ANALYSIS AND IMPROVEMENT OF LATE COMPLETION OF AIRCRAFT ENGINE MAINTENANCE USING FUZZY PROJECT MANAGEMENT TECHNIQUES AND FUZZY RESOURCE REQUIREMENT

BY

MS. LIFIA CITRA RAMADHANTI

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING (LOGISTICS AND SUPPLY CHAIN SYSTEMS ENGINEERING)
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Thesis Title	ANALYSIS AND IMPROVEMENT OF LATE COMPLETION OF AIRCRAFT ENGINE MAINTENANCE USING FUZZY PROJECT MANAGEMENT TECHNIQUES AND FUZZY RESOURCE REQUIREMENT
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ABSTRACT

This research aims to develop a method to analyze causes and to solve a late completion problem of aircraft engine maintenance jobs in a maintenance, repair, and overhaul (MRO) company. It applies fuzzy PERT/CPM methods that can determine realistic completion times and a schedule of engine maintenance jobs and develops a fuzzy resource requirement (FRR) method to determine whether the available resources are enough to conduct the maintenance activities according to the schedules. A case study is conducted in an MRO company in Indonesia. The results show that when the fuzzy activity times are estimated from real data, the fuzzy PERT/CPM methods can accurately predict the completion times of engine maintenance jobs. However, most jobs have high possibility to be completed late. Corrective actions are proposed to reduce activity times of 5 activities to make all maintenance jobs completed on time. Moreover, the developed FRR method is effective to evaluate that current available resources are sufficient to conduct all maintenance activities according to the schedules.

Keywords: Aircraft engine maintenance, Fuzzy activity time, Fuzzy resource requirement, Fuzzy PERT, Fuzzy CPM, Case Study

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LIST OF SYMBOLS/ABBREVIATIONS

Symbols/Abbreviations	**Terms**
OTP	On-time Performance
MRO	Maintenance, Repair, Overhaul
TAT	Turnaround Time
LRU	Line Replaceable Unit
ARC	Airworthiness Review Certificate
TFNs	Triangular Fuzzy Numbers
PERT	Program Review Review Techniques
CPM	Critical Path Method
FRR	Fuzzy Resource Requirement
PPC	Production Planning Control
SD	Standard Deviation
VBA	Visual Basic Application
APU	Auxiliary Power Unit
NDT	Non-destructive Test
PLC	Possibility Late Completion
TDRR	Total De-fuzzified Required Resource

CHAPTER 1
INTRODUCTION

1.1 Background

In an aviation world, an aircraft engine in good condition is needed. One way to ensure the good condition of an aircraft engine is through maintenance. Moreover, the maintenance process should be completed on time, because the late completion is highly costly. If an airline does not have high on-time performance (OTP), it will be abandoned by the customer. OTP is a measure of readiness of aircraft, crew, and other equipment to fly passengers to certain destinations. Therefore, to maintain aircraft availability and aviation safety, airlines must perform aircraft maintenance following good maintenance standards. To maintain the aircraft engines, the aviation industry needs an aircraft engine maintenance service from a company called maintenance, repair, and overhaul (MRO) company.

Maintenance is activity related to maintaining a certain level of availability and reliability of the system or components and achieving a high-quality level (Ben-Daya et al., 2009). In aircraft engine maintenance, it is a strategic process for aircraft, both for quality and economy to achieve safety level, availability, and reliability of scheduled flight (Atli & Kahraman, 2012). According to Remenyi & Staudacher (2014), to increase aircraft availability and to improve maintenance efficiency, it needs speeding up turnaround time for scheduled and unscheduled maintenance.

This research is to improve the on-time performance (OTP) of engine overhaul jobs in an MRO company in Indonesia. It is initially expected that this MRO company has low OTP since its existing planning and control system is a conventional project management system that considers constant activity times and unlimited resources. In fact, the activity times of engine maintenance are uncertain and cannot be easily estimated as a constant. Additionally, each maintenance activity needs some resources (manpower and tools). The current planning system assumes that the available resources are unlimited, which is unrealistic. Therefore, it cannot predict accurate completion times of the engine maintenance jobs and cannot control maintenance jobs to be completed on time.

1.2 Statement of problem

Based on the background, the problem that exist in the aircraft engine maintenance industry is caused by the late completion and limited resources. The late completion of engine overhauled jobs is presented in Table 1.1.

Table 1.1 The Late Completion of Engine Overhauled Jobs.

Engine Number	Start Date	Actual TAT	Actual Completion Date	Due Date	Late Completion (days)
1	30-Nov-18	334	21-Sep-19	10-May-19	134
2	17-Dec-18	370	26-Oct-19	27-May-19	152
3	29-Jan-19	445	26-Jan-20	28-Jul-19	182
4	07-Feb-19	215	16-Jul-19	11-Jul-19	5
5	04-Mar-19	324	30-Dec-19	31-Aug-19	121
6	29-Mar-19	399	04-Mar-20	27-Sep-19	159
7	10-Apr-19	309	28-Jan-20	07-Oct-19	113
8	24-Apr-19	217	16-Oct-19	04-Oct-19	12
9	30-Apr-19	240	08-Nov-19	29-Sep-19	40
10	30-Apr-19	240	08-Nov-19	29-Sep-19	40
11	02-May-19	152	16-Sep-19	06-Sep-19	10
12	06-May-19	221	20-Oct-19	05-Oct-19	15
13	17-Jun-19	179	11-Nov-19	02-Nov-19	9
14	26-Jun-19	168	10-Nov-19	03-Nov-19	7
15	10-Jul-19	199	03-Dec-19	30-Nov-19	3
16	18-Sep-19	127	01-Jan-20	28-Dec-19	4
17	11-Oct-19	60	02-Dec-19	01-Dec-19	1
18	21-Oct-19	90	12-Jan-20	05-Jan-20	7
19	30-Oct-19	96	17-Jan-20	16-Jan-20	1
20	04-Nov-19	76	11-Jan-20	06-Jan-20	5
21	18-Nov-19	68	15-Jan-20	14-Jan-20	1
22	19-Nov-19	75	23-Jan-20	21-Jan-20	2
23	20-Nov-19	75	24-Jan-20	22-Jan-20	2
24	26-Nov-19	61	20-Jan-20	17-Jan-20	3
25	02-Dec-19	138	08-Apr-20	23-Mar-20	16
26	05-Dec-19	71	04-Feb-20	02-Feb-20	2
27	30-Dec-19	103	29-Mar-20	22-Mar-20	7
28	15-Jan-20	102	17-Apr-20	07-Apr-20	10
29	04-Mar-20	59	24-Apr-20	21-Apr-20	3
30	09-Mar-20	109	16-Jun-20	31-May-20	16

Table 1.1 shows the data of 30 engine overhaul jobs starting from November 30, 2018 to March 9, 2020. It indicates that 30 engines have late completion from 1 day to 182 days. Note that the actual completion date is the start date plus the actual turnaround time (TAT). In the aircraft engine maintenance industry, there are 16 maintenance activities. It contains several reasons for the late completion are presented in Table 1.2.

Table 1.2 List of Activities That Have Delay.

Station Activity	Activity	Type of Delays	Cause of Delays
A	Incoming inspection (check data of historical maintenance record and borescope to inspect internal parts of engine)	No delay activities	
B	Forecasting and scheduling	No delay activities	
C	Disassembling into 3 parts such as major module, module, submodule parts	Broken tools.	Damage to specific tools.
D	Cleaning parts section (chemical cleaning and mechanical cleaning)	Waiting for purchase order confirmation between MRO to customer.	The length of time for approval related to future accountability as a sign of agreement on scheduled turnaround time.
F	Inspecting the engine for crack, scrap, rubs, scratch, dent, nick (non-destructive test, bench inspection, bearing inspection, wiring inspection)	There is a queue in the inspection process & overload from cleaning process.	Scheduling on the inspection section is not precise.
E	Shipping and receiving of fast track parts to vendors	Waiting disposition from engineering for some outside vendors.	There is a queue for disposition.
F1	Waiting for approval from the customer if there are findings beyond the complaint from the customer	Waiting approval from customer	If there are problems other than those complained of by the customer, it must get approval from customer.
G	Repairing the engines with various types of repairs such as shot-peening, electroplating, anodizing, miscellaneous, and thermal spray	The repair time and waiting time for shipment process confirmation from vendors are too long.	There is no accurate scheduling system & deadline for vendors in existing system
H	Planning the material procurement such as parts that must order either from outsource repair or buying new parts, and all late parts are purchased, loaned, or swapped	The manual procurement process is too long.	There was no e-procurement system in existing process.
I	Waiting for new parts or serviceable parts that have been ordered either from outsource repair or new vendors	The delivery time from vendor is too long.	There is no regulation about the delivery time between the vendor and the company.
J	Collecting the parts from in-house repair, outsource repair, new part's vendor then checking whether parts purchased are appropriate or not, and preparing parts to group into kits for assembly	Lack of resources such as manpower and tool.	Tools and manpower are asked to do the other tasks.
K	Combining the submodule from 17 submodules to 3 major modules (subassembly)	Lack of resources such as manpower and tool.	Waiting for slot of manpower and tools.
L	Assembling the module into a complete engine (final assembly)	Waiting for line replaceable unit (LRU).	Due to waiting for completeness of some LRU (line replacable unit).
		Waiting for part's document approval, manpower slot and tool problem.	Tools and manpower are asked to do the other tasks.
M	Testing the cell or engine	Test cell result bellow contractual or target.	There is something wrong in test.
		Troubleshooting during test.	
		Waiting completeness document before issued ARC (Airworthiness Review Certificate).	The length of time for complete the document like a sign of agreement.
N	Outgoing and controlling the engine quality	Waiting for test cell result approval.	The length of time for approval the final process.
O	Certifying process or serviceable	No delay activities	

This research proposes to handle the uncertainty using a fuzzy activity time. It is estimated from real activity times as triangular fuzzy numbers (TFNs), including optimistic, most likely, and pessimistic times. Three scheduling methods are evaluated to know that which one is the most accurate to predict the completion time of engine maintenance. PERT, fuzzy PERT, and fuzzy CPM methods are selected since they are simple, well-known, and use the same input data of TFNs for activity times. A fuzzy resource requirement (FRR) method is newly developed to determine the amount of required resources in each time period from the schedule of maintenance activities. The application of TFNs in this research is motivated by a research work of Tansakul & Yenradee (2020) that successfully applies TFNs to represent uncertain durations of improvement projects in banking industry.

Therefore, this thesis report involves the following issues:

1. How to estimate the triangular fuzzy numbers that represent uncertain durations of maintenance activities.
2. How to determine the most accurate scheduling method that can predicts the completion time of engine maintenance.
3. How to reduce the late completion significantly.
4. How to determine whether the available resources are sufficient to conduct the maintenance activities according to the schedule.

1.3 Purpose of study

The purpose of conducting research in the maintenance, repair and overhaul (MRO) company by paying attention to the above problems are as follows:

1. To estimate triangular fuzzy numbers (TFNs) that represent uncertain durations of maintenance activities based on real historical durations of maintenance activities.
2. To compare scheduling performances among PERT, fuzzy PERT, and fuzzy CPM for selecting a method that accurately predicts the completion time of engine maintenance.
3. To suggest corrective actions that can significantly reduce the late completion.

4. To develop the FRR method to calculate the resource requirement to determine whether the available resources are sufficient to conduct the maintenance activities according to the schedule.

Based on the problems previously written, the benefits of this study are as follows:

1. This methodological step is useful for MRO company to determine schedules of maintenance activities, to accurately predict completion times of each overhauled jobs, to identify what activities need corrective actions, and to determine whether the corrective actions are sufficient to ensure that the possibility of late completion is relatively low.
2. Providing an alternative to the production planning control (PPC) analyst of the maintenance, repair and overhaul (MRO) company in determining scheduling policy, so it can minimize the aircraft engine maintenance time.
3. Providing a new way to optimize the aircraft engine maintenance schedule by considering the fuzzy activity time and fuzzy resource requirement.
4. Aircraft engine delivery is well served then the customers feel satisfied with the services provided by maintenance, repair and overhaul (MRO) company.

1.4 Limitation and problem assumption

Given the many problems associated with one problem with the others and then to provide direction and facilitate the resolution of problems properly by following with the objectives to be achieved, the necessary restrictions are used. Limitation of problems to the research conducted, as shown below:

1. The object of research is only for engine overhaul jobs, not minor repair and maintenance jobs since the latter does not face serious problems of late completion.
2. The fuzzy activity times are estimated based on real activity times of 30 engines that are overhauled during November 30, 2018 to March 9, 2020 because data before November 2018 is too old and may not represent the current situation. Note that the real data after March 2020 is not available when this research is started.

3. This research applies project scheduling methods (PERT, fuzzy PERT, and fuzzy CPM) which are available. It does not intend to develop a new project scheduling method.

Assumptions used for the research is instead of using the target turnaround time (TAT) for planning, the actual turnaround time (TAT) is used based on the fuzzy number because it is the same as the actual outcome**.**

1.5 Systematics of report

The thesis report is organized as follows:

CHAPTER I INTRODUCTION

This chapter presents a background description of the problem related to the research to be carried out, the formulation of the problem shows the problem that arises in the aircraft engine maintenance company, the purpose, and benefits of solving the problem, limitation and problem assumption.

