaffolding or on top of the fuselage is very tedious. After examining more and more rivets and finding no cracks, it is natural to begin to expect that cracks will not be found."

Figure 2.15: Engineer working on stand

Managers and supervisors should attempt to make the job as comfortable and secure as reasonably possible (e.g. providing knee pad rests, ensuring that staging does not wobble, providing ventilation in enclosed spaces, etc.) and allow for frequent breaks if practicable.

2.9.5 Circadian Rhythms

Apart from the alternation between wakefulness and sleep, men have other internal cycles, such as body temperature and hunger/eating. These are known as circadian rhythms as they are related to the length of the day.

An example of disrupting circadian rhythms would be taking a flight that crosses time zones. This will interfere with the normal synchronisation with the light and dark (day/ night). This throws out the natural link between daylight and the body's internal clock, causing jet lag, resulting in sleepiness during the day, etc. Eventually however, the circadian rhythm readjusts to the revised environmental cues.

Figure 2.16 shows the circadian rhythm for body temperature. This pattern is very robust, meaning that even if the normal pattern of wakefulness and sleep is disrupted (by shift work for example), the temperature cycle remains unchanged. Hence, it can be seen that if you are awake at 4-6 o'clock in the morning, your body temperature is in a trough and it is at this time that is hardest to stay awake. Research has shown that this drop in body temperature appears to be linked to a drop in alertness and performance in man.

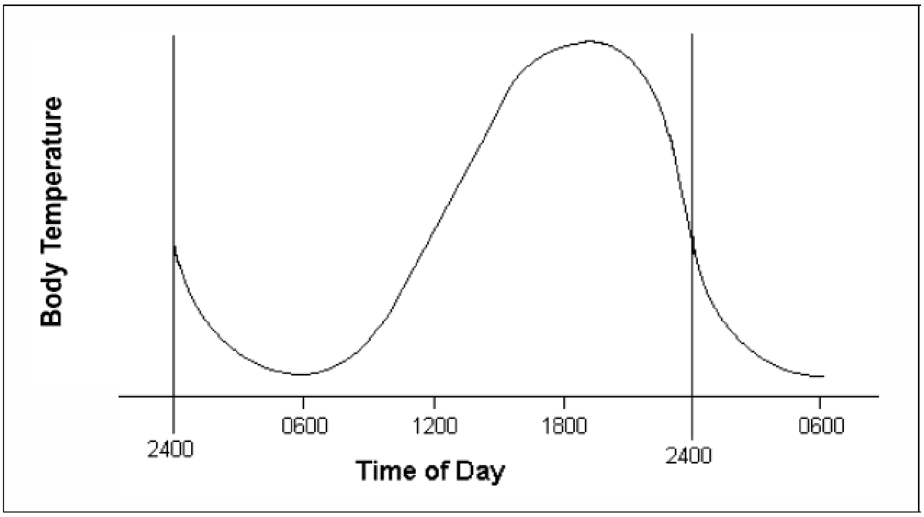


Figure 2.16: The circadian rhythm for internal body temperature

Although there are many contributory factors, it is noteworthy that a number of major incidents and accidents involving human error have either occurred or were initiated in the pre-dawn hours, when body temperature and performance capability are both at their lowest. These include Three Mile Island, Chernobyl, and Bhopal, as well as the BAC1-11, A320, and B737 incidents

The engineer's performance at this 'low point' will be improved if he is well rested, feeling well, highly motivated and well practised in the skills being used at that point.

2.10 Current Human Factor Programs in Aircraft Maintenance

MRM (Maintenance Resource Management) which later evolved into Human Factors in Maintenance (HFIM) was developed to provide primarily the training required to understand and prevent HF errors from occurring. The main breakthrough that was achieved in recent years is the emphasis given by senior management in organizations to HF programs. Many consultants and companies have enjoyed this upward focus on HF.

Several HFIM courses have evolved since ICAO required HFIM training which include those by the UK CAA, FAA as well as JAR compliant courses to ensure consistency and conformance to minimum standards set out by the governing bodies. A typical HFIM course such as the one developed to comply with JAR145 includes:

1. A General introduction to Human Factors

2. Safety Culture/Organizational factors overview

3. Human Performance, limitations and Human Error models

4. Environmental issues impacting Human Performance

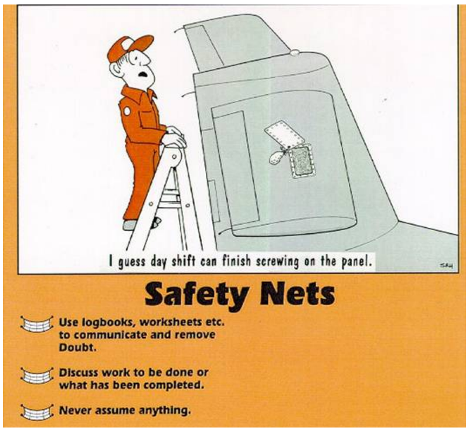
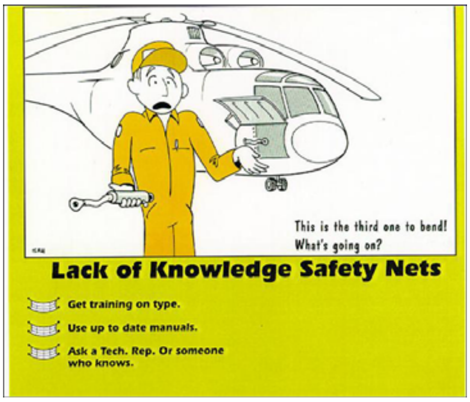
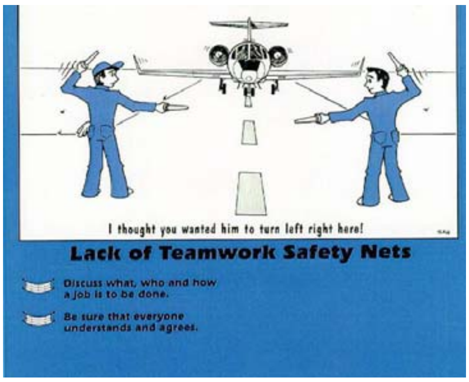
5. Procedures, Information, Tools and Practices

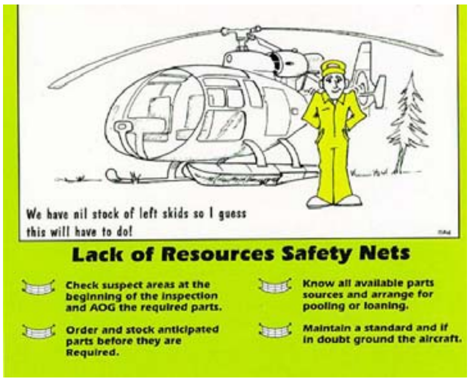
6. Professionalism, Integrity, Communication and Teamwork

7. Organization HF program including the management of HF errors

2.10.1 Dirty Dozen

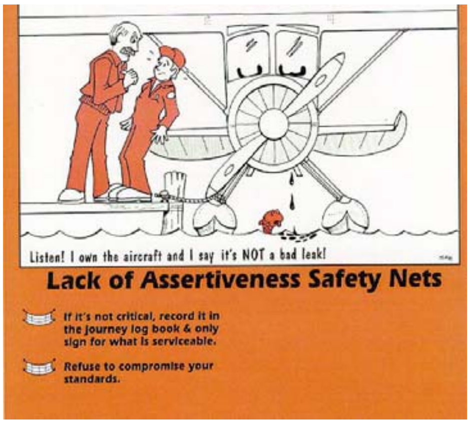
Gordon Dupont, formerly of Transport Canada, is one such consultant whose excellent “Dirty Dozen” classification of HF root causes has been widely adopted by several aviation organizations. These are encapsulated in a set of 12 posters, Figure 2.17 depicting cartoon scenarios showing what and how we should avoid it.

1- Lack of communication	2- Complacency
	
3- Lack of knowledge	4- Distraction
	
5- Lack of Team Work	6- Fatigue
	
7- Lack of resources	8- Pressure



9- Lack of assertiveness

10- Stress



11- Lack of awareness

12- Norms

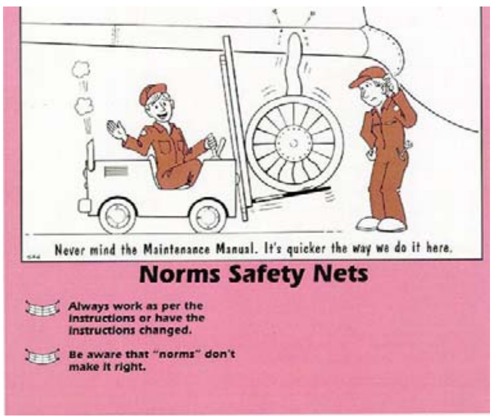


Figure 2.17 : "The Dirty Dozen." From Gordon Dupont, System Safety Services

2.10.2 MEDA [20]

Other organizations like Boeing have developed their own in-house Maintenance Error and Decision Analysis (MEDA) programs with more in depth analysis including the background of personnel that commit these HF errors to better understand the extent of solutions necessary. Most of these programs are designed to identify the HF errors, educate the personnel on their causal potential, suggest ways to contain and correct the problem and create a HF error-free environment. While many of these programs have truly made the aviation work environment safer, many of them still look at HF from a people' perspective rather than "an organization" develop programs that improve the performance of which will provide long term solutions to HFIM.

The MEDA Philosophy

Traditional efforts to investigate errors are often aimed at identifying the employee who made the error. The usual result is that the employee is defensive and is subjected to a combination of disciplinary action and recurrent training (which is actually retraining). Because retraining often adds little or no value to what the employee already knows, it may be ineffective in preventing future errors. In addition, by the time the employee is identified, information about the factors that contributed to the error has been lost. Because the factors that contributed to the error remain unchanged, the error is likely to recur, setting what is called the "blame and train" cycle in motion again.

To break this cycle, MEDA was developed in order to assist investigators to look for the factors that contributed to the error, rather than concentrate upon the employee who made the error. The MEDA philosophy is based on these principles:

- Positive employee intent (maintenance technicians want to do the best job possible and do not make errors intentionally).
- Contribution of multiple factors (a series of factors contributes to an error).
- Manageability of errors (most of the factors that contribute to an error can be managed).

Positive Employee Intent

This principle is key to a successful investigation. Traditional "blame and train" investigations assume that errors result from individual carelessness or incompetence. Starting instead from the assumption that even careful employees can make errors, MEDA interviewers can gain the active participation of the technicians closest to the error. When technicians feel that their competence is not in question and that their contributions will not be used in disciplinary actions against them or their fellow employees, they willingly team with investigators to identify the factors that contribute to error and suggest solutions. By following this principle, operators can replace a negative "blame and train" pattern with a positive "blame the process, not the person" practice.

