CRANFIELD UNIVERSITY

ARIE WIBOWO

DECISION SUPPORT METHOD FOR CONTRACTING OF NON-ORIGINAL EQUIPMENT MANUFACTURER AERO ENGINE MAINTENANCE REPAIR AND OVERHAUL SERVICE PROVIDERS

SCHOOL OF AEROSPACE TRANSPORT AND MANUFACTURING
PhD in Manufacturing

PhD
Academic Year: 2016 - 2017

Supervisor: Prof Tetsuo Tomiyama & Dr Benny Tjahjono
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This thesis is submitted in partial fulfilment of the requirements for the degree of PhD

ABSTRACT

Non-Original Equipment Manufacturer (Non-OEM) Maintenance Repair and Overhaul (MRO) service providers of aero-engines are facing challenges resulting from the rapidly changing MRO market. They need to offer innovative service solutions to airlines through, for example, PSS (Product Service Systems) offerings that combine service(s) and products. PSS can be achieved by either servitisation to add service offerings to products or productisation to add tangible products to service offerings. Currently, however, MRO contracts that include PSS offerings have been prepared based on experiences and intuitions. Ideally, these contracts should be designed to bring about a *win-win* situation for both airlines (as customers) and MRO service providers.

This research aims to develop a new robust, scientific method to prepare contracts for decision makers of non-OEM MRO service providers. The research began with studying current general situation of the PSS in the aero-engine MRO market as well as, in particular, of a Non-OEM MRO service provider. From these, this research first identified sufficient key parameters that describe MRO operations with regard to flight operations of customer airline. A computer-based simulation model was built to assess the capacity and capability of the shop floor operations taking flight operations of the customer into consideration using the discrete event simulation. The simulation model was run over a set of systematically and exhaustively created combinations of different types of services and products. This has helped in selecting the most favourable combinations services and products, which can lead to the *win-win* situation for both the airlines and the MRO service providers.

Keywords:

NON-OEM MRO; Service provider; Aero engine; Productisation; Service; configuration; Contract preparation; Discrete event simulation.

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Journal Paper

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A Solution Contract Design Method for the non-OEM Aero Engine MRO Service Provider (Prepared). (2017) A. Wibowo, T. Tomiyama, B.Tjahjono (in preparation)

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LIST OF ABBREVIATIONS

AoG	Aircraft on Ground
ARSA	Aeronautical Repair Station Association
AUR	Aircraft Utilisation Rate
BER	Beyond Economical Repair
CLSV	Cycle Since Last Shop Visit
CSN	Cycle Since New
DER	Designated Engineering Repair
DES	Discrete Event Simulation
EFC	Engine Flight Cycle
EFH	Engine Flight Hours
EGT	Exhaust Gas Temperature
EGTM	Exhaust Gas Temperature Margin
ESN	Engine Serial Number
FAA	Federal Aviation Administration
FC	Flight Cycle
FH	Flight Hours
FL	Flight Length
FOD	Foreign Object Damage
HPC	High Pressure Compressor
HPT	High Pressure Turbine
IIT	Information Technology
LLP	Life Limited Parts
LPTN	Low Pressure Turbine N
MH	Man Hours
MRO	Maintenance, Repair, and Overhaul
NTE	Not to Exceed
OAT	Outside Air Temperature
OEM	Original Equipment Manufacturer
OTP	On Time Performance
PBH	Pay/Power by the Hour
PSS	Product Service System
QEC	Quick Engine Change

RoD	Rate of Deterioration
SLA	Service Level Agreement
TAT	Turnaround time
TLSV	Time Since Last Shop Visit
TSLSV	Time Since Last Shop Visit
TMB	Time and Material Basis
TSN	Time Since New
WPG	Work scope Planning Guide

1 Introduction

1.1 Industrial Background

The deregulation of the airline industry has influenced the industry in many ways. From this deregulation, the smaller airlines industry can operate with smaller capital than before deregulation. They can outsource many aspects which are not related to the core operations, such as maintenance, ground support, and aircraft provisioning.

This situation has led to a major development is the rapid growth of Low-Cost Carrier (LCC) (Zhang et al., 2008). The most enhanced business model utilised by the LCCs is called the future virtual airline business model (Scaria, 2010). In the virtual airlines business model, an airline will operate as a service operator only, while other supporting aspects, such as the aircraft provisioning, aero engine provisioning and the maintenance requirements are outsourced. In particular, aero-engine OEMs have responded to this trend by expanding their service business model to provide after sales services, such as maintenance package which is bundled with the aero engine. This type of business model, which offers the utilisation based contract to the airlines, e.g. “Power by the Hour,” is called servitisation (Neely, 2013; Saling and O’Farrel, 2012; Smith, 2013).

Servitisation is a method to add value to the customers by adding services to the products as a bundle (Vandermerwe and Rada, 1989). Productisation is the addition of intangible service with tangible products. These approaches are to arrive at PSS (Product Service System).

The servitisation of aero-engine OEMs has pushed non-OEM MRO service providers (non-OEM MRO) into a harder position than previously. The non-OEM MROs consequently have a limited market share as OEMs only allow them on the new aero engine maintenance. The limitation of the market is also supported by the warranty agreement, which prevents the airlines from outsourcing their maintenance requirements to the non-OEM MRO service provider. In the spare parts provisioning, non-OEM MRO service providers cannot use the Parts Manufacturing Approval (PMA) parts, other than the OEMs’ genuine components. This situation has left the non-OEM service provider only being able to serve the older generation aero engine, with limited options to manage the components, which is also worsened by the obsolescence of the older generation aero engine.

There is room for non-OEM MRO service providers to improve and take advantage of some of these opportunities. Non-OEM MRO service providers have greater experience in operational and maintenance service. Both of these areas are necessary to support the airlines' flight operations. They have established supply chain network relations in the industry (MacDonnell and Clegg, 2007), which can be an advantage in retaining competitiveness. The more aero engines produced will raise the maintenance demand in the future. There is a prediction that there will be a situation when more aero engines require maintenance at once, while OEM MRO service providers will be unable to fulfil the needs due to their limited capacity. From the customer perspective, there is also need to find greater flexibility and match between supply and demand, which has led the non-OEM MRO service provider to the delivery of total operation solutions (Wibowo, Tjahjono and Tomiyama, 2016).

Other solution to retain competitiveness, non-OEM MRO Service providers need to shift their business model (Schneider, Spieth and Clauss, 2013). One of the popular trends of the aviation industry is to combine the Product and Service as a solution to the airlines (Johnstone, Dainty and Wilkinson, 2009). However, this new business model will enable the non-OEM MRO service provider to offer a new type of offering that comprises all necessary service and products to their customer as, a total solution, e.g. Pay by the Hour (PBH) or Time and Material Basis (TMB). Table 1 PBH vs TMB the difference between PBH and TMB in MRO service contract.

Table 1 PBH vs TMB

Pay by the Hour	Time and Material Basis
Flat or Fixed	Ad-Hoc (based on Workscope)
Dedicated	Uncertain
No Warranty (integrated)	Include Warranty
Performance Based	Time Based

This competitive innovation needs to be supported by an innovative method as well. However, although it is promising, the combination of products and service will generate other challenges (Wibowo, Tjahjono and Tomiyama, 2016). The most common challenge is a less managed relationship between the customer demand and the shop floor operational capacity and capability.

In addition, non-OEM MRO service providers have not only need to address the external threats, but also to counter the internal challenges, such as their shop floor operational capacity and capability management. The limited capacity and capability of the non-OEM MRO service provider have become challenges to operational strategy. One such challenge facing maintenances is the difficulty to keep up with the planned maintenance. The real maintenance work scope can only be defined when the asset (airframe or aero engine) is disassembled. Then, the unpredicted/unscheduled/unplanned maintenance will affect the Turnaround Time (TAT) as the main parameter. The need for additional repairs or spare parts provisioning will also stretch the completion date of the project. This situation has led to disruption of the operational schedule on the MRO shop floor. The disruption often increases the cost and affects the customers' trust.

The aero engine maintenance contract preparation method has not been considered yet. As a contract is one the important supporting aspects in the contract is the preparation phase (Erkoyuncu et al., 2014), a contract which binds the agreement between both parties and MRO has to fulfil the agreed offering to the customers. Currently, maintenance contracts have not been scientifically designed. Most contract preparation is based on the experience and intuition. Each of the prepared and agreed contracts relies on the bargaining based method between the NON-OEM MRO and the customers. This situation often leads to overpricing or underpricing. It has also affected on the efficiency level, as the original maintenance work scope is different to the contract agreement.

Consequently, the PSS business model of the non-OEM MRO service provider needs more sophisticated solution methods. The new method requires consideration of both the operational shop floor capacity and capability to meet the airline's flight requirements more rationally.

1.2 Research Context

Baines et al. (2007) proposed the Product Service System (PSS) as an integrated combination of the product and services that delivers value in use. PSS can be obtained through both servitisation of products method and the productisation of the service method. Vandermerwe and Rada (1989) illustrate the servitisation as the moving forwards of the company to gain competitiveness by driving the company to bundle products and services. In contrast, productisation in PSS is defined as the integration of the service and the product to the customer as the reversible approach between the service companies and the manufacturers (Harkonen, Haapasalo and Hanninen, 2015; Leoni, 2015). This definition provides the distinctions between servitisation and productisation.

This research has also considered the difference between the service provision and the goods manufacturing as the foundation of the study. One particular industry that delivers such services is the non-OEM aero engine MRO service provider. This industry has initiated a solution to their customers by bundling their service offering with an additional service offering and also with products (aero engine). The total solution offering, which adds the product and service to the base service, is called productisation.

The current trend in the aviation industry is the packaging of the aero engine maintenance with additional services or products (Wibowo, Tjahjono and Tomiyama, 2016). The current contract preparation method is not adequate to deal additional services or products combined with services, because it is often experience and intuition based. In addition, the current contract preparation method does not consider dynamic aspects of maintenance operations, such as irregular maintenance. The current method also limits the perspective on how the contract is prepared. It is prepared based on one perspective only, either from the customers' perspective or from the capacity perspective of the shop floor. The method is also less capable of taking engine conditions into consideration and the actual maintenance will differ to the planned maintenance. This situation continued to have a negative impact on the efficiency of the non-OEM MRO shop floor operations, as the actual maintenance requires more resources and time. Also, the total solution to the customers will increase the complexity of the service contract preparation.

The focus of this research is to propose a method to design a contract for a PSS in the non-OEM aero engine MRO service provider context. The proposed method involves forecasting the maintenance schedule of the aero engine and then matching it to the shop floor's operational capacity and capability. The study will attempt to find the balance between customer demand and maintenance supply. Therefore, this method will enhance the information that will benefit the contract preparation process and create a win-win solution to the service provider and the customer. The contract preparation method can be used by the contracting team within the non-OEM aero engine MRO service provider as decision makers.

Related to the concept of PSS by Baines et al. (2007) as mentioned in Chapter 2, this research will assess several configurations obtained by a PSS generation method by adding the product to the service (productisation of the service). Based on this concept, the additional service provisioning will be utilised and configured to assess its performance. Although PSS is popular in manufacturing, the PSS approach from the service provider is considered less.

1.3 Aim and Objectives

Therefore, the research aim is **"to establish a method that can assist non-OEM aero-engine MRO service providers to combine the service and product as a solution in the contract preparation phase in a rational manner."**

This research has set several objectives to fulfil the research aim aforementioned:

1. Understand the context of the non-OEM MRO service provider's service bundled offering trend in the aviation industry.
2. Identify current parameters and key factors that are involved in the contract preparation at the non-OEM MRO service provider.
3. Build a conceptual model that represents the non-OEM MRO service provider's business processes, using the parameters and key factors, and reaching decisions identified in the previous objectives.
4. Build a computer model suitable for performance simulation based on the conceptual model representing flight operations, shop floor operations and different types of services (service configurations).

5. Assess the non-OEM MRO capacity and capability performance in offering different service configurations through simulation.
6. Classify and compare the service configurations in PSS context

1.4 Research Approach

The research conducts the literature survey, including journal papers, conference proceedings, internet articles, magazines and written documents from a non-OEM MRO Company.

Then, the research conducts further observation of a contract planning workshop, semi-structured interviews and document analysis from a case company called company A. These approaches identify the current method for the non-OEM MRO's contract preparation. In this step, the research articulates the key factors, parameters and decision variables that are used in the current practice. Once the parameters, key factors and the variables are identified, the research continues to elaborate those factors to form a conceptual model. This conceptual model is converted to a computational model for Discrete Event Simulation (DES) to assess the offering performance of various combinations of the service and the product. The outcomes of the simulation are the main contract parameters, such as the TAT and availability of the aero engine fleet.

This simulation can assess how the airlines' commercial flight plans in the future will affect the readiness of operations of the shop floor. The simulation study approach is commonly used to evaluate challenges in a complex situation such as in the service innovation preparation, which incorporates the lifecycle of the assets (Tomiyama, 2001). The computer based simulation consists of two models: the maintenance prediction model and the non-OEM aero engine MRO shop floor model. The maintenance prediction model will use flight operation requirements to predict the necessary maintenance in the future. The shop floor model will represent the shop floor operational capacity and capability of the non-OEM MRO service provider.

The research can use the simulation to analyse the different combinations of service and products, which are called "service configurations". The analysis of the simulation outcome will provide crucial information regarding the readiness of the capacity and the capability to support the customers' requirements.

In the final stage, the results of the scenarios will be classified, based on the shop floor's performance measurement parameters. The classification analysis will make it easier to select the best service and product combination. This information can be used to choose the best solution for both the airlines and the non-OEM MRO service providers. Figure 1 depicted the research approach based about contract maintenance preparation phase.

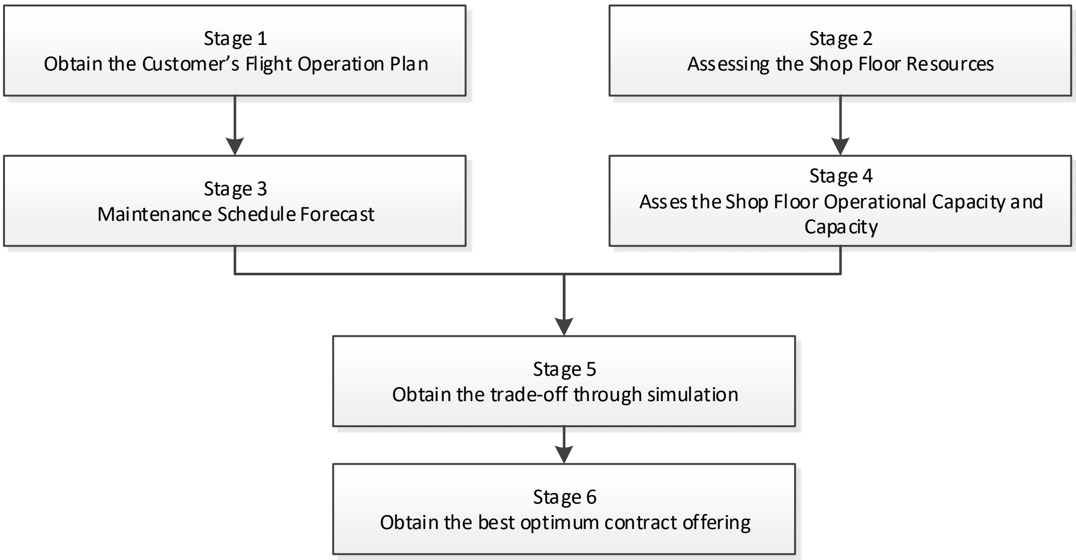

Figure 1 Contract Maintenance Preparation Phase Method

1.5 Thesis Structure

Chapter 1 –Introduction–presents the summary of the research background, problem statement and motivation, research approach and the thesis structure.

Chapter 2 –Literature Review– identifies the previous work related to this research. This chapter also addresses the research gap in the literature regarding the productisation (service with product) implementation for the service providers, particularly the implementation of the contract preparation.

Chapter 3 –Research Methodology– illustrates the methodology developed to fulfil the objectives to achieve the research aim.

Chapter 4 –Non-OEM Aero Engine MRO Service Provision Contract Preparation Method– relates to the identified parameters required to prepare the contract for the customers, linked from both the primary and secondary data. The obtained parameters then become the foundation of the model.

Chapter 5 –Computer Based Simulation Model Development– presents the different configurations of the model. These configurations relate to the possible service offering based on the supply chain network configuration. The computer model simulation is conducted to assess the measured performance of each configuration.

Chapter 6 –non-OEM MRO Service Provision Configurations– analyses different combinations of service and products from the non-OEM MRO service provider

Chapter 7 –Case Study– illustrates the case company situation. This case study will verify and validate each scenario performed to the actual characteristics of the case company’s shop floor.

Chapter 8 –Service and Product Combination Classification– presents the classification and the category of the possible combination of service and product from the non-OEM MRO service provider.

Chapter 9 –Research Discussions– discusses the findings from this research. This chapter also concludes the achievements of this research regarding the research aim and objectives. It also generates opportunities for further work and summarises the results of this thesis.

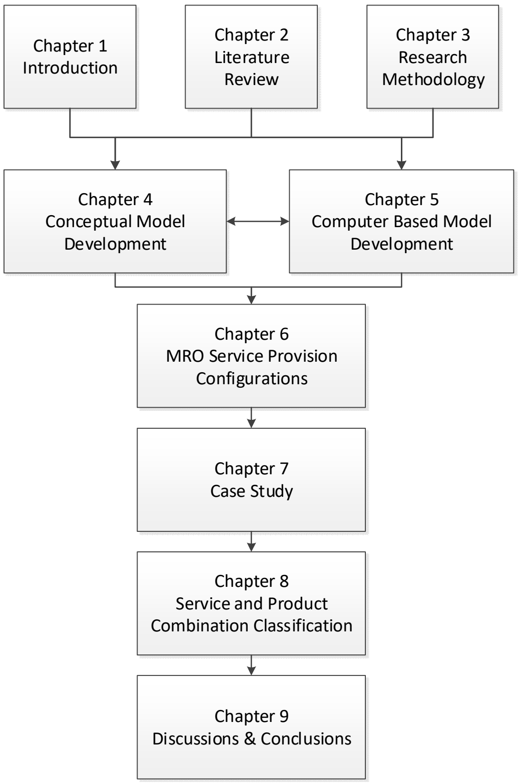

Figure 2 Thesis Structure

2 Literature Review

2.1 Overview of MRO Service Provider

From a business perspective, the goal of MRO service provider is to provide maximum quality maintenance and service to the customer efficiently and at minimum cost (Knotts, 1999). In 2004, Kinnison in his book “Air Carrier MRO Handbook” mentioned that the MRO Service Provider has a responsibility to retain the function of the aircraft, which they can perform based on the essential design role. Fu, Zhong and Zhu (2013) also stated that the MRO service provider as a stakeholder in ensuring the lifecycle of the aero engine. The definition of the MRO service provider role are to ensure safety, improve reliability and increase the economic value of the aircraft (Figure 3).

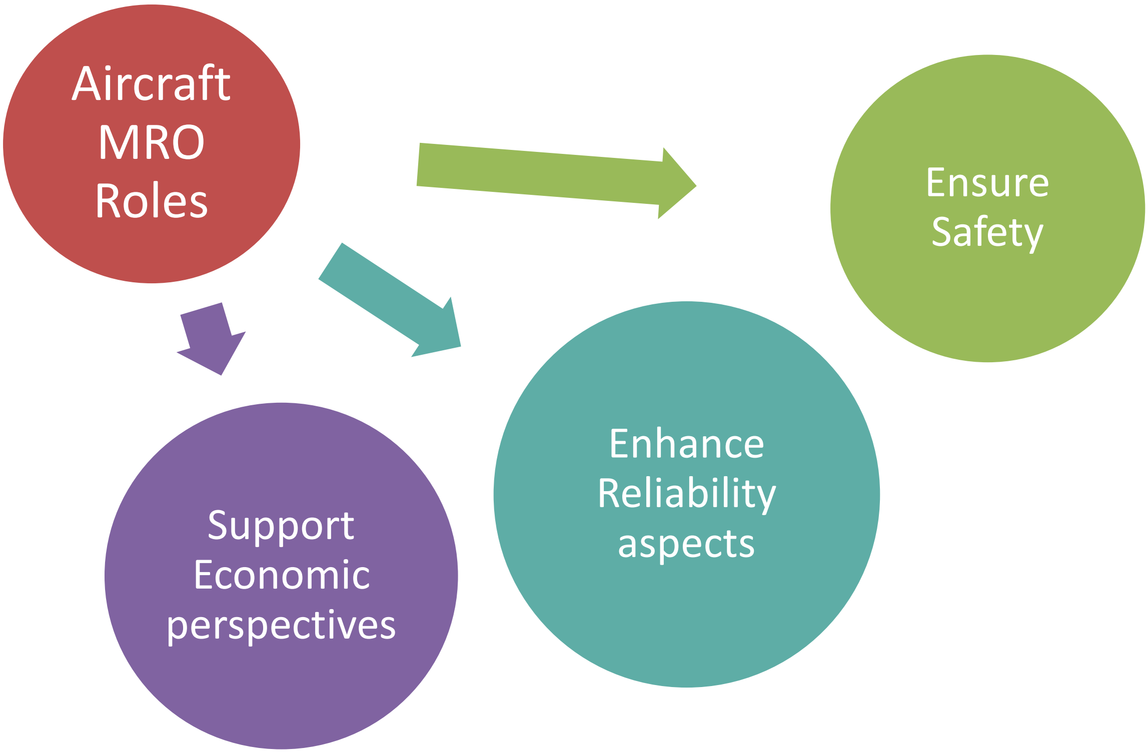

Figure 3 MRO Service Provider’s Roles

2.1.1 MRO Service Provider Types

ARSA (2014) categorised the aviation MRO based on the market structure. There are five different MROs categories: Airline MRO, Airline Third Party MRO, Independent MRO, Joint Venture MRO and OEM MRO. Further details of MRO types based on its market structure are mentioned by Table 2.

Table 2 MRO's Categories based on Market's Structure

MRO Classifications	MRO Type	Unique Characteristics
Non-OEM MRO Service Provider	Airline MRO service provider	In house capabilities (airframe, engine, component, consumable materials) Serves the large fleet from their parents only Serves many kinds of aircraft type (depending on the fleets owned by the parent)
	Airline Third Party MRO service provider	In-house capability (airframe, engine, component, avionics, structure) Higher degree of autonomy Serves main parent and third-party airline operators Serves various kinds of aircraft type
	Independent MRO service provider	Limited in-house capabilities No relation to either airlines or OEM
OEM MRO Service Provider	Joint Venture MRO service provider	Authorised MRO appointed by OEM to support the global support based on the geographical expanse
	OEM MRO service provider	Offers maintenance capabilities to the respective product type

The MRO service providers can be divided by their direct partnership with the OEM. Some MRO service providers will have a direct connection with the OEM. The airline MRO is part of the airline as a company and dedicates its service to their parent airline only. Then, the airline third party MRO service provider can serve both the parent airline and other airlines as third-party customers. The airline's third-party MRO can serve other airlines as long as they have sufficient resources to conduct the maintenance. The independent MRO is usually developed to respond to the requirements of the customers, although it has independence to manage its own operation. These MRO service providers are usually smaller organisations.

The OEM MRO can be a joint venture MRO. The joint venture is usually established on the agreement with the OEM. The OEMs can appoint an MRO service provider to become their representatives to conduct their maintenance. In addition, the OEM MRO is practically under the same management of the OEM. The OEM MRO is established to support the servitisation business model implemented by the OEM.

2.1.2 Overview of MRO Service Provider Challenges

There are various types of complexity that arise from the challenges facing the MRO service provider. The service provider has to be aware of these complexities and challenges in the contracting process, such as the uncertainties of managing the cost (Erkoyuncu et al., 2013). Moreover, various papers mention the challenges contained in the aviation industry.

The first challenge in the job shop floor emerges from the deviation between the planned maintenance and the actual maintenance on the shop floor work scope. Kurz (2016) added that uncertainty also generates from the aero engine arrival streaming. The maintenance service time at the workstations also generates random variables that relate to the labour, spare parts, and expertise availability. Another main challenge is that the MRO has to cope with the uncertainty of the aero engine arrival with limited capacity (Majcher, 2012). The MRO service provider requires adequate resources to support maintenance processes; however, they have limited capability in obtaining the resource (Aviatime, 2014; Bajestani and Beck, 2013). Another challenge facing MRO is the time limitations when fulfilling customers' requirements (Canaday, 2014). This limitation forces MRO to become more efficient in managing their spare parts by improving the scheduling and the forecast accuracy of the maintenance requirements (John L, 2013; Reopel, 2012; Cohen and Wille, 2006; and Foroughi, 2008).

2.1.3 Previous Work Related to MRO

Some literature has mentioned methodologies for the MRO service provider to tackle the challenges.

The idea of the alliance established in the MRO service provider industry has been proposed by (Kaelen, 2014). He modelled the alliances to improve aircraft availability. Schneider, Spieth and Clauss (2013) recommended the MRO service provider to align the business model to fulfil the new Product and Service offering trend in the industry.

With regard to the model incorporation to assist the decision-makers in the MRO service provider, Varelis, Stamboulis, and Adamides (2002) proposed a model that represents the aircraft engine's operational cycle. Their model incorporates the life-cycle of aero engines, which comprises of preventive maintenance, corrective maintenance, heavy maintenance, labour allocation, spare parts provision and aero engine disposal management. The higher system dynamics model was proposed to assist the decision-makers in considering the best organisational design and management change policy. Corallo et al. (2010) added one MRO service provider business model, considering implemented strategies, organisation and technology.

Another solution proposed to tackle the capacity and capability problems of MRO service providers is to outsource some of the maintenance work scopes. In 2007, Al-kaabi, Potter and Naim proposed the practice of outsourcing in the aviation MRO service provider business model. They analysed the most suitable MRO activities to be outsourced based on the MRO service provider's capabilities, followed by aligning the production process with the best outsource supplier. Chan et al. (2007) designed a decision support system (DSS) for this outsourcing. Jeeva (2008) enhanced the model by adding provider's uniqueness. The designed DSS proposed to assist the decision-makers to enhance long-term relationships through negotiation and contracting management.

Another philosophy believed to be a solution for tackling the MRO service provider's challenges is lean implementation. Mathaisel (2005) initiated lean architectural implementation in the MRO enterprise. He proposed that lean philosophy can transform the MRO and improve their processes. Ayeni, Ball and Baines (2016) investigated the adoption of lean in the MRO industry. Chang and Abdullah (2014) introduced lean production and sustainable development strategy into the MRO service provider's maintenance and management process. Ayeni, Ball and Baines (2016) extended their research on how lean implementation can be carried out through empirical studies of the MRO service provider.

Other researchers have also proposed the Six Sigma (SS) method to improve operational processes of the MRO service provider. The implementation of SS in the aircraft MRO initiated by Ho, Chang and Wang (2008) identified several critical factors, which concluded into 14 successful factors for the MRO in the SS programmes. Then, Thomas et al. (2015) reported how SS helped reduce the risk level in the supply chain management system. They stated that SS allowed the organisation to redesign the outsourcing system to stabilise the supply chain and level the schedule.

In addition, regarding the MRO service provider, several conclusions have been identified. Ii, Wittmann and Hasty (2005) investigated how the supply chain faced challenges and opportunities. They also proposed collaborative ideas based on different supplier partnerships to fulfil operations' requirements. In the spare parts supply chain management, Cohen and Wille (2006) used an information sharing methodology as a supporting programme for the MRO and the components dealer to enhance the provisioning effectiveness. This programme assists in the management of parts procurement to support the execution of the heavy maintenance. The programme combines both scheduled and unscheduled maintenance into one decision support system, which allowed them to assess and optimise cost and service. MacDonnell and Clegg (2007) enhanced the supply chain management for the MRO service provider by developing a computer-based system based on the process level model of the MRO industry. Berkholz (2009) enhanced the model to shorten turnaround time and optimise components' stock levels by developing a reliable capacity planning model to forecast the required skilled labour and the required spare parts. Ghadge, Dani and Kalawsky (2010) analysed risks of the supply chain management, before establishing a risk management framework for the aerospace supply chain system. The framework can identify the risks to find the optimum solution to mitigate the risks. Kashyap (2012) provided an overview regarding the MRO supply chain's challenges, and also proposed several approaches by utilising the Enterprise Resource Planning (ERP). Tracht et al. (2013) presented performance measurements in the MRO services supply chain to identify more significant challenges derived from either customer, suppliers, production shop or planning unit.

Then common strategy addresses the investment policy for the MRO service provider's business operations. Miller and Park (2004) reported the application of the real options framework to support multi-stage investment in the MRO service provider. The framework will minimise the deviation of the total investment by valuing a decision of spare parts provisioning for the MRO service provider to respond to uncertain demand.

From the information and technology viewpoints, Foroughi (2008) discussed how the usage of the electronic procurement strategy reduces the high MRO administrative cost. Alternatively, Zhu et al. (2012) assisted the PSS implementation by integrating three different life cycle perspective models (airlines, aircraft manufacturers, and MRO service providers) into the PSS design offering. Kurz (2016) proposed information sharing between the MRO service provider and the airlines to provide the correct information to either make an investment or to discard the opportunity.

In the shop floor operations, Boydstun et al. (2002) synthesised the MRO service provider characteristics. They proposed the principles of the MRO operation shop floor operations. These principles can be used by the analysts to propose new tools and improve operations. Finally, they made a model that represents the characteristic of the MRO shop floor operation. McLaughlin and Durazo-Cardenas (2013) assessed the cellular manufacturing adoption to the MRO service provider that improved the shop floor performance.

One of the challenges in the MRO industry is the limited labour availability. Alfares (1999) studied aircraft maintenance labour scheduling. He determined the optimum labour allocation scheduling to respond to demand. He proposed an additional workday with minimum cost. Through his calculation, the MRO service provider could save more, while still fulfilling the higher maintenance demand. Kleeman and Lamont (2005) addressed the scheduling problem of aero engine maintenance using the multi-objective genetic algorithm. They proposed the usage of the Multi-Objective Evolutionary Algorithms (MOEA) and General Multi-Objective Parallel Genetic Algorithm (GENMOP) to obtain a better scheduling solution. Stranjak et al. (2008) tackled the challenge by predicting the overhaul maintenance using agent-based simulation. They produced a tool that can be utilised to decide on the best MRO strategic policies. Ghobbar and Friend (2002) assessed the parameters that influence the maintenance demand of the aircraft. They found that plane utilisation is the source of the airlines' seasonal demand. .Reményi and Staudacher (2014) suggested the MRO service providers improve maintenance operation by optimising the schedule rules for the maintenance task. They used the model and simulation to assess the scheduling rule in a decentralised job-shop control. Bazargan and Jiang (2010) presented a model simulation of an aircraft maintenance operation at the MRO service provider. They comprised the model to be able to provide information regarding the resource requirements on a daily operational basis. The decision-makers can secure the resource requirement needs can be secured with the available resource level.

The shop floor process also consists of challenges in the complexity of the maintenance operations. A job card has an important role in the maintenance execution. To assess the language barrier in the job-card, Ma, Drury and Marin, (2010) assisted the Federal Aviation Administration (FAA) to develop a method that assesses whether language barriers have become the cause of maintenance deficiencies. Wang et al. (2012) have also addressed this matter by developing a tool called TaskCardGenerator, which can generate English-Chinese bilingual JobCard. On another, Geng et al., (2014) proposed to enhance the job card presentation. They proposed the three-dimensional job card usage to represent complex products. This three-dimensional job card allows the mechanic to conduct the maintenance task more efficiently and effectively.

Datta, Srivastava and Roy (2013) proposed the model and simulation to actively assess the resource of the mechanics to conduct maintenance on the shop floor. They need to evaluate the decision in order to improve the utilisation of the manpower. Visintin et al. (2014) have used the DES to represent the service delivery system in the aerospace industry. Ackert, (2010) and Justin & Mavris, (2015) proposed the research regarding the maintenance schedule regarding the aero engine. The aero engine maintenance cost is necessary to become the parameters in evaluating the maintenance guarantee contract and warranty to the customer. Based on those approaches, this research is combining the method to enhance the maintenance forecast, this research also taken the maintenance resource utilisation assessment to become a more scientific method to prepare a contract. The enhanced method can be used by the decision makers in acquiring the most optimum decision regarding the maintenance demand and the availability resources.

Table 3 Summary of Previous Work Related to MRO

No	Author	Product and Service General	Product and Service Strategies	Product and Service Motivation	Product and Service Operational Implementation	Product and Service Types	Servitisation	Productisation	MRO's Perspectives	Lifecycle Assessment	Availability Contract	Risk or Uncertainty	Simulation Based Research	MRO Operations	Flight Operations	Financial Perspectives	Human Resource Management	Partnership or Alliancing Strategy	Information Sharing	Customer's Perspectives	Outsourcing Strategy	Supply Chain Management	Lean Implementation	Investment Strategy	Six Sigma Implementation
1	Ackert (2010)									V			V		V	V			V						
2	Alfares (1999)													V		V	V								
3	Al-Kaabi et al (2007)															V		V			V				
4	Ayeni et al (2016)																						V		
5	Ayeni et al (2011)																						V		
6	Baines et al (2009)				V		V																		
7	Bazargan and Jiang (2003)									V				V			V								
8	Berkholz (2009)										V			V		V	V					V			
9	Bowman and Schmee (2001)												V			V									
10	Boydstun et al (2002)									V				V		V									
11	Chan et al (2007)																					V			
12	Chang & Kora (2014)																						V	V	
13	Cohen and Wille (2006)																	V	V			V			
14	Coralo et al (2010)	V																							
15	Datta & Roy (2013)								V					V		V	V								
16	Erkoyuncu et al (2009)				V						V	V													
17	Foroughi (2008)															V						V			
18	Faris II et al (2005)																	V				V			
19	Geng et al (2014)													V					V						
20	Ghadge et al (2010)															V						V	V		
21	Ghobbar and Friend (2002)									V					V							V			
22	Hao Wang (2012)													V					V						
23	Ho et al (2008)																V								V
24	Jeeva et al (2008)																					V			
25	Johnstone et al (2009)		V				V																		
26	Justin and Mavris (2012)									V	V			V	V	V									
27	Kailen et al (2014)										V							V							
28	Kashyap et al (2012)										V					V						V			
29	Kerr and Ivey (2001)		V	V			V																		
30	Kleeman & Lamont (2005)									V	V											V			
31	Koh and Lim (2011)								V		V														
32	Koh et al (2010)								V		V	V													
33	Kurz (2010)										V			V											
34	Ma et al (2010)																		V						
35	MacDonnell & Clegg (2007)																		V						
36	Mathaisel et al (2005)												V	V		V			V						
37	Mclaughlin & Durazo Cardenas (2009)													V									V		
38	Miller & Park (2004)									V															
39	Neely (2007)		V			V	V																		
40	Ng and Ding (2010)				V				V		V														
41	Ng and Nurudupati (2010)					V					V														
42	Ng et al (2011)				V																				
43	Oliva and Kallenberg (2003)				V		V																		
44	Parry et al (2011)						V																		
45	Rchid et al (2013)								V						V	V									
46	Remenyi & Staudacher (2014)									V				V											
47	Schneider et al (2013)	V																							
48	Thomas et al (2015)										V														V
49	Tracht et al (2013)													V								V			
50	Van Ostaeyen et al (2013)				V		V																		
51	Varelis et al (2002)									V				V	V		V								
52	Visintin et al (2014)													V											
53	Ward and Graves (2007)								V	V													V		
54	Sivuoso and Takala (2016)	V	V			V		V		V	V														

2.2 Overview of Product Service System

Following the previous subchapter, the MRO service provider has the advantage of having more experience in supporting airline operational requirements. They are also able to incorporate their knowledge to alter their business model to offer total solutions to the airlines. The trend of the PSS started in 2002; Mont cited Goedkoop et al. (1999) mentioned PSS as “a marketable set of goods and services, capable of jointly fulfilling a user's need”. They also stated that the product service ratio could vary in either function or economic value. Tukker (2004) defined PSS as the way to combine both the tangible products and intangible service to fulfil the client’s requirements. Based on this definition, the MRO can obtain the PSS to enhance their competitiveness.

Baines et al. (2007) defined the method to provide PSS through two different methods. The first method is a PSS, which is based on the product and adds the services to the offers (servitisation of product). Another approach builds on the service offering, with the additional product as a full combination (productisation of service) as mentioned by Figure 4.

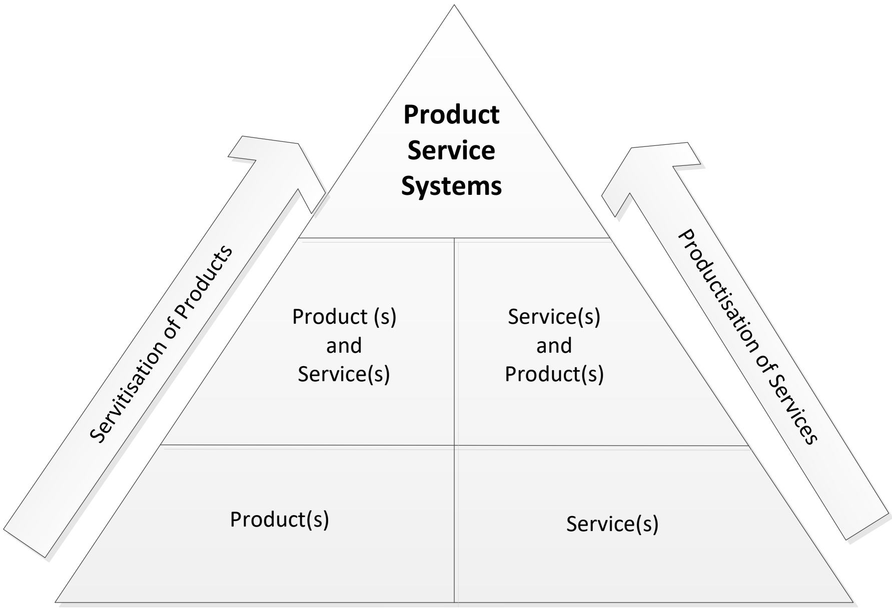

Figure 4 Product Service System (Baines et al., 2007)

2.2.1 Servitisation of Product

Servitisation has been introduced by Vandermerwe and Rada (1989) as a method to enhance the value of the product by adding the service to it. Baines et al. (2007)

present the servitisation as the transformation when the manufacturers add the service to their product.

Cook, Bhamra and Lemon (2006) and Oliva and Kallenberg (2003) illustrate the implementation of the servitisation. The transition of the manufacturers regarding the operational implications has also been addressed by (Johnstone, Dainty and Wilkinson, 2009; Oliva and Kallenberg, 2003).

Since then, research based on servitisation has been developed. However, the literature considers less about the differences between servitisation and productisation, as PSS methodology by adding product or service to the existing service offering from the service provider is generalised as the same method. The next section will illustrate in greater detail regarding productisation of service in the literature.

2.2.2 Productisation of the service

Baines et al. (2009) mentioned that productisation differs from servitisation. Productisation enables the process to shift an organisation’s capabilities and processes from selling conventional products to offering an integrated product service as a bundled value to the customers. Karni and Kaner (2013) and Alter (2012) stated that both productisation and servitisation hold the same position in the offering solution dimensions. Therefore, they argued that productising has to be treated symmetrically with the servitisation.

Harkonen et al. (2015) mentioned the productisation method as an opposite approach from servitisation to provide PSS. The service provider can conduct the productisation by incorporating an additional product or service to the current service offers. Also, Leoni (2015) assumed the PSS as a coin that consists of two sides. Each side of the coin represents the productisation and servitisation respectively. Lahy et al. (2017) also stated how servitisation means to add intangible service to tangible product, and the productisation adds tangible products to the intangible service.

Productisation is a sequence of processes for defining, systematising and concreting a service. It will make the service easier to produce and could result in greater effectivity and efficiency in the making (Valminen and Toivonen, 2009). They mentioned productisation as the process to build the service’s characteristics into a product. The process of productisation involves systematising the services and their components to become more ‘product-like’ (tangible) in the internal operation process to prepare the offerings (Guvendiren, Brinkkemper and Jansen, 2014; Valminen, 2011).

Ukko et al. (2011) determined productisation as the process of the service offering that also makes the offerings marketable. Kankaanpää and Isomäki (2013) enhanced productisation as the process that has to be a highly regulated and well-managed process based on the existing product, modified product, new product, or a combination of both before it replicated to large numbers. Hänninen, Muhos and Haapasalo (2013) proposed a need for productisation to incorporate the product lifecycle, as is required to enhance the supply chain reliability.

At the most advanced level, productisation will deliver more product-like solutions, which can be made using commodification and systematisation of their elements (Nagy, 2013). The method will be based on the decomposition or modularisation of service components to bring about combinable offerings. Suominen, Kantola and Tuominen (2009) quoted Tiensuu (2005) mentioning productisation as the realisation of an idea to become a product (goods or service), that is “sellable”.

Productisation can be defined as a process that includes actions and operations directed through several method standardisations or modularisation of a service. Another definition can define productisation as a combination of several services to a current service portfolio or an additional product as a bundle of offerings. This combination aims to ease the selling process of the product as it will make the customers understand easily if the product matches to their requirements. Consequently, it is easier for the service provider to match their offerings by knowing the customers’ requirement.

2.3 MRO PSS Contract Preparation

The integration of product and service in the aerospace industry is very popular (Baines et al., 2009; Johnstone et al., 2009; Kerr and Ivey, 2001; Neely, 2007; Oliva and Kallenberg, 2003; Ward and Graves, 2007). However, most literature mentions manufacturers (OEMs) as the main providers of the PSS. Johnstone et al. (2009) revealed that product and service have become blurred in the aerospace industry. Van

Ostaeyen et al. (2013) stated that PSS implies that between pure product and sales and pure service provision, a spectrum of different PSS options exists, in which products and services are combined to varying degrees. However, there is much less consideration given to the PSS from the non-OEM MRO service providers.

Most of the service preparation focuses on the contract agreement. The contract will define the service provision strategy configured by the service provider. Bowman and Schmee (2001) developed a simulation model that assesses costs over the life of the contract. They modelled the risk and the statistical failure to be incorporated in the model to address the financial risk for the duration of a long-term contract. Erkoyuncu et al. (2009) emphasised uncertainties as the challenges in the availability contract preparation phase in the PSS. They incorporated the uncertainty challenges in the contract cost estimation in the aerospace and defence industry. Koh et al. (2010), and emphasised the performance based contracts in the MRO industry by investigating the dynamic capability of resources to deliver the availability contract. Ng and Ding (2010) investigated the delivery of the outcomes based contract from the MRO industry rather than the maintenance and repair activities. They stated that the outcome based MRO service capability could potentially become a significant improvement in sustainability by maintaining the aircraft and providing longer flying hours. Ng and Nudurupati (2010) proposed the factors, parameters and decisions that have to be embedded if there is a substantial shift to offer the outcome-based contract. Nowicki, Randall and Gorod (2010) mentioned the servitisation contract in performance-based logistics. They detailed the modelling initiatives to conduct the research based on Performance Based Logistics (PBL) by approaching modelling initiative systems and economic strategy initiative.

Parry et al. (2011) built a framework based on the complexity factors of the contract for availability. They aligned each complexity with the contributor factors. The framework could then be used as an analysis tool for managing complexities. The framework proposed a method to reduce the complexities. First, the non-value adding factors have to be eliminated. They identified the contributor factors, and then managed the most appropriate strategy to minimise or remove the impacts. The final step was to add the value and profit generator with the supporting reason.

Guo and Ng (2011) assessed the co-production of the availability contract offering between the Ministry of Defence (MoD) and the MROs. Koh and Lim (2011) proposed research to optimise the value of a service contract using the multitasking principal-agent model to support resource allocation, as the MRO should be able to deal with many contracts. Then, Justin and Mavris (2011) evaluated the aero engine maintenance cost and the warranty requirements. Rchid et al. (2013) added the aircraft maintenance cost method using Activity Based Costing (ABC) to enhance the traditional cost calculation, which is currently employed by the airline-MROs. This cost calculation approach will enable an airline company that has MRO facilities to diversify the revenue by offering available maintenance slots to other airlines.

Table 4 Overview of MRO PSS Contract Literature Review

Author	Effectiveness and efficient delivery	Product and Service	Product and Service	Product and Service Product and Service	Product and Service	Servitisation	MRO service	Lifecycle	Lean	Availability Contract	Risk/ Uncertainty
Baines et al. (2009)	x			x		x					
Johnstone et al. (2009)		x				x					
Kerr and Ivey (2001)		x	X			x					
Neely (2007)		x			X	x					
Oliva and Kallenberg (2003)				x		x					
Ward and Graves (2007)							x	x	x		
Van Ostaeyen et al. (2013)				x		x					
Erkoyuncu et al. (2009)				x						x	x
Koh et al. (2010)							x			x	x
Ng and Ding (2010)				x			x			x	
NG and Nudurupati (2010)						x				x	
Parry et al. (2011)						x				x	
Ng et al (2011)				x							
Koh and Lim (2011)							x			x	
Justin and Mavris (2012)										x	
Rchid et al (2013)							x				

2.3.1 Decision Making Elements in MRO Industry

A framework has been used as a main tool or foundation to accommodate the complex decisions in real industry. Various researchers have mentioned the framework as it provides a rationale for predictions of the relationships among variables of a research study. The framework is used to outline a possible course of action or to present a preferred approach to an idea or thought. In the context of this research, most of the framework is developed to tackle challenges in the aero engine maintenance scheduling, cost optimisation, and optimum contract offers. The literature review also managed to verify and validate the practice and the general comparison, and identify the perspectives.

Kumar and Kumar (2004) built a framework that could help the industrial organisations plan the after-sales service design. They incorporated a framework with the customer's expectation parameters to align the delivered product and service.

Jüttner et al. (2007) developed a framework that integrates the supply chain management and marketing management. They proposed this framework in the demand chain management concept to illustrate the roles and the responsibilities of both areas. The framework includes the higher level of the operational process at the managerial levels. Cavalieri et al. (2008) established a framework to address the challenge in the management of spare parts provisioning management. Through the framework, they developed a procedure strategy to discuss the most appropriate method for each stage of the maintenance operation.

Isaksson et al. (2011) suggested a framework that is fundamental to the design of a product-service system mechanism in the aero industry. Their framework covers PSS from three stakeholders: operator, manufacturer, and MRO provider. The framework guides PSS design from assessing the need, identifying the solutions, selecting the best option, to enclosure solution.

Ng et al. (2011) proposed a framework to revise the service companies' capability of working together with their clients to create value. The core framework consists of people, information, material & equipment.

McNaught and Zagorecki (2011) discussed the challenges in the predictive maintenance by using prognostic modelling and Health and Usage Monitoring Systems as the emerging technologies. The framework can be employed as the practitioner's guide to implementing the prognostic modelling and Condition Based Monitoring (CBM).

Kelly and Ratchev (2011) introduced a framework as the foundation to build a maintenance dashboard. The framework allowed decisions to be made on whether to maintain, repair, upgrade or update the asset. This framework combines both peacekeeping and capability enhancement. Using the framework, the service provider can offer value to both the customer and manufacturer.

Justin, Briceno and Mavris (2012) built a framework that can assist aircraft manufacturers evaluate new product development. The framework proposed a methodology to assess the economic viability, presenting several parameters: the cost and revenue management, the segmentation and positioning strategy, and the competition analysis.

Erkoyuncu et al. (2014) composed a framework to address the challenges facing cost estimation at the bidding stage of complex engineering services in the defence industry. One of the applications is contracting for availability. Through this framework, they discussed the steps in the bid process initiated by the work breakdown structure and then identified the uncertainties. The study assessed the impact of each uncertainty, classified them and provided several responses to the uncertainties; thus, allowing the uncertainty to be adjusted before the final bid agreement.

Most of the papers mentioned the framework as a tool, guidance, or foundation to help the organisation to address the challenges. The framework can accommodate many parameters and the complexities of challenges.

Table 5 Overview of MRO Parameters in the Literature

No.	Author	Customer	Supply Chain	Manufacturer	MRO provider	Resources	Uncertainty
1	(Kumar and Kumar, 2004)	X					
2	(Jüttner, Christopher and Baker, 2007)	x	X				
3	(Isaksson, Larsson and Johansson, 2011)	x		x	X		
4	(Cavalieri et al., 2008)		x		X		
5	(McNaught and Zagorecki, 2011)					x	
6	Ng et al (2011)		x			X	
7	Kelly & Ratchey (2011)	x		X			
8	Justin & Mavris (2012)	x		X			
9	Erkoyuncu (2014)	X		x			x

2.3.2 Product and Service Contracting Preparation

PSS delivers performance of the product and service combination. The PSS is based on an availability based contract, Performance Based Contract (PBC) or Outcome Based Contract (OBC).

Ng and Yip (2009) assessed a different contract type, namely a Benefit Based Model (BBM) framework. They attempted to understand the provision of service in MRO that is contracted for the performance of the asset rather than providing the equipment. They also found the importance of the value co-creation of the contract provision. Therefore, they identified the challenges for the MRO in delivering the availability contract.

Meier, Roy and Seliger (2010) cited Roy and Cheruvu (2009) mentioning that the current contract in the industrial PSS is no longer valid. They illustrated the different contract types; incentive contracts, cost-reimbursement contracts, fixed-price contracts, spiral contracts, indefinite-delivery contracts and time-and-materials, labour-hour and letter contracts.

Muller and Stark (2010) illustrated the core elements of the Industrial PSS. They mentioned that the contract in the industrial PSS is tightly related to the providers and the customers, which define how they share the cost and risks. The most important foundation of the delivery integrated product and services to set the value co-creation (Figure 5).

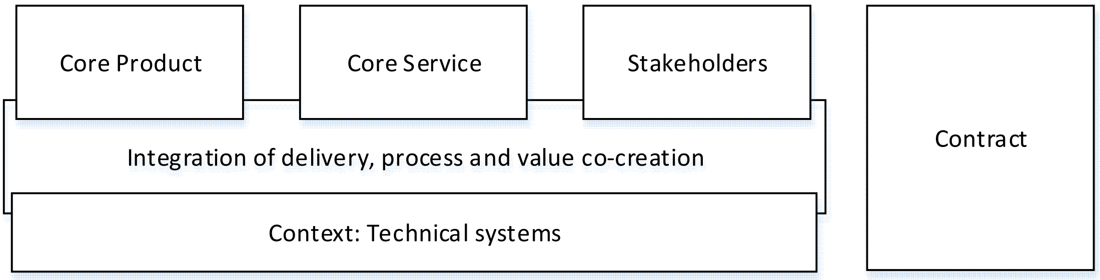

Figure 5 PSS architecture (adopted: Muller and Stark, 2010)

Ng and Nudurupati (2010) revealed the firms' challenges during the OBC's implementation within the MRO service in the defence industry. Then, Phumbua and

Tjahjono, (2011) developed a simulation model for the aero engine OEM MRO to assess the feasibility that the availability is contracting.

Kleemann and Essig (2012) discussed the PBC contract based on the Industrial and Marketing Purchasing (IMP) relationship model and related research. These relationships proposed to help the MRO suppliers and providers integrate both the product and service offering effectively.

Table 6 Summary of PSS Contract Preparation in Literature

Author	Provider	Customer	Availability contract	Type of contracts	Cost	Risk	Implementation	Shop floor
Ng & Yip (2009)	x	x	X					
Roy & Chevuru (2009)				X				
Muller & Stark (2010)	x	x			x	x		
Ng & Nurudupati (2010)			X				x	X
Phumbus & Tjahjono (2011)	x		X					X
Kleeman & Essig (2012)	x	x						

2.4 Research Gap Analysis

Based on the conducted literature review, the researcher can identify some research gaps in the area. These gaps are listed as follows:

- The research in the aviation sector regarding MRO industry is less focused than the OEM industry.
- The study in the MRO industry mostly relates to either the external factors (e.g. maintenance forecasting) or the internal factors separately. Nevertheless, external and internal factors (e.g. shop floor operations) need to be analysed simultaneously.
- The idea of the combination of the service and product as an offering from the MRO is less mentioned than the OEM which delivering product and service combination.
- The contract implementation method for the MRO organisation has not been pointed out clearly in the literature.
- The research has not entirely focused on the MRO types and characteristics.

The first gap shows the approaches of the research on the MRO industry. There are not many papers relating to the MRO service provider directly. Some articles have taken the MRO service provider as an example of their research, but not many concern on the MRO itself. Therefore, there is a need to deliver more analysis, particularly in MRO industry.

In the literature also mentioned strategy which can tackle the uncertainty demand and limited resources, and enhancing MRO operations to become more efficient. Most of the research discussed on the internal strategy is expected to assist MRO in the competitive era. While there are articles discussed on the maintenance forecast' accuracy enhancement. The application to merge those approaches is also can be developed in greater detail.

The next gap found in the literature is that productisation in MRO industry is less consider than servitisation in manufacturer area Schneider, Spieth and Clauss (2013) and Corallo et al. (2010) illustrated on how the MROs need to be more competitive and proposed to change their business model. One of the ideas of the business model is to deliver product and service as a combination. The concept of the productisation is mentioned by Sivusuo and Takala (2016). They depicted the MRO change from conventional service provisioning to one stop solution provider. However, there is a lack of concern in the productisation implementation in the MRO.

The literature also obtained on how the aviation MRO has to cope with the contracting challenges. Several types of research addressed the uncertainty and risks in the contracting for availability in the PSS servitisation context. But the literature has not defined the implementation of the contracting process for the service provider such as MRO. Consequently, there is an opportunity to deliver further investigation concerning the MRO contracting implementation.

ARSA (2014) illustrated several types of aerospace MRO. The paper mentioned on how the MRO can be categorised based on its market share characteristics. Based on the literature, this research categorised the MRO organisation into two, non-OEM MRO and OEM MRO. The limitation and challenges of the MRO are also unique. This uniqueness influence on how the MRO needs to implement their business strategy. For that reason, further research to mention the implementation of the PSS implementation in the manner of the non-OEM service provider behaviours is needed.

3 Research Methodology

This chapter explains the selected research methodology and its justification of the selected methodology and the supporting idea of these selections comprehensively. Section 3.1 presents the research method selection at high level and the rationale for choosing those methods. This section presents several research approaches based on the research purpose, implementation and the inquiry for this investigation. The strengths and the weaknesses of each data collection method in this chapter, along with the mitigation strategy, are also described in this section. Then, section 3.2 illustrates the research methodology development to achieve individual research objectives.

3.1 Research Methods Selection and Justification at a High Level

3.1.1 The rationale of the exploratory research design

Robson and McCartan (2016) discussed the exploratory research design's purposes. It is necessary to find out what is happening (less understood phenomenon), to assess new perspectives, ask questions, evaluate phenomena from different points of view, and to develop more ideas and hypothesis for further work. Based on the aim, objectives and the context of this study, this research can be defined as an exploratory research. The implementation of the service and product offering practices in the non-OEM MRO service provider has been paid little attention, and there is little information about the service offering assessment in the productisation method. Therefore, the purpose of this research is to explore the area.

3.1.2 The rationale of the mixed method research approach

The qualitative method is suitable for the initial stage of this research. It will assess the non-OEM MRO and customer in their natural settings and not in a controlled environment. As mentioned previously, the implementation of the service combined product by the MRO service provider has been paid little attention in the literature, therefore, the qualitative research method can provide the researcher with more data and will provide better description to research inquiries.

Once the primary data are collected, the qualitative data will be scrutinised and integrated to become the foundation for further research. Then a quantitative research method using computer model simulation. Follows the result of the simulation will be analysed and interpreted to generate outcomes of this study.

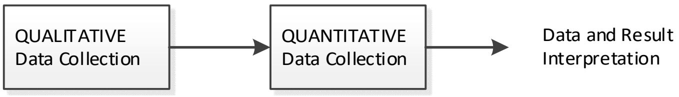

Figure 6 Sequential Exploratory Research (Creswell, 2009)

A mixed method research involves data collection in qualitative and quantitative research but also both methods in tandem, which gives the method greater strength than quantitative or qualitative alone (Creswell, 2009). Figure 6 represents the exploratory design method for a mixed method that will be used in this research. The mixed method will be able to describe and report on the phenomenon exploration and further explore the qualitative research. This mixed method is also more advantageous to the researcher who would like to build a new instrument.

3.1.3 The Rationale of Case Study Method

The case study method is suitable to fulfil the research aim because . The case study can fulfil the research's aim and objectives. It has been chosen because a case study will be able to capture the current practice taking place in the real world. In addition, a case study can give the data collection method and the involvement of the collaborating organisation (Robson and McCartan, 2016).

It is a useful method to obtain expert knowledge and to develop theories. In addition, as mentioned in Section 3.1.1 this research uses the exploratory research method. This research paradigm is the most suitable for the case study method.

This research used a single case study. The generalisability of the non-OEM MRO operations and maintenance operations are mentioned and arranged based on the International Authority Maintenance Process Requirements Document and Manufacturers Maintenance Manual or Workscope Planning Guide (WPG) (1995). The general trend of the aviation industry is commonly based on the literature, and the airlines have similar requirements and challenges regarding the operational requirements. Therefore, the references used can ensure the validity and generalisability of this research.

3.2 Research Methodology Development

Based on the high-level research approaches, the research adopted an inductive method that explores new phenomenon based on the previous work related to the research, as seen from different perspectives.

In this research, the research methodology comprises of six different steps to fulfil each of the objectives above (Figure 7). Stages 1 and 2 correspond to collecting and receiving the development of the conceptual model. This stage initiates the development of the conceptual contract model by obtaining variables, parameters and key factors for the contracting team in deciding the contract in the preparation phase. The research method utilises qualitative data collection, both primary (observations of the company) and secondary (literature), to establish the conceptual model. The third stage builds a conceptual model from the information gathered. using he inductive method. the fourth stage deals with the verification and validation of the conceptual model by building a computer based model on which the simulations can be carried out. This stage will utilise simulation will test different service and product combinations (service configurations). The fifth stage evaluates and refines all the configurations to the customers. The last step classifies the combinations of the service and product offerings to select the best service offering which is the final research outcomes of this research.

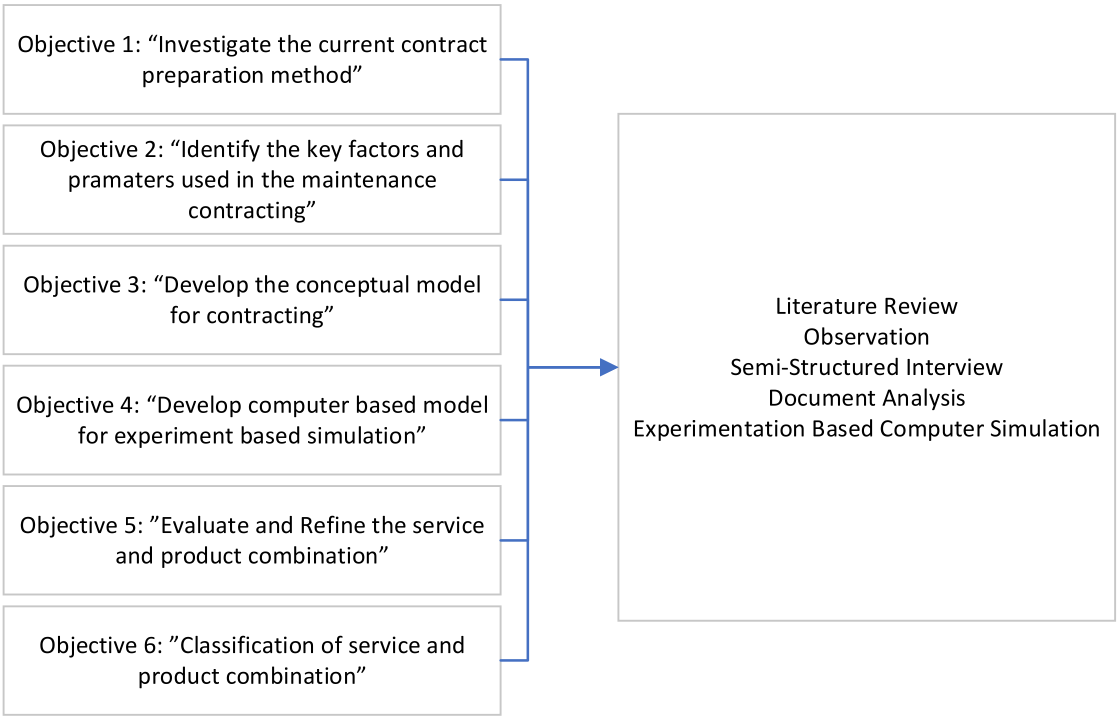

Figure 7 Development of Research Methodology

3.2.1 Objective 1: Understanding the context

Literature review on the publication of journal databases, conference proceedings, Internet articles and also magazines is conducted. The main keywords of the literature search strategy are based on an “MRO service provider” and “productisation”.

The Interview performed to fulfil the objectives. In this phase, this research carried out a site visit to interview the managers or decision makers from both the MRO service provider and their customers (airlines). The interview is conducted to plan case studies which could represent the problems from the industrial context. The interviews will be based on the face-to-face semi-structured interview base in qualitative research (Irvine, Drew and Sainsbury, 2013).

Semi-structured interviews carried out by considering their suitability to explore information concerning the respondents’ perceptions/opinions and related sensitive issues, and the same list of questions will be used for all the respondents (Louise Barriball and While, 1994). It is more reliable to gather as much information from one respondent in one timed interview.

The semi-structured interview has several key points: the most important parameters for the airlines to support their operation (demand creation), the current business concept of the MRO in offering their maintenance services to the customer (demand fulfilment), and the eagerness of the MRO to utilise the concept of the decision framework for the negotiation process.

3.2.2 Objective 2: Identify the key factors and parameters used in maintenance contracting

The next phase of the research is data collection including parameters needed for the model development in the next phase. First stage, the author utilised the observation method to obtain the information regarding the current practice at the case company. The research conducted a workshop at the case company attended by senior and middle management from both non-OEM MRO service provider A and airline S. The workshop clarified the research how airline S prepares maintenance requirements plans. Then, this information helps the non-OEM MRO service provider generate information regarding their capacity and the capability as well as the strategy to support the airline's operational requirements. The workshop covered two days and included all the non-OEM MRO supporting units from the MRO-A to provide the best assistance to the airlines.

This research also conducted the document analysis method. The document obtained from the MRO A added details of the information for the service provisioning process.

Based on these methods, the researcher could investigate the current industrial practices and then compare them with the literature. The researcher also enhanced the understanding of the service planning assessment and identified the factors and challenges of the service offering preparation.

The research conducted semi-structured interviews with experts from the MRO service provider to gather information that could not be obtained through the observation only. This interview added greater details to the information through the document analysis.

The identified parameters were categorised and combined into a conceptual model framework. The conceptual model includes important parameters in assessing the service offering configurations and their relations with each other. The theoretical model consisted of parameters that are necessary for designing a maintenance service.