CHAPTER II REVIEW OF LITERATURE

This chapter presents theories related to aircraft engine maintenance applications, scheduling methods being used, and resource constraints.

CHAPTER III METHODOLOGY

This chapter presents the steps in problem-solving from beginning to end, so the discussion and problem-solving in a structured and directed way.

CHAPTER IV DATA COLLECTION

This chapter presents the data needed to be processed in accordance to solve the problem.

CHAPTER V RESULT AND DISCUSSION

This chapter presents result, numerical example and interpretation that has been carried out from the results of data processing, by making improvements and solving the problems.

CHAPTER VI CONCLUSIONS AND FUTURE WORK

This chapter presents the conclusions of research that have been formulated in the formulation of problems and suggestion that may be beneficial to the company.

CHAPTER 2
REVIEW OF LITERATURE

This section presents related previous research works are reviewed based on the areas of application (industry type that the works are applied), objectives of the works, and techniques and methods that the works are used. Their comparison is presented in Table 2.1. The differences between previous research works and this research are discussed related to aircraft engine maintenance applications, scheduling methods being used, and resource constraints.

2.1 Maintenance

Maintenance involves activities with the objective of keeping an item functioning according to the specifications of the project and returning it to optimal conditions to avoid failures and ensure that the operations in the specifications run optimally (Junqueira et al., 2018). Maintenance can be classified into 3 types, such as:

1. Corrective maintenance: it is carried out after a breakdown occurs.
2. Preventive maintenance: it is carried out at predetermined intervals to reduce the possibility of degradation.
3. Predictive maintenance: it is carried out using a systematic application of analysis tools in order to reduce the preventive maintenance to a minimum and reduce the corrective maintenance.

Therefore, nowadays, maintenance practices are still seen as actions related to repair of equipment after it is breakdown. While the core of maintenance is an action to prevent the parts or component from failing or to repair the equipment under normal condition, but it is degraded due to operation so that it still has optimal performance. Thus, there is no equipment can operate forever because all equipment has a connection with the life limit that has been set or referred to as operational life.

2.2 Previous research

Table 2.1 The Comparison Table Between This Research and Other Research Works.

Related Works	Industry Type				Objectives								Methods												
	Aircraft Maintenance	Construction Industry	Project Network	Manufacturing Industry	Reduce Downtime	Minimize Planning	Completing on Time	Speeding Up TAT	Maintain Serviceability & Availability	Solve Tight Resource	Allocate Resources	Minimize Delay	Critical Path Method	Critical Chain Project Management	PERT	Theory of Constraints	Genetic Algorithm	Fuzzy Critical Path Method (Fuzzy CPM)	Fuzzy PERT	Linear Programming	Constraint	Goal Programming	Fuzzy Resource Requirement	Simulation Model	Harmonizing Life
(Amiolemhen & Akpomwomwo, 2016)		√					√					√	√							√					
(Agyei, 2015)		√					√						√		√					√					
(Atli & Kahraman, 2012)	√					√	√		√						√			√							
(Catana et al., 2015)			√							√					√	√									
(Chen & Huang, 2007)			√										√		√			√							
(Dinis et al., 2019)	√																		√						
(Elizabeth & Sujatha, 2013)			√										√		√			√	√						
(Gharbi, 2013)	√								√											√					
(Ghomi & Ashjari, 2002)			√						√	√	√													√	
(Huda, 2014)		√			√		√												√						
(Ihwanudin, 2017)		√			√														√						
(Junqueira et al., 2018)	√				√		√						√	√		√									

Table 2.1 The Comparison Table Between This Research and Other Research Works (Continued).

Related Works	Industry Type				Objectives								Methods												
	Aircraft Maintenance	Construction Industry	Project Network	Manufacturing Industry	Reduce Downtime	Minimize Planning Time	Completing on Time	Speeding Up TAT	Maintain Serviceability & Availability	Solve Tight Resource	Allocate Resources	Minimize Delay	Critical Path Method	Critical Chain Project Management	PERT	Theory of Constraints	Genetic Algorithm	Fuzzy Critical Path Method (Fuzzy CPM)	Fuzzy PERT	Linear Programming	Constraint Programming	Goal Programming	Fuzzy Resource Requirement	Simulation Model	Harmonizing Life
(Liang & Han, 2004)			√										√		√			√	√						
(Liu & Wang, 2007)		√					√				√										√				
(Long & Ohsato, 2008)			√			√												√					√		
(Mahargo et al., 2013)	√						√	√								√									
(Masmoudi et al., 2011)	√					√													√				√		
(Mazlum & Guneri, 2015)			√				√						√		√			√							
(Pleumpirom & Amornsawadwatana, 2012)	√				√				√													√			
(Rawi & Mukherjee, 2019)		√					√				√									√					
(Remenyi & Staudacher, 2014)	√						√	√	√															√	
(Samman & Brahemi, 2014)				√		√							√		√			√	√						
(Subash & Vijayaraja, 2017)	√				√				√																√
(Vizkia et al., 2014)		√					√								√				√						
(Wang et al., 2010)	√					√			√								√								
This Research	√				√		√	√		√					√			√	√				√		

2.3 Aircraft engine maintenance

According to Table 2.1, several studies have analyzed the problem of late completion in aircraft engine maintenance. Main causes of late completion are the long procurement time for replacement parts and long repair time of parts at suppliers (Mahargo et al., 2013). Other causes are a high workload that exceeds the capacity of MRO company, and lack of planning tools to estimate the actual workload (Remenyi & Staudacher, 2014). The late completion can be solved by changing the procurement process at the outside vendors (Mahargo et al., 2013) and by applying appropriate scheduling methods such as using decentralized scheduling (Remenyi & Staudacher, 2014). The above-mentioned previous works do not consider resource constraints in their methods. This research proposes an important step in the methodological steps that the required resource should be calculated and compared with the available resource to ensure that the available resource is sufficient to carry out the maintenance activities according to the schedules.

Here is the detail of aircraft engine maintenance activities as shown below:

1. Activity of A is incoming inspection, which is initial inspection to find out what job will be done on the engine, such as:
    - Reason of removal, the inspection by ask the customer about the reason of engine got off the airplane.
    - Historical Record is the document which contains the history of the engine (parts and components) and life limit part.
    - Borescope, the inspection to determine the state in the engine.
2. Activity B is forecasting and scheduling, the activity carried out by the production and planning control (PPC) department, engineering department and warehousing department to forecast and plan the target time for aircraft engine maintenance process.
3. Activity C is disassembly, which is the process of separating parts into major module, module, submodule parts.
4. Activity D is cleaning parts section for the engine and APU, namely chemical cleaning and mechanical cleaning.
    - Chemical cleaning to remove dirt or grease and the impurities that arise during the engine is switch on before continuing to the next process.

- Mechanical cleaning, the process of cleaning parts of the dirt stuck to the parts before continuing to the next process.

5. Activity F is inspection to check the engine/APU from crack. Types of inspection as shown below:
    - Bench inspection is visual inspection of components using measuring instrument and it consists of serviceable, repairable, condemned and sub-contractor.
    - Bearing inspection is the process requires separate method with the other parts.
    - Non-destructive test (NDT) is an inspection of parts without damaging the structure of the part.

    The output of inspection is serviceable, repairable and condemn. In addition, the output of an inspection includes if the findings within the scope of complaint from customer so it will proceed to the next process, but if there are findings beyond the complaints, it requires approval from the customer.
6. Activity E is fast track parts shipped to vendor such as shipping - receiving vendor.
7. Activity F1 is waiting for approval from the customer if there are findings beyond the complaint from customer.
8. Activity G is repair section, as follows:
    - Shotpeening is surface repair process by using sand or cleaning.
    - Electroplating is a coating process, so the parts are anti-rust.
    - Anodizing is a coating process for the iron material before painting.
    - Miscellaneous is a finishing process of iron fittings
    - Thermal spray is a coating/thickening process to maintain the original dimension.
    - Machining is turning process and grinder process.
    - Welding process
    - Brazing is soldering process for non-ferrous.
    - Heat treatment is a heating process.

9. Activity H is material planning or procurement section, such as for parts that must order either from farm out vendors (oursource repair) or to buy new parts and all late parts are purchased, loaned or swapped.
10. Activity I is waiting for new parts or serviceable parts that have been ordered either from farm out vendors (outsource repair) or new vendors.
11. Activity J is collecting parts from in house repair, farm out vendors (outsource repair), vendor for new parts then check whether parts purchased are appropriate or not and prepare parts to group into kits for assembly.
12. Activity K is sub assembly process, by merging sub-module into 17 sub-modules then into 3 major modules. Before merge into 3 major modules, rotor balancing is carried out to determine the tolerance so it can reduce the vibration when the engine in operating.
13. Activity L is final assembly process, the process of combining into 1 engine from the sub-assembly results.
14. Activity M is test cell or engine test to determine an engine performance serviceable by measuring the temperature, vibration, speed, flow, pressure.
15. Activity N is outgoing, quality engine control, which is the final quality check process of an aircraft engine.
16. Activity O is certifying process or serviceable, this test determines whether the overhaul engine has been passed or not.

2.4 Scheduling methods

In recent years, some scheduling methods have been applied in aircraft engine maintenance, such as the fuzzy CPM and PERT (Atli & Kahraman, 2012), fuzzy PERT (Dinis et al., 2019), critical path method, critical chain project management & theory of constraints (Junqueira et al., 2018). Some of these studies use a constant activity time. Some scheduling methods use fuzzy time (Elizabeth & Sujatha, 2013) such as PERT, fuzzy PERT, and fuzzy CPM methods. In fuzzy sets theory, it may use a ranking method to determine the maximum/minimum value, and use a possibility instead of a probability to measure a degree of uncertainty (Wei & Tang, 2013). Based on real data of case study in the MRO company, the duration of all activities has relatively high variation and cannot be estimated as constants. Thus, the time of activities should be estimated by fuzzy numbers and the scheduling methods being used in this research should use fuzzy activity times.

2.4.1 Program evaluation review techniques (PERT)

The objective is to schedule the sequence of work activities in the project and determine the total time needed to complete the project. According to Ben-Daya et al (2009), in maintenance activities are unique and involve unexpected needs which makes their time duration very uncertain. On the other hand, critical path method (CPM) uses a single estimate of the duration of time based on someone's judgment. Whereas, program evaluation review technique (PERT) combining uncertainty with three estimated time from the same activity to form a description of the probability of their time requirements. Three times through estimates are judgmental because they provide more information about the activities that can be carried out used for probabilistic modeling. The three values are as follows:

- o or optimistic time is the time required if execution goes extremely well.
- m or most likely time is the time required under normal condition.
- p or pessimistic time is the time required under the worst conditions.

PERT calculation using expected time as single time estimate to calculate the forward pass and backward pass. The expected time is given by Equation (2.1).

$$\frac{o+4m+p}{6} \tag{2.1}$$

where o is the optimistic time, m is the most likely time and p is the pessimistic time.

- Forward pass calculation, to find out the fastest project completion time. Here are some rules on forward pass calculation, as follows:
  - The fastest time for the initial event on day 0 is given by Equation (2.2).

    $$TE_{(j)} = 0 \tag{2.2}$$

    where $TE_{(j)}$ is the earliest time of activity j which is all activities can be started if the precedence activity has been completed.

- ❖ Unless for the initial activity, an activity bar can be started if the precedence activity has been completed.
- ❖ The earliest finish time for an activity is the same as the earliest start time plus the duration time of the activity using Equations (2.3 to 2.5).

$$EF_{(j)} = ES_{(j)} + d_j \tag{2.3}$$

$$TE_{(j)} = EF_{(j)} \tag{2.4}$$

$$TE_{(j)} = ES_{(j)} + d_j = TE_{(j-1)} + d_j \tag{2.5}$$

where $EF_{(j)}$ is the earliest finish time of activity j, $ES_{(j)}$ is the earliest start time of activity j, d_j is duration time of activity j, $TE_{(j)}$ is the earliest time of activity j, $TE_{(j-1)}$ is the earliest time of previous activity j.

- ❖ If there are 2 activities that end at the same node (more than 1 predecessor), so the earliest start ($ES_{(j)}$) is the same as the earliest finish ($EF_{(j)}$) which is the largest from the precedence activity. An event can only occur if the precedence activities have been completed. Therefore, the fastest time when an event occurs is equal to the greatest value of the fastest time for activities that end in that event using Equation (2.6).

$$TE_{(j)} = Max\left\{EF_{(j)}\right\} \tag{2.6}$$

where $TE_{(j)}$ is the earliest time of activity j, $EF_{(j)}$ is the earliest finish time of activity j.

- Backward pass calculation, to find out the most recent time of activity, it can be started and ended without delay the entire project completion time. Here are some rules on backward pass calculation, as follows:
  - ❖ In the final activity using Equation (2.7).

$$TL_{(j)} = TE_{(j)} \tag{2.7}$$

where $TL_{(j)}$ is the latest time of activity j, $TE_{(j)}$ is the earliest time of activity j.

- ❖ The latest start time of an activity is equal to the latest finish time minus the duration time of the activity using Equations (2.8 to 2.10).