Contribution of Multiple Factors

Technicians who perform maintenance tasks on a daily basis are often aware of factors that can contribute to error. These include information that is difficult to understand, such as work cards or maintenance manuals; inadequate lighting; poor communication between work shifts; and aircraft design. Technicians may even have their own strategies for addressing these factors. One of the objectives of a MEDA investigation is to discover these successful strategies and share them with the entire maintenance operation.

Manageability Of Errors

Active involvement of the technicians closest to the error reflects the MEDA principle that most of the factors that contribute to an error can be managed. Processes can be changed, procedures improved or corrected, facilities enhanced, and best practices shared. Because error most often results from a series of contributing factors, correcting or removing just one or two of these factors can prevent the error from recurring.

The MEDA Process

To help maintenance organizations achieve the dual goals of identifying factors that contribute to existing errors and avoiding future errors, Boeing initially worked with British Airways, Continental Airlines, United Airlines, a maintenance workers' labour union, and the U.S. Federal Aviation Administration. The result was a basic five-step process for operators to follow

• Event.

• Decision.

• Investigation.

• Prevention strategies.

• Feedback.

Event

An event occurs, such as a gate return or air turn back. It is the responsibility of the maintenance organization to select the error-caused events that will be investigated.

Decision

After fixing the problem and returning the airplane to service, the operator makes a decision: Was the event maintenance-related? If yes, the operator performs a MEDA investigation.

Investigation

Using the MEDA results form, the operator carries out an investigation. The trained investigator uses the form to record general information about the airplane, when the maintenance and the event occurred, the event that began the investigation, the error that caused the event, the factors contributing to the error, and a list of possible prevention strategies.

Prevention Strategies

The operator reviews, prioritises, implements, and then tracks prevention strategies (process improvements) in order to avoid or reduce the likelihood of similar errors in the future.

Feedback

The operator provides feedback to the maintenance workforce so technicians know that changes have been made to the maintenance system as a result of the MEDA process. The operator is responsible for affirming the effectiveness of employees' participation and validating their contribution to the MEDA process by sharing investigation results with them.

Management Resolve

The resolve of management at the maintenance operation is key to successful MEDA implementation. Specifically, after completing a program of MEDA support from Boeing, managers must assume responsibility for the following activities before starting investigations:

a) Appoint a manager in charge of MEDA and assign a focal organization.

b) Decide which events will initiate investigations.

c) Establish a plan for conducting and tracking investigations.

d) Assemble a team to decide which prevention strategies to implement.

e) Inform the maintenance and engineering workforce about MEDA before implementation.

MEDA is a long-term commitment, rather than a quick fix. Operators new to the process are susceptible to "normal workload syndrome". This occurs once the enthusiasm generated by initial training of investigation teams has diminished and the first few investigations have been completed. In addition to the expectation that they will continue to use MEDA, newly trained investigators are expected to maintain their normal responsibilities and workloads. Management at all levels can maintain the ongoing commitment required by providing systematic tracking of MEDA findings and visibility of error and improvement trends.

Summary

The Maintenance Error Decision Aid (MEDA) process offered by Boeing continues to help operators of airplanes identify what causes maintenance errors and how to prevent similar errors in the future. Because MEDA is a tool for investigating the factors that contribute to an error, maintenance organizations can discover exactly what led to an error and remedy those factors. By using MEDA, operators can avoid the rework, lost revenue, and potential safety problems related to events caused by maintenance errors.

2.10.3 The Reason Model [17]

Figure 2.18 depicts a modified version of the Reason model of accident causation, showing the various human contributions to the breakdown of a complex system (Reason, J. (1990) Human Error. Cambridge University Press, United Kingdom).

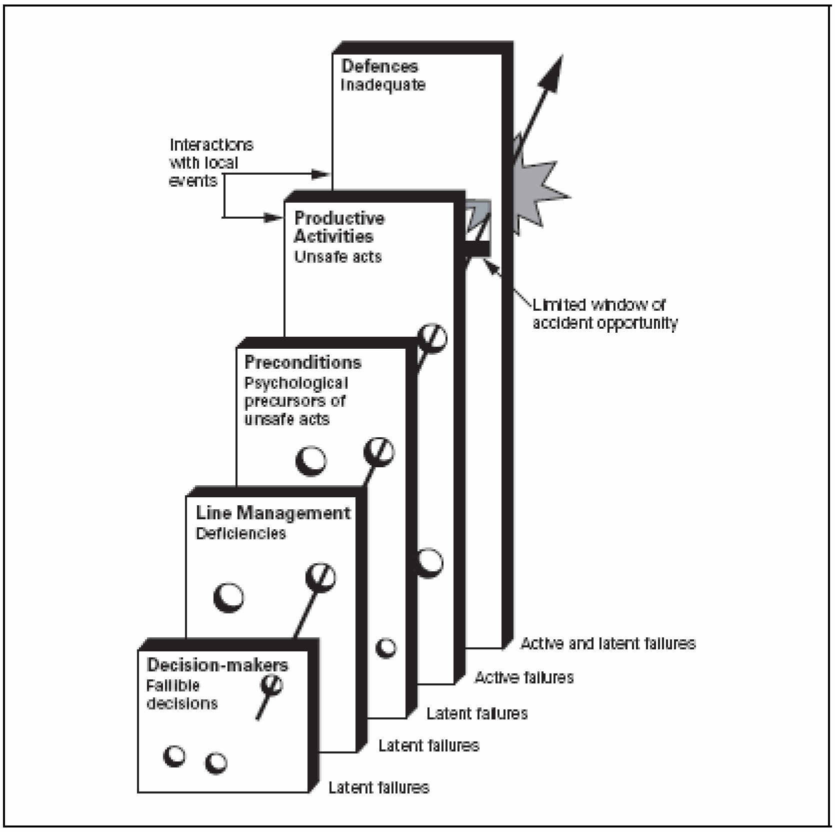


Figure 2.18 : James Reason's Model of Accident Causation (modified version, 1990)

Since its introduction in 1990, several variations have circulated among the Human Factors and accident prevention specialists, including a revised model by Professor Reason himself in 1993. This digest discusses the 1990 version, as included in ICAO Human Factors Digests No. 7 and No. 10.

Professor Reason views the aviation industry as a complex productive system. One of the basic elements of the system is the decision-makers (high-level anagement, the company's corporate or the regulatory body) who are responsible for setting goals and for managing available resources to achieve and balance two distinct goals: the goal of safety and the goal of on-time and cost-effective transportation of passengers and cargo. A second key element is line management — those who implement the decisions made by upper management. For upper-management decisions and line management actions to result in effective and productive activities by the workforce involved, certain preconditions have to exist. For example, equipment must be available and reliable, the workforce has to be skilled, knowledgeable and motivated, and environmental conditions have to be safe. The final element, defences or safeguards, is usually in place to prevent foreseeable injury, damage or costly interruptions of service.

The Reason model shows how humans contribute to the breakdown of complex, interactive and well-guarded systems — such as commercial aviation — to produce an accident. In the aviation context, “well-guarded” refers to the strict rules, high standards, inspection procedures and sophisticated monitoring equipment in place.

Because of technological progress and excellent defences, accidents seldom originate exclusively from the errors of operational personnel (front-line operators) or as a result of major equipment failures. Instead, they result from interactions of a series of failures or flaws already present in the system. Many of these failures are not immediately visible, and they have delayed consequences.

Failures can be of two types, depending on the immediacy of their consequences. An active failure is an error or a violation which has an immediate adverse effect. These errors are usually made by the front-line operator. A pilot raising the landing gear lever instead of the flap lever exemplifies this failure type. A latent failure is a result of an action or decision made well before an accident, the consequences of which may remain dormant for a long time. Such failures usually originate at the decision-maker, regulator or line management levels; that is, with people far removed in time and space from the event. A decision to merge two companies without providing training to standardize aircraft maintenance and flight operations procedures illustrates the latent failure type. These failures can also be introduced at any level of the system by the human condition, for example, through poor motivation or fatigue.

Latent failures, which originate from questionable decisions or incorrect actions, although not harmful if they occur individually, can interact to create “a window of opportunity” for a pilot, air traffic controller or mechanic to commit an active failure which breaches all the defences of the system and results in an accident. In such cases, the front-line operators become the inheritors of a system's defects because they are the ones dealing with a situation in which their actions, technical problems or adverse conditions will reveal the latent failures long embedded in a system. In a well-guarded system, latent and active failures will interact, but they will not often breach the defences. When the defences work, the result is an incident; when they do not, it is an accident.

2.10.4 The SHEL Model [17]

The “SHEL” model was first advocated by Professor Elwyn Edwards in 1972 and a modified diagram to illustrate the model was later developed by Capt. Frank Hawkins in 1975 (Figure 2.19). The component blocks of the SHEL model (the name being derived from the initial letters of its components: Software, Hardware, Environment, Liveware) are depicted with a pictorial impression of the need for matching the components. The following interpretations are suggested: liveware (human), hardware (machine), software (procedures, symbology, etc.) and environment (the conditions in which the L-H-S system must function). This block diagram does not cover interfaces which are outside Human Factors (e.g. between hardware-hardware; hardware-environment; software-hardware) and is intended only as an aid for understanding Human Factors.

