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Application and Development of Aircraft Maintenance Procedures using Lean Tools

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The jury members certify that the study conforms to acceptable standards of scholarly presentation and is fully adequate in scope and quality as a dissertation for the degree of Master in Aviation Management.

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I hereby declare that this is my original work and has never been presented for a degree or any award in any university or any academic institution of higher learning. It is all the result of my own effort and under the supervision of **Asst. Prof.Dr. M. Yildiz.**

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PREFACE

I thank to Dr M. Yildiz, my supervisor on this work, whois perfectly aware of thesis topic, concerning to aircraft maintenance, MRO processes and for his patience, support and assistance which have proved to be valuable.Since the establishment of the aeronautical industry, aircraft maintenance has been an important and integral part of the Aviation. At the heart of maintenance activities is to maintain airworthiness of the airplanes, ensuring the flight safety as well as passengers, and all of transported items by the air. Having a 25 years' experience in the field of aircraft maintenance and to follow up the further developments in the MRO sector, which became a motivated writing of this dissertation. It allows to be aware of the modern achievements in science in the field of new technologies applying in the new generation aircraft manufacturing progresses, as well as of their maintenance processes.Also like to thank for the engagement, and assistance engineers from SW Technics, Cargolux and Hydro System, that contributed to the success of this research.This study will be useful for the maintenance staff of the MRO organization, the Continuous Airworthiness Department of the Airlines as well as for researchers.

ABSTRACT

The current problem of the MRO organizations is competitiveness in the environment of the aircraft maintenance, which the main task is to improve the quality of the maintenance and reduce aircraft downtime. This study examines how the MRO can improve the procedures of an individual aircraft maintenance by implementing Lean tools, in the combination of Six Sigma methods. The aim is analysing the maintenance processes to determine the existing problems to minimize downtime of the aircraft in this area. Using the data collected from the experts of the MRO, Airlines, and an Equipment manufacturer, an analysis was made on engine replacement processes. As a result of novel tool is proposed utilizing hydraulic lift engine hoists. The result shows this approach is allowed to eliminate unnecessary tasks from the Aircraft Maintenance Manual (AMM) and also reduces a turnaround time by more than 7 hours in a single process. The measurement which is based on the final results, validates main contributions for MRO organisations through savings in time and human resources, thereby reducing maintenance cost and an aircraft down time satisfying the customer.

Keywords: MRO, Maintenance, Lean Six Sigma, Engine, Lean Implementation.

ÖZ

MRO organizasyonlarının mevcut sorunu, temel görevi bakımın kalitesini iyileştirmek ve uçak arıza süresini azaltmak olan uçak bakım ortamındaki rekabet gücüdür. Bu çalışma, MRO'nun Altı Sigma yöntemlerinin birleşiminda Yalın araçları uygulayarak bireysel uçak bakım izlek nasıl iyileştirebileceğini incelemektedir. Amaç, bu alandaki uçağın arıza süresini en aza indirmek için mevcut sorunları belirlemeye yönelik süreçleri analiz etmektir. Bakım çabası ve MRO, Havayolları ve Ekipman üreticisinin uzmanlarından toplanan veriler kullanılarak, motor değiştirme süreçleri üzerinde bir analiz yapıldı ve hidrolik asansör motor kaldırma tertibatı kullanılarak yeni bir araç önerildi. Sonuç, bu yaklaşımın, Uçak Bakım El Kitabından (AMM) gereksiz görevleri ortadan kaldırmasına ve ayrıca tek bir işlemde geri dönüş süresini 4 saatten fazla azaltmasına izin verildiğini göstermektedir. Nihai sonuçlara dayalı ölçüm, finans ve insan kaynaklarında tasarruf yoluyla MRO kuruluşlarına yönelik ana katkıları doğrular, böylece bakım maliyetini ve müşteriyi tatmin eden uçak arıza süresini azaltır.

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ABBREVIATIONS

AD - Airworthiness Directive

AMM – Aircraft Maintenance Manual

CMMS - Computer Managed Maintenance System

CSF - Critical Success Factor

CTQ - Critical to Quality

DFSS - Design for Six Sigma

DMAIC - Define Measure Analyse Improve Control

DOE - Design of Experiment

DT - Down Time

EAM - Enterprise Asset Management

EASA - European Aviation Safety Agency

EPA - Environmental Protection Agency

ERCP - Electronic Remote Control Panel

FAA - Federal Aviation Administration

FC - Flight Cycles

FH - Flight Hours

FLA - Fair Labor Association

GDP - Gross Domestic Product

GEnx - General Electric New Generation

GSE - Ground Support Equipment

HoW - House of Wastes

HSCM - Hospital Supply Chain Management

IATA – International Aviation Transport Association

ICAO - International Civil Aviation Organisation

JIT - Just in Time

LEI - Lean Enterprise Institute

LM - Lean Maintenance/Manufacturing

LSSF - Lean Six Sigma Framework

LSS - Lean Six Sigma

MOE - Maintenance Organisation Exposition

MPD - Maintenance Planning Document

MRBR - Maintenance Review Board Report

MRO - Maintenance Repair Overhaul

MSG - Maintenance Steering Group

NVA - Non Value Added

OEE - Overall Equipment Effectiveness

PAM - Process Activity Map

PDCA - Plan Do Control Act

PW - Pratt and Whitney

QEC - Quick Engine Change

QM - Quality Manual

PM – Proposed Method

RCM - Reliability Centered Maintenance

RFID - Radio Frequency Identification

RI – Removal Installation

SARP - Standards and Recommended Practices

SIPOC - Supplier Input Process Output Customer

SMED - Single Minute Exchange of Die (One Minute Die Change)

SS - Six Sigma

TAT - Turn Around Time

TC – Task Cards

TQM - Total Quality Management

TPM - Total Preventive/Productive Maintenance

TPS - Toyota Production System

VA - Value Added

VF - Visual Factory

VM - Visual Management

VSM - Value Stream Mapping

VoC - Voice of Customer

CHAPTER ONE

INTRODUCTION

In the aviation sector the maintenance, repair and overhaul is a complicated process, which holds specific and rigorous requirements outlined by aircraft and engine manufacturer, and the authorities of safety and reliability for guaranteeing the aircrew and passengers' safety. MRO refers to every action working towards the purpose of restoring or retaining an item to a state in which it is able to perform its aimed functionality (Vieira & Loures, 2016). The integration of every supervisory, managerial, and technical activities are presented in the above-stated actions in the MRO. The engineering department of the MRO, in the aviation industry is responsible for the implementation of the aircraft and engine maintenance program, evaluation of Service Bulletins (SB) and Airworthiness Directives (AD) and could be outlined as the arm of the industry performing design's function.

According to Hill et.al (2018), MRO's business model is the integration of logistic configuration and technical capacity that count the practices of outsourcing and vertical integration of the supply chain. The worldwide airline has generated a robust financial outcome in the last decade because of many factors wherein MRO was the prominent factor. As the study of Oliver Wyman's shows that there will be a major development in Asia's engine market, particularly in India and China, and this area will become the largest area, almost doubling up the in-service fleet and other linked maintenance, and the demand of repair and overhaul (Cooper et al., 2018).

The upcoming years will experience the view of enhancing the productivity of the activities of MRO wherein seventy-three percent of the firms proposing MRO services target the enhancement of the product's reliability of the undergoing activities of MRO, while sixty-four percent target to enhance the effectiveness of modern resources included in these processes (Cooper et al., 2018). Nowadays, digital and new technology services endure to evolve, however still haven't replied significant to win work in the MRO market.

1.1 Background of the study

The concept of lean is originated by Eli Whitney in 1799 and came up with the interchangeable parts' concept is configuration management (Yadav et.al, 2020). In the late 1890s, Frederic Taylor laid the foundation for the concept of scientific management with the study of organizing work, analyzing its elements, and systematically improving the performance of each of these elements (Murphy, 2011). His implemented methods and tools used in the various stages of steel manufacture allowed workers to produce significantly more product with less effort and further refinements were made by B. Frank and his wife Lillian M. Gilbreth based on time-motion studies, which developed the new manufacturing systems and processes (Smith and Hawkins, 2004).

While in 1913, Henry Ford was the first person who incorporated the lean concept in the manufacturing arrangement and promoted production's flow by investigating with movement and interchanging of various parts to accomplish work's standardization. Ford's system had a limitation of lacking variety and can be implemented to a just one specification (Yadav et al., 2020). The integration of the production system carried out by Ford is called mass-production that manufactures standard products in bulk. The flow production includes constant movements of elements via the process of production (Kamble et.al, 2020). Mass production was utilized by Ford for fabricating and assembling the parts of the vehicles in a less time. Mass production was considered the best and most widespread production method because it produced high productivity per worker and at the same time produced products at low prices (Leite and Vieira, 2015).

Lean manufacturing usually represents a paradigm shift from traditional "batch and queue," functionally adjusted mass production, to "one-piece flow," product-oriented pull production, accordingly requires tightly controlled processes in a well-maintained, order and clean operating environment that incorporates the principles of just-in-time production and continuous system-wide improvement with employee participation (Sun, 2011). The difference between traditional and Lean manufacturing paradigms approach shown in Table 1.

Table 1. Craft, Mass and Lean Thinking Compare. Source: Sun (2011).

	Craft production	Mass production	Lean Production
Focus	Task	Product	Customer
Operations	Single items	Bath and queue	Synchronized flow and pull
Overall Aim	Mastery of craft	Reduce cost and increase efficiency	Eliminate waste and add value
Quality	Integration (part of the craft)	Inspection (a second stage, after production	Prevention (built in by design and methods
Business strategy	Customization	Economies of scale and automation	Flexibility and adaptability
Improvement	Master-driven continuous improvement	Expert-driven periodic improvement	Workforce-driven continuous improvement

Using a mass system, increased the production line up to 10000 cars in the first year it is employed, with a price is decreasing 60% per a car and enabled Ford to dominates in the auto market while shares 2/3 by to 1920s (Murphy, 2011).

Realizing the importance of the philosophy of the lean manufacturing, which is to eliminate any waste in the production process and fine-tune everything according to the needs of the customer.

In1896 Sakichi Toyoda, a founder of Toyota Industries, invented a sensitive power loom that automatically detect thread breaks and stop before the defect was discovered by workers, so customers who are used Toyoda loom could weave higher quality fabrics than those who are used competitor looms. Later, Kiichiro Toyoda, a son of Sakichi and a founder of the Toyota Motor Company, before the Second World War has developed the first Toyota Production System (TPS) elements referring on his own visions which an ideal working an environment where machines, equipment and people work together like the needle a clock. (Blanco and Dederichs, 2018).

Kiichira as the new Managing Director of the plant, after a year of studying at Ford Motor Company in Detroit, American Automotive Manufacturing returned to Japan gaining knowledge and was determined to adapt the system to smaller production volumes and improve basic methods by providing for different processes in the assembly production sequence including material logistics management to match a production consumption, and also developed a network of suppliers capable of supplying components as needed, which he was called the Just-in-Time (JIT) a system within the Toyoda Group (Smith and Hawkins, 2004). Despite the use of well-known methods by the company such as 5S, Poka Yoke and Just in time, it provided for the constant correction of deficiencies in the processes, and products (Blanco and Dederichs, 2018).

“Lean manufacturing” concept is originated from the Toyota Production System (TPS) started to be used in automobile company in Japan. The system started to use around 1940s to improve efficiency and gain competitiveness in automobile sector and the concept of lean manufacturing became popular worldwide after publications by Womack and Jones in 1990 “The machine that changed the world” (Dora et.al, 2013).

Japan, was isolated from the world industry, lack of raw materials and construction aids, such as in Germany and other European countries, where eliminating waste became difficult and even in the post-war years, the situation hardly improved. To escape this difficult situation (Toyota was on the edge of bankruptcy around 1950s), Toyota Production System (TPS) was the first model of lean management that had been developed after the Second World War (Bajjou et.al, 2018). Avoidance waste considering ideas the American Edward Deming’s which offered continuous improvement process served as tool for Toyota to establish the philosophy for rapid improvement effort, minimize the waste within production process, reduce costs and achieving good quality product for customer.

Cousin Eiji Toyodo took over the company after Kiichiro’s resignation, and then travelled to the United States to study the American car manufacturing system and implemented the first Kaizen (Continuous Improvement) process in the Toyoda Group, while Taiichi Ohno joined the group, expanding its operations through JIT used the concept of waste reduction and began developing methodologies for the timely production of the necessary components and assemblies to support final assembly, while at the same time applied the concept of a supermarket system in the United States that retrieves replenished goods as consumers buy (or pull) their supermarket shelves, known as "Kanban." Today Taiichi Ono is part of Toyota’s production system called Lean Manufacturing (Smith and Hawkins, 2004, Murphy, 2011, and Brito et.al, 2019).

1.1.1 Aircraft Maintenance World Market

The important responsibility of the MRO sector in the aviation industry is returning a fully serviceable aircraft to the operator at a reasonable cost with optimal downtime and a high quality after each heavy maintenance checks (Ayeni et. al, 2011) Maintenance, repair and overhaul (MRO) an aircraft and aircraft components are a complex process that is subject to stringent airworthiness requirements defined by the aviation authorities to ensure the safety of passengers, and the crew, therefore Airlines spend billions of dollars annually to meet the established requirements, accounting for about 20% of their total operating costs (Vieira and Loures, 2016).

Aircraft Maintenance is a combination of a technical staff and Management actions with the objective of keeping an item working according to the specifications of its project or restoring it to those conditions, thus avoiding failures and ensuring an operation within acceptable specifications (Souza et.al, 2018). The maintenance processes create a significant amount of operating costs to an industrial organization (Stadnicka and Ratnayake,2017). In spite of the aircraft maintenance being carried out on a daily basis after each flight and periodically in accordance with the MP, it is not possible to avoids the defect, which requires an immediate rectification (Ayeni, 2015). This type of the maintenance is known as a reactive maintenance (Sullivan et.al, 2010) or a corrective maintenance (Toms and Toms, 2008).

Unscheduled maintenance is arising in unexpected malfunctions with the aircraft or discovered during a routine checks and scheduled maintenance that must be recovered immediately to ensure the safety requirements.Asuquo et.al (2019) provides a more comprehensive approach towards the maintenance, and he suggests that a preventive maintenance is not the optimal maintenance action, but it does have several privileges over a reactive program. By carrying out a preventive maintenance according to design parameters, the life of the equipment can be extended. The while system failures cannot be prevented, the number of defects can be decreased, therefore reaching minimizing failures on aircrafts can translate capital cost savings. By the Ayeni (2015) a proactive maintenance is consisting periodic tasks such as a routine servicing, inspection items, a part replacement, and a condition-monitoring an action, Kimos (2009) classified it as a scheduled maintenance that includes a lubrication, a filter change, a tire replacement, etc.

The facility and the resource planning are an important case faced by the aircraft Maintenance, Repair and Overhaul (MRO) organizations given the uncertainty of workloads (Duarte et.al, 2019). The work package has defined by the MP is a routine tasks and associated material requirements, that included for each task, which is grouped into scheduled a heavy maintenance visit, while reducing the MRO uncertainty for a customer aircraft(Saltoglu et.al, 2016). According to a forecast present by Kevin (2016) in the next decade, the new generation aircraft fleet will grow by approximately 530% to nearly 19,000 aircrafts globally, against 3000 aircrafts in 2015, Figure 1, and MRO spends on a new technologyAirbus A350 & Boeing 787aircrafts will be 11.1 Billion

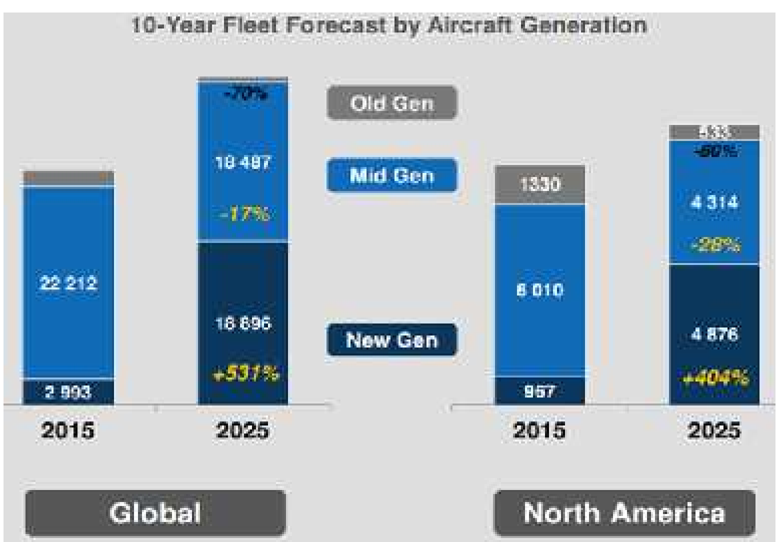


Figure 1.Fleet Forecast. Source: Kevin (2016).

in 2025 globally, against 4.4 Billion last years,Figure 2.Referring to IATA (2019), a global MRO spends in 2018 was a valued at $69 Billion, excluding overhead. This represented 9% of airlines operational costs. With 4.1% increase per an annum, the market size is estimated to reach $103 Billion in 2028, Figure 3.World MRO spends by a segment in 2018 consists of a Line 18%, a Component 20%, Base 20%, Engines 42%, Figure 4.

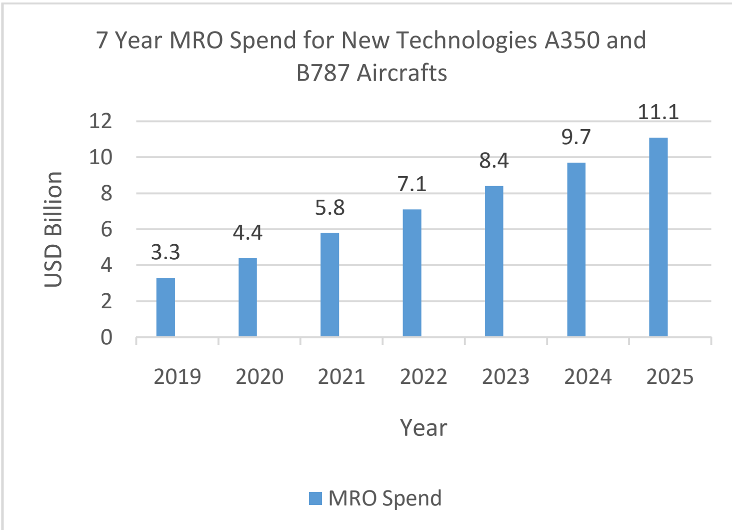


Figure 2. 7 Year MRO Spend. Source: Kevin (2016).

Figure 3. World MRO Market Forecast (2018-2028). Source: Alton Aviation Consultancy MRO Forecast (2019).

Already today, there are enough forecast publicationsconcerning growing of aviation fleet in the near future, which emphases by emerging of new generation types of aircraft and engine, while even some of the Boeing 767 will be removed fromoperation. Therefore, it is obvious that MRO organisations which are specialized onengine repair and overhaulwill have increasing workload, based on new technologies (Brown, 2017), Table 2.The growth in the aviation industry haspositive effects upon passengers and cargo sector, as it offers a variety of flight destinations, that there are positive effects generated by each stakeholder(airlines, airports, air traffic management, aircraft manufacturers, etc).

Table 2. Widebody Engine Market Shop Visit Forecast 2016-2026. Source: Aircraft Commerce (2017).

Widebody engine	Number in operations	Number built 2016	SVs 2017	10 years shop visit forecast
GE90-94B	322	0	40	388
GE90-115	1915	196	338	4460
CF6-80C2	2283	32	493	3478
CF6-80E1	554	48	164	1656
PW4000	1906	6	416	2827
RB211-524	280	0	39	261
Trent 700	1476	72	389	4006
Trent 800	350	0	69	443
Trent 900	336	24	68	936
Trent 1000	410	120	25	1359
Trent XWB	170	104	0	1441

as well it is reflected in the wide range of jobs offered (Dozic, 2019).

Figure 4. World MRO Spend by Segment (2018). Source: Alton Aviation Consultancy Forecast (2019).

Optimization of the aircraft maintenance processes is having a high interest of the scientific community as well as the aviation industry (Sprong et.al., 2020) and such processes pass through a development of the aircraft maintenance procedures. Table 3.

Karunakaran (2016) argues that the optimization is feasible in three different levels; In first, feasibility exists at an individual subtask level applying innovative methods and a time studying technique. The second optimization is at servicing cycle level. The third optimization is at a facility level, where the improvised servicing cycle with optimized tasks could lead to a significant saving in resource utilization byapplication of LSS techniques.

Table 3. Optimization Aircraft Maintenance Process. Source: Karunakaran (2016)

OPTIMIZATION OF AIRCRAFT MAINTENANCE PROCESS		
First level	Subtask level	WBS, Method and Time Study
Second Level	Servicing cycle Level	Network Techniques
Third Level	Facility Level	DoE Techniques, Sensitive Analysis

Lean principles are affecting the organisational process changes, but the experience has shown that implementation of lean alone cannot bring the requireddegree of improvement therefore it is necessary to implement incombination with other techniques like Six Sigma(George, 2002, and Karunakaran, 2016).

Thomas et.al (2015b) stated that Lean Six Sigma (LSS) one of the best methods aims to drivebusiness process including service sectors improvements through applying the key tools of both Lean and Six Sigma and combining these functions in to a single approach towardsbusiness performance implementation.

1.2 Problem status

In this context, this study was undertaken to identify the maintenance management loses of Boeing 747-8F aircrafts, powered by GEnx-2B engines during its life cycle maintenance and specifically during the engine replacement.This analysis is based on figuring out how the waste can be handled using the Lean Six Sigma optimization techniques and other proven implementation tools. With the aim of identifying andoptimization, and this study covers maintenance engineering concepts applied at various levels in the maintenance of similar new generationcivil aviation transport / cargo aircraft. It also describes how a multi-pronged optimization analysis approach successfully addresses a waste that is prevalent in various forms in theaircraft maintenance.

The process of aircraft and engine maintenance, repair and overhaul of spare parts, an electronic equipment as well as structural elements are rather complicated process. The restoration of system defects, their components and replacement of any unit, including the engine on the aircraft, is the main task of MRO, which requirestraining for each type of aircraft and mandatory to knowuse of the technical manuals and guidance material for each certifying staff thereby ensuring safety of processes andequipment.

By referring to statistical data that determine the number of engines and predicted removal cycles for shop visits, it becomes necessary to avoidsunnecessary tasks, while saving and human resources, as well as reducing aircraft downtime during maintenance.

1.3 Purpose of the study

The engine replacement is one of the critical tasks in the MRO function. Accurately identifying, and clearly prioritizing such factors helps MRO management team develop and implement Lean tools in their organisations to improve efficiency, quality and safety, thereby reducing maintenance downtime. A proper application of methods allows to develop appropriate maintenance procedures for specific tasks described in the airlines' maintenance program. This study suggests methods for improving and an optimization of the aircraft maintenance using lean tools and developing the procedure forengine replacement on the Boeing 747-8F with GEnx-2B engines.