$LS_{(j)} = LF_{(j)} - d_j$ (2.8)

Because $LF_{(j)} = TL_{(j)}$, so $LS_{(j)} = TL_{(j)} - d_j$ (2.9)

Thus, $TL_{(j)} = LS_{(j)}$ (2.10)

where $LS_{(j)}$ is the latest start time of activity j, $LF_{(j)}$ is the latest finish time of activity j, d_j is the duration time of activity j, $TL_{(j)}$ is the latest time of activity j.

- ❖ If an activity has two or more precedence activities, the latest finish ($LF_{(j)}$) of the activity is the same as the latest start ($LS_{(j)}$) of the next smallest activity. Each activity can only be started if the precedence activity has occurred. Therefore, the latest time of event occurs is the smallest value from the latest to start the activity using Equation (2.11).

$TL_{(j)} = Min\left\{LS_{(j)}\right\}$ (2.11)

where $TL_{(j)}$ is the latest time of activity j, $LS_{(j)}$ is the latest start time of activity j.

Although PERT uses fuzzy activity times, it de-fuzzifies the fuzzy activity times into a constant called a mean value. It also calculates a variance of activity time. Then based on the mean of activity time, the critical path is determined. Finally, the mean and standard deviation (SD) of the project duration are determined (see Agyei, 2015). The critical path is activities that do not have a grace period or earliest start time ($ES_{(j)}$) equal to the latest start time ($LS_{(j)}$). To determine the critical path, it is come from by the latest start time ($LS_{(j)}$) minus earliest start time ($ES_{(j)}$) which is called slack or total float ($TF_{(j)}$) = 0.

PERT does not provide the project duration as fuzzy numbers. This research proposes to estimate the project duration as fuzzy numbers using a simple statistical theory are given by Equations (2.12 to 2.15).

$$\sigma = \sqrt{\sum Variance\ of\ critical\ activities} \tag{2.12}$$
$$o = \mu - 3\,\sigma \tag{2.13}$$
$$m = \mu \tag{2.14}$$
$$p = \mu + 3\,\sigma \tag{2.15}$$

where o is the optimistic project duration (from start time to completion time), m is the most likely project duration, p is the pessimistic project duration, μ is a mean value of project duration, σ is a standard deviation of project duration.

Equation (2.12) is used to determine the SD of project duration. Then, the optimistic, most likely, and pessimistic project durations are estimated by Equations (2.13 to 2.15). The fuzzy project duration determined from results of PERT method has a disadvantage that the fuzzy project duration is always symmetrical.

2.4.2 Fuzzy program evaluation review technique (Fuzzy PERT)

An alternative way to handle uncertainty is by using fuzzy set theory rather than probability theory. According to Chen & Huang (2007), fuzzy program evaluation review technique (fuzzy PERT) method is proposed to deal with completion time management and the critical degrees of all activities for a project network. PERT method uses probability to analyze the final result or to find out the chances of completing the project within a specified time period. Whereas, fuzzy PERT method is different from PERT method because in fuzzy PERT uses the possibility to analyze which is to find out the possibility of project completion within the specified time. In the fuzzy PERT uses fuzzy logic or fuzzy set theory which is the way to model the uncertainty that arises. For duration time, the fuzzy PERT method also uses triangular fuzzy numbers such as optimistic, most likely and pessimistic time. Here are the rules for forward pass and backward pass calculations (Samman & Brahemi, 2014), as follows:

- Forward pass calculation
    - It is the same as the PERT method, in the forward pass calculation of fuzzy PERT also calculate the earliest time of the activity by using Equations (2.2 to 2.5) but under triangular fuzzy situations.
    - If there are 2 activities that end at the same node (more than 1 predecessor) using Equation (2.16).

$$TE_{(j)} = Max\left\{EF_{(j,s)}\right\} \tag{2.16}$$

But to determine the maximum value, it requires analysis using decision maker's risk index (λ) and ranking value ($R(Li)$) are given by Equations (2.17 to 2.18) (Vizkia et al., 2014).

$$\lambda = \left[\sum \frac{p_j - o_j}{(m_j - o_j) + (p_j - m_j)}\right] / t \tag{2.17}$$

$$R(Li) = \lambda\left[\frac{p_j - X_1}{X_2 - X_1 + p_j - m_j}\right] + (1-\lambda)\left[1 - \frac{X_2 - o_j}{(X_2 - X_1 + m_j - o_j)}\right] \tag{2.18}$$

where $TE_{(j)}$ is the earliest time of activity j, $EF_{(j,s)}$ is the earliest finish time of activity j under triangular fuzzy situations (s), λ is the decision maker's risk index, X_1 is $Min\{o_1, o_2, \dots, o_n\}$, X_2 is $Max\{p_1, p_2, \dots, p_n\}$, p_j is pessimistic time of activity j, o_j is optimistic time of activity j and m_j is most likely time of activity j.

- Backward pass calculation
    - It is the same as the PERT, in the backward pass for the latest time must be calculated ($TL_{(j)}$). This calculation starts from the final event in the network after ($TE_{(j)}$) calculation has been completed using Equations (2.7 to 2.10), but under triangular fuzzy situations.
    - If there are 2 activities that end at the same node (more than 1 predecessor) using Equation (2.19).

$$TL_{(j)} = Min\left\{LS_{(j,s)}\right\} \tag{2.19}$$

But to determine the minimum value, it requires analysis using decision maker's risk index (λ) and ranking value ($R(Li)$) are given by Equations (2.20 to 2.21) (Vizkia et al., 2014).

$$\lambda = \left[\sum \frac{p_j - o_j}{(m_j - o_j) + (p_j - m_j)}\right] / t \tag{2.20}$$

$$R(Li) = \lambda \left[\frac{p_j - X_1}{X_2 - X_1 + p_j - m_j}\right] + (1 - \lambda)[1 - \frac{X_2 - o_j}{(X_2 - X_1 + m_j - o_j)}] \tag{2.21}$$

where $TL_{(j)}$ is the latest time of activity j, $LS_{(j,s)}$ is the latest start time of activity j under triangular fuzzy situations (s), λ is the decision maker's risk index, X_1 is $Min\,\{o_1, o_2, \dots, o_n\}$, X_2 is $Max\,\{p_1, p_2, \dots, p_n\}$, p_j is pessimistic time of activity j, o_j is optimistic time of activity j and m_j is most likely time of activity j.

2.4.3 Fuzzy critical path method (Fuzzy CPM)

This method combines the critical path method with fuzzy set theory to tackle problems where a source of vagueness is involved so that to effectively deal with the vagueness involved in the process estimate times can use fuzzy number to reduce uncertainty. Here are the rules for forward and backward pass calculations (Rusu, 2018), as follows:

- Forward Pass Calculation
  - ❖ It is the same as the fuzzy PERT method to calculate the earliest time of the activity in forward pass rules, but the difference is in determining the maximum value with different formulas of the decision maker's risk index (β) and the ranking value ($R(Li)$) are given by Equations (2.22 to 2.23).

$$\beta = \left[\sum \frac{p_j - o_j}{(m_j - o_j) + (p_j - m_j)}\right] / t \tag{2.22}$$

$$R(Li) = \beta \left[\frac{p_j - X_1}{X_2 - X_1 + p_j - m_j}\right] + (1 - \lambda)[\frac{X_2 - o_j}{(X_2 - X_1 + m_j - o_j)}] \tag{2.23}$$

where β is the decision maker's risk index, X_1 is $Min\,\{o_1, o_2, \dots, o_n\}$, X_2 is $Max\,\{p_1, p_2, \dots, p_n\}$, p_j is pessimistic time of activity j, o_j is optimistic time of activity j and m_j is most likely time of activity j.

- Backward pass calculation
  - ❖ It is the same as the fuzzy PERT method to calculate the latest time of the activity in backward pass rules, but the difference is in determining the minimum value with different formulas of the decision maker's risk index (β) and the ranking value ($R(Li)$) are given by Equations (2.24 to 2.25).

$$\beta = \left[\sum \frac{p_j - o_j}{(m_j - o_j) + (p_j - m_j)}\right] / t \tag{2.24}$$

$$R(Li) = \beta \left[\frac{p_j - X_1}{X_2 - X_1 + p_j - m_j}\right] + (1 - \lambda)\left[\frac{X_2 - o_j}{(X_2 - X_1 + m_j - o_j)}\right] \tag{2.25}$$

where β is the decision maker's risk index, X_1 is $Min\,\{o_1, o_2, \dots, o_n\}$, X_2 is $Max\,\{p_1, p_2, \dots, p_n\}$, p_j is pessimistic time of activity j, o_j is optimistic time of activity j and m_j is most likely time of activity j.

2.5 Resource constraint

There are some previous studies related to fuzzy PERT/CPM that consider resource constraints, so they provide initial ideas for this research. Long & Ohsato (2008), managed project scheduling through a deterministic schedule under resource constraints to minimize project duration. In aircraft maintenance, it requires a method to establish a resource workload with the aim of tactical and operational planning because many projects have different planning uncertainties. Fuzzy PERT and fuzzy resource-leveling methods can solve problems related to the resource workloads (Masmoudi et al., 2011). Optimization under uncertainty of limited constraint can use fuzzy sets theory (Srizongkhram et al., 2020). Furthermore, the scheduling and resource allocation can be solved by using visual basic for application (VBA) software which is connected to Microsoft Excel software (Ghomi & Ashjari, 2002).

2.6 Visual basic for applications (VBA) software

According to Tienda (2015), visual basic for applications is the software that use programming language to performs automation in Microsoft Excel. It also adds user-defined functions. Microsoft added an integrated development environment for the VBA language, it makes easier for users to do programming. This application allows to modify the values for the fuzzy times, the precedence relationship and the continuity of activities and processes. The application has been partially implemented with C# to test the time required to compute the fuzzy times and floats obtaining for short time.

CHAPTER 3
METHODOLOGY

In conducting this research, to get the results that are following what has been formulated and it can be implemented well and structured, therefore research is carried out with the formulations are shown in below:

3.1 Models used

In order to get good results in solving problems, structured and systematic steps are needed. The model used in carrying out the proposed problem-solving to describe of how the proposed problem-solving is arranged. Based on the late completion problem of aircraft engine maintenance described in the introduction section, some techniques from previous works can determine schedule of activities considering uncertain activity time and limited resources. However, these research works are developed for other industries, not specially developed for aircraft engine maintenance, which may have different characteristics. Therefore, this research is needed to demonstrate how to analyze the late completion and suggest possible corrective actions, which are beneficial for MRO companies that overhaul aircraft engines.

3.1.1 Notation

The notations used in this model are given below:

- Indices:

i index of resource type

t index of period

j index of activity

k index of job/engine

d index of duration time

D index of due date

- Sets:

J set of all activities

K set of all jobs (engines)

- Parameters:

PLC possibility of late completion

C^p	pessimistic completion time
C^m	most likely completion time
C^o	optimistic completion time
λ	the decision maker's risk index of fuzzy PERT method
β	the decision maker's risk index of fuzzy CPM method
X_1	the minimum of optimistic times
X_2	the maximum of pessimistic times
p_j	pessimistic time of activity j
m_j	most likely time of activity j
o_j	optimistic time of activity j

3.2 Research steps

Methodological steps to analyze the late completion and suggest corrective actions are presented in Figure 3.1.

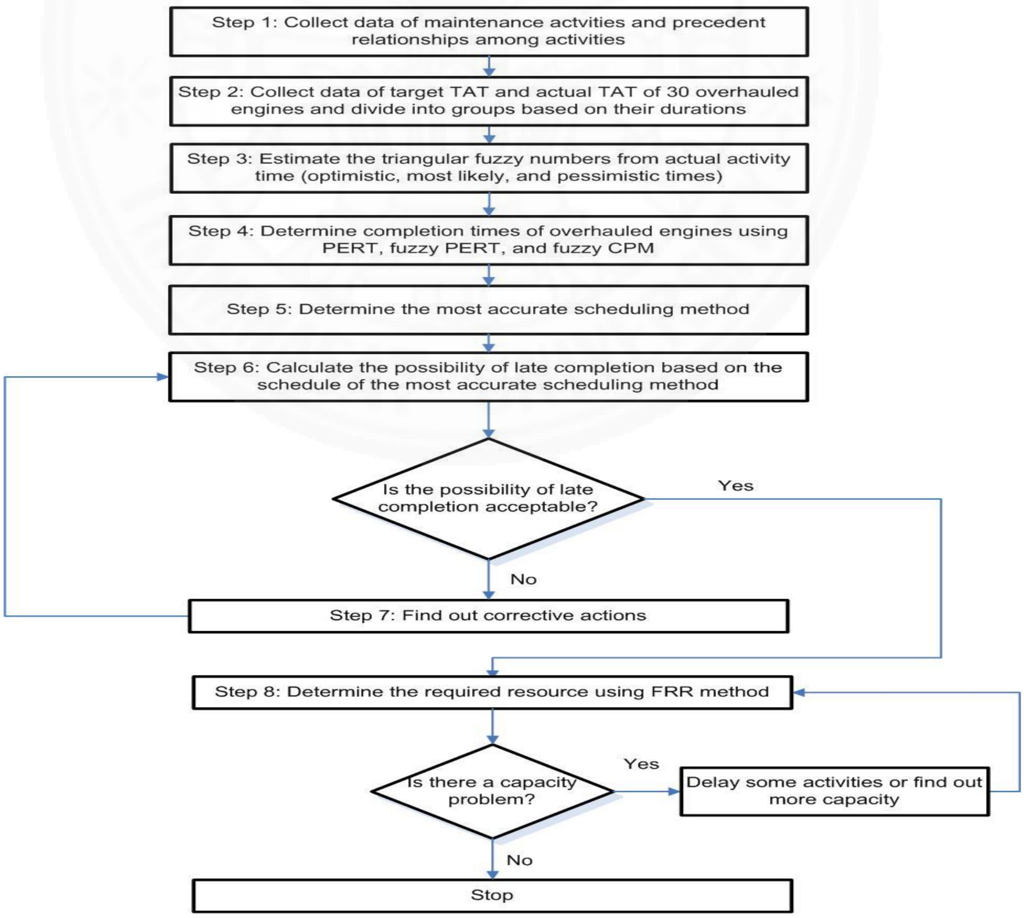

Figure 3.1 Methodological Steps.