3.2.2.1 Observation

In the initial phase, the research employed the observation method. The observation was held at a workshop by the non-OEM MRO service provider A and airline S. The data collection was initiated by observing the client's workshop. The workshop was held on 19th and 20th December 2014. A total of 45 people attended from Customer A and the Case Company. Customer A represented the Director, Fleet Managers, Planning Operations Management, Purchasing Managers and engineers. The participants for the case company consist of the Base Planning Operation Director, Chief Marketing Officer, Head of Component Shop, Engine Shop Managers, Component Shop Managers, Key Account Managers and planning engineers. The interview and the observation set out to align future customer planning with the non-OEM MRO provider's strategy. The observation has given an understanding of both the demand characteristics and the non-OEM MRO's supply strategy characteristics in general. The workshop was organised to discuss how the capacity and capability of the airline flight operation could best be achieved in collaboration with the non-OEM MRO service provider. Based on this workshop, the research could distinguish the parameters that are necessary for the airlines from other parameters.

The airline summarised the operational flight plan, which is forwarded to the non-OEM MRO service provider. The non-OEM MRO service provider translated these requirements through the resource management process and their operation policy.

The observation data collection technique has an advantage as it can obtain the information directly (Robson and McCartan, 2016). This research conducts a direct observation in situations where the non-OEM MRO service provider A has a workshop together with airline S. In this workshop, the non-OEM MRO A illustrates the preparation to support airline S's operational requirement for a year ahead. The directives characteristics of the observation have allowed the author to obtain the phenomena and actual methods conducted by the non-OEM MRO and its customers in the service offering preparation process.

3.2.2.2 Interviews

An interview is a method based on the survey approach that enables the researcher to attain the information from the sample of the population. It is usually based on the personal approach over the telephone, face to face, or through the Internet. In this process, the researcher will ask questions, and the interviewee will provide feedback (answer). Sometimes, the interviewees also provide the researcher with a supporting document to reinforce their answer.

There are three types of interviews mentioned by Robson and McCartan (2016): fully structured, semi-structured, and unstructured interview. The main difference is in the question preparation. In the fully structured, the interview questions are predetermined by a fixed word and order. In the semi-structured interview, the researcher will have a set of predetermined questions, but the questions can be amended based on the circumstances. The unstructured interview will give the researcher a deeper understanding of the questions as they are a more open-ended type of question. These kinds of questions will allow for better apreciation between the interviewer and the interviewees.

The research also conducts the semi-structured interview to improve the obtained information from the previous data collection method to enhance the validity and generalisability. Semi-structured interviews enable the author to understand the modern context. It also allows the researcher to obtain greater detail from different perspectives. This situation has made this approach one of the most important methods.

Regarding the ability to gather information, the semi-structured interview will be able to broaden the researcher's understanding and provide greater opportunity to explore each question. The semi-structured interview also enables the researcher to gather hidden information that was not obtained from the document analysis and the observation.

Once the general information was obtained from the previous method, this research utilised semi-structured interviews to enhance the information. The semi-structured interview has also enhanced the information from another perspective, such as how the non-OEM MRO service provider translates and manages customers' requirements.

The interview relates to the parameters that the non-OEM MRO service provider needs to support customers' requirements. The case company selected allows the researcher unlimited access to personnel information and the data to support the research. The company chosen can represent the situation in the aviation MRO industry as it is one of the biggest MROs in the region.

The shop visit was conducted over a period of three weeks. The data collection was obtained from the semi-structured interview methods. The study carried out interviews with senior managers, key account managers, shop floor engineers, material planners, and customers.

3.2.2.3 Document Analysis

This research has also conducted the document analysis to support the previous research stages (observation and semi-structured interviews). Both the interviews and document analysis are a suitable primary source of information for this study. The interviews provided data and information regarding the service provision planning to the customers. The researcher was given a document to enhance the details of the information.

The archival document has become the primary source of information to support the conceptual model framework. The document relating to the service provisions consists of the flow maintenance operation processes, the calculation method to assess the cost of the goods sold, contract offering agreement and proposal of the service offering to the customers. The main parameters of the document supplied more detailed components for the proposed model of this research.

Robson and McCartan (2016) discussed document analysis as one of the data collection methods, which involves written material (notices and letters) or pictures and diagrams. The author was able to obtain most of the research from written documents. These documents explain the current and shared operations of the non-OEM MRO service provider.

The researcher has access to the documents of the non-OEM MRO service provider A. These documents also provide better information and a clearer description of the non-OEM MRO operation process.

The conceptual model is represented, based on the parameters obtained in the parameters below. The conceptual model synthesised the details obtained from the literature review and the data obtained. At this stage, the information from both the company visit and literature survey have been synthesised as literature. It deals with the relation of the contract preparation method.

The conceptual model then will be used to address the verification and validation of the method to become an opportunity to explore and discover several configurations of service and product.

3.2.3 Objective 3: Develop the Conceptual Model

The conceptual model was developed based on the key parameters identified previously. The parameters are grouped, based on either customers or non-OEM MRO service provider viewpoints. There will be two large groups of parameters.

The first group is derived from the customer’s point relative to how the aero engine lifecycle management can be measured. The lifecycle management represents the maintenance demand from the airlines.

Another group is formed from the non-OEM MRO service provider’s viewpoint. These parameters relate to how the non-OEM MRO service providers carry out their maintenance operations. The parameters relate to the maintenance operation policy, spare parts provisioning policy, outsourcing policy and the maintenance decision policy.

Both groups are correlated on the basis of the maintenance demand. The maintenance demand is represented by the lifecycle management from the data obtained from the customers. The customers’ parameters obtained are utilised to predict the maintenance schedule. The maintenance schedule will be the interface between the customers’ perspective and the non-OEM MRO service provider’s perspective.

3.2.4 Objective 4: Develop a Computer Based Model for Simulation

The simulation results can assist the contracting team to enhance the efficiency, reducing the cost and increasing profits (Robinson, 2004). United Airways in 1960-1970s used the simulation in the MRO business process for their ramp facility. Law and McComas (1987) proposed the simulation to analyse and predict the situation that consumed less cost; making it more affordable. Moreover, the simulation is quick and visible to the users, which means it will be easier to understand. The implementation of the experiment to fulfil this research's objective is mentioned in Figure 8.

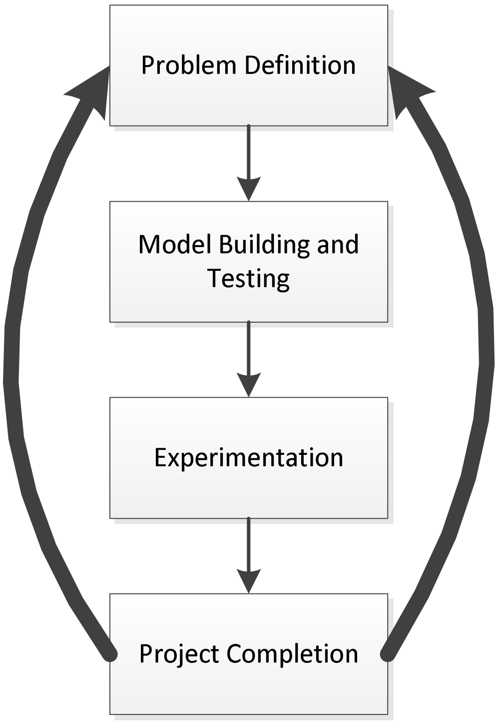

Figure 8 Simulation Projects and Overview (Robinson, 1994)

This research will utilise the computer simulation to fulfil one of its aims. Simulation is *experimentation with simplified imitation (on a computer) of an operations' systems as it progresses through time, for better understanding and improving the system* (Robinson, 2004, p.4). The design experimentation based on simulation will simulate several possible service configurations.

Through the model and simulation, there are three different approaches: System Dynamics (SD), Discrete Event Simulation (DES) and the Agent-Based Simulation (ABS). The SD will represent the specific form of continuous simulation, which accounts for a system as a set of stocks and flow (Gonçalves, Hines and Sterman, 2005). This operational level is not suitable for this model, as it more appropriate for the strategical implementation level (Borshchev and Filippov, 2004; Robinson, 2004). Most of the literature that mentioned SD is used to assess the strategic matters.

Another simulation approach is called Agent-Based Simulation. This method consists of autonomous interacting agents in a system. It models the dynamics of complex systems and complex adaptive systems that are self-organised and create a new order (Macal and North, 2010). The model examines the next event techniques to control the behaviour of the model because the state changes from time to time and involves queuing systems. In the process-based approach, “a process is defined as a sequence of operations through which an entity must pass” (Pidd, 2004, p.102). Having ABS to model the system will not be the best way to solve the problem.

Table 7 Comparison DES vs ABS (Siebers et al., 2010)

	DES	ABS
Simulation orientation	Process oriented: focus on modelling the systems in detail; not the entities	Individual-based (bottom-up modelling approach); focus is on modelling the entities and interactions between them
Modelling approach	Top-down modelling approach	Bottom-up modelling approach
control	One thread of scrutiny (centralised)	Each agent has its thread of control (decentralised)
Entities	Passive entities have something done to them while they move through the system; intelligence (e.g. decision making) is modelled as part of the scheme.	Active entities that are entities themselves that can take on the initiative to do something
Queue(s)	Queues are a key element	No concept of queues
Flow	Flows of entities through a system; macro behaviour is modelled	No concept of flows; does not present macro behaviour, it emerges from the micro decisions of the individual agents.
Input distributions	Input distributions for each maintenance to collect/measured (objective) data	Input distributions based on theories or subjective data

Agent-based modelling is used to model complex systems. The working systems in the agent-based consist of interacting, autonomous agents with behaviour and the interaction influenced by their behaviours (Macal, 2010). In addition, the agent-based simulation built by the set of behaviours and interactions of the agent, tends to be a time driven model in an unpredictable system. Some of the considerations of implementing ABS involve the aim to model the behaviours of an individual in a diverse population when agents anticipate the reaction of others in deciding, and the past is not a predictor of the future (Siebers, PO. et al., 2010). One example to describe the application of ABS is when modelling an avian flu pandemic. Siebers et al. (2010) distinguished the different characteristics between Agent Based Simulation (ABS) and Discrete Event Simulation (DES). Table 7 represents a further description of the comparison between DES and ABS.

DES predominantly uses a powerful computerised based system that takes into account the assumptions that time only exists at a determined point, this timeline is previously set (Pidd, 1998; Robinson, 2004). DES models the operating systems as a discrete sequence of events in the timeline. Each event occurs at a particular instance in time and marks a change of state in the system (Robinson, 2004). Therefore, the DES is useful for problems that consist of queuing simulations or a complex network of queues in which the processes are defined, and their emphasis is on representing uncertainty through stochastic distributions. Many of these applications occur in manufacturing and service industries, as well as queueing situations (Siebers et al., 2010).

This research uses discrete event simulation (DES) as it is more suitable than the SD, especially if the individual items within the systems have a certain procedure applied (Robinson, 2004). The DES' solution offering, matches the non-OEM MRO business process characteristics, as the SD is more abstract and does not capture the individual transactions such as machine breakdown and the arrival of parts. As the research needs to capture the individual transactions regarding the scenarios, a simulation is one of the essential tools for design, and redesigns the operations on the shop floor. The DES is used to assess the supply chain performance measurement (Anderson and Morrice, 2009; Jain et al., 2001) to represent the operational performance of the supply chain stakeholder. Moreover, DES has also been used to assess the patient queues in hospitals (Taylor and Kuljis, 1998).

3.2.5 Objective 5: Classify and categorise service and product combinations

The classification has been used to distinguish and identify the categorisation as an output. Fox (1982) used the classification to distinguish organisational life. The classification method is aimed to arrange, organise, classify and sort the groups of entities. It *arranges material in a way that tells us something about them: a mere list* *has no such character, and a good classification provides a system which has predictive value and will allow maximum information retrieval* (McCarthy, 2005).

The category of the contracting can be based on different combinations of service and products. A non-OEM aero engine MRO service provider can offer more than a service package with additional product. The combination of the service and product as one offering can be distinguished on the basis of its outcome. Adding more service can either give advantage or disadvantage to the shop floor. Therefore, the different type of combinations can be categorised based on the shop floor parameters.

This subchapter will represent configuration levels based on the classification method above. The ranking of the productisation relies on the shop floor performance measurement.

Productisation of service's PSS will represent a mix of the services and the product to the customers. Tukker (2004) has presented the PSS options based on the product provider's orientation (product-oriented, use-oriented and result-oriented). This research combines the spectrum of the PSS from the service provisioning process. The hierarchical clustering can obtain the levelling process to account for the range of each scenario of the shop floor performance measurement. The output of the research will become the dendrogram for each performance measurement of the shop floor.

A dendrogram will represent the cluster hierarchy resulting from the agglomerative hierarchical clustering analysis. A dendrogram is a branching diagram that represents the relationship of similarity among a group of entities. Milligan and Cooper (1987) mentioned hierarchal clustering as a popular method in the data clustering method. The hierarchical method consists of two parts: agglomerative and divisive. An agglomerative or 'bottom up' approach to start the observation in the individual cluster and a pair of clusters then merges as one moves up to form the hierarchy. On the other hand, the divisive method or 'top down' approach will start the observation from a cluster, and splits are performed recursively as one move down to form a hierarchy. However, the divisive method faces problems of computational complexity. Hubert et al. (2009) recommended Matlab to be used to perform an agglomerative hierarchical cluster analysis on a data set.

The classification will be able to assist the decision-makers in choosing the best service configuration on the basis of the shop floor operational capacity and capability for the flight requirements. The classification based on the performance measurement demand can be obtained to provide the information.

The result of the performance measurement in the model simulation is then classified from the results. The researcher used the hierarchical clustering analysis. Hierarchical clustering will classify the data over a variety of scales by creating a cluster tree or dendrogram. The dendrogram consist of more than a single set of clusters and in a multilevel hierarchy. This situation allows the decision-makers to decide the level of the clustering based on the application’s requirements.

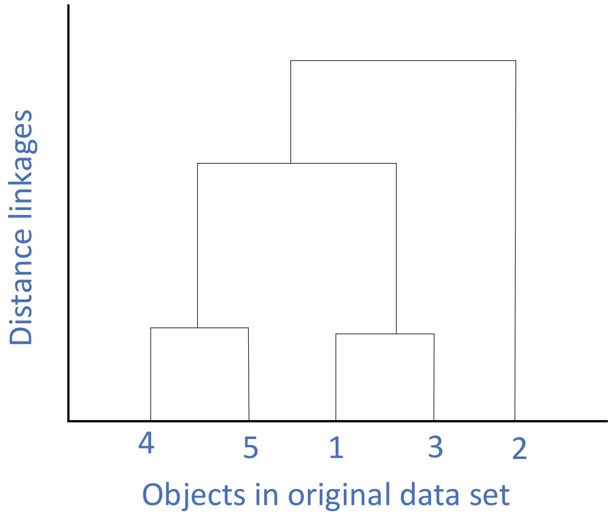

Figure 9 Dendogram (Matlab, r2017b)

In the Figure 9, the vertical axis represents the data set from five different oservations. The vertical axis defines the distance linkage between each data set. The linkage between the data sets is represented by a U-shaped lines (reverse). The U’s height provide the linkage distance between the data. Data 4 and 5 have the same distance height. The height which link cluster 2 and cluster (1,3,4, and 5) computes the distance linkage. Once, these data is computed, the user can decide on how the objects in multivariate data can be categorised.

4 Non-OEM Aero Engine MRO Contracting Method

This chapter aims to identify and assess the key factors, decision variables and parameters that are used by the non-OEM MRO service provider in the contract preparation method. The conceptual model delivered in the last section of this chapter will introduce the relationship between the client needs and the non-OEM MRO shop floor. The obtained conceptual model in this chapter will become the foundation of the following chapter. The model consists of the parameters established from the actual situation in the industry. Section 4.1 describes the overview of the service provisioning contract preparation in real industry. Section 4.2 presents the current contract preparation method employed. Section 4.3 illustrates the proposed non-OEM MRO conceptual model framework to support the service combined product offering. Section 4.4 concludes the chapter with a summary.

4.1 Overview of the Service Provision Process

There is less literature that discusses the non-OEM MRO in detail, especially concerning the contract management policy. Most of the papers mention the service contract management for the product manufacturer (servitisation of product) from PSS based product-service system (Baines et al., 2007). This study carried out the data collection to understand the real industry business, and obtained information on service contract management and its preparation in the combination of service and product contract.

The study involved a non-OEM MRO company as a case company. The site visit provided more in-depth knowledge of the non-OEM MRO provider business industry. The broad range of products, high capacity production, being one of the biggest non-OEM MRO service providers in Southeast Asia, and the ease of access have made it an ideal avenue for this research. The characteristics of this case company resemble the non-OEM MRO's typical characteristics. The fluctuating demand in maintenance has resulted in a need to develop flexible mechanisms, to rapidly respond and maintain a competitive strategy.

The study incorporated the semi-structured interviews of eleven employees. The interviewees' group consists of senior managers, middle managers, managers, and staff to enhance the understanding obtained from the workshop. The range of hierarchy is chosen to identify the strengths of the PBH based contract and to extract actual issues that exist in the operation of the case company, and thus achieve greater efficiency in decision-making.

The interview's participants consist of the Account Manager who represents the customers, the General Manager, and the Shop Floor M; the duration of each interview was about two hours. The interviews were recorded to allow for easier analysis afterwards. The interviews were conducted across six days during December 2014. The interviewees chosen had a minimum of ten years' experience in the business and the aviation industry.

Table 8 Interviewees of Case Company A

Position	Organisation
Chief Marketing Officer	non-OEM MRO
Engineering Service	non-OEM MRO
Account Manager	non-OEM MRO
EVP Base Operation	non-OEM MRO
Spare Parts Planner	non-OEM MRO
Account Director for airline G	non-OEM MRO
VP of Component Services	non-OEM MRO/ Airlines
Account Director for airline S	non-OEM MRO
VP of Base Operation	non-OEM MRO
Technical Representative	Airlines
Account Manager	non-OEM MRO

The duration of each interview was between 60-120 minutes, covering several main themes: the demand characteristics, the trend of the airlines' customer demand, the current contractual agreement, and the decision-making processes in demand fulfilment. The interviews were manually documented and recorded to understand the main barriers. The findings obtained from the interview were then used to enhance understanding of the related parameters to develop the process framework, with direct applicability to the operational level.

The list of questions are provided in Appendix B. The list of questions are developed before the site visit and enhanced based on the actual situation while conducting the research interview. The sample questions have been provided in order to assist the research in obtaining the accurate and important information easily. Further analysis is required to link and enhance the logical explanation from each information obtained.

4.1.1 Airlines Current Demand

The parameter mentioned in the interview with the VP Marketing (Chief Marketing Officer), is the ‘On Time Performance’ (OTP). OTP is the general parameter currently required by the airlines. He detailed the OTP as demand for several operational factors: the air crews, the cabin crews, passenger catering, and technical support. As the scope of non-OEM MRO provider is the maintenance area, the research is limited to the technical assistance area.

The aircrew consists of the available certified pilot and co-pilot to operate the aircraft. The cabin crew refers to the certified air stewards /stewardesses who work on the plane. Catering is responsible for providing the food and drink to be served during the flight, and the top priority of the non-OEM MRO provider is the technical support. The technical assistance should ensure the aircraft is on schedule. The support for the technical is the responsibility of the non-OEM MRO provider.

The airline customer needs the OTP to carry out their commercial operation. OTP fulfilment is an opportunity for the non-OEM MRO provider to offer all the technical support required for their operations. They also provide aspects of the supporting parameters such as engineering services to plan and produce the job card and maintenance’s work scope. The case company has responded to the airlines’ demands with the all-in-one technical solutions. For this to occur, the airlines collaborated with the non-OEM MRO provider to optimise their fleet and find the optimum balance to conduct the commercial operations. The airline needs to maintain its high-frequency operations.

As mentioned previously, the non-OEM MRO provider initially offered total support to the airlines, to provide greater reliability and availability to the business planning. This situation requires the non-OEM MRO provider to be more visionary in assessing the future demand. Based on the interview with the Chief Marketing Officer (CMO) (Figure 10), the customers’ demand parameters are availability, reliability, TAT (Turnaround Time) and spare components. The availability of the fleet and services of the airline is necessary to support the operational requirements of the services. The higher availability of the service will generate more opportunity to the airlines to have commercial flight. The availability also relates to the reliability of the assets. The reliability of the assets represents the durability of the aero engine without the involvement of any technical related situation leading to the grounding of the aircraft.. The TAT will reflect on how the non-OEM MRO service provider can offer the availability to the customers. All those parameters are necessary to support the on-time performance service to the airlines.

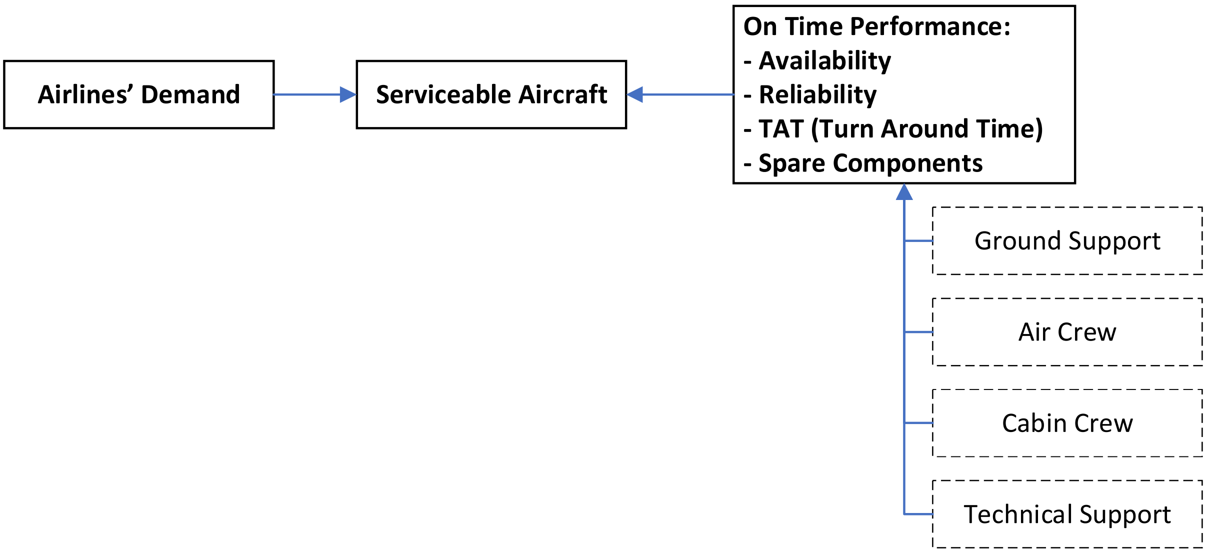

Figure 10 Airline's Demand for Flight Operation

The availability defines that there must be available aircraft on the planned schedule. The availability means that the plane is technically certified to fly (airworthy condition). Airworthy means the aircraft can fulfil the take-off list from the airline company. The list usually comprises the Hot Item List (HIL) that must be installed and accommodated into the aircraft's operations. Therefore, the non-OEM MRO service provider should support the spare parts' provision. The component spare for fast moving should be available as soon as the aircraft is grounded (AoG). The longer the spare part provisioning, the less available the aircraft is. The financial risk, such as penalty or ticket refund should be taken care of by the non-OEM MRO service providers. The reliability means that the plane or the engines should be reliable to maximise availability. The greater the reliability represents the greater the number of aircraft in operation. On the other hand, if the plane or engine needs maintenance, the non-OEM MRO service provider should conduct the maintenance as fast as possible (shorter

TAT). The shorter TAT will provide the airlines with more flight hours for commercial operations.

Finding 1

- On-Time Performance (OTP) is the most important parameter for airlines.
- The non-OEM MRO should fulfil the operational requirements of the airlines mentioned as Flight Dispatch Reliability (FDR).
- The FDR is defined as the total number of an aircraft departs in between 15 minutes of the scheduled time. Therefore, it is not only the availability, but the non-OEM MRO provider should be two steps ahead to retain its competitive edge to support its airline customers.
- The non-OEM MRO provider should prepare an efficient strategy to fulfil the airlines’ customer operations.

4.1.2 The Trend of the Airline Customers’ Demand

By observing the explanation of the case company during the workshop, the demand trend of the airlines in the region is to support a higher frequency of commercial operations. The trend of the airlines’ customers has affected the airline fleet management strategy. The airlines deploy more narrow body aircraft rather than wide body aircraft. The shift of the fleet composition has forced the non-OEM MRO service provider to adjust its production planning strategy. To maintain shorter TAT maintenance, the non-OEM MRO service providers tend to increase the supply level, such as expanding new facilities and growing the spare parts inventory level.

Besides that, the airline operational requirements have been affected by the world economic situation, such as the trend in the price of crude oil and the currency rate. To accommodate the operations, the airline customers could change operational policies such as the flight route or flight frequency.

The client's demand for the non-OEM MRO’s perspectives is unique. The general demand of the airline is to support the operational management. The operational risks and uncertainties such as technical problems are very high. It is because each fleet can consist of different aero engine configurations and specifications. This situation does not apply to just one type of aircraft, as the lessor could be different and the leased aircraft will have various types of configurations. The commonality of the fleet is less, which then results in difficulties of spare parts supply management. On the other hand, the airlines want the partnership agreement by using the pay by the hour (PBH) method. PBH makes the demand fluctuate and the risk increases.

The non-OEM MRO could not satisfy the airlines; consequently, the company shifted their offer by providing a package solution consisting of the engine and the APU for the aircraft. The company had calculated the estimated flight hours and flight cycle. The total cost of a one-year agreement divided into twelve instalments as the price of using both the engine and the APU.

Finding 2

- Based on the trend of the demand, the parameters that could be obtained from the airlines are the entire flight, the flight operations (route), fleet size, and the airline's operations policy.
- The normal parameters required by the airlines are the total number of aircraft that are available. Subsequently, not only the strategy but also the planning development of the non-OEM MRO provider should be adjusted.

4.1.3 The Current Contractual Agreement Type to Fulfil the Airlines' Demands

The contractual arrangement in the case company should accommodate the request parameters.

Not to Exceed (NTE) contract is usually offered to the older generation engines to increase the performance of the engine. Light maintenance and several small work scope contracts will be based on NTE. The NTE contract work scope usually covers the main parts of the engine, with several exclusions included in the term of the contract. The NTE cost will be fixed to the agreed agreement in the negotiation phase.

Time and Material Basis (TMB) contract is the regular basis of the agreement between the non-OEM MRO and the airlines. The TMB contract agreement refers mainly to the cost and the preparation; the TMB cost will depend on the time and material consumed in the project.

Pay by the Hour (PBH) contract will support the total flight hours produced by the aero engine. In the matter of the duration of the contract, the service provider will support all aspects of supporting the entire operation of the aero engines.

Based on the contract types, several parameters are commonly used as a basis to calculate the value of the contract. The specifications of the contracts is based on the customer's requirement, adjusted by the non-OEM MRO's recommendation.

The demand parameters are listed in the non-OEM MRO's provider offers. This offer has been initiated to incorporate many aspects, and the products offered have been intended to support the affordable commercial operations (Figure 11 Total Care Solution as the Main Service . Figure 11 shows the main product that becomes the most popular offer from the company. The trend indicates that in future the airline may demand the non-OEM MRO to provide the product as well, i.e. engine, APU, and airframe. Therefore, the case company has introduced the total care solution to their airline customers.

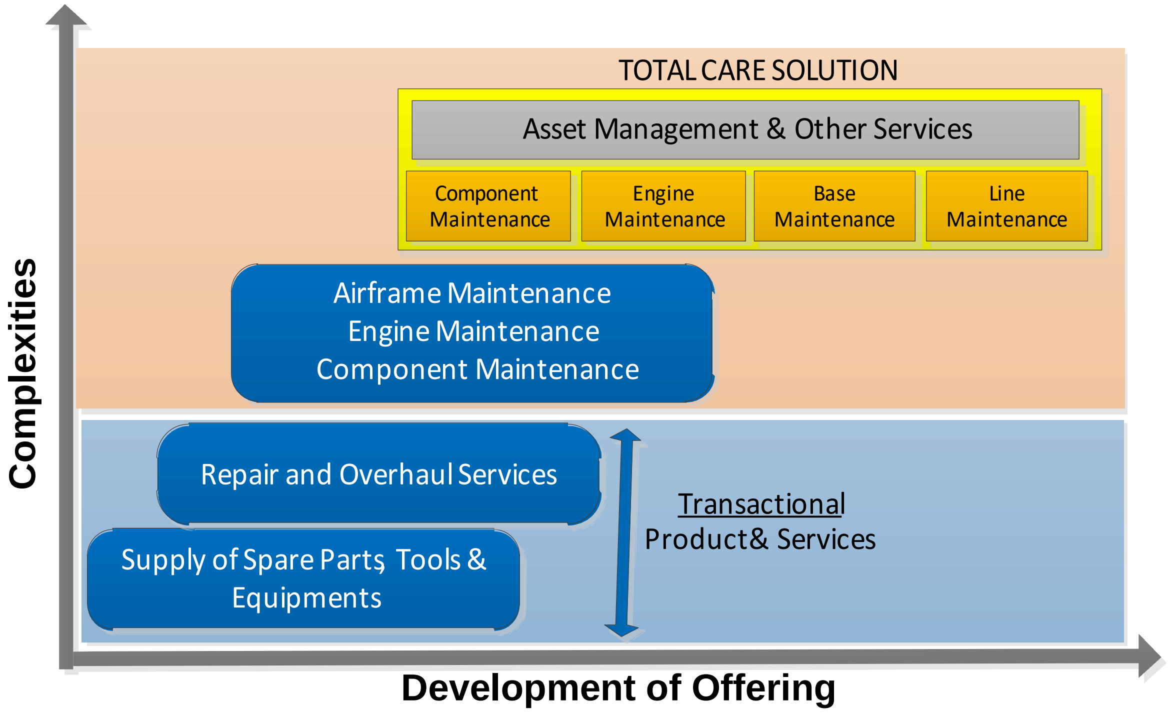

Figure 11 Total Care Solution as the Main Service provided (Hutabarat, 2011)

The Total Care Solution approach from the case company will offer advantages to the airline's customers:

a) Cost saving.

The more aircraft or the aero engines covered in the contract, the greater the opportunity for the non-OEM MRO provider to offer a more efficient price based on volume.

b) Maintenance cost as a variable cost.

The common and conventional pure maintenance offering from the non-OEM MRO service provider is represented as Time and Material Based (TMB) Contract. This type of contract will charge the airline based on the time and material used for each order. This method is becoming unpopular, as the airline customers prefer the fixed cost contract payment such as Pay by the Hour (PBH). With the total care approach, the maintenance cost can be adjusted, based on the airline's operational requirements.

c) Asset Reduced.

The total care solution can respond to the need of the low budget airline. The airlines currently do not want to take over the assets because of the increased cost of possession and spare parts management, which can be a financial burden to the airlines.

d) Risk Minimisation.

The total care solution will shift the responsibility of maintenance to the non-OEM MRO provider. It will give the airlines more room to initiate strategies. The risk is shared between the airlines, and the non-OEM MRO depends on the terms and conditions agreed.

Meanwhile, to provide a total care solution agreement, there are several challenges. The value of the contractual arrangement between the planning and the actual is often inconsistent, especially regarding the shop floor uncertainty. The real maintenance will be known when the aero engine is inspected in the shop. The work scope prediction often differs from the actual work scope. The predictions will be made from historical data and experience. The inconsistency can be very high. Another challenge is in providing the service and maintenance; the older aircraft face scarcity and obsolescence of spare parts. These are the reasons why the non-OEM MRO needs to provide service and maintenance to the older aircraft under the TMB and the NTE contracts.

Finding 3

In order to evaluate the total solution contract, the characteristics of the aero-engine need to be assessed. Based on the risk and the cost concern, the type, the age and the performance trend of the aircraft/aero-engines will become the parameters to decide the best optimum contract.

4.1.4 Decision-Making Processes in Maintenance Stage

In demand fulfilment, especially in the engine shop, a decision process is conducted. The decision-making process for the engine shop process will undergo several stages. The stages illustrate the decision-making in the demand fulfilment processes in the case company non-OEM MRO. This number illustrates how the aero engine maintenance respects the customers' requirements.

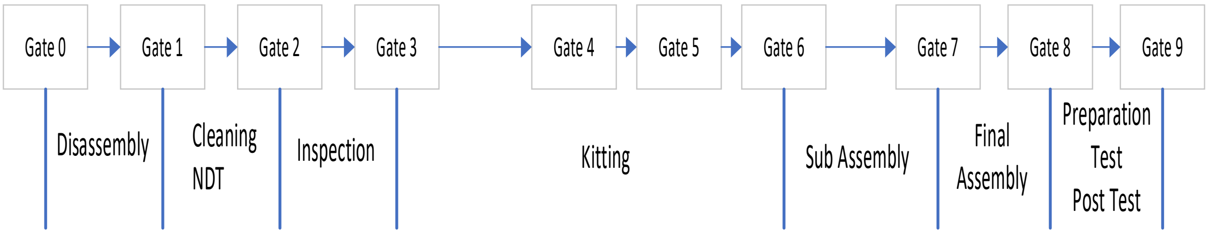

Figure 12 Gating System

Initial stage (until Gate 0)

Work scope defined as the order from the client, which is translated by the engineering services. The data obtained are from the ESM (Engine Shop Manual), Task List from the engineering unit (translating customer demand), shop visit record, Life Limited Parts (LLP) documentation and status, Service Bulletin (SB), Airworthiness and Directives (AD). Those documents will provide the information of the necessary maintenance process to the aero engine. The data will be used to estimate the work scope and the cost.

The initial stage will influence the optimum balance between the shop visit cost, frequency and the cost of the maintenance. Initially, the engineering unit has the bigger role in deciding the best work scope and LLP works. The total cost is based on the estimated direct maintenance costs, which consist of labour, materials, parts and sub contract repair cost.

Inspection Stage (Gate 1)

The next steps are preliminary inspection, cleaning and module disassembly (tear down), and the internal condition is uncovered. At this juncture, the potential failures are often seen after the teardown, and the shop will recommend any additional maintenance that is necessary (opportunistic maintenance). The decision to maintain the failed parts or deteriorated parts have to be determined.

The decision parameter to be considered is customer demand. Whether they would like to receive a ‘gold-plated’ service while the full overhaul is completed, or accept only the minimum work to support the operation until the next shop visit; the main drivers of the customer’s decision remain the cost and the TAT. The additional maintenance may increase the TAT and decrease the TOW (Time on Wing). However, to reach the best solution, severity factors have to be taken into account, as the possibility of failure can potentially harm the safety level and the reliability of the aero engine.

Repair Stages (Gate 2)

In this phase, the repairable unserviced part is placed in the inspection work bench area. The inspected module consists of four categories: serviceable, scrap, serviceable but removed from the service, and repairable. After inspection, the decision appertaining to each module will be addressed as; holding item, send to subcontractor, scrap, return as is, internal refurbishment, serviceable, and pending item.

The decision in this phase depends on the financial and the TAT. Sometimes the repair options are much cheaper than replacing with the overhaul or a new one. On the other hand, the replacement will guarantee the shorter TAT.

For several engine types, one strategy adopted by the non-OEM MRO was to buy older engines that are not operational. The spare parts were cannibalised to support the serviceable engines, and the non-OEM MRO will repair the serviceable parts and then sell to the aftermarket. This strategy is identified as the best solution for both airline and the non-OEM MRO. The repair will utilise the technicians, and the faster TAT will benefit the airlines. On the other hand, the quality and reliability of the repaired parts are different to the new ones. Also, The TAT and the delivery time, the time needed to provision, repair and service the components have to be considered.

Outsource/ In-house repair (Gate 3-4)

The decision to outsource or do the inhouse repair differs regarding the capability and slot availability from the engine shop. The slot availability refers to the workforce, certification, the special tools, materials and the skill. Several areas to consider for outsourcing are the time delay, transportation time, and the quality risk. However, outsourcing is a good option to fulfil the cost and TAT agreed with the customers.

Finding 4

Based on the decision parameters; there is a time prediction for each shop visit. The parameters are total workforce, availability, the certified capability and the provisioning decisions.

4.2 Parameters in Contracting Preparation

To obtain the parameters in the contracting preparation, this research used both the primary and secondary data source. The primary data source is obtained from industrial visit and the secondary data is obtained from the available literature.

4.3 Initial Aero-Engine’s Contract Preparation Model

As mentioned prior to the data collection phase, the interview, combined with the academic and practice has contributed to the foundation of the framework. In this study, the framework has a different approach compared to the existing practice. The first action of the proposed framework is to take the customer’s operational planning as the driver. The framework incorporates the parameters that could influence the client's planning operation, such as the operational environment and each aero engine’s severity characteristics.

Based on the data collection in the previous chapter, the most significant parameter is the time parameter (delivery time). The time parameters will affect the operational availability of the non-OEM MRO to support the operations. Furthermore, there are many sub- parameters that could have an impact on the delivery time in the non-OEM MRO operations, such as the provisioning, the resources availability, and the maintenance procedure.

On the other hand, the airline customers are concerned with the time to fulfil their On-Time Performance (OTP). OTP is mostly affected by the maintenance delivery time (TAT). It means that the shorter TAT will increase the OTP. More TOW will affect higher availability.

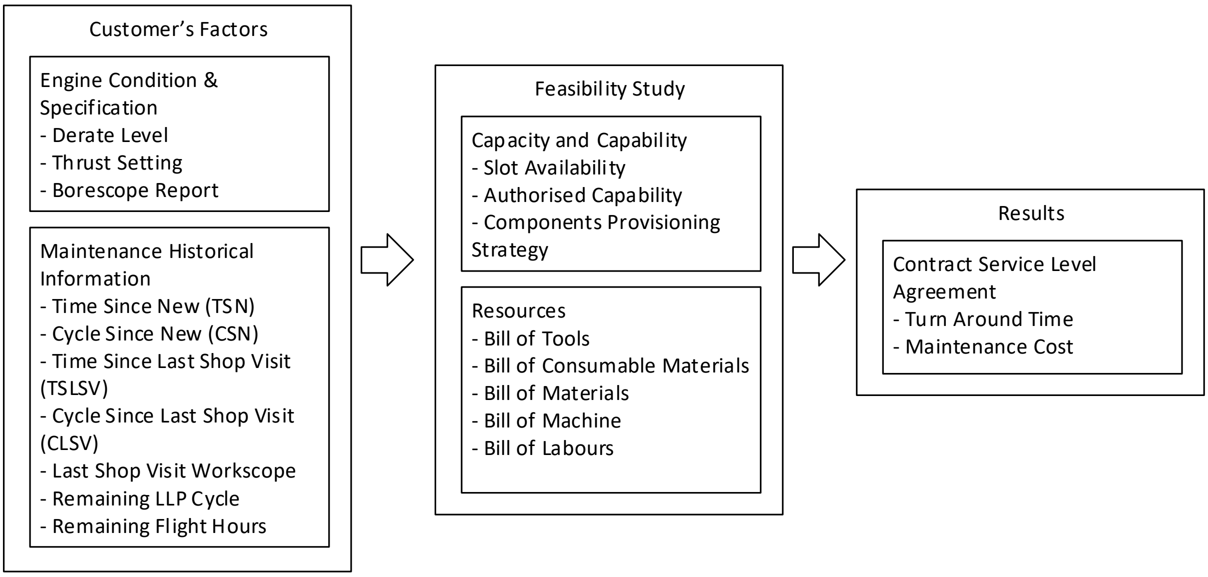

Figure 13 Conceptual Model for Current Contract Preparation

Figure 13 presents the current contract or agreement being prepared based on the ad-hoc type of agreement. The contract preparation will elaborate on whether the aero engine maintenance demand will be able to be repaired by the non-OEM MRO. The non-OEM MRO has to ensure that their capacity and capability are met with the customers' work scope and requirements. The contract preparation will consider if the non-OEM MRO see the opportunity as feasible or not. The non-OEM MRO will be able to reject the request if the shop floor is not available.

In the current contract preparation, the non-OEM MRO contract preparation depends on the workshop requirements requested by the airlines. The non-OEM MRO service provider will only ask for the maintenance history and maintain the aero engine as a pure service non-OEM MRO. This is called pure maintenance service provision based.

4.4 Proposed Aero-Engine's Contract Preparation Model

The conceptual model framework has obtained several parameters from the literature survey. The parameters obtained relate to the shop floor parameters and the airline operational parameters. The information retrieved from the literature survey support the data from the industrial visit. To enhance the level of validity of this framework, an interview to an expert has been conducted. Based on this interview, the feedbacks have been incorporated into the Figure 14.

In this method, the non-OEM MRO service provider will deliver a more proactive solution than before. The non-OEM MRO will also be able to support airlines' flights and adjust their capacity and capability to fully support the airlines' commercial flights.

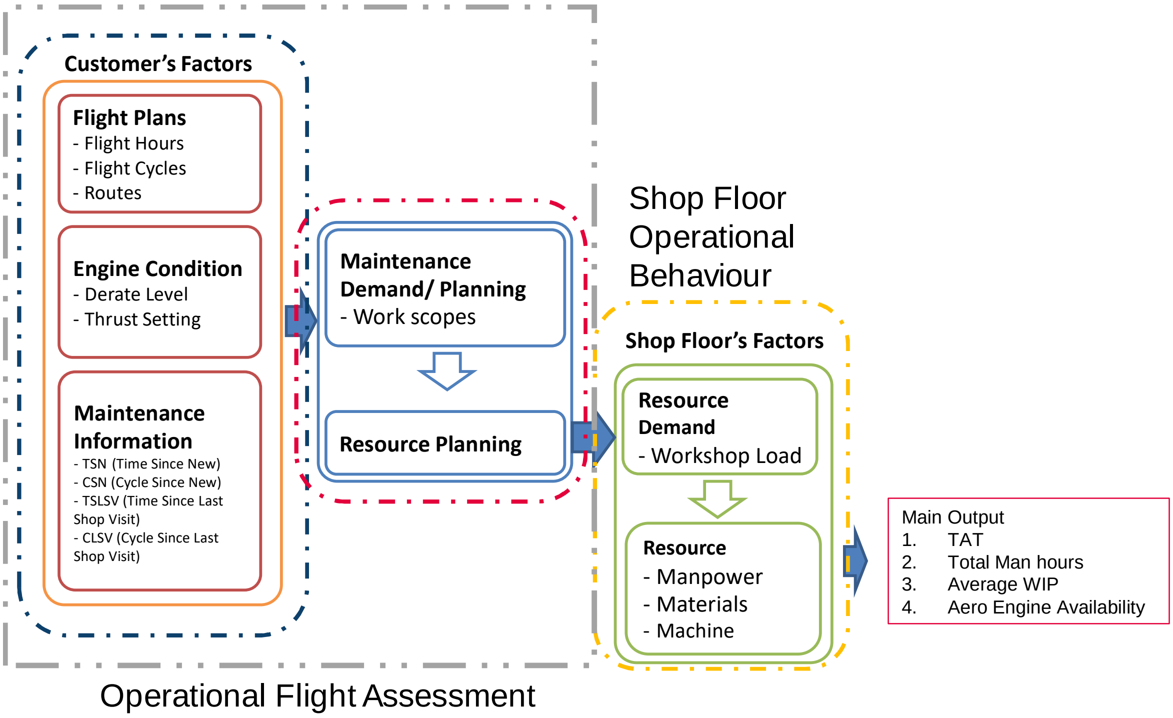

Figure 14 Proposed Conceptual Model for Enhanced Contract Preparation

The conceptual model has been developed, based on a reference both from the airline customers and the MRO provider's operational capability. The current parameters are used by the contract economical evaluation, combined with the MRO's provider supporting contributions. The characteristics or engine state are the drivers of the operations on the MRO shop floor. These parameters are the operational parameters, the severity factors and the current engine status.

In Figure 14, the proposed contract will elaborate on both the airline's requirements and the shop floor operational capacity and capability. This method, which will allow the non-OEM MRO to be able to advance their offering by supporting the airline's requirements as previously mentioned by the chief marketing officer, is On Time Performance (OTP) based parameter. This method ensures the non-OEM MRO is be able to assess the future demand for the maintenance and is also to compare their non-OEM MRO shop floor operational capacity and capability. The output of the method will be able to predict the average TAT of the aero engine maintenance, which relates to the availability of the aero engine and the total number of the aero engine that have to be prepared as spares. This method can also predict the resources that need to be established by the non-OEM MRO. These resources include the total labour, the capacity and the capability for each maintenance processes. They could also predict which maintenance process t can be outsourced to support the airline operations in the future. To enhance the level of validity of this framework, an interview to an expert has been conducted. Based on this interview, the feedbacks have been incorporated into the Figure 14.

This method is established to produce co-value of the contract for both parties. The non-OEM MRO service provider will be able to prepare all aspects required to support the customers, and also to assess the trade-off in the development of the cost and the revenue in the future.

4.5 Chapter Summary

This chapter has mentioned how the non-OEM MRO service provider translates the requirements from the customers’ perspective and fulfils the request. Based on the observation, interview and literature survey, the chapter delivers the conceptual model framework, which relates to the airline's operational requirements of the non-OEM MRO shop floor operational availability, capacity and capability. This model, represented by Figure 14, will also become the foundation for the following stages of this research.

5 Computer Based Simulation Model Development

This chapter represents how the model is developed, based on the proposed conceptual model for contract preparation in the previous chapter. Section 5.1 illustrates the parameters and the calculations to support the maintenance forecast module; Section 5.2 shows the current non-OEM MRO shop floor operations available in the literature and the actual industry; Section 5.3 depicts the shop-floor operation flow process into the computer based model, and 5.4 summarises the chapter.

5.1 Review of Maintenance Demand Planning Forecast

The maintenance demand is represented by the prediction and forecast for the aero engine to conduct a shop visit. The maintenance forecast provides information regarding the work scope of each visit and also the time when the aero engine has to receive maintenance. The main work scope of the aero engine maintenance consists of three main tasks: replacement of Life Limited Parts (LLP), performance restoration, and the unscheduled/unplanned engine removals (Justin, Garcia and Mavris, 2010).

The first common task is to replace LLP parts. Each LLP is certified for a limited time on wing and needs replacing at the end of its certified life. The LLP comprises of 19-20 different parts depending on each aero engine type (e.g. General Electric’s CFM56-3 has 19 separate LLPs). The life of LLPs varies and the main variable is based on the flight cycles.

The second common task is that aero engines’ conducted maintenance is due to the performance deterioration. The performance degradation can be caused by heat, metal erosion and component fatigue. The main performance indicator in an aero engine is the Exhaust Gas Temperature (EGT). The EGT margin (EGTM) is the common parameter which indicates whether the aero engine is in the best condition or not. The worn level of the aero engine will increase the exhaust gas temperature, reduce the gap between the operating EGT and the reference level, and consequently will decrease performance. Based on the materials and their properties, the EGT limit margin is established by the OEM. Once the EGT exceeds the limit margin, the aero engine must be sent to the shop for engine performance restoration. Engine performance restoration consists of the major core module dismantle, and airfoils (rotors and stators) are inspected, balanced, and repaired or replaced as necessary.

The work scope can be decided once the aero engine has been inspected. The most common inspection method is the Borescope inspection.

Another main work scope is the unscheduled or unplanned maintenance. The unscheduled removals can occur for several reasons, either from the sudden deterioration of the engine due to a technical fault or foreign object damage (FOD) caused by the external object ingestion during operation.

This research has integrated both the scheduled and unscheduled maintenance. The planned maintenance work scope consists either of LLP replacement, or the EGT margin performance restoration, which is embedded in this research as planned maintenance model. Moreover, the unscheduled maintenance has also been integrated based on the aero engine's technical reliability data from the case company. The maintenance forecast module will combine both maintenance elements for the duration of the contract. The maintenance model will provide information regarding the total maintenance visit required.

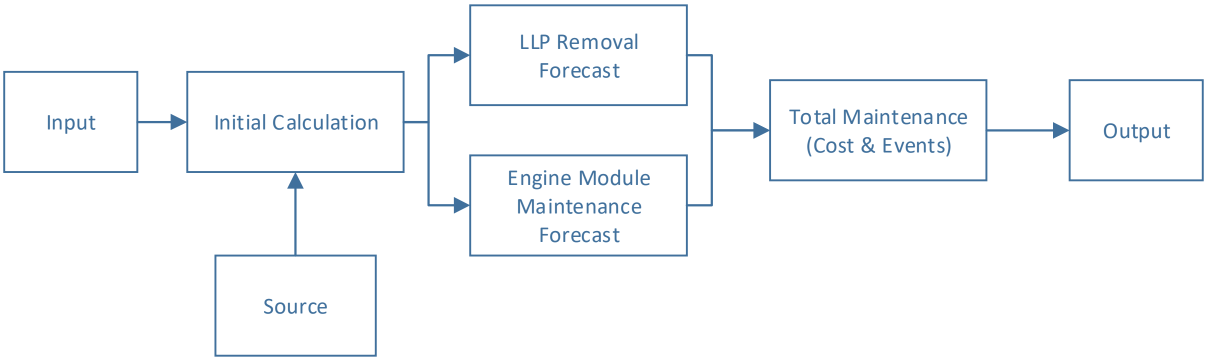

Figure 15 Maintenance Model's Diagram Flow Process

Figure 15 represents the maintenance model to predict the cost of an aero-engine's shop-visits in the future. At the initiation stage, the aero engine owner will send the requirements to the non-OEM MRO service provider. The non-OEM MRO service provider will then assess the sent requirements. The initial calculation of the aero engine maintenance will follow the maintenance manual (source) provided by the OEM. It will include the work scope, which includes the spare parts and the total labour required. The total maintenance will consist of two different models: LLP removal work scope and the engine maintenance module work scope. The LLP removal and replacement can only be done by replacing, as the LLP has its own limited time in the aero engine operation. Another work scope is the maintenance for the aero engine module and its sub module. This work scope will include the maintenance, repair and service of the components installed in the aero engine. The non-OEM MRO can decide whether to repair (internal or external) or scrap the spare parts.

LLP Replacements

In this study, the model used is CFM56-7. This engine comprises five main modules: fan, booster, High-Pressure Compressor (HPC) and High-Pressure Turbine (HPT) and Low-Pressure Turbine (LPT). There is a total of nineteen LLPs, which support engine CFM56-7. The LLP numbers can vary for each aero engine.

The LLPs' certified life (limit) is measured by the effect of the flight cycle. The declared LLP's limit is between 20.000-30.000 cycles. If the engine is operated over a long-range network, the LLPs may not need to be replaced. However, for short-range routes, they may need to be replaced two or three times during the aero engine's lifetime. To represent the range of operations, the model covers the flight leg for each aircraft (two engines).

EGT Margin Deterioration

The EGT margin measures the difference between the maximum permissible EGT (limit) and the peak of EGT margin during take-off. The EGT margin formula is represented by Equation 1.

Equation 1

$$\text{EGT Margin} = \text{EGT Redline-EGT Measured Reading}$$

Source: Ackert (2010)

EGT Margin is obtained from actual data measured while the aircraft is taking-off. The time when the pilot take the readinds depend on the aero engine type and the method provided by the manufacturer. The measured actual EGT is based on the thrust, speed, altitude and Outside Air Temperature (OAT). Then the value is compared to the EGT redline value. It is positive when the EGT is below the redline, and vice versa. The positive margin means that the aero engine can stay on wing while the negative margin means that there is a need to to corrective action.

The aero engines will have their highest EGT margin after they are overhauled or refurbished. The EGT margin is sensitive to the outside air temperature (OAT). The increment of the OAT will also increase the EGT. On the other hand, the EGT margin will be lower.

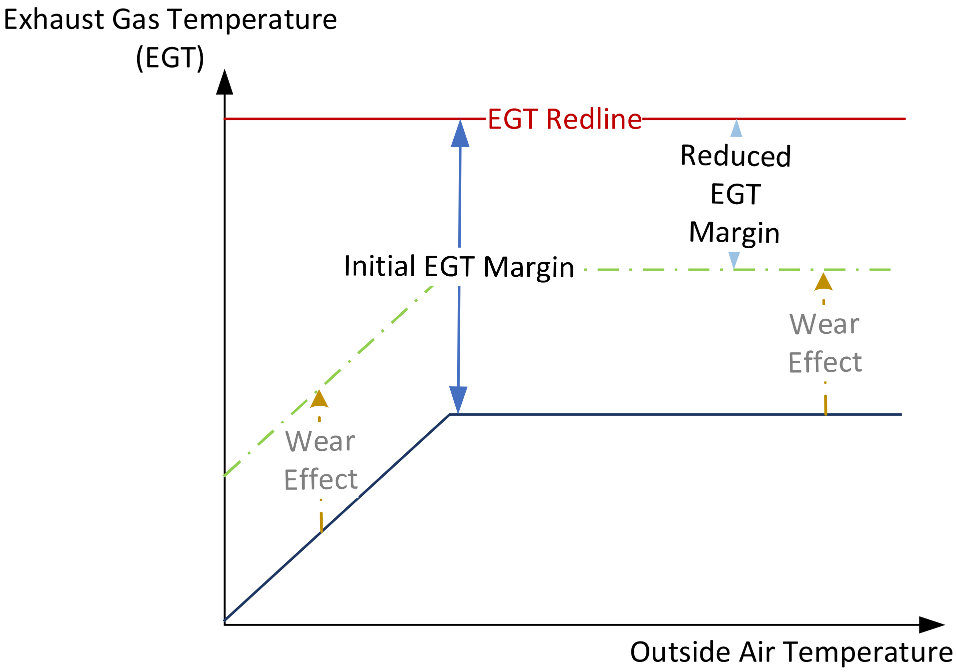

Figure 16 EGT Margin Deterioration and Wear Effect over time (Justin et. al., 2010)

Based on Figure 16, the EGT margin has risen traditionally linear up to the design corner temperature, at which point the EGT becomes saturated. The corner point temperature represents the highest EGT. The highest EGT is reached when operating at maximum thrust situation. Although it is possible to exploit the aero engine at the upper OAT beyond the corner point temperature, the aero engine thrust lever must be set to the lower level (de-rated) to avoid an EGT redline exceedance. The figure also refers on how the age of the aero engine can affect the EGT margin. For example, if a new engine may have 75^{0}C different between the max EGT and EGT at the take-off setting, the older engine will have the EGT margin become closer. This is the reason many aero engine set the take-off thrust reduced in order to keeps the EGT low and increase the aeroengine’s lifecycle.

5.1.1 Engine Removal Forecast Parameters

This research obtained the common method to conduct maintenance schedule, which is used by the non-OEM MRO service provider. The detailed document provides information regarding the key factors and parameters to assess the contract offer.

There are few lists of data input which are required to evaluate the aero engine maintenance schedule. The first group of the data relates to the general identification of the aero engine, such as the maintenance history information. Another group of data represents the airlines/customers operational status of the aero engine since new. The current practical parameter most commonly used in the industry is represented by Table 9.

Table 10 illustrated the contractual parameters used in asessing the contracting cost and the maintenance prediction in the aero engine. The data is obtained from a case company's engineering database integrated with the information obtained from the primary data.

These parameters are derivated from Figure 14 which relates to the customers' aspects. Customers' parameters then combined into an input model to the proposed method based on Figure 17. The flight operations parameters are used to assess and analyse the maintenance demand.

Table 9 Aero Engine Maintenance Contract Parameters

Redelivery Status	Redelivery Date
	Cycles provided
	Minimum EGT Margin
Hardware Limit	LPTN1 Days Remaining
	LPTN1 Estimated Fallout Date
	J-Hook Fall Estimation Date
	Remaining J-Hook
EGT Margin	EGT Margin Due Date
	Remaining EGT Days
	Estimated Remaining EGT Cycles
	Take-off Trend

	Current EGTM	
	EGT Rate of Deterioration (RoD)	
Engine Life Information	Cycle since Last Shop Visit (CLSV)	
	Time since Last Shop Visit (TLSV)	
	Engine Status Date	
	Cycle since New (CSN)	
	Time since New (TSN)	
	No. of Shop Visit	
Borescope Inspection Result	LPTN1 Due Date	
	Remaining Cycles based on LPTN1	
	HPT Due Date	
	Cycles to Go	
	J-Hook[1] Due Date	
	Flight Hours Remaining	
Applicable AD	Due Date	
	Flight Hours Remaining	
	Flight Cycle Remaining	
Life Limited Parts (LLP)	LLP Due Date	
	LLP Remaining Cycle	
Aircraft Detail	Source Company (Lessor or Owner)	
	In-Service Date	
	Thrust Level Specification	
	Utilisation	Flight Hours Reached
		Average Flight Hours per Day
		Flight Cycle Reached
		Average Flight Cycle per Day
	Engine Serial Number (ESN)	
	Aircraft Registration Number	

It is necessary to include these parameters are necessary to ensure the most suitable work scope. Then, the obtained work scope can represent the cost of the maintenance.

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[1] J-hook is used to attach the turbine blade with the shroud in the LPT Module

The relation of each parameter was linked, and the representation can be defined through Figure 13 Conceptual Model for Current Contract Preparation.

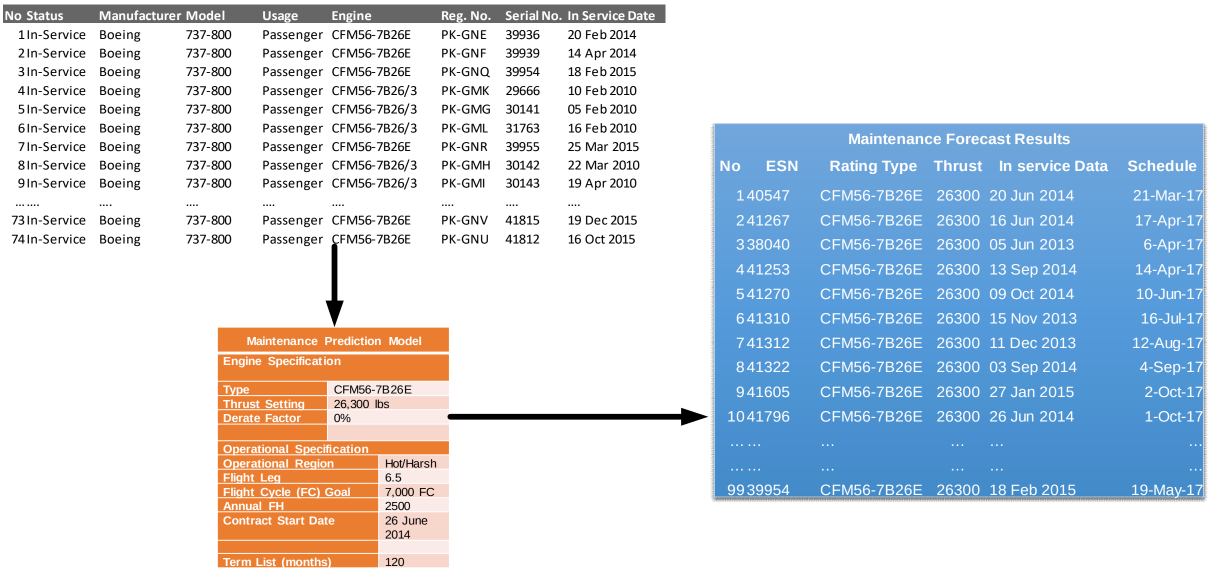
There are also different perspectives in the forecast of the maintenance parameters. In 2010, Ackert predicted the engine maintenance forecast through the maintenance cost perspective (financially). He derived the aero engine maintenance schedule through the total cost maintenance labour needed and the material in an aero engine lifecycle. This data is generated from Aircraft Commerce Aviation magazine in (Aircraft Commerce, 2007). In addition, he also mentioned the need to assess the environmental impact to predict the maintenance as it can affect the aero engine hardware deterioration.

Together with Hanumanthan et al. (2012) they also proposed how the environmental operation of the aircraft can affect the maintenance forecast. The aero engine's severity curve has become the foundation of the maintenance events' schedule, which relates to the thrust setting, operational severity, take-off-derate level, ambient temperature, aero engine age and the work scope management policies.

Those parameters then can be depicted into the aero-engine severity curve. This severity curve can only be obtained for each aero engine maintenance type. In addition, the designer of the aero engine (manufacturer) is the one who provides the severity curve to the customers.

5.1.2 Scheduling Model's Formulas

The scheduling model combines both primary and secondary data. The input data obtained from both the Maintenance Operator Guide Aircraft Commerce (Aircraft Commerce, 2007), Financial Guide for Aero Engine Operator (Ackert, 2010) and actual industry data.



No	Status	Manufacturer	Model	Usage	Engine	Reg. No.	Serial No.	In Service Date
1	In-Service	Boeing	737-800	Passenger	CFM56-7B26E	PK-GNE	39936	20 Feb 2014
2	In-Service	Boeing	737-800	Passenger	CFM56-7B26E	PK-GNF	39939	14 Apr 2014
3	In-Service	Boeing	737-800	Passenger	CFM56-7B26E	PK-GNQ	39954	18 Feb 2015
4	In-Service	Boeing	737-800	Passenger	CFM56-7B26/3	PK-GMK	29666	10 Feb 2010
5	In-Service	Boeing	737-800	Passenger	CFM56-7B26/3	PK-GMG	30141	05 Feb 2010
6	In-Service	Boeing	737-800	Passenger	CFM56-7B26/3	PK-GML	31763	16 Feb 2010
7	In-Service	Boeing	737-800	Passenger	CFM56-7B26E	PK-GNR	39955	25 Mar 2015
8	In-Service	Boeing	737-800	Passenger	CFM56-7B26/3	PK-GMH	30142	22 Mar 2010
9	In-Service	Boeing	737-800	Passenger	CFM56-7B26/3	PK-GMI	30143	19 Apr 2010
…	....	....	....	....	....	....	....	....
73	In-Service	Boeing	737-800	Passenger	CFM56-7B26E	PK-GNV	41815	19 Dec 2015
74	In-Service	Boeing	737-800	Passenger	CFM56-7B26E	PK-GNU	41812	16 Oct 2015

Maintenance Prediction Model	
Engine Specification	
Type	CFM56-7B26E
Thrust Setting	26,300 lbs
Derate Factor	0%
Operational Specification	
Operational Region	Hot/Harsh
Flight Leg	6.5
Flight Cycle (FC) Goal	7,000 FC
Annual FH	2500
Contract Start Date	26 June 2014
Term List (months)	120

Maintenance Forecast Results

No	ESN	Rating Type	Thrust	In service Data	Schedule
1	40547	CFM56-7B26E	26300	20 Jun 2014	21-Mar-17
2	41267	CFM56-7B26E	26300	16 Jun 2014	17-Apr-17
3	38040	CFM56-7B26E	26300	05 Jun 2013	6-Apr-17
4	41253	CFM56-7B26E	26300	13 Sep 2014	14-Apr-17
5	41270	CFM56-7B26E	26300	09 Oct 2014	10-Jun-17
6	41310	CFM56-7B26E	26300	15 Nov 2013	16-Jul-17
7	41312	CFM56-7B26E	26300	11 Dec 2013	12-Aug-17
8	41322	CFM56-7B26E	26300	03 Sep 2014	4-Sep-17
9	41605	CFM56-7B26E	26300	27 Jan 2015	2-Oct-17
10	41796	CFM56-7B26E	26300	26 Jun 2014	1-Oct-17
…	…	…	…	…	…
…	…	…	…	…	…
99	39954	CFM56-7B26E	26300	18 Feb 2015	19-May-17

Figure 17 Scheduling Model

Figure 17 illustrates the scheduling model proposed in this research. This scheduling model used Microsoft Office Excel as the input for the customers' parameters. The customer's data requirement is obtained in the first table mentioned the detailed information about the aero engine. Then, the input is processed through the input module (orange). Finally, the process in the excel software is processed to obtain the maintenance forecast result (blue table).