1.3.1 Sub-purposes of the study

This study proposes use of Lean Six Sigma methods (LSS) to measure the performance indicators during the engine replacement process.

1.4 Importance of the study

This study is focused on adopting Lean Six Sigma tools, which are unravelling effectiveness indicators during the engine replacement and improving maintenance procedures. This study carries immense significance in the aircraft manufacturers (Boeing), Ground support equipment and tools manufacturer (in a particular case Hydro), the B747-8 operators, MRO organisations and maintenance personnel to utilise Lean Six Sigma model for the identification of a MRO effectiveness performance and safety in different areas of the activity. The used criteria in this study helps in narrowing out the best option among various available maintenance task for determining the Lean MRO effectiveness indicators. Moreover, this study also adds a value in point of view financial aspects for MRO and Airline as well as the pool of knowledge regarding LSS and MRO effectiveness in synergies.Thisstudyforms an example on an application of LSS on MRO activities.

1.5 Limitation of the study

This study provides a detailed view of applying Lean Six Sigma to define appropriate tools for the aircraft maintenance procedure development, which in the course was no limitations are noted. With the lack ofliterature, and publications, particularly in engine maintenance andmodern engine replacement equipment, it became necessary to engage the industry professionals, experts and certifying staff to get an interview and online conference to define details of research objectives.

The MRO has solid fundamental which is subject to the certification.Taking into account the authority regulations, were another limitation is associated with the result of the study, which the intended value (preload) must be included in the described procedure for the engine replacement in dedicated aircraft. Without this, the written procedure is considered invalid for the use at this time. Although the engine replacement procedure is written, it has other restrictions associated including it in Aircraft Maintenance Manual of the Boeing 747-8F which is necessary to receive approval of aircraft manufacturer (Boeing) or an airline engineering department.

1.6 Definition of the study

Applying of the Lean Six Sigma principles and methods to achieve development ofaircraft maintenance procedures.The investigation will be carried out in according to below propose processes, Figure 5.

Figure 5. Research Approach Process.

1.7 Conceptual Framework

In this research Lean Six Sigma conceptual performance model is used for improving maintenance processes inaviation industry as well as implementation of maintenance procedures in a particular aircraft system. Keivanpour et.al (2017) stated that, in order to achievecustomer value with eliminating the waste and to meet customer demand, it is necessary to follow the context ofcontinuous improvement of Lean principles. By the Chen (2019), the accepted concept of Lean approach, createsvalue for the end-user which istotal complete management system, while eliminating wastes.

(Schroeder et.al, (2008), Zhang et.al, (2009) state that Six Sigma is an effective method forquality improvement in service sectors including in the MRO organisations in aviation industry proven on several studies.

Emphasizing upon LSS and its application in manufacturing and servicing sectors, such asaircraft maintenance, most LSS implementation projects have focused on rigorous application of the Six Sigma principles which are delivered through the effective use of a number of lean and Six Sigma tools such as, VoC, VSM, 5S,Hypothesis testing, PDCA, Standardized Work, etc (Simons, 2014).

Referring to previous knowledge based on effective research, this study will help to eliminate the duplicationand provide a useful hypothesis and suggestion for a significant investigation.

CHAPTER TWO

LITERATURE REVIEW

This chapter introduces a detailed review of the literature to describes full disclose the state-of-the-art Lean principles and tools for their application in the MRO organizations in the aviation sector, and identify leverages for improvements in an aircraft maintenance management, taking into account safety, a quality, and a time. The Chapter consists two parts Part 1 presents detailed review of Lean Production, andPart 2 is a description of MRO activities.

PART I

2.1 History of Lean and Lean Thinking

Almost many decades the lean system has driven into different industrial and service sector, that has been started from manufacturing philosophy set by Toyota Motor Corporation (Dombrowski & Malorny, 2014; Mostafa et.al, 2015) and prove success application in service industries such asaviation maintenance, private banking, restaurant and foods, training and education, public and hospitals (Thirkell & Ashman, 2014; Resta et.al and Mostafa et.al. 2015). Indeed, Toyota as thelargest automaker in the world the pioneer and leading example of Lean Manufacturing. Its growing success, from increasing sales and market shares across all global markets, to being a leader in the hybrid technology, is a compelling proof of the power of the Lean Enterprise. This continued success over the XXI century has created tremendous interest in deeper knowledge of Lean Thinking as it continues to spread throughout the world and its methods and principles are beginning to take root among Senior Managers and leaders in all sectors today (LEI, 2021). It was known as "TPS" in the 1970s, and by the late 1980s it was called "Lean Manufacturing". In the last two decades of the 20th century, it was called "Lean Thinking” or “Lean Philosophy", and nowadays the concept of "Lean Management" has been used to emphasize its all-encompassing and expansive nature (Womack and Jones, 1996; Wilson, 2009; Tasdemir and

Gazo, 2018). According to Womack and Jones (1996), an important element of Lean Thinking is its focus on value creation aimed at reducing costs, which is the first principle of Lean thinking, corresponding to the desire to increase perceived value for customers by adding value or services and avoiding wasteful activities (Rania, 2013).

The Flight Standards Office (FSDO) near Boston, which has begun to apply Lean principles, has reduced the time spent on reviewing Certification applications by 51% after using Value Stream Mapping (VSP) and the FAA showed that principles and tools of Lean management is also effective in improving service delivery processes. Thus, overall Lean Thinking needs a systematic improvement to define and eliminating waste using a pull strategy to be competitive in the global marketplace (Marchwinski, 2010; Stadnicka and Ratnayake, 2017).

According to study by Greenough (2003) the feature of Lean Thinking in aircraft maintenance is to improve efficiency and reduce waste is through use of Total Productive Maintenance (TPM) aimed at zero breakdowns and zero defects that deviate from the dedicated operational function. Total Productive Maintenance (TPM) is developed in Japan, which involves all employees, down to top, across the whole levels of the operational function (Jasiulewicz-Kaczmarek, 2013), in order to eliminate any losses in equipment and production efficiency through active team-based participation (Mostafa et.al, 2015).

2.2 Lean principles, philosophy and tools.

2.2.1 Application of Lean principles.

Lean principles and methods have been developed over 100 years, through tests and errors, and many outstanding people has contributed to their improvement, which implementation requires commitment and support from top management, as well as the active participation of all employees in the organization to achieve success (Smith and Hawkins, 2004).

Nowadays the Lean principles are used in many other service sectors to increase customer satisfaction and reducing costs that are used even on a smaller organization such as private offices or measurement laboratories (Crawford, 2016).

After investigating PW's activities, the users of lean principles, Womack and Jones (1996) concluded that the aerospace was a suitable sector for their application and success, even suggested that the aerospace industry could have an advantage over the automotive industry.

According to Grossi (2003), with the introduction of the principles, and methods of lean manufacturing created a value thanks to efficiency enterprises that are interested multiple stakeholders for that are essential to follow these priciples of implementation.

By adhering to the context of continuous improvement of Lean principles, company is able to achieve customer value with eliminating waste and to meet customer demand (Keivanpour et.al, 2017). By the Chen, (2019) the worldwide accepted concept of lean approach is to eliminate waste and create a value for end-user which complete management system providing the right amount of the right product with the right time, the right place, and the competitive price.

Referring two requirements issued by ICAO ANNEX 8 (2010) and EASA (2003) ED decision no 2003/19/R (Continuing Airworthiness), Management of airworthiness records for internal and outsourced customers need to be analysed properly to achieve better quality standards at acceptable costs and flow of information to this aspect can be improved by employing of Lean principles (Shakir, 2018). Almutairi et.al (2019), has conducted research to present Lean implementation in Hospital Supply Chain Management (HSCM) in Saudi health-care organisation and found that the proposed new conceptual framework could improve current supply chain processes using Lean principles and it can contribute enhancing HSCM performance reducing cost, eliminating wastes and ensuring on-time delivery.

The study conducted in the Brazilian regulatory agency found that it embraced its mission as value to the customers, making a control process, analysing and improving processes for excellence, and acknowledging its weakness in a culture of continuous improvement (Pascualote, et.al 2017).

In order to achieve the objectives within the organization, applying the lean implementation methods that the authors are familiar with:

- Form a team to lead or implement lean manufacturing, which will include a lean leader;
- Develop a strategy for the implementation of lean manufacturing;

Train and refresh the team and employees in lean manufacturing principles and tools;

- Develop a relation plan and communicate with all employees;
- Employ the principles, and tools of lean manufacturing (Zuliyanti et.al, 2017).

Taking into consideration above and referring to The Lean Enterprise Institute (LEI) has summarized these principles as follows: Figure 6.

1. Identify Value - Specification of the value from the end customer's perspective by the product family.

2. Map the Value Stream - Recognise every step in the value stream for every product family, removing every possible time the measures not creating value.

Figure 6. Lean Principles. Source: LEI (2021)

3. CreateFlow - Construct the value-creating measures occurring in the close series to make sure the smooth flow of the product towards the consumer.

4. Establish Pull - After the flow introduction, allow the consumers to pull a value from the upcoming upstream activity.

5. Seek a Perfection - After the specification of value, recognition of the value streams occurs, needless measures are eliminated and the introduction of a pull and a flow is carried out.

Table 4. Lean Principles and Description. Source: LEI (2021).

Lean	Description
Value	Customer needs for specific product
Value stream	Mapping the value stream
Flow	Waste removed, no delay, bottleneck, interruption
Pull	Improved flow, time to delivery need to be improved
Perfection	Steps1-4 create, Lean thinking and process improvement

Start the procedure again and carry it on until the perfection state is attained wherein the supreme value is established without any waste (Marodin et al., 2018).

2.2.2 Lean philosophy based on eight wastes.

Lean philosophy itself is a multi-dimensional approach that comprehensive a wide variety of management methods and tools, including just-in-time, quality control systems, team based work, cellular production, supplier chain management, etc. in an integrated system (Baines et. al, 2006; Ayeni et. al, 2016).

To get started, necessary to thoroughly study the five steps of Lean Principles, Table 4 and the next Lean Project Manager must be well versed in tools available to transition to Lean.

To eliminate non-value adding activity from the value stream is a main purpose of the Lean philosophy that means Lean waste is do not add value to a manufacturing and servicing processes, where can manifest in a variety forms, as defect, overproduction, waiting, Non-Utilized talent, transportation, inventory, motion, extra processing. From a customer point of view, value added activities are important and customer is willing to pay for the such activities (Glass et.al, 2016; Sanchez and Sunmola, 2017).

(Smith and Hawkins, 2004; Murphy, 2011; Ayeni, 2015; Mostafa et.al, 2015; Sanchez and Sunmola, 2017, most of the authors in their articles mention only seven types of Lean wastes, although it counts as eight considering the Non-Utilized Talents).

The core idea is to improve performance, capacity, efficiency, and rentability, continually focus on eliminating all aspects of the waste from manufacturing process that does not add value from your customers' point of view that is a collection of tools, and techniques ((i.e. best practices), Vorne, 2021). In the Table 5 countermeasure tools against the lean wastes are given.

1. Defects-the unit require rework or need to be removed from operation.
2. Overproduction-Do something before you really need. Because its serious form of waste as it results in excessive inventory that leads to use hidden other problems and loses.
3. Waiting-Time is actually wasted in the manufacturing process where the work in progress is awaiting the next step in action (no value added).
4. Non-Utilize Talent-Untapped human potentials. Lost or unused talent when management cannot ensure that potential talent of employees is used effectively or continuous feedback to improve the lean processes (Brito et.al, 2019).
5. Transport-is the unjustified movement of a primary product, work in progress, or end product.
6. Inventory-Product (raw materials, work-in-process, or end goods) quantities that over the customer demand.
7. Motion-Unreasonable movement of people leads lose productive time (movement that does not add value).
8. Extra-processing-More analysis to determine customer requirements which the waste is more difficult to detect and eliminate.

Table 5. Lean Wastes and Countermeasures. Source: www.Leanest.com(2021)

Lean	Wastes	Description	Tools
D	Defects	Error, rework, fixing issue	Poka-Yoke, Jidoka, RCA, Standardized work
O	Overproduction	Getting ahead, "just in case"	Takt Time, Kanban, SMED, Heijnka
W	Waiting	For people, information, system	Continuous flow, Standardized work
N	Non-Utilised Talent	Lost knowledge/potential	Rewards-awards, motivate, justify, recognise
T	Transportation	Movement without value	VSM, TOC, Continuous flow,
I	Inventory	More than customer needs now	JIT, Takt Time, Kanban, SMED, Continuous flow

M	Motion	Ergonomics, searching, walking	VSM, 5S
E	Extra-Processing	Repeat, duplicate steps	Kaizen (Continuous improvement)

As argue (Sanchez and Sunmola, 2017) wastage appear from, technological, non-technological and managerial reasons at the root cause of ineffectiveness.

2.2.3 Lean toolsapplicable for implementations

As stated by Smith, (2004) and Smith & Hawkins (2004) that some of the key Lean tools such as VSM, 5S, Visual Management (VM), JIT, Kanban, Jidoka, PDCA and Standardized work needed to be used in maintenance processes continuously as a proven element of Lean and Davies & Greenough, (2010) argue that many developed lean tools are uses as success within an MRO organisation including 5S, TPM, OEE, Kaizen, Poka-Yoke, process activity mapping (PAM), Kanban, computer managed maintenance system (CMMS), enterprise asset management (EAM) system, and Takt time.

MRO organisations having significant operating costs which employing Lean principles and applicable tools into maintenance activities of MRO organisations are able to improve a maintenance processes (Mostafa et.al, 2015). The study conducted by Mostafa et.al (2015) establishes a scheme for Lean Maintenance (LM) tools to demonstrate the association between maintenance wastes and the Lean Maintenance tools, which a successful integration can create more improvement advantages over time to reach high excellence status.

The MRO organisations that have a large volume scope of work are more responsive to implementation of lean tools and techniques (Ayeni et.al, 2016). Although, Srinivasan et. al (2014) and Ayeni (2015) states that it is impossible to apply all Lean tools in MRO activities (at least without adaptation), and therefore, the type of tools used will show character as they are applied in the field of aircraft maintenance and in the organisations, such as Takt time, 5S, Mistake Proofing (Poka-Yoke) are already successfully applied in the context of MRO organisations.

Kolanjiappan (2015), argue that Lean Principles and Techniques once used in the automotive sector, it is already rapidly transforming into a working procedure in many industries including MRO organisations,and which most common tools for lean manufacturing and service.

In 2000, the U.S. EPA issued the "Lean and Green SCM Framework" guidelines for reducing cost factors in connection with SCM role while improving environmental performance and in 2007 publication, the EPA created a basic for environmental stability using three lean tools such VSM, Kaizen, and 6S (5S + Safety) (EPA 2000, 2007; Tasdemir and Gazo 2018) and also included of implementation strategies of the proposed framework.

In addition, the US EPA has deployed two other lean manufacturing concepts to address water and chemical use, energy inefficiency, and climate change in their publications, in 2009 and 2011 (EPA, 2009, 2011 and Tasdemir and Gazo, 2018). Whitman et. al (2006) offer a new concept called the Waste Stream Prioritization Method (WSPM) for incorporating an environmental index in the VSM to prioritize the harmful effects of various pollutants on air and water (Whitman et.al, 2006 and Tasdemir and Gazo, 2018). Tools and techniques used to achieve lean-driven sustainability goals within different industries, service and public sectors are quite numerous which is most commonly employed for their implementations are following (Tasdemir and Gazo, 2018).

- Cellular manufacturing organizing processes into shelves, involving all available sources.
- Kanban (Pull System) and Visual Factory - Eliminate excessive inventory levels, which are the most hazardous form of waste. Provides a smooth flow of goods and information inside and outside the factory, but can still increase energy and water consumption. Kanban can be modified to use RFID or barcode technologies due to new technologies, and a warning system for the employing of JIT production (Tice et.al, 2005; Parveen et.al, 2011).
- Total Preventive Maintenance (TPM), perform scheduled or routine maintenance on equipment to prevent malfunctions.
- Total Quality Management (TQM) is a follow up improvement system referring to customer needs, and uses management.

- 5S are provides on effectiveness workspace of the organization and standardized work procedures, manuals and their implementation.Fulfils basic responsibilities of housekeeping, keeping a clean and orderly work space, reducing health risks and ensuring safety, as well as increasing job satisfaction rate (Sobral et al, 2013; Cherrafi et.al, 2016).
- Kaizen (Continuous Improvement) - forms a team, creates a creative opportunity and active action for reflection for continuous improvement and elimination of wastes that can lead to a decrease in negative impact on the environment, and health hazards within the organisation (Miller et.al, 2010; Pampanelli et.al, 2014).
- Value Stream Mapping (VSM) - Helps with visualizing the process flow at any stage for a product group to provide increased communication, allows tracking of value added and non-value added processes in the supply chain and is useful for waste elimination as well as through proper employment of VSM avoided excessive costs and use of unnecessary resources (Faulknee and Badurdeen, 2014; Chiarini, 2014; Cherrafi et.al, 2016).
- Total Manufacturing Service (TMS)-is one applied in maintenance that aims to ensure uptime, reduce cycle times, eliminate substandard production and ensure personnel safety, and improve the effectiveness of the production process, which promotes efficient use of resources to avoid wastes (Parveen et.al, 2011; Vinodh et.al, 2011, Chiarini, 2014).
- One Minute Die Change (SMED) -SMED reduces setup (changeover) time by simplifying the production processes, streamlining unnecessary intercompany procedure manuals and standardizing work and allows an opportunity the system to use smaller batch sizes as well reduce inventory levels. Profits generated by SMEDs to reduce emissions and reduced use of hazardous chemicals are noted by authors Moreira et.al, (2010), Chiarini, (2014), Cherrafi et.al, (2016), Alves et.al, (2016).

- Standardized Work (Takt Time) — Standardized work ensures that viable practices are established and documented for each process separately for the continuous elimination of waste that facilitates further improvements. It increases the utilization rated by avoiding costs, resources and times and avoiding the risk of industrial accidents (Miller et al, 2010; Chiarini, 2014; Hartini and Ciptomulyono, 2015; Cherriafi, 2016).
- Plan, Do, Check, Act (PDCA)-PDCA is a systematic approach that attempts to open up new opportunities for process improvement and simplifies the implementation and assessment of the effectiveness of certain environmental and social management systems (Wee and We, 2009; Kurdve et.al, 2014; Garza-Reyes, 2015).
- Jidoka (Autonomy) - a certain level of automation, along with the capacity of workers, increases the quality of processes and products in terms of sales. Jidoka can promote financial stability, waste disposal by reducing man-hours, material, and facility expenses and associated with a lower incidence of health and safety problems (Vinodh et.al, 2011; Folinas et.al, 2013; Kurdve et.al, 2014; Cherrafi et.al, 2016).
- TAKT (Cycle) Time - is in production, the available work times divided by required product quantity requested by customer demand and in Maintenance activity, it is the available work time for scheduled maintenance divided by the scheduled total time required (Smith and Hawkins, 2004 pp.111)
- Continues Flow (combination JIT and Kanban "Pull")- JIT and Pull-are continuous flow in production terms and main goal in production is to ensure operations is continuous flow in order to production can (potentially) run at a full capacity (Smith and Hawkins, 2004. pp132).
- Just-In-Time (JIT), is according to client demand, and turned opposite direction, "pulling". JIT goes hand in hand with Continuous Flow, Kanban, Standardized Work, and Takt Time to ensure lower inventory, increased yield, and provide necessary work space needs which related to both environmental and economic sustainabilities (Parveen

et.al, 2011; Dues et.al, 2013; Longoni and Cagliano, 2015; Campos and Vazguez-Brust, 2016).

Lean Maintenance Improvement Tolls used in MRO and service sectors are presented in the Table 6.

Table 6. Lean tools used in MRO and Service sector.

Lean tools/ Authors	Smith and Hawkins	Davies and Greenough	Kolanjiappan	EPA	Tasdemir and Gazo	Srinivasan and Ayeni
5S/6S	*	*	*	*	*	*
CMMS		*				
Cellular manufacturing			*			
JIT	*		*			
Jidoka	*		*			
Kaizen		*		*	*	
Kanban	*	*	*		*	
OEE		*				
PDCA	*				*	
Process activity mapping		*				
Poka-Yoke		*				*
SMED					*	
Standardized work	*				*	
TPM			*			
TQM			*			
Takt Time		*			*	*
Visual Management	*					
VSM	*			*	*	

2.2.4 Classification of Lean wastes in MRO service sector.

The lean shifting to the manufacturing sector is well known, however, the use of lean tools in service sector to improve quality is relatively limited and reported only benefits and approaches (Leite and Vieria, 2015). Upon successfully applied Lean in automotive companies since last centuries the idea has been studies by researches, academics and managers and, even been transferred into service industries such as aircraft maintenance, MRO, ground handling companies, banking, healthcare and etc (Song et.al, 2009). The focus on the service sector is critical due to its growing importance for the GDP of Western economies: in the European Union, the number of employees in the service sector increased to 68% by the 2000s, while in the service sector the GDP of countries in Europe is three times higher than in industrial sector (Alberto, 2010). Thus, the service sector is in constant need of new strategies and technologies, which accounts for more than half of the gross domestic product (GDP) of the population and their employment. Specifically, according to Fortes (2010), 58% of global GDP is the service sector, and in the United States, service-related occupations accounted for 79% of total employment at the beginning of this century (Leite and Vieria, 2015).

For service companies are mandatory to meet the specific requirements of each customer to stay ahead of the competition (Vignesh et.al, 2016). He has conducted research based on literature survey outlined the different approaches that lead to the successful implementation of the lean philosophy with the objective of accomplishing improved quality in the service industries. As argue Vignesh et.al (2016), despite the misconceptions that Lean can only be effective in the manufacturing sector, the results show that Lean's methods are being introduced into the service sector has led to successful positive financial results and customer satisfaction. Future, Maleyeff (2005) argues that many Lean tools are recommended for servicing environments, given that service industries differ in their mandate and that organizations should use the tools that are appropriate for their organizations. Piercy and Rich (2009), suggested that the appropriated Lean tools are applied in the service industry such as; 5S, 8 Wastes, VSM.

Quality service in the aviation industry is an important factor for success and profitability not only MRO company as well as Airlines keep their fleet sustainability (Kanakana, 2013). “After a thorough assessment, it becomes clear that the diversification of the client portfolio, team orientation and customer satisfaction using LEAN-based management (Organization

Management with Continuous Improvement Concept) have led FL Technics to a great year," notes (Lapinskas, 2019) CEO of FL Technics has finished last year with net profit of over €5,7 Million. Ioannidis et.al (2014), introduce the evident when looking at the 8 types of waste in service sector described by Bicheno and Holweg (2009) in the Table 7.Analysis of the collected materials in the process and reviewing research by other authors, there is confirmed that, the application of lean principles in the service industries are necessary and therefore will motivate the company to implement the lean tools in the business processes, in order to increase profits and to achieve customer satisfaction.

Table 7. Type of wastes in Service sector. Source: Bicheno and Holweg (2009).