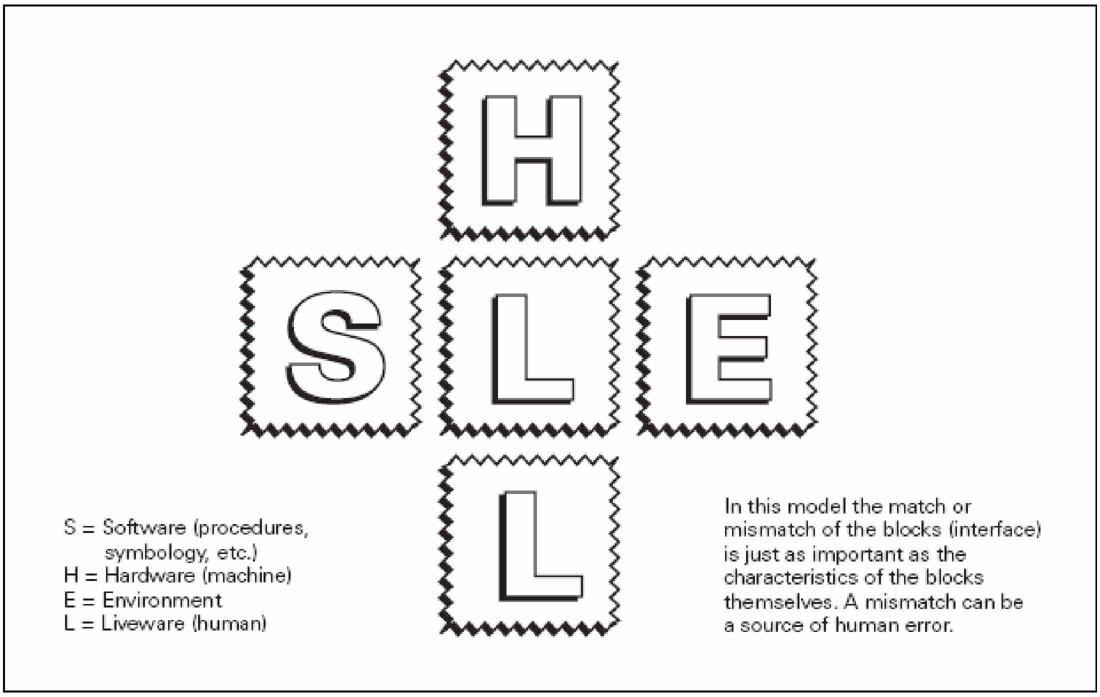


Figure 2.19 : The SHEL Model (adapted from Hawkins, 1975)

Liveware (or the human) is at the centre of the model. Human is generally considered the most critical as well as the most flexible component in the system. Yet people are subject to considerable variations in performance and suffer many limitations, most of which are now predictable in general terms. The edges of this block are jagged, and so the other components of the system must be carefully matched with them if stress in the system and eventual breakdown are to be avoided. In order to achieve this matching, an understanding of the characteristics of this central component is essential. Examples of those important characteristics are as follows:

Physical size and shape. In the design of workplace and equipment, a vital consideration involves body measurements and movements, which may vary according to factors such as age, ethnicity and gender. Human Factors inputs must be provided at an early stage in the design process, and data for these inputs are available from anthropometry, biomechanics and kinesiology.

Physical needs. People's requirements such as for food, water and oxygen are indicated in human physiology and biology.

Input characteristics. Humans possess various sensory systems for collecting information from the world external as well as internal to them, enabling them to respond to events and to carry out the required task. All senses may, however, be subjected to degradation for one reason or another, and the sources of knowledge include psychology and physiology.

Information processing. Again, these human functions have limitations. Poor instrument and alerting system design has frequently resulted from a failure to take into account the capabilities and limitations of human information processing. Factors such as stress, motivation and short- and long-term memory are involved. Psychology and cognitive sciences are the sources of background knowledge here.

Output characteristics. Once information is sensed and processed, decisions are made and/or messages are sent to muscles to initiate the desired response. Responses may involve a physical control movement or the initiation of some form of communication. Acceptable control forces and direction of movement have to be known, and biomechanics, physiology and psychology provide the background knowledge.

Environmental tolerances. Environmental factors such as temperature, vibration, pressure, humidity, noise, time of day, amount of light and G-forces can affect human performance and well-being. Heights, enclosed spaces and a boring or stressful work environment can influence human behaviour and performance. Background information is available from medicine, psychology, physiology and biology.

Liveware is the hub of the SHEL model of Human Factors. The remaining components must be adapted to and matched with this central component (Some of the descriptions of the model tend to be flight crew-oriented. This is because the model was initially developed to address interface problems in the cockpit environment).

Liveware-Hardware. This interface is the most commonly considered when speaking of human-machine systems: the design of seats to fit the sitting characteristics of the human body; of displays to match the sensory and information-processing characteristics of the user; of controls with proper movement, coding and location. The user may not be aware of an L-H deficiency, even when it finally leads to disaster, because the great virtue of human adaptability may mask the effects of such a deficiency. However, the deficiency continues to exist and may constitute a potential hazard. Ergonomics deals mostly, although not exclusively, with issues arising from this interface.

Liveware-Software. This encompasses the interface between humans and the non-physical aspects of the system such as procedures, manual and checklist layout, symbology and computer programmes. The problems may be less tangible than those involving the L-H interface and consequently more difficult to detect and resolve (e.g. misinterpretation of checklists or symbology).

Liveware-Environment. The human-environment interface was one of the earliest recognized in aviation. Initially, measures taken were aimed at adapting the human to the environment (e.g. by using helmets, flying suits, oxygen masks and G suits). Later, attempts were made to alter the environment to match human requirements (e.g. by applying pressurization, air-conditioning and soundproofing). Today, new challenges have risen, notably ozone concentrations and radiation hazards at high flight levels, and the problems associated with disturbed biological rhythms and sleep because of high-speed transmeridian travel. Since illusions and disorientation are involved in many aviation occurrences, the L-E interface must also consider perceptual errors induced by environmental conditions (e.g. illusions occurring during approach and landing). The aviation system operates within the context of broad managerial, political and economic constraints. These aspects of the environment will interact with the human via this interface. Although the modifications to these factors are generally beyond the function of Human Factors practitioners, they should be considered and addressed by those in management with the ability to do so.

Liveware-Liveware. This is the interface between people. Flight crew training and proficiency testing have traditionally been conducted on an individual basis. If each individual crew member was proficient, then it was assumed that the team comprising those individuals would also be proficient and effective. This is not always the case, however, and for many years attention has been increasingly turned to the breakdown of teamwork. Flight crews function as groups and group interactions play a role in determining behaviour and performance. In this interface, one is concerned with leadership, crew cooperation, teamwork and personality interactions. Human Factors Digest No. 2 describes current industry approaches to deal with issues associated with this interface (i.e. CRM and LOFT programmes). Staff/management relationships are also within the scope of this interface, as corporate climate and company operating pressures can significantly affect human performance. Digest No. 2 also demon-strates the important role of management in accident prevention.

3 THE USED RESEARCH METHODS

3.1 Definition of Six Sigma Methodology

What is a sigma?

Sigma is a Greek letter used as a symbol in statistics to represent the standard deviation or variation from the average or mean of a dataset.

In a typical theory of evaluation, all things or processes; those that can be measured in a continuous scale (i.e. weight, height, and length) follow a normal or Gaussian distribution.

The six sigma methodology uses this value, sigma, to measure and define the capabilities of a process.

As the standard deviation decreases, the “sigma level” of your process increases; therefore, there are better controls and less defective products or services to the customer.

What is Six Sigma?

Use of statistical tools within a structured methodology for gaining the knowledge needed to create products and services better, faster and less expensively than the competition.

Six Sigma is a business concept that answers customers’ demand for high quality and defect-free business processes.

Six Sigma is a target (Fewer than 3.4 defects or errors per million opportunities – 99.99966 perfection).

Six sigma first focuses on the customer and meeting the customers’ needs. This can include both internal and external customers. Customers want creative, high quality services and goods at a reasonable cost. Without the customer, an organization, no matter how efficient or creative, cannot survive.

What makes six sigma unique is that it does not just stay within the minds of the few who the projects directly affect; six sigma is a deep and positive cultural change for the organization. The focus of six sigma is understood at all levels of the organization, especially the executive levels.

Another key component to its success is also that six sigma is not just a method but also a positive and deep cultural change. The approach is to have the support at all levels of the organization.

Consequently, the ultimate result to improved quality in products and services is that real financial gains impact the bottom line. This is the goal for all organizations.

In summary, Six Sigma is about identifying/quantifying and eliminating the Hidden Factory through Defect Reduction and ultimately Design for 6 Sigma

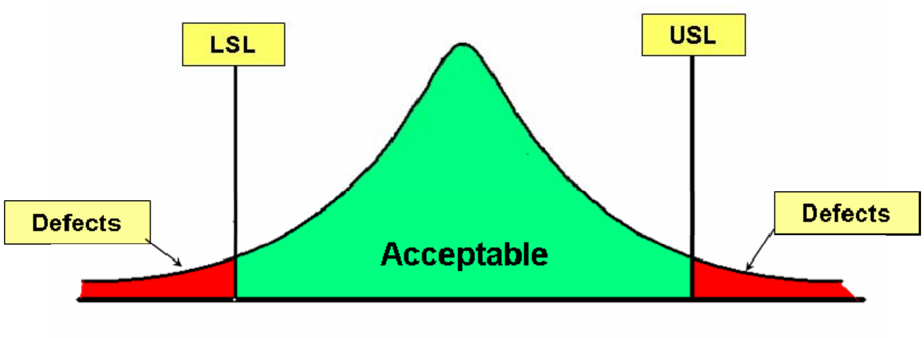


Figure 3.1 : Normal distribution

Within the normal distribution, the premise behind 6 sigma is that there is an upper (USL) and lower limit (LSL) set. Anything outside of these limits would be considered defective. The premise of 6 sigma is to stay well within these limits by using proven methodologies to identify, quantify, and mostly, control or eliminate the sources of variation.

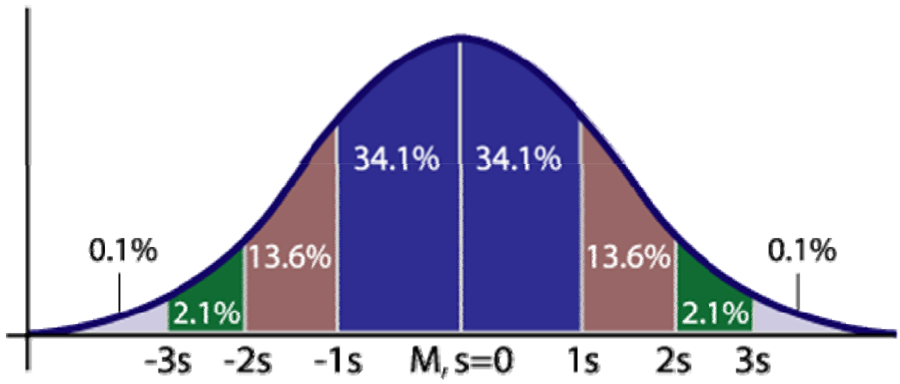


Figure 3.2 : Six Sigma is a defect rate of 3.4 per million; or an accuracy rate of greater than 99.99%

On Figure 3.2, dark blue is less than one standard deviation from the mean. For the normal distribution, this accounts for 68% of the set. For the normal distribution, two standard deviations from the mean (blue and brown) account for 95%. For the normal distribution, three standard deviations (blue, brown and green) account for 99.7%.

In practice, one often assumes that the data are from an approximately normally distributed population. If that assumption is justified, then about 68% of the values are at within 1 standard deviation away from the mean, about 95% of the values are within two standard deviations and about 99.7% lie within 3 standard deviations. This is known as the "68-95-99.7 rule".

Six standard deviations account for 99.99%. Many corporations have adopted this measure (known as Six Sigma) for Quality Control and try to achieve a defect rate of 3.4 per million.

Table 3.1 : Six Sigma – Goal

σ	*Defects per Million Opp.*
1	691,462
2	308,537
3	66,807
4	6,210
5	233
6	3.4

When comparing sigma, why choose six? In statistics, 3 sigma is the technically accepted standard for variation. Let's look at what each sigma level means in terms of defects. As we can see on the above table, at one sigma, there are 691,462 defects per million opportunities. For 3 sigma, that equates to 66,807 defects per million opportunities. At six sigma, one would have only 3.4 defects per million opportunities.