General Model Flow

The most important module is in the process model which processes the input from the customer into maintenance forecast data prediction. The data prediction is match to the engine database source which are available from the OEM and other technical publications. More detailed about the source of the aero engine maintenance flight operational assessment are based on figure below.

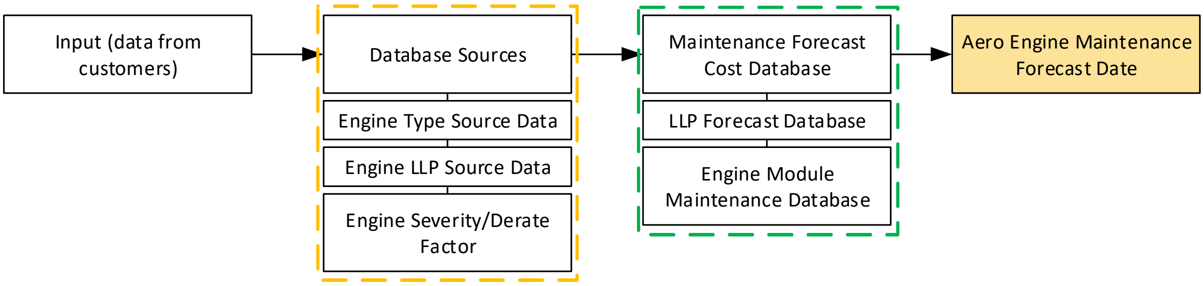


Figure 18 Model General Flow

Figure 18 shows the general model flow process proposed in this research. The input from the customer then will be calculated based on the databased sources. The database sources which include engine type sources data, engine LLP source data and engine severity factor data. Then the maintenance forecast cost database will be matched to produce aero engine maintenance forecast data.

Database Sources in this model consists of three different databases which relate to general work scope conducted for aero engine maintenance. The data relates to both engine deterioration rate data and the LLP removal forecast data. In this model, additional flight operational assessment also included in the engine severity/derate factor which correlates to the total of flight leg and environmental factor.

Then the flight operational assessment is used to predict the time and cost base forecasting. This forecast based on the LLP format database and engine module database.

Input Table

The data input of the maintenance model consists of the engine’s characteristics. The input module will be composed of the engine specification and the operational specification. The OEM has established the engine specification. Each engine type will have different thrust settings. The only option that can be adjusted is the take-off derate factor. The OEM usually adjusts the derate factor based on the operational requirements. Figure 12 illustrates the input module for the model’s calculation drivers.

Table 10 Maintenance Forecast Input Table

Engine Specification	
Type	CFM56-7B24
Thrust Setting	22,800 lbs
Derate Factor	0%
Operational Specification	
Operational Region	Hot/Harsh
Flight Leg	1
Flight Cycle (FC) Goal	10,000 FC
Annual FH	5000
Start Date	27-Apr-17
Term List (month)	120

Table 10 is representing the flight of the customer’s plan. With the database owned from the aircraft specification, aligned with the Table 9 the maintenance forecast can be obtained.

To measure the operational flight parameters based on the airlines’ flight schedule in the future, the input model needs data consisting of the environmental factors of the operational region: temperate, erosive, and hot/harsh. The temperate region illustrated for subtropical countries produce less pollution and experience lower temperatures. The hot/harsh region illustrates the situation in the desert area, such as the Middle East. Moreover, the erosive-corrosive area lies between those regions.

The flight leg input parameters illustrate the average flight duration for the aircraft in a day. This parameter usually relates to the commercial policy from the airlines. The short or long-term flight range policy will also affect the number of flight cycles (FC). The shorter flight range resulted in more FC for the aero engine. On the other hand, the longer flight range will reduce the FC. This Flight Cycle parameter is the most important parameter to measure the life span of the LLP parts.

The airline customer requirements depend on the required annual flight hours per year and the life cycle of each aircraft. The maintenance forecast event will be measured on the basis of the duration of the agreement between the airlines and the non-OEM MRO service provider.

References Data

The source module consists of several lots of data from both the literature and the current practices. The module of origin is the foundation of the tools. The module of origin contains several parameters that affect the shop visit maintenance, such as the engine module source data, engine LLP source data, and engine severity/labour cost/derate factors data.

Equation 2

$$Flight\ Cycle\ Cost\ per\ Flight\ Hour = \frac{Total\ LLP\ Replacement\ Cost}{Certificated\ Flight\ Cycle}$$

Source: (Ackert, 2010)

Engine Severity

This source module is used as the reference to relate the flight leg duration to the severity. The severity level of both the low thrust factor and the high thrust factor are different. The severity will be divided, based on the engine's age (first run and mature run). The estimation of the labour cost will be lower for the lower severity.

Derate Factors

The derate factors will also influence the engine's operational severity. The engine derate factors mean that the OEM lowers the EGT for each thrust setting. The OEM can provide the severity curve, which can be used to estimate the aero-engine deterioration based on the derate factor of the aero engine. The severity curve can be different based on the aero engine first run, the maturity run and also the average flight length per day.

Equation 3

$$Flight\ Hours\ Cost_{at\ FLight\ Leg\ N} = Severity\ Factor\ Value_{at\ Flight\ Leg\ N} * \ Performance\ Restoration\ Cost_{at\ Flight\ Leg\ N}$$

Source: Ackert (2010)

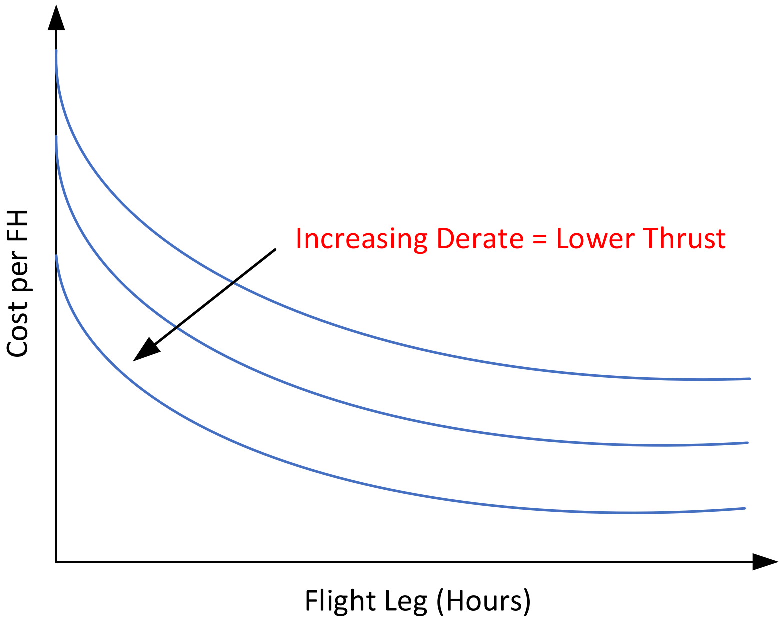


Figure 19 Effects of Engine Take-off Derate (Ackert, 2010)

Figure 19 Effects of Engine Take-off Derate (Ackert, 2010) represents the low thrust severity factors (Equation 3). This graph is taken to ensure that the graph has the same characteristics as mentioned by the manufacturers. The assumption has been made to adopt the real severity data, which is confidential (Figure 20).

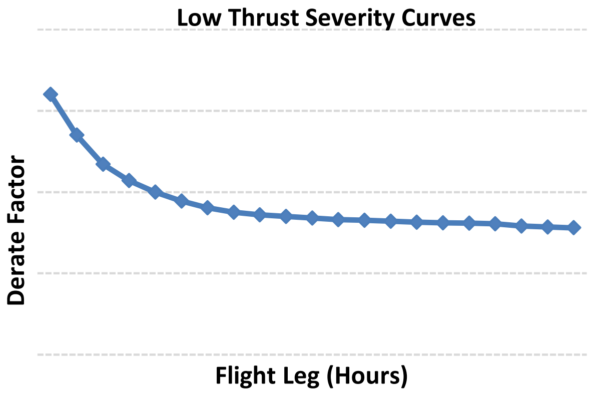


Figure 20 Low Thrust Severity Factors Curves

Region and Temperature

The module illustrates the region's operational factors at three different levels: temperate/ erosive/ and hot & harsh. To present the influences, the data, an assumption of the most difficult temperature of 30% will be more destructive, and the middle condition will affect the operation 20% higher than the temperate geographical location

Table 11 Aero-Engine's Thrust Level Setting vs Temperature (Aircraft Commerce, 2008)

Aero Engine's Thrust-Level Setting						
Standard EGT Margin = 30^{0}C						
OAT (^{0}C)	0	10	20	30	35	40
EGT Margin	125	95	60	30	15	0

Data Processes

The initial calculation module obtains the information from the input. The input data will be called the "source" as mentioned before. Several lookups formulated the situation from the input.

The initial calculation module comprises several parameters: derate factor, region factor, composite factor, rating check, rating, monthly flight hours, monthly flight cycle, ratio, and engine maturity. Those parameters have directly influenced the operational severity factors of the aero engine (Aircraft Commerce).

Equation 4

$$Monthly\ Flight\ Hours = \frac{Annual\ Flight\ Hours}{Months\ in\ a\ year}$$

Equation 5

$$Monthly\ Flight\ Cycle = \frac{Monthy\ Flight\ Hours}{Average\ Flight\ Leg\ per\ Month}$$

Equation 6

$$Flight\ Cycle\ Ratio = \frac{Monthly\ Flight\ Hours}{Monthly\ Flight\ Cycle}$$

Equation 7

$$Composite\ Factor = Derate\ Factor * Region\ Factor$$

The derate means that the engine is set to produce thrust below its capability. The derate factor influences the lifetime of the engine. The relation between the derate factors, flight duration and thrust setting was generated from data provided by Ackert (2010) and Hanumanthan (2009)

The region factor in the input module consists of three options. Each option will represent a certain value. The values presented are based on assumptions. The logical assumptions are because the more extreme the geographical situation is, the higher the chance of deterioration to an aero engine. The composite factor is the multiplication of the derate factor and the region factor. These parameters combine both the derate factor value and the region factor value to one value. This value then will be incorporated into the maintenance forecast schedule.

A rating check is applied to adjust the rating number based on the 'engine type' input data. Each engine's specification will have a different thrust setting, which is established by OEM. The certified engine thrust number is the maximum number of thrusts that the aero engine can produce in an ideal environment.

Monthly flight cycle and monthly flight hours produce a planning calculation arising from the operational planning deriving from the airline's requirements. Monthly flight hours are the total annual flight plan divided by the months in a year (12 months). The monthly flight cycle is the total flight hours divided by the flight length input. The total flight hours and the flight cycle combined can be measured as ratio parameters.

The engine maturity number indicates the shop visit interval. This presents the shop visit number for LLP replacement. The aforementioned parameters in the looked-based module are then combined with the maintenance forecast. The maintenance forecast uses the source data and the descriptive data from the article and magazine (Aircraft Commerce). The maintenance forecast module is presented in

Engine Variant	Engine Thrust	Base FL	First-Run			Second-Run		
			FC	Rest $	$ / FH	FC	Rest $	$ / FH

CFM56-7B26E*	25900	2.00	16,000	2,471,000	140.00	9,000	2,630,000	156.00
CFM56-7B26/3	25900	2.00	14000	2,471,000	155.00	9,000	2,930,000	179.00
CFM56-7B24	22800	2.00	18,000	3,320,000	136.00	12,000	1,781,000	141.00

.

The maintenance forecast is used to predict the total maintenance cost. The maintenance forecast parameters contain the aero engine’s age (first run or mature run), and the flight length. The severity factors used the data from the aircraft monitor (Ackert, 2010) and Aircraft Commerce. From the severity value, the maintenance cost is found from multiplying the maintenance cost reference (flight leg 2) with the severity curve level.

Table 12 Maintenance Forecast Indicative Predictive Cost (Aircraft Commerce, 2008)

Engine Variant	Engine Thrust	Base FL	First-Run			Second-Run		
			FC	Rest $	$ / FH	FC	Rest $	$ / FH
CFM56-7B26E*	25900	2.00	16,000	2,471,000	140.00	9,000	2,630,000	156.00
CFM56-7B26/3	25900	2.00	14000	2,471,000	155.00	9,000	2,930,000	179.00
CFM56-7B24	22800	2.00	18,000	3,320,000	136.00	12,000	1,781,000	141.00

The red coloured typed data are the reference data obtained from the Aircraft Commerce. The data represent the prediction of the total maintenance cost for time and material consumed. The reference data refer to the flight leg 1-5 and to set the flight leg;

Equation 8

$$Flight\ Cycle\ per\ day\ = \frac{Total\ Flight\ Hours\ per\ day}{Average\ Flight\ Leg\ per\ day}$$

Equation 9

$$FH = \frac{Performance\ Restoration\ Cost\ \$}{\$/FH}$$

LLP Removal Forecast Module

The next process is the LLP removal forecast. The LLP removal work scope will be based on the total cycle time provided from the input data. The output of this module combines the initial calculation module with the input data and the Maintenance Forecast Module.

The cycle limit mentioned, represents each LLP's cycle limit (Workscope Guide and Engine Workscope Planning Guide). The LLP Removal Formula adjusts the value on the basis of the maintenance forecast module and the module input (flight leg input). The module represents the age of the engine, the calculation is divided into two categories, first-run and mature-run. The newly serviced engine (refurbished or overhauled) will have a longer time on the wing until the first shop visit.

Equation 10

$$Life\ Limited\ Parts\ Cost\ (LLP\$) = \sum \frac{Total\ Life\ Limited\ Parts\ Indicative\ Cost}{Lifecycle\ Limit\ for\ each\ Life\ Limited\ Parts}$$

Equation 11

$$First\ Shop\ Visit = LLP\ Lifecycle\ Limit - Flight\ Cycle\ Fallout\ Interval$$

Equation 12

$$Stub\ Cost = LLP\ Lifecycle\ Limit - Flight\ Hours\ Fallout\ Interval$$

Equation 13

$$Shop\ Visit_N = LLP\ Lifecycle\ limit_{N-1} - Flight\ Cycle\ Fallout\ Interval$$

The cost parameters and the formula will define the shop visit's value more easily. The most important parameter is the flight cycle availability after each shop visit. This module can predict the total LLP's FC availability. The LLP$ represent the LLP cost of each shop visit. The stub $ represents the LLP's FC availability that is sacrificed to fulfil the policy management to optimise the shop visit (off-wing time).

Table 13 **LLP Removal Indicative Cost Forecast (source: Aircraft Commerce, 2009)**

ENGINE LLP SOURCE DATA			
CFM56-7B24 LIMITS & COST			
Part	EFC Limit	Cost	$/FC
Fan Disk	17,900	200,000	11.20
Booster spool	23,600	200,000	8.50
Fan Shaft	30,000	200,000	6.70
Forward Shaft	20,000	100,000	5.00
Stage 1-2 Spool	20,000	100,000	5.00
Stage 3 Disk	20,000	100,000	5.00
Stage 4-9 Pool	20,000	100,000	5.00
CDP Seal	20,000	100,000	5.00
Front Shaft	20,000	200,000	10.00
Front Air Seal	20,000	200,000	10.00
Disk	20,000	200,000	10.00
Rear Shaft	20,000	200,000	10.00
Stage 1 Dsk	25,000	100,000	4.00
Stage 2 Disk	25,000	100,000	4.00
Stage 3 Disk	25,000	100,000	4.00
Stage 4 Disk	25,000	100,000	4.00
Shaft	25,000	100,000	4.00
Conical Support	25,000	100,000	4.00

Output Module in Excel Prediction Model

Once the modules are defined and built, the output from the modules can be obtained. The output of this model will represent the time prediction for each engine to complete a shop visit. Furthermore, the model can predict the exact time (Month and Year) and the work scope required for each shop visit. The output’s module illustrated in Table 14 is the result of the table output from the aero-engine maintenance schedule.

Table 14 Output Module

Forecast MAINTENANCE EVENT		EVENT MONTH	EVENT DATE
1	Engine Shop Visit (2 Each)	26	Jun-19
2	Engine Shop Visit (2 Each)	46	Feb-21
3	Engine Shop Visit (2 Each)	66	Oct-22
4	Engine Shop Visit (2 Each)	86	Jun-24
5	Engine Shop Visit (2 Each)	106	Feb-26

The output will be used as input for the shop floor simulation model. The shop floor simulation model will be described in the next section. The aero engine input maintenance can be obtained by assessing the parameters that are represented using the module mentioned before:

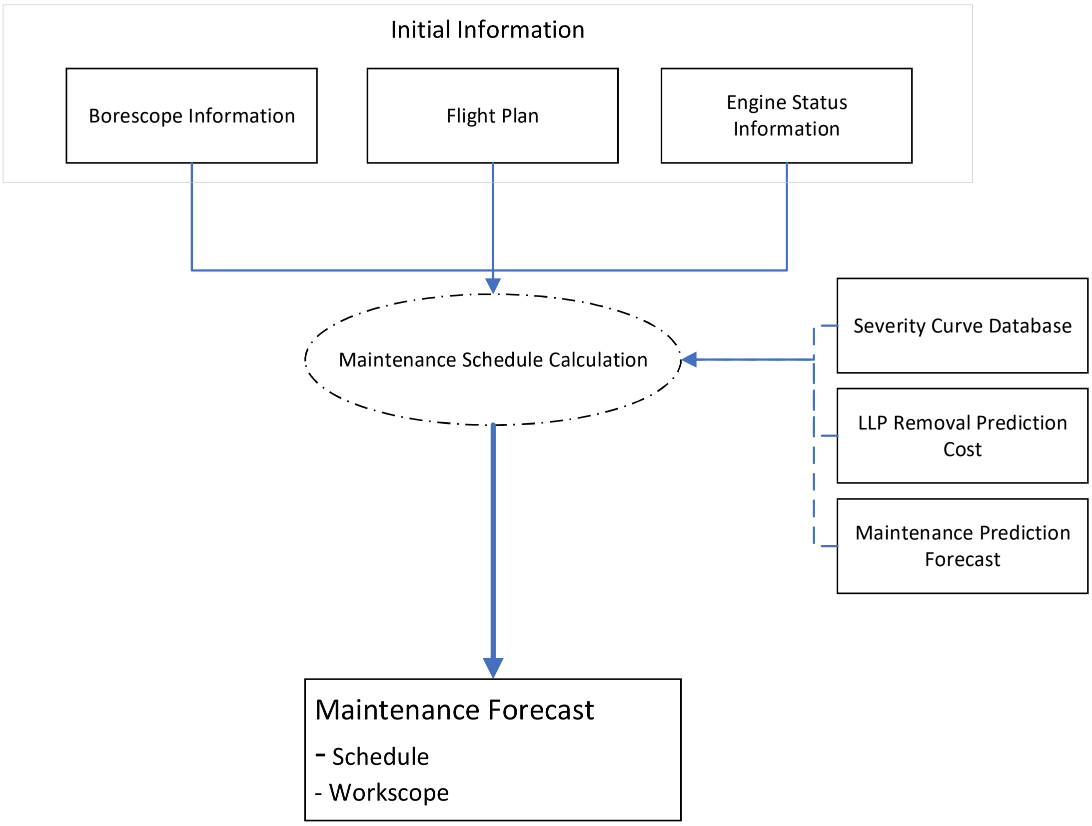


Figure 21 Maintenance Forecast Prediction Process

Figure 21 represents the maintenance forecast steps for the aero engine scheduled maintenance. The status information mentioned represents all the parameters in Table 9. The maintenance calculation can be calculated by using the provided severity estimation from the specifications and characteristics of each aero engine.

5.2 Review of Relevant non-OEM MRO Shop Floor Processes

The shop floor model illustrates the operational availability. The simulation has been chosen to represent the real industry situation in the case company. The model has material, labour, method, and machine. Each machine depicts the processes that the shop floor has performed. Each process requires a certain amount of materials, workforce, method and the machine.

The engine system, in general, will comprise several modules and levels of maintenance work scope (Figure 22). Each module will have its own work scope. The study used Witness simulation software to represent the maintenance line in the aero engine shop floor. Within Witness, a machine then illustrates each process of the work scope in the simulation software.

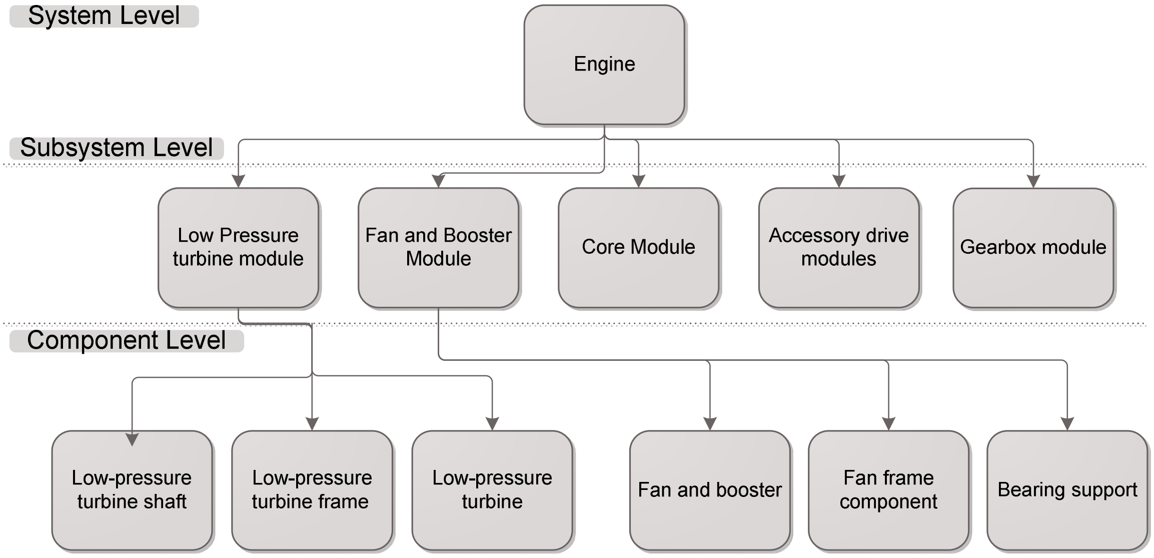


Figure 22 Aero Engine Hierarchical Level

One of the main things on the shop floor of the non-OEM aero engine MRO service provider (non-OEM MRO) is the resource availability. Therefore, the most significant are the resources to conduct the maintenance operations, which consist of workforce/labour availability, spare parts availability, the machine or tools availability and the skills or capability to conduct the maintenance on the shop floor.

The maintenance process of the aero engine requires three different aspects based on the work scope. The maintenance processes need a mechanic or labour to conduct the maintenance. Both skilled workers and unskilled labour are required for the maintenance work scope. The non-OEM MRO service provider needs to provide both the capability and the capacity.

The ability means that the non-OEM MRO service provider has the authorisation to conduct the maintenance. The authorisation is given by the airworthiness aviation authority, e.g. EASA and FAA. The authorisation can also be given by the local government in the location in which the aeroplane will be operate.

On the other hand, the capacity includes all necessary aspects of conducting the maintenance. The capability and the capacity are related, and both are dependable. The capacity is not only concerned with the slot in the shop or hangar, but also all necessary resources needed in conducting maintenance. There are mechanics, skills, tools, equipment, materials and spare parts. The mechanics also need the appropriate tools and equipment to carry out the maintenance work scope. Once the maintenance labour and tools are fulfilled, the components as the replacement to the aero-engine maintenance's work scope are necessary. The time and the correct components are required to be met by the non-OEM MRO service provider to guarantee the TAT to the customers.

This subchapter will represent the non-OEM MRO models in the shop floor operations process. The combination of the primary data and the second source data from the literature are utilised to make the models.

5.3 non-OEM MRO Maintenance Processes

This research assesses the general non-OEM MRO maintenance process from the literature. (Hanreich, 2008) Discussing the maintenance shop process operation with reference to the shop structure, they mentioned the shop would conduct engine tear down, major module tear down, cleaning, inspection, repair/service, major module rebuild, engine rebuild and the engine test. Ramudhin et al. (2008) discussed the non-OEM MRO maintenance process, from receiving the aero engine in the repair shop to returning to the customer. Further details of their non-OEM MRO maintenance process is illustrated in Figure 23.

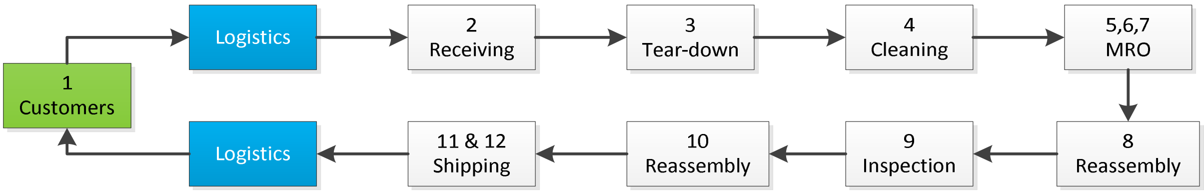


Figure 23 MRO Processes (Ramudhin et al., 2008)

Ayeni (2015) mentioned the general MRO process, which is typically used by the MRO. His general model of MRO is in Figure 24.

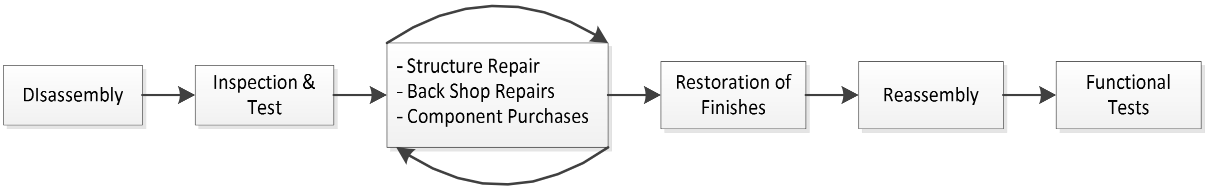


Figure 24 Typical MRO Processes

The engine overhaul production network is also stated by Kurz (2016) cited Reményi and Staudacher (2014), which is represented in Figure 25. They discussed the aero engine maintenance process in greater detail and involved customers in their model process.

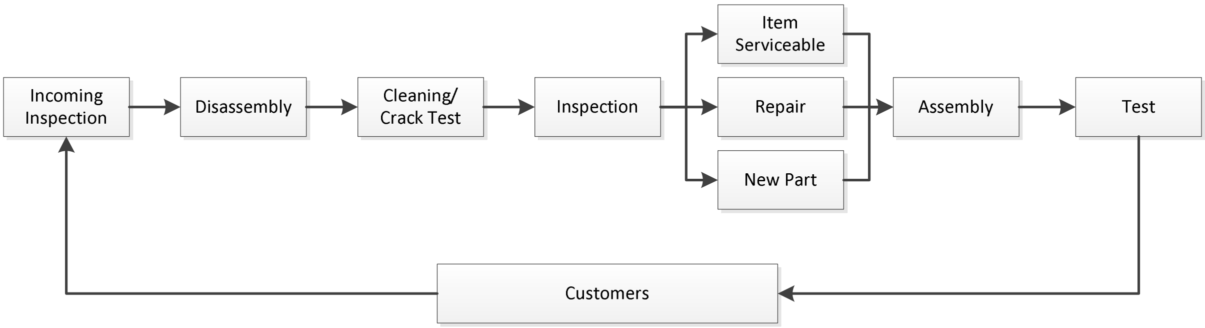


Figure 25 Internal MRO Process (Reményi and Staudacher, 2014)

In further detail, the MRO shop floor process will consist of three different stages. Stage 0 is the preparation stage before the aero engine is serviced. The stage 0 includes the preparation, aero engine arrival and the receiving process of the aero engine before it enters the shop floor.

Then in stage 1, the MRO will conduct tear down or disassembly, followed by the cleaning process and inspection, together with Non-Destructive Test (NDT). Once the aero engine spare parts have been inspected and tested, the MRO service provider can decide whether they need to ship the aero engine to the outsource or go directly to the reassembly process.

Stage 2 is when the principal components are being repaired or serviced. Once the work scope is decided, the component can be sent to the external repairs or serviced in the private facilities. Then the MRO will inspect before forwarding to the marshalling process.

Stage 3 is the reassembly processes. It conducts the aero engine reassembly process, then the final test for the aero engine maintenance for the aero engine release and re-delivery back to the customers.

In the industry, the maintenance process is represented by using gates. Each gate represents the maintenance process sequence and is utilised by the MRO to monitor the aero-engine maintenance-processes' milestones. Each gate will represent the maintenance milestones to be reported to the customers in the project. The gate systems in the industry are mentioned below:

- Gate 0: Engine induction (lead time start)
- Gate 1: disassembly completed
- Gate 2: decision for fast track component shipped for overhaul
- Gate 3: inspection completed
- Gate 4: Components or spare parts procurement
- Gate 5: components or components are ready, gathered and provided for next process (marshalling)
- Gate 6: Sub assembly for the major module
- Gate 7: Final Assembly Initiation
- Gate 8: Engine Test Cell initiation
- Gate 9: Serviceable Engine delivered
- Gate 10: Exit meeting and invoice completion

The relation between each gate and the operational process from the case company data is contained. Each gate will represent several main stages in the aero engine. The gates consist of the lower level maintenance process. The performance measurement of the gate completion is used to monitor the aero engine maintenance processes as a performance indicator. Most of the gates' completion relates to the duration or TAT as the main parameter for performance measurement.

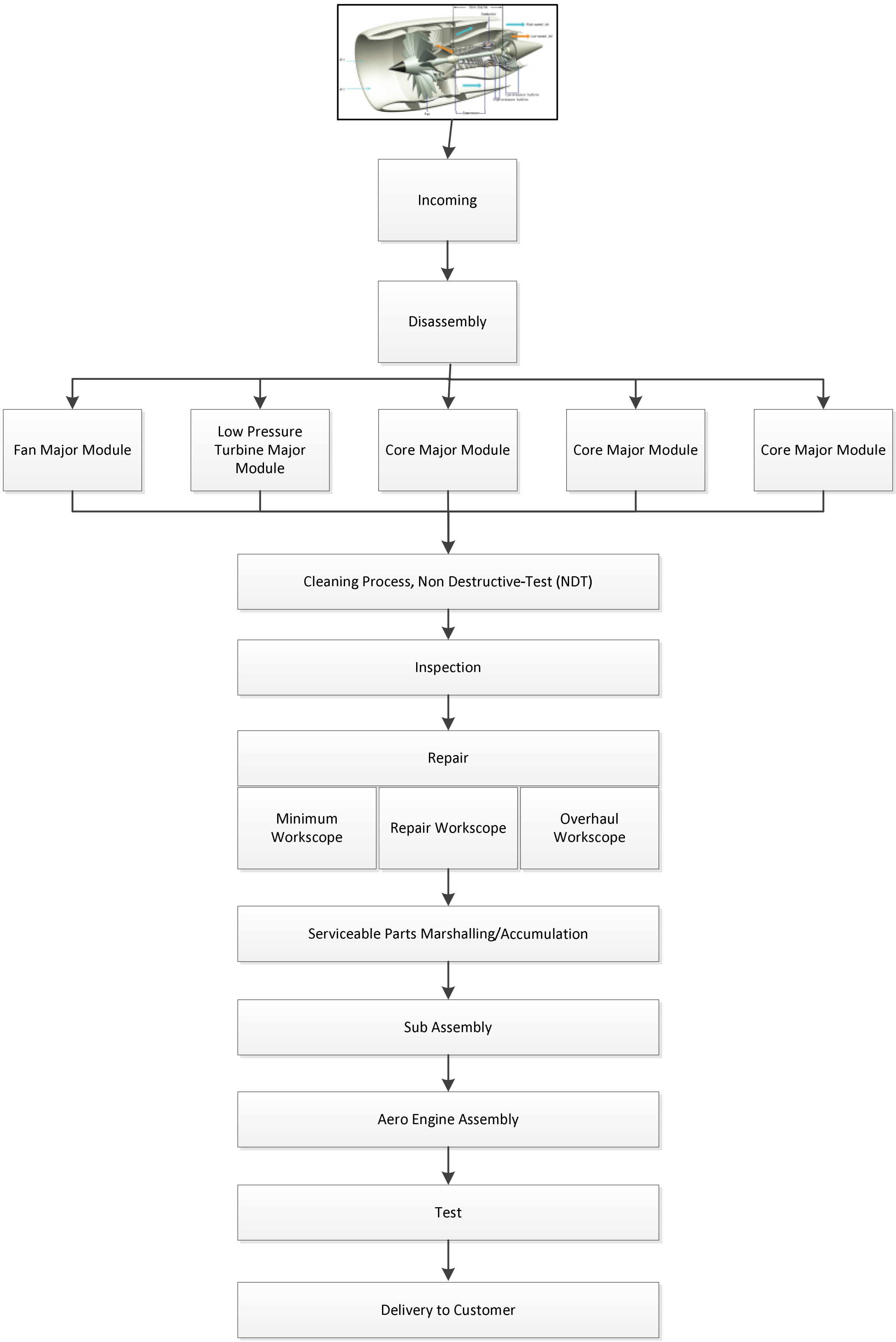


Figure 26 Aero Engine Modules Maintenance Processes

This research will enhance the details of the maintenance operations processes. Figure 26 represents the aero engine maintenance processes, including the aero engine major module maintenance processes.

5.3.1 Witness Model

The model adopted the MRO maintenance value process mentioned by CHANG and Abdullah (2014); Kurz (2016); Peregrin (2011); Raja Mohan (2009); Ramudhin et al. (2008); and Reményi and Staudacher (2014). This model represents the maintenance process of a generic aero engine MRO service provider’s process, which consists of receiving, disassembly, cleaning, Non-Destructive Test (NDT), inspection, repair, marshalling, assembly, test and delivery.

The discrete event simulation was chosen in this research. The maintenance shop floor processes will use the given procedure from the OEM’s work scope planning guide. The situation on the shop floor matches the DES’ key features and aim. The DES could represent the maintenance’s processes. The procedure of the maintenance operations is fulfilled by the advantages using the discrete event. Each procedure and the processes of the aero engine on the shop floor are represented in a machine symbol.

Lanner’s Witness software program has been considered as the simulation software which the researcher use as the researcher has more knowledge in Witness. Cranfield University has full version license of Witness. This situation has given Witness more value than any other DES based simulation software.

One of the best Discrete Event Simulation software is Witness of Lanner. It is a commercial platform that has the ability to model business applications both in manufacture and service provision. The functionalities in Witness can represent the shop floor operations’ functionalities adequately. This subchapter will highlight the functions that relate to the maintenance processes:

Witness has allowed the user to utilise the attributes to the model. The model’s attributes in Witness Software (2012): Attributes, Variables and Distributions. The attributes are used to identify the aero engine ID or Engine Serial Number (ESN) for each aero engine and also the spare parts are derived from the aero engine. The variables will also enable the user to analyse and assess the performance of each maintenance operation by counting the complete processes in an aero engine machine process. Moreover, the distributions can represent the situation of uncertainty for each maintenance process cycle times.

Elements stand for the entities provided by Witness software. There are several entities that can be used for this research:

1. Machine: this machine represents e for each maintenance sequence in this investigation. Its user-friendly GUI provides the user with a computer's logic to make, push and pull the parts from and to other machines. In detail, the machine can be incorporated with breakdown time, labour allocation, cycle- time and distribution profile to each of the logics. In the maintenance process, a user has to define the cycle time, allocated time, and the shift process, which becomes the input of the model in this research.
2. Labour
   In this research, labour represents the mechanics that have to be allocated to each maintenance process. There is a need to forecast the labour availability and the skills, which can affect the maintenance delivery time. The labour in this model is rule based on the work shifts and the labour guidelines stated in the engine maintenance manual. The mechanics have to be supported by available tools to conduct the maintenance processes.
3. Tools
   Tools are a resource to be used in each maintenance process. Tool availability, tool breakdowns and tool repair time are needed to represent the processes.
4. Parts
   Parts in this research represent the aero engine and the components that support the aero engine itself. The aero engine is the object of the maintenance. The disassembly process is represented as a ‘production type machine in the witness. A part (aero engine component) can be produced into several different parts as the output. These components also represented by parts element in the Witness software.

The developed final model generates from both the literature review information and site visit. The model is developed from the information provided by the maintenance documents, observations of a non-OEM aero engine MRO service provider company and the literature. Then the research utilised the data from the company to conduct computer simulation for the validation. The Model represents the shop-floor processing of the whole aero engine (QEC). It will then be disassembled into five different major modules: Fan Major Module, Low-Pressure Turbine (LPT), Core Major Module, Accessories and Gearbox Major Module. The models are derived from Figure 14 in the previous chapter. The maintenance forecast model represents the aero engine maintenance schedule of the airline's flight operation and the aero engine status, data maintenance information data. On the other hand, the aero engine shop floor is also represented in the Witness model software. A computer based model simulation is a shop floor model, built on data supplied by the maintenance manual provided by the OEM.

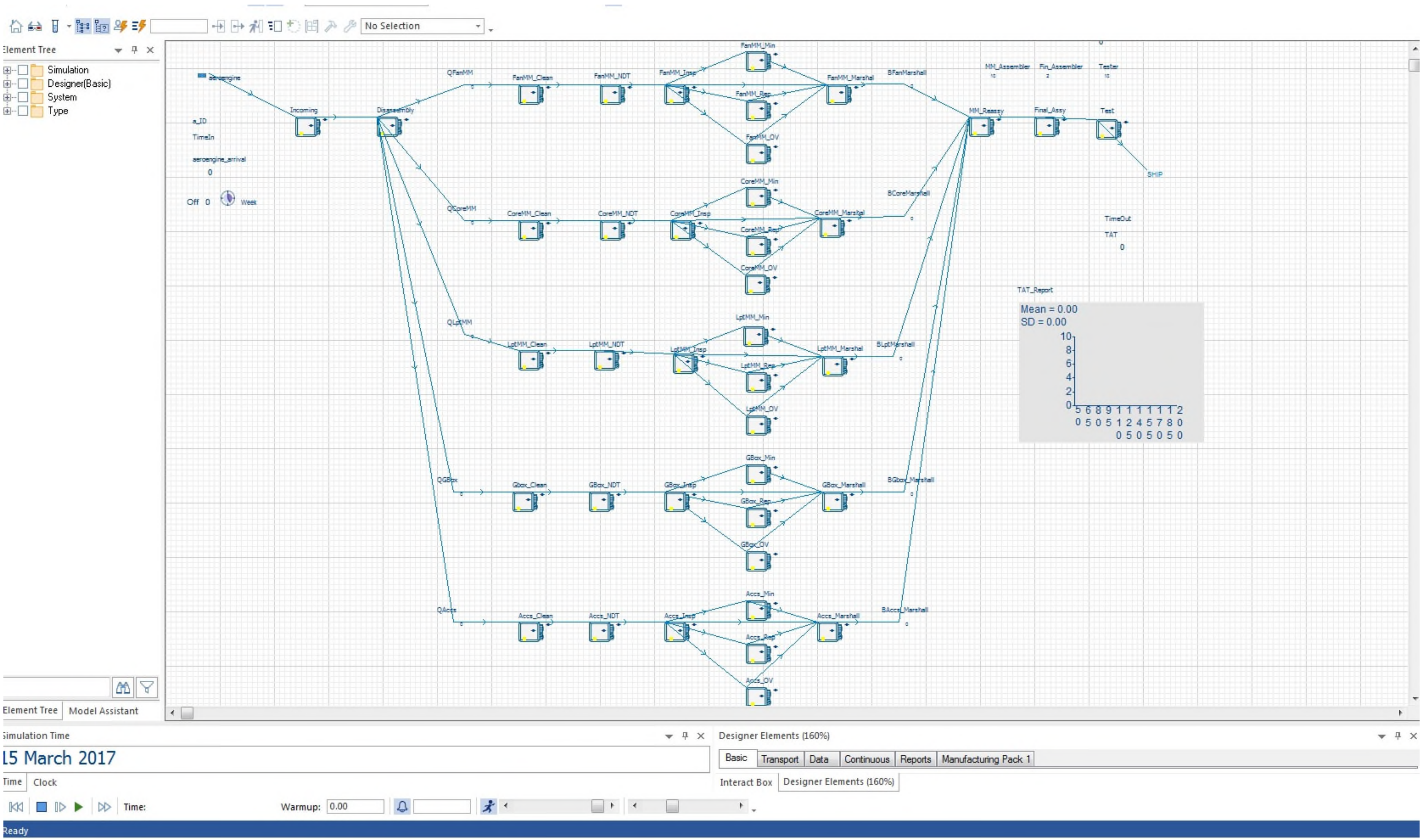


Figure 27 Example of Model in Witness Software

5.3.2 Model's Assumptions

Several assumptions incorporated into the model

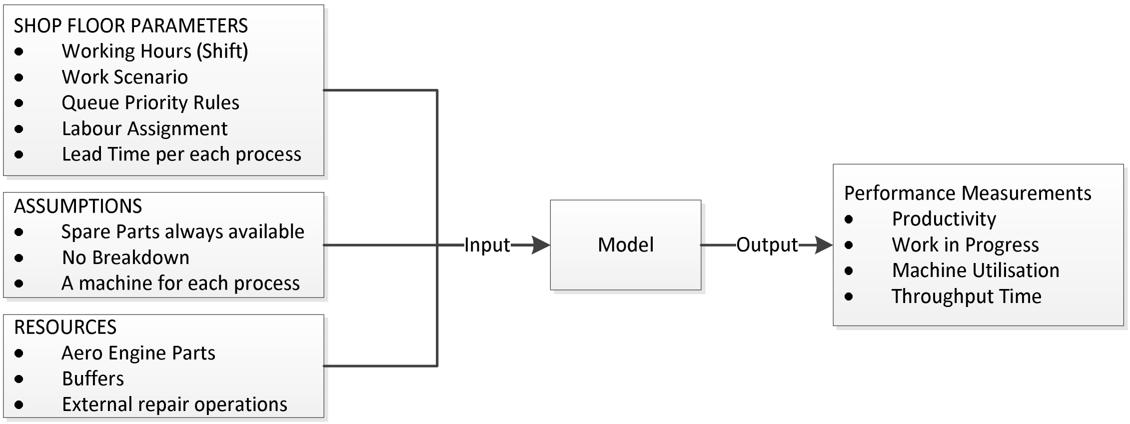


Figure 28 Model Structure Developed

The input shop floor parameters consist of the shift hours' policy, the workflow scenario, queue priority rules, labour assignment and lead time per each process. Shifts per week for the non-OEM aero engine MRO service provider's shop floor: Monday to Friday, with half day shift on Saturday. The work scenarios present the rules for positioning the parts in each process. The sequences for each maintenance operation of the parts will be based on the stochastic approach. In the maintenance process, each process has to involve a mechanic or an engineer. Therefore, in this research, each maintenance process is added to the requirements.

The model will not be able to adopt the real process; therefore, this research made several assumptions but did not ignore the characteristics of the actual situation of the model adoption. In this model, the spare parts and parts such as the aero engine will always be available. However, the time and the process to obtain the components are incorporated. A machine represents each maintenance process in the Witness simulation software.

The elements to support the model, such as the aero engine as a part, the buffer before maintenance process and the external repair operations are also included in this model. Each parameter is illustrated in the model.

Once the model has been developed, the performance measurement is obtained. These performance measurements are based on (Law and McComas, 1987) the shop floor:

1. Throughput time (turnaround time/TAT or lead time)
2. Productivity in the maintenance model is represented by the rate of the output for each input (Atayero et al., 2013)
3. Work in progress
4. Maintenance resource utilisation.

5.3.3 Model's Validation

Balci (1995) has discussed the validation, verification and testing techniques for the simulation. His taxonomy is represented by Figure 29.

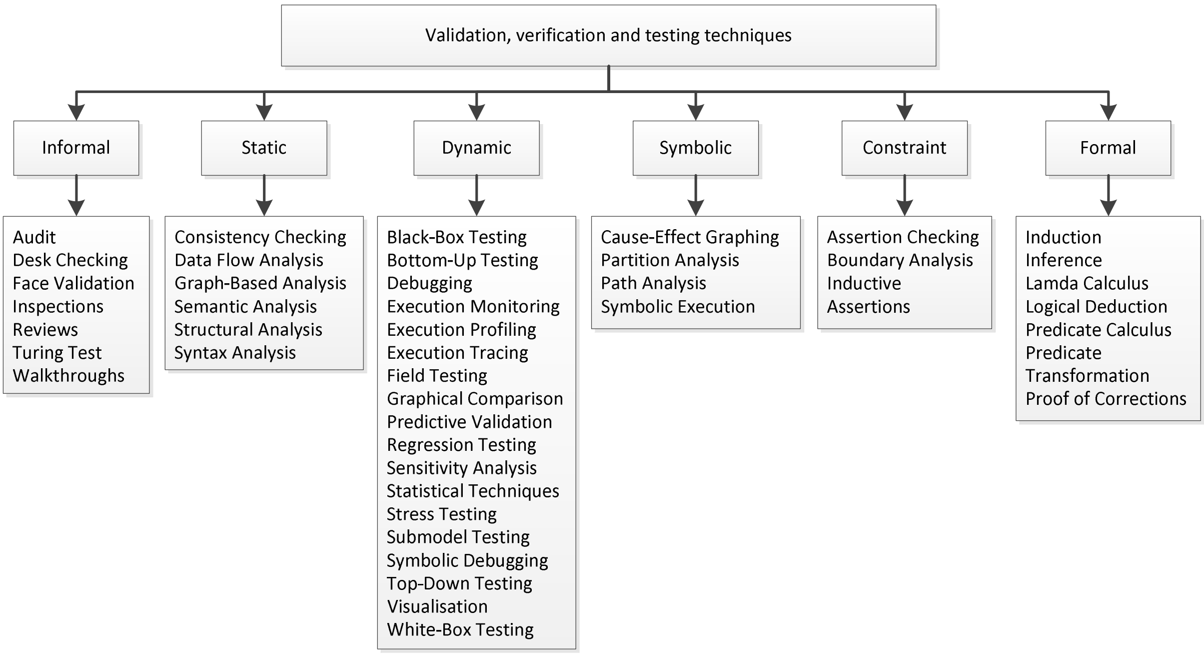


Figure 29 Taxonomy of Validation, Verification and Testing Techniques (Balci, 1995)

Even though the model diagram and network are combined from both the literature and the company's document, the research must ensure that the model used has similar functions and characteristics. It is important to prove that the model is correct to increase the confidence in the model and its results (Robinson, 2004).

To ensure the model is adequate for conducting the case study, this model needs to be validated. The validation processes can be conducted using several methods.

Robinson (2004) mentioned the validation types of the model contain four categories Conceptual Model validation, data validation, white-box validation, black-box validation, experimentation, and solution validation. However, it is impossible to prove that the model is correct. However, the model verification and validation are concerned with creating sufficient confidence in a model for the results to be accepted (Robinson, 2004):

5.3.4 Black Box Validation

Although the conceptual model is simplified, the content and the assumptions of the proposed model must be accurate. This research will adopt the black box validation as it is the best method in this situation. The black box validation will compare the maintenance process outputs in the case company and the output of the designed model. Black box validation has advantages in macro level scope to fulfil the research purpose at hand. One of the main parameters which needs to be validated is the maintenance cycle time for each maintenance. The different input is based on the interviews. The maintenance cycle time used the triangular distribution. Validation and experimentation sequence for the current model has been done by comparing the output of the model, which is equal to or less than 10%. The sequence of the validation was conducted by using the iteration process to ensure the output value is not more than 10% deviation, represented by Figure 30.

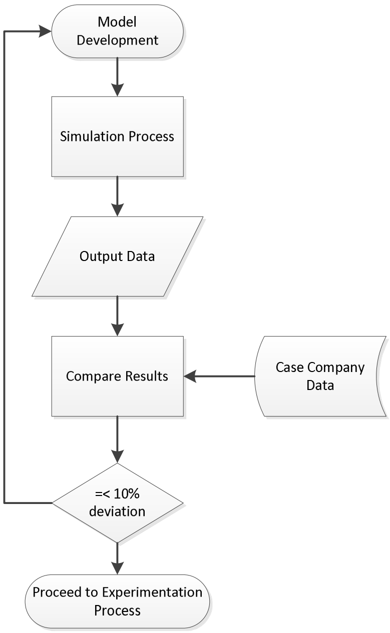


Figure 30 Black Box Validation Process

The most important parameters in the maintenance provisioning performance are the turnaround time (TAT) or throughput time. Throughput time is calculated as the amount of time required for a product to pass through a manufacturing process; thereby it develops from raw materials into a component or sub-assembly. The throughput time is derived from four steps of the production process: process time, inspection time, transfer time and wait time. Process time is the amount of time it takes the company to produce the product. Also, the terms of the throughput time are the manufacturing lead time which represent the period between the placement of an order and the shipment of the completed order to the customer. A short manufacturing lead time is a competitive advantage; many customers want the delivery of their products as soon as possible following the placement of the order.

The standard deviation of the actual TAT for each engine from the case company compared to the TAT produced by the model should not be more than 10%. To compare the case company’s non-OEM aero engine MRO shop floor operation, the validation process utilised the data from the enterprise. The arrival of the aero engine is 41 in a year. The arrival of the aero engine combines with a fixed labour group working six days per week. Each day consists of two shifts and day six will be composed of only one shift.

To ensure the model output is verified and validated, further analysis has been conducted. The analysis utilises different pseudo random numbers (PRN) in the Witness model simulation. The output data represent that this model and the TAT output from this model can be verified and validated. The data output of the TAT from the witness model is described in Table 15. The TAT between the scenarios is stochastic. Therefore, the idea of the analysis from the model is to use at least five different pseudo random numbers.

Table 15 Engine Arrival Time Profile

Engine Number	Induction Date	Duration in Days	Duration in Hours	Cumulative time at (hours)	Cumulative time at (Minutes)
0	01/01/2016	0	0	0	0
1	12/01/2016	11	264	264	15840
2	20/01/2016	8	192	456	27360
3	27/01/2016	7	168	624	37440
4	15/02/2016	19	456	1080	64800
5	28/03/2016	42	1008	2088	125280
6	01/04/2016	4	96	2184	131040
….	….	….	….	….	….
40	26/12/2016	3	72	8640	518400

To enhance the validity of the model, the model utilised five different PRNs to assess the variety of TAT. Based on Table 16, it can be seen that the deviation is maximum 0.85 from model's TAT. The total TAT from each maintenance model is also presented by Table 16.

Table 16 TAT Results for each PRN for Scenario 3 (Validation)

No	PRNs	TAT
1	PRN 1	84.72
2	PRN 7	84.39
3	PRN 77	84.32
4	PRN 88	83.97
5	PRN 14	85.2

The validation process of the model in the actual industry configuration used scenario 3. The service provisioning configuration between non-OEM MRO-A and Airlines G as the case study represents the characteristics of the non-OEM MRO with the ability to outsource the spare parts and collaborate with the external repair vendor.

The validation case set for the duration of the time and maintenance contract is for 365 days. Moreover, the percentage between the model throughput and the actual TAT.

Equation 14

$$Deviation = \frac{|Actual - Model|}{Actual} x100\%$$

$$\boldsymbol{Deviation = \frac{|85.36 - 79.73|}{79.73} x100\% = 7.06\%}$$

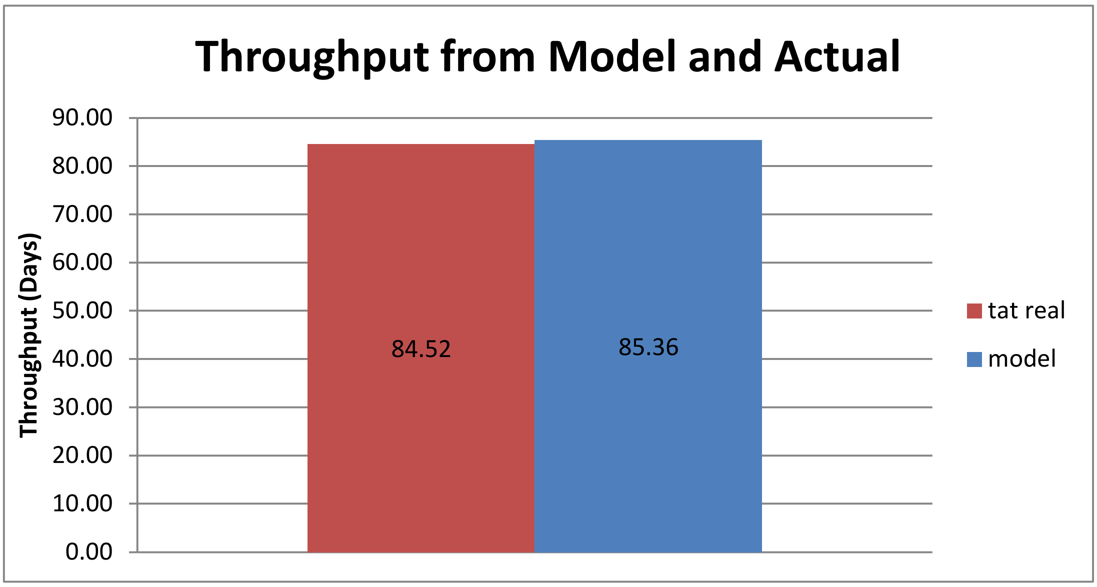


Figure 31 Throughput from Model vs Actual

5.4 Chapter Summary

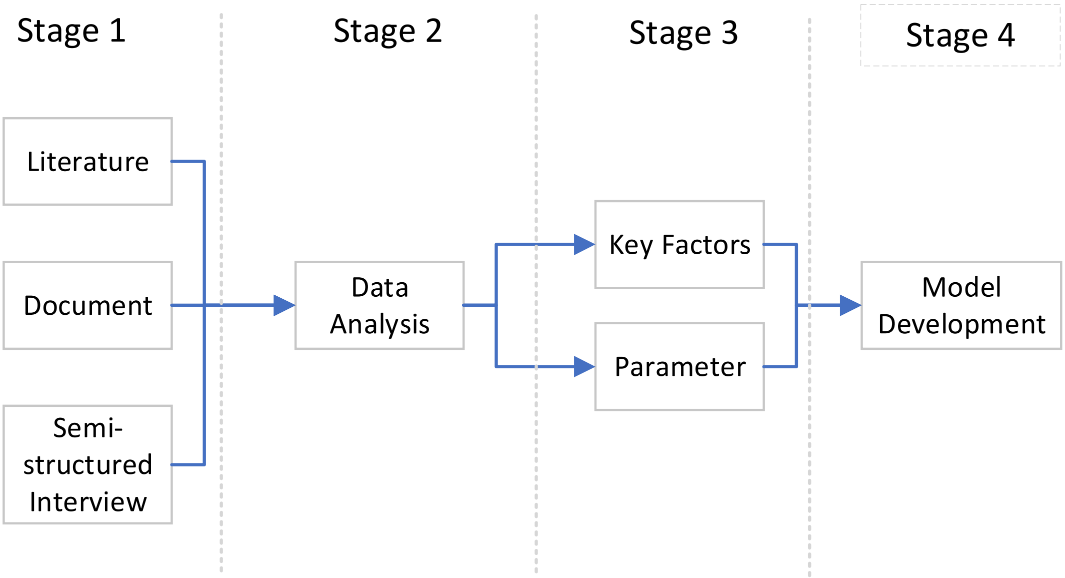


Figure 32 Model Development

This chapter can be summarised through the Figure 32 Model DevelopmentThe model is developed through data collection obtained from the literature and industrial visit (semi-structured interviews and document analysis). The information obtained then analysed to become the list of key factors and parameters which are important to the contracting decisioln. These key factors and parameters then linked to become foundation for the proposed method. The proposed method is visualised into a model to represent the actual situation which can also carry out the dynamic value of the parameters.

This chapter presented the model development of the non-OEM aero engine MRO shop floor. The shop floor represents the general maintenance shop floor based on the literature and verified from the document from the case company. The model development is expanded into more detailed processes by adding the major module aero engine processes. The computer model has considered the complexity of the aero engine maintenance process on the shop floor. This research utilises the discrete event simulation, which uses Witness from Lanner. The validation process includes the main performance parameters comparison between the data from the case company and the model output.

6 Non-OEM MRO Service Provision Configurations

This chapter illustrates how the non-OEM aero engine MRO service provider combines its offering by combining a variety of services. As mentioned previously, MRO service providers consist of different units that are responsible for various types of spare parts. Therefore, the MRO service provider can offer a different solution based on the service on offer. This chapter consists of: Section 6.1 introduces this section. Section 6.2 The component’s model, which represents the working units department in the non-OEM MRO service provider utilised in the model. Section 6.3 accounts for the type of simulation process and the results. Section 6.4 illustrates the simulation strategy conducted for the model. Section 6.5 accounts for the experimental procedures involved in this simulation that represent how the model works for each scenario. Moreover, section 6.6 summarises the chapter.

6.1 Introduction

The non-OEM MRO service provider can offer different types of offers depending on the customers’ requirements. The non-OEM MRO service provider does not only need to be able to provide a conventional maintenance service, but it also needs to guarantee to support the airlines’ technical requirements during the asset’s operation. This situation has been represented from a position where the low-cost airlines require the non-OEM MRO service provider to fulfil their needs regarding all technical support aspects for the commercial flight. The LCCs tend to outsource the technical needs rather than invest more capacity and capability in maintenance facilities. Currently, they tend to outsource all these parameters to a third party (Al-kaabi, Potter and Naim, 2007). They illustrate all the aspects from an airline that can be provided by an MRO Service Provider. Baines et al. (2007) proposed a combination of product and service, PSS, as a solution to the customers through two different methods: product based and service based solutions. The product based service will become the PSS through the servitisation of production method. On the other hand, the service based PSS will need additional services or product to become a PSS solution. This chapter will present how the non-OEM MRO service provider can combine its offering configuration with additional services or products to the customers, and how the combination can benefit both the non-OEM MRO service provider and the customer.

6.2 Model’s Components Definition

The previous chapter mentioned that the non-OEM MRO service provider has to rely on the resources on the shop floor. This chapter will relate to how the service can be produced from the non-OEM MRO’s particular service business unit with other department which can offer additional services.

The non-OEM MRO maintenance operations model is formed from a number of processes. Each process requires machine, labour, skill and the spare parts (material). This research acknowledges the aero engine Workscope Planning Guide (WPG) from the aero engine’s manufacturer. Working from these assumptions, this research assumes the non-OEM MRO service provider has all the available resources, such as spare parts and mechanics. The maintenance processes flow is a combination from the manual of the primary data and the secondary data (Reményi and Staudacher, 2014; Visintin, Porcelli and Ghini, 2014). This research provides further details of the maintenance process by utilising the sub-major module parts.

Figure 33 illustrates the aero engine shop floor. The aero engine maintenance processes consist of several maintenance sequences. Each maintenance process is different as it depends on the aero engine maintenance work scopes. This work scope will determine the total maintenance processes, the required resources and the total TAT required.

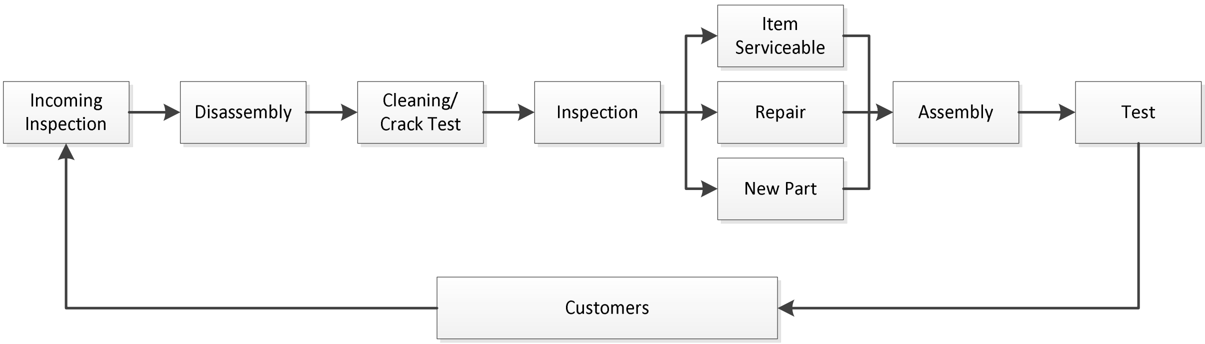


Figure 33 MRO Maintenance Process (Hessburg, 2000)

In offering the solutions, the aero-engine’s Service Business Unit (SBU) can add more services to the customers. These additional services are then combined as a bundle to become a complete maintenance repair and overhaul service provider organisation. A non-OEM MRO service provider can have more than one business service unit. These business service units are main hangars, material or spare parts provisioning units, delivery services and leasing services. The processes are configured to incorporate additional processes to the shop process. The shop processes are based on the Enterprise Resource Planning (ERP) and Repair Station Manual (RSM), which is commonly used by the MRO service provider generally (Hessburg, 2000; Kinnison, 2004).

6.2.1 Main Hangar

The main hangar in this model is represented as a base station. This base station is responsible for dismantling the aero engine from the aircraft. In this situation, the aero engine will arrive as Quick Engine Change Configuration (whole aero engine). Besides an ad-hoc agreement, the main hangar can also generate the aero engine maintenance demand. The arrival of the aero engine can be either planned or unplanned. Most of the requirements are established on the ad-hoc contract agreement. In this model, the maintenance requirement for the unscheduled aero engine maintenance is requested from the main hangar.

6.2.2 Maintenance Engineering Services

The maintenance engineering services are responsible for assessing the maintenance work scope for the incoming aero engine. This engineering service will ensure the technical manual is implementable to the assets. They must synchronise the maintenance operation with the regulations. The maintenance engineering services are also responsible for assessing the preliminary inspection report and the historical maintenance document from each asset.

The maintenance technical services consist of reliability engineering and maintenance engineering services. The reliability engineering administers the reliability programme of the asset. Their reports led to the adjustment of the maintenance programme. Then, the maintenance engineering also responsible for assessing and generating the job cards for the shop floor unit as well as the applicability of the maintenance’s work scope on the shop floor. In this research, the engineering services’ processes are integrated into the model. Based on the assumptions, engineering fully utilises the maintenance shop floor process and is always available as this does not distract the general maintenance operation flow processes. Figure 34 represents the engineering service role on the maintenance shop floor.