7 types of waste in service sector
Duplication like re-entering data, repeating details on forms and similar
Delay in terms of customers waiting for service delivery
Lost opportunity to retain or win customers by ignoring them, unfriendliness
Unclear communication with customers or internally leading to clarification circles
Incorrect inventory being out of stock and hence not able to deliver
Movement in terms of handing over orders, queuing customers several times and similar
Error in the service transaction including product damage in product-service bundle

Analysis of the collected materials in the process and reviewing research by other authors, there is confirmed that, the application of lean principles in the service industries are necessary and therefore will motivate the company to implement the lean tools in the business processes, in order to increase profits and to achieve customer satisfaction.

2.3 Six Sigma

The Six Sigma design aimed to reach sustainable customer satisfaction through its permanent focus on customer needs (Seth & Rastogi, 2004). Paying attention on customer requirements and problems that affect customer satisfaction, Six Sigma eliminates potential performance degradation before they occur by focusing on processes of variables that are Critical to Quality (CTQ), (Snee, 2004 and Hill.et.al, 2018). The Define, Measure, Analyse, Improve and Control (DMAIC) cycle inherent within Six Sigma describes data-centric process improvement approach (Gijo, 2011; Pande et.al, 2014) and in theory, completion of each cycle of DMAIC will realise projected goals, improve performance of the company and sustain quality (Gijo et.al, 2010; Ahmed 2019),Figure 7.

Therefore, the companies are focusing on adding value, systematically reducing and removing waste using Lean tools whilst employing Six Sigma to focus on and remove the Critical to Quality (CTQ) issues affecting an organization performance (Drohomeretski et.al, 2014). The Six Sigma DMAIC principles with integration of Lean tools can be produce a range of advantages for the customer. Similarly, the application of Six Sigma in MRO facilities has also bring significant attention thanks J. Welch's work in moving forward Six Sigma as the key business improvement strategy at General Electric (Deshmukh & Chavan, 2012). Thomas et.al. (2015a) has conducted Monte Carlo analysis of the malfunctions of aircraft Display Units (DU) using the standard model of Six Sigma methodology providing a predictive cost model for DU replacements and suggests different maintenance strategies which helpful at different stages in the life of the DUs.

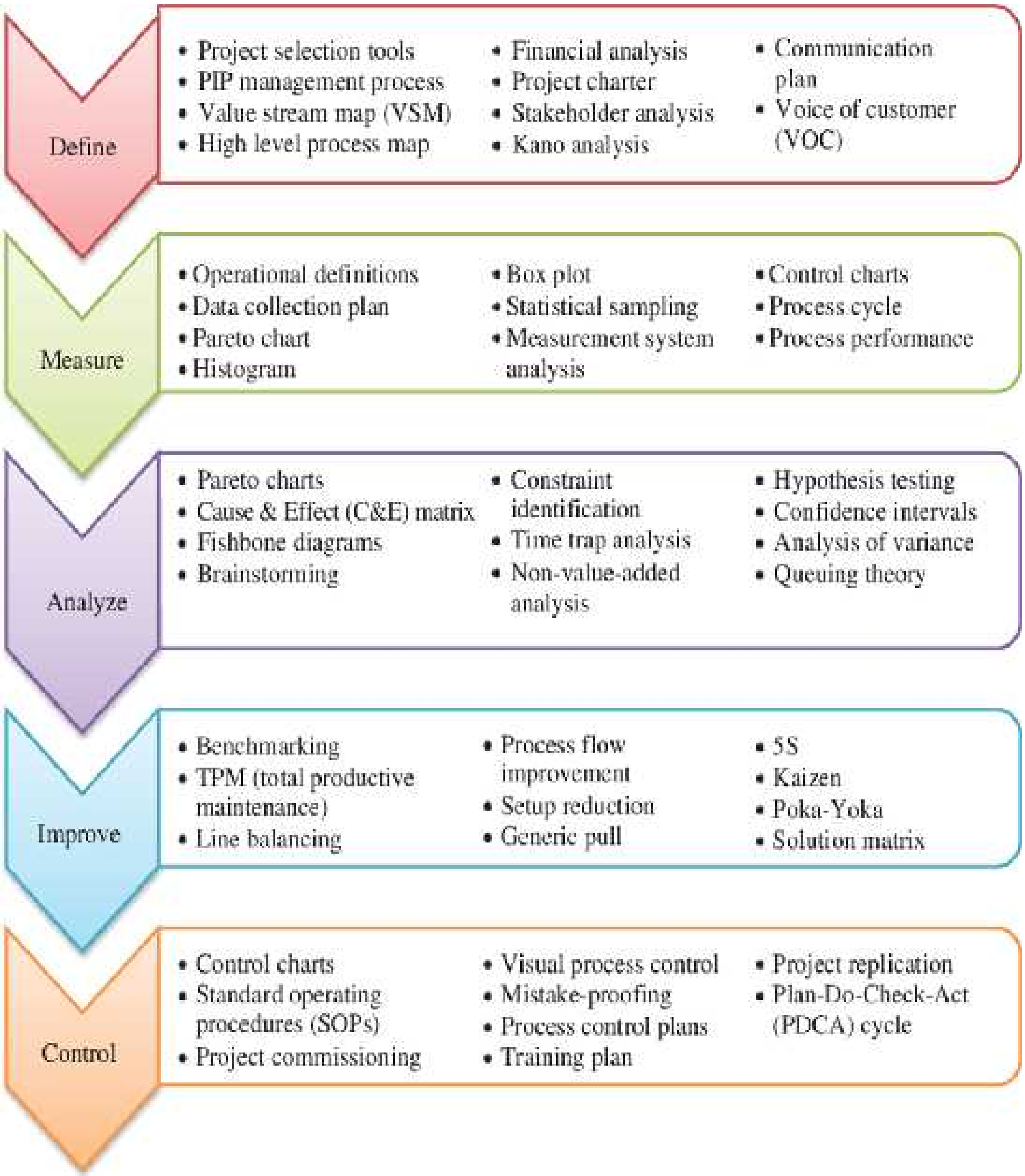


Figure 7. Six Sigma process tools. Source: S. Ahmed (2019).

Six-Sigma methodology can be used within any organisation including MRO sector as an effective strategy to eliminate problems that aims for better quality in the aircraft maintenance (Sabry, 2014).

2.3.1 Six Sigma Implementation.

Hwang (2006) found that the implementation of six sigma projects in aerospace companies and that human error and wrong data collection were major causes of six sigma project failures in aerospace sphere. Mostafa et.al. (2015) developed a conceptual framework integration Lean thinking in to maintenance systems and whilst Price (2010) implemented a combined Lean/TQM methodology in to aircraft maintenance in order to manage human errors which having huge effect quality and safety leading to improvement of business effectiveness.

(Schroeder et.al, (2008), Zhang et.al, (2009) state that Six Sigma is effective method for quality improvement in service sectors including healthcare and financial services and its success application in the MRO organisations in aviation industry proven on several studies.

(Chakrabarty and Kay, 2006), has confirm that the mentioned CSF with financial benefits are most important for the successful application of SS in service sector including MRO organisations. Schroeder et al. (2008) found that SS emphases improvement process with DMAIC and following,

- training,
- employee feedback,
- team works,
- customer's perspective,
- financial characteristic metrics,
- suppliers chain,
- communication and solving problems techniques.

Cagnazzo and Taticchi (2010); Suhaiza and Sivabalan (2011);Attarwala et.al, (2011) and Tariq and Ahmed-Khan, (2011) argued that Six-Sigma methodology is a more accepted effective strategy to eliminate problems within any organization that intended to reach better quality in its activity. But the strategy is split into two different methodologies:

1. Problem solving that represented in DMAIC,
2. Preventative that known as the design for Six-Sigma (DFSS) which consists of DMADV (DMA and Design, Verify). Using root cause analysis as a tool of Six-Sigma can lead to know the reasons about non compliances.

Leong and Teh (2013) suggested five CSF's model for implementation Six Sigma quality program;

- Top management commitment-for solving the causes of results process variation,
- Teamwork - any problem solving actions by teams to great a value adds

- Training and education - plan and design for development the Six Sigma projects.
- Cultural change -Management function to collect employees' survey, plan to cultural change and obligate jobs and empower staff in decision-making.
- Organizational infrastructure: Identification needed to be in place prior to introduce Six Sigma program in an organization.

Laureani and Antony (2012) tried to defined another important factors of CSF's of Six Sigma quality program;

- management commitment,
- cultural change,
- linking Lean Six Sigma to business strategy and leadership styles.

As state Sabry (2014) referring to Ching-Chow (2004) that conducted fifteen CSFs of Six-Sigma quality program in the different industries in Taiwan to determine their importance and implementation processes, found that training is first priority and followed by;

- top management involvement and commitment,
- cultural change,
- communication with all employees to achieve congruence,
- linking Six-Sigma to business strategy, and
- linking Six-Sigma to customers.

2.4Application of Lean Six Sigma in aircraft maintenance.

Lean Six Sigma model was proposed by George (2002) for employing Lean and Six Sigma approaches to achieve parallel benefits using both principles and (Corbett, 2011,Thomas et.al, 2015b) found that Lean Six Sigma (LSS) aims to improve business process adopting Lean tools for business performance enhancement. Traditional LSS model is gaining wider acceptance as an improvement strategy range of industries and sectors as well as production improvement environments (Hill et.al, 2018).

However, LSS is being most successfully applied in healthcare sector, (Laureani et.al, 2013), in building development (Van den Bos et.al, 2014) and, different are of education (Thomas et al., 2015b). Emphasizing upon LSS and its application in manufacturing and service sectors, such as aircraft maintenance most LSS implementation projects have focused on rigorous application of the Six Sigma principles DMAIC which are delivered through the effective use of a number of lean and Six Sigma tools such as VoC, ToC, CTQ, DOE, VSM, SIPOC and 5S (Albliwi et.al, 2015, Chakravorty & Shah, 2012, Chen& Lyu, 2009, & Gnanaraj et.al, 2011, Vinodh, Gautham, & Ramiya, 2011, and Vinodh, Kumar,& Vimal, 2012, Joseph, 2020) (Figure 8).

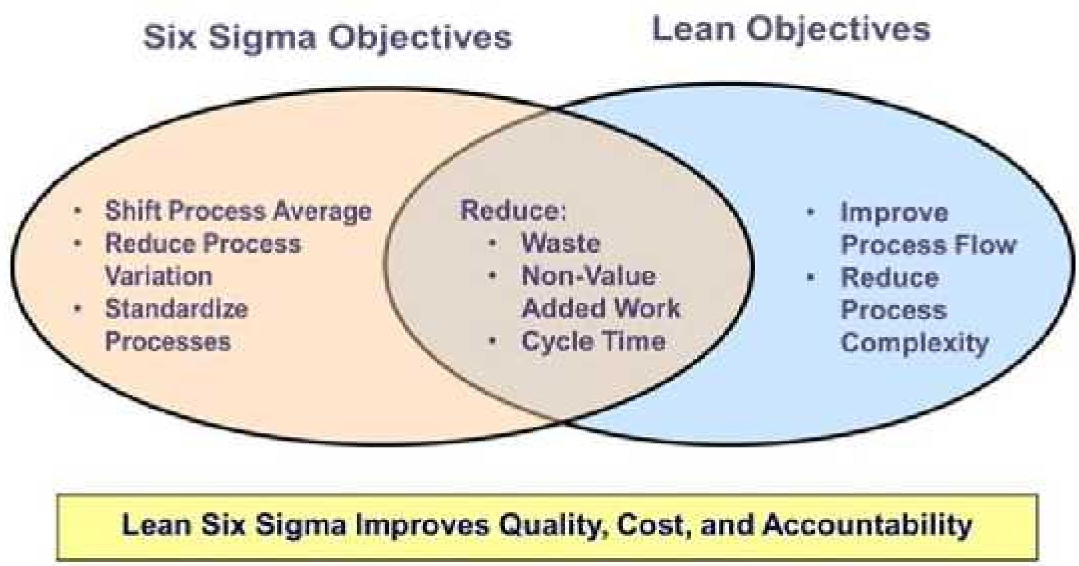


Figure 8. Lean Six Sigma Combination. Source: Norma Simons (2014).

Hill et.al (2018) state that, in spite of applying LSS within manufacturing and production industries are effective, although their application in areas Maintenance Overhaul and Repair (MRO) activities and supply chain operations is less well advanced. Just academic studies do exist on the application of real Lean implementations in MRO functions (De Jong & Beelaerts, 2016, Kumar et.al, 2015 and,Ayeni et.al, 2016).

Karunakaran (2016) state applying concerning to reducing aircraft maintenance downtimes through simulating the new "future state" slowly adapting LSS methodology through 5 stage six sigma DMAIC approach, its improvements in performance through the LSS approach (Hill.et.al, 2018). Thomas et al. (2015b) has conducted an integrated Lean and Six Sigma framework in to an aircraft assembly using a matrix approach towards the simultaneous application of both Lean and DMAIC and this integration has provided a useful direction to the effective implementation of LSS in an aerospace design. In order to embarking on new business improvement strategy based on application LSS and integrated Lean and SS concept the MRO organisations are need to fully understand the benefits of dual approaches, to define clearly their operation mode working effectively (Hill.et.al, 2018), Figure 9.

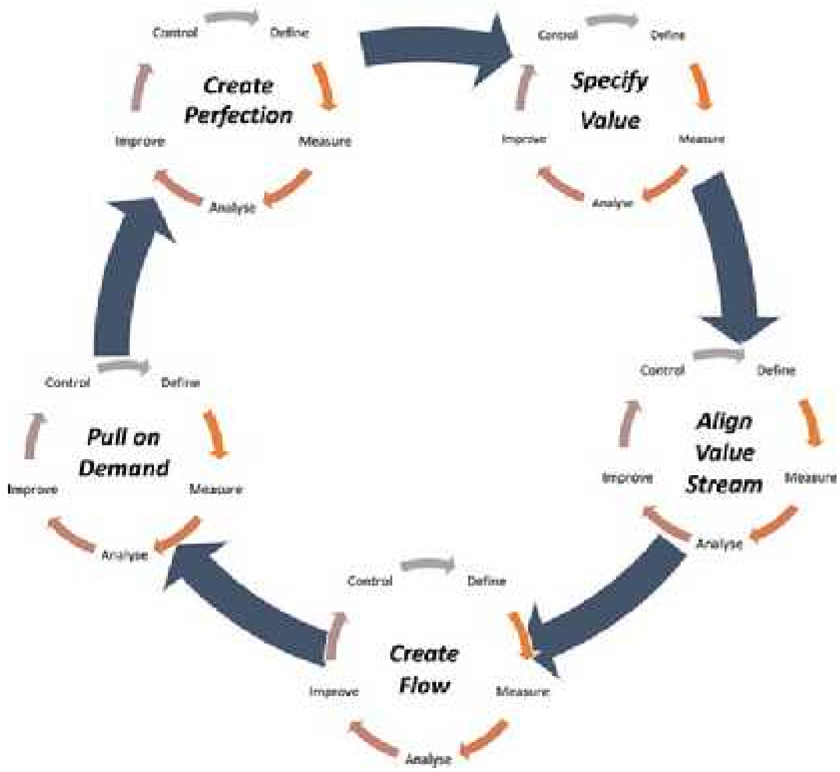


Figure 9. The Generic Lean Six Sigma Framework. Source: Hill et.al (2018).

Referring to Thomas et.al (2015b) the author Hill et.al (2018) and the team initially developed a conceptual LSS framework and following a series of repeating developments in an attempt to improve its effectiveness and suitability to MRO implementation.

Figure 9, shows the generic form of the LSS Framework (LSSF) adopted by team in the study and It shows that each of the Six Sigma DMAIC principles are applied accordingly to each of the Lean principles stages It is clear that the LSSF is trying to provide a balanced approach to the parallel application of Lean and Six Sigma, as the DMAIC cycle is implemented at every stage in the Lean thinking cycle(Hill.et.al, 2018).

2.6 LEAN MRO.

The maintenance process is to serve the production and service facilities of high productivity quality and safety. It consists scheduled and unscheduled actions plan carried out to retain a physical unit or equipment to the acceptable operating conditions (Faccio et. al, 2014).

If taking into account modern operation systems, that designed on sensor-driven management systems that provide alerts, alarms, and indications, consequently, maintenance costs are expected to be higher in the near future and of course maintenance interval is significant reduced affecting to down time of maintenance actions. By the Tinga (2013) and Sanchez and Sunmola (2017) the maintenance costs are proportional to the downtime (DT) that is the time interval when equipment/system is down for maintenance until it is back to the normal operational conditions.

Global competition, changing market shares, has been significant pressure to MRO organisation to increase profit margins while optimising and streamlining business strategy to manage more effectively how it minimises maintenance cost, reduces aircraft down time and establish accurate job standards (Ayeni and Baines, 2016).

Sanchez and Sunmola (2017) state that, for Lean MRO organisations involved to aircraft maintenance, the critical success (CSF) factors are: process management, organizational structure and infrastructure, education level and certified training, activity monitoring and evaluation of performance, technological competence, supplier chain management, users' appreciation and consultant participation. Taking into account relatively late application of Lean in the aviation MRO industry and lack in literature directly relating this subject, Ayeni and Baines(2016) has conducted research via an industry wide survey questionnaire involving industry leaders, professionals and maintenance executives to define key features and critical success factors within the MRO organisation Lean processes.

The increased DT is the result of non-value added (NVA) activities or wastes within the improper maintenance process, that one of best options is to apply Lean Thinking strategies into all activities between service provider and customers (value stream) (Mostafa et.al, 2015). Baluch et.al (2012) and

Mostafa et.al (2015) emphasised that LM is prerequisite for success of a lean manufacturer as it provides a holistic approach to the function of maintenance, and consequently the lean integration in any MRO processes is carried through adopting lean principles which begins with specifying the customer value (Bhasin, 2015).

Davies and Greenough (2010) offer to conduct more researches to apply lean principles into MROs maintenance operations and Ghayebloo and Shahanaghi (2010) suggest a multi-objective decision-making (MODM) model in order to determine at least the minimal level of maintenance requirements (i.e. labour, GSE, electronic testers and spare parts) which gives satisfies expected reliability level with the use of the lean concept. Soltan and Mostafa (2014) introduce an options for measuring maintenance strategies based on lean and agile components to eliminate and control responsiveness during maintenance processes.

While referring to studies on TPM concept, it was observed that there is an interconnection between TPM and LM emerged as an effective maintenance.

The study of McCarthy and Rich (2004) considered lean principles in total productive maintenance system (lean TPM) which conceptualises the application of lean-specific tool and techniques in TPM, the system is focused on maintaining equipment in its allowed operational limit and continually improving its productivity. However, as argue Mostafa et.al (2015), an integrative structure of lean thinking or lean TPM (e.g. principles, practices/tools, waste identification, and value stream mapping (VSM)) within the MRO activities are not fully established and provides an opportunity to study to develop and propose a process for lean thinking to be integrated to the MRO operation.

TPM having single bundle which contained four practices: Productive Maintenance (MP), maintenance optimisation, new technology equipment, and safety improvement that does not provide for specialists as a maintenance optimisation or new generation equipment (Dumrak.et.al, 2015). Previous study by Mostafa (2011) extended the TPM practices, offered by Shah and Ward (2007), to include housekeeping, cross-training and maintenance technicians team work, operations (autonomous maintenance), and the work orders tracking and can be concluded that TPM is considered as the foundation for the maintenance process within MRO organisation which must be supplemented with some lean practices.

The idea Lean Maintenance was invented after 1990 and defines (Smith, 2004) as a proactive maintenance strategy applied planned and scheduled maintenance actions through application of Reliability-Centered Maintenance (RCM) decision logic, empowered by action teams and generates an intended result by minimising consumption of inputs (Smith & Hawkins, 2004).

Adopting lean principles into the maintenance, repair, and overhaul (MRO) operations, significantly could reduce unscheduled downtime (DT) through optimising maintenance process activities and reducing maintenance overhead (Mostafa et.al. 2015).

To meet the need for lean MRO of modern complex equipment, it is necessary to effectively organize cloud infrastructure - for stakeholders and MRO resources (MRO service providers, MRO service consumers) using a MRO cloud platform which MRO stakeholders can easily obtain information and knowledge to solve their MRO problems or request MRO service, consequently it becomes important to develop a concept and model of Lean MRO (Zhang et.al, 2015). Taking into account that the Lean is systematic approach for the elimination of wastes from manufacturing, servicing and production processes arising overburden and irregularity, however in MRO industry it consists defect detecting, system assembly and disassembly, part inspection and rectification, handover, design and testing (Geng et.al, 2014), Zhang et.al (2015) suggested the concept of Lean MRO as a defined method, systemic waste minimize for the MRO stakeholders, to take a closed-loop product life cycle Management (PLM), information management approach, Figure 10.

According to Maier and Fadel (2009) "Affordance-based relational design theory" in order to attain goal of lean MRO modern complex equipment, the MRO stakeholder should provide acceptable information between parties.

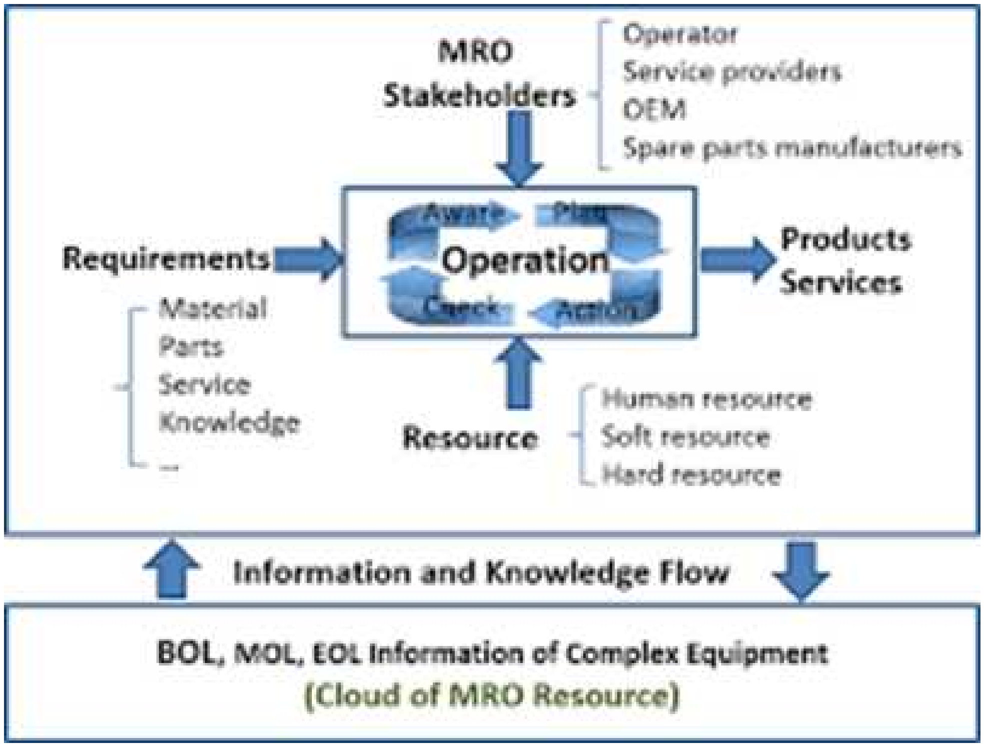


Figure 10. A Lean MRO Model for Complex equipment. Source: Zhang et.al (2015).