3.2.1 Step 1: Collect data of maintenance activities and precedent relationships among activities

Maintenance is a combination of several actions to maintain engine performance. The aircraft engine maintenance process starts from the incoming inspection, forecasting, and scheduling, then conducts the required maintenance until the engine is finished and ready to be sent to the customer. Therefore, aircraft engine maintenance activities are complicated and have a relationship between activities called precedent relationships. Based on real practice of the MRO company of the case study, the aircraft engine overhaul works are divided into 16 activities are given in Table 4.1 of Chapter 4, data collection.

3.2.2 Step 2: Collect data of target TAT and actual TAT of 30 overhauled engines and divide into groups based on their durations

There are 30 historical data of overhauled engines. The data include the target turnaround time (TAT) and the actual TAT. Due to high data variability, it is necessary to divide the engines into different groups. There are 12 activities which are divided into 2 groups and 2 activities which are divided into 3 groups based on the duration of the target TAT of the engine. Low, medium, and high durations belong to groups 1, 2, and 3, respectively. This grouping makes it easier to analyze the fuzzy data. Then, the actual TAT of the engine is also grouped based on the target TAT group. The result of grouping is shown in Table 5.1 of Chapter 5, results and discussion.

3.2.3 Step 3: Estimate the triangular fuzzy numbers from actual activity times (optimistic, most likely, and pessimistic times)

This step is to estimate the fuzzy numbers that represent uncertain durations of maintenance activities based on actual historical durations of maintenance activities. Firstly, the histogram of the activity times is created to help visualize the variations of the activity times. For example, the histograms of groups 1 and 2 of activity C are presented in Figure 5.1 and Figure 5.2, respectively of Chapter 5, results and discussion.

3.2.4 Step 4: Determine completion times of overhauled engines using PERT, fuzzy PERT, and fuzzy CPM

Although PERT uses fuzzy activity times, it defuzzifies the fuzzy activity times into a constant called a mean value. It also calculates a variance of activity time. Then based on the mean of activity time, the critical path is determined. Finally, the mean and standard deviation (SD) of the project duration are determined (see Agyei, 2015). PERT does not provide the project duration as fuzzy numbers. This research proposes to estimate the project duration as fuzzy numbers using a simple statistical theory. Equation (2.12) is used to determine the SD of project duration. Then, the optimistic, most likely, and pessimistic project durations are estimated by Equations (2.13 to 2.15). The fuzzy project duration determined from results of PERT method has a disadvantage that the fuzzy project duration is always symmetrical.

Here is the steps of PERT diagram and fuzzy PERT/CPM diagram, as shown below:

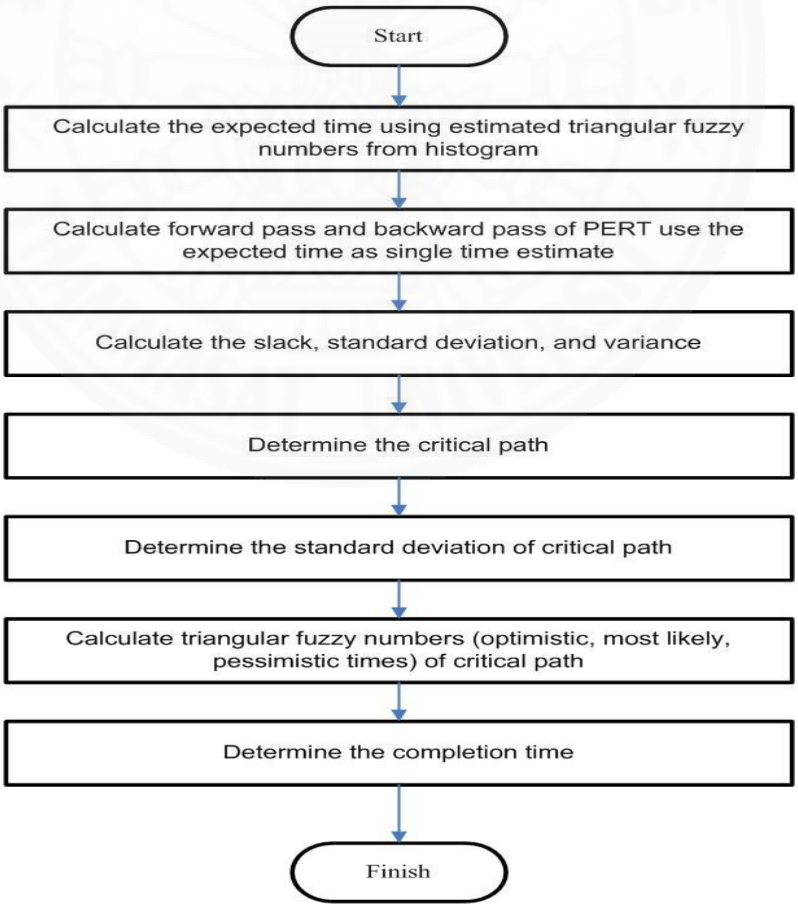

Figure 3.2 The Steps of PERT Diagram.

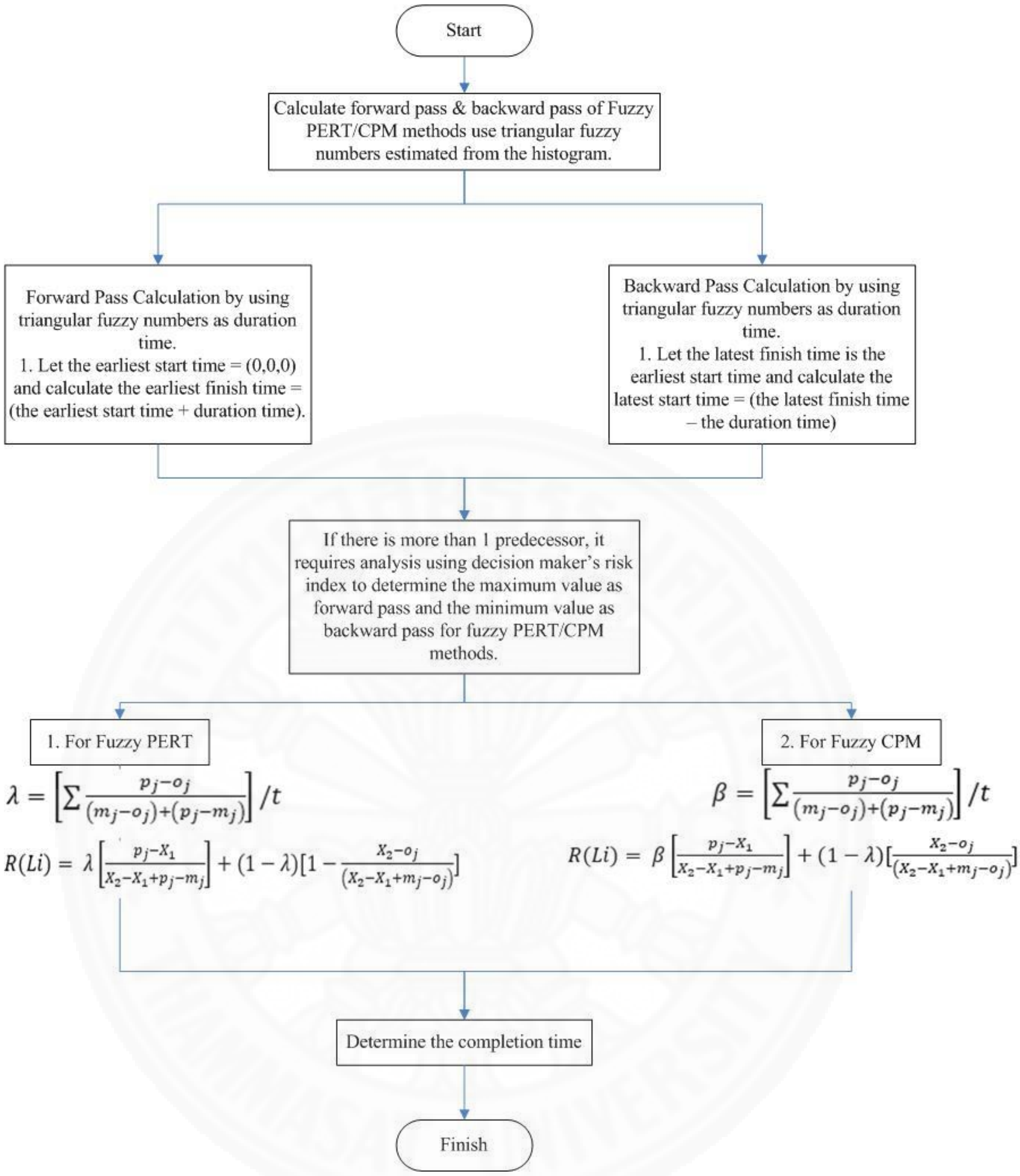

Figure 3.3 The Steps of Fuzzy PERT & Fuzzy CPM Diagrams.

3.2.5 Step 5: Determine the most accurate scheduling method

The results of planned completion times (fuzzy numbers) are compared with the actual completion times in the scatter plot. If the actual completion time is falling among the planned fuzzy completion times (not higher than the pessimistic completion time and not less than the optimistic completion time), the method has accurate prediction of completion time.

3.2.6 Step 6: Calculate the possibility of late completion based on the schedule of the most accurate scheduling method

The most accurate scheduling method is used to generate a schedule for maintenance activities of 30 overhauled engines. The start time of engine overhaul is the arrival time of the engine at MRO company. The planned fuzzy completion times of each engine is compared with the due date to calculate the possibility of late completion. The due date is the date promised by the MRO company to the customer, which is normally including some provisions for delays.

The possibility of late completion (PLC) is calculated based on 2 conditions. Figure 3.4 shows condition 1 that the due date is between the most likely and pessimistic completion times. Figure 3.5 shows condition 2 that the due date is between optimistic and most likely completion times. The *PLC* is the ratio of area 1 per total area of the triangle of fuzzy numbers. The *PLC* under conditions 1 and 2 is calculated by Equation (3.1) and Equation (3.2), respectively.

$$PLC = \frac{(C^p - D)^2}{(C^p - C^o)(C^p - C^m)} \quad \text{for condition 1} \tag{3.1}$$

$$PLC = 1 - \frac{(D - C^o)^2}{(C^m - C^o)(C^p - C^o)} \quad \text{for condition 2} \tag{3.2}$$

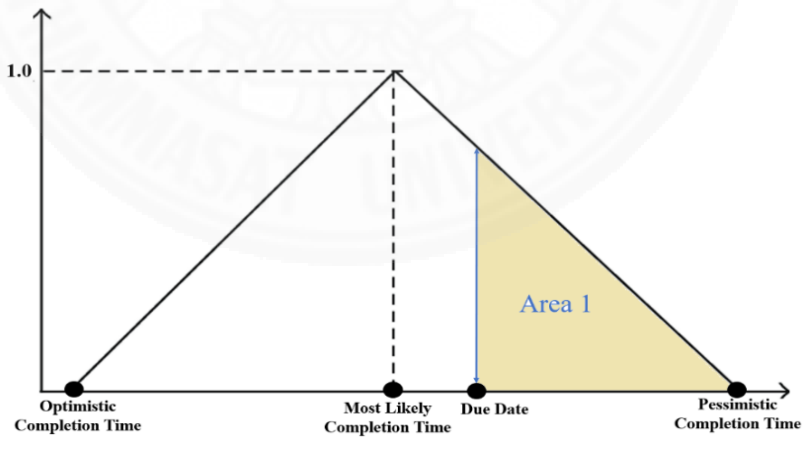

Figure 3.4 Condition 1.

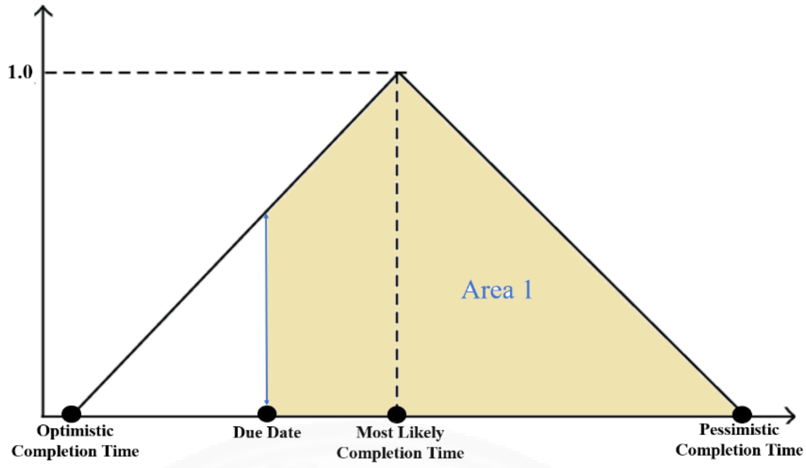

Figure 3.5 Condition 2.