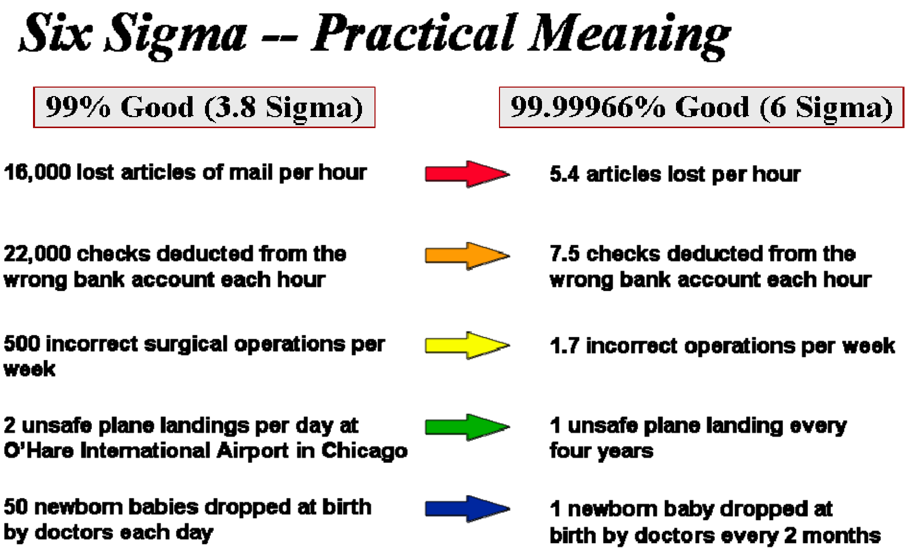


Figure 3.3 : Six sigma practical meaning [6]

In the practical sense, when considering critical processes, one can see the need to work towards six sigma because 3 sigma is no longer acceptable. If we cannot accept these defects, then the customer should not accept these defects also [6].

Understanding the behavior of process variables and problems can be described in this chart. Within a given specification, the results can be off-target in one or more directions or can vary in all kinds of directions. The goal of six sigma is not only to reduce the spread in the variation but also to center it so that the customer can be assured high-quality, on target product/service to a very high degree of certainty. The six sigma methodology identifies the processes that are off-target and/or have a high degree of variation. The goal of six sigma is to change the process from off target and with lots of variations to on-target and with much less variation.

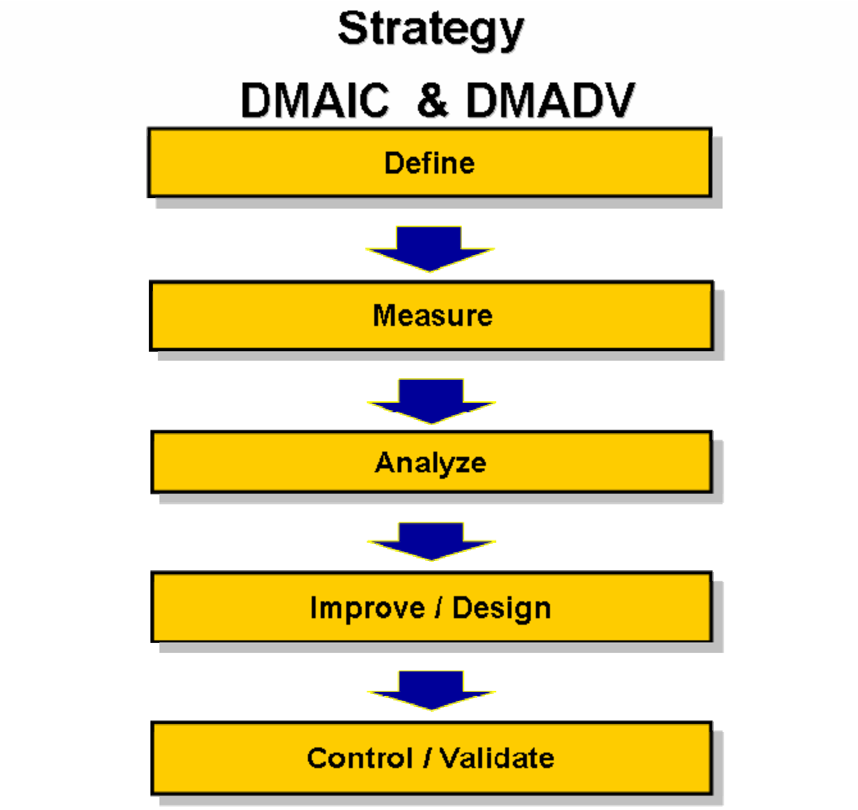


Figure 3.4 : Six Sigma strategy

There are two strategies for six sigma;

1- DMAIC, and

2- DMADV

The DMAIC methodology, instead of the Design methodology, should be used when a product or process is in existence at the company but is not meeting customer specification or is not performing adequately.

DMAIC is;

1- **D**efine the project goals and customer (internal and external)

2- **M**easure the process to determine current performance

3- **A**nalyze and determine the root cause(s) of the defects

4- **I**mprove the process by eliminating defects

5- **C**ontrol future process performance

The definition for the DMADV is; A product or process is not in existence at the company and one needs to be developed.

DMADV is;

1- **D**efine the project goals and customer (internal and external) deliverables

2- **M**easure and determine customer needs and specifications

3- **A**nalyze the process options to meet the customer needs

4- **D**esign (detailed) the process to meet the customer needs

5- **V**erify the design performance and ability to meet customer needs

3.1.1 DMAIC

Define Phase

The first step is to define the process. It is important at this stage all members of the team understand the process. This gives a common foundation for the team activities. Likewise, this is a good time to identify the outputs for measurement and the inspection and test. Also, at this stage, the team can estimate the sigma level at each stage.

The project scope sets the boundaries and goals for the team. One of the first objectives is to establish a Problem statement which is specific and measurable. It can also state the current state, the impact of the current state in measurable means (such as cost), and be objective.

This helps to establish a common and clear understanding about the project. It is a key to involve not only the executive members. For most six sigma projects, the goals and objectives should be obtainable in a reasonable time period, from 3 months to one year. Another common objective in most projects includes an improvement of 50% or better; in addition, monetary gains are sometimes set as objectives. For example, a project may be expected to save a minimum of $75,000; another project can have a minimal savings of ¼ million dollars.

The project scope should also identify key milestones in terms of completion. If the project is not completed within 120-160 days, there should at least be a major milestone to maintain the energy and make the goals obtainable. Short time schedule for completing have an improved likelihood of success.

Finally, the project must focus on identifying the customers, their needs and their requirements. In most processes, there are usually multiple customers; it is critical to determine all the customers, not just the final customer. The team can stratify the customer, maybe ranking them as primary, secondary, tertiary, etc. Different customers will have different but complementary needs; it is the integration of the different needs that makes the final product or service successful. Therefore, it is a key to understand the needs and the requirements of the customer. There is a distinction from needs and requirements. The need of a customer is the output that establishes the relationship between the supplier and the customer.

In the first step of the strategy process, one must define the process, inputs and outputs. At this step, one selects the output characteristics and identifies key process input and output variables.

One of the key tools for this step is process mapping. The importance of process mapping is to map what is REALLY going on, not just map what documents say should go on. It should capture ALL steps of the process.

Process mapping identifies all value added and non-value added and process steps, process inputs, and process and product outputs and data collection points. The output is the variable or item or feature which is deemed critical by the “customer”. The inputs are any variable which impact the output.

Measurement Phase

The second phase of the DMAIC method is the measurement phase. This phase is extremely important because one quantifies the existing capabilities.The measurement phase establishes the input/output variables, the capability of process, the defects and the sigma level of the process. It serves to verify that variation is due to the process and not the measurement system.

The purpose of the measurement phase is to:

- Identify and define defects
- Identify key input variables (X's) and key output variables (Y's). This consequently, determines the relationship between the inputs and defects.
- Document the existing process or establish a data collection system for your X's and Y's if one does not exist
- Evaluate measurement system or establish for each key output variable using cause and effects matrix, failure mode effects analysis, etc.

So what is a defect? A defect is any nonconformance to the specifications. In finding the problem, one has to know how to look for the appropriate problems. It is critical to understand the importance of defects.

Measurement is a key step because it establishes the capability and needs. Often, people may underestimate this stage because they feel that the do not need to look beyond their current measurement system; however, it is very important to not fall into this easy trap. True inputs can be difficult to find; sometimes, the input is actually several layers back and is well hidden. Therefore, it is very important to recognize and understand that the outputs (Y's) are determined by the inputs, the X's. Like a complex math formula, the output Y is a function of many different input variables, X's.

Thus, if one knows enough about the X's, one can more accurately predict Y without having to measure it. However, if one does not know much about the X's, then one has to resort to inspection and testing.

In addition, controlling the X's will reduce the variability in Y, which decreases the number of defects, cycle time, and possibly, eliminate/reduce non-value-added tasks such as inspection, testing, and rework.

The measurement stage looks for defects per unit; notice that when one determines the six sigma level, it establishes the defects per million. This number is the number that drives the plant-wide improvement. This number also allows one to benchmark within and across the companies.

$$\mathbf{DPMO} = \frac{\textbf{Total \# defects x 1,000,000}}{\textbf{(\# of Opportunities for Error) x (\# of units)}}$$

Figure 3.5 : The calculatıon formula for DPMO

To calculate sigma level, one first needs to determine three items: units, defects, and opportunities. Unit is the item produced or being serviced. Defect is any event that does not meet the customer's requirements. Opportunity is a chance for a defect to occur.

From these values, one can calculate the defects per million opportunities. The calculation for the DPMO is shown on Figure 3.5. Once the DPMO is determined, one can look at a sigma chart and estimate the sigma level.

We have to remember that the goal of the six sigma is zero defects; therefore, the higher the sigma level, the lower the number of defects.

Table 3.2 : DPMO and Sigma Level

DPMO	Sigma Level	DPMO	Sigma Level
1000000	-3.4	158655	2.5
999997	-3.0	66807	3.0
999968	-2.5	22750	3.5
999767	-2.0	6210	4.0
998650	-1.5	1350	4.5
993790	-1.0	233	5.0
977250	-0.5	32	5.5
933193	0.0	3.40	6.0
841345	0.5	0.29	6.5
691462	1.0	0.02	7.0
500000	1.5	0.00	7.5
308538	2.0	0.00	8.0

Table 3.2 is the sigma level chart. As seen in the chart, the number DPMO establishes the sigma level for the process. Ideally, if we look at what would be the most desirable level, one would look at a sigma level of 7.5 to 8.0 defects per million opportunities.