The lean MRO model adopts a hybrid maintenance strategy, which consists of condition based maintenance, scheduled maintenance, and very less unscheduled maintenance where provides facts for stakeholders to make feasible decisions for lean MRO activities.

In aviation lean MRO in integration with a maintenance program, allows the elimination of non-productive and unrequired tasks from the critical paths of process-event, making the performance of the maintenance team better, the yield of organised maintenance actions is enhanced and the efficiency of the supply chain is increased.

PART II

2.7 The Aviation System.

In the "Aviation System" participates three major groups shared as aviation industry (supply side) which includes Airlines, Maintenance, Operations, the Customers (demand side) Passengers, Leisure, Charters and Regulatory authorities (institutional side) International and Contracted States Regulatory Authorities. However, the basic levels of aviation value chain where met the problems with high operating cost structures, concerning to capital investment in long term assets (Yildiz, 2019), Figure 11.

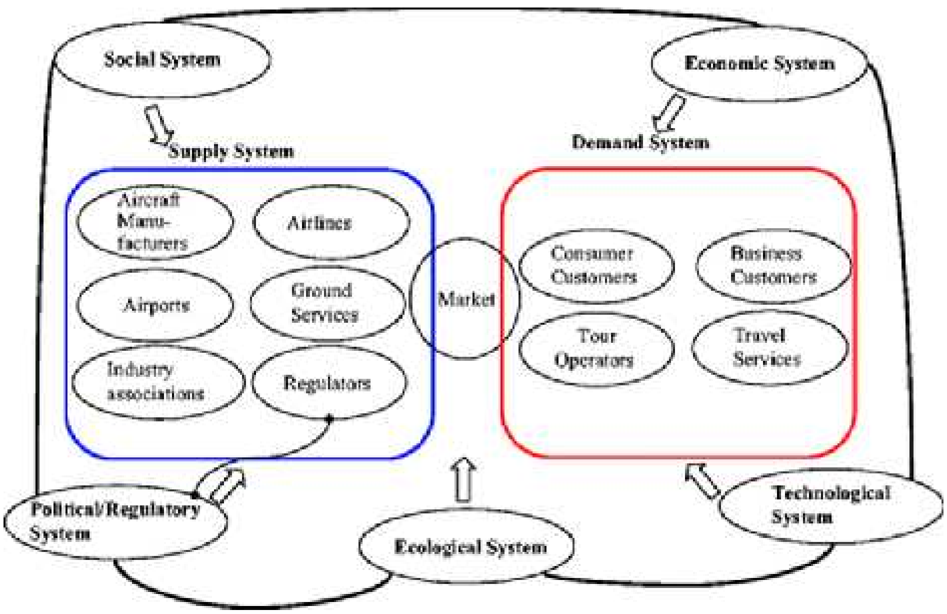


Figure 11. The Aviation System Schematic. Source: Yildiz (2019).

Today, air transport is an important means of traveling across continents for leisure and business purposes and thus ensuring human interaction and integration of the global economic system (Yildiz, 2019).

The aviation system is a legacy system that has grown during century and all the components of the system in aviation are open interaction between their environment as a close-loop. All civil airlines are operating into a wide range of destination, which not having own airports, maintenance is often outsourced to third parties, ramp servicing is almost provided by ground handling companies and air traffic control provides by the ATC of countries which they overfly (Harris & Stanton, 2010).

Integration is manifested in the globalization and internationalization of different cultures, modern technologies, extensive world business and a high level of education, therefore, civil aviation has a very huge contribution to the process of their unification (Bonser, 2019).

Aviation affects the economy, creates jobs for a new generation around the world and contributes to the sustainable development of new technologies - this is a view of the scale of the aviation industry, which provides 65.5 million jobs and about three trillion dollars in economic impact says M. Gill (2018). The evolution of the current and future aviation system is based on modern aircraft and navigation technologies, system operations and neo-fuels that are being created for the existing aviation ecosystem. Using the readiness and achievability framework, looking to the future as well analyzing energy sources (alternative fuels, hydrogen, battery, nuclear energy), air operations (flight information, flight phases) and new technology components (for example, distributed propulsion, hybrid wing surface, boundary layer absorption, box wing, new composite and chemical materials) will change the future of aviation industry. Based on these facts, being development of non-traditional aircraft concepts (supersonic aircraft, urban air transport mobility) and their expected impact on the aircraft fleet and aviation system.

2.8 Maintenance History.

A maintenance organization is subject to regular changes because of uncertainty and the drive for service excellence and for that reason establishing a maintenance organization requires a developed method that influences the effectiveness of the organisation (Ben-Daya et.al, 2009). All of these new sectors now call themselves aeronautical MRO organizations (Sahay, 2012).

Applicability of the MSG-3 includes details for assigning tasks and intervals between tasks for all systems and components of the aircraft and also allows changing the service interval. Obviously, all aircraft produced today will follow the MSG-3 concept and the implementation of the recommendations resulting from the MSG-3 analysis will be the basis for the airline in developing an optimal maintenance program (Ghobbar, 2010), Table 8.

Table 8. Overhaul Control Strategy Summary. Source: Ghobbar (2010).

Category	Maintenance action	Requirements/restrictions
Hard-Time	Overhaul/Replace item at specific time interval	Overhaul will “zero time” the item
On-Condition	OC checks at specified time	OC check must give reasonable

	intervals. Regularly scheduled collection of OC data. Overhaul required when item exceeds specified limits for OC or OC data	assurance of satisfactory operation until the next check. OC data must ascertain continuing airworthiness and/or show reliability degradation-failure imminence
Condition Monitoring(No overhaul control)	No scheduled overhaul/repair. Item is operated to failure	Failure must have no direct adverse effect on flight safety. Hidden functions must have regularly scheduled verification test. Data collection/evaluation program required for overhaul surveillance

It is important to note that the main difference between equipment and machinery maintenance and aircraft maintenance is that aircraft maintenance is mandated to be monitored by regulatory authorities, such as the FAA, CAA, EASA etc., and therefore the aircraft maintenance process is highly following MSG-3 (IATA, 2012) Figure 12.

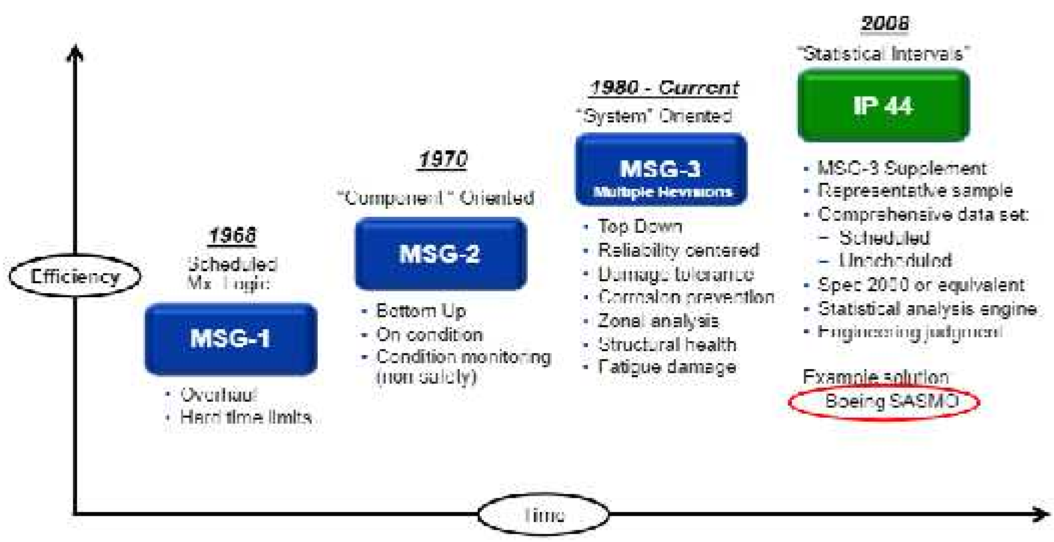


Figure 12. Aircraft Maintenance Processes and Philosophy Evaluation. Source: IATA (2012).

End of 70th, United Airlines, by the request of Department of Defence, developed a methodology for effective maintenance programs based on civil airline practices (McLoughlin and Beck, 2006) and then implemented it as Reliability-Centered Maintenance (RCM) (He Ren et.al, 2017), later on 1980 MSG were first published task-oriented concept inherent of aircraft system and component maintenance, in order to avoid unnecessary maintenance task therefore increase efficiency and reliability. The introduced new methodology MSG-3, became the main industry standard in the development of maintenance programs (Sahay, 2012; Urdu, 2015; Ezzat, 2020) analyses system failure from top down, Table 9.

Table 9. Difference between MSGs. Source: Ezzat (2020).

	MSG-1	MSG-2	MSG-3
Hard Time	✓	✓	✓
On Condition	✓	✓	✓
Zonal Inspection Program	x	x	✓
Condition monitoring	x	✓	x

- MSG-1 is action taken for development of scheduled maintenance logically analyzing the previous defects.
- MSG-2 is Process oriented and employed "Condition Monitoring" maintenance concept.
- MSG-3 is task oriented and based on the inherent reliability of while aircraft systems and components, to avoid unnecessary maintenance task, thus achieve increased effectiveness of airlines and MRO organizations.

Ahmadi et.al (2010) stated that, all commercial airlines, increasing interest now being placed on using the Maintenance Steering Group (MSG-3) methodology for establishing initial scheduled maintenance programs published in an MRBR.

The MSG-3 is designed and developed with reference to the Reliability-Oriented Maintenance (RCM) concept, considered for use in civil aircraft and the MSG-3 analysis studies are applicable to an introductory maintenance program for new generation aircraft. This document has been generated through the MSG-3 process by the aircraft manufacturer, based on Maintenance Review Board (MRBR) reports. And the document drawn up by the manufacturer, called the "Maintenance Planning Document" (MPD), is developed on the basis of the MRBR, therefore the MPD is used by airlines to develop their own MPs approved by the regulatory authorities (Chen, 2014).

Whittaker (2018) has studied comparative analysis of two major aviation safety systems, MSG-3 (Maintenance Steering Committee, version 3) and ICAO’s, SMS (Safety Management Systems) and found that these two safety systems have a significant impact on the entire aviation industry. In spite of

MSG-3 being introduced decades prior to SMS, both MSG-3 and SMS have had the same effect on airline operations.

The ATA MSG-3 methodology is nowadays commonly used in aircraft maintenance and application of MSG-3 is one of the solutions, how to make maintenance more effective and adequate to the elevated complexity and continue used for decades in the aviation industry (FAR 25/ CS-25). (Kostial et. al, 2017).

2.9 Maintenance Organisation Legislation.

Standards and Recommended Practices (SARP) ICAO for the Personnel Licensing and Operation of Aircraft — International Commercial Air Transport were first adopted by the Council of ICAO on 14 April 1948 and 10 December 1948 accordingly pursuant to the provisions of Article 37 of the Convention on International Civil Aviation (Chicago, 1944) and designated as Annex 1 and Annex 6 to the Convention, consequently became on force on 15 September 1948 and 15 July 1949 (ICAO Annexes 1, 6), Table 10.

According to a revised policy on international airworthiness, the Amendment 161 to the Annex 1 and Amendment 23 (f) to the Annex 6 Part 1, it was approved by the Council on 5 November 1998 (ICAO Annexes).

Before issuing amendment 161 and 23 operator was responsible for airworthiness of aircraft and maintenance as the management of maintenance organisation is also manager of the operator, where an important amount of stress was on compliance with maintenance practices.

Consequently, By the decision of European Parliament Regulation (EC) No 1592/2002 and of the Council of 15 July 2002 on common rules within the industry of the civil aviation announce of set up a European Aviation Safety Agency” (EASA),(hereinafter referred to as the ‘basic Regulation’) and having

Table 10. Amendments to ICAO Annex 1 and Annex 6. Source: ICAO (2009).

Amendment	Source	Subject(s)	Adopted, Effective, Applicable
161	Air Navigation Commission	Amendment of SARPs for aircraft maintenance technicians/engineers/ mechanics and Specification for	10 Mart 1997 21 July 1997 5 November 1998

23(f)	Air Navigation Commission	Personnel Licences New and revised provisions concerning continuing airworthiness to reflect the use of approved maintenance organizations and to clarify the responsibilities of the operator and the maintenance organization	19 March 1998 20 July 1998 5 November 1998

regard to this regulation, The COMMISSION REGULATION (EC) No 2042/2003 of 20 November 2003 has consolidated the continuing airworthiness defining in particular Article 3, Annex 1(Part M); Article 4, Annex 2 (Part-145); Article 5, Annex 3 (Part-66) and Article 6, Annex 4 (Part-147) thereof, Figure 13.

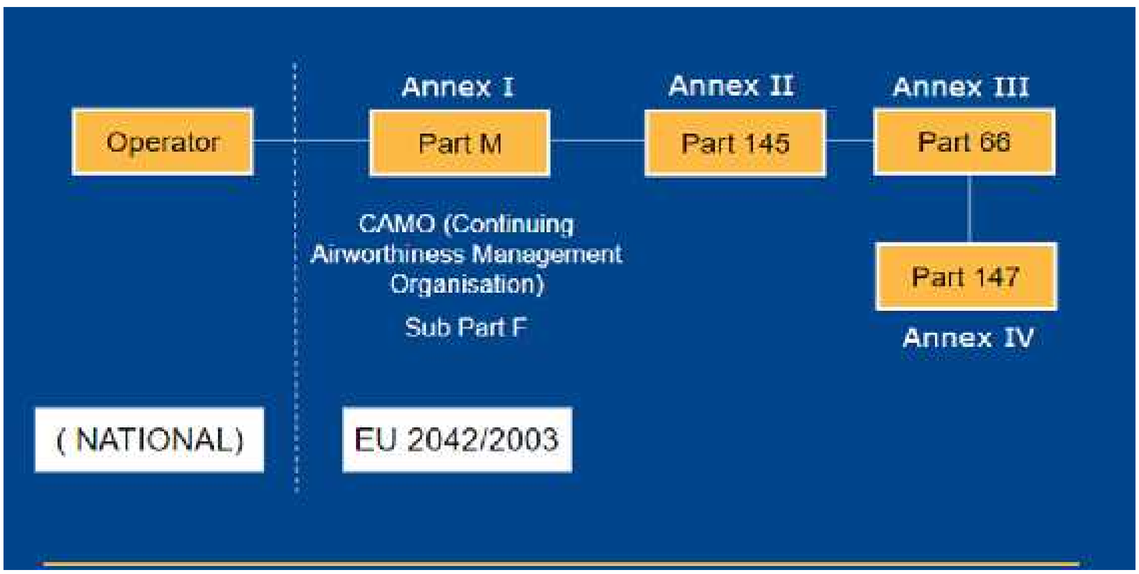


Figure 13. Relations between EASA Parts. Source: EASA (2021).

2.10 Maintenance and MRO objectives.

In order to permanently improve the Lean within the MRO industry, it is necessary to understand the main purpose of the organisation, as well as important to define its main objectives.

The available assets like factory, hardware and aircraft equipment provide a usage capacity and are worn out over time. To keep serviceability, repair and/or improve high level maintenance requires an appropriate MRO management (MROM), company objectives and strategies (Bierer et.al 2016). He states that the main objective of MRO is the high level of;

- Reliability and quality
- Health and Safety

- Resource availability,
- Financial sustainability

and established maintenance strategies as;

- reactive/corrective,
- proactive/preventive, predictive/condition based etc.

Ayeni (2015) argue that, to ensure the first objective of the MRO industry relating to safety and reliability of the aircraft system, equipment and human resources rely on proper scheduled maintenance actions and solving unscheduled maintenance occurrences on time.

Formally established organisation structure of the MRO - is the process optimization of resources (certifying staff, stock availability, new technology), all together to achieve the organisation strategies and objectives (Bonde and Fulzele, 2013). By the (Al-Kaabi et al, 2007) and (Sanchez and Sunmola, 2017) the main objective of MRO organisations is to retain or restore aircraft in condition in which they can safely perform its required operation within the acceptable limit. Taking into account the advances in information technology and cooperation between the operator and the MPO, direct access to vendors and aviation authorities who published SBs and ADs would have a significant impact on the effectiveness of MRO in terms of fulfilling its main goals and objectives for its customer.

2.11. Maintenance CostComponents

One of the unavoidable operating costs of an airline is maintenance costs (Saltoglu et.al, 2016), which each airline is being conducted study to optimize and cost management of maintenance planning (Vega et.al, 2016), whileZuidberg (2014) predicted, that the profitability of most airlines in the world is under constant pressure, despite the global economic growth, thus airlines do not receive sufficient profit.

The turnaround time (TAT) term is for scheduled maintenance is defined as downtime (DT), besides the costs of maintenance, crews, equipment, and materials, there is another cost, downtime cost when scheduled maintenance is not completed on a given time frame (Saltoglu et.al, 2016).

Reactive (corrective) maintenance action will never disappear from the aviation industry, because it's outside of the control maintenance staff and flight crew, however, the migration to digitalisation and new technologies using preventive maintenance concept and early detection of system degradation is possible to reduce the system failure and the corresponding costs associated to repair.

Kinnison (2012) and Ayeni (2015) has classified 2 type of maintenance tasks; ON aircraft maintenance that task performed on aircraft itself that can be carry out with or without taking aircraft out of service and OFF aircraft maintenance, that the work is carried out as an unscheduled, with taking aircraft temporarily out of service depending on type function and by the requirements of airline. Analyzing the maintenance operations by Kinnison (2012), Olaniyi (2015), Vieria and Loures (2016) and Jalil et.al (2017) stated that aircraft maintenance considered as scheduled-that includes routine and detailed inspection set up on operator maintenance program (48H, weekly, A, B, C. D checks), Table 11.

As noted above the MSG-3 processes is developed by FAA according to advisory circular (AC 121-22B, 2010) and closely incorporation with Industry Steering Committee (ISC) which using collected data from manufacturer, airlines operators and regulatory aviation authorities consequently perform analysis of each maintenance tasks, in order to develop a schedule maintenance programme for an aircraft type.

The final results of analysis maintenance review board report (MRBR) is introduced to the regulatory authorities the FAA and EASA for approval and then the approved report MRBR is then incorporated into the Maintenance Planning Data (MPD), issued for each aircraft and operator (Murphy 2011). Using the MPD, the operator creates its own maintenance program which must be approved by their CAA (McLoughlin and Beck, 2006).

Table 11. Maintenance check interval adaptation.

Check	Interval	Location	Description	Duration
Line	Daily/36H/48H	At gate or apron maintenance area	Daily(before flights or in transit) Visual inspection, fluid level, wheel and brakes, emergency equipment	1-3 hours
		Hangar or apron	Scheduled maintenance items	Up to 24

A	500/750/1000 F/H	maintenance area	airframe and engine.	hours
C	24Month or 6000 F/H	Hangar	Structural airframe inspection, scheduled maintenance and non-routine, system tests	3 days to 1 week
D	6/8/12 Years	Hangar	Major structural inspection of the airframe after paint removal; engines, landing gear and flight control removal, electronic equipment removal, and system component removal	1 month and more

Traditionally maintenance checks are splitted up into regular inspection items referred to as Line checks that include preflight, A and B checks, as well as heavy checks C and D. Other checks are planned in advance on an aircraft which may be product reliability improvement and redesign interior or exterior of the aircraft (Murphy, 2011). Pogacnik et.al (2015) describes Line Maintenance activities where include pre-flight checks, daily/weekly checks, aircraft servicing, refueling/defueling, de/anti icing, visual control that usually require short downtime of the aircraft. Base Maintenance activities require scheduled down time of the aircraft and planned in advance for heavy maintenance work packages according to aircraft flying hours/cycles or by calendar. These checks include C checks, D checks, 6 Years checks, 8 Years checks or 12-Years-checks and other non-routine maintenance items, usually arising from unpredicted defects. Saltoglu et.al (2016) referring to Eurocontrol, in spite of airlines maintenance programs being improved according to the Maintenance Steering Group (MSG) 3-task oriented principle, the letter check definition is still preferable in the aviation industry. However, in reality depending on MRO organizations and aircraft types, the scope of work and labor hours will vary.

2.12 Aircraft engine maintenance

An aero engine is an important element of an aircraft, which differs in several degrees of complexity, therefore, it requires a proper scope of services to be performed at each stages of scheduled maintenance (Fornlof et.al, 2016).

All types of the aircraft engines (turbofan or turbojet) internal-combustion chamber, low and high pressure compressor (LPC and HPC) and turbine section and their parts are subject to wear. Kjelgaard (2019), argue that this is the result of high vibration, friction, the very high exhaust gas temperature (EGT), internal corrosion (especially when an aircraft operates in salt-laden or polluted environments), and the damage caused by accidental ingestion of foreign object debris (FOD). In addition, the huge physical stresses which rapidly rotating jet engine parts such as compressor blades and turbine blades are subject to causes wear, which can cause metal fatigue, cracking and eventual failure of the parts. As a result, engine maintenance is an expensive part of the aircraft and overhaul is mandatory after certain period of use according to manufacturer engine maintenance program, replacement of rotating parts (called life limited parts), service of details, and change of consumables.

The inherent reliability of the engines does not exclude breakdowns and performance deterioration and aim of engine maintenance is to prevent these breakdowns as well as to recover performance at a minimum cost. As the aero engine is the core component of aircraft, it has to meet high standards of safety and reliability therefore regular shop visit maintenance with disassembling and replacement of parts is required. (Vidyasagar, 2020).

Off wing maintenance of the engine is not only complicated process and time-consuming and long term, but also very expensive (Fornlof, 2016). It is merely estimated 42% of the total maintenance cost per an aircraft (IATA, 2019).Recently entered into service (EIS) engines as a GEnx-1B/2B equipped on the aircrafts Boeing 747-8F and Boeing 787-8/9/10, will typically require light maintenance, to overcome initial technical issues, within several thousand flight hours (EFH) on wing and Heavy Shop Visit which can be in excess of six years from the date of the entry to service, Table 12.

Table 12. GEnx engines in Operation. Source: Boeing.com (2021).

Aircraft type	Engine type	Number in operation	Number of engine
Boeing 747-8	GEnx-2B	568	2272
Boeing 787	GEnx-2B	1489	2978

Widebody aircrafts are for about 20% of the world fleet of about 28,000 commercial aircraft in 2017 and will entered into service of several new-generation widebodies, with new engines that power them such as; the 747-8, 767, 777 and 787; and the A330, A350 and A380 families (Daniels, 2017).Today cargo operator market is competitive, with a number of cargo operators that include AirBridge Cargo Airlines, Cargolux, Kalitta Air, National Air Cargo and Silk Way West Airlines ownership of Boeing 747-8F with GEnx-2B engines (Atlas Air, 2020).Each engine having scheduled shop visit after defined life cycles or performance deterioration for refurbishment to restore initial operational characteristics.