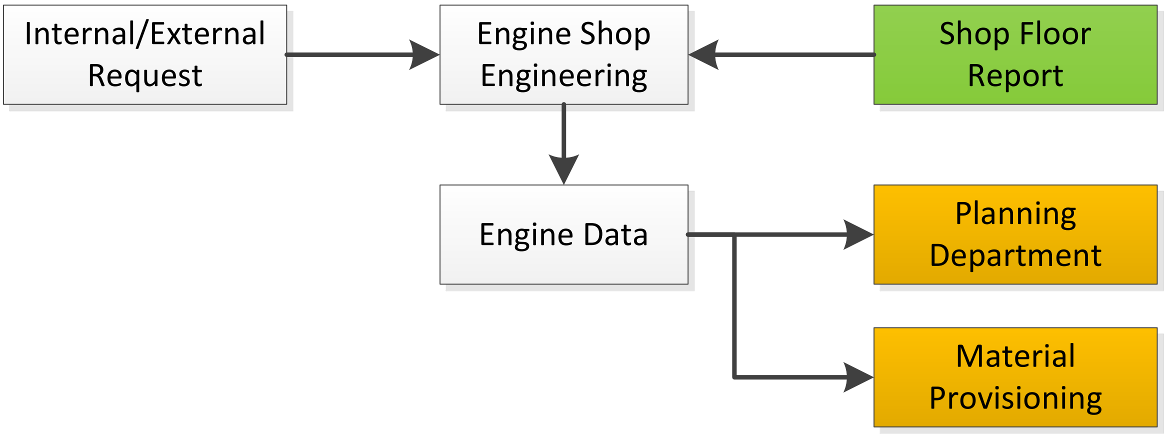


Figure 34 High-Level Engineering Processes (TCS, 2013)

6.2.3 Spare Parts Provisioning Service

In the MRO industry, components or components are also called materials. A material unit, components or spare parts department is a unit which has responsibility for the circulation of the components to support the maintenance processes. The MRO company usually has a list of the fast-moving parts. The fast-moving parts then will be purchased and stored in the warehouse. This business unit has several responsibilities to ensure availability of the components. This unit of activity has a major role to support the maintenance process, such as:

1. To ensure the certification of airworthiness. This certification will also represent the quality and the operational ability level of the spare parts. Also, they must monitor the certification status of aero engine components.
2. To manage the aero engine components' interchangeability and administer the availability. This management will enhance the efficiency of the inventory level growth.
3. To manage The MRO service provider in providing the spare parts pooling offering agreement.
4. Responsible for component reliability and quality. This responsibility required the unit to build the facility such as component warehouse.
5. To ensure that the aero engine components meet quality and serviceability requirements. This business unit should assess component deterioration, and manage the unapproved components programme.

In this research, the spare parts provisioning department is represented as one block as a unit. All the processes conducted by the thus unit are combined into a machine.

6.2.4 Delivery Services

The other important unit in MRO service provision is the logistics service provider. The logistic provider can be either under the same management or third-party logistic process. Another circumstance in the case company is when the logistic provider has been spun off as an independent business unit. This service can offer the logistic service as an additional service. In some cases, the airline, as the customer, could also take over the logistic provision required by them, or either outsource to the MRO service provider or outsource to a big logistic company.

This logistic delivery service will have responsibility to receive goods from the customers. It should ensure the aero engine is in a safe environment. It needs to fulfil export and import regulations, including the customs solution support. In this research, all delivery service’s tasks are combined as a compulsory service, which is added to the model. The delivery service unit will provide the delivery service with the aero engine to the customers.

6.2.5 OEM or Leasing Services

This research has added a potentially new method to deliver a product as a bundle to the current service provisioning. The concept of the productisation has mentioned that the service could also include the product to be bundled with their service offering. They can obtain the aero engine/ assets from another provider. in this situation, the model will represent the manufacturers (OEMs) or leasing service provider, as the aero engine provider.

The aero engine provisioning is based on the customers’ requirements. The non-OEM MRO service provider holds this responsibility. The steps to take the non-OEM MRO service provider to the next level involve becoming the solution provider by supporting the airlines’ commercial operation requirements.

6.3 Model’s Simulation

The use of the model and simulation is necessary to study the performance of a company system, as the experimentation of using the system itself will be disruptive, not cost-effective and simply impossible (Law and McComas, 1987). Therefore, this research conducts the experimentation through the simulation-based model using computer-aided methodology software.

Varelis, Stamboulis and Adamides (2002) have assessed the aero engine maintenance using system dynamics. They have measured the model to evaluate the aero engine availability based on performance metrics: total cost, performance factors and total labour from the aero engine maintenance. They assess the decision variables of the human resource, space availability, and the maintenance policy. One constraint is the engine flight hours from each aero engine. They used system dynamics model is used to assess the operational performance at the higher level.

This research objective is to evaluate the performance measurement of each maintenance process at the shop floor level. Therefore, this research used the Discrete Event Simulation (DES). The DES is not only commonly used in the manufacturing shop floor process; subsequently, this research uses the DES simulation software because the characteristics will be able to represent shop floor production manufacturing process in more detail.

This research uses Lanner® Witness Simulation software. This software can represent the maintenance sequence of the non-OEM MRO service provider shop floor and is equipped with the GUI, which makes it more user-friendly and easier to use.

6.3.1 Simulation Instrumentation for the Shop Floor

This research experimentation consists of two phases. This phase will assess the maintenance demand through the airline commercial operation requirements. The maintenance demand is translated at the time when the maintenance will occur. In the second phase, the maintenance schedule becomes the input for the shop floor model. The general flow of this research is illustrated in Figure 35. The first stage is to use the maintenance historical aero engine input as the based parameters to obtain the scheduled maintenance. The obtained scheduled maintenance then becomes the input to the shop floor operation models in Witness. The simulation result will represent the output of the shop floor operational capacity and capability for the maintenance events required. These steps are depicted the conceptual model mentioned by Figure 14 in Chapter 4.

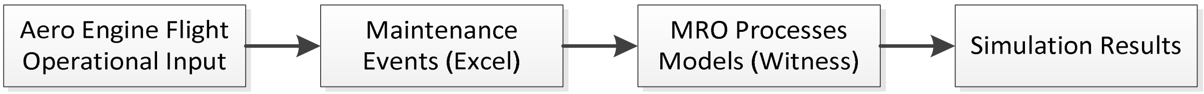


Figure 35 Experiment Instrumentation

In the first stage, the aero engine maintenance forecast is achieved by completing EFH and the EFC of commercial airline operation. The EFH and EFC then synchronise with the flight operational and geographical condition of the operating environment. The status of a factor depends on the severity level, which is supported by Ackert (2010) and Hanumanthan et al. (2012). The research uses Excel based tools to determine the maintenance forecast events.

Then, the research uses the data to assess the shop floor's performance. The research uses the generic non-OEM MRO service provider's shop floor model based on the maintenance sequences, mentioned by Ramudhin et al. (2008); Reményi and Staudacher (2014). This research enhanced the model to become more detailed in the maintenance process. The model used the maintenance processes from the aero engine maintenance as Quick Exchange Configuration (QEC) to become five different major modules.

The research has also verified and validated the non-OEM MRO shop floor operation model by using the black box method validation. A non-OEM aero engine MRO service provider has provided adequate information to conduct this validation. The deviation of the output and the meantime is below 10%. These parameters are TAT and productivity.

Then the experiment will amend the shop floor operation line to include other service provisions. These service additions are external repair vendor, spare parts provisioning services, the aero engine provision and the logistics service provider. Once the maintenance forecast is obtained, the maintenance shop floor can assess the requirements. The most important parameters in the non-OEM aero engine MRO service provider's shop floor are the resources of the shop floor. In this model, the maintenance process is a machine. The maintenance process could not exclude the mechanics. Therefore the machine involves the labour in the system.

Varelis, Stamboulis and Adamides (2002) showed the importance of the aero engine arrival pattern, the numbers of machines, the scheduled maintenance time intervals and the spares availability. This research assessed the aero engine numbers from the Flight Data Global®. The Flight Data Global provides information regarding necessary maintenance historical data regarding aircraft fleet of the customers, e.g. in-service date, engine serial number, TSN, CSN, TSLSV, CSLSV and the redelivery date. The parameters are the input to predict the maintenance schedule in the future. This data provides information relating to the total aero engine in service from the research object (airline A), the aero engine type/specification and initial service date. With this information, the research can obtain the maintenance time intervals. In addition, this research also includes the aero engine unscheduled maintenance, supplied by the trend of the aero engine input project per year from the non-OEM MRO service provider A. Another enhancement is the adoption of the Ackert's approach to include the aero engine geographical condition, the usage (EFH) and thrust setting factor to obtain the maintenance event forecast.

This research focuses on how each implementation of the contract can affect the shop floor maintenance process. Therefore, the KPI for the maintenance shop floor is found from the TAT and the cost of production. The TAT will relate to the cycle time for each maintenance process, and the cost of output relies on the total man hours of several configurations.

6.3.2 Simulation Variables

The maintenance service provision follows a similar common flow process as in the manufacturing. Therefore, the measures of performance in manufacturing could be used in the maintenance service provider.

As mentioned previously, there are similarities between the manufacturing shop floor and the MRO service provider shop floor; the research assessed the same performance measurement (Key Performance Indicator/KPI) as in the manufacturing. Law and McComas (1987) suggested that the measures of performance in the manufacturing simulation are based on several parameters. The following are throughput of the total jobs in certain duration of time; the time for the system to complete one job; the time that the jobs spend in the queues; the delivery time for each job; the total work in progress on the shop floor; the total level of utilisation for each maintenance process; the breakdown level percentage of the machine; the proportion of jobs that must be reworked or scrapped because of defects in the production; and the Return of Investment for the manufacturing process. Those parameters have also been supported by Corallo et al. (2010).

However, the shop-floor's characteristics and behaviour in the contract preparation is less considered. This research will enhance the non-OEM MRO shop-floor's performance by incorporating the airline's commercial operation requirements to the model and simulation to obtain the shop floor performance measurement. The combination of those demands and the maintenance capability will be able to provide better information and a win-win solution.

6.3.2.1 Input Parameters

Through the performance measures output, several inputs become the input parameters for the non-OEM MRO service operations. The customer requirements as input for the MRO activities are provided by Al-Kaabi, Potter and Naim (2007). They presented the concept of MRO service outsourcing from the airlines in Figure 36.

Figure 36 Maintenance, Repair and Overhaul Outsourcing

Source: (Al-Kaabi, Potter and Naim, 2007)

The configuration of service provision will be based on the additional service's delivery besides aero-engine's SBU. In this research, the key input parameters will be built on the airline's commercial operations policy. The total aero engine fleet will be assessed on the aero engine specification and characteristics. Then, the research will assess the operational requirements, including the geographical condition of the operating environment. The output of the assessment will produce the maintenance schedule.

6.3.2.2 Key Performance Indicator

There is key performance indicator in the contract agreement relating to the shop-floor's performance. To the customer, the technical delays (TAT) are one of the most important KPIs to support On Time Performance Requirement Level. The TAT can directly affect the flight operational customers.

Another important KPI is the cost of the maintenance process, this relates to the cost of production. For the non-OEM MRO service provider, the most important parameter concerns the total labours needed to support the customer operation. Regarding assumptions, there is less difference in the spare parts or material needs to conduct the maintenance. The aero engine maintenance process will be based on the OEM's manual guide.

In the PSS offering contract, customers tend to have different kinds of parameters such as availability the number of serviceable assets, which they can use to conduct their commercial or mission operations (Erkoyuncu et al., 2009). This research used Discrete Event Simulation to represent the availability parameters of the shop floor. The DES has been implemented in the MRO operations to provide information on availability parameters by Bazargan and Jiang (2010). Nutaro et al. (2012) used DES to assess the availability from chemical plant production, and Juan et al. (2009) assessed the availability by using the DES in civil engineering structures.

The main parameter provided to the customers is the availability. Availability is defined as the performance measurement of the repairable system, which represents the capability of whether a system is operating satisfactorily at any point in time. Availability in this research refers to the number of the serviceable engines that can be supplied by the provider for the customers' requirements.

Equation 15

$$\boldsymbol{Availability = \frac{Engine\_supplied_{at\ a\ duration\ of\ time}}{Engine\_required_{at\ a\ duration\ of\ time}}}$$

In this research, the availability is on average per machine unit. Similarly mentioned by Schryver, Nutaro and Haire (2012), availability is the conventional definition of the intrinsic availability of M subject to input x. M itself has defined activities: time idle, productive and inoperable (Equation 16).

Equation 16

$$Intrinsic_{availability} = \frac{Uptime\ of\ Engine}{Uptime\ of\ Engine + Time\ Lost\ to\ failures\ of\ Engine}$$

On the other hand, in the aviation industry, the availability is defined as the total uptime (even when it is not operated, but it is able to operate) – downtime or maintenance duration. The total maintenance used will depend on the reliability of the engine itself. Therefore, the percentage of the availability is presented by Equation 17.

Equation 17

$$\begin{aligned} &Total\ Availability\ (days\ per\ year) \\ &\quad = \frac{Tota\ Days\ of\ Maintenance\ x\ Total\ Maintenance\ per\ year}{Total\ Engine's\ Availability\ Required\ per\ year\ (days)} \end{aligned}$$

To support the availability, the main parameter to include is the TAT from the aero engine maintenance process. Also, the availability related to the reliability (time lost to failures) of the aero engine. This research cited Ackert (2010) by adopting the methodology to predict the maintenance events of an aero engine as average input to the model. The model used several input parameters that relate to the operational details, such as the geographical condition of the flight environment, the total flight cycle needed and flight hours needed. This calculation will describe the maintenance events as the input and the reliability number of an engine.

The maintenance events will depend on the engine deterioration provided by the flight parameters and then compared against the shop floor performance. The aero engine reliability is dependent on the total number of aero engine removals in its lifecycle. The reliability of the aero engines can be influenced by the EGT Margin deterioration, LLP Replacements, Hardware deterioration, and Foreign Object Damage (FOD). The EGT margin is the factor that relates to the efficiency level decrease of the aero engines. Another factor is the gap increment between the turbine blade’s tip and the cowl. The LLP needs replacing due to expiration of functionality and after certain cycle times of the aero engines. Hardware deterioration caused by the operating environment of the aero engine: crack, stress, and chip to the turbine blade. Moreover, the Foreign Object Damage (FOD): this situation occurs when the aero engine ingests foreign objects.

There are also parameters that need to be implemented to the maintenance forecast analysis as they influence the aero engine reliability as well. These parameters are grouped on the basis of the aero engine specification, thrust rating, operational severity, age status, and the work scope management policies. The thrust rating will affect the component deterioration rate; in the higher thrust the component will be under greater stress and suffer a higher rate of deterioration. The operational severity will relate to the flight length associated with the environment and the derate factor as well. The geographical situation of a runway can affect the EGT margin of the aero engine. The less EGT margin there is will influence the shop visit frequency to regain the EGT margin. The age status can relate to the hardware deterioration and the LLP expiry time. The work scope management policies will also affect the shop visit of the aero engine; the maintenance schedule can be decided based on the opportunity maintenance. The aero engine owner can determine whether they replace the LLP during the planned maintenance or add more work scope during a shop visit.

To support the reliability forecast maintenance, the OEM as the manufacturer and the designer of the aero engine provides an engine severity curve for each model produced. Each severity curve depends on the thrust rating and flight length profiles (Hanumanthan et al., 2012).

6.3.3 Aircraft MRO Supply Chain Reference Model

Based on MacDonnell and Clegg (2007) this research has identified four organisations that are mentioned as the core supply chain players in aircraft maintenance repair and overhaul.

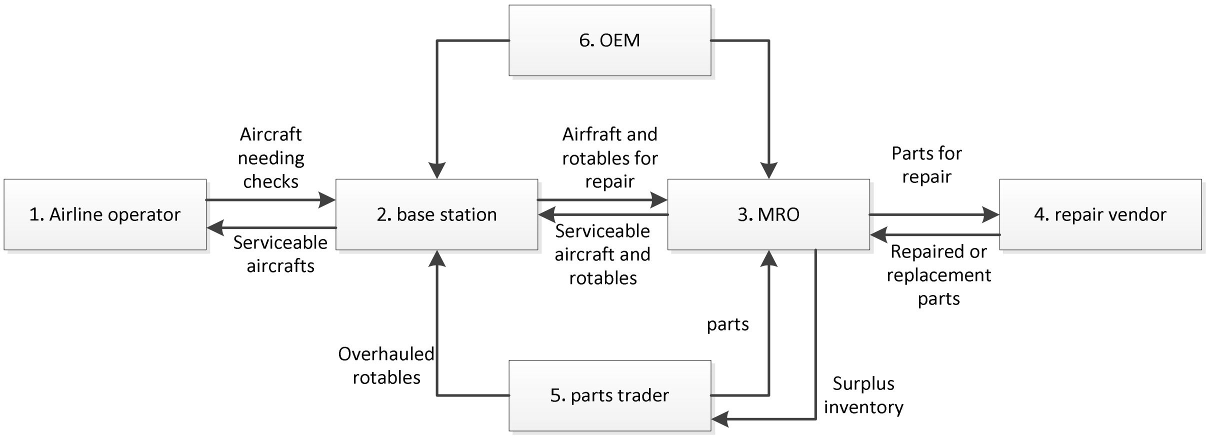


Figure 37 The Aircraft MRO supply chain reference model - physical flows

source: MacDonnell and Clegg (2007)

Based on Figure 37, this research will conduct experiments that consist of different MRO's business unit's stakeholders. This research will have the non-OEM MRO as the main role of the model; the configuration always includes the non-OEM MRO service provider. However, based on the productisation, the offering can be layers or a spectrum which define through the contract service offering.

MRO: conduct maintenance and provide all technical aspects to support the airline's operational requirements

Repair vendor: outsource vendors that support the non-OEM MRO service provider in the maintenance of the spare parts. Outsource can be conducted if the non-OEM MRO service providers have or do not have any capability/capacity to deliver the work scope.

Parts Trader: provides the asset management relating to the spare parts or components. One of the examples is the pooling parts agreements when the non-OEM MRO should provide the availability of elements whenever an aircraft needs them. It is similar to an exchange components agreement with a certain service level agreement to the customers.

OEM/lessor: in the supply chain system, this OEM or lessor could provide both the airline and the non-OEM MRO service provider with a total asset, such as an aero engine.

Base station: the place to conduct maintenance, whether minimum or overhaul. It could be ramp/apron in the airport or hangar. The base station usually conducts letter-check for airframe maintenance (Hessburg, 2000). In this letter-check maintenance work scope, aero engine maintenance checks are included as part of the routine maintenance schedule.

The combination of those additional stakeholders can also represent different service provisions with various service level output parameters, from the conventional ‘time and material’ based contract (TMB) to the total solution contract to support customer operations. Table 17 Model Configurations represents the combinations of service configurations based on the MRO supply chain model.

Table 17 Model Configurations

No	Shop Floor Model Configurations	Services				
		MRO Shop Floor	Repair Vendor	Parts Trader	Aero Engine Provisioning	Irregular Maintenance
1	Configuration 1	V				
2	Configuration 2	V	V			
3	Configuration 3	V	V	V		
4	Configuration 4	V	V	V	V	
5	Configuration 5	V	V	V	V	V
6	Configuration 6	V		V		
7	Configuration 7	V		V	V	
8	Configuration 8	V		V	V	V
9	Configuration 9	V			V	
10	Configuration 10	V			V	V
11	Configuration 11	V				V
12	Configuration 12	V	V			V
13	Configuration 13	V	V	V		V
14	Configuration 14	V		V		V
15	Configuration 15	V	V		V	
16	Configuration 16	V	V		V	V

6.4 Simulation Strategy

Experimentation based research is determined by the service provision strategy of the non-OEM MRO service provider. The non-OEM MRO service provider can combine several service provisioning configurations to fulfil a variety of customer requirements. The combination of different strategies will be modelled in the non-OEM MRO provider shop floor model.

Each row area represents how the non-OEM MRO service provider can configure its service provision. However, there is very little consideration given to provide a method for assessing the best configuration to support the customers' requirements. This research will conduct simulation by using a model that can represent the shop floor level. In this situation, the model can provide better information to assess shop floor operational capability and capacity readiness.

The various offerings from the non-OEM MRO service provider consist of a few service provisions combined into one. At the most advanced level, the non-OEM MRO service provider is not only offering the service delivery but also the total solution, which includes both the service and the product as a combination to support their total operation. Table 17 represents several service provision configurations that can be offered and combined by the non-OEM MRO service provider to customers.

6.4.1 Assessment of the customer operations requirements

The research assesses customers' actions in the future. This requirement is related to the commercial flight operation and number aero engine they have.

The airline has also started to outsource the operation unit (Al-kaabi, Potter and Naim, 2007). They mentioned that the airline tends to outsource the uncritical operation unit to support the operation. They reviewed that areas such as line maintenance must not be outsourced. The line operation has a significant role in supporting direct operations related to time. The other operation units, such as base maintenance, are safe to be outsourced.

However, (Knotts, 1999) has related the civil aircraft performance implication to the aircraft service focus. He mentioned that the important parameter of the airline operations: Aircraft Dispatch Reliability (ADR), Direct Maintenance Cost (DMC), and other technical parameters (TAT, and Reliability).

These parameters will directly affect the commercial operation of the airlines. ADR represents the percentage of revenue departure that does not incur a delay or cancellation of technical problem's result (ATA, IATA, and ICCAIA, 1992). The DMC represents the total labour and material costs consumed in performing maintenance. The most popular parameters are the availability of the aero engine. The availability level of the aero engine is derived from the TAT and the reliability. TAT represents the total duration of the maintenance. Reliability refers to the amount of total maintenance downtime at certain times.

6.4.2 Assessment of the non-OEM MRO shop floor operational processes

This subchapter illustrates the non-OEM MRO's shop floor requirements during the operation process. This subchapter also discusses the possible combinations of configurations that may be used to provide the service offering.

The general maintenance process consists of the core business in non-OEM MRO. In the aero engine shop floor, the service provider will include induction, inspection, borescope, service, repair or overhaul, major module disassembly, and quick engine change (QEC) disassembly. In this maintenance process, the non-OEM MRO service provider will have resources, which consist of mechanics, spare parts, machines, tools, methodology, and expertise.

All supported departments will also provide service to the aero engine. This research assumed all supporting operation units, including quality engineering, technical services, the PPC control and the other supporting units, are contained in the operation.

6.4.3 Assessment of the Maintenance and Demand correlation

In the aviation industry, the business model has shifted in the last decade, from simple maintenance service provider to the availability asset management provider. It was initiated by the Rolls Royce' Power by the Hour (PBH) in the aero engine provisioning. Rolls-Royce provides the aero engine's utilisation offering contract. The leasing system allows the airlines to use the aero engine without possessing the aero engine; this PBH agreement enables the airline to pay for just the total flight hours. All necessary support, such as maintenance, will become the responsibility of the providers. This scheme is also offered by airframe manufacturers such as Boeing.

The airlines have also responded by extending their requirements to make it easier for them to support their commercial plan. The non-OEM MRO service providers also need to change their offering to become more competitive. They need to integrate the product into the core service as a bundle of the total solution to the airlines.

This solution can consist of different combinations and configurations of the service(s) as a solution. Each of the services can be combined and configured to supply the airline requirements. Nowadays, the demand or maintenance events required have to deal with the operations of the aircraft. However, the aircraft availability metrics are less considered in the literature (Yongquan et al., 2014)

This research utilises a model that represents a distribution term integrated into the Witness model's element to represent the operations and the maintenance demand of the requirements. As mentioned in the previous chapter, this phase will assess the maintenance events in the future, which represent the application for the shop floor process.

6.5 Experimental Procedures

This research utilises the experimental based simulation to assess the effect of the airline operations to the shop floor capacity and capability. The simulation will synchronise the client's flight operations and the maintenance shop floor capacity and capability (Figure 38).

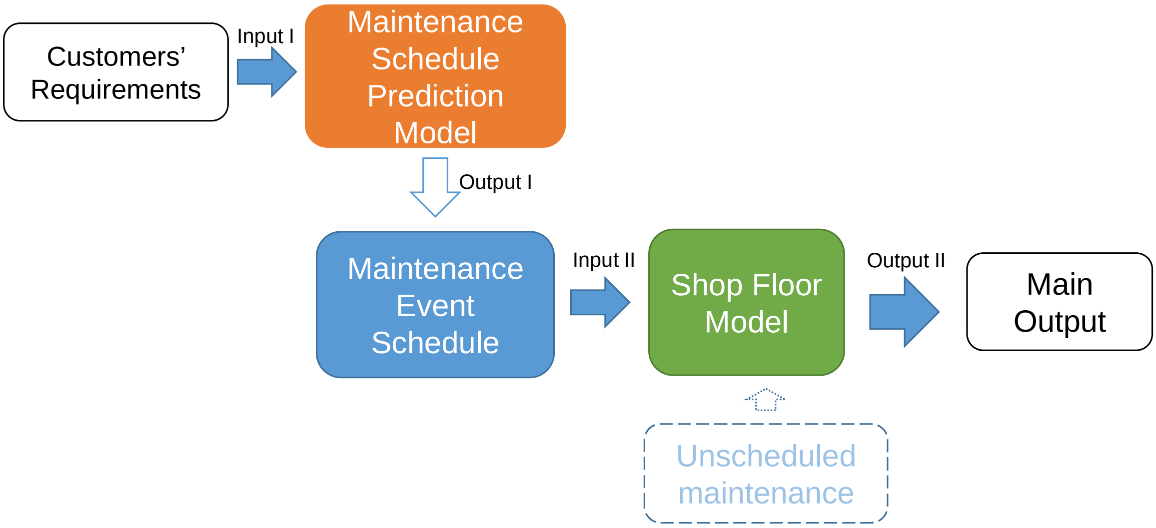


Figure 38 Simulation Stage's Process

6.5.1 Pre-experimental designs (One-Shot Case Study)

In the pre-experimental design, the researcher studies a single group and provides an intervention during the experiment (Creswell, 2003). This design includes a pre-test measure, followed by a treatment and a post-test for a single group (Creswell, 2003).

The research will conduct maintenance to assess a single case study between airline A with the non-OEM MRO service Provider A. The initial experiment conducts the maintenance forecast simulation. The research used the example of airline A's aero engine fleet. The aero engines consist of 74 CFM 56-7Bs that operate in the tropical climate. The airline has the policy to rotate the fleet to fulfil its commercial procedure. Therefore, the Engine Flight Hours and the Engine Flight Cycle for the future operation need assessment. The scheduled maintenance prediction evaluates the total EFH and EFC. Additional data for the unscheduled maintenance is based on the case company's data. The aero engine forecast maintenance for the fleet will become the input for the non-OEM MRO shop floor model.

The non-OEM MRO shop floor model in this research represents the regular maintenance processes of the aero engine maintenance. The shop floor model illustrates the repair work scope from the QEC level to the major module work scope level.

6.5.2 Conceptual Model’s Parameters

The experimentation consists of two processes. The first process assesses the customers’ flight operation, and the second process will assess the shop floor capacity and capability. The correlation of that parameter becomes the maintenance forecast for the aero engine.

The maintenance model event consists of three different cases: the performance restoration, the LLP replacement, and repair because of ageing or unscheduled removal (Justin and Mavris, 2011). This research requires common parameters, such as the number of aero engines, in service date, previous maintenance’s date and also the operation plan for the customers to schedule maintenance. The aero engine arrival depends on the maintenance prediction using flight operations parameters mentioned in the previous chapter: engine flight hours (FH): engine flight cycle (FC), aero engine derate factor specification, aero engine historical maintenance and the environmental conditions.

6.5.2.1 Airline Input Parameters

The airline input parameters in the model are dependent on the customer’s factors for engine shop forecaster. The aero engine data input obtained from real live data of the assets from the Flight Data Analyser® from Flight Global Data Analyser (Flight Global Data Analyser, 2016). This form of data base provides all information regarding the historical data of the aircraft and the aero engine. The database used by the marketing department to assess the requirements of the airlines can then be used as the foundation for the non-OEM MRO’s offering. The database consists of information, e.g. the utilisation data, the history of the operation, the owner. Data obtained include the status of the aero engine maintenance, manufacturers, the model of the aircraft used, the engine type (related to thrust settings), and the in-service date.

The thrust setting will vary in the maintenance events schedule. The more thrust the aero engine has, the more frequent the requirement for maintenance. The service date will relate to when the aircraft maintenance needs to be sent to the non-OEM MRO service provider. It will comprise the flight operation of the plane, with the assumption that the aircraft is operating in the same operational region, with an average 6.5 flight hours per day and annual date of 2500 FH. The in-service date is the time the aircraft starts its operation. The illustration of the aero engine operation maintenance is in Table 18.

Table 18 Aero Engine Input Parameters

Engine Specification	
Type	CFM56-7B26E
Thrust Setting	25,900 lbs
Derate Factor	0%
Operational Specification	
Operational Region	Hot/Harsh
Flight Leg	6.5
Flight Cycle (FC) Goal	7,000 FC
Annual FH	2500
Start Date	26 June 2014
Term List (month)	360

The main basis for the formulation of this model is the severity curve mentioned by (Ackert, 2010; Hanumanthan et al., 2012; Justin and Mavris, 2011). However, the severity curve in this model works on the assumption relating to its confidential status. The severity curve that was used in this research is slightly different to the severity curve mentioned by (Hanumanthan et al., 2012). However, the trend and the pattern of the severity curve is similar (the data for the severity curve is different for each aero engine and only published by the OEM). This curve is affected by the derate factor, the thrust setting and the flight hours..

This research uses the aircraft monitor model from aircraftmonitoring.com to assess the maintenance forecasting. This Excel based model can predict the maintenance forecast in the mean time of the aero engine cycle.

Table 19 mentioned the output of the maintenance prediction model.

Table 19 Aero Engine Maintenance Model Output Examples

No	ESN	Rating Type	Thrust	In service Data	Schedule
1	40547	CFM56-7B26E	26300	20 Jun 2014	Mar-17
2	41267	CFM56-7B26E	26300	16 Jun 2014	Apr-17
3	38040	CFM56-7B26E	26300	05 Jun 2013	Apr-17
4	41253	CFM56-7B26E	26300	13 Sep 2014	Apr-17
5	41270	CFM56-7B26E	26300	09 Oct 2014	Jun-17
6	41310	CFM56-7B26E	26300	15 Nov 2013	Jul-17
7	41312	CFM56-7B26E	26300	11 Dec 2013	Aug-17
8	41322	CFM56-7B26E	26300	03 Sep 2014	Sep-17
9	41605	CFM56-7B26E	26300	27 Jan 2015	Sep-17
10	41796	CFM56-7B26E	26300	26 Jun 2014	Sep-17

6.5.2.2 non-OEM MRO Service Provider Parameters

The research assumed several parameters for the shop floor operational model, such as the shift policy, part routes (maintenance decision scenario), the labour allocation and the operation cycle time for each maintenance process.

The shift policy of the non-OEM MRO service provider is common; it includes Monday to Saturday with two shifts each day. Each shift consists of 8 hours. However, there is only one shift on Saturday. This shift management is based on the maintenance policy dedicated by the non-OEM MRO service provider A, related to the authority's regulation.

The part routes or scenarios follow the flow of the maintenance process on the shop floor of the non-OEM MRO service provider. This model is limited at the higher level, which limits the major module parts. The subparts that support the major module have not been incorporated into the model. However, the main idea is to assess the shop floor operations, and the parts work scope and processes have been taken into account for the process in the model.

The mix and match in the validation process provide the operation throughput time of the model. The black box validation process is used, which relates to the input and output of the system only. There is no data provided by the non-OEM MRO service provider regarding activity in the maintenance processes, such as the average cycle time for each maintenance process. The non-OEM MRO service provider's only concern is for the input and the output of the project. Therefore, the black box validation is the best method to validate the model.

6.5.3 Shop Floor Model Configurations

mentioned the main non-OEM MRO maintenance sequences. The maintenance sequence will present the aero engine maintenance, based on the aero engine's Workscope Planning Guide (WPG).

Table 20 Maintenance Processes

No	Maintenance Processes
1	Induction process
2	Engine Disassembly
3	Clean and NDT
4	Inspection
5	Service_Repair
6	Marshalling
7	Sub Assembly
9	Final Assembly
10	Test

The model in this research represents the aero engine non-OEM MRO shop floor. The model will consist of the maintenance processes, from the induction process to delivery process.

The first step is the induction process. The induction process is where the preliminary inspection is conducted. In the real situation, it consists of both the technical and paperwork documentation activities. The paperwork includes the Maintenance Bulletin from the aviation authorities (i.e. USA's Federal Aviation Administration and European Aviation Safety Agency), historical maintenance documentation and the airline's work scope requirements. In this research, the paperwork maintenance cycle time is standard and similar to each configuration scenario. The technical work scope will consist of the general visual inspection and borescope inspection. The general visual inspection will provide information regarding the external condition of the aero engine. The borescope inspection will obtain further details regarding the aero engine condition. The actual maintenance is amended on the finding of the preliminary report. The report of the inspection is sent to the engineering services and Production Plan and Control Department (PPC). The technical services team will determine the most suitable maintenance work scope. Then, the PPC will convert the maintenance work scope to a task card. A task card provides the manual to conduct the maintenance on the shop floor. This model excludes the documentation work process to provide further details on the shop floor.

Once the aero engine inspection is completed, a decision will be reached as to whether to conduct further maintenance. If the decision from the work scope is to conduct further maintenance, the shop floor will dismantle the aero engine maintenance. The aero engine disassembly will be sent to five different major module repairs. The number of the main modules can vary, depending on the manufacturer's specifications. The scope of this research is to use the CFM 56-7B aero engine as the case object, which consists of six different major modules: fan major module, major core modules, high-pressure turbine (HPT) modules, low-pressure turbine (LPT) modules, accessory drive modules, and controls & accessories modules. Each major module has a different process and maintenance line process.

Once disassembled, the above modules will be cleaned and tested. The test will decide if any other additional maintenance is required. The test, referred to as a nondestructive test will vary, depending on the work scope. On the other hand, if the non-OEM MRO shop floor does not have any capability or capacity to service a major module, they could send it to an external repair vendor.

The Clean and NDT is a subsequent process on the non-OEM MRO shop floor. Each major module has a different clean and NDT process depending on the specification and the work scope. In several scenarios, a cleaned and tested major module can also be sent to the outsource repair vendor. It is common that the required work scope can differ from the planning, following the cleaning and NDT processes.

The shop floor will then conduct the inspection process. The inspection process usually takes place on the bench (bench inspection) with qualified inspectors. In this process, the shop floor will also decide on the necessary maintenance. It is often that the actual maintenance will differ to the planned maintenance. The inspection process can also provide information as to whether the non-OEM MRO service provider needs to send it to the external repair vendor. The non-OEM MRO service provider can also conduct the service and repair within its facility, once they have the capacity and capability.

The next stage is the core of the maintenance, which is service and repair processes. The service process will conduct the light work scope such as greasing, while the repair involves the work performed to return the spare parts to their functional design. The service and repair process will undertake the maintenance of the components. This process also decides whether to replace the spare parts. The spare parts replacement is listed in the service and repair process of this model. The model has included the details of whether to maintain, repair or to replace the spare parts as one of the machine processes on the shop floor. The decision of the maintenance work scope is represented by the proportion of total work scope data from the case company.

Once the components are serviced, repaired or replaced, the next MRO process is the marshalling or accumulating. This process will manage all aero engine maintenance before reassembly. The accumulation process can also respond to the aero engine spare parts replacement. The triangular distribution represents the uncertain time of the accumulation process. Triangular distribution is provided by the Witness to be utilised in the maintenance cycle time. The limited data from the case company has made the triangular distribution the best solution to represent the actual situation.

Subassembly and final assembly will involve reassembling the serviced or serviceable parts. Triangular distribution represents the sub-assembly uncertain cycle time. The sub-assembly will built the sub-major modules to become a major module. The final assembly will involve the major module becoming a Quick Engine Change (QEC) or a whole aero engine.

The test process will use the engine test cell to assess the operational ability of the aero engine. This research assumes that the maintenance process conducted is always successful. On completion of the aero engine test, it can be returned to the customer. The trial process will obtain the aero engine specification after the maintenance. The information will be useful for the commercial operation.

This model includes the shipment or delivery process. The delivery process will include the aero engine maintenance, such as packaging, wrapping and aero engine preservation.

6.5.4 Shop-Floor Model Experiment Assumptions

It is not possible to add all complexities of the non-OEM MRO shop floor. Due to the lack of information and data, the simulation based model in this simulation makes several assumptions. This research implements several assumptions without reducing the model's aim. The model aims to represent the real situation in the non-OEM MRO service provider's shop floor. Therefore, the assumptions are:

1. Labour policy and shifts. The labour in this model will represent the entire group of mechanics. The total number required for each process is assumed as fulfilled. The shifts will follow the operation of the non-OEM MRO service provider A. The shifts consist of 5.5 days; a full shift consists of a day (AM) or Night (PM) shift. The half-day shift represents the Saturday shift, the duration of which is just the morning. As this simulation used the day as a time parameter, the shift will represent how many days in a week.
2. Spare Parts Replacement Process. The process of the Beyond Economical Repair (BER) of the work scope decision combines the machine's cycle time.
3. Documentation and paperwork. The required documentation is excluded in this model. The model will only represent the process and the operation conducted on the shop floor. Although there is a task card and job card for each mechanic, the main aim of this model is to assess the cycle time of the maintenance process. However, this model adds parts called ppc_doc to represent the first in first out (FIFO) of the aero engine from a maintenance process.
4. Spare Parts. The model assumes the components are always available. This assumption means that there is no obsolescence yet to the serviced aero engine fleets.
5. Buffers. The model utilises additional buffers to fulfil the requirements of the software. The data to represent the available buffers in the non-OEM MRO service provider is less considered.
6. New Spare Parts Arrival time. A process also needs to identify the arrival time of the spare parts. The ordering, processing and delivery time for the new aero

engine components taken into a maintenance process is referred to as marshalling.

7. Machine Cycle Time. The machine cycle time is obtained from the aero engine maintenance process in the non-OEM MRO A. The model used the triangular distribution to represent each maintenance cycle time process.
8. Maintenance Route (Maintenance Decision). The maintenance decision in the aero engine maintenance is set to fulfil the available data. The maintenance route has been established to fulfil the validation process.
9. Scheduled and Unscheduled Maintenance. Some of the model configurations will use the scheduled and unscheduled maintenance generated from the base station. The base station represents additional maintenance, such as unscheduled maintenance from other customers, and unpredicted maintenance occurrences.

6.5.5 Experimentation Scenarios

The experimentations will represent all possible configurations on the shop floor. All additional service provisioning will then be added to the generic non-OEM MRO shop floor model. The previous subchapter has mentioned that each configuration model will provide the configuration combinations from the service units. The combination of the service processes in the model configurations is in Table 17 Model Configurations.

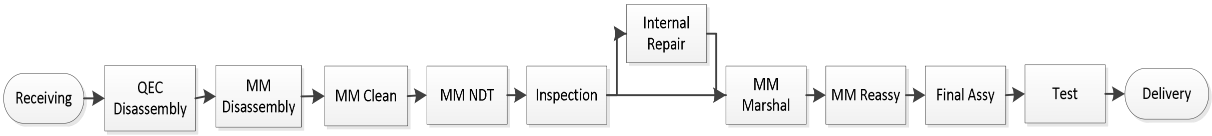


Figure 39 Scenario 1

Figure 39 represents scenario one: the offering as a pure non-OEM MRO service provider. The configuration will only consist of the general maintenance sequence on the non-OEM MRO shop floor. In this scenario, the non-OEM MRO service provider will support the aero engine maintenance appertaining to the scheduled maintenance resulting from the ad-hoc maintenance service. The non-OEM MRO service provider will allow the aero engine maintenance to be serviced in its facility. In this scenario, the non-OEM MRO shop floor cannot conduct the maintenance service for components that are excluded from the non-OEM MRO authorised capability list.

The aero engine arrival will be directly received. At this stage, the non-OEM MRO will conduct a preliminary inspection, general visual inspection and borescope inspection. Engineering will verify the additional document in the form of a preliminary report document, consisting of any possible additional work scope that needs to be conducted. The engineering department has responsibility to decide the workscope. In this situation, the engineering process has been incorporated into a machine in the model. The total time between the engineering preparation and the time the aero engine is being processed is added to the cycle time. The probability distribution of the work scope is planned, and any additions decided on reflect case company projects in the current year. Then the aero engine maintenance moves to the major module disassembly process. The major module in this research will be divided into six different major modules mentioned in the previous chapter. The conduction of the service consists of cleaning, nondestructive test (NDT) and the inspection of components. Once the aero engine is inspected, there will be a classification of whether the component should be serviced/repaired/replaced or can be directly assembled. The decision to maintain repair/replace is made on the inspection result. The internal repair is conducted while the other serviceable components are held in the marshalling/pooling warehouse for the next reassembly stage. The reassembly stage will consist of two different levels: the major module reassembly and the aero engine reassembly. The final inspection is conducted during the test. In this situation, the trial time process includes the final adjustment for the aero engine. The delivery process will include the preparation, packaging, preservation work scope before its return to the customer.

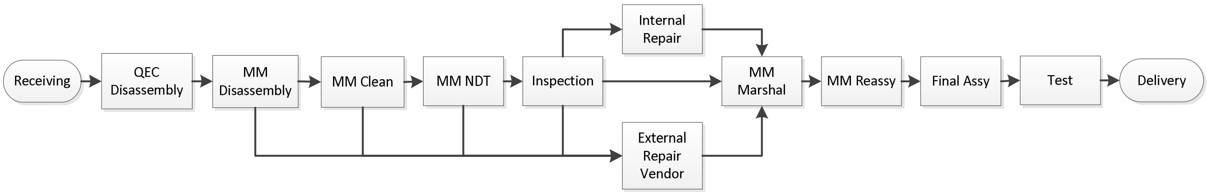


Figure 40 Scenario 2

Scenario 2: of the non-OEM MRO shop floor and external repair vendor. The external repair vendor will assist the non-OEM MRO to provide the maintenance. The model will represent the external repair vendor in the repair of major modules. The external repair vendor has responsibility for any components excluded from the authorised capability list, owned by the non-OEM MRO. The components can be sent directly from the MM disassembly process stage. They could also be sent after the major module disassembly, as the actual work scope of the maintenance service cannot be identified until a certain point is reached. The external repair vendor process in this model includes the sub process, such as packaging, sending and receiving process. The serviceable spare parts are sent back to the accumulating process.

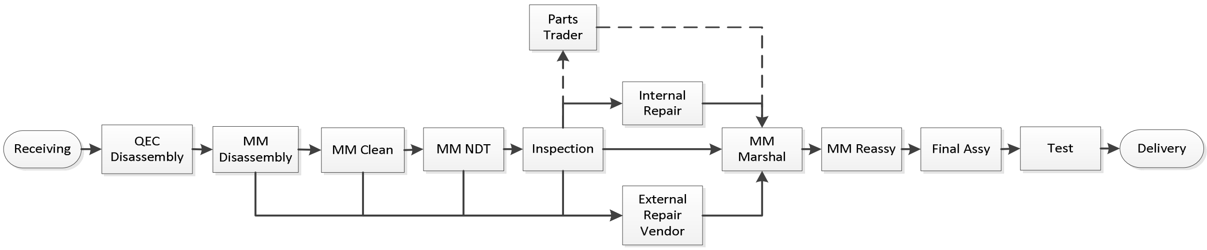


Figure 41 Scenario 3

Scenario 3 (Figure 41): MRO Shop Floor + Repair Vendor + Parts Trader. The non-OEM MRO service provider will provide the external repair and the spare parts provisioning together. Therefore, the non-OEM MRO will have further responsibilities. The additional components trader has given the non-OEM MRO more capability to conduct the work scope. The spare parts trader could also pool the components, which enables the non-OEM MRO to swap the unserviceable components with serviceable components. It is also necessary for the non-OEM MRO to have additional service in provisioning the spare parts required for the maintenance; therefore, the customers do not need to provide for themselves. This situation will reduce the provisioning time process. The combination of the spare parts trader and the external repair vendor assumed, can enhance the TAT performance level, while improving the non-OEM MRO shop floor utilisation.

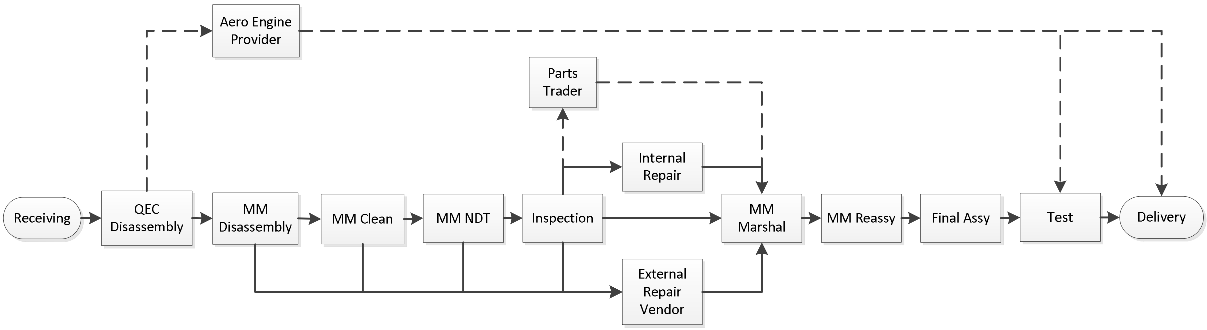


Figure 42 Scenario 4

Scenario 4 (Figure 42): MRO Shop Floor + Repair Vendor + Parts Trader + Aero Engine Provider. in this scenario, the non-OEM MRO service provider can assist the customers to provide the aero engine. However, the non-OEM MRO service provider will outsource it to either the OEM or Aero Engine Lessor. This configuration is necessary to support an availability contract offering to the customer. The situation will enable the non-OEM MRO to maintain aero engine readiness, although they have limited maintenance capacity and capability. The additional service provisioning in this scenario represents the additional spare engine provisioning. In this scenario, the non-OEM MRO has more capability to include an availability (total aero engine readiness) level in its service offers.

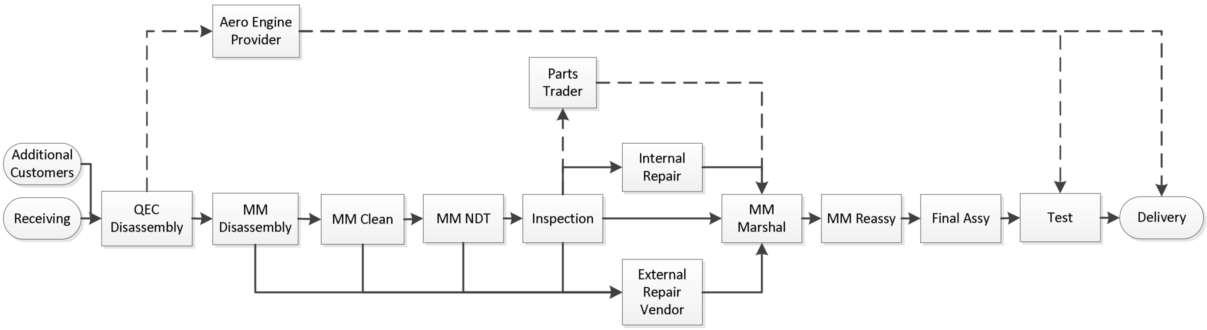


Figure 43 Scenario 5

Scenario 5 (Figure 43): MRO Shop Floor + Repair Vendor + Parts Trader + OEM + Base Station. In this configuration, the non-OEM MRO will offer all required maintenance, both scheduled and unscheduled. The non-OEM MRO can offer the maintenance service provision to more than one airline. The base station in this model represents the generation of the maintenance requirement, both from the dedicated customers or any additional customers.

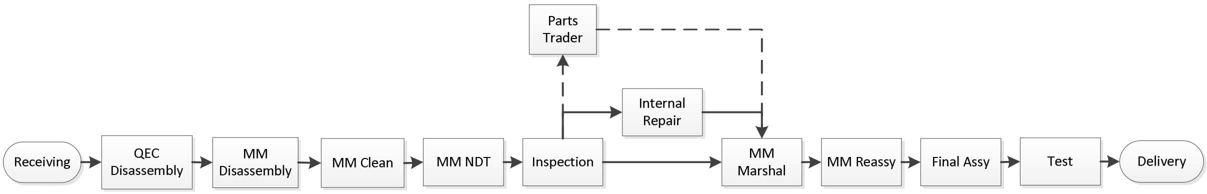


Figure 44 Scenario 6

Scenario 6 (Figure 44): MRO Shop Floor + Parts Trader. This configuration will enable the non-OEM MRO service provider to support the customers by provisioning the components. In this scenario, the non-OEM MRO can shorten the time to provision components during maintenance. The spare parts provisioning of additional service requires most of the maintenance processes in the shop floor. Additional spare parts traders will reduce the provisioning time only, which are far less effective in reducing the maintenance TAT compared to the efficiency enhancement to the total TAT.

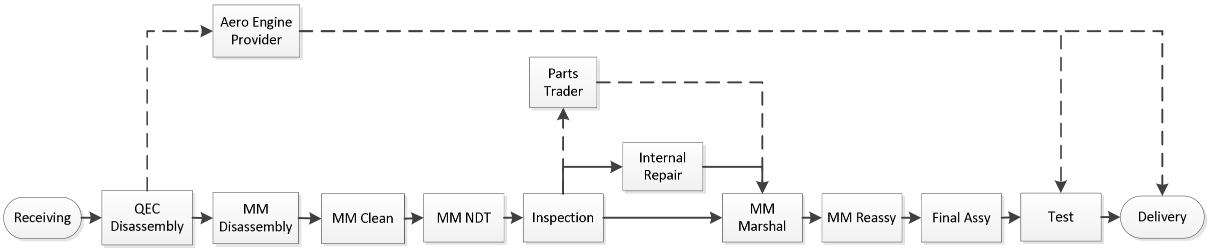


Figure 45 Scenario 7

Scenario 7 (Figure 45): MRO Shop Floor + Parts Trader + OEM. This scenario enables the non-OEM MRO to provide both components to perform the maintenance. This scenario allows the non-OEM MRO to provide the additional aero engine to the customer. With limited capacity and capability, the non-OEM MRO service provider can guarantee the total aero engine readiness to support the customers' operations.

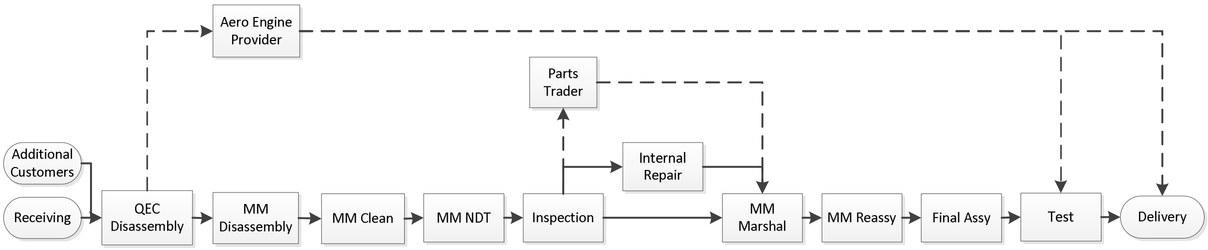


Figure 46 Scenario 8

Scenario 8 (Figure 46): MRO Shop Floor + Parts Trader + OEM + Base Station. The additional base station enables the non-OEM MRO to support more than one customer. The new additional OEM element has also enabled the non-OEM MRO to support the aero engine readiness and the customers' operational requirements.

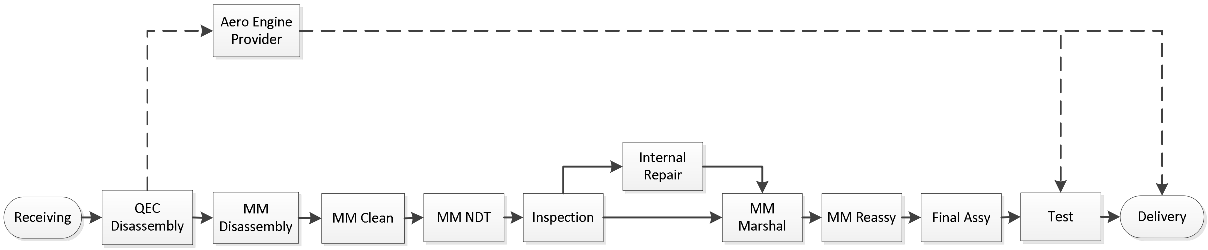


Figure 47 Scenario 9

Scenario 9 (Figure 47): MRO Shop Floor + OEM: In this situation, the non-OEM MRO can provide few aero engines to the customers. The collaboration with the OEM can enhance the service offering from the pure maintenance service provision by adding the product to the service as part of the solution.

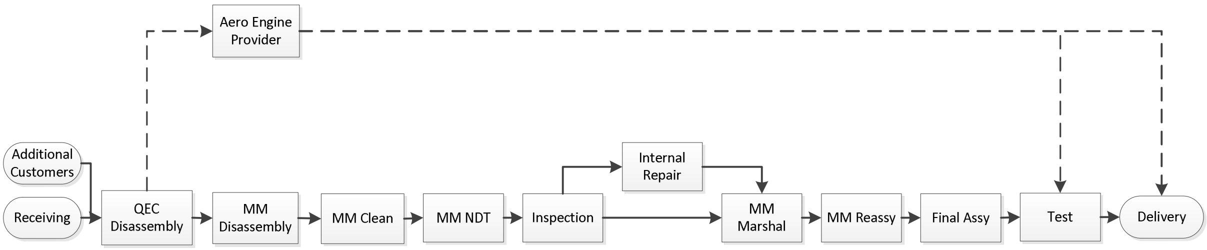


Figure 48 Scenario 10

Scenario 10 (Figure 48): MRO Shop Floor + OEM + Base Station. The additional base station will enable the non-OEM MRO shop floor to provide service for both the scheduled and unscheduled maintenance. The additional OEM will assist the non-OEM MRO to provide an enhanced solution to the customers.

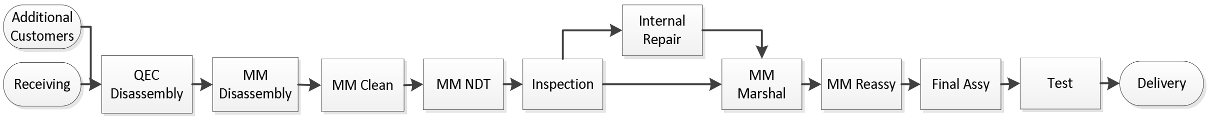


Figure 49 Scenario 11

Scenario 11 (Figure 49): MRO Shop Floor+ Base Station. The additional base station will generate more maintenance requirements. The non-OEM MRO service provider needs greater capacity and capability to hold this configuration.

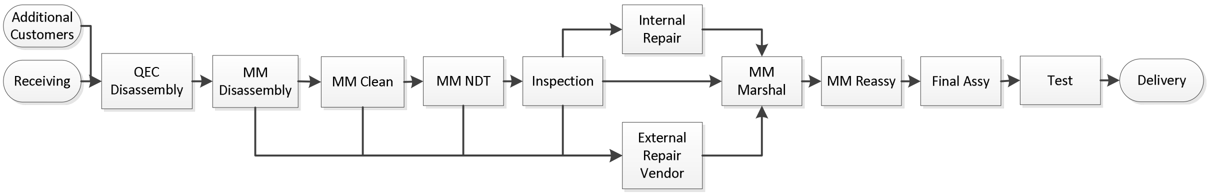


Figure 50 Scenario 12

Scenario 12 (Figure 50): MRO Shop Floor + Repair Vendor + Base Station. The additional repair vendor to the non-OEM MRO and base station will enable the service provision enhancement. The offering can provide both the scheduled and unscheduled maintenance. Nevertheless, the repair vendor can tackle the limited shop floor capacity and capability of the shop floor.

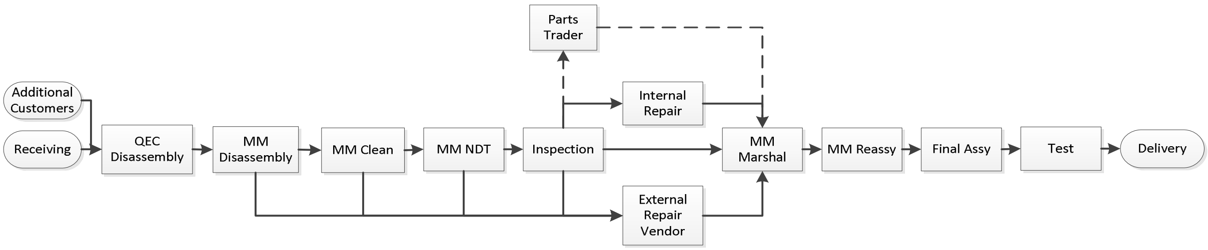


Figure 51 Scenario 13

Scenario 13 (Figure 51): MRO Shop Floor+ Repair Vendor + Parts Trader + Base Station. The additional MRO shop floor, repair vendor, parts trader and base station are the common configurations in the non-OEM MRO. The repair vendor will enhance the capacity and capability of the shop floor to support the limited major module capacity and capability maintenance. The parts trader will enable the non-OEM MRO service provider to choose the best distributor and specification to guarantee the quality of the maintenance. Although non-OEM MRO has limited capability and capacity, the additional service provisioning configuration will be able to support non-OEM MRO and enhance its performance.

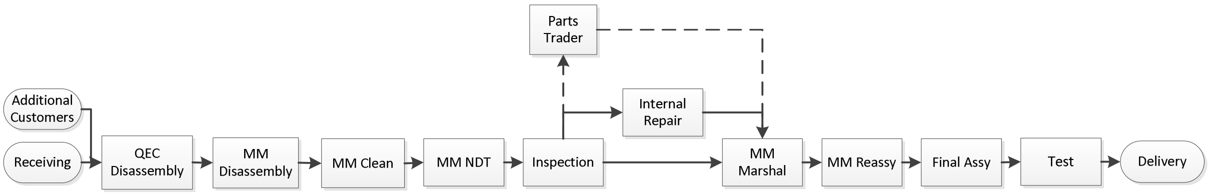


Figure 52 Scenario 14

Scenario 14 (Figure 52): MRO Shop Floor+ Parts Trader + Base Station. The non-OEM MRO service provider usually has the total capability to conduct all maintenance. However, it requires the spare parts provisioning to be able to offer the maintenance package offering to the customers.

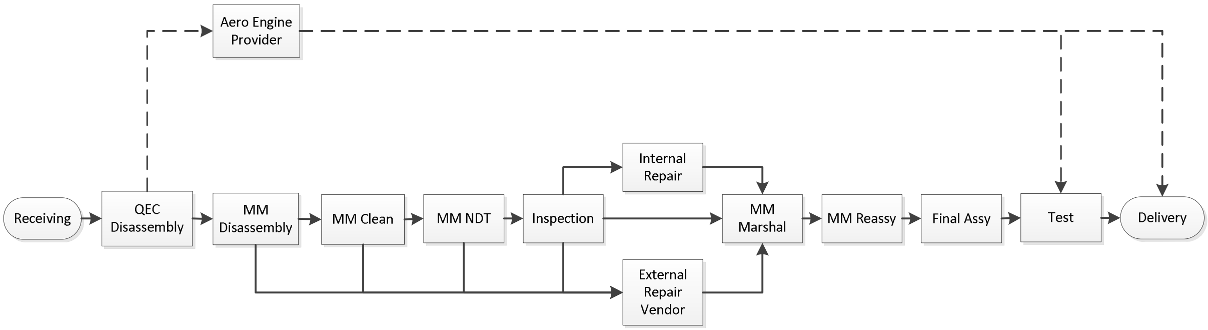


Figure 53 Scenario 15

Scenario 15 (Figure 53): MRO Shop Floor + Repair Vendor + OEM. This configuration is usual for the limited capability and capacity non-OEM MRO. The non-OEM MRO addresses the limitation by adding service provisionings, such as external repair outsources and the aero engine provisioning.

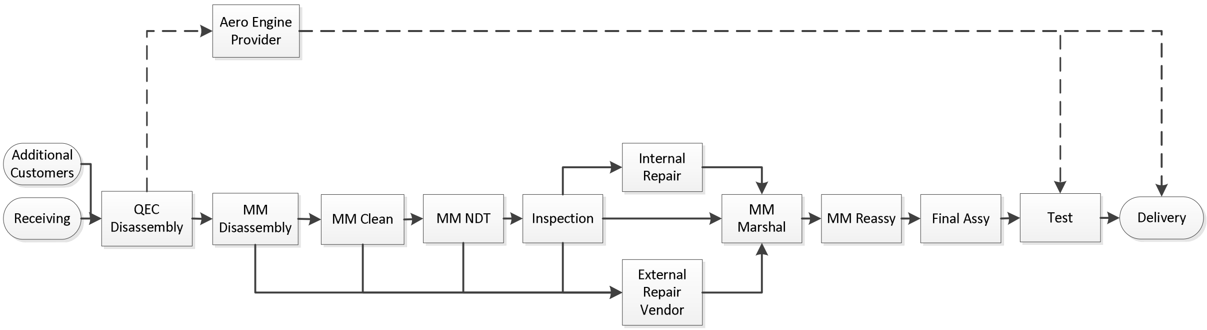


Figure 54 Scenario 16

Scenario 16 (Figure 54): MRO Shop Floor + Repair Vendor + OEM + Base Station. This configuration enables the low capability non-OEM MRO to provide for more customers. in this scenario, the organisation can outsource all capability to fulfil the customers' enquiries.

6.6 Chapter Summary

This chapter presents how the research utilises the experimentation from the computer model simulation. To represent the service configuration of the non-OEM MRO service provider, the model considered different combinations of service configurations using Discrete Event Model Simulation. The relation between the aero engine maintenance demands based on the customers' flight operations and the operation of the non-OEM MRO shop floor operations is detailed in this chapter. The experimentation scenarios will assess the type of the service configuration from the productisation of service methodology, adding more services and products (i.e. aero engine, spare parts) to provide the offering to the customers.

7 Scenario Simulation

In the case study chapter, the research will conduct the computer based simulation in order to analyse possible scenarios in a view to combine the service and the product. Section 7.1 introduces this section which illustrates the case study's background. Section 7.2 shows maintenance demand forecast involved in this research. Section 7.3 represents the shop floor operational capability as a result in assessing both the customers' demand and the shop floor's available resources. Section 7.4 the results then depicted by graphs which represent the shop floor performance. Section 7.5 discusses the classification of the service delivery. and section 7.6 summarised the chapter's case study based on the result.

7.1 Introduction

The simulation result models the maintenance shop floor process from the aero engine maintenance input from the case company A with airline G. Based on the case study, the input data of the total aero engine fleet from airline G is assessed into the model.

This simulation result output will consist to shop floor performance measurement. These are (1) Throughput time/ turnaround time (TAT); (2) Work in Progress WIP; (3) Level of Utilisation; (4) Productivity; (5) Man hours needed for each job; and (6) total person hours needed.

The input of the maintenance demand is the same. The maintenance demand covers seventy-four aero engines. Based on the flight operation described in the previous chapter, these will be ninety-nine of the total scheduled maintenance. The 99 maintenance are scheduled based on the flight cycle and flight hours which will be reached in 10 years of the contract duration. The unscheduled maintenance also includes several scenarios. The unscheduled maintenance is the average total of the maintenance in the contract duration period. The unscheduled maintenance represents the required additional maintenance.