If the possibility of late completion time is relatively low (less than 20%), it is acceptable. Otherwise, improvements are needed to reduce the *PLC*. The *PLC* of each engine overhauled job is presented in Table 5.6 of Chapter 5, results and discussion.

3.2.7 Step 7: Find out corrective actions

If the possibility of late completion is relatively high for many overhauled jobs, it needs to improve some non-critical activities and extend further. If one critical activity like activity G is reduce so activities H and I become critical activities, so that's why it needs to reduce all together. The critical activities with relatively long fuzzy times are candidates for improvement. Note that the critical activities are identified by fuzzy PERT and fuzzy CPM methods. Reasons for long fuzzy times should be explored and corrective actions should be identified. Management team should estimate after the proposed corrective actions are implemented what are shorter fuzzy times of the improved activities. Based on the shorter fuzzy times, the new schedule of overhauled jobs is regenerated and the new fuzzy completion times are estimated. If the possibility of late completion after implementing the corrective actions is not acceptable, more effective corrective actions should be identified.

3.2.8 Step 8: Determine the required resource using FRR method

If the possibility of late completion is acceptable, it is necessary to check the resource capacity problem using the newly developed Fuzzy Resource Requirement

(FRR) method because it is suspected that another reason for late completion is caused by the resource capacity problem.

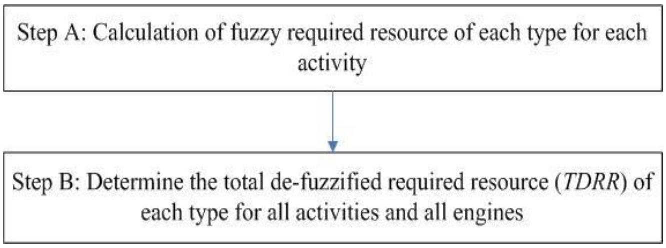

Figure 3.6 Block Diagram of FRR Method.

Figure 3.6 shows a block diagram of the FRR method. Step A is to calculate the fuzzy required resource of each type for each activity. Step B is to determine the total de-fuzzified required resource (*TDRR*) of each type needed by all activities of all engines. Because of the large number of activities on each engine, it requires a software, namely visual basic for application (VBA) software to calculate the fuzzy required resource. The steps in the VBA process is presented in Figure 3.7.

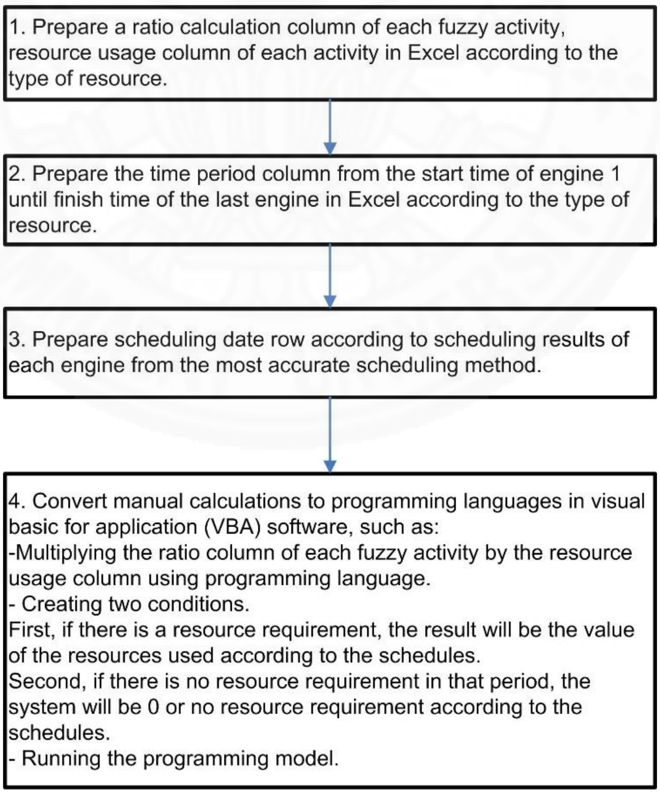

Figure 3.7 VBA Process Diagram.

If the *TDRR* is greater than the available resource, it has a capacity problem and it needs to delay some activities or find out more capacity. Otherwise, there is no resource capacity problem.

3.2.9 Conclusions and recommendations

This step contains conclusions from the results of research on analysis and improvement of late completion of aircraft engine maintenance with limited resources and conclusions based on the results of data collection and processing that have been carried out and supported by the theoretical basis used to support this research. In addition, it contains suggestions that are used to add new inputs that have not been discussed so that they are more detailed and useful for further research.

3.3 Expected result

The expected result of this research is to reduce the late completion time and reduce the capacity problem in aircraft engine maintenance scheduling by considering the limited resource and using the estimated fuzzy time which is predicted to be the same as the real situation. This is very useful so that the aircraft engine maintenance can be completed on time.

CHAPTER 4
DATA COLLECTION

4.1 Data collection

All models are implemented using visual basic for application and Microsoft Excel on Intel Core i7-8th Gen processor. The main data needed are the due date data and the actual time (TAT) data from overhaul engine maintenance. This study consisted of 30 overhaul engine data samples. In addition to the due date data and the actual TAT data, other data are also needed such as the resource usage and the availability resource. Each aircraft engine that carries out maintenance must go through 16 maintenance activities and each activity has a precedence relationship. Aircraft engine maintenance activities are presented in Table 4.1.

Table 4.1 Aircraft Engine Maintenance Activities.

Activity	Activity Names	Precedent Activities
A	Incoming inspection (check data of historical maintenance record and borescope to inspect internal parts of engine)	-
B	Forecasting and scheduling	A
C	Disassembling into 3 parts such as major module, module, submodule parts	B
D	Cleaning parts section (chemical cleaning and mechanical cleaning)	C
F	Inspecting the engine for crack, scrap, rubs, scratch, dent, nick (non-destructive test, bench inspection, bearing inspection, wiring inspection)	D
E	Shipping to and receiving of fast track parts from vendors	F
F1	Waiting for approval from the customer if there are findings beyond the complaint from the customer	F
G	Repairing the engines with various types of repairs such as shot-peening, electroplating, anodizing, miscellaneous, and thermal spray	F1
H	Planning the material procurement such as parts that must order either from outsource repair or buying new parts, and all late parts are purchased, loaned, or swapped	F1
I	Waiting for new parts or serviceable parts that have been ordered either from outsource repair or new vendors	H
J	Collecting the parts from in-house repair, outsource repair, new part’s vendor then checking whether parts purchased are appropriate or not, and preparing parts to group into kits for assembly	E, G, I
K	Combining the submodule from 17 submodules to 3 major modules (subassembly)	J
L	Assembling the module into a complete engine (final assembly)	K
M	Testing the cell or engine	L
N	Outgoing and controlling the engine quality	M
O	Certifying process or serviceable	N

Aircraft engine maintenance activity diagram are presented in Figure 4.1.

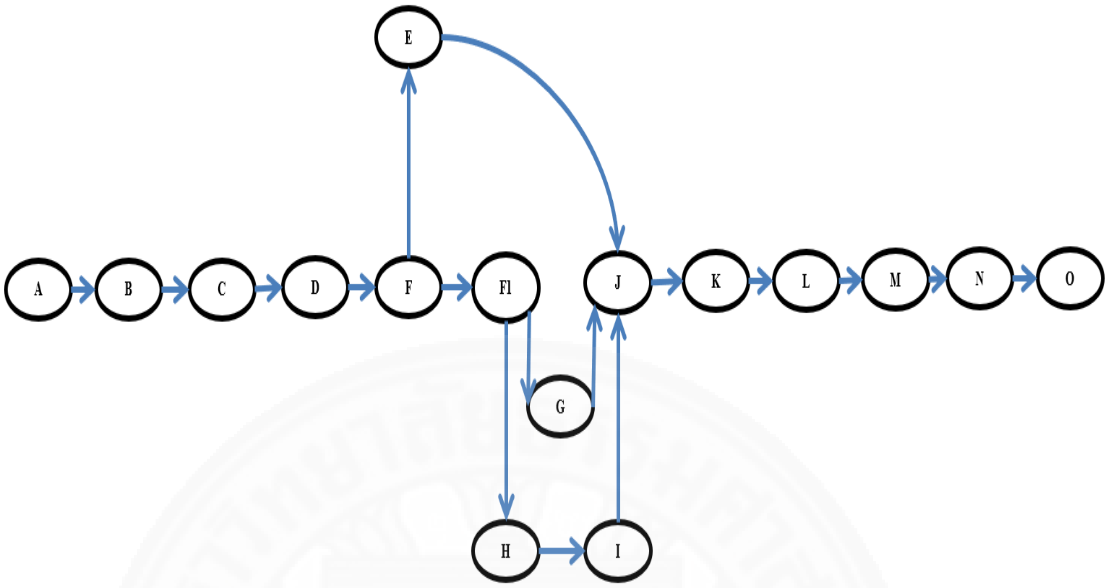

Figure 4.1 Aircraft Engine Maintenance Activity Diagram.

4.1.1 Resources data

Resource is the supporting system to the maintenance process. In this case, there are 2 types of critical resource, such as manpower and tool. Tool is a device that can be used to produce an item or achieve a task. Tool consists of special tools, standard tools and locally manufactured tools. Special tools are tooling specially designed by manufacture and identified by designated tool number and description. Standard tools are tooling not available through normal channels of trade, but procurable from a specific tool manufacturer. There is no special identification and defined by name only. Locally manufactured tools are simple tooling designed by manufacture, locally manufactured by the operator and describe by nomenclature and illustration. In this case by considering special tools. The special tools are presented in Figure 4.2.

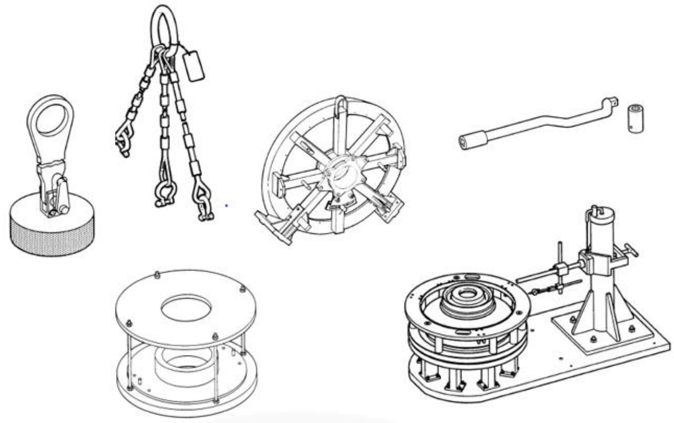

Figure 4.2 Special Tools.

There are two types of manpower resource and three types of tool resource. All activities need manpower resources, but some activities need tool resources. The resources data include resource usage and available resource of each type are presented in Table 4.2.

Table 4.2 The Resources Data.

<table>
<tr><th>Activity</th><th>Manpower Type</th><th>Resource Usage of Manpower</th><th>Available Resource of Manpower</th><th>Activity</th><th>Tools Type</th><th>Resource Usage of Tools</th><th>Available Resource of Tools</th></tr>
<tr><td rowspan="2">F</td><td rowspan="2">Type 1 of Manpower</td><td rowspan="2">6</td><td rowspan="2">30</td><td>C</td><td rowspan="3">Type 1 of Tool</td><td>30</td><td rowspan="3">180</td></tr>
<tr><td>K</td><td>30</td></tr>
<tr><td>C</td><td rowspan="13">Type 2 of Manpower</td><td>6</td><td rowspan="13">180</td><td>L</td><td>30</td></tr>
<tr><td>D</td><td>2</td><td>D</td><td rowspan="4">Type 2 of Tool</td><td>15</td><td rowspan="4">150</td></tr>
<tr><td>E</td><td>2</td><td>E</td><td>5</td></tr>
<tr><td>F1</td><td>2</td><td>J</td><td>15</td></tr>
<tr><td>G</td><td>6</td><td>M</td><td>10</td></tr>
<tr><td>H</td><td>8</td><td>F</td><td rowspan="2">Type 3 of Tool</td><td>50</td><td rowspan="2">350</td></tr>
<tr><td>I</td><td>15</td><td>G</td><td>30</td></tr>
<tr><td>J</td><td>16</td><td colspan="4" rowspan="6"></td></tr>
<tr><td>K</td><td>6</td></tr>
<tr><td>L</td><td>4</td></tr>
<tr><td>M</td><td>3</td></tr>
<tr><td>N</td><td>2</td></tr>
<tr><td>O</td><td>2</td></tr>
</table>

Activities A and B do not require any resource because they involve a meeting between the company and the customer in checking the history of the engine and planning the maintenance time to be agreed by both parties.

CHAPTER 5
RESULT AND DISCUSSION

5.1 Case study

This case study occurs in a maintenance, repair and overhaul (MRO) company in Indonesia, especially in engine shop department. The problem of company is the late completion problem of aircraft engine maintenance jobs and the activity times of engine maintenance are uncertain, it cannot be easily estimated as constants and it does not consider resources in the maintenance scheduling.