During year 2020, about 500 Boeing 747-8 F aircrafts are continued to fly around the world despite the consequences of the pandemic, thereby meeting customer requirements, Table 13.

Table 13. Boeing 747-8 firm orders and delivery. Source: Boeing. com (2021).

DATA	Customer	747-8I	747-8F	Delivered	Unfilled
2005	Cargolux	–	14	14	–
2005	Nippon Cargo Airlines	–	8	8	–
2006	Business Jet / VIP	8	–	8	–
2006	Atlas Air	–	14	10	4
2006	Volga-Dnepr Airlines	–	6	6	–
2006	Lufthansa	19	–	19	–
2007	Cathay Pacific	–	14	14	–
2009	Korean Air	10	7	17	–
2012	Air China	7	–	7	–
2012	Customer X	--	2	2	
2013	Silk Way Airlines	–	5	5	–
2014	AirBridgeCargo	–	7	7	–
2016	UPS Airlines	–	28	20	8
2017	Customer X	2	-	1	1
2021	TOTAL	48	107	140	13

At the same time, after certain flight hours and cycles, the aircraft needed a periodical maintenance of the airframe, system and engines. Currently, the traditional bootstrap method is used for engine replacement in many type of aircrafts by the MRO organisations which requires more time and human resources (Table 14).

Table 14. Engine Replacement M/H and Time using bootstrap method.

Airlines	Aircrafts	Engine type	Man Hours	Duration	Method
Virgin Atlantic	A340-600	RR Trent 500	240 M/H	24 Hours	Bootstrap

Austrian Airlines	B777-300	GE90-90B	450 M/H	48 Hours	Bootstrap
Cargolux	B747-8F	GEnx-2B	150 M/H	21 Hours	Bootstrap
SW Airlines	B747-8F	GEnx-2B	217 M/H	31 Hours	Bootstrap
Avrora Airlines	A320-221	CFM56-5B	168 M/H	26 Hours	Bootstrap

2.13 Specification and classification critical factors.

Baines et al., (2009) set up a comprehensive ‘Principal Model’ that introduced of important operational characteristics of MRO organisation, including the production-centred concept presented by Hill (2000) and service-centred maintenance operation that were presented by Silvestro et.al (1999), Collier and Meyer (1998). There are presented key characteristics of maintenance operations were identified as into "Structural and Infra-structural" characteristics based on their production and service orientations, as listed in

the Figure 14.

Structural characteristics	Infra-structural characteristics
Process and Technology	Human Resources
Capacity	Quality control
Facilities	New Product/Service Range and introduction
Supply Chain Positioning	Performance measurement
Planning and Control	Supplier Relations
	Customer Relations

Figure 14. Characteristic of Leanness Operation. Source: Baines et.al (2009).

Amanda et.al (2002) and Ayeni and Baines (2016) argue that the determined 11 key characteristics of processes are "Leanness" achievement of best class MRO company. The influence these characteristic within of Lean were observable and enable help to extent of Leanness in the different processes within an any service organisation and the investigation analysis is identified characteristics of operation refer that Lean efforts have been most directed towards the "Process & Technology" as shown in Figure 15.

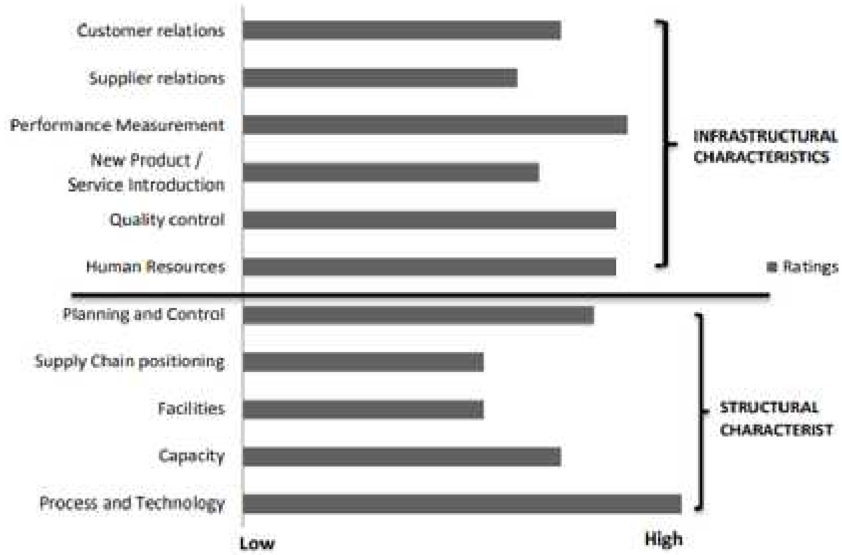


Figure 15. The influence of Lean within identified key characteristics of operation. Source: Baines et.al (2009).

Therefore, analysis of the synthesised result dictate importance of the direction the Lean effort to the "Planning and Control" that have achieved relatively good success in the strategic business are. This achieving of Lean within the "Process and Technology" and "Planning and Control" areas is relatively proportional to the positive outcome with the optimisation of product availability and interaction between two processes. The analysis also showed that the Lean has been most effectively in the area of "Human Resources", "Quality Control" and "Performance Measurement". Consequentially, effective Lean tools and techniques will also be accurate measuring metrics to evaluate the performance of various operating systems within MRO system and as indicate analysis Just-in-time (JIT), 5S and Takt Time included and adopted to the Lean MRO processes (Ball et al, 2016).

Evaluation of the studies shows, that the lean tools adapted within the MRO industry present a clear success. Effective JIT implementation is used in inventory reduction (Kros et.al, 2006), there is evidence that labour productivity has been improved using a reduction in work-in-progress (WIP).

Boute et.al, (2004) made a similar proposition that the effect of JIT implementation is mostly realised in WIP reduction would also contribute to the reduction in overall turnaround time (TAT). Furthermore, the "5S" tool is used as a team based approach to organizing work space and successful implementation contributes to significant reduction of the 8 wastes (Ball et.al, 2016) to ensure that it is accurate, arranged with modern design, efficient and capable for quality output. Other tools such as continuous improvement approach and Six Sigma principles also gives similar result in benefits in particularly in the output parameters.

Cutting Non-Value Add (NVA) within MRO organisations accomplishing aircraft maintenance activities goes via Lean tools implementing taking into account specific maintenance processes (Jasiulewicz-Kaczmarek, 2013). Several Lean tools applicability has been considered on previous studies that identified the key elements are and including VSM, 5S, Visual Management (VM) (Smith and Hawkins, 2004), by the Davies and Greenough (2010) offer key tools that involved to maintenance processes in MRO organisation are 5S, TPM, OEE, Standards, VSM, Inventory Management (IM), and Visual Management as well as they targeted 8 LM tools delivering objectives in a pharmaceutical industry, accordingly Okhovat et.al (2012) present Six Lean tools that fits in the maintenance activities that includes Visual Control (VC), 5S, eight wastes, Single minute Exchange of Die (SMED), and Poka-Yoke (mistake proofing).

Presented Lean Maintenance tools are demonstrated in the Figure 16.

	Previous study																	
Lean maintenance tool	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
TPM	*	*	*	*		*	*			*	*			*		*	*	
5S/CANDO	*	*	*	*	*		*		*		*		*	*	*	*		
Kaizen (continuous improvement)	*	*	*	*						*		*		*	*	*	*	*
CMMS/EAM	*					*	*				*			*			*	
Distributed MRO storerooms	*	*				*								*				
RCFA/FMEA	*		*	*		*		*			*						*	
PdM	*	*				*								*			*	
Autonomous maintenance		*					*			*				*			*	
SMED		*			*		*		*									
Poka-Yoke			*	*	*				*	*	*	*	*		*	*		
PDCA										*	*					*		
OEE				*														
Kanban				*				*					*		*	*	*	
Jidoka													*					*
JIT/inventory management			*	*			*						*		*	*		*
RCM						*	*	*			*			*			*	
Process mapping (VSM)				*						*			*			*		
Maintenance and reliability group				*										*				
Work standardisation	*		*	*				*				*		*	*	*		
Story boarding			*	*														
Visual control			*	*	*				*						*			
Work order system			*											*			*	
Self-audit				*														
Supplier association				*														
Open book management		*		*														
Empowered maintenance team												*		*				
Multi-skilled work team												*						
Maintenance crew training and learning							*					*						
Hoshin planning										*							*	*
A3										*								

Figure 16. Lean Maintenance practices/tools reported in previous studies. Source: Okhovat (2012).

Note: 1 – Baluch et al. (2012); 2 – Clarke et al. (2010); 3 – Davies and Greenough (2003); 4 – Davies and Greenough (2010); 5 – Djurovic and

Bulatovic (2014); 6 – Huang et al. (2012); 7 – Irajpour et al. (2014); 8 – Kolanjiappan and Maran (2011); 9 – Okhovat et al. (2012); 10 – Önder (2014); 11 – Qiang et al. (2011); 12 – Romano et al. (2013); 13 – Smith and Hawkins (2004); 14 – Smith (2004); 15 – Tendayi and Fourie (2013); 16 – Verma and Ghadmode (2004); 17 – Yile et al. (2008); 18 – Zwas (2006).*Presence of the lean maintenance practice within the study.

CHAPTER THREE

METHODOLOGY

The approach to the search method for the gathering of data, started by first identifying the data sources, the scope frame considered relatively to studies topic and the keywords. Initially, defined a broad selection of databases covering journals, conference proceedings, theses, books, online web pages of different companies, as well as articles from trade journals including Scopus, Mendeley, Science Direct (Elsevier), Academia, Research Gate and Emerald. Analysing these databases, referenced to redirect to additional sources of information were discovered such as the "European Journal for Operational Research", "Journals of Engineering Design and Education for Business", "International Journals of Automotive Technology", and "Quality in Maintenance Engineering",“Aircraft Engineering and Aerospace Technology”, “International Journal of Mechanical Engineering and Technology (IJMET)”, “International Journal of System Assurance Engineering and Management”.

In order to Identify necessary literature for the research, used of an array of keywords which were carefully combined to select a host of articles and publications. Keywords like Lean, Lean Six Sigma, Lean MRO, Maintenance Repair Overhaul, MRO, Organisation, Engine, Engine Replacement, Aerospace, Airline, New Generation, GEnx, Lean Implementation, PM System were used and the combinations shown in the Table 15.

Table 15. Keywords Combinations of the study.

Literature search N	Keywords	Total Publications
L1	Lean MRO+Lean Implementation	61
L2	Maintenance Repair Overhaul	72
L3	Lean Six Sigma+Organisation	11
L4	Engine+Engine Replacement	27
L1	Lean Service	12
L6	Lean+Critical Success Factor	33
L7	Engine+New Generation	38

For completeness, an Internet search was also conducted using several aviation online webpages, including airlines, manufacturer of aviation parts and components, MRO organisations, statistical and financial companies and international aviation authority databases. The literature reviews indicate that the Lean is particularly applicable within the MRO sector of the aviation/aerospace industry. However, the various Implementation strategies is absent on some maintenance structures within the MRO organization which distinct lack of understanding Lean philosophy that contribute to the long term its application for success. This will subsequently lead to widen the effectiveness of Lean in mitigating industry challenges and how Lean can be successfully realised within this context which enhances competitive advantage (Ayeni, 2015). Outcomes from the current research dictate that the Lean tools and techniques are not enough to achieve a company goals and objective, therefore it is necessary combination it with Six Sigma priciples to obtain intended performance during engine replacement on the aircrafts B747-8F with engines GEnx-2B.

As the main approach to the thesis problem, DMAIC process is selected to be used. DMAIC process methods Definition, Measurement, Analyze, Improve and Control steps, as defined under article 2.3 Six Sigma section. Tools which are listed in the literature for use with each process step are listed as a summary in Figure 7. The tools selected to be used for this thesis are given in the Table 16.

Table 16. DMAIC tool used in this thesis.

Define	High level process map
Measure	Process performance
Analyze	Non value added analyse
Improve	Process flow map
Control	Standard operating procedures

Definition-in order to draw high level process map, on an engine removal installation task cards are defined for the purpose of this thesis.All tasks are listed in their accordance and in their order of application.

Measurement-consist integration of the process map and definition of the measured elements to increase process flow performance.

Analysis-consist to define Non value added task cards from the traditional engine replacement tools and an equipment, while eliminating unnecessary tasks in the maintenance procedure process flow.

Improvement-after definition of the NVA task, to improve an engine replacement process using the proposed method to achieve an intended objective.

Control-The task that was developed and need to introduced to aircraft manufacturer Boeing for their approvals.

This study utilises the qualitative methodology to unravel development of aircraft maintenance procedures using Lean tools to determine effectiveness indicators in the aviation industry. Qualitative data collected from different of non-experimental research strategies including secondary data records, field or process observations, task card analyses, case studies, critical incidents, or surveys/interviews (Wiggins and Stevens, 2016).

In particular, based on AMM references will be conduct the task cards analyses how to improve the engine replacement procedures on the aircraft Boeing 747-8F aircraft applying lean Six Sigma combination methods. The Figures 18 and 19 show task card references of the engine replacement procedures using bootstrap method, which need to adopted and find alternative application.

Taking into account that location of inner and outer engine heights is different from the ground level, procedures are need to be carefully described in the AMM reference subtask (Figure 17).

Ground Clearance	Minimum (M)	Maximum (M)
M	1.90	2.10
N	0.73	0.99
P	6.52	6.48

Figure 17. Ground Clearance Boeing 747-8. Source: Airport Planning Document, Boeing (2012).

Under this thesis advancements in technology that could impact the further procedures of MRO in the aviation sector are regarded.

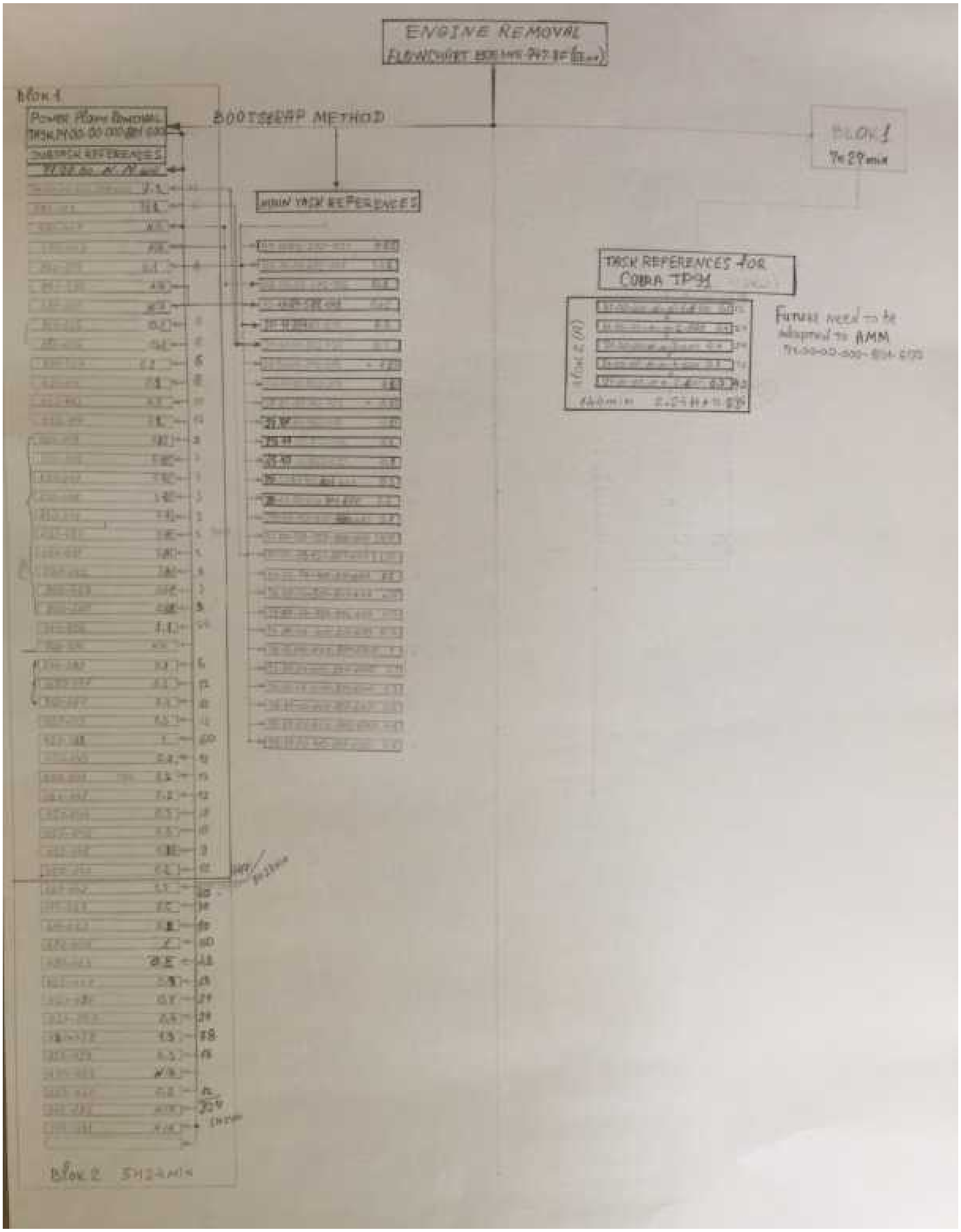


Figure 18. Engine Removal Process Map.

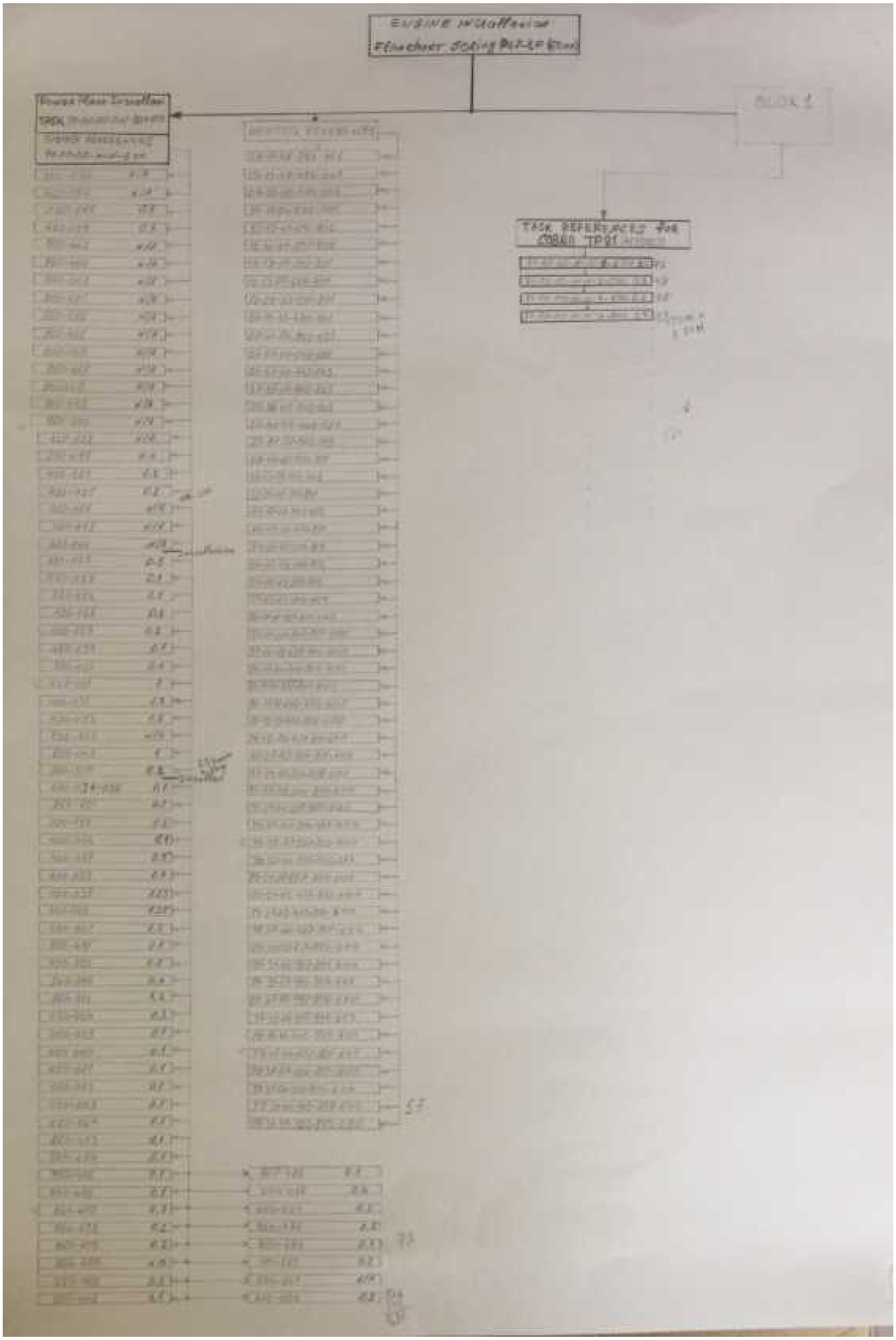
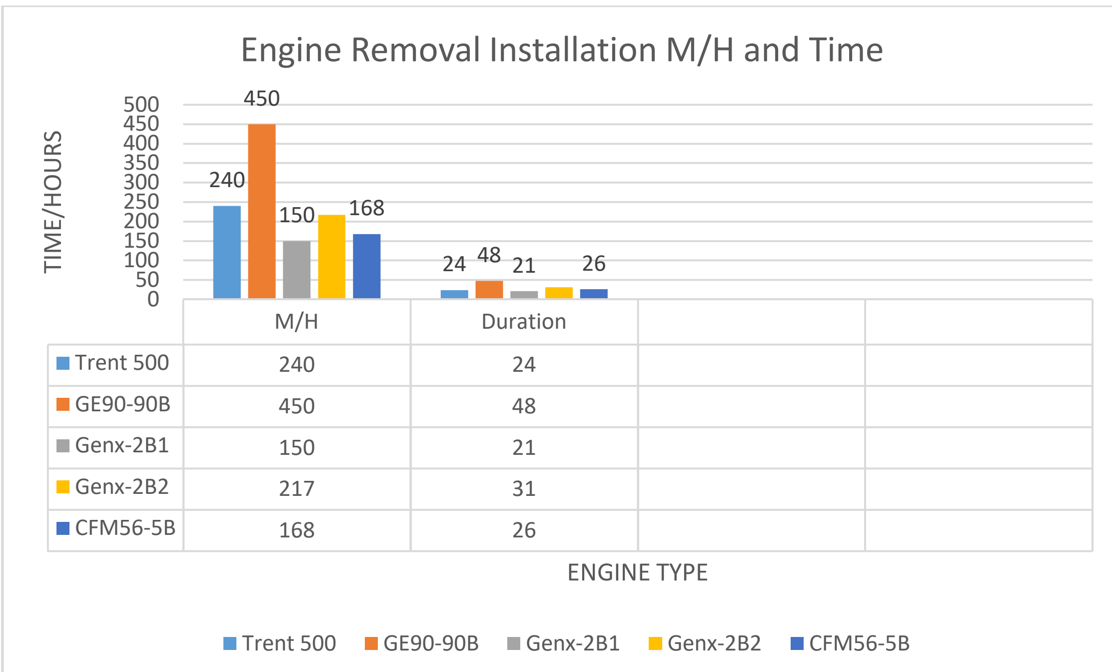


Figure 19. Engine Installation Process Map.