What makes six sigma different than other initiatives is that decisions and efforts are made from facts and data rather than "gut" feelings. For every action, there is a some method to quantify, not just qualify, its effect on the goals of the organization.

Analyze Phase

The third stage of the six sigma process improvement model is the Analyze phase. At that stage, once the baseline has been established, one must now determine why the problem exists. This phase establishes the baseline capability for potential and overall key output variables.

Purposes of the Analysis Phase are;

1- Establish baseline capability for key output variables (potential and overall)

2- Examine both the process and data for analysis

3- Determine and validate the root causation of project problem

4- To reduce the number of process input variables (x's) to a manageable number

5- To determine the presence of and potential elimination of uncontrolled variables

In order to analyze the data and/or process, there are many different tools to use. Such analysis tools are capability studies, multi-vari, hypothesis testing, ANOVA (Analysis of Variables), DOE (Design of Experiment), histogram, Pareto, cause and effect and root cause analysis. These methods are used to narrow the inputs, X's, that are truly causing the problems in the output.

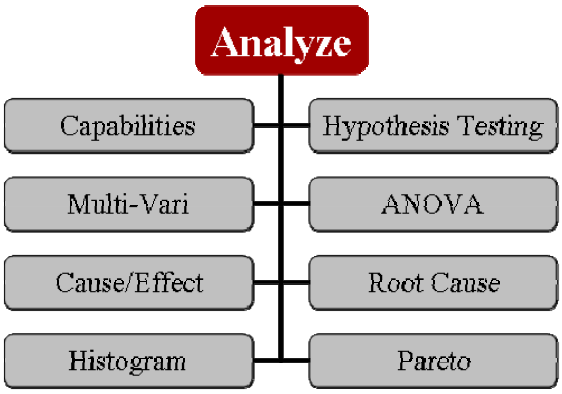


Figure 3.6 : Some of the Analyze Tools

Improvement Phase

The fourth stage is the improvement phase. At this stage the key variables that negatively affect the outputs that were identified in the analysis phase will be verified through a series of experiments. DOE Factorial experiments are also used to gain more knowledge about the main effects and interactive relationships.

Control Phase

The control phase is the last phase. Once the key variables have been identified and the improvements have been validated, the control plan for sustaining the gains must be developed and implemented. This plan needs to be specific with specific time frames and roles identified. The plan needs to be documented and communicated to all affected personnel. The plan should include methods to continually monitor the long-term delivered capability and performance. Finally, the control plan verifies the benefits and cost savings of the project. Control techniques are used to ensure the changes to the processes can maintain the improvement. Then the team can establish and implement the changes for long-term control. Some of the common techniques for controlling the improvements are: establish a control plan, Statistical process control, mistake proofing, and automated controls. Project reviews should continually monitor the program to ensure that the organization/department is holding the gains. Ultimately, the goal is to design for six sigma.

3.2 Understanding Human Factors concept with using Six Sigma Methodology

As long as there is an activity or process that produces some sort of output, then six sigma can be applied to it. Output can be a physical product or information or concept. Within an organization, one can look at all the departments that this may include and some more. Unlike other methodologies, six sigma is not limited to only the manufacturing sector. All divisions in a department can benefit from using the 6 sigma methodology. As long as there is a process with an output, then there is a place for six sigma, since every function has a customer and some deliverable to the customer. We have to remember, a customer can be both internal and external.

In the following part (Part 4 of this thesis) the six sigma concept has been used to identify the root causes of the problem which are raised because of the human error.

4 APPLICATIONS AND RESULTS

In this thesis I have had an opportunity to review the occurrences and findings data those have been listed in the files of the Quality Department of one of the certified private company in Turkiye as an aircraft and its components maintenance.

The Six Sigma methods have been used to evaluate the data and eliminate the errors that have been resulted from the internal and external audits of the subjected company processes and products.

To better understand the methods the followings have been documented for Six Sigma concept;

Phase 1 Definition of the problem

Phase 2 Measure of the problem

Phase 3 Analyze the data

Phase 4 Improve the process

Phase 5 Control the corrected process

From now on the above listed phases will be described for the data above mentioned.

4.1 Phase 1- Definition of the problem

An incident has occurred on the X type of aircraft (for the confidentiality of the occurrence and commercial data the details of the occurrences about the company name, aircraft type, manufacturer, registration and owner have not been mentioned). The aircraft was jacked for replacing of both main landing gear and nose gear dynamic and static seals by the chief inspector as requested by the work order. During lowering the aircraft, after oil seal change on main landing gears and nose landing gear aircraft stability was lost and aft jack cracked the fuselage skin at stage 1338. Skin, aft pressure bulkhead and surround structure was damaged. The following pictures have been taken just after the occurrence. The maintenance center informed customer, civil aviation authority and the manufacturer of the aircraft. The manufacturer of the aircraft has sent an investigator team immediately by customer request to analyze the cost of the corrective action of the occurrence/problem. The manufacturer of the aircraft has sent detailed prices as following;

$ 1,230,000 for fixed price labor (this includes the damage survey),

$ 188,000 for parts,

$ 85,000 for airfare,

$ 68,000 for freight for tooling and parts,

Sum of the above cost would be $ 1,571,000.

Customer decided to ground (not use) the aircraft.

4.2 Phase 2 - Measurement of the problem

The customer decided to ground the aircraft for the serviceable spare parts of other same type of the aircraft because of the cost of the maintenance since they have bought the aircraft for $2,500,000.

Figure 4.1 : A view of the occurence

Figure 4.2 : A view of the occurence

Figure 4.3 : A view of the occurence

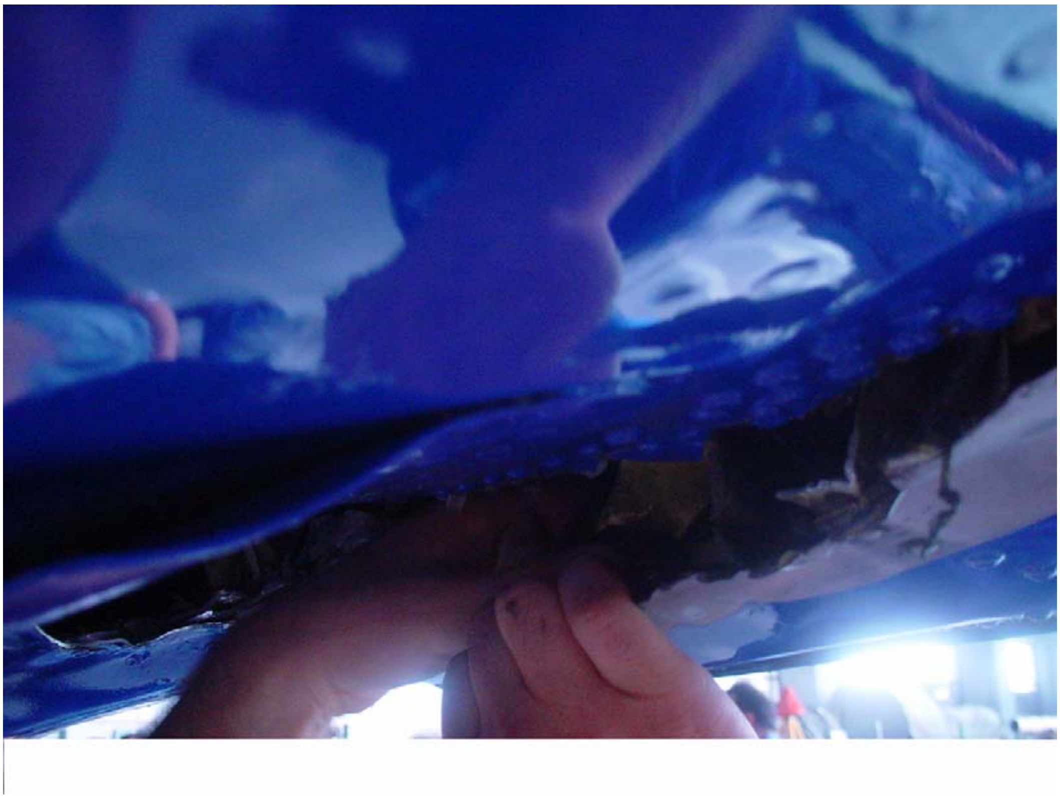


Figure 4.4 : A view of the occurence

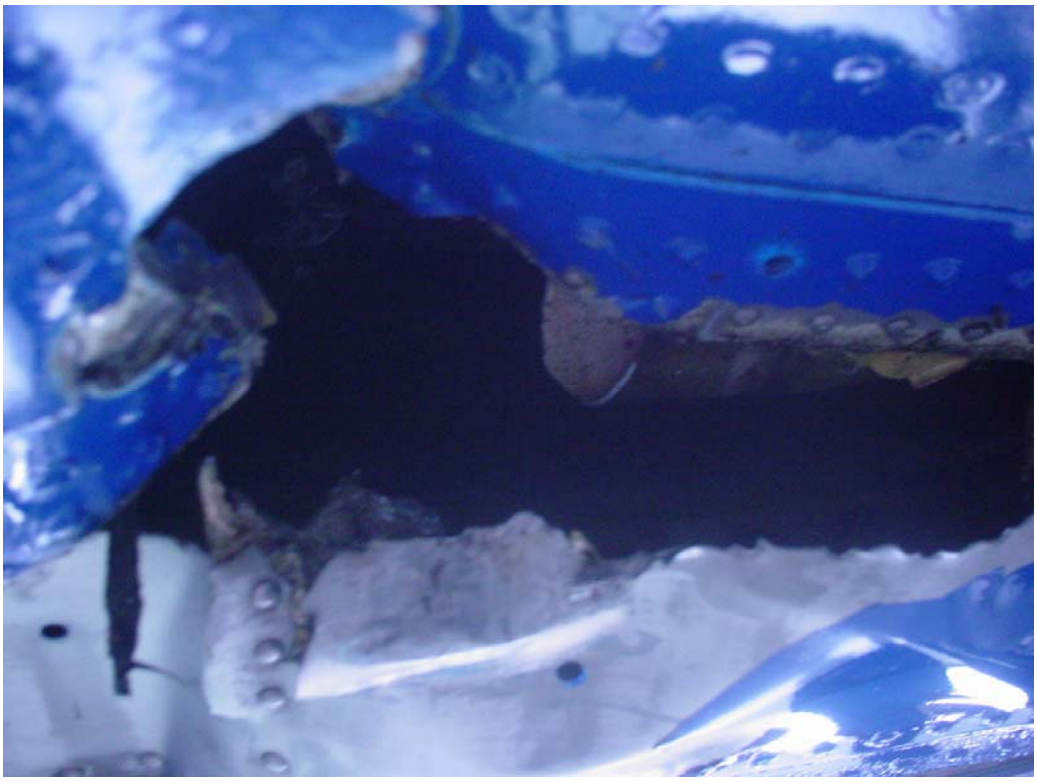


Figure 4.5 : A view of the occurence

Figure 4.6 : A view of the occurence

After the occurrence the quality department of the company set a team from the quality, engineering and maintenance department to investigate the occurrence and find out the route cause to prevent the reoccurrences.