5.2 Result of case study

Objective 1 of this research is to estimate triangular fuzzy numbers that represent uncertain durations of activities based on real historical data from the histogram by performing Steps 1, 2, and 3 of Chapter 3, methodology. Based on the result of Step 1, the difference is quite high so it needs to reduce the high variability by grouping at Step 2 then time can be controlled properly, otherwise the project will be delay. Based on the result of Step 2, the grouping results are presented in Table 5.1. After grouping, then estimating the triangular fuzzy numbers from histogram of actual activity times at Step 3. The estimated fuzzy activity time is presented in Table 5.1 but for example of grouping on the histogram especially for groups 1 and 2 of activity C are presented in Figure 5.1 and Figure 5.2.

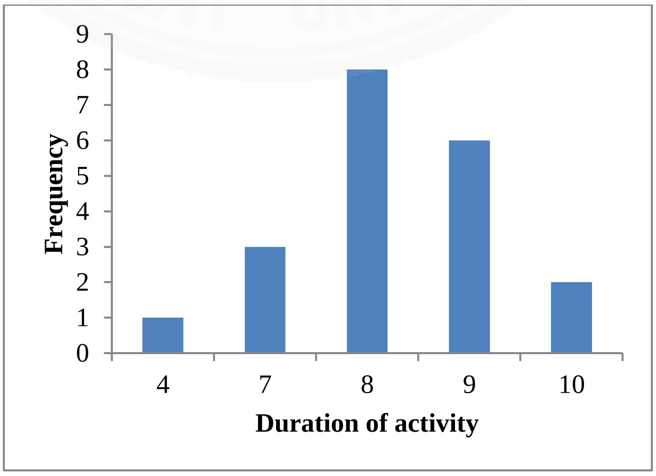

Figure 5.1 The Histogram of Group 1 of Activity C.

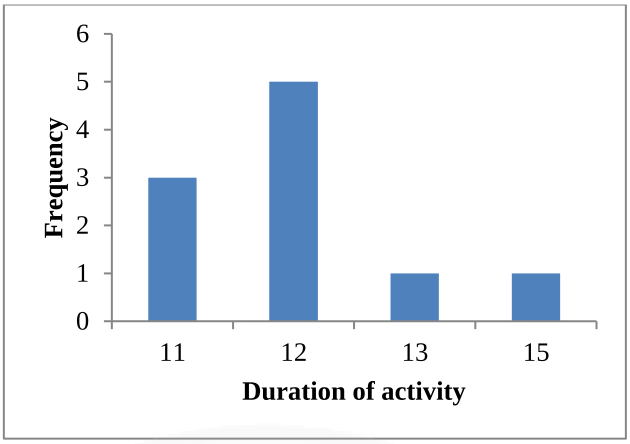

Figure 5.2 The Histogram of Group 2 of Activity C.

Table 5.1 The Fuzzy Activity Time for All Engines from The Grouping Results.

Activity	Group	Engine Number	Optimistic Time	Most Likely Time	Pessimistic Time
C	1	9,10,12,14,15,16,17,18,19,20,21,22,23,24, 25,26,27,28,29,30.	4	8	10
	2	1,2,3,4,5,6,7,8,11,13.	11	12	15
D	1	1,2,3,4,5,7,9,10,11,12,13,14,15,16,17,18,19,20, 21,22,23,24, 25,26,27,28,29,30.	0.5	1.3	1.5
	2	6,8.	1.5	1.8	2
E	1	1,2,3,4,5,7,9,10,11,12,13,14,15,16,17,18,19,20, 21,22,23,24, 25,26,27,28,29,30.	0.5	1.3	1.5
	2	6,8.	1.5	1.8	2
F	1	All Engines	3	4	5
F1	1	All Engines	3	4.5	12
G	1	9,10,12,16,19,29.	10	90	90
	2	14,15,17,18,20,21,22,23,24,25,26,27,28,30.	11	20	75
	3	1,2,3,4,5,6,7,8,11,13.	47	60	182
H	1	14,15,17,18,20,21,22,23,24,25,26,27,28,29,30.	3	6	26
	2	1,2,3,4,5,6,7,8,9,10,11,12,13,16,19.	8	25	45
I	1	9,10,12,14,15,16,17,18,19,20,21,22,23,24,25, 26,27,28,29,30.	1	2	25
	2	1,2,3,4,5,6,7,8,11,13.	4	10	40
J	1	9,10,12,14,15,16,17,18,19,20,21,22,23,24,25, 26,27,28,30.	7	10	45
	2	1,2,3,4,5,6,7,8,11,13,29.	7	30	100
K	1	9,10,12,16,19,29.	5	15	15
	2	14,15,17,18,20,21,22,23,24,25,26,27,28,30.	10	11	18
	3	1,2,3,4,5,6,7,8,11,13.	9	11	12
L	1	9,10,12,14,15,16,17,18,19,20,21,22,23,24,25, 26,27,28,29,30.	4	6	11
	2	1,2,3,4,5,6,7,8,11,13.	9	11	12
M	1	9,10,12,14,15,16,17,18,19,20,21,22,23,24,25, 26,27,28,29,30.	3	5	9
	2	1,2,3,4,5,6,7,8,11,13.	6	7.5	10
N	1	All Engines	0.5	2	3
O	1	All Engines	0.5	2	3

Based on Figure 5.1 and Figure 5.2, the optimistic activity time is estimated by a minimum time needed to complete the activity, the most likely time is the time that has the highest frequency, and the pessimistic time is the maximum time needed to complete the activity (Pathak, 2014). Thus, fuzzy times of activity C is 4, 8, and 10 for group 1 and 11, 12, and 15 for group 2. Based on Table 5.1, note that activities A and B involve a meeting process between the company and the customer to check historical data of the engine and planning the maintenance time to be agreed by both parties. They have negligible durations, so these two activities are not included. Thus, Objective 1 is achieved.

Objective 2 is to determine the most accurate scheduling method in predicting the completion time by performing Steps 4 and 5. The fuzzy completion times from PERT method are compared with the actual completion time as shown in Figure 5.3. The fuzzy PERT and fuzzy CPM methods use different formulas to calculate the decision maker's risk index. Both formulas can be seen in the article by (Samman & Brahemi, 2014) and (Rusu, 2018). However, both methods result in the same schedule of activities and completion time of overhauled jobs. The completion times from fuzzy PERT/CPM methods are compared with the actual completion time as shown in Figure 5.4. Here is the numerical example of PERT, fuzzy PERT/CPM calculation for Engine 1.

5.2.1 Numerical example of PERT calculation

This example is used to demonstrate how to calculate the completion time of engine 1 with PERT method. First, calculate the expected time using estimated triangular fuzzy numbers from histogram. The expected calculation is presented in Table 5.2. Second, calculate forward pass and backward pass using the expected time. Third, calculate the slack, standard deviation and variance. The result of Steps 2 and 3 are presented in Table 5.3.

Table 5.2 Expected Time Calculation.

Activity	Precedence	Optimistic Time	Most Likely Time	Pessimistic Time	Expected Time
A	-	0	0	0	0.00
B	A	0	0	0	0.00
C	B	11	12	15	12.33
D	C	0.5	1.25	1.5	1.17
F	D	3	4	5	4.00
E	F	0.5	1.25	1.5	1.17
F1	F	3	4.5	12	5.50
G	F1	47	60	182	78.17
H	F1	8	25.33	45	25.72
I	H	4	10	40	14.00
J	E, G, I	7	30	100	37.83
K	J	12	26	29	24.17
L	K	9	11	12	10.83
M	L	6	7.5	10	7.67
N	M	0.5	2	3	1.92
O	N	0.5	2	3	1.92

Table 5.3 PERT Result of Engine 1.

Activity	Early Start	Early Finish	Late Start	Late Finish	Slack	Standard Deviation	Variance
A	0	0	0	0	0	0	0
B	0	0	0	0	0	0	0
C	0	12.33	0	12.33	0	0.67	0.44
D	12.33	13.5	12.33	13.5	0	0.17	0.03
F	13.5	17.5	13.5	17.5	0	0.33	0.11
E	17.5	18.67	100	101.17	82.5	0.17	0.03
F1	17.5	23	17.5	23	0	1.5	2.25
G	23	101.17	23	101.17	0	22.5	506.25
H	23	48.72	61.45	87.17	38.45	6.17	38.03
I	48.72	62.72	87.17	101.17	38.45	6	36
J	101.17	139	101.17	139	0	15.5	240.25
K	139	163.17	139	163.17	0	2.83	8.03
L	163.17	174	163.17	174	0	0.5	0.25
M	174	181.67	174	181.67	0	0.67	0.44
N	181.67	183.58	181.67	183.58	0	0.42	0.17
O	183.58	185.5	183.58	185.5	0	0.42	0.17
	Project	**185.50**					

Based on the result, the slack value comes from the late start time ($LS_{(j)}$) minus the early start time ($ES_{(j)}$). Fourth, from the slack value, it can determine the critical path. The activities on the critical path such as activities A, B, C, D, F, F1, G, J, K, L, M, N, O, because critical path is the activity which has a slack value of 0.

Fifth, determine the standard deviation of critical path use Equation (2.12) of Chapter 2, review of literature. Sixth, calculate the triangular fuzzy numbers of critical path to get the completion time use Equations (2.13 to 2.15).

Table 5.4 The Completion Time of Engine 1.

Critical Path	Activity Time	Variance
A	0	0
B	0	0
C	12.33	0.44
D	1.17	0.03
F	4	0.11
F1	5.5	2.25
G	78.17	506.25
J	37.83	240.25
K	24.17	8.03
L	10.83	0.25
M	7.67	0.44
N	1.92	0.17
O	1.92	0.17
μ	185.51	758.39
Standard Deviation (σ)		27.54
Optimistic Time		Pessimistic Time
$\mu - 3\sigma$		$\mu + 3\sigma$
102.89		268.13

Therefore, the optimistic completion time of engine 1 is 102.89, the most likely completion time of engine 1 is 185.51 and the pessimistic completion time of engine 1 is 268.13.

5.2.2 Numerical example of fuzzy PERT/CPM calculations

This example is used to demonstrate how to calculate the completion time of engine 1 with fuzzy PERT and fuzzy CPM methods. First, calculate forward pass and backward pass using triangular fuzzy numbers from the histogram to get the completion time.

Table 5.5 Fuzzy PERT/CPM Calculations of Engine 1.

Activity	Duration			Precedence	Fuzzy Early Start			Fuzzy Early Finish		
	Optimistic Time	Most Likely Time	Pessimistic Time		O	M	P	O	M	P
A	0	0	0	-	0	0	0	0	0	0
B	0	0	0	A	0	0	0	0	0	0
C	11	12	15	B	0	0	0	11.00	12.00	15.00
D	0.5	1.25	1.5	C	11.00	12.00	15.00	11.50	13.25	16.50
F	3	4	5	D	11.50	13.25	16.50	14.50	17.25	21.50
E	0.5	1.25	1.5	F	11.00	12.00	15.00	11.50	13.25	16.50
F1	3	4.5	12	F	14.50	17.25	21.50	17.50	21.75	33.50
G	47	60	182	F1	17.50	21.75	33.50	64.50	81.75	215.50
H	8	25.33	45	F1	17.50	21.75	33.50	25.50	47.08	78.50
I	4	10	40	H	25.50	47.08	78.50	29.50	57.08	118.50
J	7	30	100	E, G, I	64.50	81.75	215.50	71.50	111.75	315.50
K	12	26	29	J	71.50	111.75	315.50	83.50	137.75	344.50
L	9	11	12	K	83.50	137.75	344.50	92.50	148.75	356.50
M	6	7.5	10	L	92.50	148.75	356.50	98.50	156.25	366.50
N	0.5	2	3	M	98.50	156.25	366.50	99.00	158.25	369.50
O	0.5	2	3	N	99.00	158.25	369.50	99.50	160.25	372.50

For activity J has more than 1 predecessor, it requires a decision maker's risk index (λ) analysis with fuzzy PERT is given as:

$$[0+0+\frac{15-11}{(12-11)+(15-12)}+\frac{1.5-0.5}{(1.25-0.5)+(1.5-1.25)}+\frac{1.5-05}{(1.25-0.5)+(1.5-1.25)}+\frac{5-3}{(4-3)+(5-4)}+\frac{12-3}{(4.5-3)+(12-4.5)}+\frac{182-47}{(60-47)+(182-60)}+\frac{45-8}{(25.33-8)+(45-25.33)}+\frac{40-4}{(10-4)+(40-10)}+\frac{100-7}{(30-7)+(100-30)}+\frac{29-12}{(26-12)+(29-26)}+\frac{12-9}{(11-9)+(12-11)}+\frac{10-6}{(7.5-6)+(10-7.5)}+\frac{3-0.5}{(2-0.5)+(3-2)}+\frac{3-0.5}{(2-0.5)+(3-2)}]/16$$

$$\boldsymbol{\lambda = 0.875} \tag{5.1}$$

For J activity has 3 precedence activities using Equation (5.2).

$$TE_{(j)} = Max\{TE_{(e)}\ , TE_{(g)}\ , TE_{(i)}\} \tag{5.2}$$

$$TE_{(j)} = Max\{(11.50, 13.25, 16.50) + (7,30,100); (64.50, 81.75, 215.50) + (7,30,100)\ ; (29.50, 57.08, 118.50) + (7,30,100)\}$$

$$TE_{(j)} = Max\ \{(\mathbf{18.50}, 43.25, 116.5)\ ; (71.5,111.75, \mathbf{315.5})\ ; (36.5,87.08,218.5)\}$$

After knowing the decision maker's risk index value then determine the greatest value of precedence activities use the ranking value are given as:
X_1 = 18.50 and X_2 = 315.50.

$$R\left(L_{E-J}\right) = 0.875 \times \left[\frac{116.5-18.5}{(315.5-18.5)+(116.5-43.25)}\right] + (1-0.875) \times \left[1 - \frac{315.5-18.5}{(315.5-18.5)+(43.25-18.5)}\right] = 0.237 \tag{5.3}$$

$$R\left(L_{G-J}\right) = 0.875 \times \left[\frac{315.5-18.5}{(315.5-18.5)+(315.5-111.75)}\right] + (1-0.875) \times \left[1 - \frac{315.5-71.5}{(315.5-18.5)+(111.75-71.5)}\right] = 0.553 \tag{5.4}$$

$$R\left(L_{I-J}\right) = 0.875 \times \left[\frac{218.5-18.5}{(315.5-18.5)+(218.5-87.08)}\right] + (1-0.875) \times \left[1 - \frac{315.5-36.5}{(315.5-18.5)+(87.08-36.5)}\right] = 0.432 \tag{5.5}$$

Based on the results of ranking value, the maximum value on activity G with fuzzy PERT method. Therefore, $TE_J = TE_G$ or (71.5, 111.75, 315.5).