The model has taken the detail into the sub major module maintenance on the shop floor. The lower level of the spare parts and component levels are taken into the maintenance process in a machine. The subparts which comprise the major module (smaller components) have not taken into this research. Therefore, several assumptions are mentioned as a limitation of this model. The input material such as spare parts assumed will always be available. The labour allocation is based on the group consisting of employees. This model is not concerned with the number of minimum labour requirements in each process. Each maintenance process will have a dedicated labour group. Each maintenance process presents one maintenance process.

7.2 Maintenance Demand Forecast

7.2.1 The aero engine specification input

Table 21 shows the aero engine information example as the input for the model in this research. This data was obtained from the Flight Data Analysis from Airline A. The total number of aero engines to be conducted in this maintenance contract is 74, which was previously mentioned.

Table 21 Aero Engine Information Examples

No	Status	Model	Engine	In **Service Date**	**Age (Yrs)**	**Hour**	**Cycles**
1	In-Service	737-800	CFM56-7B26E	20 Feb 2014	3	8273	5448
2	In-Service	737-800	CFM56-7B26E	14 Apr 2014	3	7772	5181
3	In-Service	737-800	CFM56-7B26E	18 Feb 2015	2	5245	3588
4	In-Service	737-800	CFM56-7B26/3	10 Feb 2010	7	20894	13533
5	In-Service	737-800	CFM56-7B26/3	05 Feb 2010	7	20993	13328
6	In-Service	737-800	CFM56-7B26/3	16 Feb 2010	7	20774	13513
7	In-Service	737-800	CFM56-7B26E	25 Mar 2015	2	5232	3425
8	In-Service	737-800	CFM56-7B26/3	22 Mar 2010	7	20415	13394
9	In-Service	737-800	CFM56-7B26/3	19 Apr 2010	7	19046	12321
10	In-Service	737-800	CFM56-7B26/3	09 Jul 2010	7	19564	12651
11	In-Service	737-800	CFM56-7B26/3	11 Aug 2010	7	19097	12565
12	In-Service	737-800	CFM56-7B26/3	21 Sep 2010	7	18882	12252
13	In-Service	737-800	CFM56-7B26/3	22 Oct 2010	7	18710	12106
14	In-Service	737-800	CFM56-7B26/3	17 Aug 2010	7	18881	12564

Once the data consisting of the historical maintenance and the specification is obtained, the decision-makers can predict the future maintenance event based on the average maintenance requirements. In this situation, the airline has the similar operation requirement each day for ten years.

Table 22 Engine Specification Input (example)

Engine Specification	
Type	CFM56-7B26E
Thrust Setting	25,900 lbs
Derate Factor	0%
Operational Specification	
Operational Region	Hot/Harsh
Flight Leg	6.5
Flight Cycle (FC) Goal	7,000 FC
Annual FH	2500
Start Date	26 June 2016
Term List (month)	120

Once the customer information data is obtained, the data can be used to predict the maintenance forecast in the future. Table 22 represents the example of an aero engine operation which is operated by a customer. The input data from Table 21 will then be processed using the parameter in Table 22.

7.2.2 The aero engine maintenance event scheduled

Once the aero engine input maintenance and the operational factors have been taken into the ‘input module’, the decision-makers can obtain the aero engine maintenance scheduled maintenance. Then, the scheduled maintenance can be used as the input for the non-OEM MRO shop floor. In addition, the unscheduled maintenance based on the non-OEM MRO data has also been taken on the shop floor. The unplanned or unscheduled maintenance are generated from the main hangar or base station in the model. The unscheduled or unplanned maintenance arrival pattern is adopted from the non-OEM MRO company’s actual data in a year.

Table 23 represents the aero engine scheduled maintenance for each aero engine. In this table, the assumption of the total aero engine maintenance events for ten years will be about 99 maintenance events. Each aero engine work scope will vary. However, at least, this event will represent the routine shop visit.

Table 23 Aero Engine Maintenance Scheduled Event.

No	ESN	Rating Type	Thrust	In service Data	Schedule
1	405x	CFM56-7B26E	26300	20 Jun 2014	Mar-17
2	412x	CFM56-7B26E	26300	16 Jun 2014	Apr-17
3	380x	CFM56-7B26E	26300	05 Jun 2013	Apr-17
4	412x	CFM56-7B26E	26300	13 Sep 2014	Apr-17
5	412x	CFM56-7B26E	26300	09 Oct 2014	Jun-17
6	413x	CFM56-7B26E	26300	15 Nov 2013	Jul-17
7	413x	CFM56-7B26E	26300	11 Dec 2013	Aug-17
8	413x	CFM56-7B26E	26300	03 Sep 2014	Sep-17
9	416x	CFM56-7B26E	26300	27 Jan 2015	Sep-17
10	417x	CFM56-7B26E	26300	26 Jun 2014	Sep-17
…	….	….	….	….	….
…	….	….	….	….	….
…	….	….	….	….	….
99	399x	CFM56-7B26E	26300	18-Feb-15	12-Jun-27

Once the aero engine maintenance event from the fleet is obtained, the decision-makers will have to conduct the shop floor assessment through the shop floor simulation model in the next chapter.

7.3 Shop Floor Operational Capability Result

This subchapter will assess the information to the shop floor. Once those parameters are obtained, the decision-makers will be able to manage the most efficient implementation to outsource provisioning. The information will also inform the policy makers on the investment level trade-off between the demand and the feasibility profit for each shop floor configuration. However, there is need to conduct further analysis to assess the shortage in the maintenance process.

In this subchapter, the presented figure is based on the scenario 1. The other scenarios will be represented in the **Error! Reference source not found.**. The numbers represented below will present on how the capacity and the capability of the scenario 1. Scenario 1 is when the non-OEM MRO service provider conducts its offering as pure maintenance service provider.

7.3.1 Number of Operations for each Maintenance Process

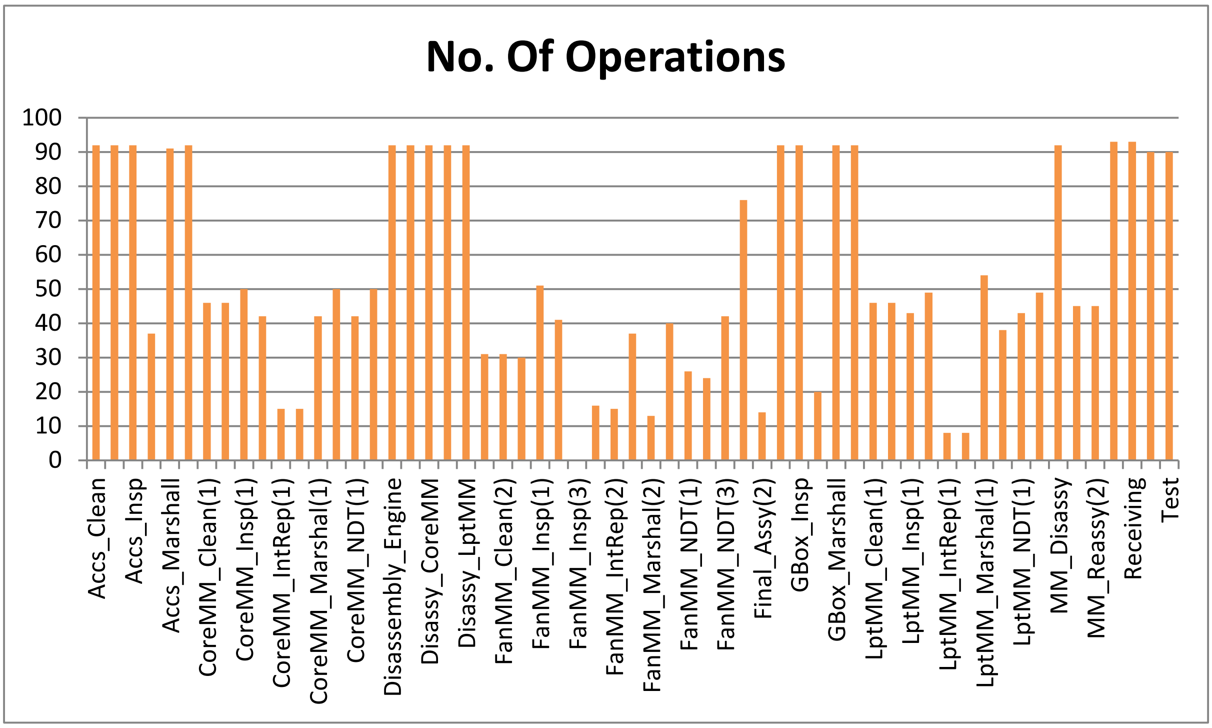


Figure 55 Number of Operations for each machine Process in Scenario 1

Figure 55 Number of Operations for each machine Process in Scenario 1. The number of operations in this graph represents the total number operations or cycles that the machines have completed. This number presents the total number of transactions for each maintenance process. The graph shows that most of the non-OEM MRO service provider has similar maintenance process. A complete maintenance process for an overhaul work scope normally needs 90 calendar days.

Based on the figure, the non-OEM MRO service provider will need more capacity and capability in the joint maintenance processes such as cleaning, inspection, marshalling, disassembly for the sub-major module, inspection, major module disassembly, the preliminary inspection test, the receiving and the test. This information provided can give a further illustration of what will happen to the non-OEM MRO service provider if they use the first scenario to fulfil the customer’s operations requirements in the future.

7.3.2 Busy level for each maintenance process

The busy parameter represents on how long the machine spent as busy. The activities of the maintenance process on the shop floor can account for the utilisation of the aero engine maintenance. In the discrete event simulation, the activity level of each process can be assessed. The decision-makers can utilise the information to implement the outsourcing provisioning strategy.

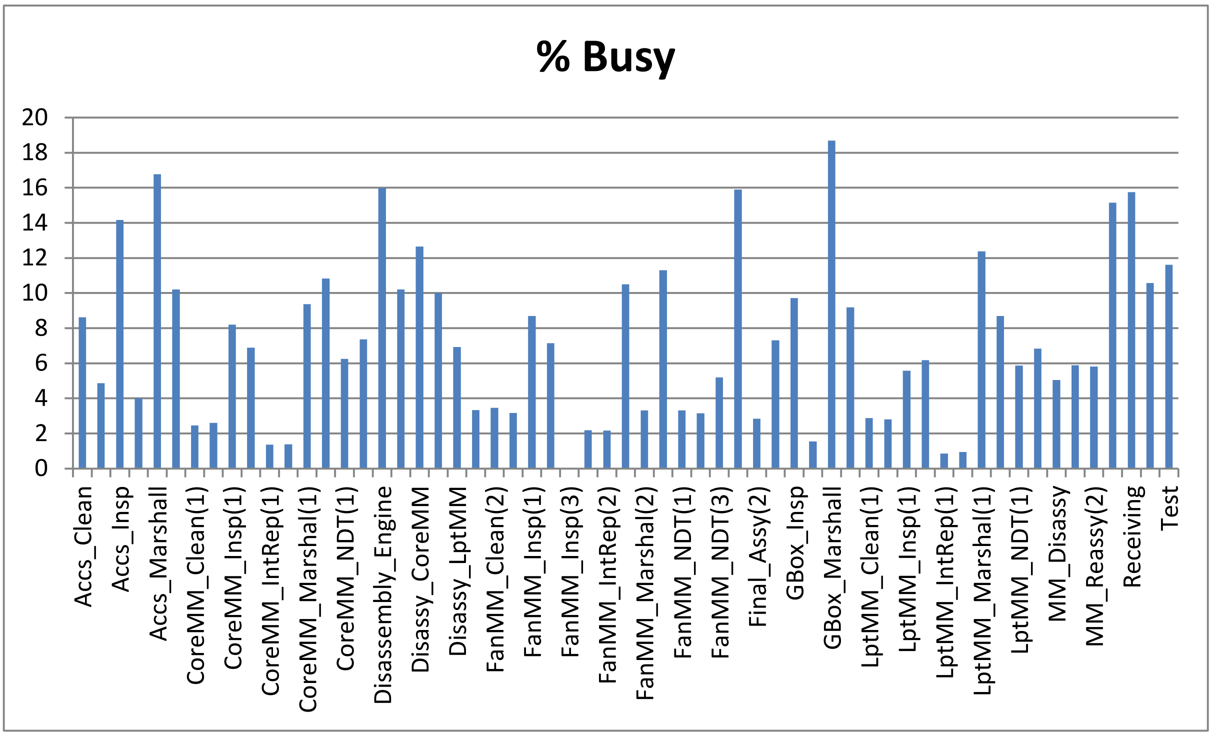


Figure 56 Busy Level in Scenario 1

The activity standards of the aero engine maintenance process for each level is represented by Figure 56. This figure indicates that the busiest maintenance process is the gearbox marshalling. The marshalling process of the gearbox module in this scenario has the longest time to finish. This situation is related to the previous subchapter referring to the level of blockage.

Based on the figure, the common busiest maintenance process is in the gearbox marshalling process. This situation has affected to the other following parameters which will be mention by next subchapter. Then, the %busy followed by accessories' marshalling, the engine disassembly and the Fan's NDT. The accessories major modules have many smaller spare parts which require more time than the other major module. In addition, the engine disassembly requires time as it has much complex procedures that the aero engine mechanics need to follow. The FanMM NDT then followed as it has many large-sized components (fan blades).

7.3.3 Blocked Maintenance Process

In this situation, the blocked process defines on the percentage time that the machine spent in a blocked state. The blocked state is relating to the machine state of busy which mentioned in the previous subchapter 7.3.2. The blocked state can be generated to wait for following process or waiting for labour to arrive. Based on the limited capacity and capability, the maintenance system operation may suffer blockage. The blocked process is usually caused by the uneven rate between the input and the cycle time of the maintenance process. However, the policy to add maintenance capacity is not always the solution.

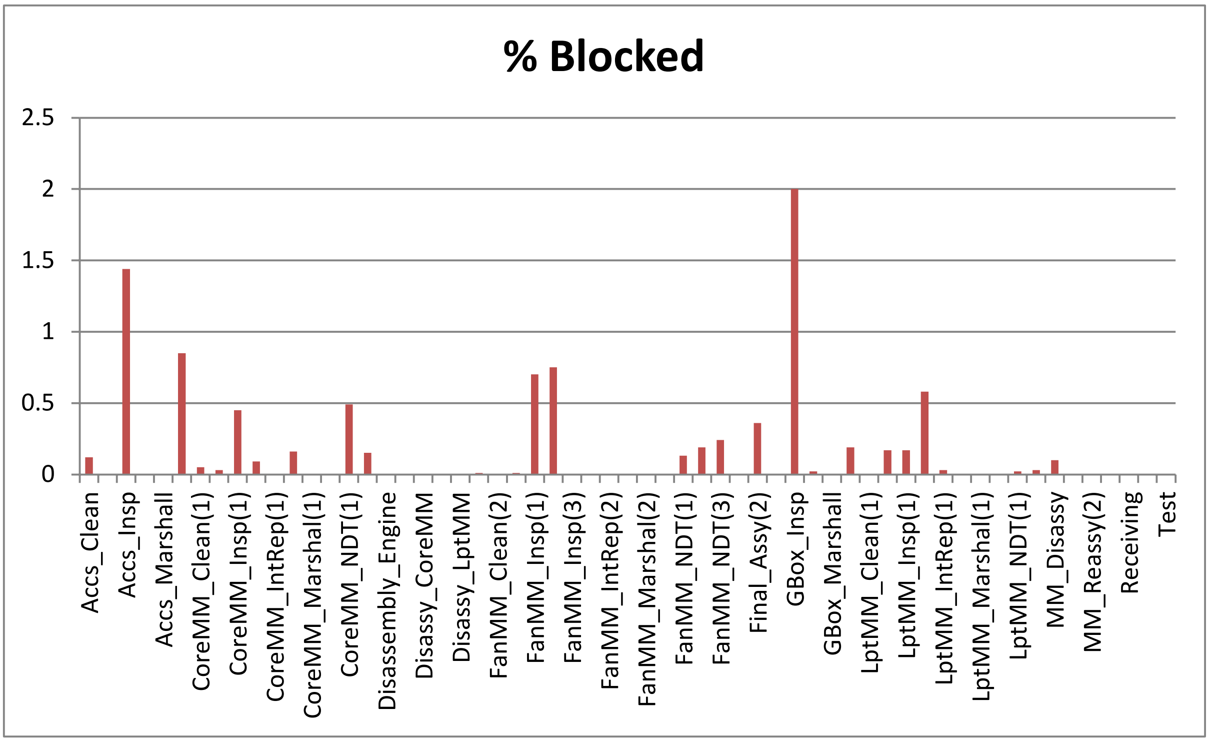


Figure 57 Blocked Level for each process in the Scenario 1

Figure 57 illustrates the degree of blockage in each process in scenario 1. The aero engine maintenance process from this configuration will have the greatest degree of blockage from the gearbox Inspection. This situation is caused by the limited capacity and capability in the gearbox inspection process. However, the level of blockage in this maintenance is about 2% which will have little effect on the rest of the maintenance process.

As illustrated in Figure 57 most of the blocked process is gearbox inspection. Followed by the accessories inspection and marshalling. The gearbox inspection happens to need more time rather than other parts inspection. Then, this accessories inspection has also blocked as it needs the other accessories in the marshalling process. Therefore, the non-OEM MRO service provider needs to concern in enhancing the capacity and capability in managing the maintenance line for both the accessories module and the gearbox.

7.3.4 Cycle Waiting Labour for each maintenance process

Labour has an important part role to play on the shop floor. The mechanic conducts most of the maintenance processes. In this model, the maintenance process will combine the availability of the engineer, tools, machine and the skills.

Figure 58 provides information regarding the percentage of the maintenance process which needs to wait for labour to be available. The labour in this maintenance represents the mechanic conducting the maintenance. It is related to previous parameters indicating that the most processes which need more labours the gearbox marshalling. Therefore, we can assume that the gearbox marshalling process has less labour than it should have.

Based on Figure 58, the most maintenance process which requires more labour is the gearbox marshalling process. Then followed by the FanMM NDT and the receiving process (maintenance process). Therefore, related to the previous parameters mentioned before, it can be seen that this non-OEM MRO service provider need more labour to support their maintenance operation ability.

By using this information obtained from the witness model simulation, the decision makers can be informed in deciding the best policy towards the non-OEM MRO shop floor operation ability. The proposed method from this research can generate a result which then can be used to implement the most efficient investment strategy to the maintenance shop floor. Based on these parameters, the decision-makers will be able to ascertain which process that is less effective between maintenance processes. This information will also be obtained for each maintenance configuration process. In this case, as the example adopted, the non-OEM MRO service provider has fewer labours as required.

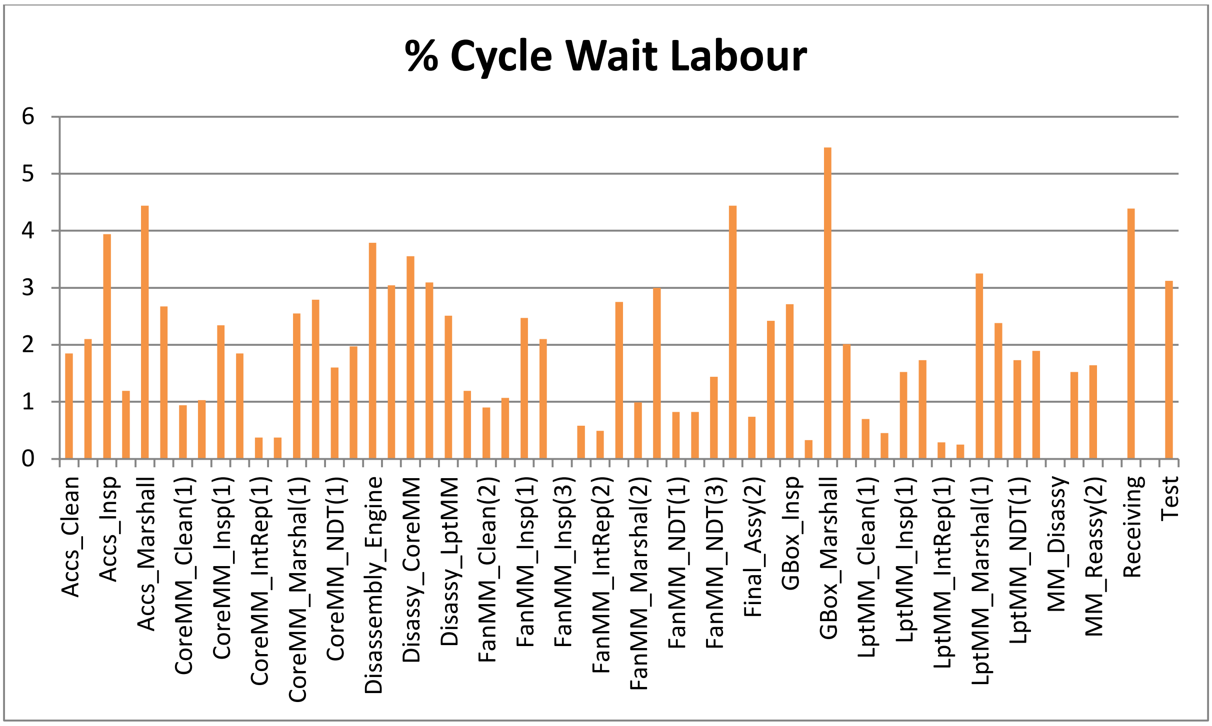


Figure 58 Process Wait for labour in Scenario 1

Once the decision-makers and the customers have selected the best scenario to accommodate the requirements, the policy makers can also see the least efficient the aero engine maintenance and develop a more informed decision-making process.

7.4 Output Level Performance Results

The performance measurement from the shop floor operations has been obtained. The experimentation has been conducted through five different Pseudo Random Numbers (PRNs) to enhance the validity and clarity of the output 24

Witness simulation software provides the random numbers for the user. The PRNs can be configured in each of the distribution function in a machine or process. The machine cycle time uses the exact figure or the distribution. The randomness of the distribution result can be obtained by adding the PRNs for each maintenance cycle time. Therefore, the model will use several PRNs to identify the validity of the shop floor model.

Pseudo Random Numbers (PRNs) is a sequential number which is randomly provided by Witness. The model has taken the PRNs to enhance the stochastic level of the model and simulation which represents the uncertainty of the real situation. The PRN numbers used are 1, 7, 77, 88, and 14 for each distribution.

7.4.1 Throughput Time or TAT

Throughput time or turnaround time is the most significant parameter in the aero shop engine floor. The TAT represents the total number of days since the aero engine entered the engine shop to the delivery back to the owner. In the aviation industry, the aero engine will give benefit only if it can fly. Therefore, the TAT can determine the total aero engine readiness for the duration of the contract.

Total days for maintenance can be derived from the total maintenance the aero engine needs throughout the contract duration, multiplied by the maintenance’s duration (TAT). The throughput means the maintenance time required for the aero engine. In the non-OEM MRO environment, throughput is called Turnaround Time (TAT). The throughput time is calculated from the aero engine’s arrival on the shop floor until it is shipped from the non-OEM MRO service provider.

Figure 59 illustrated the average TAT for each scenario. A contract duration of 10 years between airline G and the non-OEM MRO service provider A has led to variances in the TAT. The additional outsource of the service provision, the parts provision, and the aero engine lease varies in several scenarios.

Table 24 Scenario with Different PRNs

No	Scenario	TAT					Average	Std Deviation
		PRN 1	PRN 7	PRN 77	PRN 88	PRN 14		
1	Scenario 1	86.53	87.27	86.42	86.26	87.3	86.756	0.49
2	Scenario 2	86.62	85.87	86.32	85.45	85.52	85.956	0.51
3	Scenario 3	84.72	84.39	84.32	83.97	85.2	84.52	0.46
4	Scenario 4	78.24	78.74	77.28	78.34	77.83	78.086	0.55
5	Scenario 5	78.52	78.41	78.61	78.42	79.26	78.644	0.35
6	Scenario 6	85.83	86.34	86	86.26	86.03	86.092	0.21
7	Scenario 7	79.63	79.98	79.14	79.09	78.94	79.356	0.43
8	Scenario 8	78.46	78	77.96	79.37	78.76	78.51	0.58
9	Scenario 9	80.83	80.73	79.34	80.13	80.21	80.248	0.59
10	Scenario 10	79.91	80.69	80.61	81.36	80.52	80.618	0.52
11	Scenario 11	91.12	92.14	90.33	91.54	90.1	91.046	0.84
12	Scenario 12	89.25	88.91	89.78	88.9	87.6	88.888	0.80
13	Scenario 13	89.49	88.74	88.49	89.26	88.35	88.866	0.49
14	Scenario 14	87.35	87.12	87.17	86.82	87.91	87.274	0.40
15	Scenario 15	79.7	79.06	78.84	78.1	77.93	78.726	0.72
16	Scenario 16	79.52	78.52	78.55	78.39	80.05	79.006	0.74

The parts trader will provide the required components for the maintenance execution. This will shorten the duration in provisioning the components. It is mentioned in scenario 3; the non-OEM MRO service provider has also combined outsource for major module repair. This policy can be helpful if the non-OEM MRO service provider does not have authorisation to repair it or when they have full capacity.

Scenario 11 has the highest average TAT level with 89.97 days in a maintenance event. This situation is due to the service provider not collaborating with the parts trader and OEM. The non-OEM MRO service provider provides the service offering to the unscheduled maintenance and another airline in this scenario. Additional work and maintenance demands have resulted in the higher TAT for this scenario. In this configuration, the major module can be sent to external repair vendor. However, this strategy is not adequate to reduce the TAT level significantly.

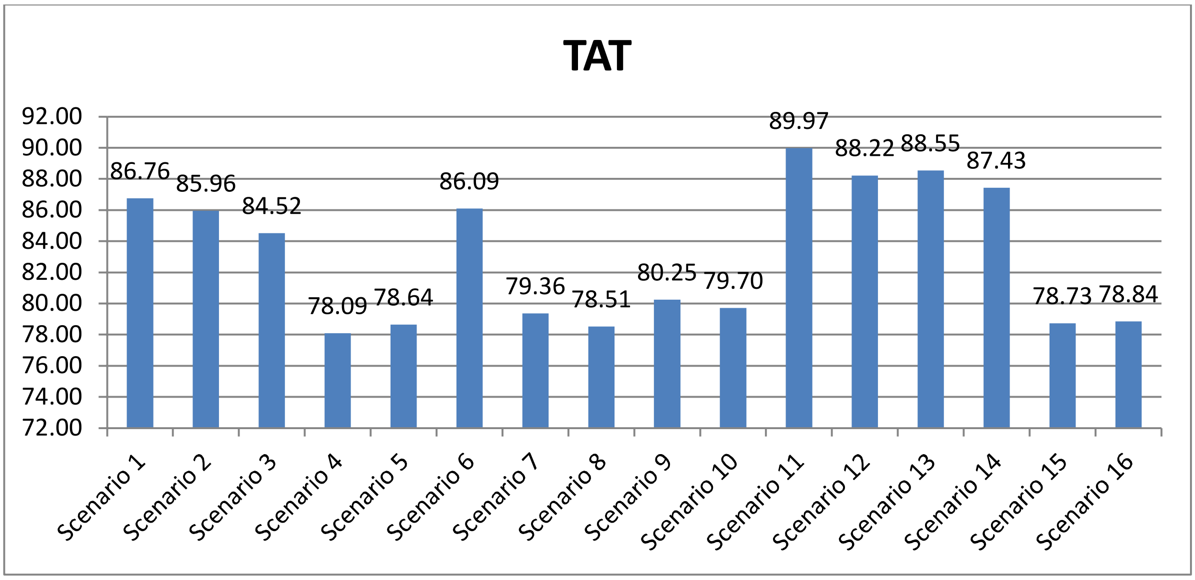


Figure 59 Average Turnaround Time (TAT) for each scenario

Based on Figure 59, there is a trend to the TAT. The TAT will become faster if the non-OEM MRO service provider implements the outsourcing configuration to its shop floor operations. As in the scenario 2, the average TAT will shorten due to the external repair vendor involvement. This situation, caused by the maintenance, can be sent to the repair vendor as external repair outsource.

In scenario 3, the situation differs to scenario 2. In scenario 3, the non-OEM MRO service provider adds the parts provisioning offering to the customer. The parts trader will be responsible for the defective spare parts provisioning. It can serve spare parts pooling, and trade to shorten the parts provisioning, compared to buying from the OEM service provider. However, this will not reduce the TAT as much as being supplied from the components trader; the non-OEM MRO service provider still needs to conduct the maintenance disassembly process to obtain the components. They have to carry out the process to the component level work scope. Therefore, the components trader configuration in this situation does not imply much to the TAT performance.

In scenario 4, the non-OEM MRO service provider configures the relationship with OEM or lessor as the aero engine provider. In this situation, the non-OEM MRO service provider can swap or return the aero engine in the QEC (Quick Engine Configuration) form. The QEC swap can take place in the first process. In this case, the non-OEM MRO service provider does not have any requirements to do further maintenance procedures. Therefore, the TAT can be shortened significantly.

In the scenario 5, the non-OEM MRO service provider will collaborate with the repair vendor, parts trader, and OEM/lessor. The configuration can address the non-OEM MRO’s limited capacity and capability. The base station in this situation also offers the unscheduled maintenance work scope repair from another airline as well.

In the scenario 6, the non-OEM MRO service provider obtain the components to the spare parts trader. They enhance the level of partnership to become availability based contract in providing the components. This situation increases the TAT performance. The partnership with the non-OEM MRO service provider will beneficial in reduce the TAT level to the airlines. However, it will not be significantly shortened. However, this configuration still makes the non-OEM MRO shop floor operation do a high number of the maintenance operations. The components outsourcing will slightly increase the TAT performance of the shop floor.

Scenario 7 is based on scenario 6 with the OEM/lessor involvement. The OEM/Lessor is responsible for providing the aero engine in the QEC form. It is the fastest and easiest way as the non-OEM MRO service provider only needs to remove it from the aircraft or the aero engine as it is to be sent to the OEM/Lessor. Then, the OEM will assist the non-OEM MRO service provider to supply a serviceable aero engine.

In scenario 8, the non-OEM MRO service provider adds the unscheduled maintenance. It is possible that orders will be received from the other airlines. This situation impacts the increase of the maintenance requirements for the non-OEM MRO shop floor operation. Therefore, the TAT is slightly higher. A small increase is caused by the assistance given to the outsourcing configuration with the Parts Trader and OEM/lessor.

In scenario 9, the non-OEM MRO service provider is responsible for the scheduled maintenance only. In this scenario, the non-OEM MRO service provider collaborates with OEM/Lessor to provide the aero engine. In this scenario, the TAT will shorten compared to Scenario 8.

Scenario 10 is scenario 9 with an additional unscheduled maintenance offering (base station). In this scenario, the TAT will be slightly higher than in scenario 9. The OEM seems to help the non-OEM MRO service provider to increase the TAT performance significantly.

In scenario 11, the non-OEM MRO service provider does not take outsourcing policy. In this scenario, the non-OEM MRO service provider also provides the base station (unscheduled maintenance). This scenario will have the highest turn-around time level of the non-OEM MRO service provider.

Scenario 12 has adopted scenario 11 with additional external major module repair vendor collaboration. The external vendor will be responsible for fixing the aero engine major module for the non-OEM MRO service provider. The outsource can happen if the non-OEM MRO service provider does not have any capacity or does not have a slot to conduct the maintenance. By collaborating with the external repair vendor, the TAT performance is better than without help from the external repair vendor (scenario 11).

Scenario 13 is scenario 12 with an additional policy to outsource the spare parts to support the non-OEM MRO shop floor operation. It is clear that the assistance of the additional parts trader will increase the average TAT. The addition of the components will increase the chance that the non-OEM MRO service provider increases the TAT. The situation involves the non-OEM MRO service provider must conduct processes of the aero engine to more detailed work scope (for component). The same capacity of the maintenance only will increase the TAT.

Scenario 14 is the configuration where the aero engine non-OEM MRO service provider relies on the spare parts provisioning from the spare parts trader. In this scenario, the non-OEM MRO service provider also accommodates the aero engine unscheduled maintenance into the offering. The components provisioning outsource policy will slightly increase the TAT performance level.

Scenarios 15 and 16 have similarities in outsourcing their shop floor operations to the repair vendor and OEM/lessor. The difference is the base station involvement for scenario 16. The unscheduled maintenance offering in scenario 16 will stretch the average TAT from the non-OEM MRO service provider. It indicates that the repair vendor outsourcing and the OEM/lessor will assist the non-OEM MRO service provider in retaining their TAT performance. Therefore, additional capacity through outsource repair and parts provisioning could increase the TAT performance.

7.4.2 Total Man hours

One of the parameters in the contract preparation is the cost of production. In this research, the cost production is the total man hours. Any other parameter such as material is assumed to be the same for each work scope. Each work scope and the price of spare parts are assumed the same from the same components distributor. Therefore, the acknowledgement of total man hours is necessary. Also, the main profit generator in service provider is the labour utilisation.

Table **25** represents the total man hours needed for each configuration. In this research, we used at least five Pseudo Random Numbers (PRNs) to see the deviation between each result. As mentioned in the table, the deviation is less and unaffected the result.

Figure 60 presents the total man hours needed to finish the contract duration based on the situation. The total man hours required for each scenario represented by Equation 18.

Equation 18

$$Total\ Manhours = (\sum Sum\ of\ Number\ of\ Jobs\ needed * average\ time\ per\ jobs$$

As the pure non-OEM MRO service provider, the total man hours in scenario 1 is around 14407. This parameter is in days. Therefore, the total man hours has to be multiplied by a number of days worked.

Table 25 **Total Man hours**

No	Scenario	Total Man hours					Average	Std Deviation
		PRN 1	PRN 7	PRN 77	PRN 88	PRN 14		
1	Scenario 1	14408.89	14478.06	14315.66	14418.31	14414.37	14407.06	58.26
2	Scenario 2	11475.12	11464.06	11419.06	11421.13	11375.36	11430.95	39.92
3	Scenario 3	11304.83	11294.6	11248.89	11272.83	11262.95	11276.82	22.85
4	Scenario 4	9781.52	9799.82	9685.69	9819.05	9731	9763.416	54.41
5	Scenario 5	23498.98	23437.41	23415.09	23407.11	20451.63	22842.04	1336.77
6	Scenario 6	14032.8	14082.29	14022.93	13999.55	14021.7	14031.85	30.70
7	Scenario 7	12192.97	12164.81	12093.44	12096.78	12065.65	12122.73	53.60
8	Scenario 8	27953.79	26067.04	26877.55	26098.8	27488.7	26897.18	835.65
9	Scenario 9	12490.12	12551.6	12423.96	12421.07	12416.35	12460.62	59.19
10	Scenario 10	26761.13	27194.66	23209.4	29598.32	28090.57	26970.82	2366.43
11	Scenario 11	35985.87	35906.55	35772.09	35865.15	32197.14	35145.36	1649.91
12	Scenario 12	28682.87	28814.56	28529.5	28609.93	25498.47	28027.07	1417.41
13	Scenario 13	28369.68	28426.11	28293.45	28251.38	25506.45	27769.41	1266.83
14	Scenario 14	27515.37	27509.43	27499.37	27455.05	23077.7	26611.38	1975.53
15	Scenario 15	9916.63	9926.3	9896.09	9868.64	9821.72	9885.876	42.12
16	Scenario 16	23626.85	23660.95	23574.69	23588.17	22052.58	23300.65	698.51

The additional spare parts trading configuration in scenario three has reduced the total man hours slightly. By adding the spare parts provisioning, the non-OEM MRO service provider still should do more of the disassembly processes at the lower level than the non-OEM MRO service provider. Therefore, the addition of the spare parts trader will not reduce the man hours worked significantly.

In scenario 4, the non-OEM MRO service provider can also offer the aero engine provision to its customers. The OEM or lessor can provide the QEC configuration. In some cases, the non-OEM MRO service provider does not require any maintenance processes. The aero engine can be swapped with the serviceable aero engine in the shortest time. Therefore, the total man hours needed is lower than before. This scenario will allow the shop floor to outsource most of the work. The non-OEM MRO service provider will need less resource with this configuration. The lowest number of man hours needed is in scenario 4. In this scenario, this depends on the non-OEM MRO service provider outsourcing both the repair and the spare parts provisioning. Therefore, less manpower will be used to fulfil the maintenance demand in this situation.

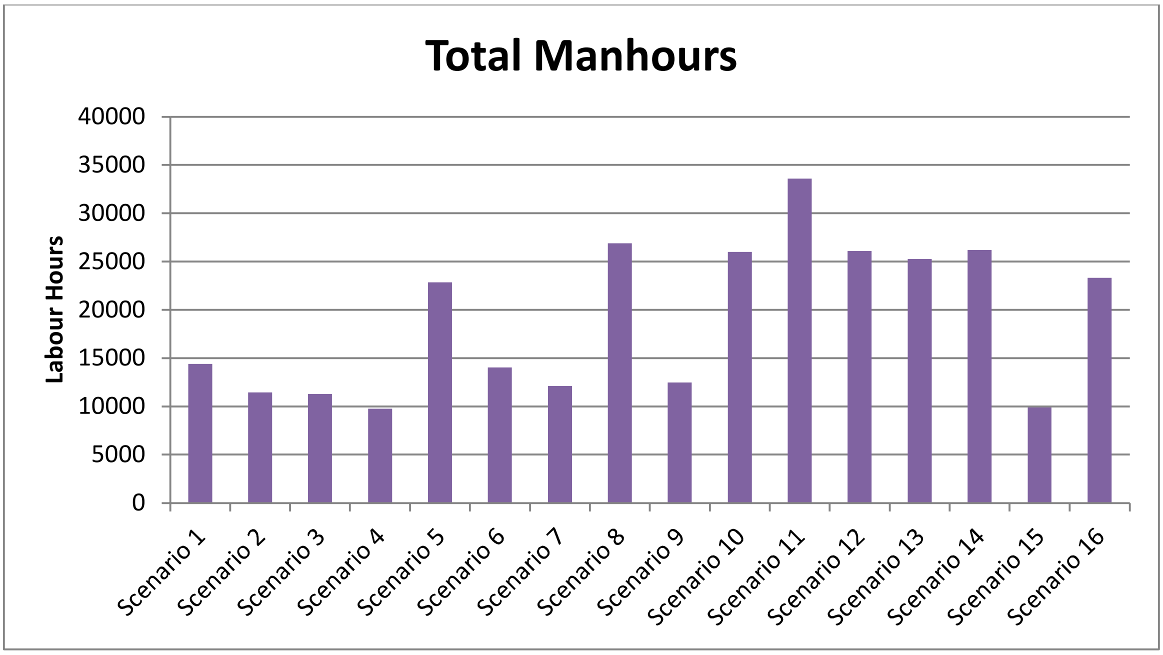


Figure 60 Total Manhours

The most sophisticated configuration is in scenario 5. In this scenario, the non-OEM MRO service provider is adding the Repair Vendor, parts trader, OEM/lessor or the base station. Much of the work can be outsourced to reduce the total maintenance operations. The most significant factor can increase the total man hours for the service provider. This configuration will also incorporate the base station. A base station means that the non-OEM MRO service provider will not only be accommodating the scheduled maintenance, but also the unscheduled maintenance.

In the scenario 6, the non-OEM aero engine MRO service provider also provides the spare parts provisioning. The spare parts provisioning as mentioned previously, will not be able to reduce the total man hours significantly. The non-OEM MRO service provider still needs to conduct the maintenance and disassembly process.

In scenario 6, the non-OEM MRO service provider will add the components provision as a bundle to its customer. In scenario 7, the OEM or lessors have a responsibility to provide the aero engine. Based on the simulation, this configuration can reduce the man hours needed to the customers. The OEM can assist the non-OEM MRO service provider to tackle the limited capacity and capability. The additional spare parts provisioning will be able to reduce the total marshalling time with less effect on the reduction of man hours.

By adding a base station to the previous scenario, seven configurations have resulted in increased man hours. The repair vendor and the OEM are the best combinations to be included in the configuration.

In the base station of the non-OEM MRO and aero engine provider (OEM or lessor) configuration (configuration 10), the total man hour's level l is like configuration 8. The additional scheduled maintenance and unscheduled maintenance from the customer also increases the maintenance demand and the processes for the non-OEM MRO service provider. In comparison to configuration 8, the spare parts provisioning will increase the total labour.

In scenario nine, the non-OEM MRO service provider creates a configuration by adding the OEM/lessor to its operational service. As the contract in the configuration will only manage the scheduled maintenance, the total man hours needed is less. The addition of the OEM will also reduce the total man hours significantly, compared to the conventional non-OEM MRO service provider configuration.

Scenario 11 has the highest total for labour. In this situation, the non-OEM MRO configuration acts as a simple maintenance service. With the additional unscheduled maintenance, it will increase the maintenance processes operation to fulfil the demand. It means that if the non-OEM MRO service provider has the advantage in the low labour rate, scenario 11 can be used to obtain more profit, due to the possibility of a higher profit margin.

In scenario 12, the non-OEM MRO service provider configures the operation with the repair vendor to fix the major module parts. The external repair vendor will assist the non-OEM MRO shop floor in case there is no capacity or capability at the time. The base station causes the most factors that increase the total man hours.

In the non-OEM MRO service provider configuration 13, a similar amount of man hours are needed. Adding the parts trader in the configuration will decrease the total man hours number slightly. The spare parts provisioning in the configuration will also help to reduce some of the maintenance process operation in the contract duration.

In scenario 14, the repair vendor of the aero engine is deducted. This deduction increases the total man hours.

Scenario 15 has the lowest man hours' requirement. The non-OEM MRO service provider configured with the Repair Vendor and OEM. The scheduled maintenance contract will also provide the aero engine maintenance. Although the scheduled and unscheduled maintenance is provided, the additional configuration of the OEM and repair vendor will help the shop floor operation's limited capacity and capability. This configuration required the lowest man hours in this case

The last scenario in configuration 16 adds the base station, supported by the repair vendor and OEM. The unscheduled maintenance generated by the base station will also increase the total man hours to the non-OEM MRO service provider.

The additional provisioning for the unscheduled maintenance will increase the labour. Therefore, it is not only the number of jobs that will increase; the total labour requirement will do the same.

7.4.3 Average Work in Progress (WIP)

The average WIP represents the total number of the aero engines which are serviced on the shop floor. The number of aero engines conducted on the shop floor can provide the total number of aero engine spares for the customers. However, the additional parameter - the annual operational requirements - has to be included. The information can beneficial to the aero engine shop manager in deciding the best investment strategy. The investment strategy can be either adding more aero engines or adding shop floor capabilities.

Table 26 Average Work in Progress (WIP)

No	Scenario	Average WIP					Average	Std Deviation
		PRN 1	PRN 7	PRN 77	PRN 88	PRN 14		
1	Scenario 1	8.93	9.04	10.65	8.89	9.05	9.312	0.751
2	Scenario 2	12.72	10.57	8.92	10.61	10.59	10.682	1.349
3	Scenario 3	14.66	10.43	8.7	8.69	9.71	10.438	2.471
4	Scenario 4	15.37	11.01	9.23	7.58	8.4	10.318	3.097
5	Scenario 5	8.63	9.41	9.84	7.94	10.65	9.294	1.052
6	Scenario 6	8.91	8.94	8.87	10.68	12.73	10.026	1.696
7	Scenario 7	11.59	7.82	7.71	7.66	11.45	9.246	2.077
8	Scenario 8	13.56	15.97	11.52	10.65	12.12	12.764	2.082
9	Scenario 9	7.89	7.87	7.76	12.98	7.78	8.856	2.306
10	Scenario 10	9.68	18.74	7.77	7.5	12.15	11.168	4.624
11	Scenario 11	12.99	18.37	9.47	11.13	18.28	14.048	4.098
12	Scenario 12	9.45	31.71	9.61	9.09	12.54	14.480	9.730
13	Scenario 13	12.94	18.25	13.22	16.81	17.22	15.688	2.440
14	Scenario 14	4.12	8.97	7.84	4.06	16.22	8.242	4.970
15	Scenario 15	7.72	7.65	7.71	7.62	12.53	8.646	2.172
16	Scenario 16	6.99	13.98	12.38	9.47	7.95	10.154	2.955

Average work in progress (WIP) can represent the total number of the average aero engines on the shop of the floor. The total number in Figure 61 represents the number of aero engines requiring maintenance that are in the process. It can account for the average aero engine numbers daily. The average WIP indicates the total number of aero engines that need to be conducted on the maintenance shop floor. It excludes outsourced aero engines.

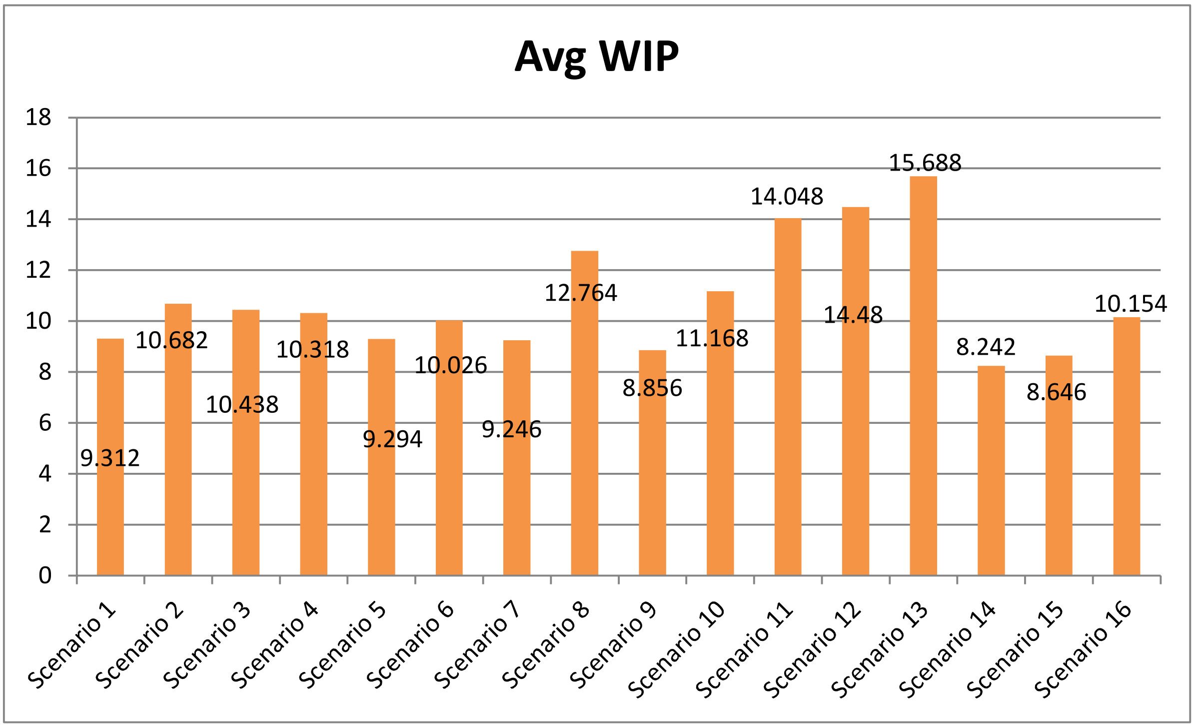


Figure 61 Work in Progress (WIP) levels for each scenario

Figure 61 illustrates the average WIP on the shop floor operation. The WIP represents the complete aero engine that has not been shipped due to the delay in the process. The number of WIP can provide information on how many aero engines should be prepared to trade off the aero engines on the shop floor.

Scenario 1 is the pure non-OEM MRO service provider which provides maintenance to the airline. This configuration is being utilised by an airline non-OEM MRO which dedicate their service to its parent airline. The contract in this configuration is related to the scheduled maintenance. In this matter, the assumption of the non-OEM MRO shop floor operation capacity and capability is always available.

In scenario 2, the addition of an external repair vendor to the major module will reduce the maintenance span time. The shorter TAT means that the shop floor can serve more aero-engines. The limited capacity and capability have led the non-OEM MRO service provider to outsource some of its projects to the customer. Therefore, the aero engine maintenance needs more time on the maintenance shop floor. The maintenance process needs to conduct the assembly process.

In scenario 3, the average WIP will be less on the shop floor, as the aero engine can be finished earlier due to the addition of spare parts provisioning process. The spare parts provisioning will reduce the average WIP to the aero engine.

In scenario 4, the amount of the additional aero engine as spare can be reduced. In this configuration, the non-OEM MRO are supported by the repair vendor, parts trader, and OEM. This configuration increases the maintenance process efficiency.

In scenario 5, although the non-OEM MRO service provider provides the unscheduled maintenance, the average WIP is less. The configuration of the shop floor production with additional spare parts, repair vendor and the base station can become the trade-off for the limited shop floor operational capacity and capability.

Scenario 6 represents the non-OEM MRO with the spare parts provisioning. The average WIP per day’s increases to 10.026; more configurations will hold up the aero engine maintenance further on the shop floor.

Scenario 7 is similar to scenario six but adds OEM. The average WIP listed to the 9.246; represents the more efficient shop floor configuration to cope with the non-OEM MRO service provider shop floor operational capacity capability.

Scenario 8 has increased the average WIP to 12.764. The additional base station has also forced the shop floor limitation to stretch the average WIP. The unscheduled maintenance and ad-hoc maintenance requirements can affect the shop floor operational performance.

Scenario 9 has the non-OEM MRO service provider with the OEM configuration. The OEM enhances the shop floor performance significantly. This scenario and configuration assist the non-OEM MRO service provider in tackling the shop floor operational limitation.

In scenario 10, the non-OEM MRO service provider needs more spare engines. The average WIP in this configuration is around 11.2.

In scenario 11, the non-OEM MRO service provider has to provide the unscheduled aero engine maintenance. In this scenario, the non-OEM MRO has to provide more maintenance events. Therefore, the non-OEM MRO needs to add more spare engines to support the offer.

Scenarios 12 and 13 have the highest average total aero engine in the shop floor. They both offer the unscheduled maintenance as well. Additional maintenance needs to be accommodated by the non-OEM MRO service provider. The non-OEM MRO service provider itself only collaborates in managing the spare parts provisioning. The spare parts provisioning may shorten however the time to repair and overhaul still need time.

Scenario 14 combines MRO, parts trader and a base station in the non-OEM MRO service provider configuration, which can also enhance the shop floor performance significantly. Based on this configuration, the non-OEM MRO service provider can reduce the aero engine spares to its customers to about eight aero engines.

Scenario 15 the non-OEM MRO, repair vendor OEM configuration, can also enhance the offering to the customers. Through this configuration, the non-OEM MRO service provider can obtain an average WIP of around 8,6 which is higher than the previous scenario.

Scenario 16 the non-OEM MRO, Repair Vendor, OEM and base station increase the amount of WIP on aero engines on the shop floor. This situation is related to the number of the aero engine that is still in maintenance process (service or dismantled). This scenario can also increase the need for aero engine spares to10.

The lowest of the WIP is the same for scenarios 1, 3, and 9. Scenario 1,3, and 9 have the similarity of not having the unscheduled maintenance. This type of scenario is dedicated to the scheduled airline maintenance. However, scenario 9 incorporates the unscheduled maintenance. The limitation in the collaboration has allowed the non-OEM MRO service provider to hold more assets or aero engine retention in the facility. In scenario 8, the non-OEM MRO service provider only collaborates with the OEM in providing aero engines. This situation has led the non-OEM MRO to take more responsibility in providing the assets.

Based on the graph, it can be concluded that the average WIP on the shop floor is caused by the total maintenance demand from the customers. The high number is the result of the maintenance events generated from the base station. The base station gives the unscheduled maintenance both from the dedicated customer airline or other airlines.

7.4.4 Aero Engine Readiness Availability

The output (‘availability’ parameter) of this research is to represent how many aero engines are work in progress daily. In this case, the non-OEM MRO service provider has to maintain a total of 74 aero engines from the customer. Therefore, the trade-off between the aero engine in the shop floor and the airline operation requirement has to be calculated.

The total availability of this research is based on Service Level Agreement (SLA), related to how the non-OEM MRO service provider guarantee the availability of the aero engine to the airline. To obtain the availability number of this research is represented by Equation 19.

Equation 19

$$Aero\ Engine\ Availability = \frac{(Total\ Aero\ Engines - Average\ Aero\ Engine\ Work\ in\ Progress)}{Total\ Aero\ Engines} x100\%$$

Based on the previous assumption, the aero engines in total maintenance under the non-OEM MRO service provider A’s responsibility is 76. However, this result is the initial step to provide aero engine availability in the future. The total availability has to synchronise with the aero engine fulfilment requirements by the airlines. The total aero engine numbers per day will vary depending on the season. In the high season, the total aero engine requirement is greater than an off-peak season.

Scenario 1 non-OEM MRO as pure maintenance service provider: The availability increases in this scenario as it has no other constraints. The non-OEM MRO service provider is doing all the maintenance work scope by itself. Therefore, the non-OEM MRO service provider does not need to depend on the external repair or provider.

Scenario 2 non-OEM MRO + repair vendor: As the average WIP is increased, the availability of the aero engine readiness will decrease. The non-OEM MRO service provider will outsource work scopes to external repair. Therefore, the undone spare parts or major module are still the non-OEM MRO service provider's responsibility. This configuration means the non-OEM MRO service provider still needs to implement the maintenance processes before the outsourcing process.

Scenario 3 MRO + Repair Vendor + Parts Trader: The parts trader will increase the availability of the aero engine to the customers. The parts trader will ensure more jobs for the shop floor process. The spare parts provisioning configuration requires the non-OEM MRO service provider to conduct the maintenance and dismantle process at the lower level of the aero engine. Therefore, a greater number of aero engines will be undergoing maintenance on the shop floor.

Scenario 4 MRO+ Repair Vendor + Parts Trader + OEM: Scenario 4 adds the OEM from scenario 3. The OEM will increase the availability of the aero engine readiness. However, more of the maintenance work scope requires shop floor operational capacity and capability. Therefore, the non-OEM MRO service provider has to conduct more maintenance processes on the shop floor.

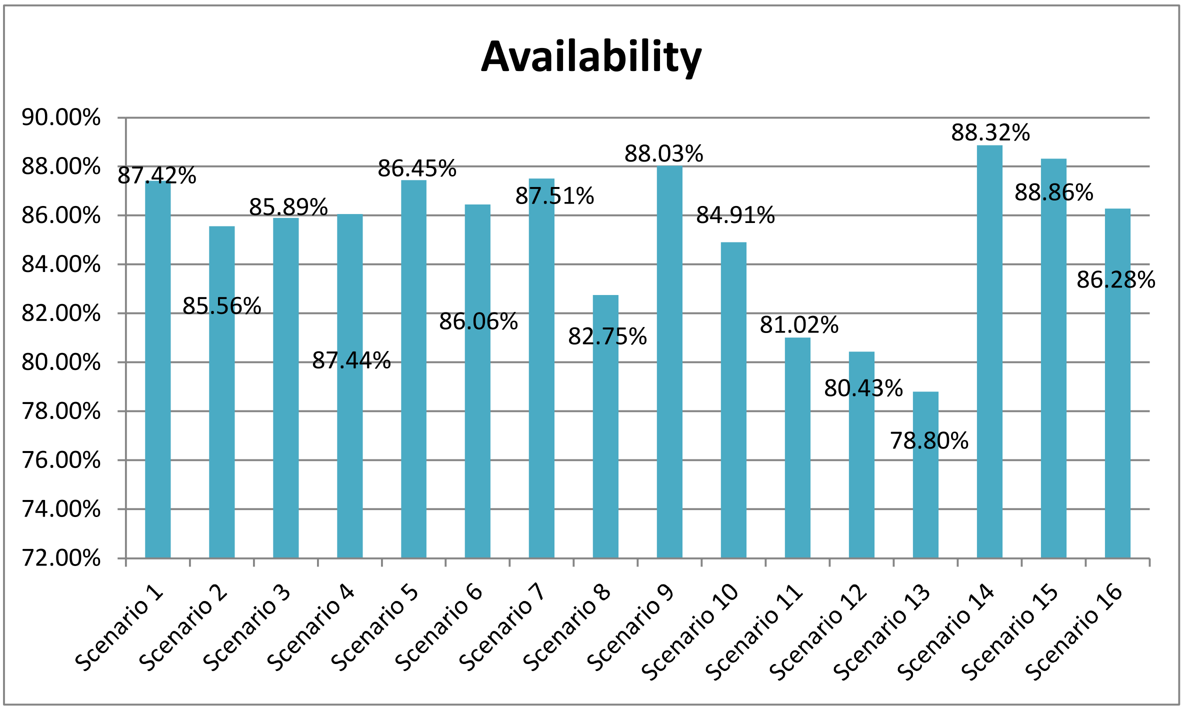


Figure 62 Availability

Scenario 5 MRO + Repair Vendor + Parts Trader + OEM + Base Station: Scenario 5 has added the base station to its configuration. A bases station role is to provide not only the scheduled maintenance from the dedicated customers but also the unscheduled maintenance from other customers. This configuration generated more maintenance requirements to the non-OEM MRO service provider. The increasing maintenance demand will also increase the maintenance process operation on the shop floor.

Scenario 6 MRO + Parts Trader: The parts trader with the non-OEM MRO service provider will reduce the capability of the non-OEM MRO service to provide aero engine availability. The parts trader configuration requires the non-OEM MRO service provider to conduct more maintenance processes. Therefore, the aero engine WIP will have a slightly high number.

Scenario 7 MRO + Parts Trader + OEM: The Parts Trader and OEM will increase the availability to 87.51%. The OEM configuration will increase the engine availability. The non-OEM MRO service provider can outsource the major module maintenance to the external repair vendor.

Scenario 8 MRO + Part Trader + aero engine provider + Base Station: In this scenario, the total aero engine availability is around 82.75%. This situation is caused by the additional base station which increases the total maintenance requirements of the shop floor. Although the new engine provider and component provides is added to the configuration, the total aero engine availability reduces as there will be more aero engines on the shop floor each day.

Scenario 9 MRO + aero engine provider: In this situation, the non-OEM MRO shop floor configuration will offer higher availability level of the aero engine to the customers. This configuration relies on the provisioning of the aero engine. However, it is not possible to swap the additional aero engine spares with new aero engines. Therefore, the non-OEM MRO shop floor has to provide more aero engines on the shop floor on an average daily basis.

Scenario 10 MRO + OEM + Base Station: The configuration of this scenario will be able to provide aero engine availability of 84.91%. The reduced availability in this scenario is caused by the additional base station element. This element will increase the unscheduled maintenance to the shop floor. The additional unscheduled maintenance without any capability enhancement will increase the TAT. The TAT increment effects on how much the aero engine readiness level.

Scenario 11 MRO + Base Station: Scenario 11 will allow the configuration to add the non-OEM MRO shop floor to the base station. Without any outsource, the non-OEM MRO can obtain Aero Engine availability of 81.02%. The conventional non-OEM MRO shop floor will conduct the entire maintenance work scope on the shop floor. The additional base station will reduce the readiness of the aero engine maintenance by the non-OEM MRO. The non-OEM MRO holds more aero engines on the shop floor per day.

Scenario 12 MRO + Repair Vendor + Base Station: Scenario 12 can only provide aero engine availability of 80.43%. The lower availability is caused by, the large number of aero engines undergoing maintenance on the shop floor. The additional external outsources of the repair vendor will have no effect as it has not been able to deal with the extra maintenance requirements from the base station.

Scenario 13 MRO + Repair Vendor + Parts Trader + Base Station: Scenario 13 will provide aero engine availability of around 78.8%. This scenario will allow the unscheduled maintenance to be serviced in the non-OEM MRO. Both ad hoc and maintenance schedules can be provided for by this scenario. Therefore, the shop floor in this configuration will have more aero engines being serviced on the shop floor on a daily basis.

Scenario 14 MRO + Parts Trader + Base Station: The configuration of the parts trader and base station will enhance the aero engine availability to 88.32%. The new parts trader will allow the non-OEM MRO to conduct the maintenance process more efficient as the outside organisation handles the spare parts provisioning. Therefore, although the non-OEM MRO can provide the scheduled and ad-hoc maintenance, there will be fewer aero engines serviced on the shop floor.

Scenario 15 MRO + Repair Vendor + OEM: This configuration will result the aero engine availability increase to 88.86% slightly higher than in scenario 16. In this scenario, the configuration of the external repair vendor and the aero engine provisioning will allow the non-OEM MRO to obtain higher aero engine availability.

There will be fewer maintenance operations conducted on the shop floor as more of aero engines will be outsourced to the repair vendor, and the OEM will provide the aero engine pooling swap.

Scenario 16 MRO + Repair Vendor + OEM + Base Station: The additional repair vendor combined with the OEM will enhance the amount of aero engine maintenance in the shop floor. Therefore, the aero engine availability level is about 86.28%. The additional repair vendor and the OEM cannot enhance the effectiveness of the maintenance processes due to a number of maintenance operations required.

Based on the aero engine availability, greater aero engine availability can be obtained once the maintenance reaches a more efficient level. The faster maintenance processes will reduce the retention period of the aero engine on the shop floor each day. The non-OEM MRO shop floor configuration will allow for different availability. Once the output range of each parameter is obtained, the decision-makers can also assess which maintenance processes must be enhanced to obtain more efficient maintenance procedures. Section 7.6 will represent the parameters that can be obtained from this research. These parameters will allow the decision-makers to implement a more detailed investment strategy and policy to the shop floor.

7.5 Service and Product Combination Classification

A cluster analysis method has most frequently as the classification tools in the marketing area (De Chernatony, 1988; Punj and Stewart, 1983). The ranking of the service configuration will ease the decision makers in resolve the contract offering process as it can be a guideline for them in the offering phase. The characteristics of the classification can be obtained as it can give better insight into both the decision makers and customers from different perspectives (Mayer, 2016). In this research, the classification are based on the most significant contract offering parameters of non-OEM MRO service providers.

The sample of data can be obtained from the experimentation. The sample is necessary to support and generate the productisation method of the service spectrum. The samples of the service configuration from the previous chapter can assess the performance of the offering based on the airlines' requirements and the non-OEM MRO shop floor operational capacity and capability. The classification of the PSS based on the service can be identified and grouped into several classifications. This research supports a method to assess the productisation method and enhance the preliminary classification mentioned by (Wibowo, Tjahjono and Tomiyama, 2016). The method will take into account the dynamic behaviour of the shop floor, and the uncertainty of the non-OEM MRO service capacity and capability to the customers have to be incorporated. Therefore, the service provisioning process can be classified from its performance measurement result accurately. This chapter will provide the classification of the non-OEM aero engine MRO service provisioning offering based on the performance measurement using Hierarchical Clustering Analysis.

The dendrogram used to classify the results of certain parameters to assist the decision-makers in deciding the best scenario. The parameters will vary depending on the needs. Once the hierarchical clustering analysis is obtained, the result will allow the decision-makers to choose the best scenario based on the value range of each scenario. The value range result of each scenario can become beneficial information to the contract design team during the contract preparation phase.

There are two ways of reading the hierarchical clustering, bottom-up or up-down based on perspective. This approach utilises the bottom up to characterise the scenarios based on the performance measurement. Once the hierarchical clustering has been obtained the decision-makers can predict the range output of the TAT based on the scenarios that they have.

7.5.1 Hierarchical Level based on TAT

The main parameters of the shop floor performance measurement are the TAT or the throughput for the aero engine to be serviced.