For this purpose followings have been documented on the investigation report;

1- All structural task cards have been reviewed. It has been observed that all corrosion detected parts of the aircraft task cards have been released properly by the qualified technicians/certifying staff.

2- All non routine cards of the aircraft have been reviewed after the test flight of the aircraft. All of the non routine cards have been documented that all of them released properly by the qualified technicians/certifying staff.

3- The technicians who were working on the aircraft during the subjected maintenance were not qualified on the specified aircraft. They did not have the proper license to work on the subjected aircraft to perform the maintenance.

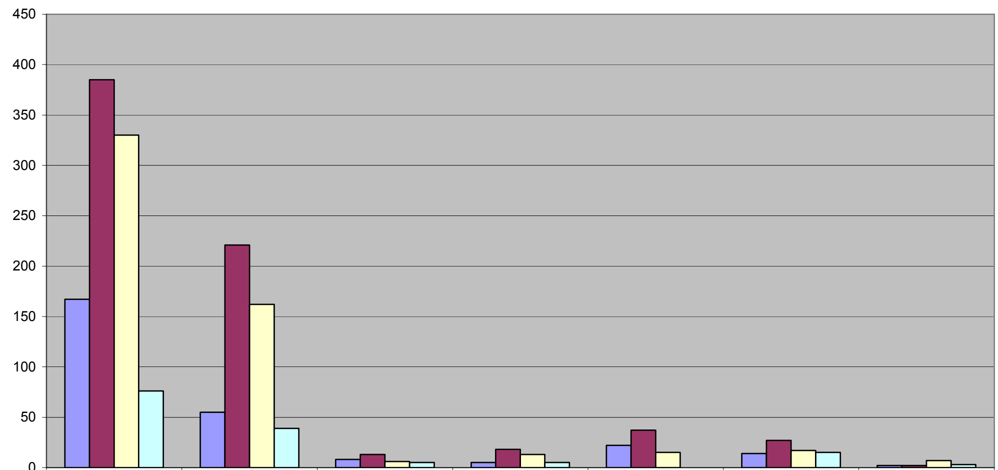
4- Similar task cards have been done before properly by the other maintenance staff many times properly. The licensed personnel were the main difference.

5- Conclusion: It has been recorded that the occurrence was because of the human factor error. After the occurrence, the maintenance center decided to train all personnel about human factor errors.

6- Corrective action: 1- Quality Manager trained all maintenance related personnel (523 people) on Human Factor Training. 2- The Training Manager and other qualified instructors trained 20 mechanics and 20 avionics on the subjected aircraft first. And after these trainings, the maintenance center instructed the maintenance personnel on the other aircraft types. 3- The Quality Department started more frequent audits on the maintenance personnel and products.

4.3 Phase 3 - Analyze the data

The followings are the data graphs those have been gathered from the Quality Department audit findings data of this company. The audit findings have been classified as listed on the following graph. The number of the findings has been indicated on the Y-axis of the graph and the classifications have been listed on the X-axis of the graph.



	factor type 1 HUMAN FACTOR	factor type 2 DOCUMENT DEFIENCY/ERROR	factor type 3 TOOL DEFICIENCY	factor type 4 EDUCATION DEFICIENCY	factor type 5 INCONVENIENCE OF SETTLING	factor type 6 ENVIRONMENTAL PROBLEM	factor type 7 CALIBRATION/ MISMEASURING
2003	167	55	8	5	22	14	2
2004	385	221	13	18	37	27	2
2005	330	162	6	13	15	17	7
2006	76	39	5	5	0	15	3

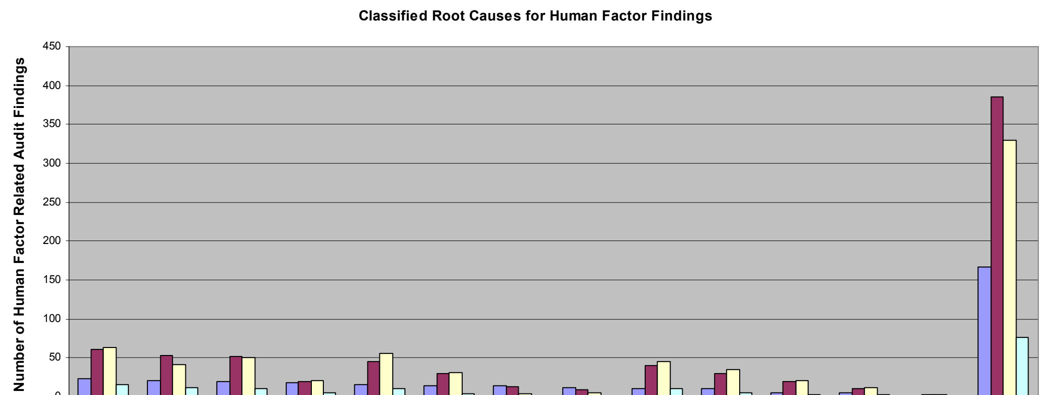
Figure 4.7 : Classification of the audit findings for 2003, 2004, 2005 and 2006.

Above graph, Figure 4.7, shows that the Human Factor is the statistically significant factor of the audit findings. The classifications of the findings have been done with the quality auditors' team. The audit team has conducted audits during the years 2003, 2004, 2005 and 2006. They have added the external audits which have been done by the customers' quality auditors externally.

Table 4.1 : Classified root causes of the human errors

	2003	2004	2005	2006
1- Incorrect installation of components	23	61	63	15
2- Fitting the wrong parts	21	53	41	12
3- Electrical wiring discrepancies	19	52	50	10
4- Loose objects left in the aircraft	18	20	21	5
5- Inadequate lubrication	16	45	55	10
6- Cowlings, access panels, and fairing not secured	14	30	31	4
7- Fuel/oil caps and refuel panels not secure	14	13	4	1
8- Landing gear lock pins not removed before departure	11	9	5	0
9- Not following regulations or procedures	10	40	45	10
10- Equipment misuse or equipment defects	10	30	35	5
11- Organizational (supervision/discipline)	5	20	21	2
12- Behavior (misjudgment/misperception)	5	10	12	2
13- Physical Circumstances (night, etc.)	1	2	2	0
TOTAL	167	385	330	76

Under Human Factors the followings were the classified root causes of the human errors (Table 4.1 and Figure 4.8);



	1- Incorrect installation of components	2- Fitting the wrong parts	3- Electrical wiring discrepancies	4- Loose objects left in the aircraft	5- Inadequate lubrication	6- Cowlings, access panels, and fairing not	7- Fuel/oil caps and refuel panels not	8- Landing gear lock pins not removed	9- Not following regulations or	10- Equipment misuse or equipment	11- Organizational (supervision/di	12- Behavior (misjudgment/ misperception)	13- Physical Circumstances (night, etc.)	TOTAL
2003	23	21	19	18	16	14	14	11	10	10	5	5	1	167
2004	61	53	52	20	45	30	13	9	40	30	20	10	2	385
2005	63	41	50	21	55	31	4	5	45	35	21	12	2	330
2006	15	12	10	5	10	4	1	0	10	5	2	2	0	76

Figure 4.8 . Classified root causes for the human factor findings

4.4 Phase 4 - Improve the process

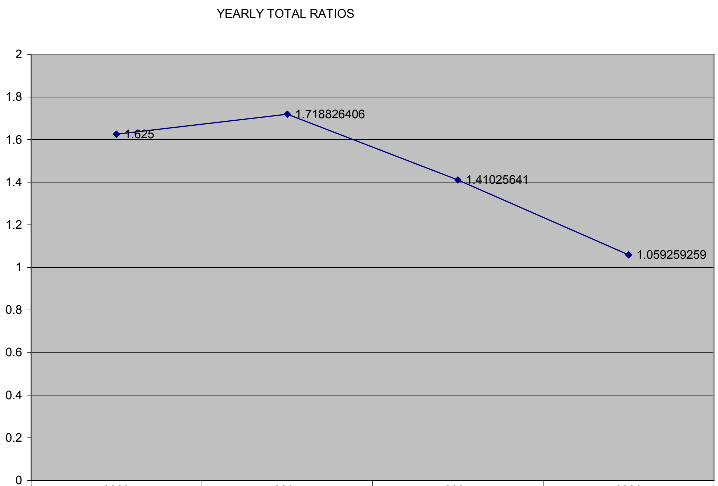
Since the statistically significant factor has been found that the root cause of the findings is human factors the Human Factors Training has been started for the maintenance personnel by the Quality Department of the company as of October 2005. Quality Department initiated a Crew Coordination Concepts program “to equip all maintenance personnel with the skill to use all resources to improve safety and efficiency”. First year results were remarkable:

- 523 employees received training (2/3 workforces)

- Maintenance ground damage cost cut by 66%

- Dramatically curtailed upward trend in injuries

The next year (2006) audit findings showed that statistically significant root cause was still human factor; however the ratio was decreasing compared to the previous year. Of course the Human Factors training was not the main cause for the decreasing ratio. We should not disregard the other development factors like management decisions for hiring the right people, buying the required tool and constructing a new building for the maintenance personnel for their resting area during the break time of their work. All these positive developments helped to decrease the number of the findings in 2006 compared to 2003, 2004 and 2005 (Figure 4.9).



	2003	2004	2005	2006
YEARLY TOTAL RATIOS	1.625	1.718826406	1.41025641	1.059259259

Figure 4.9 : The number of the findings in 2006 compare to 2003, 2004 and 2005 are decreased

The numbers of the audits have been calculated from the checklists. It has been assumed that each checklist which has been used during the audit has 10 questions as an average value. From this assumption, the following Table-4.2 has been used for the calculation of the sigma level of the company's all processes;

Table 4.2 : Data for calculation of the sigma levels

Years	Number Of Performed Audits	Average Number of Questions For Each Of The Audit	Total Number Of Questions	Total Number Of Findings	DPMO	Sigma Level
2003	36	10	360	167	463888.9	1,59
2004	103	10	1030	385	373786.4	1,82
2005	132	10	1320	330	250000.0	2,17
2006	47	10	470	76	161702.1	2,49

Figure 4.10 shows that by using chi-square test it is statistically significant that wach years' number of audit findings are different.

Figure 4.11, 4.12, 4.13 and 4.14 shows the level of the sigma for 2003, 2004, 2005 and 2006.