It is important to note that, it was necessary to optimize the replacement of the engine using modern equipment and which, with a smaller human resources perform these task provided for in the maintenance program. In the process of research and studying various articles on the topic, were discovered universal equipment for replacing all types of engines, which makes it possible to quickly replace aircraft engines with less manpower and also allows reducing the reduction in downtime of the aircraft. This equipment is produced by a plant located in Germany called Hydro KG, a specialized company in the production of ground support equipment for servicing aircraft, landing gear, system components and engines.

Table 17. Engine Removal and Installation M/H/Time diagram. (Refer to Table 14).



3.1 Proposed system-The hydraulic engine lift hoist (HELH).

The proposed system (PM) has been designed to ensure quick engine replacement and also to minimize malfunctions and technical risks. The use of this equipment has tremendous advantages due to the reduction in human resources costs, the minimum use of tools, and also to reduce the aircraft downtime. The PM Engine Change System is an economical and highly efficient system solution for engine maintenance applicable and compatible with all modern commercial and military aircraft (Glaser 2021). PM is an incredible modern design and multipurpose system that allows to replace almost all types of engines mounted on wing an aircraft.

Characteristics:

- Universal, innovative and automated engine change system for wing-mounted engines;
- Interchangeable and universal adapters for all types of the engines
- Full automatic movements and lift up and down of engine, dolly and cradle or transportation stand
- Consist of main Master Unit and interchangeable Slave unit which connected with a cable of 4 pillars
- 2 lifting beams to engine stand, 4 lifting adapters connected to transportation stand and 4 lifting lugs to the system.
- Each pillar can be controlled independently via Electronic Remote Control Panel,
- Movement and operations are possible in 3 axes,
- Airbus and Boeing approved for application during engine replacement.

Figure 20. Universal Cobra (PM) system. Source: Hydro System KG (2021).

Optional accessories:

Load cell calibration kit,Laser module,Transportation trailer,

Data logger,Inclination sensor,Removal and installation tool.

CHAPTER FOUR

RESULTS OF THE STUDY.

4.1 Defining of engine removal installation processes.

The main goal in this study is to reduce the processes of time frame required to replace the engines of wide-body aircraft using and rank the LEAN tools, applying Lean Six Sigma methods. First stage started to analyse engine shop visits forecast to define importance of this study (Table 2). Then conducted interviews with maintenance staff of several maintenance organisations to give their contribution to the engine replacement processes for proper identification objectives. In the process of studying this topic, it is also found that in the near future the number of new generation aircraft and equipped engines will be increased accordingly.

In order to find out possible ways to solve this problem, were addressed to several aviation companies to find out the methods and used equipment for replacing engines on their fleet and some information have been obtained from on online sources. All respondent's answers were a similar, that the engine replacements carrying out using a bootstrap method that takes more than 20 hours.Engine removal and Installation time frame of 5 Airlines is indicated in the Table 14.

Known of the modern engine replacement equipment so called PM which, having capability to save an amount of time and human resources. Then, was addressed to the manufacturer to get more details of the characteristics and functionality of components that are used on this equipment and the data provided by the manufacturer proves its highest performance during engines replacement. Having sufficient data collected and the results of experts' opinions from the airlines and MRO organizations, where carried out experiments to identify the time, measuring steps of engine replacement process by bootstrap method analysing more than 200 task cards reference from the AMM Boeing 747-8F.

4.2 Measuring of the datafor engine replacement applying DMAIC methods.

The measurement focused on identifying the internal value stream and identifying negative factors using a bootstrap, aimed at providing detailed timelines for further elimination of their implications.

In order to measure the time for replacement of the engine, initially obtained planning information, preparation of the place of work, delivery of the change equipment to certifying staff, their preparation before connecting to the engine pylon, an overview of the number of personnel involved in the process and, ultimately, its installation to the pylons of the engine to be removed. It takes some time to prepare the bootstrap kit in the presence of all parts and assemblies. After the registration of the tool kit in the logistics department and it is deliveries to certified personnel. Further, after the next inspection and check, it is assembled in the complete set in the front and rear pylon mount assemblies. The next one is mounting to the pylon.

All these processes take about 3-4 hours with the participation of 7-8 staff. This flow is one of Lean's tools, the so-called VSM.VSM is a method that enables an organization to obtain a complete view of the value stream (Faulknee and Badurdeen, 2014; Tyagi et al, 2015). Thus, VSM is effective for management to visually observe product flow information and waste identification (Rohac and Januska, 2015). Based on the measurement of the current state of the processes, data analysis is planned and further tools are implemented to improve value streams (Ishak et al, 2018).Ishak et.al (2018) has conducted the case study project focuses on the waste elimination through the implementation of VSM in the composite repair workshop and has concluded that this method is highly recommended to implement in other aviation-related organizations, therefore minimizing costs and reducing the time in maintenance processes.

The bootstrap kit consists of two parts, forward and aft tool assembly accordingly mounting to engine attachment points.Forward attachment tool assembly is consisting 12 main elements, 2 manual lever hoist and 36 pins and pin retainers. Aft attachment tool assembly accordingly consist 12 main elements, 2 manual lever hoist and 24 pins and pin retainers, Figure 21-22, Table 18).

All these parts must be assembled on the ground before the engine replacement process, the dynamometers must be checked to their respective calibration date, visual inspection of arrow pointers indication on “ZERO”.

Figure 21. Traditional Bootstrap Kit. Source: Hydro (2021).

Table 18. Bootstrap assembly KIT elements. Source: Boeing AMM (2021).

Forward Bootstrap Elements	Aft Bootstrap Elements
Load cell (2 locations)	AFT Rear BEAM Assy
6-Ton Hoist (2 Locations)	AFT LIFT ARM Assy
FWD Outboard ARM Assy	Load Cell (2 locations)
FWD Center BEAM Assy	3-ton hoist (2 locations)
FWD Center Support BEAM	AFT Front Outboard ARM
FWD Inboard ARM Assy	AFT Outboard BEAM
FWD Support ARM Assy	AFT Outboard Fix BEAM
FWD Attach Fitting Assy	AFT Inboard Front ARM
FWD Lift Link Assy (2 location)	AFT Inboard BEAM
Pin Retainer (18 locations)	AFT Inboard Fix BEAM
PIN (18 locations)	PIN and Retainer (24 location)

Total assembly process to fit to the engine pylons for both units are necessary 5.24 hours for forward and 3.36 hours for aft attachment tools. In the table calculated the times for each element separately, Table 19.

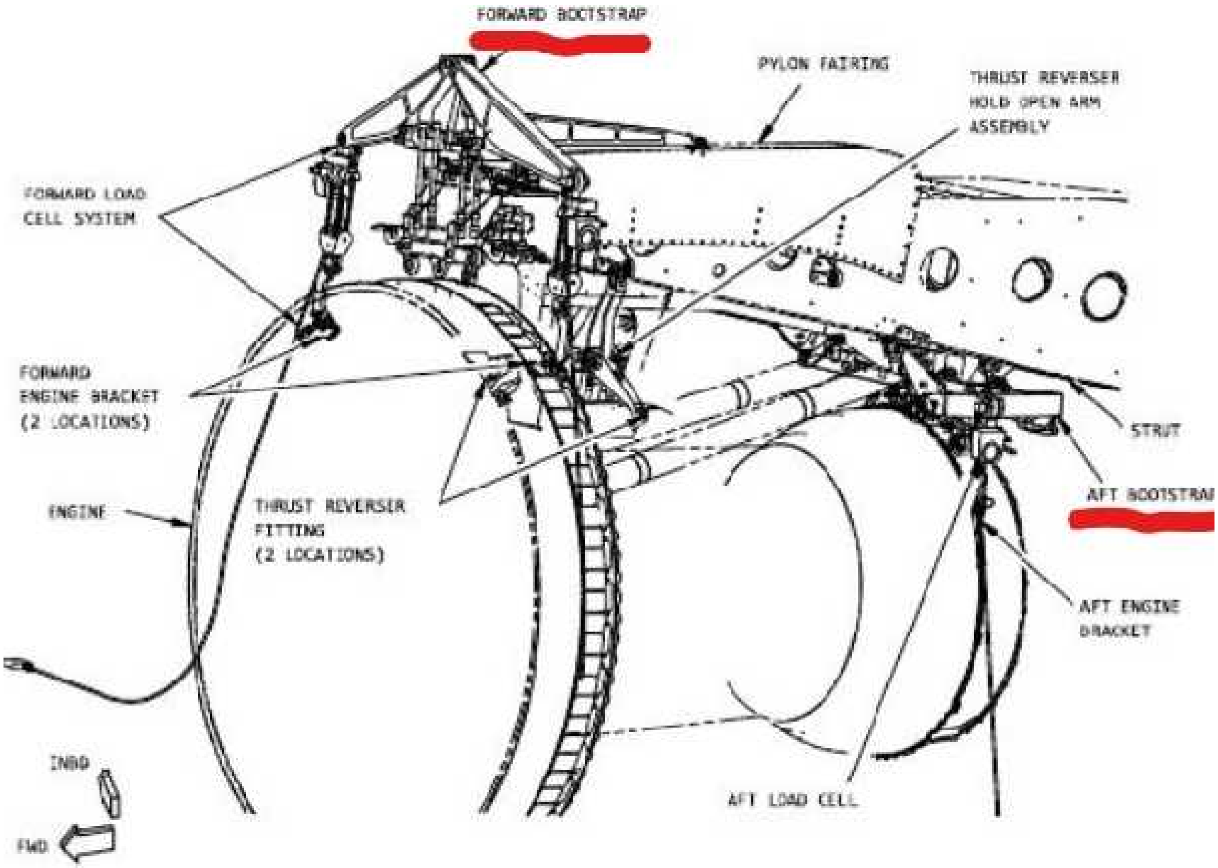


Figure 22. Bootstrap assembly fitted to engine pylon. Source: Boeing 747-8 AMM (2021).

In order to measure the timeframe necessary for assembling of the bootstrap the attention was paid to data collection from the experts of 5 MRO organisation carrying out definitely the same work. Referring to statistical sampling used nearly scheduled engine replacement process on Boeing 747-8F equipped GEnx-2B the data collected stated in the Table 12.

It is important to note that the process of connecting parts and assemblies of the bootstrap begins near the engine, and then the assembled two parts front and rear assemblies are reinforced to the pylon. At least 4 people work on the connecting lines standing on the ladders. As the connection process ends, 6-ton hoist begins to attach to the engine to be removed and slowly over an hour or more continues, loosening the bolts and then controlling with the handle, loading force onto the engine, controlled from four dynamometers, the engine goes down to the stand for transportation. The reverse process for installing the engine follows the same methods.

Bootstrap Assambly	Installation h/min	Removal h/min
Load cell (2 locations)	0.1/6	0.1/6
6-Ton Hoist (2 Locations)	0.1/6	0.1/6
FWD Outboard ARM Assy	0.25/15	0.15/9
FWD Center BEAM Assy	0.35/21	0.2/12
FWD Center Support BEAM	0.35/21	0.2/12
FWD Inboard ARM Assy	0.25/15	0.1/6
FWD Support ARM Assy	0.25/15	0.1/6
FWD Attach Fitting Assy	0.2/12	0.2/12
FWD Lift Link Assy (2 locations)	0.2/12	0.1/6
Manual Lever Hoist (4 locations)	0.3/18	0.2/12
PIN (12 locations)	0.3/18	0.2/12
AFT Rear BEAM Assy	0.35/21	0.25/15
AFT LIFT ARM Assy	0.1/6	0.15/9
Load Cell (2 locations)	0.1/6	0.1/6
3-Ton Hoist (2 locations)	0.1/6	0.1/6
AFT Front Outboard ARM	0.25/15	0.1/6
AFT Outboard BEAM	0.3/18	0.2/12
AFT Outboard Fix BEAM	0.3/18	0.2/12
AFT Inboard Front ARM	0.2/12	0.1/6
AFT Inboard BEAM	0.3/18	0.2/12
AFT Inboard Fix BEAM	0.3/18	0.15/9
PIN and Retainer (60 locations)	0.4/24	0.4/24
TOTAL	5.21H/321 min	3.36H/216 min

Table 19. Bootstrap assembly Removal Installation time frame.

NOTE: Total Task Card is 27 items and Include 8.57 Hours and based on involving 7 maintenance personnel.

Figure 23. Bootstrap Assembly fitted on pylon. Source: S2aerospace (2021).

In order to conducting proper analysis of the collected data on the problem of engine replacement on the aircraft Boeing 747-8F with GEnx-2B engines, the measuring of the assembly and disassembly of the bootstrap was not sufficient to determine the complete picture of the cause of the time frame. Therefore, the focus was directed to the study of the analysing of Aircraft Maintenance Manual, in order to apply the proper tools for process improvement.

Systematic approach of elimination of the shortcomings that restricted the quick replacement of the engine and the even distribution of human resources, there was the complexity of the bootstrap applications written in AMM which takes times. Replacing the engine using a bootstrap at each event and stage takes above 20 hours and about 200 man hours.

Before removals of the engine from wing it is necessary to carry out 27 items main tasks and 51 items subtasks that starting process to disconnection of electrical wire bundles from engine pylons, disconnection of Fuel, Hydraulic tube lines, QEC components (if necessary), engine preservation and etc (Table 20).

Referring to removal process analysis around 12.51 hours are needed to detached the engine from the wing.

Table 20. Engine Removal Task Card References. Source: Boeing 747-8 AMM (2021).

Task Reference	Task Description	Man Hours
07-11-05-202-001	Support the Airplane for Engine Removal and Insatallation	0.1/6
07-11-08-492-007	Tail Support Jack at Jack point III	0.2/12
08-00-00-582-006	Level the airplane with Inclinometers	N/A
10-11-04-582-001	Parking with Engines Removals	0.2/12
20-11-33-480-801	Attach Nacelle Surface Personnel Equipment	0.2/12
20-41-01-862-021	Static Ground Proceure	0.2/12
27-51-00-042-016	Traling Edge Flap Deactivation	0.2/12
27-51-00-862-019	Traling Edge Retraction	0.3/18
27-81-00-042-023	Retracted Leading Edge Flap Deactivation	0.4/24
27-51-00-862-019	Leading Edge Flap Retraction	0.4/24
29-11-00-802-048	Hydraulic System Depressurization Deactivation	0.5/30
45-10-00-862-032	Display of existing Faults	0.15/9
70-00-01-910-801-G00	Electrical Connector Disconnection and Connection	0.3/18
70-41-00-400-801-G00	Lockwire Installation (Removal) (caps)	0.2/12
70-41-00-400-801-G00	Safety Cable Installation	0.4/24
71-00-00-720-805-G00	Test 11 Fan/LPT Trim Balance-Functional Test	N/A
71-00-03-620-801-G00	Engine Preservation	1.2/72
71-00-04-400-801-G00	Engine and Shipping Stand with support Equipment Instal.	0.5/30
71-00-04-510-801-G00	Flightline Movement on an Engine	N/A
71-00-04-990-836-G00	Split Engine Component (LRU Replacement)	N/A
71-00-05-000-801-G00	Power Plan Fan Stator Module to Engine Removal	N/A
71-11-04-000-801-G00	Fan Cowl Panels-Removal	1/60
71-11-04-010-801-G00	Open the Fan Cowl Panels	0.1/6
71-12-02-000-801-G00	Thrust Reverser PDOS Actuator Removal	0.3/18
78-31-00-000-801-G00	Open the Thrust Reverser	0.2/12
78-31-00-400-802-G00	Close the Thrust Reverser	0.2/12
78-31-00-910-807-G00	Deactivate the Thrust Reverser for Ground Maintenance	0.2/12
TOTAL Task Card/Time	Engine Removed	447min/7.27H

For the installation of the engine on wing where analysed 55 main task card and 73 subtasks to calculate the time spend during this processes (Table 21).

Procedure installation of the aircraft engine usually vary widely from the removal process, because of there are many task list of instructions can be provided as a guideline for particular engines where large number of design variations within each type or category.

Table 21. Engine Installation Task Card References. Source: Boeing 747-8 AMM.

Task Reference	Task Description	M/H
07-11-01-582-001	Jack Airplane	0.3/18
07-11-08-492-007	Tail Support Jack at Jack point III	0.2/12
08-00-00-582-006	Level the airplane with Inclinometers	N/A
10-11-04-582-001	Parking with Engines Removals	0.2/12
12-12-01-610-802	Hydraulic Reserviour Servising	0.3/18
12-12-01-610-805	Hydraulic Reserviour Fluid Check	0.1/6
12-13-07-210-801	Integrated Drive Generator Oil Level Inspection	0.1/6
12-13-07-600-801	Integrated Drive Generator Oil Fill	0.2/12
12-22-03-610-801	Engine Oil Change Servising	0.4/24
20-11-33-480-801	Attach Nacelle Surface Personnel Equipment	0.1/6
20-41-01-862-021	Static Ground Proceure	N/A
27-51-00-442-043	Traling Edge Flap Activation	N/A
27-51-00-862-019	Traling Edge Retraction	N/A
27-81-00-042-023	Retracted Leading Edge Flap Deactivation	N/A
27-51-00-862-019	Leading Edge Flap Retraction	N/A
28-22-00-700-801	Valve Adapter Shaft-Operational Test	0.3/18
28-22-00-705-108	Engine Spar Valve-Operational Test	0.1/6
30-21-00-710-801	Operational Test Engine Inlet Anti-Ice System	0.1/6
45-10-00-862-050	Configuration Display Data Page	0.1/6
46-13-00-470-801	Onboard Network System LRU Software Installation	1/60
54-05-03-212-801	No1 Strut FWD and AFT Engine Mount Assamblies	N/A
54-05-03-212-802	No2 Strut FWD and AFT Engine Mount Assamblies	N/A
54-05-03-212-803	No3 Strut FWD and AFT Engine Mount Assamblies	N/A
54-05-03-212-804	No4 Strut FWD and AFT Engine Mount Assamblies	N/A
70-00-01-910-801-G00	Electrical Connector Disconnection and Connection	N/A
70-41-00-400-801-G00	Lockwire Installation (caps)	0.2/12
71-00-00-800-810-G00	Power Plant Test Referance Table	0.1/6
71-00-03-630-802-G00	Engine On-Wing Depreservation	1/60
71-11-04-400-801-G00	Fan Cowl Panels Installation	1.5/90
71-11-04-410-801-G00	Close the Fan Cowl Panel	0.3/18
71-11-11-400-803-G00	Thrust Reverser Hold-Open Rods Installation	0.4/24
71-12-01-400-801-G00	Fan Cowl PODS Actuators Installation	0.2/12
71-12-02-400-801-G00	Thrust Reverser PODS Actuator Installation	0.4/24
71-21-00-200-801-G00	FWD Engine Mount Visual Inspection	0.2/12
71-21-00-200-802-G00	AFT Engine Mount Visual Inspection	0.2/12
71-21-03-200-801-G00	Engine Mount Bolts and Nuts Inspection	0.2/12
71-21-04-210-801-G00	Thrust Link Visual Inspection	0.2/12
72-21-00-200-811-G00	Fan Stator Case Yoke Fittings, Bolts, Nuts Inspection	0.4/24
72-25-00-200-803-G00	Fan Hub Frame Mount Lug Detailed Inspection	0.3/18
72-50-00-200-802-G00	Turbine Rear Frame Aft Engine Mount Lugs Inspection	0.3/18
73-21-05-470-801-G00	EEC Configuration Data Function	0.3/18
73-21-05-471-802-G00	EEC Software Installation	0.5/30
73-21-05-910-801-G00	EEC Maintenance Switch Operation	0.1/6
77-31-00-470-801-G00	EMU with the ONS Maintenance Laptop software Inst.	0.5/30
77-31-00-470-802-G00	EMU Onboard Sofware Installation Verification	0.2/12
77-31-00-700-801-G00	EMU TO THE ONS Generating Client Credential	N/A
77-31-00-990-804-G00	EMU Onboard Sofware Verification Installation	0.2/12
77-31-00-990-806-G00	Flight Compartment Switch Location	0.1/6
77-31-01-910-801-G00	EMU Maintenance Switch Operation	0.3/18
78-11-01-000-801-G00	Primary Nozzle Removal	1/60

78-11-01-400-801-G00	Primary Nozzle Installation	1/60
78-31-00-000-801-G00	Open the Thrust Reverser	0.4/24
78-31-00-400-802-G00	Close the Thrust Reverser	0.4/24
78-31-00-910-808-G00	Activate the Thrust Reverser for Ground Maintenance	0.3/18
78-31-01-820-802-G00	Thrust Reverser Partial Adjustment	0.5/30
TOTAL Task Card/Time	Engine Installed	912min/15.12H

The tasks list that must be accomplished when installing an aircraft engines including reconnecting of electrical wire bundles, hydraulic and fuel supply tubs, installation of inlet cowls, exhaust gas path components, engine controls cables, and engine mounting connections to the airframe. It should be emphasized that engine replacement procedures are always included in the appropriate maintenance manuals and manufacturer’s instructions at any stage of engine removal or installation.Considering that the engines of commercial aircraft are very heavy (depending on the types of aircraft, they vary between 4 and 9 tons), by all means, safety measures must be strictly observed during the installation of the engines. Before they are installed on an aircraft, they must first be positioned to the nearest millimetre at the engine compartment under wing, which requires about 8 technicians and laser tuning. After carefully preparing and attaching the lift assembly units to the engine, you can begin to slowly raise the engine to the pylon and then reinforce them with the bolts, that take time for full torqueing. Installing the engine takes an average of 15 hours. Mistakes are absolutely excluded, since the engines are the most vulnerable component of the aircraft that is responsible for the safety of the aircraft and passengers.

Therefore, the manufacturer of the PM system (Figure 20) has conducted a study to determine the timing of removal and installation of engines on some Airbus aircraft with the participation of equipment specialists.Several such tests have been carried out with airlines purchasing this system to study the effectiveness of this product.After several successful tests, Airbus has approved the use of PM systems on airplanes Airbus and certified this equipment as a maintenance tools and include it in the approved list of equipment date base. This system consists of the two main elements electronically operated, using remote control panel and 4 adapters which are controlled by one person, thereby reducing human resources and ensuring the safety of personnel. The measurement carried out shows preliminary engine replacement time on different aircraft types;

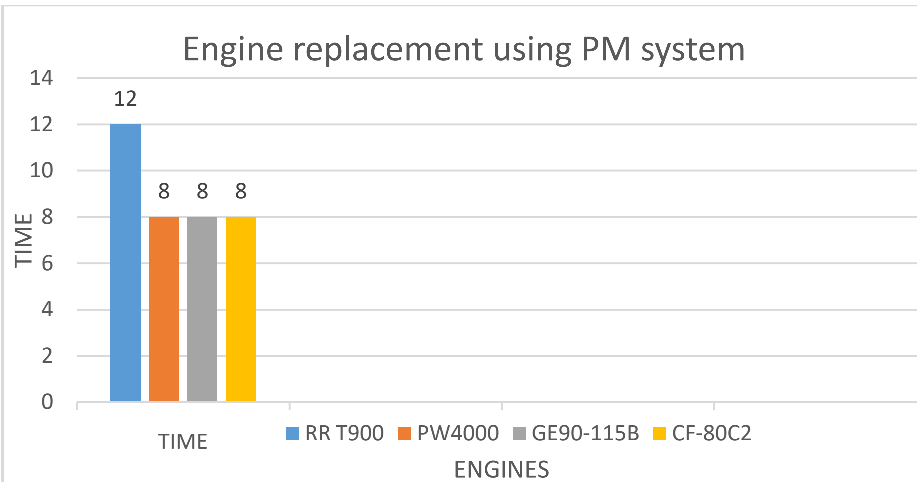
RR T900 engine replacement with PMincluding removal and installation time is completed at approximately± (20 min) 12h.