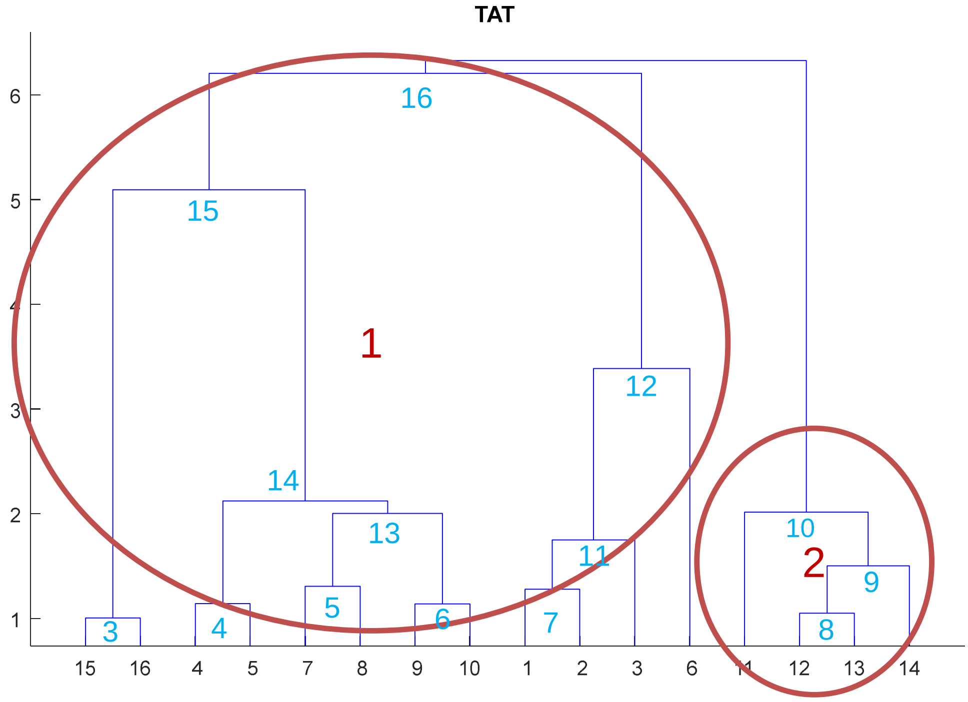


Figure 63 TAT Hierarchical Clustering Level Analysis based on TAT

Based on the hierarchical clustering method, the result of each performance measurement in the configuration can be obtained. There are various ranges of performance measurement output from this method. The range output of the 78-70 days TAT can be produced from the first node. The first node consists of scenarios: 4, 5, 6, 7, 8, 9, 10, 15 and 16 (node 1). This node has a range of the TAT between 78.03 - 80.25; and Node 2 (11,12,13 and 14) will have 84.52-8.07.

The hierarhical clustering method used the distance linkage which represent the similiarity of the data. The output data from each scenario is grouped into two bi nodes, Node 1 and Node 2. Each node has Node 1 consists of Node 16. The derivatived node are 12, and 15. Node 15 is consisted of node 3 and 14. Those nodes are correlated based on the value from scenario included in 78.09-80.16; TAT of these scenarios are related to the adding service provisional and the product to the initial offering. The other node, 12 which includes node 7, 11 and 12 are valued between 85 and 86 days of TAT. And Node 10 which consist of 8 and 9 are relate to the scenarios which need TAT between 87-91. The grouping and classification of this node will ease the decision makers in choosing the best scenario based on TAT's requirements from the customers.

The classification of the service combination is easily depicted through the hierarchical level clustering analysis by Figure 63 TAT Hierarchical Clustering Level Analysis based on TAT. Further range to analyse different node will present more detail about the range which each scenario offers.

This node has the non-OEM MRO and service combination as the main mix. It is evident that the aero engine provisioning can be the best solution to obtain shorter TAT. The MRO service provider can collaborate with aero engine provisioning agreement. Therefore, whenever the MRO service provider does not have any capability or capacity they could swap the unserviceable aero engine with the spare aero engine provided by the aero engine certification. Therefore, this process can reduce the maintenance operations process and shorten the TAT.

7.5.2 Hierarchical Level based on Total Man hours

Figure 64 illustrated the classification of a different cluster of scenarios based on the range of the total man hours needed. The left parts of the first node represents the scenarios: 5, 8, 10, 11, 12, 13, and 14. The remaining groups have the range between 2284 – 3545,6; another node provides the scenarios which are ranged between 9763 to 14407 man hours. The node of the classification will ease the decision makers in assessing the total man hours needed in the contract preparation. The man hours needed will be beneficial to evaluate the readiness of the mechanics to conduct the maintenance.

The total man-hours performance measurement is not as same as the TAT.in some scenarios; the man-hours will be higher as the service combination will require more maintenance, such as the spare parts provisioning. In the spare parts provisioning, the shop floor will need to conduct more maintenance processes to achieve the components level. Most of the aero engine maintenance processes should go through the components level.

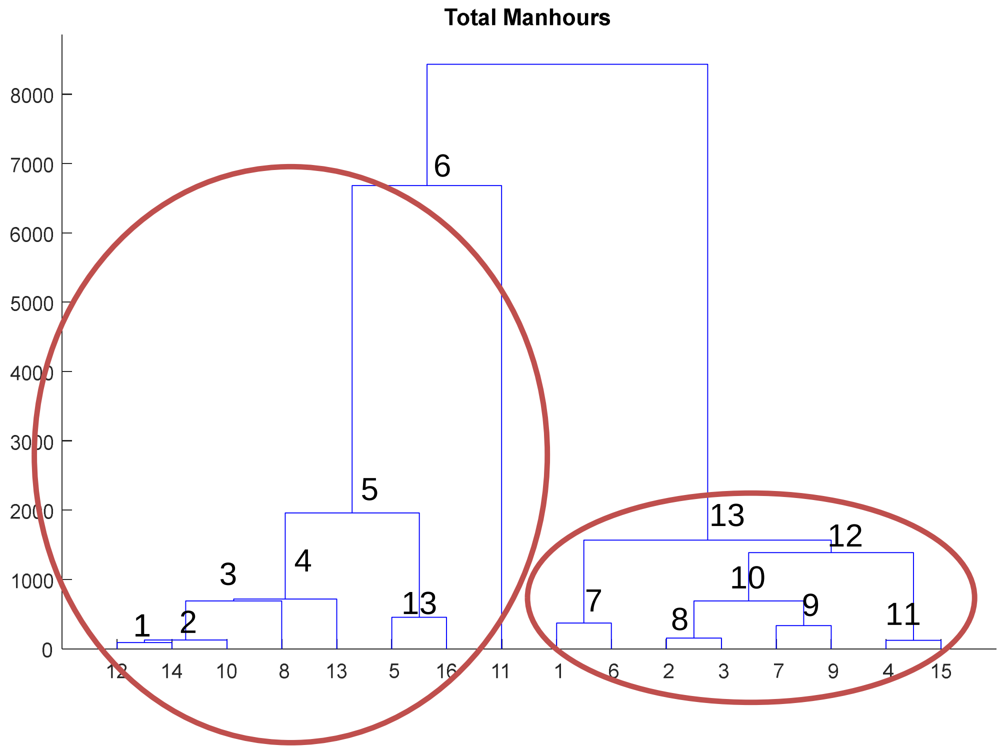


Figure 64 Hierarchical Level for Total Man hours

Based on the MRO service provision configuration, the additional total manhours will be higher for the MRO service provider with the irregular maintenance offering. The irregular retention in this research is obtained by the total number of aero engines visit for unplanned work. The work scope is related to the unscheduled maintenance.

Based on Figure 64, the nodes are representing the group of manhours range required for each scenario. Node 13 combine the scenarios which require total manhours between 22000 to 28000 manhours. Scenario 11 which has 35000 manhours is the highest in the case. Node 13 are representing the scenarios which needs less manhours than the Node 5. Node 13 are representing the scenarios which require 9.000 to 14.000 manhours. The classification and grouping of this value will enable the decision makers to estimate the total manhours for each scenario they would like to implement.

From the MRO service provider’s perspective, high labour means higher profit. In this research, the assumption of the work scope is the same as the aero engine manual; the components parts assumed similar as sold by the OEM. Therefore the only cost differential is in the cost of labour. The total margin cost can be further adjusted based on the MRO service provider's policy. The profit generated from an aero engine shop floor comes from the man power consumption, as 80% of the cost is for spare parts.

7.5.3 Hierarchical Level based on Average WIP

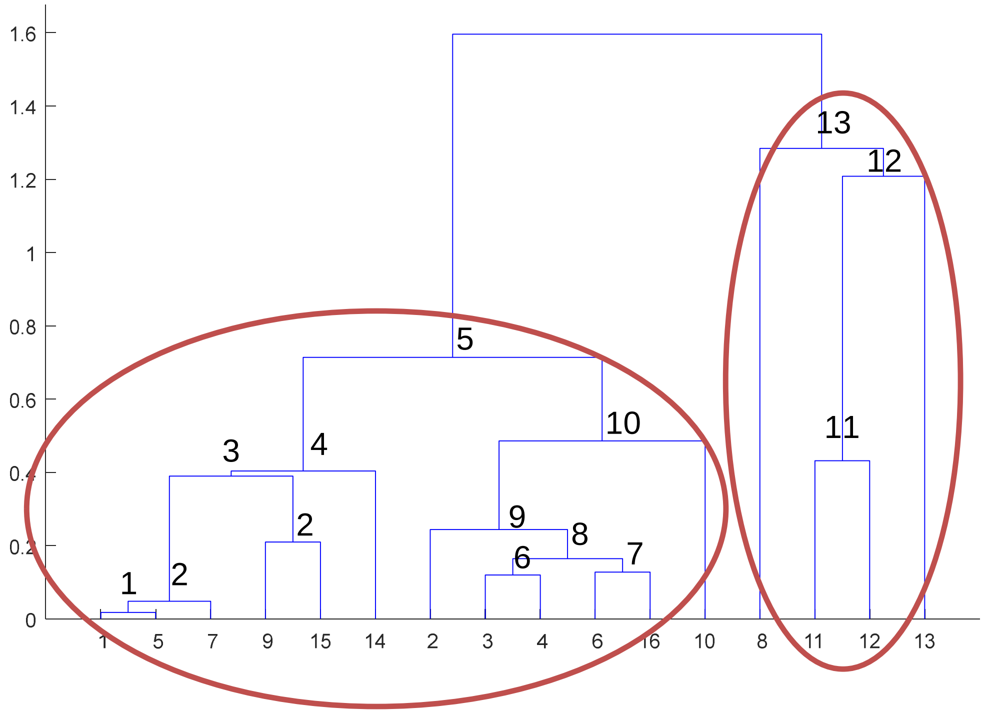


Figure 65 Hierarchical Cluster Analysis for Average WIP for each scenario

Figure 65 depicted the range classification based on the service combination (scenario). The left side which represents the combination 1, 5, 7, 9, 15, 14, 2, 3, 4, 6, 16, 10 are given a range of the average WIP aero engine on the shop floor between 9-11 averages WIP. On this group of scenarios, it means that the MRO has to prepare aero engine spare around that number. Another node, which is on the right side, gives the decision makers information that this scenario requires the average aero engine to support customers A is between 12-15.

Each node represent the similarity linkage between each scenario that can be implemented by the case company. The nodes level are node 5 and node 13. Node 5 represents the total aero engine which is being maintenanced in the shop. Node 5 will represent several scenarios which have between 8 to 11 of aero engine at a time. Scenario 10 represents the highest in the Node 5, as it is closer to Node 2 and Node

5 (10.682) than to the lowest WIP in Node 11 (12 WIP); Scenario 10 is combined in Node 5. In Node 13, Scenarios have average WIP between 12 to 15 of aero engine at a time in the maintenance shop floor. The Nodes will allow the contracting team in predicting the need of available spare aero engines to fulfill the contract's requirement.

The average WIP represents the whole aero engine that is being serviced on the shop floor. in this study, the total aero engine fleet is about 74 engines, and the MRO needs to provide as many aero engines as it can. This data shows the average number of WIP representing the total aero engine spares that should be prepared to fulfil 100% of total number aero engines.

It is evident that the service without outsourcing will be the most common scenarios which need more aero engine spares. The spare engine needs to be obtained by the MRO to provide the irregular maintenance service. The additional maintenance demand will also result in a busier shop floor and increase the blockages and queues on the shop floor.

7.5.4 Hierarchical Level based on Aero Engine Availability

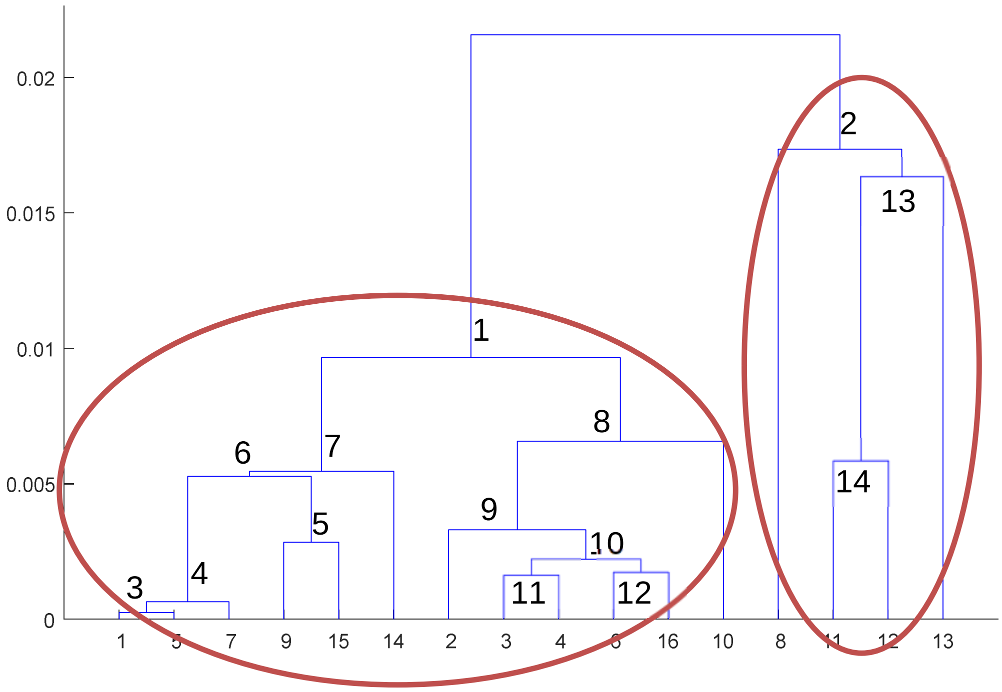


Figure 66 Hierarchical Level Clustering Analysis for Aero Engine Availability

Figure 66 related to the Figure 65, as the aero engine availability, is the derivation of the average WIP on the shop floor. The Node 1 (scenario 1,5,7, 9,15,14,2,3,4,6,16 and 10) is representing the scenarios which have a higher level of aero engine availability towards the customers' requirements than Node 2 (scenario 8,11,12 and 13). Node 1 consists of Node 6 and 8. Node 1 grouped all scenarios which offer 84%-88% of aero egine availability. Another node (Node 2) is representing scenarios which has 78%-82% of aero engine availability.

The aero engine availability relates to the number of aero engines on the shop floor that need to be provided to the customer. In this research, the total aero engine fleet is 74 aero engines. The aero engine availability

The hierarchical cluster analysis will be like the average WIP. The aero engine availability is the number of the total aero engines ready and the customers' requirement. The highest number of the spare aero engines is generated when the MRO service provider also support the unscheduled maintenance.

The fewest spares of the aero engine are achieved in scenarios 14 and 15 with eight aero engines. Scenario 14 related the MRO with additional spare parts provisioning and scenario 15 with additional repair vendor and OEM. The outsourcing policy with the collaboration to the external repair vendor's maintenance TAT cycle time will make positive contribution. The more the MRO provides additional services by outsourcing, the more the MRO has to lead with the additional spare engines.

7.6 Chapter Summary

This chapter mentions the simulation steps. Each simulation result is presented in the figures and graphs. The results can provide the decision-makers with more sophisticated information regarding the maintenance requirements and the maintenance resource capacity and capability. The scenario configuration model and simulation assist the policy makers to make informed provision decision when offering maintenance contracts. Once the non-OEM MRO has decided on the most optimum configuration to meet the airline's requirements, the policy makers can also assess the performance of each maintenance process.

The simulation result could allow the decision-makers to evaluate the best investment policy strategy. They could assess the trade-off between the total investment requirements with the feasibility value of the contract offered.

This chapter also represents the different outputs of the shop floor based on the supply chain configuration of the non-OEM MRO service provider. Through the supply chain MRO configuration mentioned by MacDonnell and Clegg (2007), The experimentation conducts sixteen different configurations of aircraft MRO supply chain management. Each configuration will represent the operational policies carried out by the non-OEM MRO service provider.

The case study implemented is to analyse the maintenance demand from the airline G to be supported by the non-OEM MRO A. The airline and non-OEM MRO service provider have a close partnership and have made a significant innovation in the bundling service and product to fulfil the mission operation. Airline A has a fleet of 76 aero engines. They operate these aero engines under the umbrella of planned maintenance.

Then this research assessed each aero engine and the average commercial flight policy to obtain the maintenance event schedules. The total maintenance event for the fleet over a period of 10 years will be a total of 99 maintenance events. Also, the non-OEM MRO service provider offers the unscheduled maintenance, which is represented in different scenarios or configurations.

The research then conducts the discrete event simulation for the non-OEM MRO shop floor operation. The non-OEM MRO service configuration will represent its capacity and capability to fulfil the airline A’s demand. Based on the performance measurement illustrated in the graphs, it can be seen how the shop floor operational capacity and each configuration can react to the maintenance demand.

This chapter also has identified that the hierarchical cluster analysis can beneficial in organising and categorising the service combination provisioning. Through this clustering method, the result can be used as advance information for the decision makers. The decision makers will be able to achieve the best service combination product configuration based on the output they required. The categorised results are obtained by incorporating both the customers’ requirement and the non-OEM MRO service provider’s capacity and capability. Therefore, this classification can be beneficial for the decision makers as information to manage the best strategy or solution in the future.

Currently, the additional product to the service core offering is not importantly necessary. There is trade-off for each scenario although the scenario seems promising as the best achievement could be obtained for the other performance.

8 Summary, Discussion & Conclusions

This chapter will provide a summary of the research findings and further discussions to the implications of this research's area. Subchapter 8.1 presents the key research findings from this research. Subchapter 8.1.5 describes the quality and generalisability of findings from this research. Subchapter 8.2 verifies the fulfilment of the research aim and objectives. Subchapter 8.3 will conclude the research. Subchapter 8.4 presents the contributions for both theory and practice. Subchapter 8.5 depicts the research's limitation and the further recommendation for future works.

8.1 Summary

8.1.1 Literature Review

The literature review in this research has considered the MRO service provider and the productisation of service as a method in PSS. The literature search conducted is based on the method of PSS implementation of the non-OEM aero engine MRO service provider. In the PSS area, most of the literature discussed servitisation methods to deliver PSS. PSS is seen as a total solution which combines both the product and the service to offer the utilisation as a solution to the customers (Goedkoop et al., 1999). In contrast, the literature review in this investigation focused on the productisation of service as a route to arrive at PSS. The servitisation method as defined in this research is the process to increase the value of service.

In the literature, the most common and popular study is about the lean implementation on the MRO service provider. The lean philosophy has been proposed to be implemented on the shop floor. The idea of the lean implementation is to reduce unnecessary maintenance processes. The lean implementation of the MRO was also followed by shop floor level strategy such as cellular manufacturing.

In the literature, there is few consideration regarding the type of the MRO service provider. However, the MRO service provider can be classified and categorised into several classifications. Aeronautical Repair Station Association (ARSA) has illustrated several types of MRO Service providers based on the market approach and the customer orientation. This research has used the ARSA classification to investigate the non-OEM MRO Service provider in further detail. Non-OEM MRO service provider can be defined as all MRO's business which does not have direct partnership with OEM regarding the operations on their contract. In this research, non-OEM MRO includes airline third-party and independent MRO.

The MRO industry has faced the same challenges for the last decade. One of the most significant threats is the servitisation of the manufacturing as a new trend. The OEM has expanded their business model into the after sales market such as maintenance. The shifted OEM's business model to the aviation industry has reduced the opportunity for the non OEM MRO Service provider. This situation has forced the non-OEM MRO service provider only to be able to serve older generations of aero engine. In addition, the obsolete level of the older generation has become one of the threats. Therefore, an opportunity emerges to investigate the non-OEM MRO service provider.

8.1.2 Conceptual Model Development

The proposed conceptual model is an enhancement of the current contract preparation method for the non-OEM MRO service provider. In this proposed method, the decision makers will be able to approach customers and propose service offerings more proactively. The current contract preparation is mostly based on decision makers' intuition and experience, which is a reactive approach in which the decision makers prepared a contract and respond to each client's enquiry at a time.

The decision makers of, particularly, airline third party MRO will be able to have more detailed flight schedules as the customers' requirements. In addition, the decision makers will be able to assess whether their capacity and capability are adequate to support the clients and to hold a long-term contract. This might become a business opportunity for the non-OEM MRO service provider.

The developed conceptual model was used as foundation to build the simulation model (discussed in Chapter 5). Through simulations, the decision makers will be able to analyse and assess 'what-if' analysis of different scenarios of service provision that they can provide to the customers.

8.1.3 Simulation Model Development

The scenarios and operations in this simulation model are based on the literature, Workscope Planning Guide (WPG) and the documents on the case company's quality procedure. These documents are commonly used by MRO service providers around the world. The ability to assess the actual shop floor situation has given an advantage to this research.

The computer simulation software, Witness, was used for simulation. Through the simulation model, the decision makers can have more flexibility in assessing the shop floor capacity and capability. Computer based model simulation is the best method to evaluate the complex process such as the aero engine MRO’s shop floor.

The simulation model will also help the decision makers to conduct “what-if” analysis regarding future information. For instance, the increased capacity and capability may increase risks. The unbalance in investment can lead to blockage of the operations and maintenance. However, the additional investigation might be necessary to obtain better picture.

8.1.4 Service Provision Configurations

The service provisioning by non-OEM MRO service providers can be based on the combination of additional services or additional products. As mentioned by Baines et al. (2007), the approach combining the ‘services with additional product(s)’ or ‘product with additional service(s)’ leads to a Product Service System (PSS). Identifying the customer's requirements can help the non-OEM MRO service provider to define the best configuration of additional services or products as an offering.

Different service provisioning strategies can be modelled in the shop floor simulation. The additional service such as additional spare parts provisioning, aero engine spare provisioning and outsourcing of some operations can offer different benefits to the customers. The usage of the simulation model can optimise the service offering.

The classification of the non-OEM MRO service provider can be obtained from the shop floor performance. The classification of the scenarios can benefit the decision makers in deciding the best configuration to fulfil the offerings. The classification used a hierarchical clustering analysis method.

The hierarchical clustering represents the PSS productisation into an arrangement as an ascending series of branches in dendrograms. The dendrogram will make information retrieval for the decision-makers far easier to compare between each scenarios (McCarthy, 1995).

The main idea of adding aero engine spares seems one of the best solutions to enhance the availability. For a shorter term, additional aero engine as a spare can be a good solution. However, additional spare aero engines will increase the risk of the higher demand for maintenance in the future. The total number of aero-engines has to align with the needs of the airlines based on flight operations. The simulation method allows the assessment of the timing to purchase and provide extra aero engine as well as the best time to enhance the capacity and capability of the shop floor.

Outsourcing strategy can also be one of the best options, but it comes with the cost to the non-OEM MRO service provider. The outsourcing strategy can become the best solution for a short-term maintenance demand, because the non-OEM MRO service provider can increase their capacity and capability quickly. However, in the quality perspective, there is a great drawback that the non-OEM MRO service provider cannot be involved in ensuring the quality of the maintenance work conducted by the external repair vendor.

Each simulation scenario will have different impacts on the shop floor performance. TAT might be the most significant parameters in the contract. Through TAT, non-OEM MRO can evaluate the needs of the operations. Longer TAT means that non-OEM MRO service provider needs more capacity. Shorter TAT can reduce the average WIP and increase the aero engine availability. Additionally, to aim the shortest TAT, the non-OEM MRO service provider needs to assess other parameters, such as trade-off cost for outsourcing. The scenarios will give the decision makers more opportunities to come up with the best maintenance offering.

8.1.5 Quality and Generalisability of Findings

The research proposed the enhanced method to assist the non-OEM MRO service provider in implementing productisation. A conceptual model was obtained from the literature and the case company’s document. The conceptual model has also been converted into a simulation model to fulfil the objective of this research. The simulation model has been gone through the validation process which compared the actual TAT information from the case company with the proposed simulation output. The difference between the actual data and the simulation results is less than 10%. This difference supports that the model is acceptable as the foundation of this research.

The model has adopted to the real actual industry and has been validated through the case company's document. The data about the maintenance cycle time and the operational procedure are obtained from an expert in the case company. The scenarios of the maintenance flow have also been approved by the case company. Although this model employed several assumptions, the model behaviour is close to how the shop floor actually operates. The model can also be applied to other aero engine types with minor modification.

Other non-OEM MRO service providers can also use this model as long as the maintenance work flow processes are based on the WPG published by the manufacturers. However, shop floor models should be adjusted including cycle time, capacity and machine capability. In addition, there is also a different policy required in the decision making, such as outsourcing policy which is based on the capacity and capability of each non-OEM MRO service provider.

The proposed method can also be used by any other MRO industries such as ship industry or defence equipment. However, the data and the characteristics in predicting the customers' requirements and the maintenance provider are different.

8.2 Discussions

The deliverables of this research can assist the decision-makers of the non-OEM MRO service provider in determining the best service configuration to fulfil the customers' requirements. With the proposed method, a non-OEM MRO service provider will be able to implement productisation of services to provide the best offering to their clients. The method incorporates the maintenance events prediction then uses it to analyse the non-OEM MRO shop floor operational availability. This availability indicates as to whether the non-OEM MRO has the capability and capacity to propose the service configuration offers. Also, the decision-makers can identify which maintenance process operation needs more investment to enhance the shop floor performance. The maintenance forecast will be related to the severity curve characteristics of the aero engine, in parallel with the flight operation requirements. Then, the non-OEM MRO shop floor performance can be analysed using Discrete Event Simulation. The combination of these tools will provide a dendrogram or hierarchical clustering, which can be used to compare each service configuration.

Looking at the first objective a research question can be formulated. *How the PSS can be provided by service providers?* in the the literature review results have been synthesised to produce several outputs: the definition of productisation, the methodology to conduct productisation; the motivation of productisation and the implementation of productisation. Also, the literature review has opened the gap to carry out this research. Productisation of the service in the PSS is far less considered. Therefore, this gap has enhanced the motivation to carry out this research.

Then, "*What are the parameters used by the MRO Service provider in preparing contractual agreement decisions*?".Moving on to second objective, the current key factors and parameters in maintenance have been identified (Chapter 3). The observation of the customers' requirements has been performed to obtain the parameters in preparing service provisioning from the non-OEM MRO's perspective. The data has been supported by the document analysis and semi-structured interviews. Further details of the data representing the parameters, key factors and decisions have been obtained by combining all information.

Next research question is on *"How the parameters are linked in the contracting preparation?"* The third objective answers this research question to the conceptual model which represents the key factors and parameters mentioned in the previous objective to become a foundation in the decision-making. The identified parameters were then synthesised and related to delivering the main parameters required by the customers (see Figure 14).

The conceptual model can be presented into the model to ease the contracting team in translating the proposed method. The fourth research question is *"What is the suitable model for preparing the method?"*. The fourth objective is to develop a maintenance shop floor model for Discrete Event Simulation (DES). The maintenance shop floor model elaborates both the customers' and non-OEM MRO's perspectives. This model matches maintenance client's demand with the non-OEM MRO maintenance supply and connect the customer requirements to the shop floor parameters representing service performance.

The next research question is *"How the service configurations affect the shop floor performance parameters?"*. The fifth objective illustrates the 'what if analysis' assessment through experimentation for each service process configuration of the non-OEM MRO service provider in offering services. The model will become the foundation of the computer model-based simulation. What if analysis will categorise each service based on the classification or its performance as the following objective. The experiment will accommodate "what if analysis" consisting of several scenarios representing service provisioning configuration. The experimentation will assess the service offering performance measurement of non-OEM MRO. The simulation model could also generate the information used to analyse future investment strategy

"How to classify the best configuration for each service performances?". The sixth objective is achieved by the analysis using hierarchical clustering analysis. Through the classification and categorisation of different service configurations, the decision-makers can more easily compare each service provision for future customers. The result can provide an illustration for the decision makers to scientifically determine the best solution from both the client and the non-OEM MRO's.

8.3 Conclusions

From the first objective, the research can conclude that airlines goals shifted from conventional function and safety oriented maintenance to on-time performance support. Contracts moved from the traditional Time and Material Based (TMB) approach to availability based contract and even to the contracting for capacity. The contract preparation method needs to change from experience and intuition based to more scientific one.

The second objective identified the key factors and parameters in preparing the contract. Those parameters are based on the customer's perspective and the MRO's perspective. The first category will relate on how the airline operate their aircraft. The customers parameters include the status and the information about the assets (aero engine) such as historical maintenance information, flight hours and flight cycle consumed, time since new, time since last shop visit, and additional information regarding safety notifications. Then, this research also has taken airline flight operations into consideration. Operational policy and commercial flight plans will also impact in the maintenance events frequency.

From the non-OEM MRO perspective, all the parameters related to the maintenance operation processes were identified. These parameters are related to total labour, skills/expertise, machines, tools and equipment.

In achieving the third objective, the research developed conceptual model about the relationships among those parameters above (Figure 14). This figure was discovered to have a gap in order between the airlines' flight operations requirements and the non-OEM MRO shop floor operations. This gap is filled with lifecycle parameters of the aero engine. These lifecycle parameters assess the maintenance demand and include maintenance historical information of the aero engines, elaborated with the flight operations factors (e.g. routes, geographical condition or take-off derate factor). This means that the non-OEM MRO shop floor capacity can be evaluated once the maintenance demand information is obtained.

The fourth objective is to develop the simulation model. The conceptual model is converted into two different models. The first model simulates the lifecycle of aero engines and generates maintenance events. This model was implemented on excel to calculate the maintenance event. Then, the research employed DES to simulate the shop floor model operations because it can represent the situation based on consecutive events (queue) with no change in the system (assigned system and procedure). The model was validated through the black-box validation method. This method relies on comparison between total output of the actual shop floor and the model output (Figure 31). The proposed method needs more sophisticated data concerning average cycle time of each maintenance process. However, in the actual industry, the cycle time for each maintenance process is less important than the total time required.

This study generated 16 different service configurations. Each of the configuration is assessed through the simulation systematically. The configurations are consisting pure MRO service provision with the other different services, such as components provider, logistics provider, external outsource repair vendor (outsource), and aero engine provisioning.

Based on the different configuration characteristics, the research can conclude that there is classification of service offering based on its impact to the shop floor performance. Adding more service provision is not always be the best solution for both non-OEM MRO and airlines. It can be counter-productive depending on the capacity and the requirements. For example, the adding components provisioning should be easier and the major module outsourcing repair should shorten TAT. However, the components provisioning may increase TAT. This situation is caused as the non-OEM MRO needs to execute more maintenance operations to take the components. More maintenance operations result on longer process on the shop floor. Another example is adding aero engines as spares is not the best solution for the non-OEM MRO. The additional aero engine spare will cause longer TAT in the future. With the same capacity and capability, at a certain time, the non-OEM MRO will have more maintenance processes which results in longer TAT. Finally, using these features of the tool and method, it was demonstrated that simulation-based contract preparation support is possible, and this will improve the accuracy to calculate the cost as well as future investment opportunities.

8.4 Contributions

8.4.1 Contributions to Knowledge

There are two main contributions to knowledge can be obtained from this research. The first is an enhanced method of the contracting preparation for non-OEM aero engine non-OEM MRO service provider. Second the research proposed a revised view about the PSS.

8.4.1.1 An Enhanced Method for Contracting Preparation

This research has proposed an enhanced contracting preparation for a non-OEM aero engine MRO service provider. In the literature, contracting preparation is only mentioned from one perspective only; either the customers' perspective or the maintenance provider only. This method integrates both the customer and maintenance requirements. Currently the non-OEM MRO service provider needs to be more competitive by providing different type of services as a solution to the customers. The method will evaluate both the customers' requirements and the providers' business operational capacity and capability

The non-OEM MRO will be able to assess the trade-off of the combination of the service and product which they offer. To arrive at the best win-win solution for both the customers and the non-OEM MRO, the decision makers need to conduct several steps depicted in Figure 67.

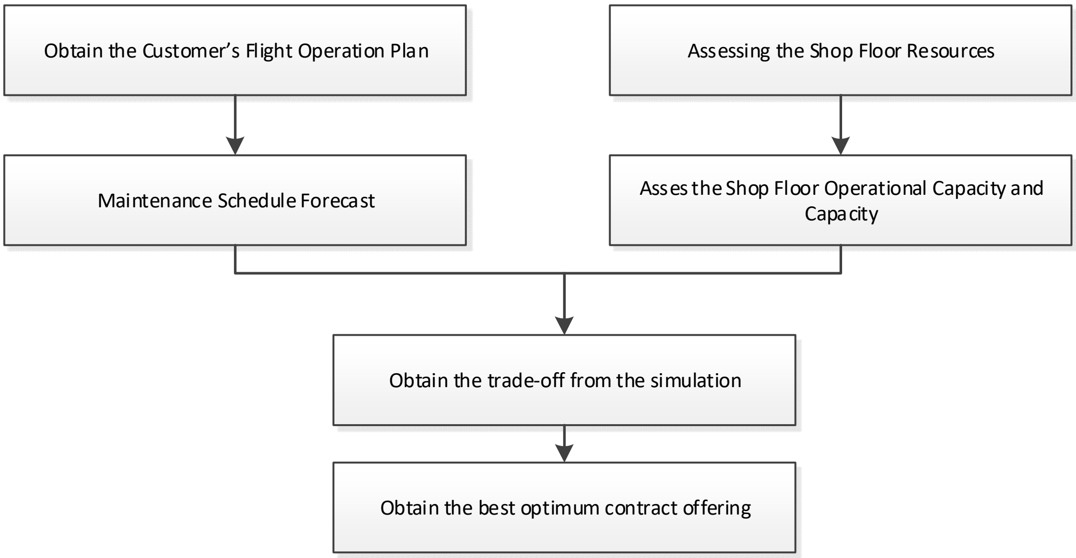


Figure 67 Contract Maintenance Preparation Phase Method

8.4.1.2 PSS from Service Provider's Viewpoint

This research proposed a method to analyse the difference between product and service configuration in forming a PSS. Based on the PSS' triangle by Baines et al. (2007) (Figure 4), the PSS can be obtained from either a product or service.

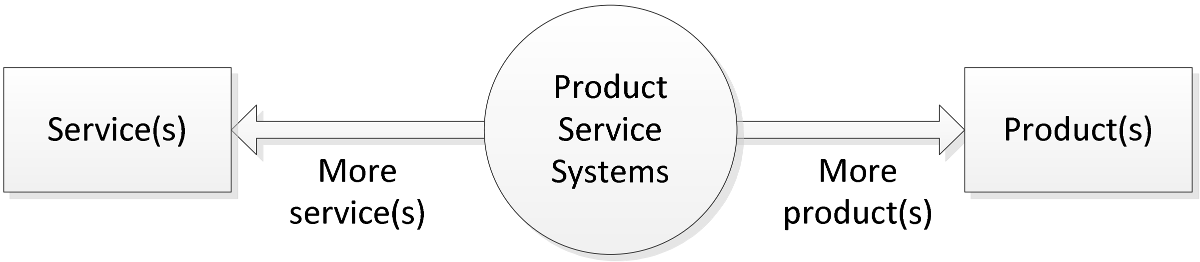


Figure 68 PSS Spectrum Concept

Figure 68 presents the product service system as a combination of services and products. This figure accounts the ratio between services and products. The movement of the PSS level whether to right side (more product) or to left side (more service) will affect to the shop floor performance measurement level. This variable ratio between services and products is another contribution of this research.

However, based on the service provider perspective, a PSS can be obtained from several levels based on the composition of the service and the additional products.

The service and production combination can represent different level of benefits and can be illustrated in Figure 69. This figure depicts the composition of the PSS between the service and products which can be combined as a solution. The PSS can consist of the product only or service only.

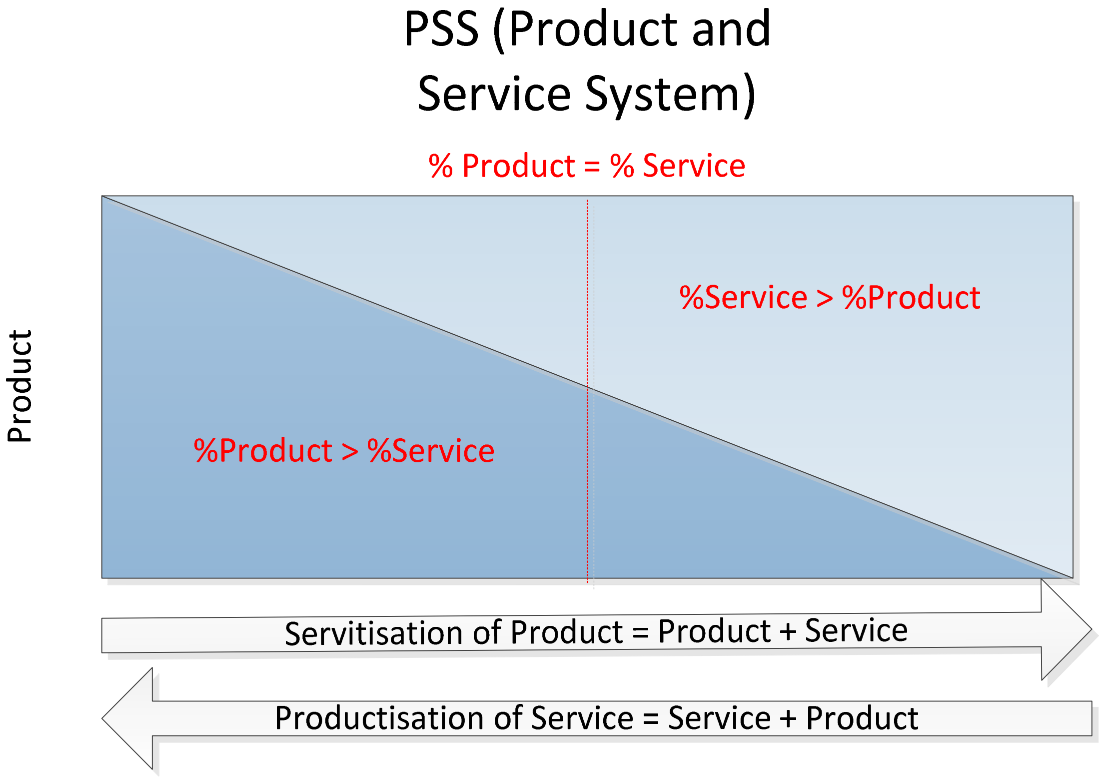


Figure 69 PSS Combination

8.4.2 Contribution to Practice

8.4.2.1 Integrated Assessment of Outcome/ Requirements and Shop Floor Capacity and Capability

The level of productisation obtained from the model can be used by the non-OEM MRO service provider to assess its readiness to provide a configuration of services or PSS productisation. During the contract preparation phase, the non-OEM MRO gives less consideration to the shop floor operational availability. Contracts are proposed based on the experiences and intuition of the contract manager. With this proposed method, the non-OEM MRO could offer a more a more effective contract with more scientific justification. The information provided from this approach will inform the decision-makers of the best scenario (the weight of the product and the service) for the provisioning which takes into account both perspectives.

Chapter 7.5 presented on how the outcomes of this research can suggest a range of performance parameters (such as TAT). This helps decision makers in the contract preparation phase, while clearly showing the principal parameters of the service combination and the trade-off among options.

8.4.2.2 Investment Strategy Assessment

The model can offer information for future investment strategy. Simulation can provide information regarding about a future, once the service configuration is set. The simulation calculates a better picture regarding the feasibility of the contract offering, by showing whether it is necessary to invest more in the machine (capacity enhancement) or to add extra aero engines as spare. Therefore, the decision makers can understand what strategy/actions they need to do with the shop floor.

8.4.2.3 Strategic Decision Making for Business Development Support

Figure 70 illustrated productisation options in the non-OEM MRO service offering. The non-OEM MRO service provider can enhance its offering by adding spare parts provisioning services, then followed by the solution to add the major module provisioning (spare pooling) to shorten TAT. In the next stage, they might pool the spare aero engines to support the airline’s flight operations. Moreover, the fully capable non-OEM MRO can provide the total solution for the airlines. In this most sophisticated offering, the non-OEM MRO needs to combine and configure all necessary product and services to fulfil the service level agreed with the customers. This research proposed a method which can be beneficial to the decision makers in choosing the best productisation level based on the demand and their capability/capacity.

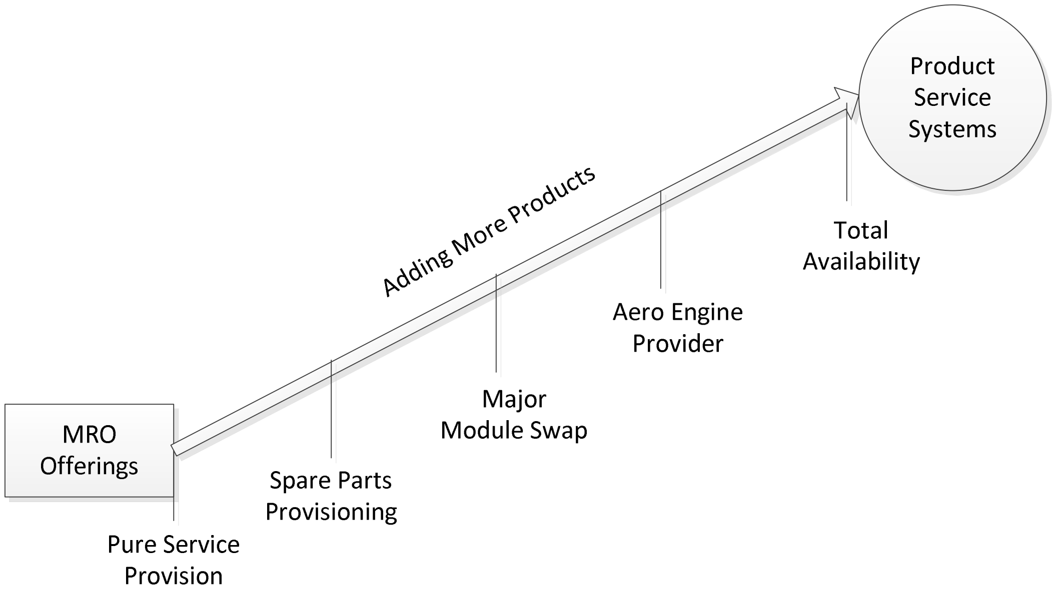


Figure 70 Non-OEM MRO Service Provider's PSS Offering Level in the productisation method

8.5 Research Limitations and Future Works

8.5.1 Research Limitations

The research has been conducted in the arena of a non-OEM MRO service provider as a scope of this investigation. The scope was selected based on the interest of the author who has been working in the aviation sector as an account manager. There is an opportunity to extend the scope.

The limitations of the research lie in the selection of parameters. The time of the simulation is represented in days. The parameter has been simplified as there was a data access problem. However, in the future hour-based parameters can be used for the flight operations procedure. The model validation has also a limitation, because the black-box validation was conducted to mitigate the biases that may arise.

Several assumptions have been implemented in this research software model includes the maintenance forecast model. The maintenance forecast model has used a mock severity curve. The adoption of the mock severity curve is based on the available literature and the company's document. The main idea is to adopt the real shape of the curve (Hanumanthan, 2009). The actual severity curve is confidential and can only be obtained from the OEMs as the aero engine designer. The severity curve is related to the additional geographical conditions mentioned by Ackert (2010). In the model implementation in the experimentation based simulation, there are also several assumptions regarding the components in the typical configuration. These aspects consist of the shift in labour, total number of mechanics for each maintenance process, the route of the parts in the maintenance shop floor, and the buffer utilisation in this model. The shift management in the model has been adopted by the case company A consisting of 8 hours each per day with a total of 41 shifts per week. The shift input is assumed to be the same for the model implementation. The labour allocation in the model is always assumed available with the same expertise and experience. The level of the skills and experience of the labour can enhance the TAT level of the maintenance. The route of the spare parts in the model is implemented to fulfil the 10% deviation based on the actual data. Due to the usage of the black box validation, the data regarding the route and the maintenance cycle time is given far less consideration in the industry. The replacement of spare parts always considered as available. The machine cycle time represents the total time that the non-OEM MRO process. This time is including the delivery time, posting time, and the necessary works. These assumptions are also implemented in the external resource repair and internal repair. For further works, the assumptions can be minimised by obtaining more detail data regarding the maintenance shop floor characteristics based on the actual operations for each case.

8.5.2 Future Works

The scope of the study in the non-OEM MRO industry may also be implemented in the related service industry. These non-OEM MRO activities may differ to the other industries; however, they have the same philosophy. It will be useful if there is an approach to monitor the productisation implementation in the future. Real live information in the productisation methodology will allow the non-OEM MRO service provider to make its offering more competitive.

The model can be improved from either the customers’ viewpoint or the non-OEM MRO’s resource viewpoint. To enhance the detail the researcher has to assess the characteristics of the maintenance requirements by adding additional parameters. To enhance the non-OEM MRO shop floor model, additional work is required to clarify how the maintenance operations are conducted on the shop floor. Risks and uncertainties parameters need to be improved to reflect the reality better.

The productisation business model can be delivered to the customers. However, the optimum level of scenarios which provides the best of availability is the focus for this future's research. To be able to fulfil customer availability requirements, the non-OEM MRO service provider needs to optimise their investment strategy between the investment in the equipment, investment in the penalty cost and the investment in adding spare engines. These parameters need to be weighed before the non-OEM MRO can accurately deliver the customers' requirement.

Another future research topic is that this research can provide information for decision makers' investment strategy. For example, the non-OEM MRO can decide whether to invest in the aero engine spares or increase capacity by further analysis of each scenario relating to customer fulfilment. The decision makers could obtain the trade-off between the aero engine investment and capabilities towards the agreement's value.

In addition, this proposed method can be one of a promising way to support the capability contract as the more advanced type of contract than the availability contract. Through this proposed method based on this research, the solution provider's decision makers can obtain the information regarding the capability and the capacity that they need to have or enhance to support the customers' demand.

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APPENDICES

Appendix A MRO Contract Example

Appendix A represent the minimum example of an MRO service provider contract service provisioning. This template is edited and adopted based on the case company’s contract form.

Contract Information	Date: $$$
Subject: $$$$	Reference: $$$
Prepared by: $$$	Approved by: $$$

No.	Desription
1.	Workscope
2.	Service Level 2.1 xxx 2.2 xxx
3	Work scope Requirement 3.1 xxx 3.2 xxx
4	Work’s Procedure
5	Time and Place for Work Handing 5.1 xxx 5.2 xxx 5.3 xxx

6	Cost and Expenses 6.1 xxx 6.2 xxx 6.3 xxx
7	Payment Method 7.1 xxx 7.2 xxx 7.3 xxx
8	Spare Parts Management-
9	Customer's Rights and Obligatory a) xxx b) xxx c) xxx d) xxx
10	MRO Service Provider's Right and Obligatory a) xxx b) xxx c) xxx d) xxx e) xxx f) xxx g) xxx
11	Subcontractor (External Vendors)
12	Incident and Accident (Additional Work scope)
13	Technical Representative
14	Contract's Information (Time Requirement)

CONTRACT AGREEMENT APPENDIX A

AIRCRAFT and AEROENGINE TYPE of Customer X

No	A/C Type	A/C Reg	MSN	ENGINE TYPE	ESN
1	X	X	X	X	x

CONTRACT AGREEMENT APPENDIX B

Airframe and Cabin Maintenance

1. Workscope
2. Workscope's Exclusions
3. Test
4. Cost and Expenses
5. Aircraft Readiness (day available)

CONTRACT AGREEMENT APPENDIX C

Spare Parts Management

1. Workscope
2. Pay by the Hour (PBH) Workscope
3. Time and Material (TMB) Workscope
4. Turn Around Time (TAT)
5. Warranty

CONTRACT AGREEMENT APPENDIX D

Aero Engine Maintenance

1. Workscope
2. Pay by the Hour (PBH) Workscope
3. Time and Material (TMB) Workscope
4. Turn Around Time (TAT)
5. Warranty

CONTRACT AGREEMENT APPENDIX E

Spare Parts Provisioning

1. Description

2. Spare Parts Management
3. Inventory Management
4. Spare Parts Storing
5. Spare Parts delivery
6. Spare Parts’ certification
7. Spare Parts’ clearance
8. Engine Spare

CONTRACT AGREEMENT APPENDIX F

Engineering Service

1. Workscope
2. Aircraft Manual Management
3. Maintenance Program
4. Dispatch Guide
5. Reliability Control Program
6. Airworthiness Directives, Service Bulletin and Technical Publications
7. Engineering Performance

CONTRACT AGREEMENT APPENDIX G

Handling, Shipment and Additional Services

1. Workscope
2. Cost

CONTRACT AGREEMENT APPENDIX H

Cost and Expenses

1. Power by the Hour Contract (PBH) Cost
2. Time and Material Base Contract (TMB) Cost

CONTRACT AGREEMENT APPENDIX I

Work Detailed Information

- Time and Place
- Aircraft Type
- Aircraft Registration
- Aero engine Serial Number (ESN)

- Cost
- Turn Around Time
- Start
- End

CONTRACT AGREEMENT APPENDIX J

Service Level

1. Aircraft Readiness
2. Dispatch Reliability

CONTRACT AGREEMENT APPENDIX K

Penalty

1. Aircraft Readiness Fulfilment
2. Dispatch Reliability Fulfilment

CONTRACT AGREEMENT APPENDIX L

Detailed Workscope

Appendix B Interview Results

A list of questions have been developed based on the research questions and the objectives. The list of questions are provided in order to assist the researcher in obtaining more accurate information from the actual situation. The questions is enhanced and developed based on the situation while conducting the interview.

Semi structured interview has enhanced the data to be more broad but also necessary to the research.

Initial Questions	
1.1	How does the organisation design the contract? The contract has been initiated by the MRO to offer product and service to the airline. In the meantime, the MROoffered or improve the offers of the contract through the Opportunity of improvement (OFI) which lead to the higher level of the contract agreement. The contract has been adjusted by the customer's demand and operational planning to the future (AS) In the component contract, the company have to mention the accessibility and the availability of the components needed by the airlines. The accessibility and the availability means the fee that has to be provided in order to provide the operational management of the airlines. Access fee means the fee to guarantee that the service provider will provide the needed spare parts or components, whichever the methods, the service provider will guarantee all (AN) The contract has been designed and drafted in order to provide the needs of the airlines, operations and comply with the capabilities of the service provider. Before the MRO as the technical division of an airlines, then in 2003 the MRO has spun off from its parent company. The parent company which is airline does not have any assets in doing the maintenance for their fleet. To bond and to support the parent airline, MRO provide a contract to serve maintenance to airlines. It does not only for the parent airline, but also other airlines over the world (DW). The initial contract with the customers, such as customer G has been initiated with the help of the consultant. The draft of the contract has been offered as is initially designed and have been improved based on the service provider improvement (NP).
1.3	What tools, techniques, and philosophies that were used in the design process? Statistical, MTBUR through utilisation of the engine or APU's (TJ)
1.4	What factors are taken into consideration in designing the contract? In designing the contract, particularly PBH, they have to concern about how much to cost they have to consume to provide component. The correlation of those components and the maintenance (base maintenance and line maintenance). To estimate the cost, the material's value has to be related

	with the inflation and the rate of salary has to be related to the customer price index (CPI). (DY) The frequency of the fleet from airlines, the feedback, information from the customers for opportunity for improvement (AY) To valuing the contract, the GMF has to conduct the preliminary inspection for each aircraft/ engines/ components that will be covered by the contract. This preliminary inspection will be needed to review the necessary work scope to be conducted in supporting provisional support (NP)
1.5	What information is needed during the design of the contract? To design a contract, the productions' units will arrange the decision into several stages. They will conduct preliminary inspection to estimate the cost and the price. The information from the preliminary inspection will provide the MRO to estimate the cost. Then the data from the last shop visit report will be correlated to the workscope planning guide from the manufacturer. From the information before, the shop could decide which maintenance has to be conducted (minimum service, performance service, or overhaul service) (TJ). Focusing on the activities regarding the documentary record, the quality needed, the TAT, and the other supporting service which affect the speed delivery. All of that based on the CAMP (AS) The PBH contract will cover all the maintenance conducted for all fleet, therefore the base maintenance, line maintenance and all supporting maintenance aspects have to considered (NP)
1.6	What were the enablers and the barriers to support this process? The barrier is in deciding the fixed cost contract. The maintenance will come with the non-routine maintenance that will only be seen after the borescope or preliminary inspection. The unseen breakage will affect the longer TAT and higher cost as well. While the Online Fleet Highlight from the manufacturer, that could provide information about the problem or trouble faced by worldwide airlines who are using the common type of engines or airframe (TJ). To develop such as decision framework, the company has not review the detailed parameters that could affect the increasing demand of SLA. (NP) The company has experience in supporting operational for its parent airlines and have outstation across the region to support the operational support (YD)

Contract Types	
2.1	What kind of contracts that offered? To fulfil the customer's expectation, the company has provided contracts into three types: time and material basis (TMB), the power by the hour contract (PBH), Not to exceed contract (NTE) (TJ)
2.2	What the different of the contracts? On TMB, the customer will only pay the consumed manhours and material consumed on the project. NTE Contract will offered with the highest limit of price (TJ).

	The PBH will sum the total utilisation in the contract’s term and relate to the total cost of maintenance that need to be conducted in order to fulfil the utilisation planning (NP)
2.3	What are their advantages and the disadvantages of the contracts? PBH could save the cost and the time to provision consumable materials. Advantages in cheaper based on high volume price (Jumadi) The PBH contract has been made to support the needs of the airlines. PBH contract will be useful to maintain or help the airline’s cashflow. While with TMB contract, the maintenance cost will be fluctuated and will be more difficult in concerning the operational cost. In the term of the PBH, the MRO will receive some advantage in receiving the fixed income for the term time being. Another advantage is volume based provisioning will support the service provider to expand and investing (NP)
2.4	How do you consider the most suitable contract to the customers? For most of the high-risk components, usually the older generation of parts, usually the most suitable parts is by using the TMB. So, there is no unexpected ‘high cost’ above the predicted maintenance cost (TJ)

PBH Contract	
3.1	Could you tell me about the history of this contract? The contract actually has been agreed between the airlines and MRO, however the payment method is different, could be TMB or NTE, or PBH. With the PBH contract asked by the airlines, as they could be more secure in applying their financial strategy. The maintenance cost in each month will be fixed and not fluctuated (TJ). The contract design is initiated by a consultant provider, and until now the template still be followed (NP) The concept of PBH has started when the GMFAA spun off from GA. GA has passed their maintenance’s supporting assets to GMFAA. GA let GMFAA to support all operational support for GA, therefore the contract is established (DW)
3.1.1	How the PBH contract was conceived? The routine maintenance of the engine will be forecasted and predicted through the utilisation planning of the airlines. then, the task list of the maintenance project will be prepared by the engineering and PPC (TJ) The PBH contract was conceived as the MRO has an agreement to support GA’ operational support in 24/7 (NP) If we talked about OEM, they have superior control regarding the technology and they are tending to monopolise the repair station business industry. The OEM initiated the contract through the total solution (YD) The MRO’s strategies to become the total solution provider for the customers. MRO has capability to deliver maintenance from line maintenance (BD Check, transit Check, Daily Check) to base maintenance (DW)

3.1.3	How the PBH contracts changed or influenced the company? To cover this PBH, engine shop has to overview or reviews all of the aspects that needed to be concern. Which optimum balance point that could be develop. The preparation of the resources to fulfil the expected event as effect the airline's operations (TJ).
3.1.3.1	How its effect the business process in the organisation? In provisioning the mature engine, the engine shop tend to buy 5 engines, while two for serviceable, while other three will be tore down in order to obtain the parts. This way is more effective and efficient rather than order the parts per piece (TJ)
3.1.3.2	How its effect the business strategy of the organisation? The innovation in offering different kind of products, providing the engine as a whole to the customer (TJ)
3.1.3.3	What are the challenges of applying this type of contract? The inaccuracy sometimes happens since the route and the utilisation of each aircraft will be different. Therefore, there is deviation in MTBR and the usage. This condition has led to longer TAT and more spare parts to change (TJ)
3.1.4	Which unit is involved? Utilisation Data come from the Engineering Unit and the forecasting & production unit to prepare the readiness of the resources (TJ)
3.1.4.1	Which particular person should be contacted? (PY),(YD) (TJ)
3.1.4.1.1	What is their role in the contract decision? TEA will provide the data utilisation in order to estimate the maintenance events in the term of the contract's length. AMS will obtain opportunity and the requirement from the customers (TJ)
3.1.4.1.2	Why they have to be involved? Mentioned on previous question (TJ)

Customer's Expectation	
4.1	What are the customer's expectations? Many engine's shop customers do not have any capability or dedicated unit to conduct the engineering function, therefore they would like the GMF to take over the engineering performance and perform the workscope prediction as good as the engine can (TJ). While the crude oil price is increasing, small airlines like SJY have to survive by conducting several strategies. The airlines needed to make some customisable and flexible maintenance procedure; therefore, the GMF hopefully can provide all the operational needs of the airline's operations. The faster TAT prediction for non-routine maintenance, especially AoG (DWS)

	There is some notification from Sriwijaya regarding the maintenance's TAT (WS). The airlines have to relate the profit for each aircraft from the cost per seat. They have to keep the portion of their profit to the cost they expend for each seat (NP) The airlines have big expenses for fuel, aircrew, and maintenance. Currently they are tending to concern on their core business and do not want to manage the maintenance for their assets, because it needs high investment. They tend to expense the cost for operational, so they are asking MRO to support them to 'fly' (YD). The difference of the customer's expectation is based on its policy for beautification. Like airline G has special maintenance program to provide the cabin performance, while CItilink does not have that kind of policy (DW)
4.1.1	How you measure their expectation? Asked the AMS, airline G gave the customers with customer satisfaction form on the exit meeting (TJ) The customer needed to be provided with the fixed price, the expectation for each airline will be different, airline S only concern for serviceable and only for revenue in their operational, while some airlines like garuda Indonesia has to be gold plated maintenance level (YD)
4.1.2	How you fulfil their expectation? Organisation restructurisation, through dedicated personnel. Improving 4Ms: Manpower, Material, Method and Machine (Tools & Equipment). (WS) To reduce the ground time, the shifting of the maintenance procedure, from tearing down each module by modify the engine into an assy like cabin parts. They change the module as an assy to reduce the ground time (YD)
4.2	What is the company's expectation offering this contract? The more accurate actual TAT and shorter agreed TAT for special request, e.g. AoG (DWS) The MRO could perform and implement this strategy as the MRO has experiences and they can customise the needs by providing the older engine which is not covered by the OEM (YD)
4.2.1	How the companies accommodate this expectation? The MRO like GMF has more advantages in offering the total support since it has outstations all over the regions. And most of the OSA have capabilities to support the engine troubleshoot (YD)
4.2.2	What is the performance indicator that you assign? The deviation between the predicted maintenance's TAT and the actual TAT (WS) The performance indicator transtaled into SLA (YD)

PBH Contract Delivery	
5.1	What factors have to be prepared to deliver this type of contract? Internal factors and external factors from the engine's preliminary inspection (TJ) In the PBH contract, the PBH value has to be considering the manhours and manpower which is needed to be reviewed for future maintenance. For routine maintenance, all the needs are mentioned in the MPD but the non-routine has not been accurate. The non-routine maintenance will be depending on MRO's capabilities, daily maintenance, operational and utilisation, the geographical (NP)
5.1.1	What are the consequences for delivering the higher level of demand? Missaccuracy in predicting the resources needed (Jumadi) To fulfil the airline S' demand, the MRO has appointed dedicated group of personnel in three shifts, while the material coordinator has been choosen each personnel for each aircraft (WS) For dedicated market such as the B737 Classic, the MRO still can obtain profit through by investing what the market wants. The higher demand means the capability to offer premium maintenance and component provision while the other needed lower level maintenance such as for LCC airlines (YD)
5.1.1.1	What are the main factors that have to be concern? The main factors that affect the delay is the rectification process that have to 'wait the manufacturer's decision regarding the structure or flight control maintenance (WS) The customer will keep rely on the MRO as if the MRO could provide solution with reasonable price (YD) The initial condition of the engine (TJ) To estimate the valur contract of PBH, all involved unit have to submit the CoGS in supporting the maintenance plan for the future (DW)
5.1.1.1.1	How do you manage the resources? The available resources will be adjusted regarding the workscope mentioned by engineering service and the need from the production unit (TJ) Tools and equipment has been modernised to shorten the removal and installation process. Personnel addition to fulfil 3 dedicated shifts mentioned before. Outsource the supporting workscope such as cleaning (WS) In upgrading the capability, such as the CFM56-3 to CFM56-7 actually there is a lot commonality. Therefore, there is less special tools that needed to be procured (YD) For the covered capability, the engine/ parts/ component will be serviced in the shop, while for non-of the capability list, the MRO still have to responsible to manage the delivery to the other parties (DW)
5.1.1.1.2	How do you manage the policy?

	Each month there will be a report of total available manhours (TJ) The most strategical policy to increase the quality and shorten the TAT is by detailing the project's barchart from day parameters to hours. The rectification order for complex troubleshooting will be conducted by the production engineer. Monitoring Sheet for Jobcard to assess the project's contol tools. Extend the responsibility of the PPC coordinator to purchase the needed material for non-routine (WS)
5.1.1.1.3	How do you apply the strategy? The strategy applied to expand the capability by overview and predict the workscope based on the specification, while mind several aspects to be set up and the expandable volume (TJ) Dedicated line/ slots and manpower, the prime customer treatment policy, early planning and preparation to fulfil next year Sriwijaya's utilisation planning. MRO has built more hangar and dedicate three slots particularly provides only for airline S (WS) The best example is the case for airline S, the airlines contract term has ended with the lessor, to keep the aircraft serviceable, and the MRO applied strategy as maintenance reserve. The MRO bought an old engine, then the total maintenance to repair the engine to a serviceable condition is summed. And the MRO made the engine to become serviceable until certain limit (i.e. 2000 cycle) and then compare to the aircraft utilisation, the valur of the contract can be obtained. The total cost of the maintenance for the whole cycle and the fee for initial restoration then payed by the airlines through instalment scheme. (YD)
5.1.1.2	How do you describe these factors relating to the SLA? The early planning is set earlier from 30 days before the maintenance to 60 days before the maintenance. Therefore, needed material will be provisioned and purchased earlier, and concern about the operation of the aircraft, e.g. aircraft carrying marine product needs more concern in the structure repair. (WS) When the procedure is completed and the personnel could apply it, the TAT will be on time (TJ)
5.1.1.2.1	How do you rank these factors? All the factors are equal. Each parameter are related and interconnected (TJ)
5.1.1.2.3	What indicators that you have to consider? The maintenance control sheet. This MCS will assess the finished Jobcard and the left JobCard to be done (WS)
5.1.2	What are the maintenance activities that have to be concern? Sriwijaya has prepared the CRIMI material planning. MRO need to apply replacement strategy to reduce the TAT. (WS)
5.1.2.1	What are the maintenance activities that have to be added?