Chi-Square Test

Hypotheses:

H_o: All groups the same

H_a: At least one different

Group	Total Number of Questions	Total Number of Findings	Expected	Chi-sq
2003	360	67	248.322	50.225
2004	1030	385	1426.923	110.411
2005	1320	330	1223.077	7.681
2006	470	76	281.678	125.906
Totals-------->	3180	858		

294.223 **<--------Chi-Sq**

df---> 3

7.815 **<---------Critical Chi-Sq**

0.000 **<--------- p-value**

Figure 4.10 : P value is less than 0.05 which means that each year's audit status is statistically different than each other

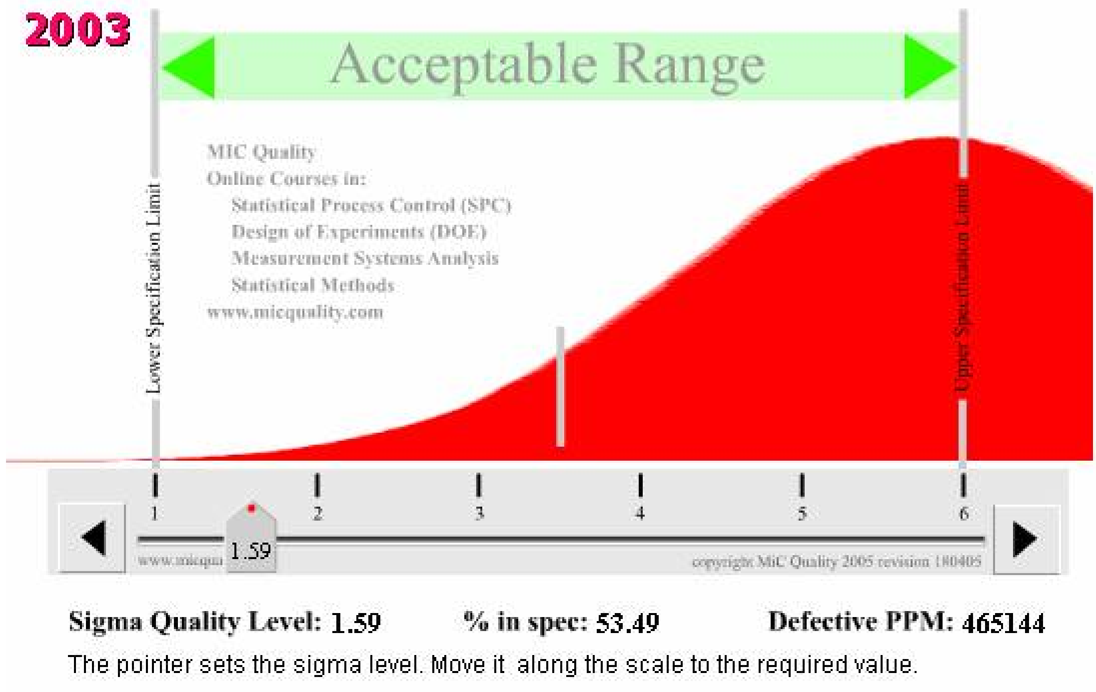


Figure 4.11 : The Sigma Level for 2003

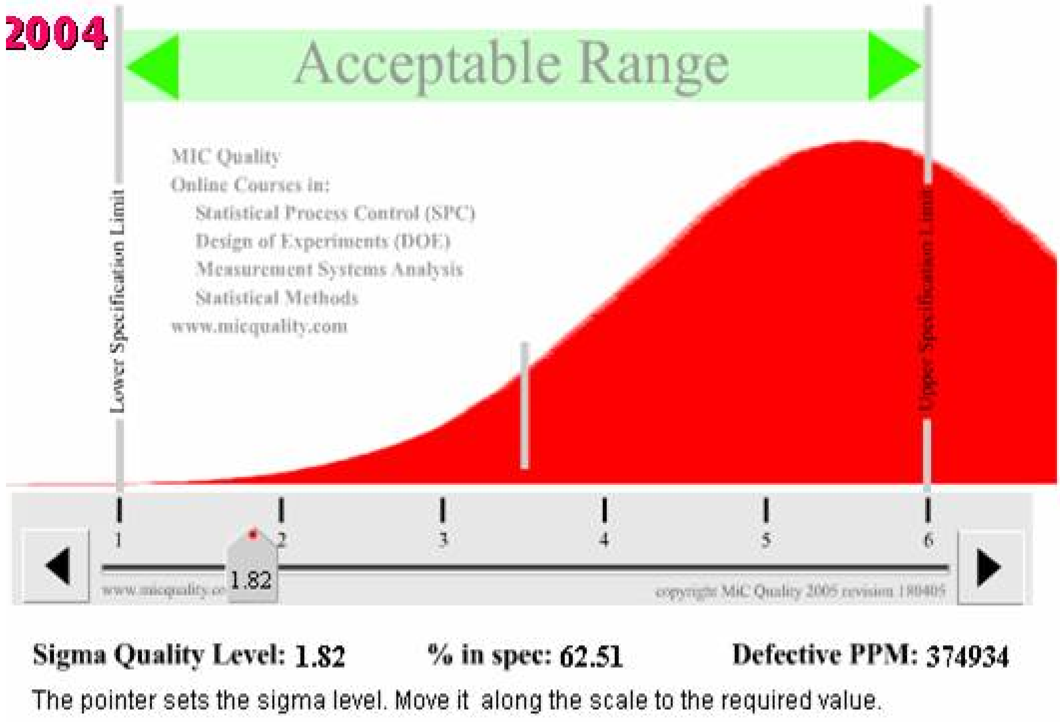


Figure 4.12 : The Sigma Level for 2004

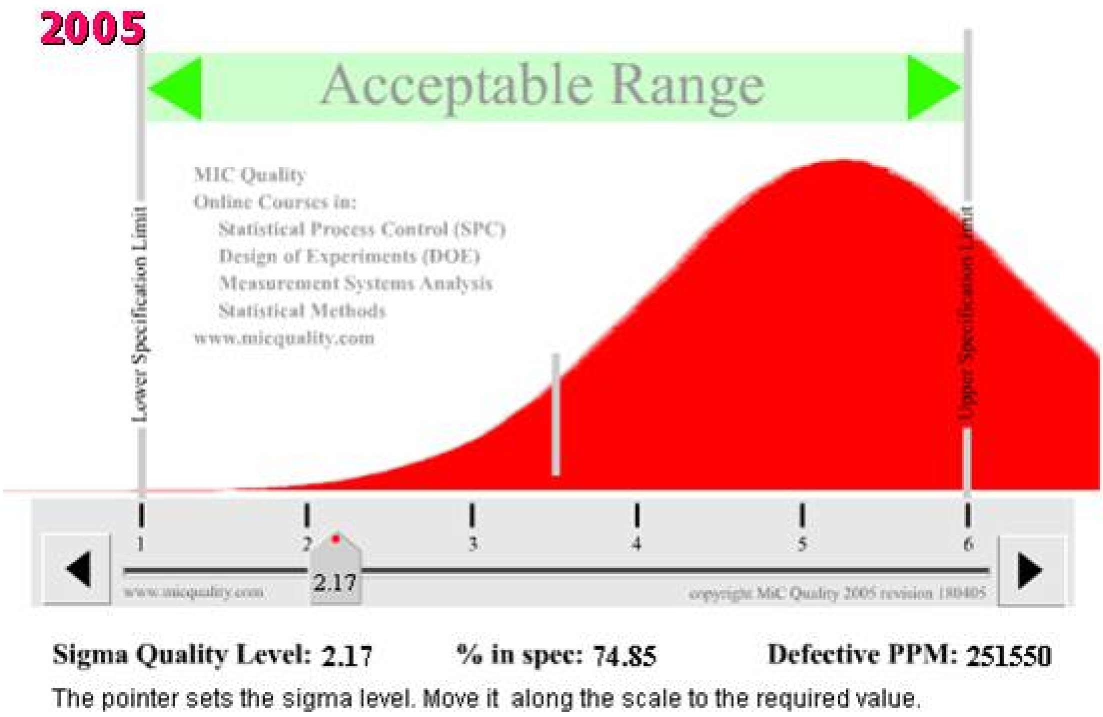


Figure 4.13 : The Sigma Level for 2005

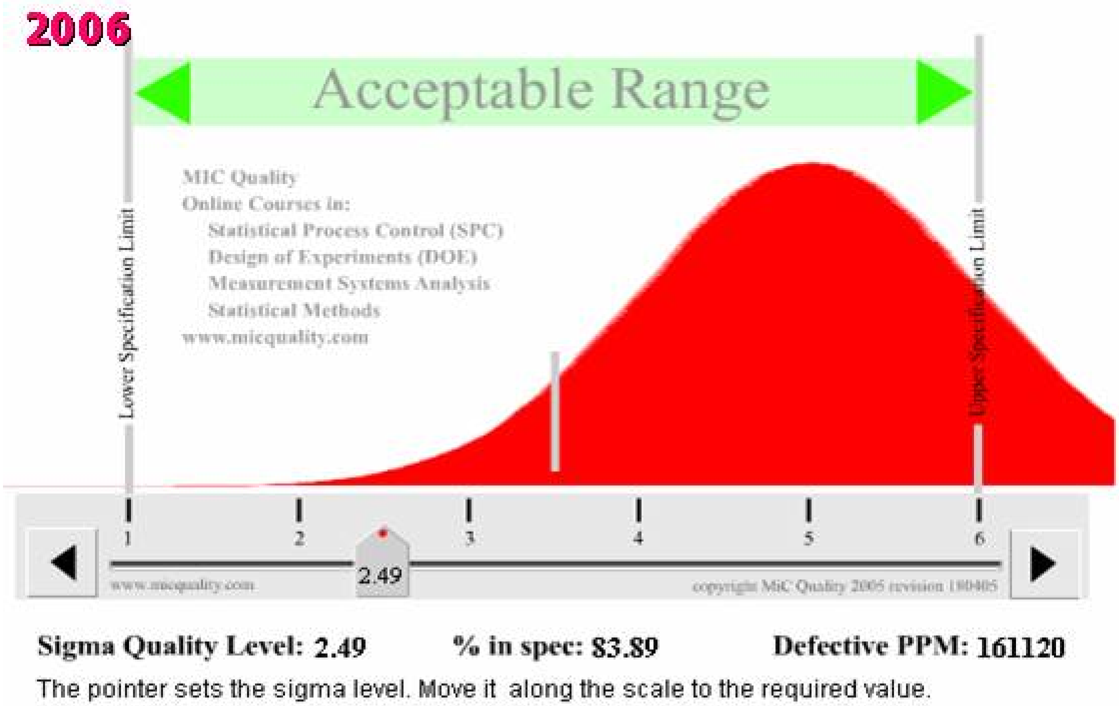


Figure 4.14 : The Sigma Level for 2006

It is statistically significant that the sigma level of the audit status for the previous year has been increased.