PW4000 engine removal and installation period is completed at the estimated timeframe is 8 h.

GE90-115B engine replacement time with PMis completed nearly at 8h.

CF6-80C2 engine replacement with PM completed within 8h including removal and installation time, Table 22.

Table 22. Engine Replacement time frame using PM system. Source: Hydro (2021).



Referring to the provided information about capabilities of the PM and its features, it was obvious that it significantly reduces the time to replace the engine, creating added value and success customer satisfaction.

4.3 Analysis of collected data to define engine replacement process and timeframe on Boeing 747-8F with engine GEnx-2B.

In this study was developed to analyse engine replacement optimization procedure on the Boeing 747-8F airplanes in order to define applying of acceptable equipment application to aim increasing effectiveness indicator for airlines and MRO organization.

The focus was on the increasing of volume and number of engines to be removed in the future for scheduled shop visit and it was strategic approach to optimize the engine replacement process while ensuring that the quality of the process is maintained at the highest level. The starting point for the study was to conduct a detailed analysis of operations in 5 stages and each process was mapped over time to characterize the overall process and their relationship to each other, Table 23-24.

1. Determine the assembly framework of the bootstrap elements and fit it to the pylon.
2. Determine the disassembly framework of the bootstrap elements and remove from the pylon

3. To analyse the process of engine removal time using the AMM tasks.

4. To analyse the process of engine installation time the using AMM tasks.

5. Data analysis using the PM system.

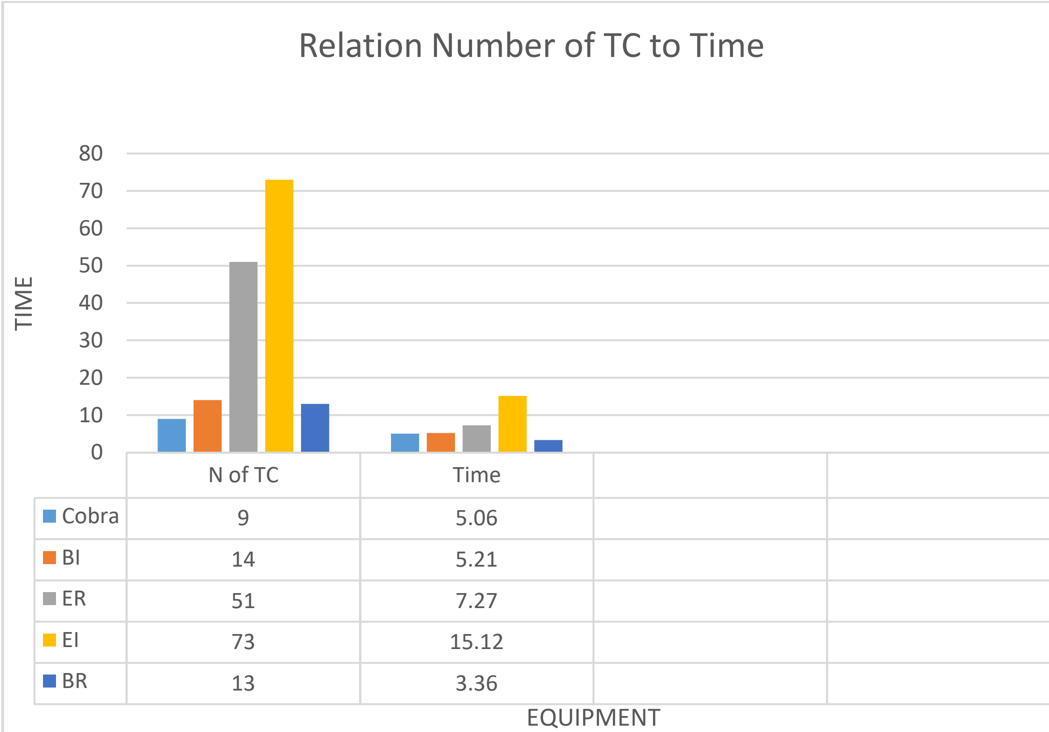
Table 23. Engine Removal and Installation Task Card and Time on the Aircraft Boeing 747-8F.

	Bootstrap Assembly Installation	Bootstrap Assembly Removal	Engine Removal Task Card	Engine Installation Task Card	PM System Use Removal/Installation
N of Task Card	14	13	51	73	9
Time	5.21 H	3.36 H	7.27 H	15.12 H	5.06 H

As indicated on the table, total task cards for bootstrap operation consist 27 task card and 8 hours 57 minutes' time to removal and installation.

Referring to the Boeing 747-8F airplane AMM the total removal and installation task number is 124 items with operational times 31 hours and 36 minutes. Aprovided data by the supplier of the PM system with the application of the system, significantly reduced the time for replacement of engines on another type of aircraft with different engine models.

Table 24. Relation between Number of TC and Time.



BI-Bootstrap Installation, BR-Bootstrap Removal

EI-Engine Insatallation, ER-Engine Removal

The preliminary performance of the analysis indicates that the engine replacement process using bootstrap assembly is does not create added value. This negative effect affecting to MRO organizations in terms of human resources and supply chain operations as well as for airlines that suffer losses due to aircraft down time and also in financial terms.

Applying the Cobra systems MRO organisations having chance to achieve 2 goals;

1. Avoiding to carry out the unnecessary task cards during engine replacement belonging to bootstrap operation.
2. Avoiding loses of extra time during the engine replacement.

By analyzing the engine replacement time of the 4 companies using PM system, with a comparison of the manufacturer's data, significant progress can be observed, Table 25-26.

Table 25. Engine Replacement Time frame of the different type of aircrafts. Source: Hydro (2021).

Airlines	Aircraft	Engine	Time
BA	B777-200	GE90-85B	2.50
HAECO	B747-400	RB211-524	4.05

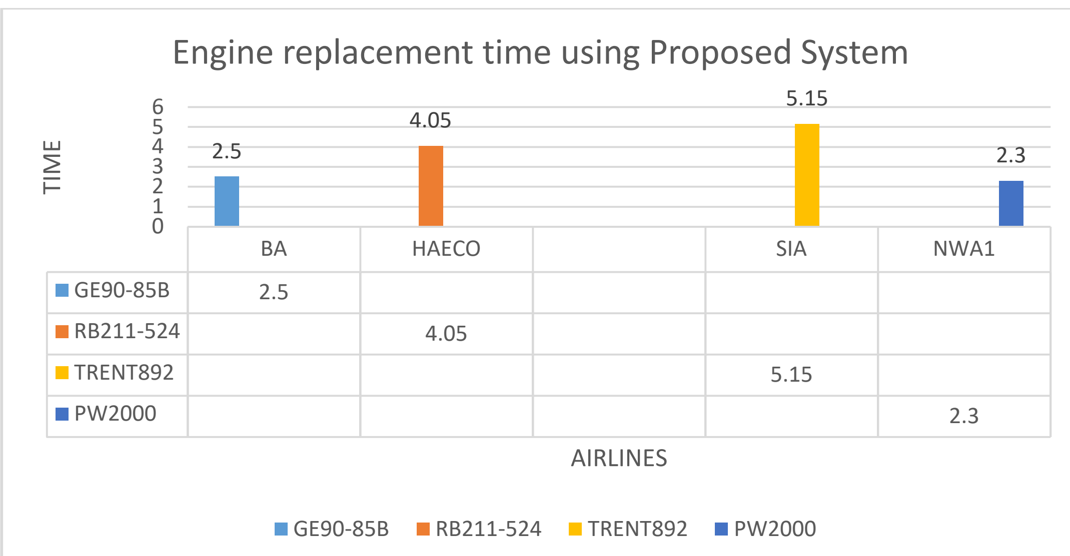
SIA	B777-312	TRENT892	5.15
NWA	B757-200	PW2000	2.30

The table and figure illustrate the engine replacement duration records using PM system in different types of aircraft with different engine model.

In order to come to the final calculations, the base elements of this study, considered;

- number of task cards,
- analysed time of removal and installation of the engine on 747-8F with engines GEnx-2B and
- provided parameters by the manufacturer of PM system in results of carried out during engine replacement test processes on the aircrafts Boeing 747-400 with RB211-524 engines and the Boeing 777-312 with engine GE90-85B.

Table 26. Engine Replacement time using PM system. Source: Hydro (2021).



Referring to the parameters of this study, we will determine the time of the engine replacement process using the bootstrap method and the theoretical data of PM systems, thereby determining the number of hours of completed task cards, reduction of replacement time, and also to determine the feasibility of using this equipment on this aircraft, Table 27.

Table 27. Parameters for Testing.

Equipment	Bootstrap method	PM system
Aircraft	Boeing 74708F	Boeing 747-8F

Engine	GEnx-2B	GEnx-2B
N of TC	27	9
Time required	8.57	5.06
M/H	68.56	20.24

PM system=5.06x4=20.24

Bootstrap=8.57x8=68.56

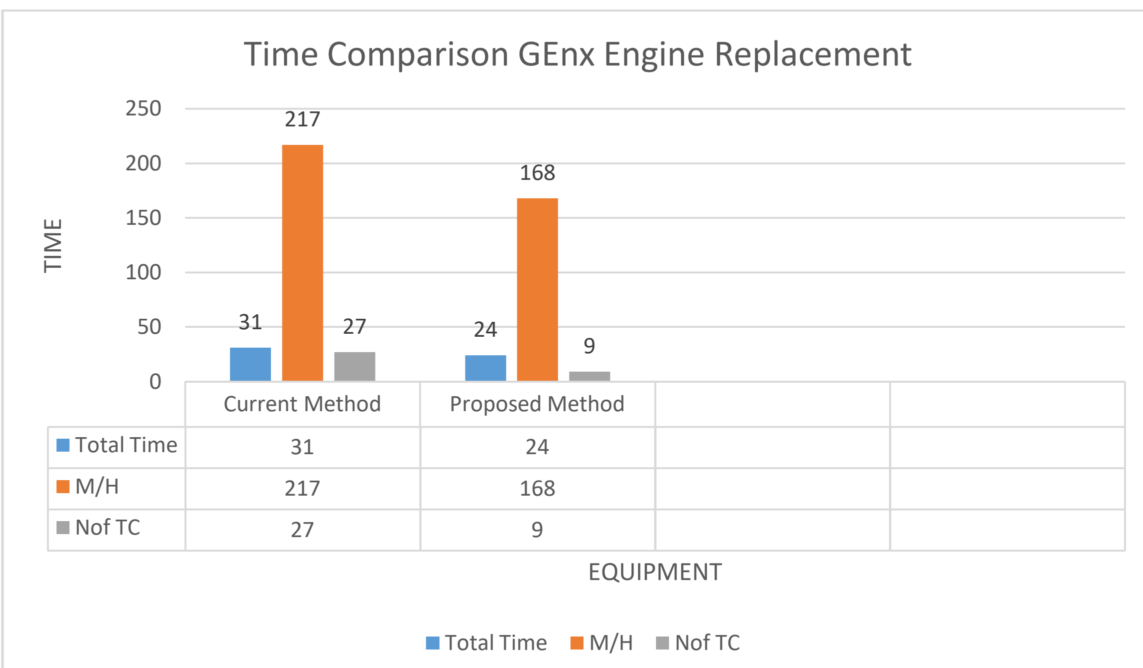
Available Extra M/H=48.32

217-48.32=168.68M/H/7=24hours.

Used this case, the execution of 18 task cards is consisting 68.56 man-hours, which gives staff savings in MRO, thereby additionally the logistics department is excluded from the process of engine replacement that was involved in checking and delivering the bootstrap and tools kit to employees. Taking into account the fact that each engine has its own bootstrap, it can be assumed that with the acquisition of PM system, the MRO facility can get rid of the bootstrap storage space. More important performance is that down time of the aircraft is reduced at 6 hours which meets customer satisfaction.

As far as the process of this study in progress there are no any evident or information using the PM system on the aircraft Boeing 747-8F with engines GEnx-2B. Most of operators of this type using bootstrap method on engine replacement in their fleet (Table 28).

Table 28. Engine Replacement time difference on the engine GEnx-2B.



Another reason of the restriction for the Boeing 747-8F is that the procedure for replacement has not been introduced in AMM with application of the PM system, therefore constraint the airlines ability to use of PM system.

Therefore, a way out of this situation lies in the fact that it is necessary to describe appropriate engine replacement procedure and entry it into AMM which need to be approved by aircraft manufacturer to use of PM systems on this type of aircraft. The critical point in using this procedure is to determine the load setting factor applied to the engine when replacing.

In the table of the analysis report that allow airlines to prepare their own procedure to get approval from manufacturer to use the system for implementation maintenance processes on engine replacement.

For the purpose of improve this thesis project were decided to write this procedure, using PM user manuals, AMM references and based own calculation. In the next section is described a full procedure of engine replacement.

4.4 Implementation of the process of engine replacement by using new procedures adapted to Proposed Method System.

For the introduction of a new procedure for engine replacement, there are certain problems caused by the inexperience of personnel in the use of PM systems (Figure 24). To solve this problem, a three-part of implementation program is needed;

1. To set up a training programme use of PM system involving

manufacturer training syllabus and detailed learning of the equipment user manual,

2. Formulation of experienced maintenance staff, to carry out such work, and

3. At the first stage to dedicate quality control supervisor for fulfilment of work.

Figure 24 Proposed method in Operation. Source: Hydro (2021)

In addition to training activities, team gathering for work execution and control functions, the management team should return to analyse the value stream activities in order to identify the limitations in the system that need to be removed from the process. To this end, it is necessary to develop an internal procedure in MOE and QM. MOE should describe the detailed procedure for the use of PM systems and QM, respectively, should pay special attention to the maintenance of the PM systems itself, determine its periodic maintenance and visual inspection work on the parts, assemblies and external components of the equipment, to maintain it in serviceable condition. As operation of the equipment is improved, its lead to reduce the risk factors, ensuring safety requirement of maintenance staff, aircraft and the engine. It is recommended to determine a special team of operators for the management of PM system in order to improve operational performance, obtaining of experience and effectiveness in engine replacement processes as well as time saving. In this way, improvement process is achieved at any time and on any type of aircraft carrying out engine replacement.

Below are detailed engine replacement procedures. But, in order to use this procedure, it is necessary manufacturer approval and entry it to the AMM of the respective aircraft.

4.4.1 PM System application for engine Replacement on the aircraft B747-8F with engine GEnx-2B.

TASK 71-00-00-400-801-G00.

ENGINE REMOVAL PROCEDURE.

ITEMs need to be added to AMM 71-00-00-000-801-G00.

Table 29. Amendments to AMM to the section C, Tools/Equipment.

Reference	Description.
SPL-15143 (Part N: TP91-G)	Hoist-Engine, Hydraulic Lift
SPL-15141 P/N TPBAE0A0	Lifting Adapter-Cobra
SPL-19148 P/N TPBBE0A0	Lifting Beam-Cobra
SPL-19149 P/N TPBLA0D0	Lifting Lug-Cobra
SPL-15142 P/N GET710002.	Inflatable Bag-Aft Engine Mount

4.4.2 SUBTASK (for Cobra) 71-00-00-N-N-1-G00. (0.2 h/12 min).

Referring to SUBTASK 71-00-00-200-039-G00, Use the Hold-Open ROD Attachment tool from the Cobra tool kit box P/N (refer to user manual Cobra system) (take away SPL-10927) according to Figure 403, as follow: This tool must be provided by Hydro with Cobra system tool kit, Table 29.

4.4.3 SUBTASK 71-00-00-N-N-2-G00. (0.6h/36min)

Prepare the engine stand SPL-13680 or SPL-13681 or SPL-11645 (Figure 412) to install the engine to engine shipping stand and install the forward and aft engine stand support brackets on the engine. Put the engine stand on the centreline under the engine and make sure that you keep the engine stand on the center line. Install lift adapters to the stand. (0.4 h/20-24 min).

Prepare the COBRA system for engine removal from the aircraft.

Use the Cobra Instruction Manual to check (Hydraulic and Electrical Line, Mobile Panel, Tools, Accessories and etc). (0.2 h/12-15 min).

Position the COBRA TP91-G (The hydraulic lift engine hoist), SPL-15143, master and slave units to the lift adapters and connect them on both sides of the engine stand by means of the hose package.

1) Make sure that the master unit is on the outboard side of the engine.

2) Install the Lifting beams, SPL-19148, to the engine stand, SPL-11645.

3) Connect the Lifting adapters, SPL-15141 to the Lifting beams SPL19148.

4) Connect the Lifting lugs, SPL-19149, to the Lifting adapters SPL-15141.

5) Connect the lifting lugs, SPL-19149 to the master and slave units, SPL-15143, of the hydraulic lift engine hoist.

6) Prepare the hydraulic lift engine hoist to full operation as follows;

a) Connect all hydraulic and electrical power connections between the master and slave units, SPL-15143.

b) Connect and activate external electrical power to the master unit of the hydraulic lift engine hoist, SPL-15143.

c) Adjust the master and slave units, SPL-15143 to make sure that they are in the neutral position at the transversal and lateral movement axis.

d) Adjust the two units to make sure that the crossbeams and the load cells are in the correct positions

e) Use the electronic remote control panel (ERCP) of the hydraulic lift engine hoist to select the correct load sheet for the engine stand combination and position of the engine.

f) Make sure that the maximum preload of (refer to user manual) lb (kg) is applied to the load sheet.

NOTE: The ERCP will display the maximum preload of (refer to user manual) lb (kg) at the FWD PRELOAD entry. The hydraulic lift engine hoist applies the maximum preload of (refer to user manual) lb (kg) at the FWD and AFT pillars equally.

CAUTION: DO NOT LIFT THE FORWARD END OF THE ENGINE ABOVE THE AFT END. THE UPPER FAN CASE WILL HIT THE THRUST REVERSER AND DAMAGE TO THE THRUST REVERSER WILL OCCUR.

4.4.4SUBTASK 71-00-00-N-N-3-G00.

4.4.5 SUBTASK 71-00-00-N-N-4-G00.

Remove the forward and aft engine mount bolts as follow (Figure 413, 414); (0.7h/42min)

1. Disconnect the forward (70) and aft (80) engine mount as follows (Figure 413, 414):

a) Loosen each of the bolts (73) and (81) by 1/2 turn.

b) Continue to loosen each of the forward mount bolts by 1/2 turn at a time until there is gap underneath the head of each of the bolts.

c) Make sure that there is no gap between the upper and lower mating surfaces of the engine mounts.

d) If there is a gap between the upper and lower mating surfaces of the engine mounts, make sure that the ERCP is still in APM mode.

e) Use the ERCP hydraulic lift engine hoist, SPL-15143, to deactivate the APM mode and to adjust each pillar and the load on the engine mount to close the gap until PRELOAD is displayed at all four pillar.

f) Activate APM on the ERCP of the hydraulic lift engine hoist, SPL-15143.

NOTE: DO NOT EXCEED THE HOIST LOAD LIMIT SPECIFIED IN STEP, SUBTASK 71-00-00-N-N-2-G00, 6(f).

g) Remove the four forward and aft engine mount bolts (73), (81) and washers (74), (82).

h) Remove the four-barrel nut retainers (72), (84) and barrel nuts (71), (83) that attaches to the four bolts forward and aft engine mounts (73), (81).

NOTE: Do Not reuse barrel nuts P/N SL4081C14SP1. Discard them.

NOTE: The protection assembly is part of the bootstrap engine kit (P/N SPL-10927). Hydro must provide the same in the Cobra tool kit this item.

WARNING: MAKE SURE THAT WORKSTANDS AND PERSONNEL ARE AWAY FROM THE ENGINE BEFORE YOU LOWER IT. THE ENGINE CAN MOVE RELATIVE TO THE STRUT WHEN THE SHEAP PINS ARE NOT IN

THE UPPER ENGINE MOUNTS. INJURIES TO PERSONNEL AND DAMAGE TO EQUIPMENT CAN OCCUR.

4.4.6 SUBTASK 71-00-00-N-N-5-G00.

Use the ERCP of the hydraulic lift engine hoist, SPL-15143, to lower the engine and the engine stand from the strut pylon to the ground as follows; (0.7h/42min)

1. At the ERCP on the hydraulic lift engine hoist deactivate the APM mode.
2. Operate the Hydraulic lift engine hoist slowly lower the engine with attached the engine stand is approximately (refer to user manual)in. from the ground.
3. Slowly rotate the engine and stand until the Digital Inclinometer or bubble level with digital readout reads ZERO.
4. Make sure that you control clearances between the engine, the strut, the nacelle and the stand-ground level.
5. Slowly Lower the engine and the engine stand down until the stand is on the ground.

NOTE: IF YOU WILL INSTALL A NEW ENGINE APPLY MASKING TAPE, G50314 OR EQUIVALENT, ON THE GROUND TO RECORD THE CORRECT POSITION OF THE ENGINE STAND WHEELS BENEATH THE WING WHEN YOU INSTALL THE ENGINE.

6. Remove these tools from the removed engine or stand;

a) The inflatable bag, SPL-15142 (if installed),

b) The Digital Inclinometer, COM-17619, (or bubble level with digital readout),

c) The thrust link protector, K78012-84 (if installed)

7. Do these steps to move the engine away from the airplane:

a) Turn off external electrical power to the master unit of the hydraulic lift engine hoist, SPL-15143,

b) Disconnect and stow all electrical and hydraulic lines between the master and slave units of the hydraulic lift engine hoist, SPL-15143,

c) Move the master and slave units away from the engine stand,

d) Carefully move the engine stand with the engine until it is clear of the aircraft.

TASK 71-00-00-400-801-G00.
ENGINE INSTALLATION PROCEDURE.

4.4.7 SUBTASK 71-00-00-N-N-1-G00.

Install the Power Plant with the Cobra Hydraulic Lift Engine Hoist. (0.7h/42min).

1. If it is necessary install the protection assembly on the LPT turbine rear frame shield (Figure 412, AMM).

NOTE: The protection assembly is part of the Cobra engine change tool kit, SPL-10927. Hydro must provide this part.