	The APU maintenance, especially in repairing turbine wheel in assembly process often failed. Therefore, the remaintenance have to be added to the prediction (TH)
5.1.3	How does the maintenance work scope affect the resources? The work scope needed a new measurement meter to prevent the remaintenance (TH)
5.1.4.1	How do you manage the previous activities to predict the contract's value? To predict the resources that is needed, the service provider has prepared the borescope event several times in a year. It is similar to health monitoring but it is done manually (YD)
5.1.4.1.1	What method did you use to predict? Currently the method used is by the intuition of the seniors or the engineers in the production area (NP)
5.1.4.1.2	How this method's affect the level of the accuracy? The missaccuracy will be resulted in the bomb cost for the material and manpower consumed for the non-routine maintenance work scope, as in PBH all the workscope bundled in one package price (NP)
5.1.4.1.2.1	How your plan in using another method to predict more accuracy level? The work scope has to be improved by the use of the six sigma for each job card, this jobcard will be evaluated the total number of needed manpower and materials. While evaluating and assessing the dirty finger print for each non-routine workscope (NP)
5.1.4.2	How do you manage the cost breakdown? To valuing the PBH contract is by dividing the total maintenance cost in the duration of the contract and divide by the flight hours as many as the total flight hours in the duration of the contract (NP)
5.1.4.2.1	What are the factors are considered in the cost breakdown? For low flight hours, the rate will be high. While PBH will count by the ratio of FH and FC especially for engine and components. The day will be 365 days per year, maximum ground time allowed will be 8 times, AoG only allowed one time and the total availability of each aircraft will be 354 days per year (NP)
5.1.5.2.3	How do you manage the resources? Currently to manage the material and manpower, there is a system called MCS to monitor the consumed material for each maintenance. While in the base maintenance is still coverable but not for the line maintenance (NP)
5.1.5.2.4	How do you manage the capability? The under capability could affect the robbing parts occurred and often the NFF cases are happened (NP)

Technical perspectives	
6.1	How do you think from the technical perspectives? For 100% reliability, the technical delay distribution could be influenced by the airport's aspects, technical and weather. While the dispatch reliability could be influenced by the quality of the mechanics, the tools used and the availability of the special tools (DY)
6.2	What are the challenges in the technical perspectives? With the aircraft manufacturer designed the 95% of availability, the MRO have to relate the condition mentioned by the manufacturer by the current condition that MRO possess, the mechanic's quality, the tools owned and the special tools owned (DY)

Accuracy	
7.1	How is the accuracy between contract value estimation with the real cost? Sometimes the accuracy between the planning and the actual happen, it happens because the different of the MTBR. The aircraft has been operated above the recommendation utilisation. E.g. APU usage (TJ) The deviation between the predicted the actual maintenance could happen (DW)
7.1.1	Why that is happen? In the meantime, of the contract agreement, the airlines could modify its strategies, adding some fleets, adjust the route, and increase the frequency (DW)
7.2	How do you use the historical data to increase the level of accuracy? Engine shop could assess the condition and predict the workscope through the lst shop visit record and the documented utilisation of the aircraft. From those documents, the shop will assess how many FC and FH then predicted the material that have to be changed and the total manpower that need to be prepared (TJ)

Customer's satisfaction	
8.1	How do you measure customer's satisfaction in the contract?
8.1.1	What are the indicators that represent the customer's satisfaction mentioned in the contract? The customer needed the exact of clearer of target TAT for every matter that happen (DWS)
8.1.3.1	How the customers do mention their demand? The quality and the TAT of a workscope that has to be done as target defined (DWS)

	Airline C will pass over the maintenance plan and the utilisation plan to MRO in order to ask MRO's support. So, in planning their operational utilisation, Citilink acknowledge the MRO to plan and prepare the resources that are needed (DW)
8.1.3.1.1	How do you translate these demands? The demands mentioned will be transferred into the engineering side first, then proposed the TAT and the Cost to the AMS (TJ) The demand from the airlines is only concern about the availability of the aircraft. While in the current practice, there are a lot of supporting aspects needed to be mind: base maintenance, line maintenance, reliability, maintainability, materials, allotment's, material, Dispacth Deficiency Guide, etc (NP) Currently the demand for the supporting operational is focus on the airframe and components. The main idea of the demand is how the aircraft is serviceable. To support this aircraft need base maintenance or line maintenance. The optimum point between the utilisation and the maintenance have to be obtained by the MRO (DY) In the negotiation to the airline, the service provider asked the total solution (DW) For providing the material or component to support the maintenance, the airlines do not want to invest or possess assets to support their maintenance. All supporting assets are handed over to MRO (AP)
8.1.3.1.2	What method are you using to represent this demand? To represent the demand, the airlines and the MRO is translated by parameter called SLA. The SLA have to be maintained from the airline maintenance. If the SLA have to be 100% means that there have to be 100 serviceable aircrafts on the hangar. (DY) The contract's component that is agreed is the SLA
8.1.3.2	How the organisation concern to the customer satisfaction? To supported the airline' expected availability, the MRO has to design all the needed aspects to fulfil the planning of operational utilisation (DY)
8.1.3.2.1	What is the organisation strategy? The MRO with the airlines, has to seek the optimum maintenance cost, for each optimum cost (FH, FC and Calendar Days) for each aircraft, the chance to have the most efficient maintenance will be obtained (DY)
8.1.3.2.2	How your plan to expand the organisation? To deliver the customer's demand and fulfil the assets to conduct the maintenance work scope, the shop has set up several resources to be expanded. The capability of the shop, the supporting aspects such as environmental supporting needs, logistical needs, and the equipment planning and monitoring such as SWIFT (TJ) The initial strategy for the engine is based on pooling. The company intent to provide engines to all small airlines in the region. If the classic aircraft operated by small airlines is maintain by MRO, the spare and the opportunity to take more market share is still open (YD)

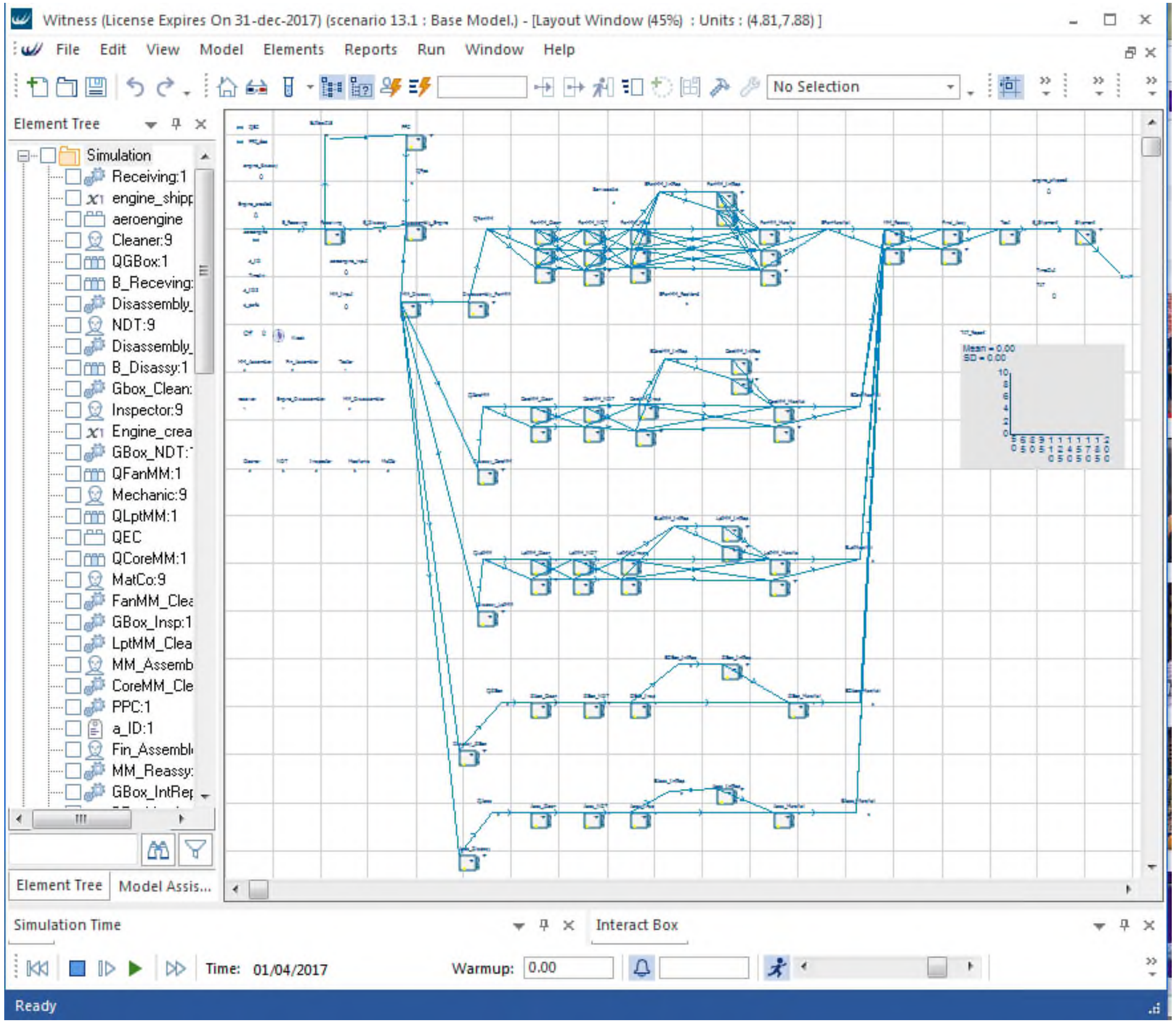
8.1.3.2.3	How do you develop new business unit to develop this organisation? To fulfil the demand of the airline G, the MRO could cover all the operational supporting needs through PBH contract. To provision the aircraft and its supporting aspects needed to concern about its maintenance. Therefore, MRO has capability to ensure that the aircraft will be efficient since they are chosen to purchase. The most commonality in a fleet of an airlines will lead to the reduced inventory and less investment. The standards and the quality have to be defined by GMF in order to reach the most efficient state of the fleet (NP) To compete with the OEM, the MRO has no power. Therefore, the MRO have to improve their current strategy by bundling not only the engine but also APU. The strategy is like criss subsidies between the engine and the APU. Through the bundling the price MRO offered could be cheaper and have additional value (YD).
8.1.3.2.5	Which unit has direct impact? The engineering, forecast and planning, and marketing (TJ)

Appendix C Experimentation Scenario in Witness Software

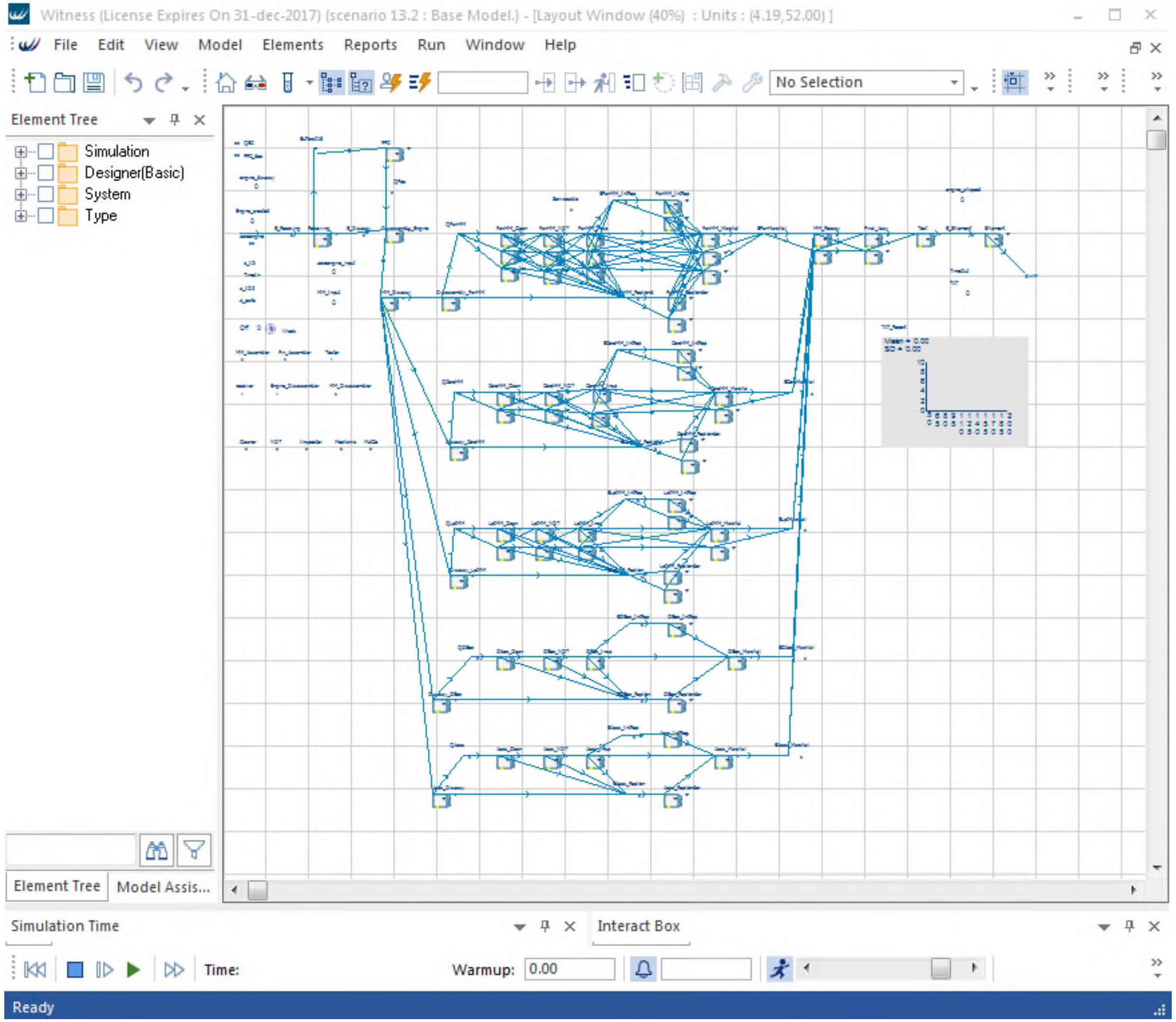
Appendix C represent configuration which then simulated using Witness Simulation software. Each of this model in this appendix is representing different service and product configuration which can be offered by non-OEM MRO service provider.

The service provision configuration is based on the MRO as service provider. Each scenario is developed based on the additional service or product to be added in contracting offer.

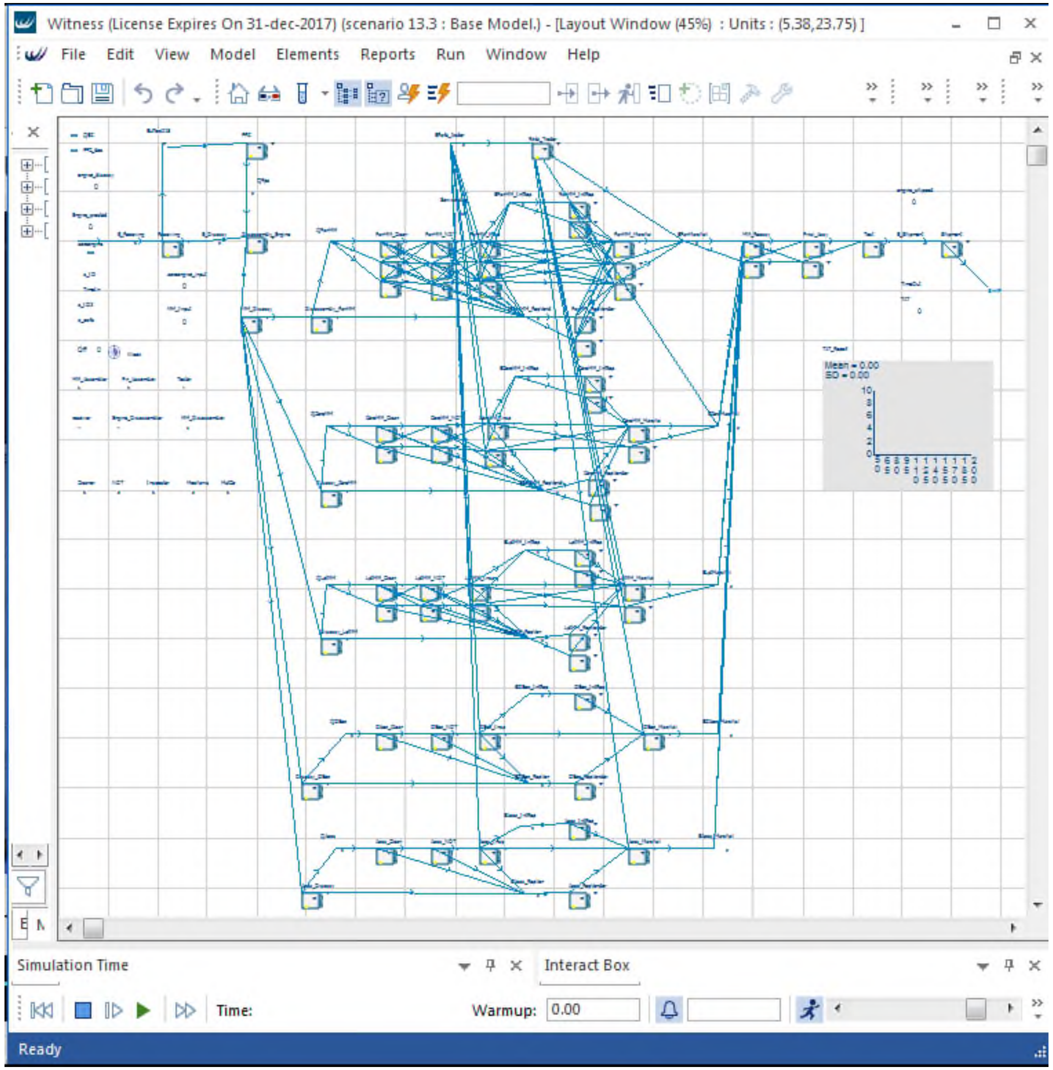
C.1 Scenario 1



C.2 Scenario 2



C.3 Scenario 3



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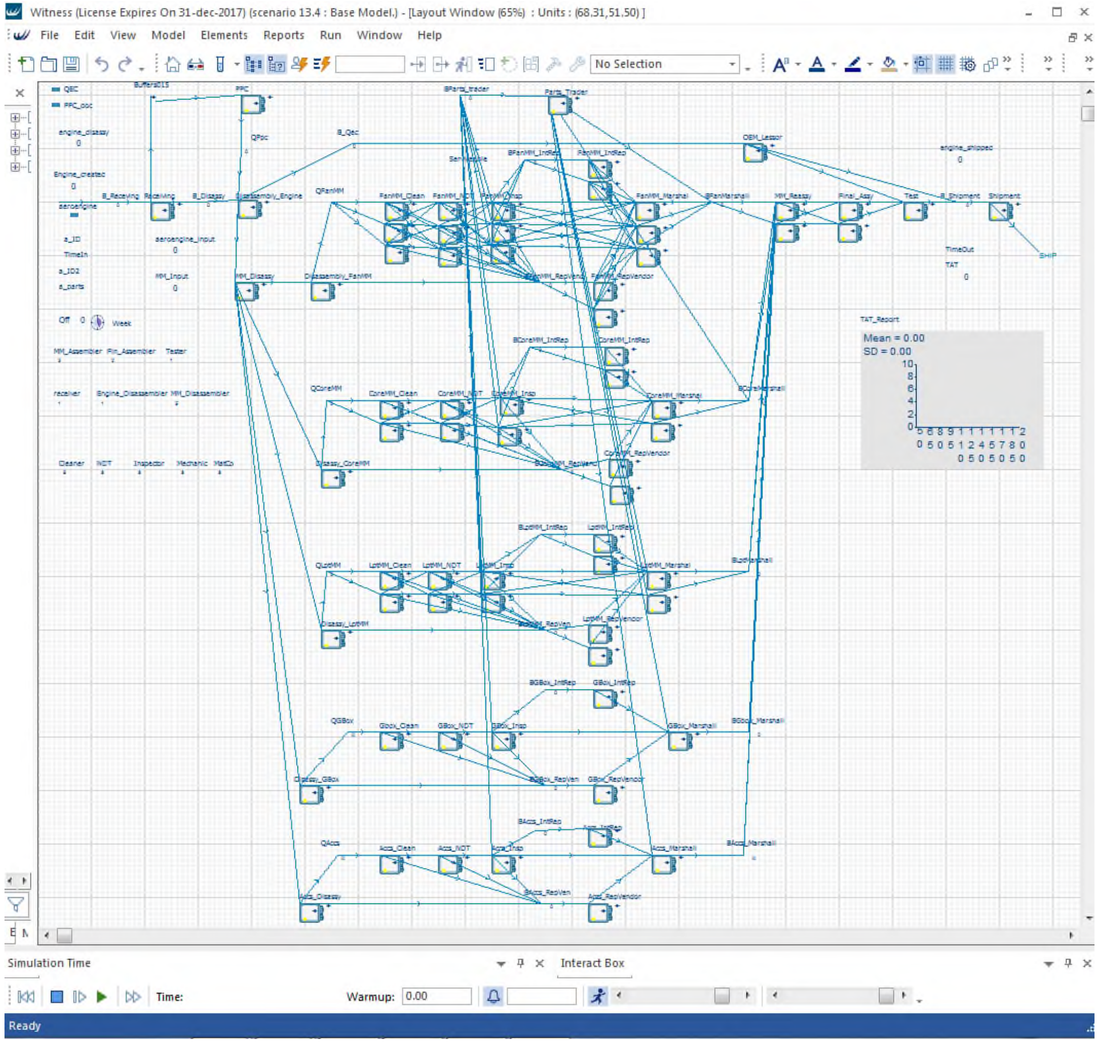
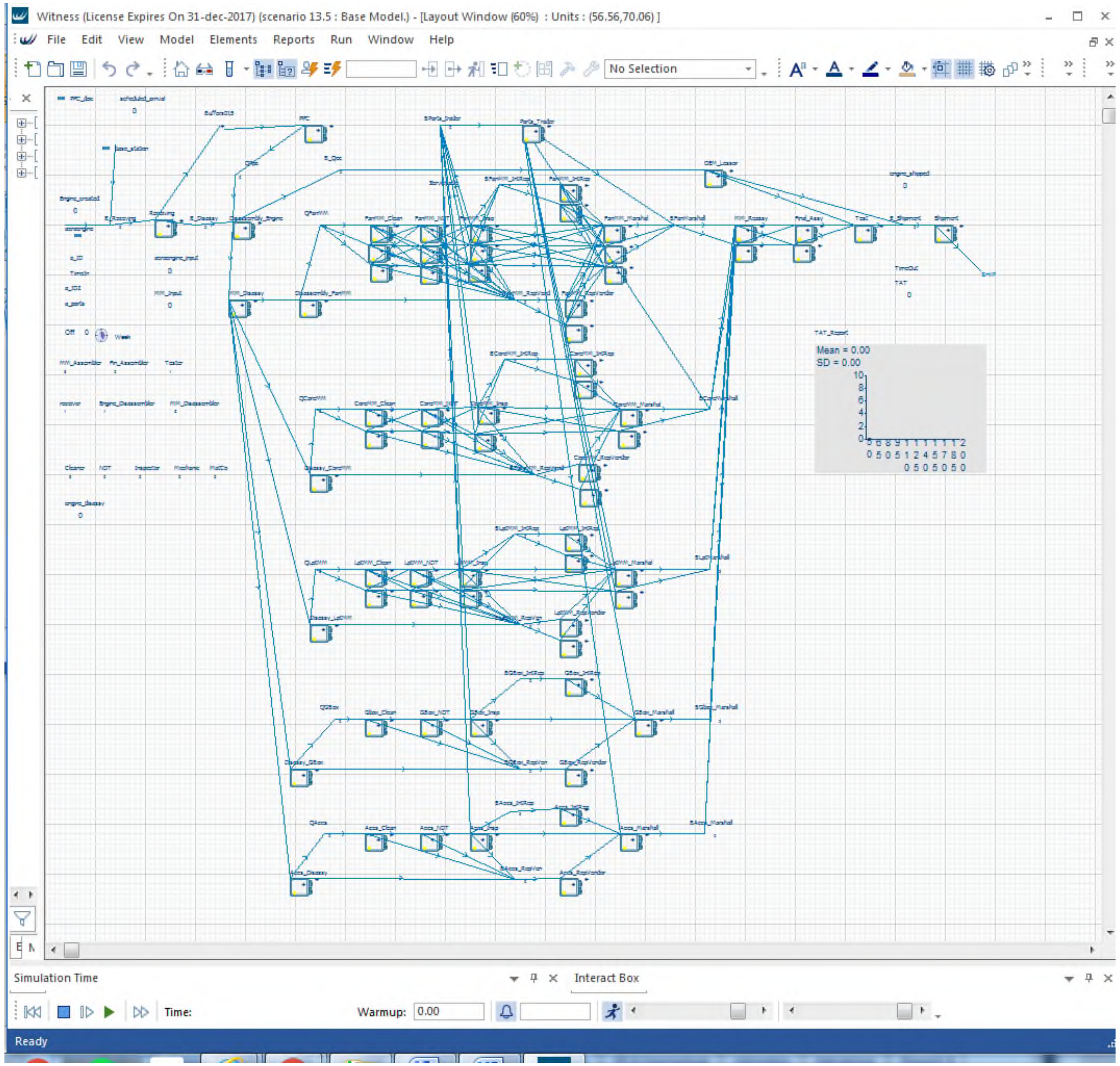
Ready

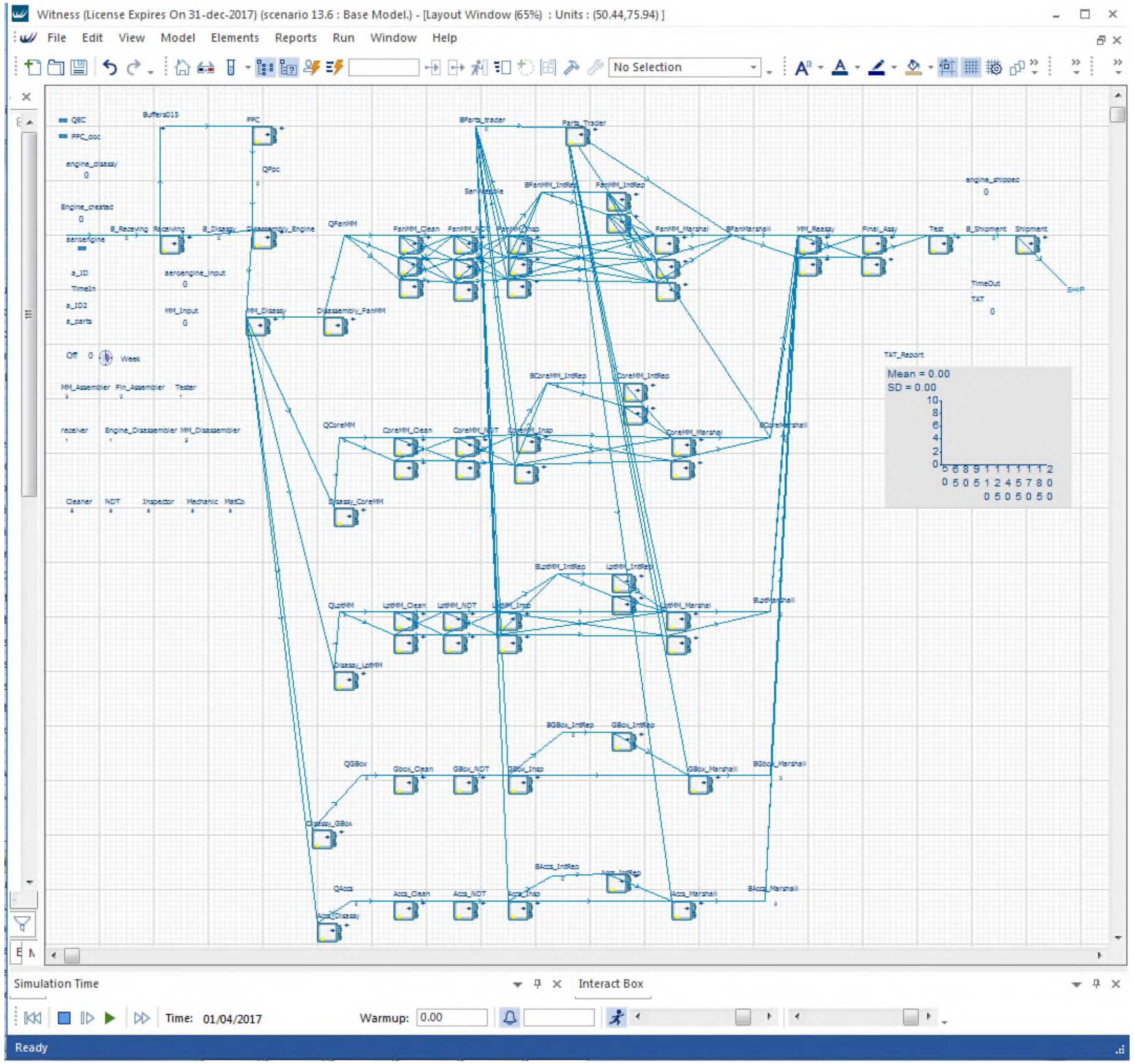
C.4 Scenario 4



C.5 Scenario 5



C.6 Scenario 6



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SD = 0.00

Simulation Time

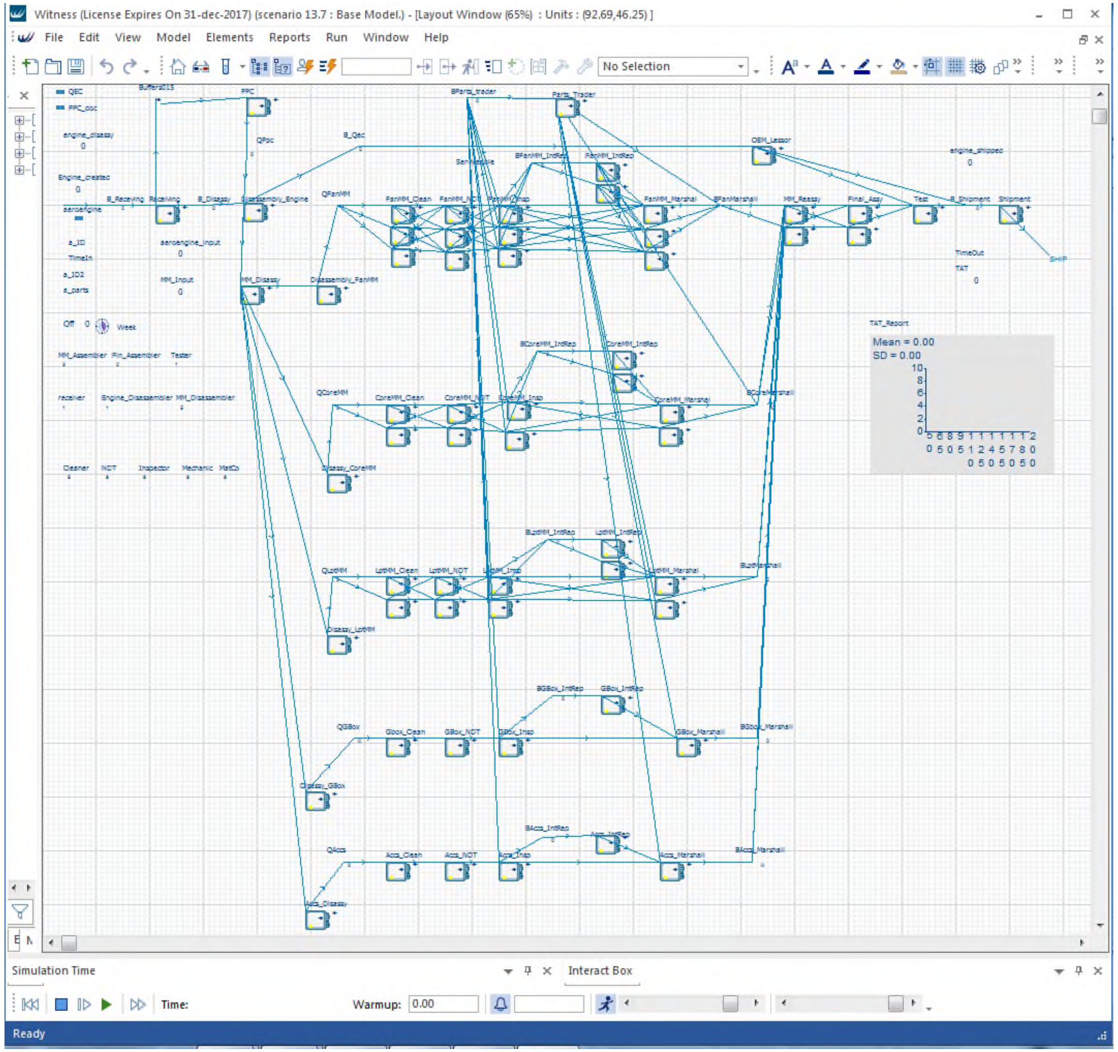
Time: 01/04/2017

Warmup: 0.00

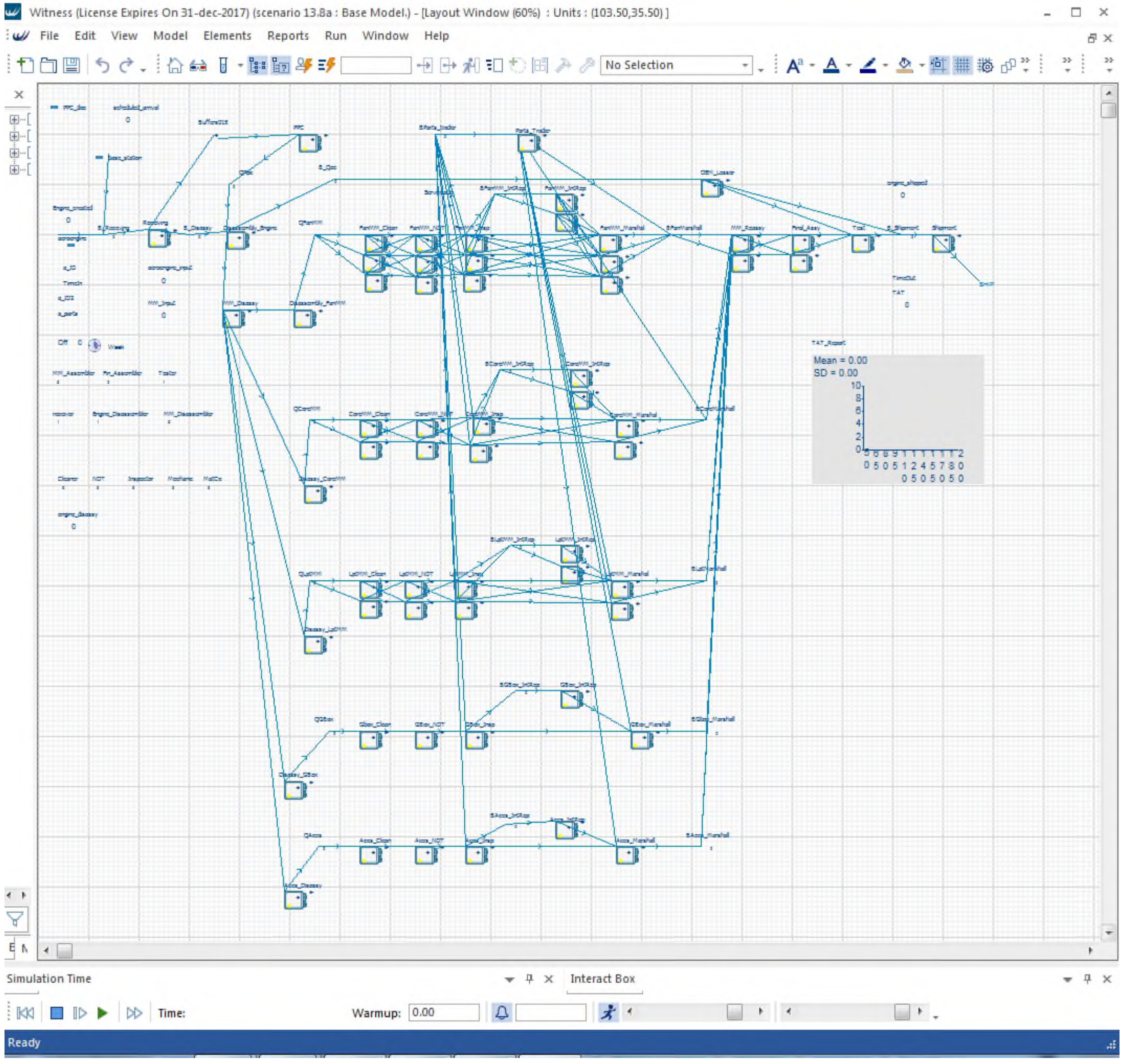
Interact Box

Ready

C.7 Scenario 7



C.8 Scenario 8



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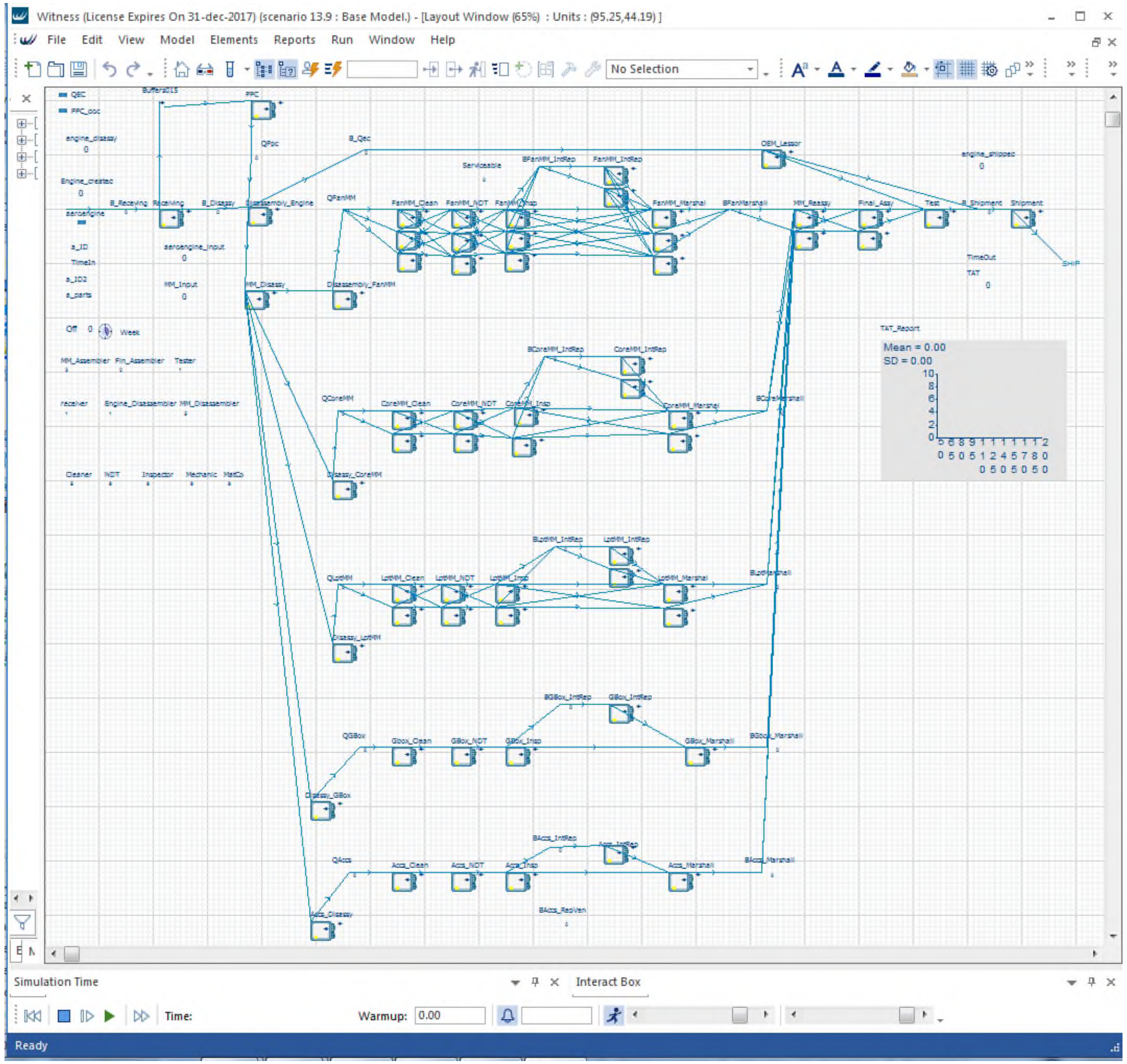
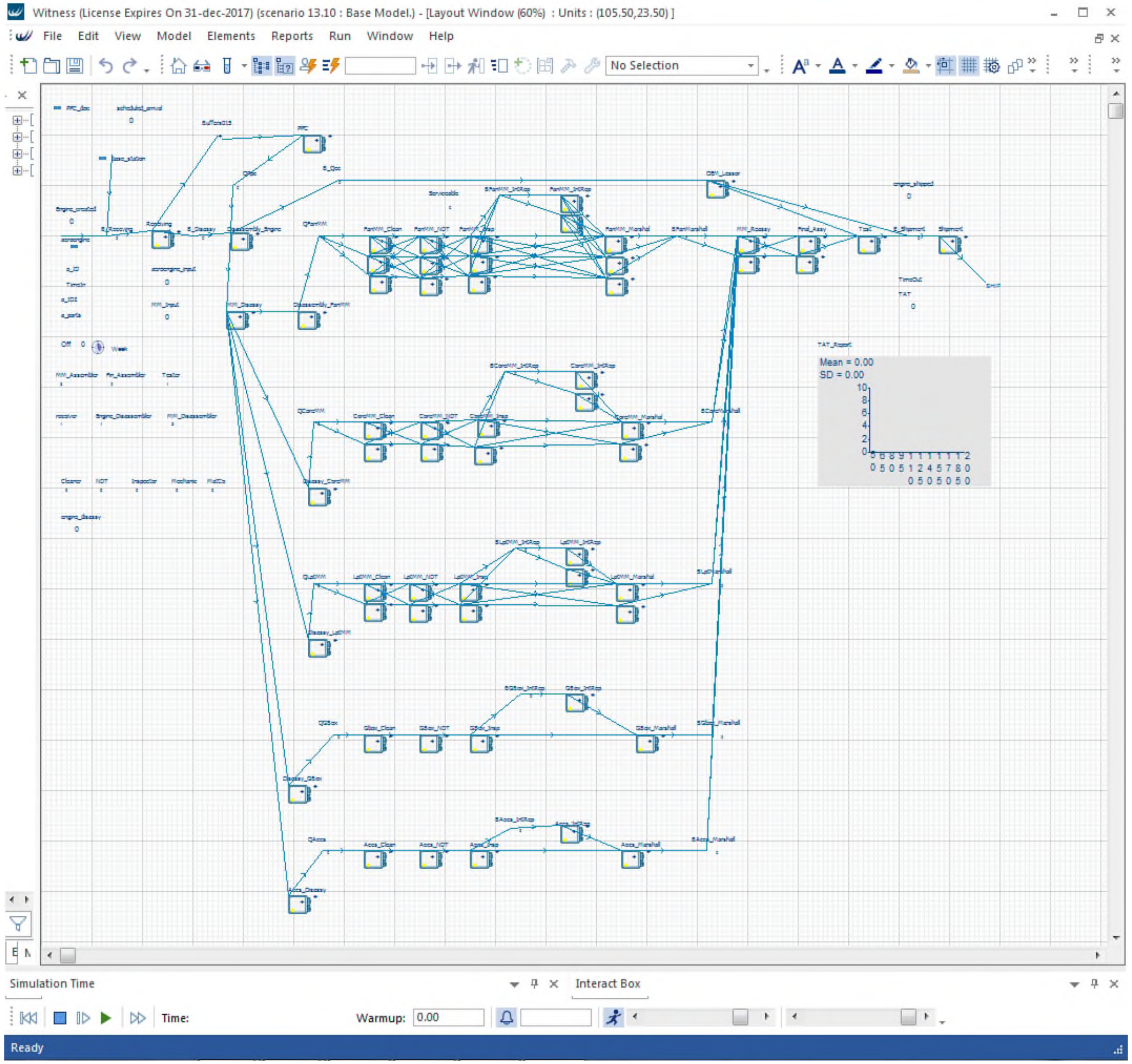
Mean = 0.00
SD = 0.00

Warmup: 0.00

C.9 Scenario 9

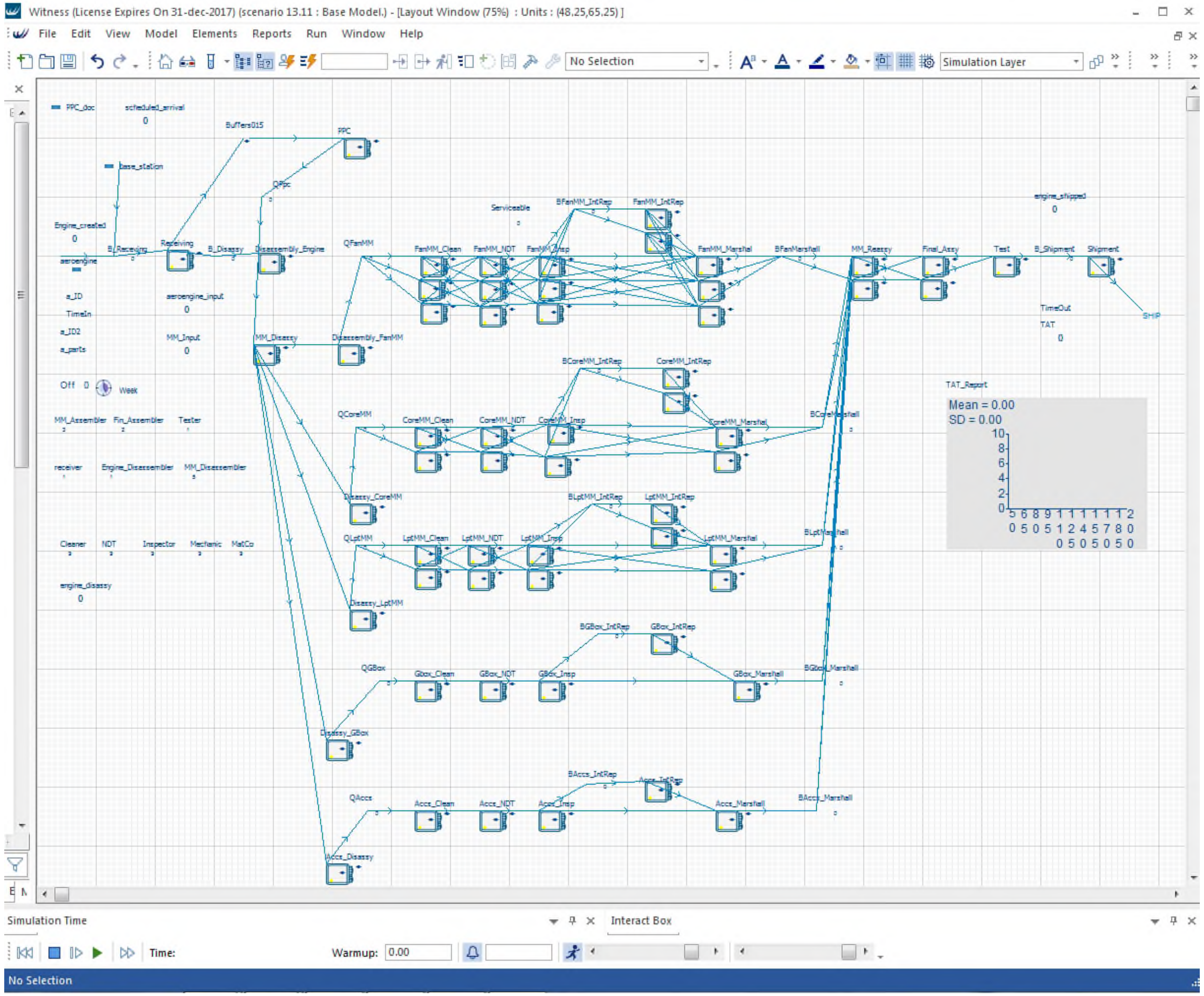


C.10 Scenario 10



Warmup: 0.00

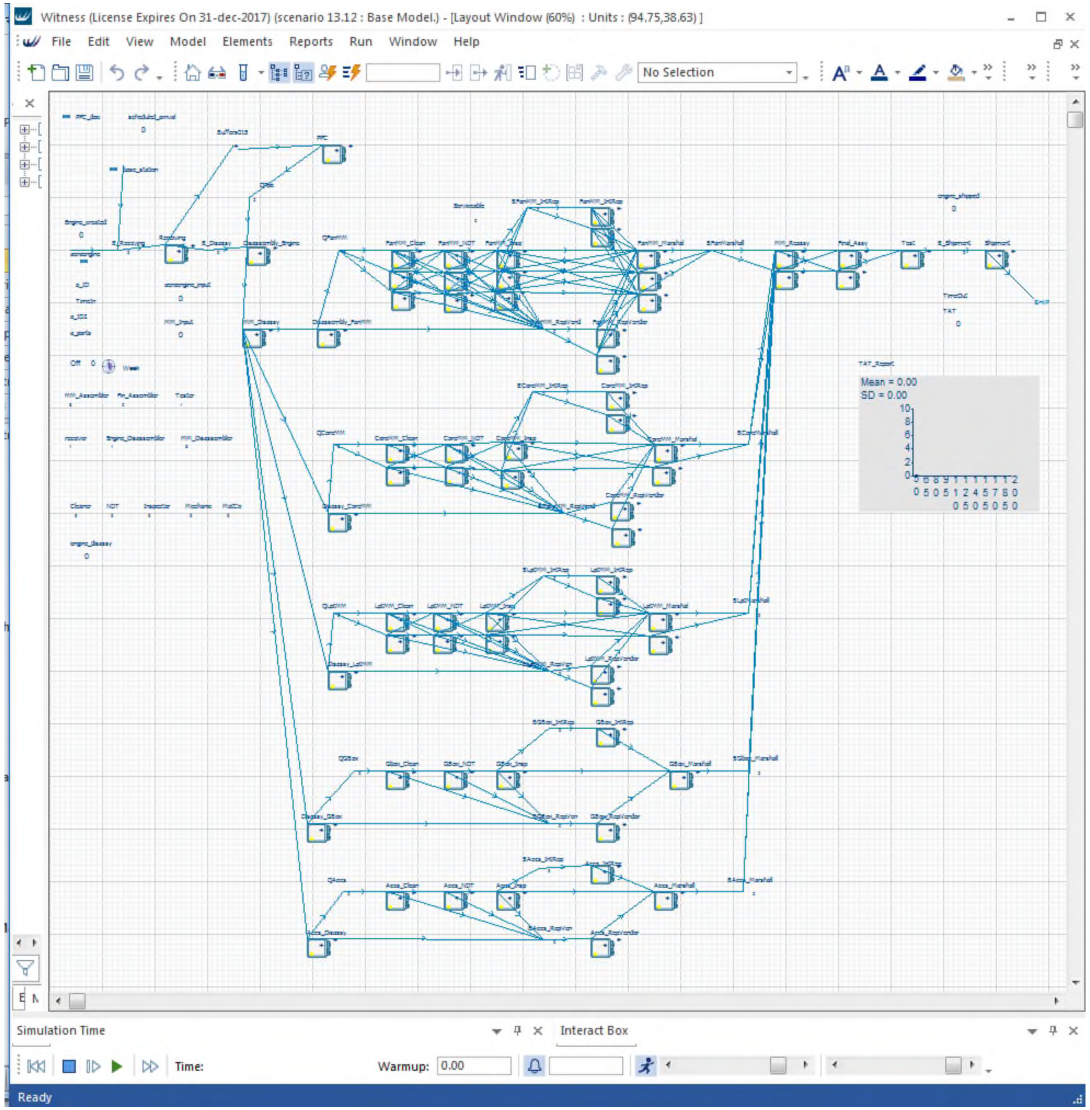
C.11 Scenario 11



Witness (License Expires On 31-dec-2017) (scenario 13.11 : Base Model.) - [Layout Window (75%) : Units : (48.25,65.25)]

Warmup: 0.00

C.12 Scenario 12



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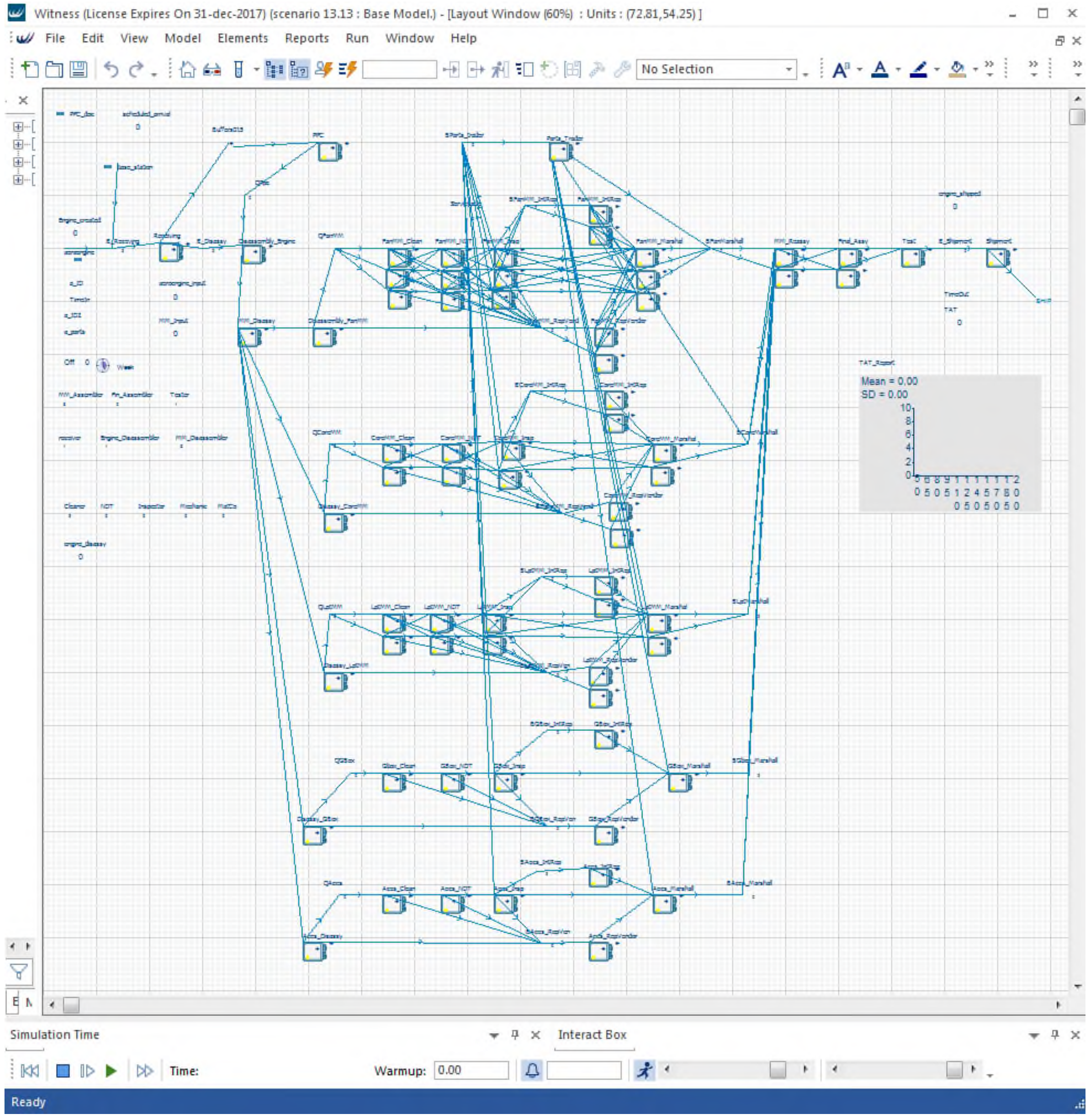
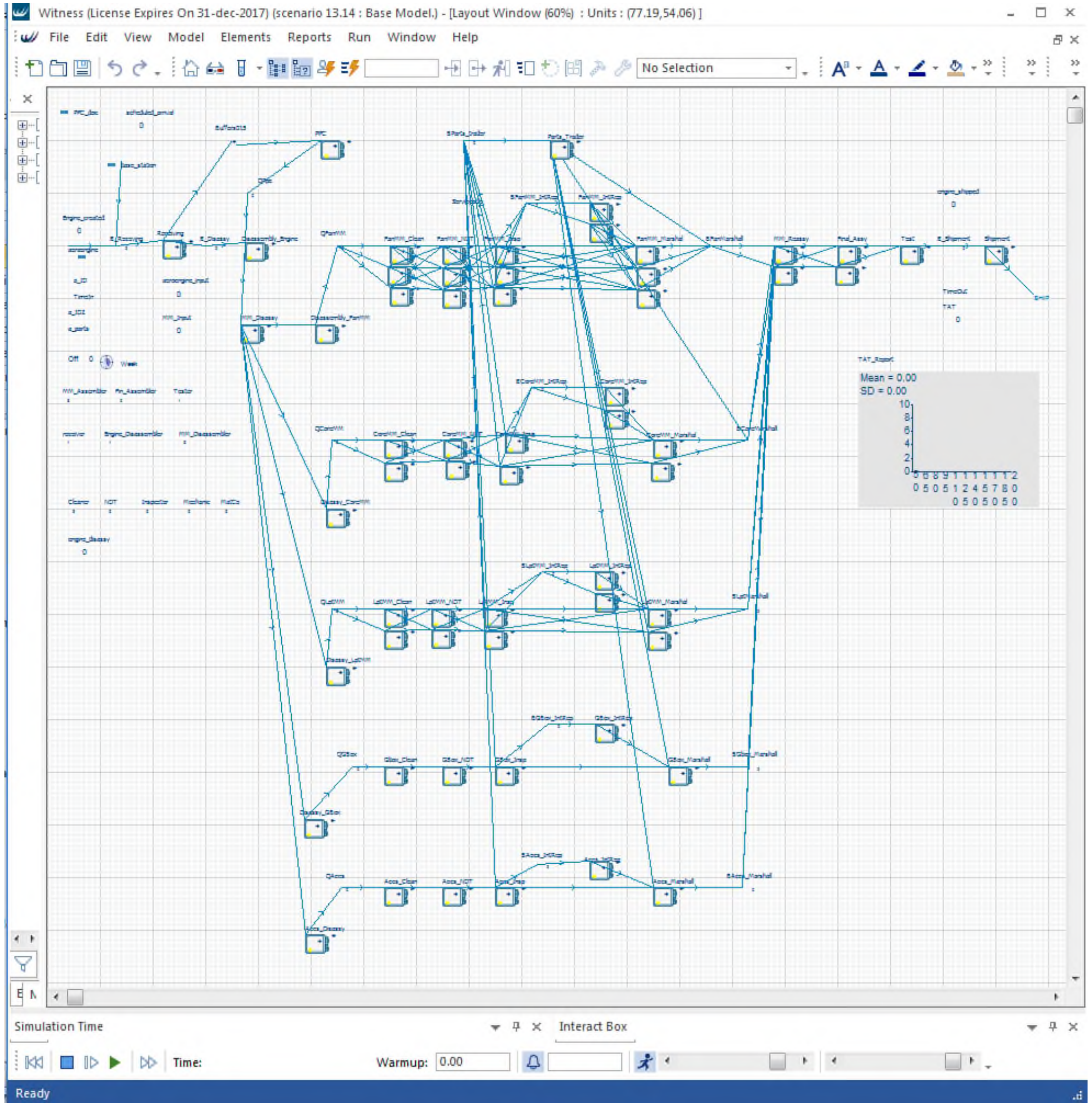
Warmup: 0.00

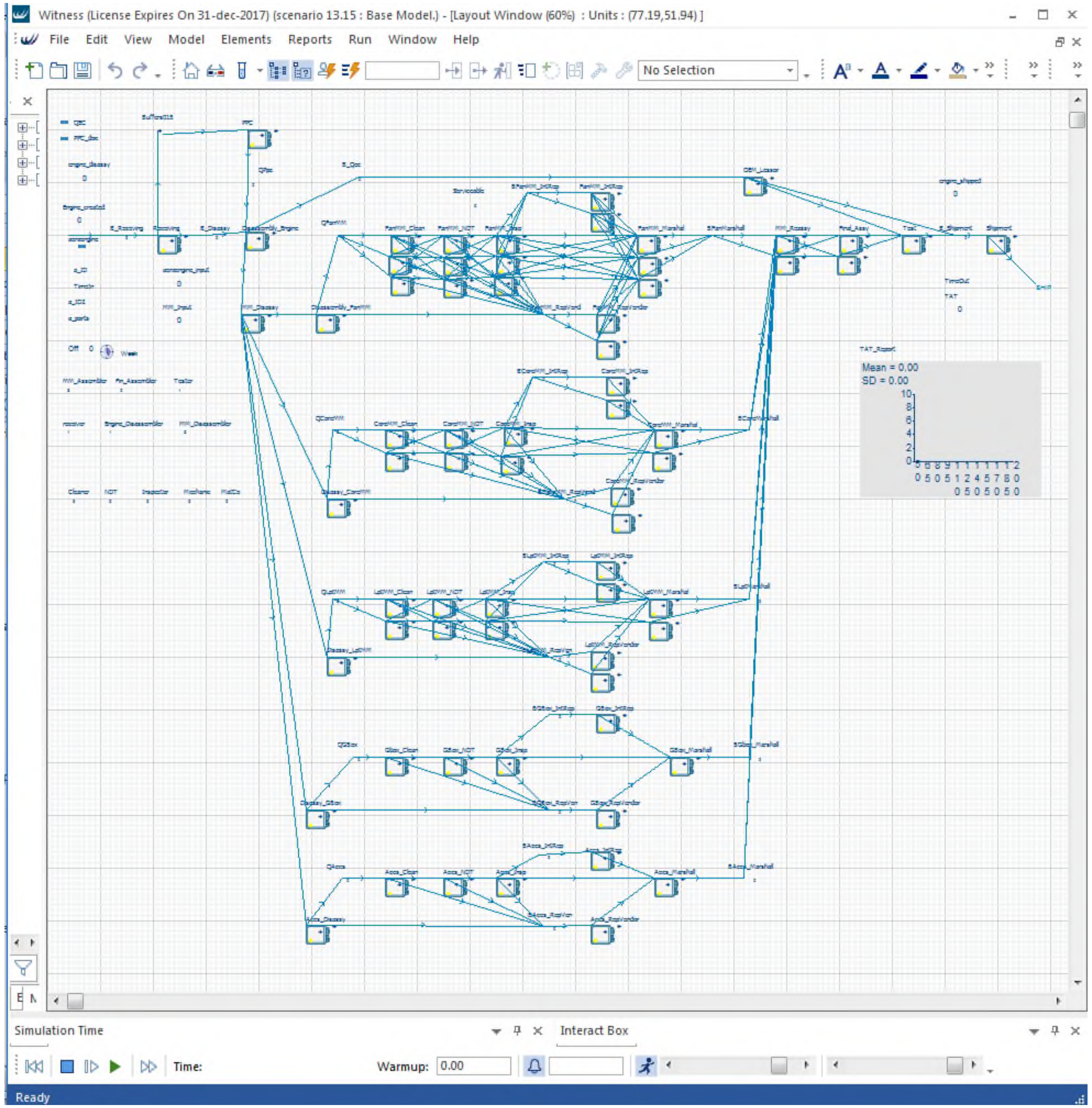
C.13 Scenario 13



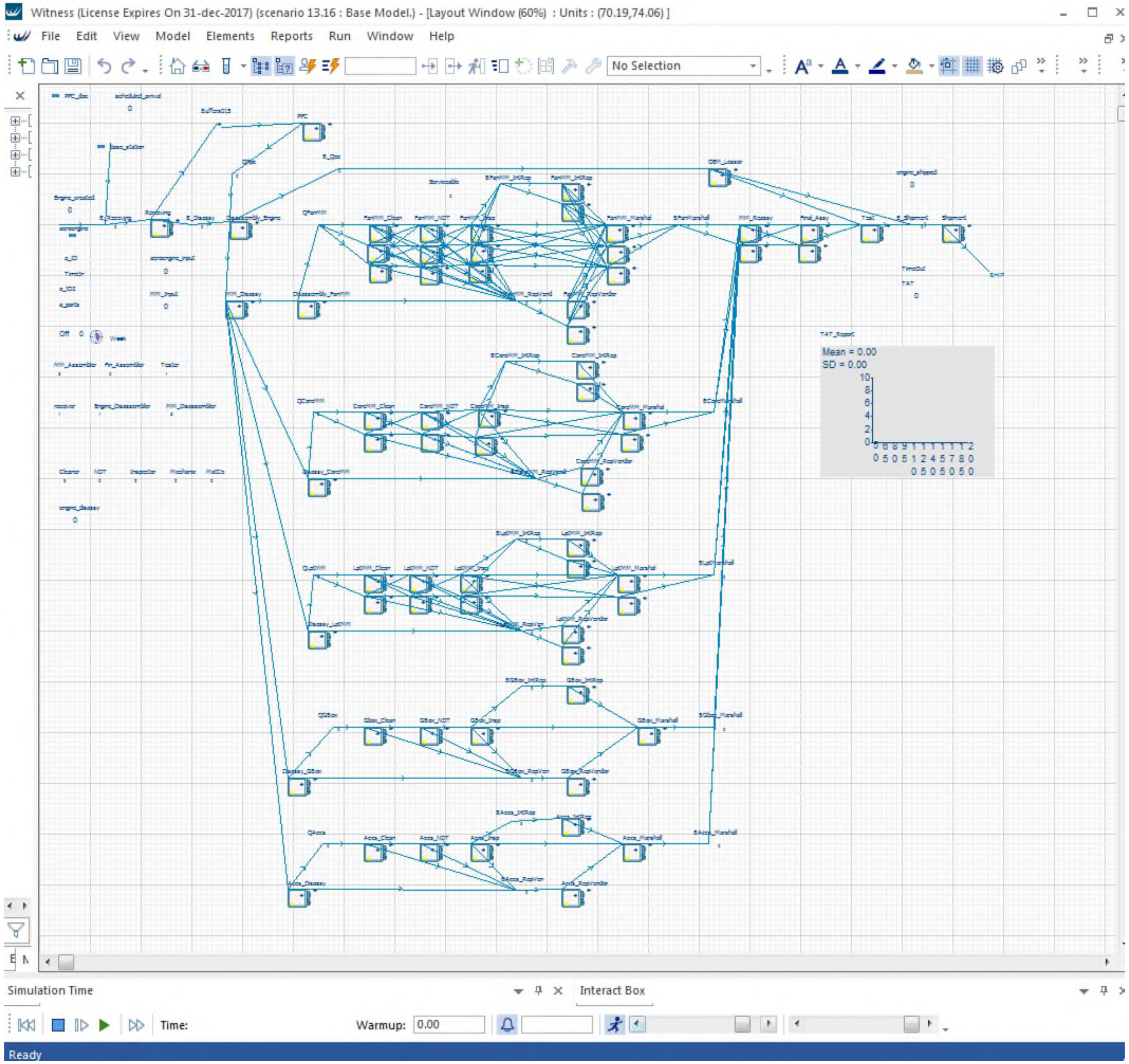
C.14 Scenario 14



C.15 Scenario 15



C.16 Scenario 16



Appendix D Utilisation for each Machine Operations

Each of the scenario then simulated to obtain the informaton regarding the shop floor operation performance for each scenario. The shop floor performance is vary for each scenario.