4.5 Phase 5 - Control the corrected process

In the control phase the Quality and the Training Departments worked together to implement the improve phase with the audit findings.

Clearly the Quality Department of the maintenance company has bought into Maintenance Resource Management or "MRM". Quality Department initiated a Human Factor Training program "to equip all maintenance personnel with the skill to use all resources to improve safety and efficiency." The two day workshop covers organizational routines, assertive behaviors, leadership styles, stress management, decision-making, and interpersonal skills. The results after the first year of Human Training Program were remarkable:

- 523 out of the targeted 523 personnel received training which means all trained
- Maintenance ground damage costs were reduced by 66%
- Occupational injuries were down 27%

5 CONCLUSION AND DISCUSSION

As the nature of human is variable depending on many factors, a systematic approach to measure the performance and reduce errors is very difficult. However this is essential for reducing human factors in aircraft maintenance errors. As the basic approach in six sigma methodology is “if you can not measure it, you can not improve it”, this thesis identifies human factors as the “Y” of the problem and tries to identify probable causes of human factor errors, or in six sigma terminology, problem “X”s. This sets up a methology to analyse human factor errors in aircraft maintenance using the six sigma approach. Using this approch a sample real life problem is defined and as a result of this very significant accident, human factor errors are analyzed by evaluating the data on findings as a result of audits conducted by QA department and the identified solution is implemented such that the improvements are also visible and permanent.

This thesis also shows that human factors in aircraft maintenance are a very critical element to consider in reducing maintenance errors. What is shown here is that the old school approach of “fire the technician who did the error” is not the right way to resolve the problem. The more effective way is to evaluate the reasons, namely the “why”s of that human factor in the error and reduce or eliminate the reasons underlying such that this error or similar errors will not occur whoever the person conducting the maintenance action is. To do this, a systematic approach works the best, also to reduce the variation in analyzing the problem from case to case. For this reason, it is shown that six sigma methodoly is not only effective for manufacturing environment problems but also very useful for human factor analysis in aircraft maintenance.

It is presented in the previous studies that human factors had been a subject where various other solution methods had been presented before. The basic difference of this study is that it uses the six sigma methodology which allows:

- only 3.4 defects per million opportunities that is an acceptable standart for aviation assuming realistically that zero defect is not possible, which is a number that not only evaluates short term performance but also takes into consideration the long term shift in fixed systems,

- it is a measurement based technique where the probability of biased analysis due to human involvement is minimized, where an example is that the errors in maintenance are not evaluated as single events by named persons but as a sample of a much larger population of events,

- and uses statistical tools to analyze the data that results in a realistic solution by means of considering the variations possible from the obtained data where an example to this is that there is always a minimum number of data points required to obtain a statisitcaly significant result, and the more data availible, the more reliable analysis is possible, resulting in an engineering oriented solution for human factors in aircraft maintenance.

Relying on the fact that most of the management personel in aviation maintenance has an engineering background, this approach could prove to be easy to understand and widely applicable to human factors analysis in aircraft maintenance.

Again, the best way to promote Human Factors awareness is by training. There are a host of other HF briefs and resources available from military and civilian safety and aviation agencies.

- An effective operational risk assessment process

- Incorporate HF into safety program

- HF council/board

- Ongoing HF training for all personnel

Devoting time and resources to Human Factors as a stand-alone program may prove inefficient and administratively burdensome. However, a structured Human Factors program does fit very well under the umbrella of the Organization’s Operational Risk Management process (ORM).

The intent of ORM is to minimize risk associated with maintenance safety. As we have already seen, problems with the human link in the operational chain may present the greatest risk or set of risks to operational readiness. To date, there have been many examples documenting the outstanding success of ORM. In this regard, it becomes paramount that safety personnel become ORM specialists.

Another way to ensure that Human Factors programs can be promulgated is by incorporating one into an organization's Safety program. This does not require any added administrative processes. Rather, incorporation of a Human Factors necessitates an ongoing program of training and awareness.

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APPENDIX

DEFINITION OF TERMS

Accident

An aviation accident is an occurrence on board an aircraft resulting in injury or death to one or more persons.
The U.S. National Transportation Safety Board definition of an aviation accident is as follows:
An occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight and all such persons have disemboweled.

Aircraft Maintenance Technician (AMT)

Due to the increasing complexity of new aircraft, maintenance is becoming a more critical function. In the early days of aviation, aircraft maintenance was considered a higher level of automotive maintenance not far removed from that of an automobile and similar skills could be successfully employed in either endeavour. Such consideration could not survive for long as aircraft technology quickly developed into a much more complex technology. Today aircraft maintenance technicians must know a good deal about system theory, be able to perform complex tests and interpret results, maintain structural elements that differ greatly from typical riveted aluminum structures and evaluate sensitive electronic and automated systems where a mistaken application of the simplest task can cause considerable loss in damage. Trends in aircraft and systems development clearly indicate that future aircraft technicians, in order to perform successfully, will need to be highly educated and trained to the level of a degree in engineering or its equivalent.

Aviation Incident

An aviation incident is an occurrence other than an accident, associated with the operation of an aircraft, which affects or could affect the safety of operations.
Other countries adopt a similar approach, although there are minor variations, such as to the extent of aviation-related operations on the ground, covered, as well as with respect to the thresholds beyond which an injury is considered serious or the damage is considered substantial.

Chi Square Test

A chi square test, also called "test of association", is a statistical test of association between discrete variables. It is based on a mathematical comparison of the number of observed counts with the number of expected counts to determine if there is a difference in output counts based on the input category. Use with Defects data (counts) & defectives data (how many good or bad). Critical Chi-Square is Chi-squared value where p=.05.

Data

Data is factual information used as a basis for reasoning, discussion, or calculation; often this term refers to quantitative information

Defect

A defect is any nonconformity in a product or process; it is any event that does not meet the performance standards of a Y.

Defective

The word defective describes an entire unit that fails to meet acceptance criteria, regardless of the number of defects within the unit. A unit may be defective because of one or more defects.

Discrete Data

Discrete data is information that can be categorized into a classification. Discrete data is based on counts. Only a finite number of values is possible, and the values cannot be subdivided meaningfully. For example, the number of parts damaged in shipment produces discrete data because parts are either damaged or not damaged.

DPMO

Defects per million opportunities (DPMO) is the number of defects observed during a standard production run divided by the number of opportunities to make a defect during that run, multiplied by one million.

EASA (European Aviation Safety Agency)

Civil Aviation Authority of the European Union

FAA (Federal Aviation Administration)

Civil Aviation Authority of the United States of America

General aviation

All flying by civil aircraft other than high capacity air transport aircraft, gliders and sport aviation.

Hull-Loss Accident

A hull-loss accident is one where the damage to the plane is such that it must be written off, or in which the plane is totally destroyed.

IATA

The International Air Transport Association - was founded in Havana, Cuba, in April 1945. It is the prime vehicle for inter-airline cooperation in promoting safe, reliable, secure and economical air services - for the benefit of the world's consumers. The international scheduled air transport industry is now more than 100 times larger than it was in 1945. Few industries can match the dynamism of that growth, which would have been much less spectacular without the standards, practices and procedures developed within IATA. At its founding, IATA had 57 Members from 31 nations, mostly in Europe and North America. Today it has over 270 Members from more than 140 nations in every part of the globe.

ICAO (International Civil Aviation Organization)

The ICAO is the UN (United Nations)'s technical agency for aviation which establishes international standards and recommends practices for aircraft operations and maintenance.

JAA (Joint Aviation Authorities)

Joint Civil Aviation Authorities of the civil aviation.

JAR OPS Part 1 (JAR OPS1)

JAR-OPS Part 1 prescribes requirements applicable to the operation of any civil aeroplane for the purpose of commercial air transportation by any operator whose principal place of business and is in a JAA Member State.

Maintenance area

A general locality in which are grouped a number of maintenance activities for the purpose of retaining or restoring material to a serviceable condition.

Maintenance engineering

The application of techniques, engineering skills, and effort, organized to ensure that the design and development of aircraft systems and equipment provide adequately for their effective and economical maintenance.

Maintenance (material)

1. All action taken to retain material in a serviceable condition or to restore it to serviceability. It includes inspection, testing, servicing, and classification as to serviceability, repair, rebuilding, and reclamation.
2. All supply and repair action taken to keep a force in condition to carry out its mission.
3. The routine recurring work required to keep a facility (plant, building, structure, ground facility, utility system, or other real property) in such condition that it may be continuously used at its original or designed capacity and efficiency for its intended purpose.

Make safe

One or more actions necessary to prevent or interrupt complete function of the system (traditionally synonymous with “dearm,” “disarm,” and “disable”). Among the necessary actions are:

1. install (safety devices such as pins or locks);
2. disconnect (hoses, linkages, batteries);
3. bleed (accumulators, reservoirs);
4. remove (explosive devices such as initiators, fuzes, detonators); and
5. intervene (as in welding, lockwiring).

Maintenance status

1. A non-operating condition, deliberately imposed, with adequate personnel to maintain and preserve installations, material, and facilities in such a condition that they may be readily restored to operable condition in a minimum time by the assignment of additional personnel and without extensive repair or overhaul.
2. That condition of material that is in fact, or is administratively classified as, unserviceable, pending completion of required servicing or repairs.
3. A condition of material readiness that reports the level of operational readiness for a piece of equipment.

P-Value

The p-value represents the probability of concluding (incorrectly) that there is a difference in the samples when no true difference exists. It is a statistically calculated by comparing the distribution of given sample data and an expected distribution and is dependent upon the statistical test being performed. For example, if two samples are being compared in a t-test, a p-value of 0.05 means that there is only 5% chance of arriving at the calculated t value if the samples were not different (from the same population). In other words, a p-value of 0.05 means there is only a 5% chance that you would be wrong in concluding the populations are different. P-value < 0.05 = safe to conclude there's a difference. P-value = risk of wasting time investigating further.

Sigma

The Greek letter s (sigma) refers to the standard deviation of a population. Sigma, or standard deviation, is used as a scaling factor to convert upper and lower specification limits to Z. Therefore, a process with three standard deviations between its mean and a spec limit would have a Z value of 3 and commonly would be referred to as a 3 sigma process.

SHY145, JAR 145 and IR Part 145

These documents establish the requirements to be met by an organisation to qualify for the issue or continuation of an approval for the maintenance of aircraft and components.

SHY66, JAR 66 and IR Part 66

For the purpose of documents, the competent authority shall be the authority designated by the civil Aviation Authority to whom a person applies for the issuance of an aircraft maintenance licence.

Training

Activity under the supervision of an appropriate instructor for the purpose of practical instruction for the issue or renewal of a licence or rating. Includes aircraft type endorsement/conversion and navigation exercises conducted as part of a course of the training.

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