Whereas, for activity J has more than 1 predecessor, it requires a decision maker's risk index (β) analysis with fuzzy CPM is given as:

$$[0+0+\frac{15-11}{(12-11)+(15-12)}+\frac{1.5-0.5}{(1.25-0.5)+(1.5-1.25)}+\frac{1.5-05}{(1.25-0.5)+(1.5-1.25)}+\frac{5-3}{(4-3)+(5-4)}+\frac{12-3}{(4.5-3)+(12-4.5)}+\frac{182-47}{(60-47)+(182-60)}+\frac{45-8}{(25.33-8)+(45-25.33)}+\frac{40-4}{(10-4)+(40-10)}+\frac{100-7}{(30-7)+(100-30)}+\frac{29-12}{(26-12)+(29-26)}+\frac{12-9}{(11-9)+(12-11)}+\frac{10-6}{(7.5-6)+(10-7.5)}+\frac{3-0.5}{(2-0.5)+(3-2)}+\frac{3-0.5}{(2-0.5)+(3-2)}]/16$$

$$\boldsymbol{\lambda} = \mathbf{0.875} \tag{5.6}$$

For J activity has 3 precedence activities using Equation (5.7).

$$TE_{(j)} = Max\{TE_{(e)}, TE_{(g)}, TE_{(i)}\} \tag{5.7}$$

$$TE_{(j)} = Max\{(11.50, 13.25, 16.50) + (7,30,100); (64.50, 81.75, 215.50) + (7,30,100); (29.50, 57.08, 118.50) + (7,30,100)\}$$

$$TE_{(j)} = Max\ \{(\mathbf{18.50}, 43.25, 116.5); (71.5, 111.75, \mathbf{315.5}); (36.5, 87.08, 218.5)\}$$

After knowing the decision maker's risk index value then determine the greatest value of precedence activities use the ranking value are given as:

X_1 = 18.50 and X_2 = 315.50.

$$R(L_{E-J}) = 0.875 \times \left[\frac{116.5-18.5}{(315.5-18.5)+(116.5-43.25)}\right] + (1-0.875) \times \left[\frac{315.5-18.5}{(315.5-18.5)+(43.25-18.5)}\right] = 0.342 \quad (5.8)$$

$$R(L_{G-J}) = 0.875 \times \left[\frac{315.5-18.5}{(315.5-18.5)+(315.5-111.75)}\right] + (1-0.875) \times \left[\frac{315.5-71.5}{(315.5-18.5)+(111.75-71.5)}\right] = 0.609 \quad (5.9)$$

$$R(L_{I-J}) = 0.875 \times \left[\frac{218.5-18.5}{(315.5-18.5)+(218.5-87.08)}\right] + (1-0.875) \times \left[\frac{315.5-36.5}{(315.5-18.5)+(87.08-36.5)}\right] = 0.508 \quad (5.10)$$

Based on the results of ranking value, the maximum value on activity G with fuzzy CPM method. Therefore, $TE_J = TE_G$ or (71.5, 111.75, 315.5).

Fuzzy PERT and fuzzy CPM methods directly use fuzzy activity times. Details of the fuzzy PERT steps can be seen in the article by (Samman & Brahemi, 2014), while those of the fuzzy CPM steps can be seen in the article by (Rusu, 2018). The project durations obtained from fuzzy PERT and fuzzy CPM are fuzzy numbers, and they are non-symmetrical (distance from pessimistic to most likely may be different from the distance from most likely to optimistic values). Based on the numerical example at Step 4, it applies to all engines. The fuzzy completion times from PERT, fuzzy PERT/CPM methods for all engines are compared with the actual time as shown in Figure 5.3 and Figure 5.4.

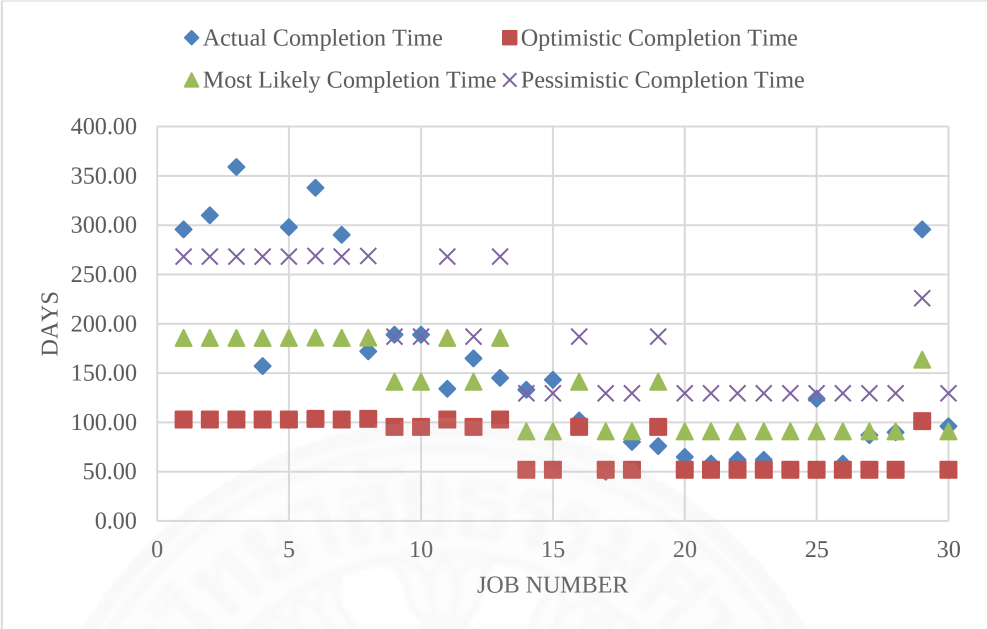

Figure 5.3 Planned Fuzzy Completion Times of Overhauled Jobs of PERT Method.

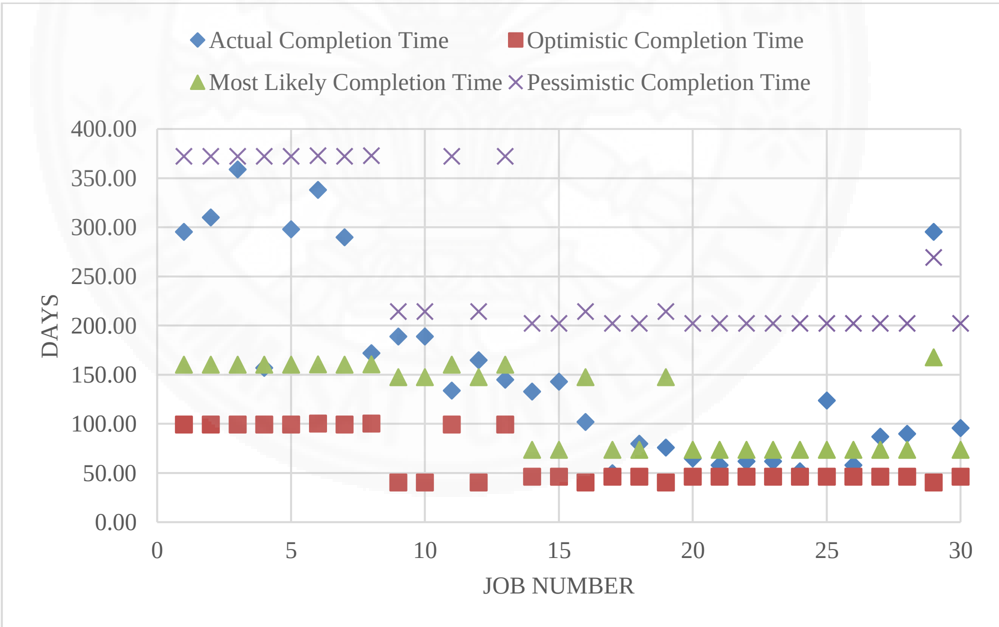

Figure 5.4 Planned Fuzzy Completion Times of Overhauled Jobs of fuzzy PERT /CPM Methods.

Based on Figure 5.3 and Figure 5.4, the most accurate method is fuzzy PERT/CPM methods because the actual completion times of 29 out of 30 jobs (except job number 29) are falling among the planned fuzzy completion times (not higher than the pessimistic completion time and not less than the optimistic completion time). Thus, the objective 2 is achieved. Then, the possibility of late completion (*PLC*) obtained from the most accurate scheduling method (fuzzy PERT/CPM methods) by performing Step 6 and considering the arrival date of each engine is presented in Table 5.6 (see before improvement column). Based on the current performance in the company is unacceptable because the company can't manage it well, so it needs the improvement by 2 scenarios.

Table 5.6 Possibility of Late Completion of Each Engine.

Engine Number	Possibility of Late Completion (PLC)		
	Before Improvement	After Improvement	
		Scenario 1	Scenario 2
1	76.83%	43.05%	0%
2	76.83%	43.05%	
3	63.62%	16.14%	
4	81.76%	55.14%	
5	63.62%	16.14%	
6	63.07%	15.15%	
7	63.62%	16.14%	
8	76.25%	41.49%	
9	33.10%	26.85%	
10	33.10%	26.85%	
11	95.27%	88.37%	
12	33.10%	26.85%	
13	90.83%	77.44%	
14	25.81%	13.34%	
15	17.33%	6.08%	
16	80.06%	75.57%	
17	99.41%	90.72%	
18	79.04%	73.65%	
19	92.26%	77.26%	
20	93.20%	79.99%	
21	97.15%	89.91%	
22	93.20%	75.90%	
23	93.20%	75.90%	
24	99.15%	89.47%	
25	40.33%	28.04%	
26	96.02%	86.52%	
27	70.51%	41.77%	
28	70.51%	41.77%	
29	99.78%	89.96%	
30	70.51%	43.15%	
Average	72.28%	52.39%	0%

Based on Table 5.6, the existing on-time performance (OTP) of the MRO company is not satisfactory since it has relatively high *PLC* (before improvement), so it needs to improve some activities to reduce some non-critical activities and extend further. If one critical activity like activity G is reduce so activities H and I become critical activities, so that's why it needs to reduce all together. There are two scenarios of the proposed corrective actions as shown in Table 5.7. From Table 5.7, Scenario 1 is to improve operations of 4 activities (Activities G, H, I, and J). It is estimated that the corrective actions of Scenario 1 can significantly reduce the pessimistic activity times of 4 activities. The reduction of pessimistic activity times results in the lower *PLC* as shown in Table 5.6. However, the *PLC* of Scenario 1 is still too high to be accepted. The MRO company needs further improvements. Therefore, Scenario 2 is proposed. Scenario 2 is to improve operations of 5 activities (Activities G, H, I, J, and K). Unlike Scenario 1 that only pessimistic activity times are reduced, Scenario 2 can reduce both most likely and pessimistic activity times of 5 activities. Note that the fuzzy times after improvement presented in Table 5.7 are examples for some engines because the magnitude of improvements are different among engines. The comparison between due date and fuzzy completion times of all engine overhauled jobs presented in Figure 5.5 reveals that the pessimistic completion time is earlier than the due date for all engine overhauled jobs. Therefore, the *PLC* of Scenario 2 is zero for all engines. Therefore, objective 3, to suggest corrective actions that can significantly reduce the *PLC*, is achieved.