D.1 Machine Utilisation (No. of Operations)

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13	Scenario 14	Scenario 15	Scenario 16
Receiving	79.87	79.61	79.97	79.7	55.89	79.73	80.49	75.95	79.48	51.5	53.33	55.09	53.96	65.97	79.72	52.82
Disassembly_Engine	80.22	80.22	79.36	79.84	57.1	79.55	79.63	76.9	79.58	51.56	55.83	55.03	55.43	66.86	80.35	53.16
Disassembly_FanMM	86.75	87.01	86.61	88.95	77.5	86.89	88.98	86.88	88.75	75.17	70.71	71.18	71.08	78.82	88.95	75.69
Gbox_Clean	90.28	93.32	93.16	94.18	87.1	90.6	91.89	90.16	92.17	80.9	75.76	83.8	83.22	82.65	93.91	86.49
GBox_NDT	88.61	92.44	92.51	92.6	85.72	87.46	90.51	88.47	90.22	76.58	71.63	81.75	81.92	79.11	93.04	86.03
FanMM_Clean	95.62	97.53	97.46	97.77	95.34	95.69	96.26	95.76	96.4	91.72	89.86	93.83	93.89	92.65	97.82	94.88
GBox_Insp	85.57	92.88	91.94	93.25	85.98	85.71	88.55	85.1	88.57	70.9	64.15	82.4	81.78	74	93.2	85.52
LptMM_Clean	96.5	97.39	97.32	97.56	95.07	96.18	96.79	96.51	97.08	92.76	91.24	93.75	93.3	93.75	97.56	94.8
CoreMM_Clean	96.45	97.09	97.12	97.55	94.8	96.5	97	96.47	97.08	93.62	91.17	93.45	93.07	94.15	97.63	94.37
PPC	84.85	84.85	84.77	84.77	67.23	84.84	84.58	82.57	84.82	63.72	66.03	66.5	65.96	74.98	84.67	64.64
MM_Reassy	92.57	92.41	92.89	93.73	87.17	92.71	93.95	93.05	93.58	85.77	83.51	83.88	83.15	88.45	93.7	86.43
GBox_IntRep	98.11	98.73	99.06	99.15	98	98.53	98.62	98.37	97.95	93.75	90.68	97.68	97	95.57	98.89	98.38
FanMM_NDT	94.9	97.91	97.7	98.24	95.96	94.9	95.76	94.84	95.85	90.06	88.2	94.64	94.66	91.38	98.2	95.5
GBox_RepVendor	0	89.61	89.85	92.15	80.88	0	0	0	0	0	0	71.99	73.21	0	91.79	79.06
CoreMM_NDT	91.09	94.56	94.41	95.4	90.42	91.44	92.67	91.45	92.29	83.78	80.09	87.84	88.03	85.57	95.46	89.6
LptMM_NDT	91.82	95.04	95.06	96.26	90.88	91.53	93.06	91.54	93.11	84.68	80.57	88.92	88.55	86.58	95.8	90.69
Disassy_GBox	86.91	86.75	86.88	89.06	77.14	87.04	89.25	86.95	88.87	75.24	70.92	71.14	70.7	78.73	89.08	75.99
FanMM_Insp	92.72	97.43	97.45	98.03	95.34	92.73	93.63	92.94	93.93	86.05	82.75	93.88	93.74	88.36	97.87	95.15
FanMM_RepVendor	0	93.65	93.61	94.49	89.51	0	0	0	0	0	0	86.41	85.61	0	94.72	88.49
CoreMM_Insp	90.09	94.31	94.4	95.39	90.51	90.18	91.71	90.26	91.71	80.66	75.94	88.7	88.31	83.67	95.54	90.13
CoreMM_IntRep	98.18	98.89	98.94	99.28	98.12	98.34	98.52	98.28	98.43	96.47	95.35	97.56	97.67	97.34	99.01	98.05
LptMM_Insp	92.13	95.72	95.46	96.41	92.45	91.89	93.28	91.56	93.55	83.64	80.4	90.11	90.16	86.07	96.8	92.07

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13	Scenario 14	Scenario 15	Scenario 16
Disassy_CoreMM	83.79	83.98	83.6	86.58	73.06	83.83	86.47	83.54	86.11	70.24	64.55	65.17	64.62	74.17	87.01	70.34
FanMM_IntRep	97.29	99.25	99.61	99.67	98.91	98	98.24	97.57	97.89	95.2	94.48	98.19	98.58	96.13	99.48	98.48
LptMM_IntRep	98.81	99.66	99.84	99.68	99.75	99.18	99.39	99.15	99.09	96.84	95.39	99.03	99.37	97.83	99.73	99.2
CoreMM_RepVendor	0	92.7	93.79	94.65	87.03	0	0	0	0	0	0	83.37	82.89	0	93.94	85.05
Disassy_LptMM	90.56	91.13	90.82	92.64	84.67	91.29	92.35	90.88	91.91	82.95	79.3	80.34	80.13	85.61	92.44	83.41
LptMM_RepVendor	0	94.35	94.06	95.02	87.83	0	0	0	0	0	0	81.64	83.19	0	94.56	86.96
Final_Assy	87.86	88.19	87.88	90.12	78.43	88.51	90.26	87.97	90.12	77.11	73.14	72.65	73.6	80.44	90.12	75.92
GBox_Marshall	75.86	76.7	76.7	79.7	59.17	76.99	80.27	76.97	80.61	55.5	47.92	48.04	48.78	61.94	80.28	56.84
Test	85.26	85.34	86.01	85.61	69.83	85.53	86.13	83.7	85.42	68.8	68.16	68.62	68.02	75.78	86.53	65.32
FanMM_Marshal	89.38	88.86	89.16	91.06	81.44	91.19	92.6	91.03	90.65	79.33	75.35	75.61	76.33	84.91	90.66	79.32
CoreMM_Marshal	87.24	87.51	88.48	89.87	78.59	88.84	90.67	89.1	89.64	76.25	71.5	72.79	73.46	82.26	89.64	76.17
LptMM_Marshal	86.65	86.63	87.11	88.81	76.87	86.86	88.88	86.83	88.85	74.65	70.28	70.7	70.3	78.19	88.68	75.81
OEM_Lessor	0	0	0	94.1	82.89	0	94.02	93.45	93.98	79.96	0	0	0	0	94.3	80.94
Shipment	89.43	89.39	89.9	89.88	77.2	89.83	89.85	87.71	89.37	75.7	76.67	77.78	76.52	83.13	89.46	75.66
Parts_Trader	0	0	96.48	96.93	93.52	89.17	92.06	89.68	0	0	0	0	90.87	84.25	0	0
MM_Disassy	94.84	94.87	94.8	95.54	90.57	94.87	95.43	94.57	95.68	89.98	87.95	88.24	87.66	91.27	95.6	90.33
Accs_Clean	89.41	94.37	94.39	95.15	90.11	89.19	90.94	89.46	91.2	79.4	74.6	86.36	86.43	80.65	95.53	89.79
Accs_NDT	86.27	94	93.9	95.29	88.16	85.91	88.15	86.41	88.17	72.8	63.88	84.07	83.49	75.74	95.16	88.32
Accs_Insp	80.45	91.59	91.42	93.46	83.17	80.59	83.86	80.26	83.76	61.64	52.35	77.51	76.46	65.7	93.25	84.03
Accs_IntRep	94.8	98.13	99.35	99.7	97.86	95.52	96.34	95.59	95.81	90.25	88.8	95.14	96.36	93.07	98.61	96.81
Accs_RepVendor	0	88.47	88.38	90.33	79.94	0	0	0	0	0	0	71.11	71.02	0	90.41	76.89
Accs_Disassy	93.03	92.85	92.81	94.34	87.98	92.75	94.17	92.83	94.12	86.97	84.2	84.48	83.59	88.77	94.35	86.85
Accs_Marshall	78.78	78.86	78.1	81.76	62.45	78.33	81.9	78.74	81.97	58.98	51.99	51.28	52.05	64.46	82.01	60.77

D.2 Machine Busy Level in percentage

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13	Scenario 14	Scenario 15	Scenario 16
Receiving	15.75	15.97	15.68	15.92	34.65	15.92	15.49	18.9	16.14	37.95	36.65	35.5	35.97	26.83	16.02	37.05
Disassembly_Engine	15.98	15.75	16.46	16.13	34.21	16.43	16.25	18.4	16.2	38.49	35.42	35.79	35.66	26.23	15.7	37.3
Disassembly_FanMM	10.2	9.99	10.24	8.59	17.52	10.2	8.6	10.21	8.64	19.11	22.54	22.62	22.34	16.49	8.64	18.95
Gbox_Clean	7.3	5.2	5.2	4.45	9.77	7.23	6.18	7.56	5.97	14.64	17.47	12.16	12.7	12.67	4.66	10.04
GBox_NDT	9.19	6	6.2	5.71	11.29	9.37	7.59	8.93	7.94	17.73	20.31	14.08	14.26	15.24	5.49	11.62
FanMM_Clean	3.32	1.95	1.91	1.73	3.55	3.3	2.82	3.2	2.77	6.27	7.49	4.66	4.63	5.47	1.66	3.84
GBox_Insp	9.72	5.52	5.85	5.11	9.97	9.94	8.28	10	8.5	18.83	22.09	12.38	13.12	16.4	5.32	10.38
LptMM_Clean	2.84	2.21	2.2	1.93	3.94	2.96	2.56	2.71	2.38	5.47	6.41	5.07	5.38	4.75	1.92	4.26
CoreMM_Clean	2.53	2.18	2.11	1.87	3.83	2.51	2.04	2.49	2.15	4.75	5.71	4.73	4.99	4.08	1.8	4.13
PPC	15.15	15.15	15.23	15.23	32.77	15.16	15.42	17.43	15.18	36.28	33.97	33.5	34.04	25.02	15.33	35.36
MM_Reassy	5.85	5.82	5.62	4.8	10.11	5.63	4.76	5.47	4.97	11.27	12.83	12.5	12.97	8.98	4.86	10.67
GBox_IntRep	1.54	0.64	0.52	0.34	1.19	1.15	1.03	1.13	1.47	4.61	5.59	1.25	1.3	2.95	0.52	1.08
FanMM_NDT	3.89	1.62	1.8	1.43	3.16	3.91	3.32	4.01	3.26	7.53	8.69	4.23	4.23	6.69	1.44	3.54
GBox_RepVendor	#N/A	8.16	7.82	6.79	13.06	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	17.81	17.14	#N/A	7.08	14.83
CoreMM_NDT	6.8	4.23	4.41	3.65	7.51	6.69	5.68	6.69	5.77	12.46	14.46	9.54	9.36	11.03	3.52	8.12
LptMM_NDT	6.35	3.79	3.74	2.97	6.77	6.37	5.42	6.47	5.4	11.89	14.18	8.67	8.63	10.19	3.14	7.07
Disassy_GBox	10.01	10.21	9.97	8.47	17.8	10	8.33	10.1	8.52	19.08	22.38	22.57	22.67	16.53	8.63	18.65
FanMM_Insp	5.28	1.88	1.83	1.47	3.3	5.36	4.65	5.27	4.46	10	11.61	4.55	4.54	8.5	1.62	3.63
FanMM_RepVendor	#N/A	6.35	6.39	5.51	10.49	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	13.57	14.32	#N/A	5.28	11.48
CoreMM_Insp	7.55	4.33	4.25	3.52	7.19	7.53	6.25	7.5	6.42	14.11	16.56	8.61	8.75	12.18	3.49	7.44
CoreMM_IntRep	1.37	0.78	0.49	0.49	0.9	1.27	1.15	1.26	1.24	2.53	2.82	1.36	1.2	1.84	0.66	1.1
LptMM_Insp	5.88	2.96	3.05	2.64	5.27	5.97	5.05	5.85	4.95	11.33	13.11	6.69	6.75	9.73	2.37	5.6
Disassy_CoreMM	12.65	12.57	12.72	10.6	21.15	12.76	10.67	12.93	10.75	23.31	27.73	27.47	27.8	20.35	10.33	23.28
FanMM_IntRep	2.17	0.57	0.31	0.25	0.86	1.61	1.39	1.9	1.7	3.77	4.33	1.4	1.09	3.05	0.39	1.19
LptMM_IntRep	0.91	0.23	0.12	0.15	0.18	0.65	0.45	0.67	0.71	2.28	2.79	0.54	0.36	1.42	0.21	0.35
CoreMM_RepVendor	#N/A	6.04	5.84	5.07	9.87	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	13.04	12.65	#N/A	5.15	11.35
Disassy_LptMM	6.93	6.57	6.68	5.52	11.4	6.53	5.8	6.78	6.01	12.81	15.09	14.83	14.56	10.84	5.88	12.17

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13	Scenario 14	Scenario 15	Scenario 16
LptMM_RepVendor	#N/A	4.76	4.77	4.1	8.56	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	10.95	10.67	#N/A	4.08	9.07
Final_Assy	9.37	8.98	9.18	7.5	15.54	8.81	7.56	8.85	7.65	17.07	19.98	20.03	19.73	14.55	7.48	17.16
GBox_Marshall	18.68	18.43	18.44	15.56	32	18.05	15.51	18.02	15.33	34.84	40.91	40.67	40.66	29.81	15.49	33.92
Test	11.62	11.38	11.03	11.38	23.4	11.35	10.88	12.95	11.44	24.69	25.26	24.93	25.4	18.88	10.71	27.1
FanMM_Marshal	8.37	8.78	8.55	7.01	14.6	6.95	5.83	7.03	7.4	16.27	19.39	19.09	18.65	11.89	7.3	16.18
CoreMM_Marshal	10.09	9.74	8.97	7.95	16.76	8.8	7.42	8.7	8.25	18.76	22.4	21.37	20.86	14.09	8.23	18.71
LptMM_Marshal	10.54	10.48	10.24	8.85	18.26	10.41	8.81	10.36	8.72	19.95	23.29	23.22	23.53	17.19	8.92	19.18
OEM_Lessor	#N/A	#N/A	#N/A	5.75	15.84	#N/A	5.8	5.97	5.84	19.12	#N/A	#N/A	#N/A	#N/A	5.52	17.4
Shipment	10.57	10.61	10.1	10.12	22.8	10.17	10.15	12.29	10.63	24.3	23.33	22.22	23.48	16.87	10.54	24.34
Parts_Trader	#N/A	#N/A	3.52	2.91	5.74	9.9	7.57	9.68	#N/A	#N/A	#N/A	#N/A	7.4	14.1	#N/A	#N/A
MM_Disassy	5.05	5.02	5	4.21	8.88	5	4.48	5.22	4.32	9.64	11.3	11.38	11.31	8.41	4.29	9.58
Accs_Clean	8.63	4.58	4.53	3.82	7.85	8.71	7.2	8.44	7.14	16.43	19.1	10.61	10.61	13.62	3.53	8.65
Accs_NDT	10.2	4.68	4.73	3.72	8.86	10.18	8.51	9.95	8.52	19.25	23.07	11.54	11.38	16.57	3.69	9.13
Accs_Insp	14.17	6.18	6.27	4.88	11.96	14.32	12.24	14.51	12.21	27.31	31.99	15.37	15.66	23.88	5.04	11.87
Accs_IntRep	4.01	1.17	0.48	0.22	1.44	3.24	2.78	3.23	3.25	7.31	8.31	2.57	2.35	5.17	1.08	1.83
Accs_RepVendor	#N/A	9.88	9.7	8.59	16.28	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	21.58	20.11	#N/A	8.32	18.46
Accs_Disassy	4.87	5.27	5.11	4.28	8.83	5.12	4.39	5.12	4.22	9.51	11.31	11.22	11.78	8.34	4.33	9.43
Accs_Marshall	16.78	16.79	17.17	14.36	29.47	16.96	14.47	16.86	14.25	32.43	38.07	38.36	38.07	27.68	14.24	30.98

D.3 Machine Blocked Level in Percentage

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13	Scenario 14	Scenario 15	Scenario 16
Receiving	15.75	15.97	15.68	15.92	34.65	15.92	15.49	18.9	16.14	37.95	36.65	35.5	35.97	26.83	16.02	37.05
Disassembly_Engine	15.98	15.75	16.46	16.13	34.21	16.43	16.25	18.4	16.2	38.49	35.42	35.79	35.66	26.23	15.7	37.3
Disassembly_FanMM	10.2	9.99	10.24	8.59	17.52	10.2	8.6	10.21	8.64	19.11	22.54	22.62	22.34	16.49	8.64	18.95
Gbox_Clean	7.3	5.2	5.2	4.45	9.77	7.23	6.18	7.56	5.97	14.64	17.47	12.16	12.7	12.67	4.66	10.04
GBox_NDT	9.19	6	6.2	5.71	11.29	9.37	7.59	8.93	7.94	17.73	20.31	14.08	14.26	15.24	5.49	11.62
FanMM_Clean	3.32	1.95	1.91	1.73	3.55	3.3	2.82	3.2	2.77	6.27	7.49	4.66	4.63	5.47	1.66	3.84
GBox_Insp	9.72	5.52	5.85	5.11	9.97	9.94	8.28	10	8.5	18.83	22.09	12.38	13.12	16.4	5.32	10.38
LptMM_Clean	2.84	2.21	2.2	1.93	3.94	2.96	2.56	2.71	2.38	5.47	6.41	5.07	5.38	4.75	1.92	4.26
CoreMM_Clean	2.53	2.18	2.11	1.87	3.83	2.51	2.04	2.49	2.15	4.75	5.71	4.73	4.99	4.08	1.8	4.13
PPC	15.15	15.15	15.23	15.23	32.77	15.16	15.42	17.43	15.18	36.28	33.97	33.5	34.04	25.02	15.33	35.36
MM_Reassy	5.85	5.82	5.62	4.8	10.11	5.63	4.76	5.47	4.97	11.27	12.83	12.5	12.97	8.98	4.86	10.67
GBox_IntRep	1.54	0.64	0.52	0.34	1.19	1.15	1.03	1.13	1.47	4.61	5.59	1.25	1.3	2.95	0.52	1.08
FanMM_NDT	3.89	1.62	1.8	1.43	3.16	3.91	3.32	4.01	3.26	7.53	8.69	4.23	4.23	6.69	1.44	3.54
GBox_RepVendor	#N/A	8.16	7.82	6.79	13.06	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	17.81	17.14	#N/A	7.08	14.83
CoreMM_NDT	6.8	4.23	4.41	3.65	7.51	6.69	5.68	6.69	5.77	12.46	14.46	9.54	9.36	11.03	3.52	8.12
LptMM_NDT	6.35	3.79	3.74	2.97	6.77	6.37	5.42	6.47	5.4	11.89	14.18	8.67	8.63	10.19	3.14	7.07
Disassy_GBox	10.01	10.21	9.97	8.47	17.8	10	8.33	10.1	8.52	19.08	22.38	22.57	22.67	16.53	8.63	18.65
FanMM_Insp	5.28	1.88	1.83	1.47	3.3	5.36	4.65	5.27	4.46	10	11.61	4.55	4.54	8.5	1.62	3.63
FanMM_RepVendor	#N/A	6.35	6.39	5.51	10.49	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	13.57	14.32	#N/A	5.28	11.48
CoreMM_Insp	7.55	4.33	4.25	3.52	7.19	7.53	6.25	7.5	6.42	14.11	16.56	8.61	8.75	12.18	3.49	7.44
CoreMM_IntRep	1.37	0.78	0.49	0.49	0.9	1.27	1.15	1.26	1.24	2.53	2.82	1.36	1.2	1.84	0.66	1.1
LptMM_Insp	5.88	2.96	3.05	2.64	5.27	5.97	5.05	5.85	4.95	11.33	13.11	6.69	6.75	9.73	2.37	5.6
Disassy_CoreMM	12.65	12.57	12.72	10.6	21.15	12.76	10.67	12.93	10.75	23.31	27.73	27.47	27.8	20.35	10.33	23.28
FanMM_IntRep	2.17	0.57	0.31	0.25	0.86	1.61	1.39	1.9	1.7	3.77	4.33	1.4	1.09	3.05	0.39	1.19
LptMM_IntRep	0.91	0.23	0.12	0.15	0.18	0.65	0.45	0.67	0.71	2.28	2.79	0.54	0.36	1.42	0.21	0.35
CoreMM_RepVendor	#N/A	6.04	5.84	5.07	9.87	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	13.04	12.65	#N/A	5.15	11.35
Disassy_LptMM	6.93	6.57	6.68	5.52	11.4	6.53	5.8	6.78	6.01	12.81	15.09	14.83	14.56	10.84	5.88	12.17

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13	Scenario 14	Scenario 15	Scenario 16
LptMM_RepVendor	#N/A	4.76	4.77	4.1	8.56	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	10.95	10.67	#N/A	4.08	9.07
Final_Assy	9.37	8.98	9.18	7.5	15.54	8.81	7.56	8.85	7.65	17.07	19.98	20.03	19.73	14.55	7.48	17.16
GBox_Marshall	18.68	18.43	18.44	15.56	32	18.05	15.51	18.02	15.33	34.84	40.91	40.67	40.66	29.81	15.49	33.92
Test	11.62	11.38	11.03	11.38	23.4	11.35	10.88	12.95	11.44	24.69	25.26	24.93	25.4	18.88	10.71	27.1
FanMM_Marshal	8.37	8.78	8.55	7.01	14.6	6.95	5.83	7.03	7.4	16.27	19.39	19.09	18.65	11.89	7.3	16.18
CoreMM_Marshal	10.09	9.74	8.97	7.95	16.76	8.8	7.42	8.7	8.25	18.76	22.4	21.37	20.86	14.09	8.23	18.71
LptMM_Marshal	10.54	10.48	10.24	8.85	18.26	10.41	8.81	10.36	8.72	19.95	23.29	23.22	23.53	17.19	8.92	19.18
OEM_Lessor	#N/A	#N/A	#N/A	5.75	15.84	#N/A	5.8	5.97	5.84	19.12	#N/A	#N/A	#N/A	#N/A	5.52	17.4
Shipment	10.57	10.61	10.1	10.12	22.8	10.17	10.15	12.29	10.63	24.3	23.33	22.22	23.48	16.87	10.54	24.34
Parts_Trader	#N/A	#N/A	3.52	2.91	5.74	9.9	7.57	9.68	#N/A	#N/A	#N/A	#N/A	7.4	14.1	#N/A	#N/A
MM_Disassy	5.05	5.02	5	4.21	8.88	5	4.48	5.22	4.32	9.64	11.3	11.38	11.31	8.41	4.29	9.58
Accs_Clean	8.63	4.58	4.53	3.82	7.85	8.71	7.2	8.44	7.14	16.43	19.1	10.61	10.61	13.62	3.53	8.65
Accs_NDT	10.2	4.68	4.73	3.72	8.86	10.18	8.51	9.95	8.52	19.25	23.07	11.54	11.38	16.57	3.69	9.13
Accs_Insp	14.17	6.18	6.27	4.88	11.96	14.32	12.24	14.51	12.21	27.31	31.99	15.37	15.66	23.88	5.04	11.87
Accs_IntRep	4.01	1.17	0.48	0.22	1.44	3.24	2.78	3.23	3.25	7.31	8.31	2.57	2.35	5.17	1.08	1.83
Accs_RepVendor	#N/A	9.88	9.7	8.59	16.28	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	21.58	20.11	#N/A	8.32	18.46
Accs_Disassy	4.87	5.27	5.11	4.28	8.83	5.12	4.39	5.12	4.22	9.51	11.31	11.22	11.78	8.34	4.33	9.43
Accs_Marshall	16.78	16.79	17.17	14.36	29.47	16.96	14.47	16.86	14.25	32.43	38.07	38.36	38.07	27.68	14.24	30.98

D.4 Machine Total Operations Level in percentage

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13	Scenario 14	Scenario 15	Scenario 16
Receiving	4.39	4.42	4.35	4.39	9.46	4.35	4.02	5.15	4.39	10.55	10.02	9.41	10.07	7.2	4.26	10.14
Disassembly_Engine	3.79	4.03	4.18	4.03	8.69	4.02	4.12	4.7	4.22	9.95	8.75	9.18	8.91	6.9	3.95	9.54
Disassembly_FanMM	3.04	3	3.15	2.45	4.98	2.92	2.43	2.91	2.61	5.72	6.74	6.2	6.59	4.7	2.42	5.36
Gbox_Clean	2.42	1.48	1.64	1.23	3	2.05	1.93	2.26	1.85	4.27	5.42	3.86	3.94	3.9	1.44	3.41
GBox_NDT	2.01	1.56	1.27	1.56	2.67	2.38	1.73	2.14	1.81	4.44	4.85	3.53	3.37	3.57	1.48	2.26
FanMM_Clean	1.05	0.51	0.63	0.48	1.07	1	0.9	0.99	0.81	1.88	2.38	1.49	1.42	1.74	0.52	1.25
GBox_Insp	2.71	1.6	1.68	1.4	3.08	3	2.3	2.88	2.42	5.38	6	3.66	3.7	4.35	1.48	3.12
LptMM_Clean	0.58	0.37	0.47	0.45	0.86	0.68	0.6	0.55	0.53	1.29	1.05	1.13	1.09	1.07	0.51	0.72
CoreMM_Clean	0.99	0.72	0.76	0.55	1.34	0.97	0.72	0.99	0.68	1.46	2.24	1.79	1.79	1.54	0.55	1.5
PPC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MM_Reassy	1.58	1.64	1.48	1.44	2.63	1.66	1.29	1.48	1.44	2.96	3.51	3.37	3.66	2.53	1.4	2.83
GBox_IntRep	0.33	0.29	0.12	0.04	0.33	0.29	0.33	0.33	0.45	1.23	1.77	0.33	0.53	0.82	0.16	0.25
FanMM_NDT	1.03	0.47	0.47	0.33	0.85	1.07	0.81	1.11	0.81	2	2.22	1.12	1.05	1.7	0.34	0.92
GBox_RepVendor	#N/A	0	0	0	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0	0	#N/A	0	0
CoreMM_NDT	1.79	1.19	1.09	0.94	1.99	1.81	1.48	1.75	1.6	3.37	3.7	2.51	2.4	2.94	1.01	2.2
LptMM_NDT	1.81	1.09	1.07	0.76	1.87	1.83	1.5	1.81	1.48	3.33	3.96	2.4	2.32	2.75	0.82	1.99
Disassy_GBox	3.09	3.04	3.15	2.47	5.06	2.96	2.42	2.95	2.61	5.68	6.7	6.28	6.63	4.74	2.29	5.36
FanMM_Insp	1.52	0.51	0.49	0.37	0.89	1.44	1.34	1.4	1.3	2.67	3.07	1.18	1.36	2.3	0.42	0.93
FanMM_RepVendor	#N/A	0	0	0	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0	0	#N/A	0	0
CoreMM_Insp	2.1	1.19	1.15	1.07	1.99	2.01	1.87	2.01	1.71	4.09	4.4	2.28	2.42	3.41	0.97	1.99
CoreMM_IntRep	0.37	0.1	0.1	0.12	0.21	0.35	0.31	0.39	0.33	0.68	0.72	0.33	0.37	0.49	0.18	0.18
LptMM_Insp	1.62	0.84	0.88	0.76	1.46	1.68	1.46	1.71	1.38	3.25	3.43	1.97	1.95	2.79	0.66	1.66
Disassy_CoreMM	3.55	3.45	3.68	2.82	5.79	3.41	2.86	3.53	3.14	6.45	7.72	7.36	7.59	5.47	2.66	6.38
FanMM_IntRep	0.53	0.18	0.08	0.08	0.23	0.39	0.37	0.53	0.41	1.03	1.19	0.41	0.33	0.82	0.12	0.33
LptMM_IntRep	0.27	0.06	0.04	0.04	0.06	0.16	0.16	0.18	0.21	0.62	0.82	0.14	0.12	0.41	0.06	0.1
CoreMM_RepVendor	#N/A	0	0	0	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0	0	#N/A	0	0
Disassy_LptMM	2.51	2.3	2.49	1.84	3.93	2.18	1.85	2.34	2.07	4.24	5.61	4.83	5.32	3.55	1.68	4.42

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13	Scenario 14	Scenario 15	Scenario 16
LptMM_RepVendor	#N/A	0	0	0	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0	0	#N/A	0	0
Final_Assy	2.59	2.36	2.49	1.97	4.23	2.38	2.1	2.57	2.03	4.79	5.53	5.73	5.4	3.86	2.05	4.62
GBox_Marshall	5.46	4.88	4.86	4.74	8.83	4.96	4.22	5.01	4.07	9.65	11.18	11.29	10.56	8.25	4.24	9.24
Test	3.12	3.29	2.96	3.01	6.77	3.12	2.98	3.35	3.13	6.51	6.57	6.45	6.57	5.34	2.75	7.57
FanMM_Marshal	2.25	2.36	2.29	1.93	3.96	1.86	1.57	1.93	1.96	4.4	5.26	5.31	5.02	3.2	2.04	4.5
CoreMM_Marshal	2.67	2.76	2.55	2.18	4.65	2.36	1.91	2.2	2.12	4.99	6.1	5.84	5.68	3.66	2.13	5.12
LptMM_Marshal	2.81	2.89	2.66	2.34	4.87	2.73	2.31	2.81	2.42	5.4	6.43	6.08	6.17	4.62	2.4	5.01
OEM_Lessor	#N/A	#N/A	#N/A	0	0	#N/A	0	0	0	0	#N/A	#N/A	#N/A	#N/A	0	0
Shipment	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Parts_Trader	#N/A	#N/A	0	0	0	0	0	0	#N/A	#N/A	#N/A	#N/A	0	0	#N/A	#N/A
MM_Disassy	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Accs_Clean	1.85	0.99	1.07	1.03	2.01	1.64	1.56	1.85	1.48	3.74	4.07	2.34	1.89	3.2	0.94	1.56
Accs_NDT	2.67	1.31	1.27	0.99	2.38	2.88	2.63	2.71	2.59	5.75	6.74	3.37	3.41	4.6	1.15	2.55
Accs_Insp	3.94	1.77	1.77	1.23	3.41	3.94	3.25	3.9	3.25	7.48	8.79	4.15	4.27	6.61	1.36	3.33
Accs_IntRep	1.19	0.41	0.16	0.08	0.37	0.82	0.86	1.03	0.86	2.22	2.42	0.9	0.62	1.56	0.25	0.62
Accs_RepVendor	#N/A	0	0	0	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0	0	#N/A	0	0
Accs_Disassy	2.1	1.89	2.08	1.38	3.19	2.14	1.44	2.05	1.66	3.52	4.49	4.3	4.63	2.89	1.32	3.72
Accs_Marshall	4.44	4.35	4.73	3.88	8.07	4.72	3.63	4.4	3.78	8.59	9.94	10.36	9.88	7.86	3.75	8.24

D.5 Machine Total Operations Level to Wait Labour level in percentage

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13	Scenario 14	Scenario 15	Scenario 16
Receiving	93	93	93	93	200	93	93	107	93	220	207	206	208	151	93	216
Disassembly_Engine	92	92	92	93	199	92	92	107	92	219	206	204	207	151	92	215
Disassembly_FanMM	92	92	92	78	160	92	78	92	78	174	205	204	206	150	78	172
Gbox_Clean	92	66	66	58	120	92	78	92	78	173	205	151	153	150	58	125
GBox_NDT	92	61	61	54	111	92	78	92	78	173	205	139	142	150	54	114
FanMM_Clean	92	53	53	46	97	92	78	92	78	174	205	125	126	150	46	105
GBox_Insp	92	52	52	46	91	92	78	92	78	173	205	113	115	150	46	94
LptMM_Clean	92	71	71	60	123	92	78	92	78	175	205	159	161	150	60	131
CoreMM_Clean	92	81	80	68	141	91	77	92	78	172	202	177	179	147	67	151
PPC	93	93	93	93	200	93	93	107	93	220	206	205	208	151	93	216
MM_Reassy	90	89	89	75	155	89	76	90	77	171	199	196	199	147	74	167
GBox_IntRep	20	8	6	4	14	14	12	14	18	57	70	15	16	37	6	13
FanMM_NDT	92	40	40	34	73	92	78	92	78	174	205	99	100	150	34	81
GBox_RepVendor	#N/A	74	71	62	118	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	160	155	#N/A	64	134
CoreMM_NDT	92	61	60	50	102	91	77	92	78	172	202	130	131	147	49	110
LptMM_NDT	92	55	55	45	96	92	78	92	78	175	205	126	127	150	45	103
Disassy_GBox	92	92	92	78	160	92	78	92	78	173	205	204	206	150	78	172
FanMM_Insp	92	32	32	28	59	92	78	92	77	174	204	79	80	150	28	63
FanMM_RepVendor	#N/A	67	68	57	112	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	140	144	#N/A	56	118
CoreMM_Insp	92	53	52	43	87	91	76	92	78	172	202	104	106	147	43	90
CoreMM_IntRep	30	16	12	10	20	27	25	27	28	54	63	29	26	40	13	24
LptMM_Insp	92	48	48	39	83	92	78	92	78	175	205	105	105	150	39	88
Disassy_CoreMM	92	91	90	77	157	91	77	92	78	172	202	200	202	147	76	171
FanMM_IntRep	31	8	5	4	14	27	22	28	26	57	69	22	16	48	7	19
LptMM_IntRep	16	4	2	2	3	11	8	11	12	37	46	10	6	25	3	6
CoreMM_RepVendor	#N/A	52	51	45	87	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	114	113	#N/A	46	99
Disassy_LptMM	92	92	92	78	161	92	78	92	78	175	205	204	206	150	79	172

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13	Scenario 14	Scenario 15	Scenario 16
LptMM_RepVendor	#N/A	61	62	54	111	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	141	139	#N/A	54	118
Final_Assy	90	89	88	75	154	89	75	90	76	170	199	196	198	147	74	167
GBox_Marshall	92	92	91	77	159	91	77	91	77	173	204	202	204	150	77	170
Test	90	89	88	87	185	89	87	102	88	204	198	196	198	146	86	201
FanMM_Marshal	90	92	88	75	152	72	62	72	77	173	203	202	194	125	78	168
CoreMM_Marshal	92	90	85	73	148	79	69	81	77	171	200	197	190	129	75	168
LptMM_Marshal	92	91	91	77	160	91	77	92	77	174	203	201	204	150	79	169
OEM_Lessor	#N/A	#N/A	#N/A	14	38	#N/A	14	14	14	44	#N/A	#N/A	#N/A	#N/A	14	43
Shipment	90	89	88	89	192	89	89	104	90	212	198	196	198	146	88	210
Parts_Trader	#N/A	#N/A	32	27	52	91	69	88	#N/A	#N/A	#N/A	#N/A	67	129	#N/A	#N/A
MM_Disassy	92	92	92	78	160	92	78	92	78	174	205	204	207	150	78	172
Accs_Clean	92	48	49	40	89	93	79	92	78	176	208	116	117	153	40	92
Accs_NDT	92	42	43	34	80	93	79	92	78	176	208	104	104	153	34	82
Accs_Insp	92	39	40	32	76	93	79	92	78	176	208	100	100	153	32	78
Accs_IntRep	37	11	4	2	13	30	25	29	30	67	76	23	22	47	10	17
Accs_RepVendor	#N/A	66	66	58	109	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	149	139	#N/A	57	124
Accs_Disassy	92	93	94	79	162	93	79	92	78	176	208	208	210	153	79	172
Accs_Marshall	91	92	93	79	162	92	78	91	78	176	207	207	209	153	79	170

Appendix E Simulation Results

Once the simulation is conducted, the simuation result can be obtained for each contracting parameters. Each scneario will affect vary to the contracting parmaeters.

E.1 Turn Around Time (TAT)

No	Scenario	TAT					Average	Std Deviation
		PRN 1	PRN 7	PRN 77	PRN 88	PRN 14		
1	Scenario 1	86.53	87.27	86.42	86.26	87.3	86.756	0.49
2	Scenario 2	86.62	85.87	86.32	85.45	85.52	85.956	0.51
3	Scenario 3	84.72	84.39	84.32	83.97	85.2	84.52	0.46
4	Scenario 4	78.24	78.74	77.28	78.34	77.83	78.086	0.55
5	Scenario 5	78.52	78.41	78.61	78.42	79.26	78.644	0.35
6	Scenario 6	85.83	86.34	86	86.26	86.03	86.092	0.21
7	Scenario 7	79.63	79.98	79.14	79.09	78.94	79.356	0.43
8	Scenario 8	78.46	78	77.96	79.37	78.76	78.51	0.58
9	Scenario 9	80.83	80.73	79.34	80.13	80.21	80.248	0.59
10	Scenario 10	80.14	79.41	78.97	79.47	80.52	79.702	0.62
11	Scenario 11	89.03	90.95	89.52	90.26	90.1	89.972	0.73
12	Scenario 12	88.15	88.42	90.08	86.86	87.6	88.222	1.20
13	Scenario 13	87.79	88.32	88.95	89.33	88.35	88.548	0.60
14	Scenario 14	87.81	87.37	86.74	87.3	87.91	87.426	0.47
15	Scenario 15	79.7	79.06	78.84	78.1	77.93	78.726	0.72
16	Scenario 16	78.43	78.14	78.64	78.93	80.05	78.838	0.74

E.2 Productivity

No	Scenario	Productivity															Average	Std Deviation
		PRN 1			PRN 7			PRN 77			PRN 88			PRN 14				
		IN	OUT	PRO	IN	OUT	PRO	IN	OUT	PRO	IN	OUT	PRO	IN	OUT	PRO		
1	Scenario 1	93	90	1.033	93	90	1.033	93	89	1.045	93	90	1.033	93	90	1.033	1.036	0.005
2	Scenario 2	93	89	1.045	93	89	1.045	93	90	1.033	93	89	1.045	93	89	1.045	1.043	0.005
3	Scenario 3	93	88	1.057	93	89	1.045	93	90	1.033	93	90	1.033	93	88	1.057	1.045	0.012
4	Scenario 4	93	88	1.057	93	89	1.045	93	89	1.045	93	90	1.033	93	89	1.045	1.045	0.008
5	Scenario 5	233	224	1.040	233	221	1.054	233	223	1.045	233	224	1.040	200	192	1.042	1.044	0.006
6	Scenario 6	93	90	1.033	93	90	1.033	93	90	1.033	93	89	1.045	93	89	1.045	1.038	0.006
7	Scenario 7	93	89	1.045	93	90	1.033	93	90	1.033	93	90	1.033	93	89	1.045	1.038	0.006
8	Scenario 8	226	215	1.051	210	202	1.04	218	204	1.069	210	203	1.034	221	213	1.038	1.046	0.014
9	Scenario 9	93	90	1.033	93	90	1.033	93	90	1.033	93	88	1.057	93	90	1.033	1.038	0.011
10	Scenario 10	208	205	1.015	214	205	1.044	183	176	1.04	193	188	1.027	220	213	1.033	1.032	0.012
11	Scenario 11	229	216	1.060	220	210	1.048	224	213	1.052	206	197	1.046	207	198	1.045	1.050	0.006
12	Scenario 12	202	197	1.025	212	198	1.071	226	219	1.032	206	201	1.025	206	196	1.051	1.041	0.020
13	Scenario 13	222	211	1.052	211	202	1.045	222	211	1.052	210	198	1.061	208	198	1.051	1.052	0.006
14	Scenario 14	175	168	1.042	166	162	1.025	147	144	1.021	175	168	1.042	152	146	1.041	1.034	0.010
15	Scenario 15	93	90	1.033	93	90	1.033	93	90	1.033	93	90	1.033	93	88	1.057	1.038	0.011
16	Scenario 16	211	207	1.019	217	206	1.053	207	198	1.045	207	203	1.02	216	210	1.029	1.033	0.015

E.3 Average Daily WIP Report

No	Scenario	Average WIP					Average	Std Deviation
		PRN 1	PRN 7	PRN 77	PRN 88	PRN 14		
1	Scenario 1	8.93	9.04	10.65	8.89	9.05	9.312	0.751
2	Scenario 2	12.72	10.57	8.92	10.61	10.59	10.682	1.349
3	Scenario 3	14.66	10.43	8.7	8.69	9.71	10.438	2.471
4	Scenario 4	15.37	11.01	9.23	7.58	8.4	10.318	3.097
5	Scenario 5	8.63	9.41	9.84	7.94	10.65	9.294	1.052
6	Scenario 6	8.91	8.94	8.87	10.68	12.73	10.026	1.696
7	Scenario 7	11.59	7.82	7.71	7.66	11.45	9.246	2.077
8	Scenario 8	13.56	15.97	11.52	10.65	12.12	12.764	2.082
9	Scenario 9	7.89	7.87	7.76	12.98	7.78	8.856	2.306
10	Scenario 10	9.68	18.74	7.77	7.5	12.15	11.168	4.624
11	Scenario 11	12.99	18.37	9.47	11.13	18.28	14.048	4.098
12	Scenario 12	9.45	31.71	9.61	9.09	12.54	14.480	9.730
13	Scenario 13	12.94	18.25	13.22	16.81	17.22	15.688	2.440
14	Scenario 14	4.12	8.97	7.84	4.06	16.22	8.242	4.970
15	Scenario 15	7.72	7.65	7.71	7.62	12.53	8.646	2.172
16	Scenario 16	6.99	13.98	12.38	9.47	7.95	10.154	2.955

E.4 Total Manhours

No	Scenario	Total Manhours					Average	Std Deviation
		PRN 1	PRN 7	PRN 77	PRN 88	PRN 14		
1	Scenario 1	14408.89	14478.06	14315.66	14418.31	14414.37	14407.06	58.26
2	Scenario 2	11475.12	11464.06	11419.06	11421.13	11375.36	11430.95	39.92
3	Scenario 3	11304.83	11294.6	11248.89	11272.83	11262.95	11276.82	22.85
4	Scenario 4	9781.52	9799.82	9685.69	9819.05	9731	9763.416	54.41
5	Scenario 5	23498.98	23437.41	23415.09	23407.11	20451.63	22842.04	1336.77
6	Scenario 6	14032.8	14082.29	14022.93	13999.55	14021.7	14031.85	30.70
7	Scenario 7	12192.97	12164.81	12093.44	12096.78	12065.65	12122.73	53.60
8	Scenario 8	27953.79	26067.04	26877.55	26098.8	27488.7	26897.18	835.65
9	Scenario 9	12490.12	12551.6	12423.96	12421.07	12416.35	12460.62	59.19
10	Scenario 10	26761.13	27194.66	23209.4	24663.63	28090.57	25983.88	1996.81
11	Scenario 11	35342.34	33953.9	34504.5	31902.51	32197.14	33580.08	1485.48
12	Scenario 12	25324.51	26209.15	27950.14	25591.74	25498.47	26114.8	1078.82
13	Scenario 13	26610.87	25255.89	22344.6	26595.67	25506.45	25262.7	1744.21
14	Scenario 14	27090.95	26052.1	26862.21	25513.4	25506.45	26205.02	742.71
15	Scenario 15	9916.63	9926.3	9896.09	9868.64	9821.72	9885.876	42.12
16	Scenario 16	23626.85	23660.95	23574.69	23588.17	22052.58	23300.65	698.51

Appendix F Paper and Publications

F.1 Paper 1 IPSS Conference 2016

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Procedia CIRP 47 (2016) 24 – 29

www.elsevier.com/locate/procedia

Product-Service Systems across Life Cycle

Towards an Integrated Decision Making Framework for Aero Engine MRO Contract Management in the Productisation Context

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Abstract

One of the most critical elements in the 'productisation' of service adopted by today's aero-engine Maintenance Repair and Overhaul (MRO) companies is the match between customer demands and the operational capabilities of the MRO shop. Currently, the service contract is offered based upon experience and intuition rather than on scientific approach. This paper presents an integrated decision making framework to design contracts that considers demand and operational parameters. In addition to literature survey, the approach adopted in building the framework is a case study research, which obtains data from semi-structured interviews, observations and the company archives. Two main perspectives, dynamic operational parameters and shop floor operational parameters, were identified as essential and pertinent to the design and management of the service contract in the productisation context. The framework will incorporate both perspectives to support productisation.

Peer-review under responsibility of the scientific committee of the 8th Product-Service Systems across Life Cycle

Keywords: IPSS; Service Provider; non-OEM MRO; Contract; Productisation

1. Introduction

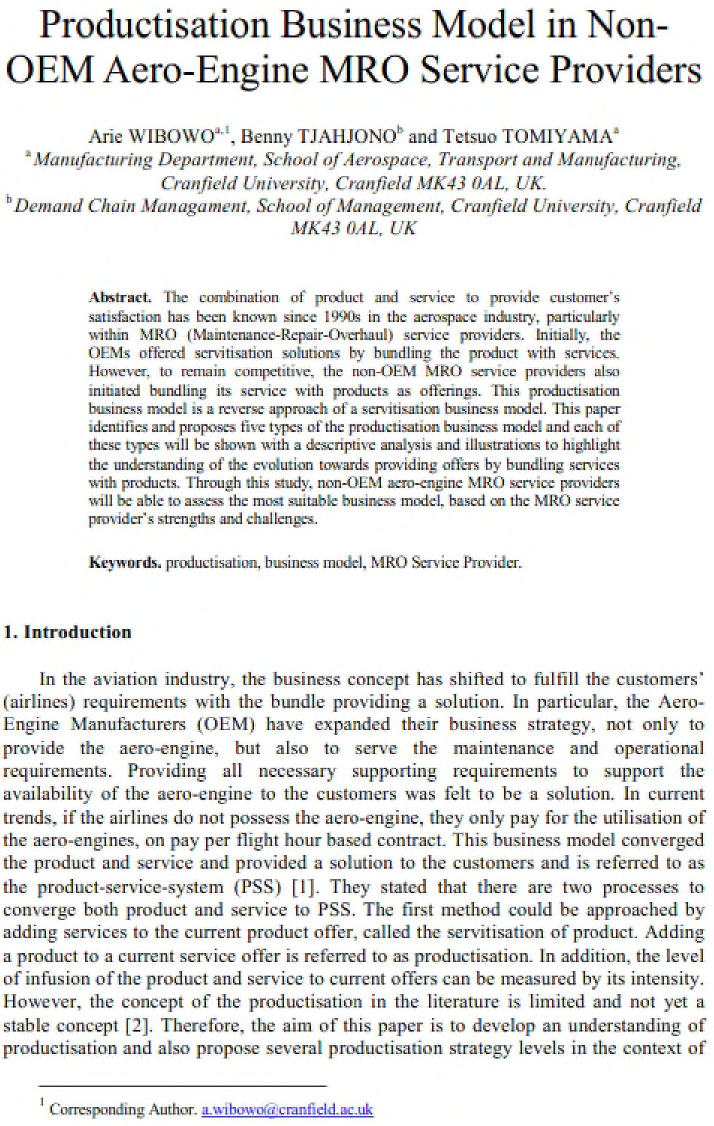
The aviation industry has evolved its business model based on the servitisation concept. Aero-engine Manufacturers (OEMs) have offered the new business model using utilization-based selling, i.e., availability based contracts. This allowed OEMs to expand their core business as manufacturers to MRO (Maintenance-Repair-Overhaul) service. OEM MRO now supports all the operational requirements of the assets (i.e. aero-engine). This situation results in shifting risks and uncertainties to the service provider from customers [1]. Many approaches have been conducted to minimize risks and uncertainties, such as enhanced sensor technology application regarding health monitoring and prognosis in real time [2]. This data will then be used to take the advantages from condition based maintenance. Through this philosophy, OEMs have secured their position in the aftermarket MRO service provision. An OEM MRO service provider has a higher state of readiness, as they are supported by larger resources, has greater capacity and capability than a non-OEM MRO service provider, and has the OEM's authorisation [3].

Traditionally, *non-OEM MRO service providers* were offering repair-only services. This trend, however, forced them to become more competitive in retaining their market, despite their handicaps compared with OEM MRO. They now deploy a similar business model to their competitors, i.e., combining their service offer with products. This business model is called productisation. In addition, non-OEM MRO service providers are obliged to offer lower cost solutions with higher flexibility (e.g., shorter maintenance lead time) than their competitors.

To do so, non-OEM MRO service providers need better contracting design capability. Traditionally, their contract design method didn't have to be sophisticated beyond experience and intuition. However, since now a new contract requires to be more precise and robust in estimated cost, TAT, and other key performance indicators, the contract design

Peer-review under responsibility of the scientific committee of the 8th Product-Service Systems across Life Cycle
doi:10.1016/j.procir.2016.03.049

F.2 Paper 2 ICMR Conference 2016



Productisation Business Model in Non-OEM Aero-Engine MRO Service Providers

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Abstract. The combination of product and service to provide customer's satisfaction has been known since 1990s in the aerospace industry, particularly within MRO (Maintenance-Repair-Overhaul) service providers. Initially, the OEMs offered servitisation solutions by bundling the product with services. However, to remain competitive, the non-OEM MRO service providers also initiated bundling its service with products as offerings. This productisation business model is a reverse approach of a servitisation business model. This paper identifies and proposes five types of the productisation business model and each of these types will be shown with a descriptive analysis and illustrations to highlight the understanding of the evolution towards providing offers by bundling services with products. Through this study, non-OEM aero-engine MRO service providers will be able to assess the most suitable business model, based on the MRO service provider's strengths and challenges.

Keywords. productisation, business model, MRO Service Provider.

1. Introduction

In the aviation industry, the business concept has shifted to fulfill the customers' (airlines) requirements with the bundle providing a solution. In particular, the Aero-Engine Manufacturers (OEM) have expanded their business strategy, not only to provide the aero-engine, but also to serve the maintenance and operational requirements. Providing all necessary supporting requirements to support the availability of the aero-engine to the customers was felt to be a solution. In current trends, if the airlines do not possess the aero-engine, they only pay for the utilisation of the aero-engines, on pay per flight hour based contract. This business model converged the product and service and provided a solution to the customers and is referred to as the product-service-system (PSS) [1]. They stated that there are two processes to converge both product and service to PSS. The first method could be approached by adding services to the current product offer, called the servitisation of product. Adding a product to a current service offer is referred to as productisation. In addition, the level of infusion of the product and service to current offers can be measured by its intensity. However, the concept of the productisation in the literature is limited and not yet a stable concept [2]. Therefore, the aim of this paper is to develop an understanding of productisation and also propose several productisation strategy levels in the context of

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F.3 Paper 3 TES Conference 2016

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The 5th International Conference on Through-life Engineering Services (TESConf 2016)

Designing Contracts for Aero-Engine MRO Service Providers: Models and Simulation

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Abstract

The aero-engine Maintenance-Repair-Overhaul (MRO) service provider has begun to adopt the product-service system (PSS) offering in order to maintain their competitiveness. Such total solution approach combines an availability-based service contract with product offerings (e.g., leasing). The current MRO service provider's contract design method is inadequate to support this offering. Miscalculation often occurs, because many of the decisions are often based on intuitions and experiences, resulting in lower quality, higher cost and longer turnaround time for the maintenance. This paper proposes an enhanced contract design method that is more scientific through the simulation modelling. The models incorporate both customers' requirements and the shop floor's operational availability. The paper provides discussion on how the results of the simulation of the models can be used to support decision making and the design of availability based contracts.

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Keywords: Availability-based contract; aero-Engine MRO; non-OEM MRO; service; contract design;

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1. Introduction

The MRO (Maintenance-Repair-Overhaul) service providers of aero-engines are changing their business model due to high competitive pressure of the market. The traditional business model was a "garage model" in which engines are maintained whenever they need maintenance. Over the last decade, OEM engine manufacturers started to introduce availability-based contracts, which is a "servitisation business model" that combined products (engines) with services.

In order to compete with OEMs, nowadays non-OEM MRO service providers also offer availability-based contracts by bundling service with products. It is a reverse approach of the servitisation from the manufacturers [1]. However, traditionally, service contracts for the garage model were designed primarily looking at only capacities mostly based on intuition and experiences. On the other hand, availability-based contracts should be designed scientifically, i.e., using models and simulation performed on them, because availability should be correctly understood, evaluated, and guaranteed. By doing so, both the MRO service provider and the customers (airlines) can identify a win-win solution.

This research aims at to obtain a better contract design method for availability-based contracts. To achieve the aforementioned aim of this research, the following research objectives were set.

- To identify the key parameters and factors which must be considered during contract design.
- To build a model about flight operations based on the identified key parameters.
- To build a model of the shop floor based on the identified key parameters.

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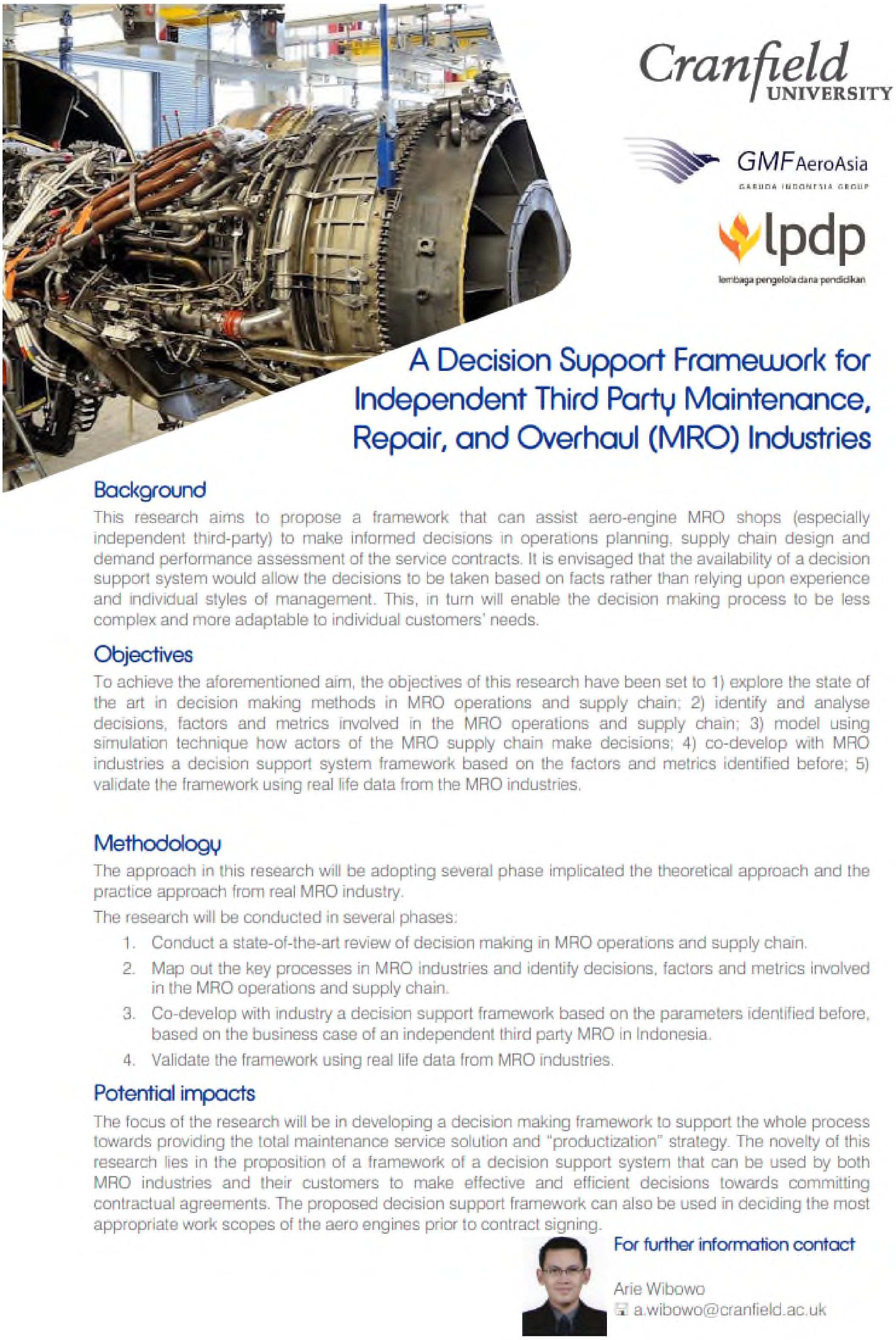
F.4 Leaflet Presented in Criscom Research Workshop 2015



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A Decision Support Framework for Independent Third Party Maintenance, Repair, and Overhaul (MRO) Industries

Background

This research aims to propose a framework that can assist aero-engine MRO shops (especially independent third-party) to make informed decisions in operations planning, supply chain design and demand performance assessment of the service contracts. It is envisaged that the availability of a decision support system would allow the decisions to be taken based on facts rather than relying upon experience and individual styles of management. This, in turn will enable the decision making process to be less complex and more adaptable to individual customers' needs.

Objectives

To achieve the aforementioned aim, the objectives of this research have been set to 1) explore the state of the art in decision making methods in MRO operations and supply chain; 2) identify and analyse decisions, factors and metrics involved in the MRO operations and supply chain; 3) model using simulation technique how actors of the MRO supply chain make decisions; 4) co-develop with MRO industries a decision support system framework based on the factors and metrics identified before; 5) validate the framework using real life data from the MRO industries.

Methodology

The approach in this research will be adopting several phase implicated the theoretical approach and the practice approach from real MRO industry.

The research will be conducted in several phases:

1. Conduct a state-of-the-art review of decision making in MRO operations and supply chain.
2. Map out the key processes in MRO industries and identify decisions, factors and metrics involved in the MRO operations and supply chain.
3. Co-develop with industry a decision support framework based on the parameters identified before, based on the business case of an independent third party MRO in Indonesia.
4. Validate the framework using real life data from MRO industries.

Potential impacts

The focus of the research will be in developing a decision making framework to support the whole process towards providing the total maintenance service solution and "productization" strategy. The novelty of this research lies in the proposition of a framework of a decision support system that can be used by both MRO industries and their customers to make effective and efficient decisions towards committing contractual agreements. The proposed decision support framework can also be used in deciding the most appropriate work scopes of the aero engines prior to contract signing.

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