2. Align the transportation stand (100) and engine (101) into the correct position under the pylon, make sure that you keep the engine stand on the center line and wheels are unlocked.
3. If it is necessary, remove the duct support, SPL-13500 from the engine anti-ice duct on top of the inlet. (TASK 71-00-00-020-058-G00).
4. If it is necessary, remove the engine mount stabilization transportation equipment, SPL-10929 from the aft and forward engine mounts (Figure 412), (TASK 71-00-00-020-051-G00).
5. If you will use the inflatable bag, SPL-15142, position the tool on the engine, just forward of the aft mount and under the thrust link.
6. Prepare the COBRA system for engine removal from the aircraft. Use the Cobra Instruction Manual to check Hydraulic and Electrical Line, Mobile Panel, Tools, Accessories and etc. (0.2 h/12-15 min).
7. Install the lifting beams, SPL-19148, to the engine stand.
8. Connect the hydraulic lift engine hoist, SPL-15143, to the engine stand as follows:

a) Connect the lifting adapters, SPL-15141, to the lifting beams, SPL-19148.

b) Position the master and slave units of the hydraulic lift engine hoist, SPL15143, on both sides of the engine stand.

c) Make sure that the master unit is on the outboard side of the engine.

d) Connect the lifting Lugs, SPL-19149, to the lifting adapters, SPL-15141.

e) Connect the lifting lugs, SPL-19149, to the master and slave units of the hydraulic lift engine hoist, SPL-15143.

9. Use the Operating Manual to prepare the hydraulic lift engine hoist, SPL-15143, as follows:

a) Connect all hydraulic and electrical connections between the master and slave units.

b) Activate external power to the master unit of the hydraulic lift engine hoist, SPL-15143.

c) Adjust the two units to make sure that they are in the neutral position at the transversal and lateral movement axis.

d) Adjust the two units to make sure that the crossbeams and the load cell are in the correct positions.

e) Use the ERCP of the hydraulic lift engine hoist, SPL-15143, to select the correct load sheet for the engine.

f) Make sure that you apply the maximum preload of lb ((kg) refer to user manual)) to the load sheet.

NOTE: The Electronic Remote Control Panel (ERCP) will only display the maximum preload of (refer to user manual) lb (kg) at the FWD_PRELOAD entry. The hydraulic lift engine hoist, SPL-15143, applies the maximum preload of (refer to user manual) lb (kg) to the FWD and AFT pillars equally.

CAUTION: DO NOT LIFT THE FORWARD END OF THE ENGINE ABOVE THE AFT END. THE UPPER FAN CASE WILL HIT THE THRUST REVERSERS. DAMAGE TO THE THRUST REVERSERS WILL OCCUR.

4.4.8 SUBTASK 71-00-00-N-N-2-G00.

Lift the engine with engine stand to the strut according to below steps: (0.8h/48min)

1. Put a Digital Inclinometer, COM-17619, (or bubble level with digital readout) on the stand.

2. Calibrate Digital Inclinometer, COM-17619, (or bubble level with digital readout) to ZERO.

3. Use the hydraulic lift engine hoist, SPL-15143, to lift the engine and stand to the strut and stop when engine stand approximately (refer to user manual) in. from the ground.

4. Slowly rotate the engine and stand clockwise (left engine looking forward) or counterclockwise (right engine looking forward) until the Digital Inclinometer, COM-17619, (or bubble level with digital readout) reads the recorded value from the removal procedure.

5. Slowly rotate the engine and stand clockwise until the Digital Inclinometer, COM-17619, (or bubble level with digital readout) reads (refer to user manual) degree (left engine looking forward) or counterclockwise (refer to user manual) degree (right engine looking forward).

6. Make sure that you control clearances between the engine, the strut, the nacelle and the stand-ground level.

CAUTION: MAKE SURE THAT THE SHEAR PINS FOR THE FORWARD MOUNT ARE LOWER THAN THE SHEAR PINS ON THE AFT MOUNT WHEN YOU LIFT THE ENGINE. IF YOU DO NOT OBEY THIS INSTRUCTION, DAMAGE TO THE FLANGE ON THE TOP OF THE ENGINE CAN OCCUR.

7. Slowly lift the engine stand until there is approximately (refer to user manual) inches (mm) between the engine mounts on the engine mount fitting on the pylon strut.

CAUTION: MAKE SURE THAT YOU ALIGN THE SHEAR PINS ON THE FORWARD MOUNT WITH THE PYLON BUSHINGS DURING ENGINE INSTALLATION. IF YOU DO NOT OBEY THIS INSTRUCTION, DAMAGE TO THE SHEAR PINS OR PYLON BUSHINGS CAN OCCUR.

8. Make sure that you keep the forward mount shear pins in line with the forward pylon bushings.

9. Use the ERCP hydraulic lift engine hoist, SPL-15143, to actuate the ZERO OUT function.

10. Make sure that no part of the engine or stand is in contact with the aircraft when you actuate the ZERO OUT function.

11. Slowly move up the engine and stand until a clearance of (refer to user manual) in. (mm) to engage the shear pins and bring the interface surfaces of the forward and aft mounts together.

12. Examine the upper and lower mating surface of the forward and aft mounts and use the ERCP to adjust the pillars as required to make all of the clearances the same and make sure the surfaces parallel.

13. Make sure that the clearance on the inboard side of the engine mount is the same as clearance on the outboard side of the aft engine mount are the same.

14. If the surface clearances are not the same, do one of these steps to align the aft engine mount:

a) Slowly, inflate the inflatable bag, SPL-15142, until the surface clearance are the same.

b) Use a 2 inch by 4 inch, 4-7 feet long wood lever, STD-1208, to adjust the position of the aft engine mount until the surface clearances the same.

COUTION: MONITOR THE TOTAL LOAD ON THE FORWARD AND AFT ENGINE MOUNS DURING SHEAR PIN INSTALLATION. IF THE LOAD INCREASES BY MORE THAN THE LIMIT GIVEN, DAMAGE TO THE SHEAR PINS CAN OCCUR.

CAUTION: MAKE SURE THAT YOU ALIGN THE SHEAR PINS ON THE FORWARD MOUNT WITH THE PYLON BUSHINGS DURING ENGINE INSTALLATION. IF YOU DO NOT OBEY THIS INSTRUCTION, DAMAGE TO THE SHEAR PINS OR PYLON BUSHINGS CAN OCCUR.

15. Continue to lift the engine until the forward and aft mounts touch the engine mount fittings on the pylon strut.

16. Make sure that you keep the forward mount shear pins in line with the forward pylon bushings until the mount and pylon surfaces touch.

17. Continue to slowly lift the load until PRELOAD is displayed at all four pillars on the ERCP of the hydraulic lift engine hoist, SPL-15143.

WARNING: MONITOR THE LOAD CELLS ON THE FORWARD AND THE AFT HOISTS. IF THE LOADS ARE MORE THAN THE LOAD GIVEN, THE ENGINE CAN FALL. THIS CAN USE INJURIES TO PERSONNEL OR DAMAGE TH THE EQUIPMENT.

18. Activate AUTOMATIC PRELOAD MAINTAINING (APM) on the ERCP of the hydraulic lift engine hoist, SPL-15143.

19. Make sure that PRELOAD is displayed at all four pillars on the ERCP of the hydraulic lift engine hoist, SPL-15143 before you activate APM.

20. Examine the aft engine mount and the aft engine mount fitting contact surfaces for excessive clearances:

a) Use a feeler gauge, STD-405, to examine all of the edges of the contact surfaces for excessive clearances.

b) If clearances are less than (refer to user manual) in. (mm) continue with the engine installation.

c) If clearances are greater than (refer to user manual) in (mm) do as follows;

d) Use the ERCP of the hydraulic lift engine hoist, SPL-15143, to deactivate the APM mode.

e) Lower or raise each pillar on the ERCP to remove the clearances between the aft engine mount and the aft engine fitting contact surfaces.

f) Continue to adjust each pillar until PRELOAD is displayed at all four pillars

g) Activate APM on the ERCP of the hydraulic lift engine hoist. SPL-15143.

4.4.9 SUBTASK 71-00-00-N-N-3-G00.

Install engine mount bolts. Refer to; (0.6h/36min)

SUBTASK 71-00-00-420-032-G00

SUBTASK 71-00-00-420-033-G00

SUBTASK 71-00-00-020-055-G00

4.4.10 SUBTASK 71-00-00-N-N-4-G00.

Disconnect the engine from the stand and Cobra system.

(0.4h/24min)

1. Use the ERCP of the hydraulic lift engine hoist, SPL-15143, to lower the stand until only the load of the empty stand displays on the ERCP.

a) Reference the Cobra Operating Manual for the hydraulic lift engine hoist, SPL-15143, to determine the correct display.

b) Make sure that all attach points between the stand and the engine are loose.

c) Disconnect the forward and aft engine stand from the mounts on the engine. Refer to AMM.

d) Use the ERCP of the hydraulic lift engine hoist, SPL-15143, to slowly lower the engine stands to the ground.

e) Slowly Lower the engine stands down until it is approximately (refer to user manual) in. (cm) from the ground.

f) Slowly rotate the engine stands until it is at the correct angle with the ground.

g) Make sure you are monitor the clearances between the engine stand the pylon strut and the nacelle surfaces

h) Slowly lower the engine stands down until it is on the ground and move away from the aircraft.

i) Turn off external electrical power to the master unit of the hydraulic lift engine hoist, SPL-15143.

j) Disconnect and stow all electrical and hydraulic lines between master and slave unitsof the hydraulic lift engine hoist, SPL-15143.

k) Disconnect the lifting lugs, SPL-19149, from the master and slave units of the hydraulic lift engine hoist, SPL-15143.

l) Move the master and slave units away from the engine stand.

m) Remove the lifting lugs, SPL-19149, from the lifting adapter, SPL15141.

n) Remove the Lifting adapters, SPL-15141, from the lifting beams, SPL-19148.

o) Carefully pull the engine stand aft until it is clear of the airplane.

p) Remove the Lifting beams, SPL-19148, from the engine stand.

q) Remove the forward and aft engine stand support brackets from the engine. (Refer to AMM)

NOTE: Follow the installation procedure in accordance to AMM for final task card accomplishment.

4.4.11 Measurement elements and final result of the study

In this section, we will illustrate some experimental results. During of the study, the data obtained from five airlines were used, two of them directly operating the Boeing 747-8F, which participated maintenance experts in aircraft and engine maintenance, heads of engineering departments, one representative of the manufacturer of universal equipment for engine replacement on any type of aircraft, and consequently were collected sufficient reliable information to measure the data of the desired process and improve it by necessity.

The main objective of the study was being development of the maintenance procedures using the methods Lean Six Sigma (LSS). Furthermore, in order to increase effectiveness in companies more frequent implementation of Lean and Six Sigma tools are necessary (Grudowski et.al, 2015).

The outcome of the current study shows that the combination of lean tools with Six Sigma methods justifies the hypotheses envisioned to achieve the goal and expected performance during engine replacement on B747-8F aircraft with GEnx-2B engines. From the short review above, key findings are emerging following results:In the first step were analysed the time used during engine replacement on five airlines to define M/H spend employed bootstrap method. Referring to Table17, it is obvious that the process on all airlines are more than 20 hours, involving 7 or 8 certifying staff. As a study focused on the engine GEnx-2B, here we compare the results of the proposed method with those of the traditional methods.

Measurement carried out based on collected data from Aircraft Maintenance Manual task cards for Engine removal and Installation (Figures 18, 19), defining number of elements for bootstrap assembly KIT and Removal Installation time on and from pylon (Figures 21, 22, 23), Engine removal and installation time frame referring to AMM task references (Table 20, 21), Engine replacement time frame using PM system (Table 22).

Table 30. Measurement Elements for Engine RI.

AMM Task Reference		Bootstrap KIT Elements		Bootstrap RI Timeframe		Engine RI Timeframe		Engine RI using Cobra System
Removal TC N	Installation TC N	FWD	AFT	Installation	Removal	Removal	Installation	
51	73	50	38	5.21 H	3.36 H	7.27 H	15.12 H	9 H

Referring to Table 28, engine replacement time difference on the engine GEnx-2B using Bootstrap and PM System, this is an important finding in the understanding of the study which the final decision on the choice and amount of data for analysis will be based on these data. Comparative analyses using bootstrap and PM show the differences between TC, M/H and the time required to replace the engine. It is characterized by a decreasing maintenance task cards by 18 items, saving man hours by 68 hours and the engine replacement time being reduced by 7 hours. These 3 elements are the main indicators of this study.

Using this data, the efficiency of the MRO organisation and Airlines is measured by translating them into a financial performance. Actions to eliminate unnecessary tasks from AMM procedures have significant positive characteristics on the activities of the maintenance provider and customer.

Table 31. Difference in Profit between Bootstrap and PM System usage.

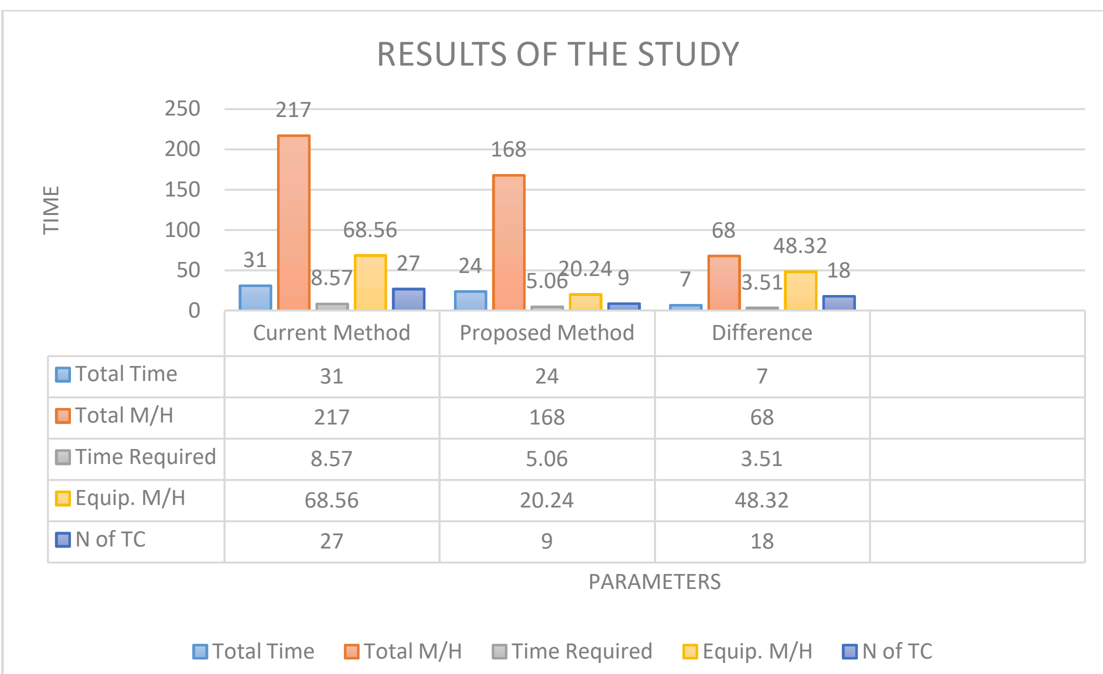
Equipment	Bootstrap method	Cobra sys method	Difference in Profit
Aircraft	Boeing 74708F	Boeing 747-8F	
Engine	GEnx-2B	GEnx-2B	
Total Time	31	24	7 H
Total M/H	217	168	68 M/H

N of TC	27	9	18
Time required	8.57	5.06	3.51 H
Equipment used M/H	68.56	20.24	48,32 M/H

The explanation of the calculations is given below;

Using four maintenance staff for PM system total M/H spend is equal to 20.24 H. Bootstrap M/H availability need to provide eight persons which equal to 68.56 H. MRO's Available Extra M/H is reached equal to 48.32 H, hereby total M/H need for engine replacement reduced to 168 H therefore engine replacement time is consisting 24 hours using of Cobra system. Moreover, reduced labor required costs in supply chain, expecting space availability in the stock, control and delivery/redelivery of bootstrap equipment to maintenance team, transportation cost within organisation from of reallocation of equipment and tools, well as time and effort spent undergoing non-value-added tasks (Tables 32 and 32).

Table 32. Result of the Study.



If to take into account the fact that each engine has its own bootstrap type, the use of Cobra significantly affects the overall activity of the MRO, which a result of this improvement, costs are expected to reduce direct expenses for the bootstrap (Figure 25).

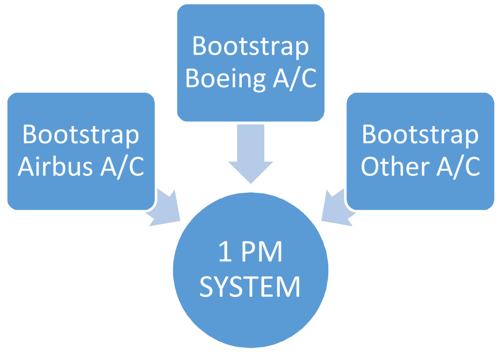


Figure 25. Proposed Method System Suitability.

4.5 Control of the proposed method.

The control process of this project is supervised by the base maintenance manager, conducting visual monitoring of the process of this work to detect non compliances and errors. If necessary, draws up a plan for additional training of technical personnel and if its demands, proposes other methods and tools for further implementations of the engine replacement process as well as to act accordingly improve the quality of work and the safety procedure.All implementation proposal must be discussed and taken by top management and interacting between departments.

Using the Lean tools and Six Sigma methods, an acceptable scheme has been developed to improve the efficiency of the engine replacement process on the aircrafts Boeing 747-8F with GEnx-2B engines as stated in the Table 33.

Table 33. DMAIC applicable tools and actions for engine RI.

STEPS	TOOLS	ACTION
Define	High level process map	Identification the level of engine RI
Measure	Process performance	Measuring of the collected data for engine RI
Analyze	Non-value-added analysis	Analysis of processes and definition of timeframe for engine RI
Improve	Process flow improvement	Implementation of the new procedures
Control	Standard operation procedures	Standard engine RI procedure is set up

Another change incorporated in to the Improvement stage was the introduction to the production planning department to make data records of the equipment, to perform routine maintenance on it, order hard-time spare parts and to control the maintenance interval. And the engineering department is responsible for monitoring the changes in the documents introduced by the manufacturer, changes in the user manuals, and technical support for the operation.

CHAPTER FIVE

DISCUSSION

Summarizing the findings of the analysis on the GEnx-2B engine replacement on the aircraft Boeing 747-8F, it should be noted that the developed procedure applying Cobra system, using the LSS method is written and included in section 3.4 chapter 3. The findings show that this method improves optimisation of the AMM card tasks, affecting to reducing process time of engine replacement.This reduces labor costs, by the reducing the number of MRO certifying staff and through the use of an optimized value-oriented approach while minimizing the wastes (Hill et al, 2018). This will have influenced to reduce aircraft downtime and increased productivity in other maintenance areas. The result of reduced down time of the aircraft less to seven hours under the maintenance action, therefore increases the aircraft availability of the airlines and the financial income of the company.

This research is based on the application of the integrated concept of the Lean Six Sigma method to improve the maintenance processes in the MRO organization. In previous studies, the main areas of the study the LSS application were focused on the activities of the entire organization. These results go beyond previous reports, showing that, this work is expanding the use of LSS methods to the different area or systems of aircraft maintenance and removes the restrictions on the concentration on the general activities of the MRO organizations. In this study, the main focus was on development of maintenance procedures for optimization of the GEnx-2B engine replacement on the aircraft Boeing 747-8, which does not allow the use of new equipment, due to the absent a removal and installation procedures in the AMM. Based on the positive results of the study, a missing AMM procedure was developed and written, however, because of this potential limitation it cannot be used without the approval of the aircraft manufacturer and the equipment designer. Another limitation of this, lack of maximum preload value at the FWD PRELOAD entry that is important for determining the values of the maximum preload at the FWD and AFT pillars of the Cobra system and the values of the deflection angles on the digital inclinometer installed on the engine stand.

Boeing has no objection to the use of equipment according to the issued NTO, and leaving the decision to the B747 operators. Engineering departments of the airlines or dedicated MRO organisations, can develop a similar engine replacement procedure using Cobra system, therefore addressing the intention to both manufacturers to obtain missing data and request inclusion of this procedure in the AMM Boeing 747 for future use. It is important to note, that the present evidence relies on publication of the NTO and confirmation from the equipment manufacturer.

The adoption of the Lean Six Sigma methods transferring to separate system of the aircraft, such as engine replacement based on MRO context is first study of its kind. Similar project can be helpful to increase the area of application of maintenance and operations impacting positively on the profitability of the company. The use of standard tools were as effective approaches to enable the LSS methods to identify the variables affecting performance.

CHAPTER SIX

CONCLUSION

Experts and analysts predict an increase in the aircraft fleet in the near future and the volume of workload of the MRO organisation will increase accordingly. The competitive environment encourages of the MRO's a full assessment of the organization's capabilities and aircraft maintenance processes to reconsider their future plan, to be prepared for the influx of the airline's customer demand. In this context, the application of LSS principles and methods can be driven tools to achieve the goal. The concept to use of Lean aims to add value to an organization by eliminating waste, and Six Sigma techniques contribute to its continuous development. Combination of Lean and Six Sigma is an extremely powerful methodology that can save organizations huge amounts of money and time. The focus of the research has been on development aircraft maintenance procedures, in particular for engine replacements, which were previously overlooked. The results of the study clearly evidence that traditional maintenance planning and control process need to be reconsidered in view of the applicability LSS tools and techniques. Traditional methods are usually based on the improvements of an operator's maintenance program, with the ability to extend heavy maintenance check intervals or life limited parts replacement, although the study confirms that update of AMM procedures is also one of the method for improvement the quality, safety and efficiency of aircraft maintenance. In addition, due to the complexity of the aircraft equipped with new technologies, maintenance costs are increased accordingly, however, the costs can be reduced alternatively using new technologies and modern maintenance tools. The same approach can be applied for replacing landing Gear replacement on an aircraft or structural repairs, and modification of any systems. Finally, the results of this study evidence that the use of a new engine replacement tool applying updated procedure can reduce the down time by seven hours, freeing four certifying staff from this work and transferring them to a different maitenance area. The presented a new procedure in this study can be adopted by CAMO airlines and other maintenance organizations to make revisions on AMM in order to reduce maintenance costs and to meet customer satisfaction. The contribution of the study allows the airlines to increase aircraft utilisation and for MRO organisation for optimization man hours' availability and eliminate wastes stated in the contents of this study. The LSS tool can be adapted to MOE and QM MRO while maintaining the application of these tools in the organization's activities. The skills, knowledge and understanding given by Lean Six Sigma is increasingly important in today's business environment. Organisations are need employees necessary to know how to make processes more efficient, how to increase the quality of service and how to save time and money that can ultimately be reinvested back into the organisation.

Further research in this context can be conducted to analyses compliance with of the lean tools the EASA Part 145 requirements, as well as the application of Six Sigma methodology on CAMO organizations which will render the same effect improving the performance of the MRO and ensuring the safety of the airlines.One of the important forms of waste that is not included in the "Seven Waste" is the untapped human potential that leads to unpredictable losses in enterprises (loss of motivation, creativity, talent and ideas).

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