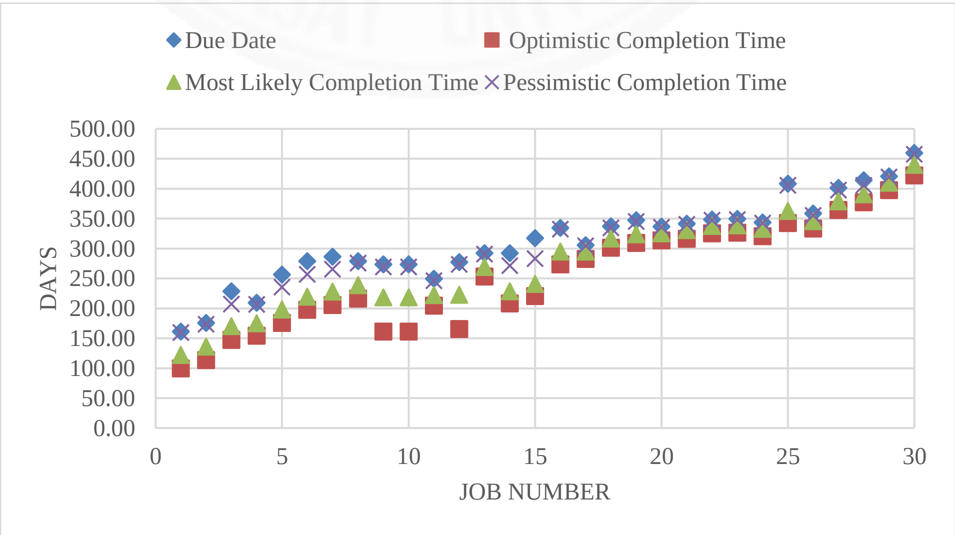

Figure 5.5 The Comparison of Due Date with Fuzzy Completion Times (Scenario 2).

Table 5.7 Proposed Corrective Actions to Reduce the *PLC*.

Activity	Fuzzy Time Before Improvement			Fuzzy Time After Improvement						Cause of Long Activity Time	Proposed Improvement Action		Why Is It Possible?	Why Did Not Do This in The Past?
				Scenario 1			Scenario 2				Scenario 1	Scenario 2		
	O	M	P	O	M	P	O	M	P					
G	47	60	182	47	60	75*	47	50*	60*	The repair time and waiting time for shipment process confirmation from vendors are too long.	Set the deadline for vendors and provide scheduling tool to plan repair activities	Set the deadline & penalty agreement for vendors and provide scheduling tool to plan the repair activities.	By set the deadline & provide scheduling tool for vendors, it will reduce the waiting time of repair process.	There is no accurate scheduling system & deadline for vendors in existing system.
H	8	25.33	45	8	25.33	30*	8	14*	20*	The manual procurement process is too long.	The procurement process is held by e-procurement to reduce the time both for the vendor selection or negotiation process.	The procurement process is held by e-procurement to reduce the time for the vendor selection and negotiation process and create a vendor database in the e-procurement system.	Other MRO companies use e-procurement successfully.	There was no e-procurement system in existing process.
I	4	10	40	4	10	25*	4	7*	14*	The delivery time from vendor is too long.	Set earlier due date of delivery to avoid the delay from the vendor.	Set earlier due date of delivery and set penalty conditions in a long-term agreement with vendors.	Long-term agreements can attract good vendors.	There is only short-term agreement with vendors now.
J	7	30	100	7	30	45*	7	14*	20*	Lack of resources such as manpower and tool.	Change the workflow to improve resource efficiency.	Analyze the resource requirement and implement the proposed FRR system.	The proposed FRR system is effective to foresee resource problems. It is possible to allocate resources to avoid delay due to insufficient resources.	There is no exiting system that can effectively calculate the required resource.
K	12	26	29	-	-	-	12	14*	18*		-			

5.2.3 Numerical example of fuzzy required resource (FRR) method

This example is used to demonstrate how to calculate the TDRR of type 1 tool from only activity C assuming that two engines are overhauled. First, the calculation of fuzzy required resource of type 1 tool for activity C is presented in Table 5.8.

Table 5.8 Fuzzy Required Resource of Type 1 Tool for Activity C.

Activity	Fuzzy Activity Time (days)			Target Activity Time (days)	Resource Usage (units)	Optimistic Required Resource (units)	Most Likely Required Resource (units)	Pessimistic Required Resource (units)
	Optimistic Time	Most Likely Time	Pessimistic Time					
C	11	12	15	10	30	$0.909 \times 30 = 27.27$	$0.833 \times 30 = 25$	$0.667 \times 30 = 20$

Based on Table 5.8, the resource is required for 30 units each day for 10 days (target activity time). When the real activity time in the most likely situation is 12 days (longer than the target time), it has idle time mixed with the operation time. This means that the same amount of required resource is distributed over longer time. Thus, the amount of the required resource per day is reduced proportionally (by a ratio of $\frac{10}{12}$ or 0.833). In calculating the fuzzy required resource for all activity and all jobs/engines using visual basic for application (VBA) software by changing the mathematical model into a programming language because of the large number of activities. Therefore, to assist the company in the calculation process, this software is required to implement the calculation.

Second, Table 5.9 shows how the *TDRR* of type 1 tool is calculated. Under most likely situation, activity C of engine 1 is started on November 30 and completed on December 11. Under pessimistic situation, activity C of engine 1 is completed on December 14. On December 14, activity C of engine 1 is still conducted under pessimistic situation and activity C of engine 2 is still conducted under all situations. The *TDRR* of type 1 tool is calculated using Equation (5.11).

$$TDRR_{it} = \sum_{j \in J, k \in K} (R^{p}_{ijkt} + 2\, R^{m}_{ijkt} + R^{o}_{ijkt})/4 \tag{5.11}$$

where $TDRR_{it}$ is total defuzzified required resource of resource type *i* in period t,

R^{p}_{ijkt} is pessimistic required resource of resource type *i* from activity *j* of job *k* in period t,
R^{m}_{ijkt} is most likely required resource of resource type *i* from activity *j* of job *k* in period t,
R^{o}_{ijkt} is optimistic required resource of resource type *i* from activity *j* of job *k* in period t,
J is set of all activities, and K is set of all jobs (engines).

Table 5.9 *TDRR* of Type 1 Tool from Activity C of 2 Jobs.

Time Period	Fuzzy Required Resource						*TDRR* of Type 1 Tool
30-Nov-18	27.27	25	20	-	-	-	24.32
01-Dec-18	27.27	25	20	-	-	-	24.32
02-Dec-18	27.27	25	20	-	-	-	24.32
03-Dec-18	27.27	25	20	-	-	-	24.32
04-Dec-18	27.27	25	20	-	-	-	24.32
05-Dec-18	27.27	25	20	-	-	-	24.32
06-Dec-18	27.27	25	20	-	-	-	24.32
07-Dec-18	27.27	25	20	-	-	-	24.32
08-Dec-18	27.27	25	20	-	-	-	24.32
09-Dec-18	27.27	25	20	-	-	-	24.32
10-Dec-18	27.27	25	20	-	-	-	24.32
11-Dec-18	-	25	20	-	-	-	17.50
12-Dec-18	-	-	20	-	-	-	5.00
13-Dec-18	-	-	20	-	-	-	5.00
14-Dec-18	-	-	20	27.27	25	20	29.32
15-Dec-18	-	-	-	27.27	25	20	24.32
16-Dec-18	-	-	-	27.27	25	20	24.32
17-Dec-18	-	-	-	27.27	25	20	24.32
18-Dec-18	-	-	-	27.27	25	20	24.32
19-Dec-18	-	-	-	27.27	25	20	24.32
20-Dec-18	-	-	-	27.27	25	20	24.32
21-Dec-18	-	-	-	27.27	25	20	24.32
22-Dec-18	-	-	-	27.27	25	20	24.32
23-Dec-18	-	-	-	27.27	25	20	24.32
24-Dec-18	-	-	-	27.27	25	20	24.32
25-Dec-18	-	-	-	-	25	20	17.50
26-Dec-18	-	-	-	-	-	20	5.00
27-Dec-18	-	-	-	-	-	20	5.00
28-Dec-18	-	-	-	-	-	20	5.00
Fuzzy Situations	Optimistic	Most likely	Pessimistic	Optimistic	Most likely	Pessimistic	
Activity	C			C			
Engine or jobs	1			2			

Defuzzification is used to get a crisp value from fuzzy numbers that represent uncertain data. In literature, there are mainly 2 methods for defuzzification, which are median method and centroid method based on beta distribution. It is proven that the median method can reduce the error rate of defuzzification when compared with the centroid method based on beta distribution (Chen, 2010; Kayalvizhi et al., 2016). Note that this research applies the median method as shown in Equation (5.11). Meanwhile, the use of beta distribution in triangular fuzzy numbers is required to meet the distribution requirements and first convert the membership function into a probability distribution and then compute the expected value (Leekwijck & Kerre, 1999; Rahmani et al., 2016). However, this research applies fuzzy PERT/CPM which use possibility in its application instead of probability. Therefore, Equation (5.11) is more suitable for use in this type of problem. Objective 4 of this research is to develop FRR method to check whether the available resources are sufficient to conduct the maintenance activities according to the schedule, which is Step 8 of the methodology. Table 5.10 shows the $TDRR_{it}$ of type 1 tool from March 31, 2019 to October 22, 2019, which is the most critical resource in the most critical periods. It reveals that there is no capacity problem for type 1 tool for all periods because the $TDRR_{it}$ are less than the available resource. Therefore, it does not need to delay some activities or find out more capacity. Note that other resource types are less critical than the type 1 tool, and there is no capacity problem too. However, if a resource type has insufficient capacity, some related activities may be delayed to reduce the amount of required resources, or more resources should be provided. Therefore, objective 4 is achieved.

Table 5.10 Total De-fuzzified Required Resource ($\mathrm{TDRR_{it}}$) of Type 1 Tool.

Time Period	*TDRR* of Type 1 Tool	Available Resource of Type 1 Tool	Is There Capacity Problem of Type 1 Tool?
31-Mar-19	107.81	180.00	No
01-Apr-19	132.13	180.00	No
02-Apr-19	132.13	180.00	No
03-Apr-19	122.58	180.00	No
04-Apr-19	124.83	180.00	No
05-Apr-19	124.83	180.00	No
06-Apr-19	128.53	180.00	No
07-Apr-19	118.11	180.00	No
21-Jun-19	126.00	180.00	No
22-Jun-19	135.38	180.00	No
24-Jun-19	129.39	180.00	No
12-Sep-19	148.88	180.00	No
13-Sep-19	139.88	180.00	No
25-Sep-19	150.54	180.00	No
26-Sep-19	137.42	180.00	No
16-Oct-19	153.88	180.00	No
17-Oct-19	160.89	180.00	No
22-Oct-19	137.88	180.00	No

CHAPTER 6
CONCLUSIONS AND FUTURE WORK

This research aims to improve the on-time performance (OTP) of engine overhaul jobs in an MRO company in Indonesia. It proposes a methodological step to collect data, construct fuzzy project scheduling methods, analyze possibility of late completion of engine overhauls, propose corrective actions for the late completion, and determine fuzzy resources needed by all overhauled jobs. Based on historical data of 30 engine overhauled jobs, the fuzzy activity times are estimated. By comparing the planned fuzzy completion times of 3 methods and the actual completion time, the method that accurately predicts the completion time is fuzzy PERT/CPM because the actual completion times of most jobs are falling among the planned fuzzy completion times. Then, the possibilities of late completion of 30 engine overhauled jobs are determined. Results show that the possibilities of late completion are relatively high, which is the same as the actual on-time performance of this MRO company. This research proposes two scenarios of corrective actions. Scenario 2 that is capable of significantly reducing most likely and pessimistic times of 5 critical activities are proposed to the MRO company since it can reduce the possibility of late completion of engine overhauled jobs to zero. Based on the resource requirement calculation using the FRR method, the *TDRR* is less than the available resources for all resource types. Thus, there is no resource capacity problem when the overhauled jobs are conducted according to the schedules generated by fuzzy PERT/CPM methods.

This research has theoretical and practical contributions. Theoretical contributions are as follows:

1. This research proposes a general methodological step to analyze and improve the on-time performance of engine overhauled jobs of an MRO company in Indonesia. The methodological step is also useful for other MRO companies that encounter late completion problems.
2. It demonstrates using a case study that when the fuzzy activity times are estimated from real activity times, the fuzzy CPM and fuzzy PERT methods can reasonably predict the fuzzy completion times of engine overhauled jobs since

the actual completion times are falling among the planned fuzzy completion times.

3. The Fuzzy Resource Requirement (FRR) method is newly developed to analyze the resource capacity problem. The FRR method reveals that the late completion problem of this MRO company is not caused by insufficient resources.

Practical contributions are as follows:

1. The planned fuzzy completion times obtained from fuzzy PERT/CPM methods are more practically useful than constant completion time obtained from a general project management software since the fuzzy completion times also provide the on-time performance under the best and worst cases.
2. The possibility of late completion calculated from the planned fuzzy completion times and the due date provides very useful information for MRO company. If the possibility is high for any overhauled job, the company should strictly control the job. Additionally, some corrective actions should be identified to significantly reduce fuzzy activity times of the critical activities.
3. This research demonstrates using a case study that some corrective actions can be identified to reduce relatively long fuzzy times for critical activities to ensure that the engine overhauled jobs are completed on-time. It motivates MRO companies to apply the methodology of this research to improve their on-time performances.

This research has a limited scope to consider only engine overhauled jobs and fuzzy project scheduling techniques. Thus, further research may extend to cover major and minor repair jobs as well. Simulation-based approaches may be used instead of the fuzzy project scheduling techniques. When the schedule of maintenance jobs is not feasible because the resource available is not sufficient, some activities should be delayed. A further study to determine what activities should be optimally delayed is needed.

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