

MAINTENANCE STRATEGY DEPLOYMENT OF HVAC SEMI HERMETIC COMPRESSOR USING ANALYTICAL HIERARCHY PROCESS AHP METHOD



BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (MAINTENANCE TECHNOLOGY) WITH HONOURS



Faculty of Mechanical and Manufacturing Engineering Technology



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Bachelor of Mechanical Engineering Technology (Maintenance Technology) with Honours

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DECLARATION

I declare that this Choose an item. entitled Maintenance Strategy Deployment of HVAC Semi Hermetic Compressor Using Analytical Hierarchy Process (AHP) Method is the result of my own research except as cited in the references. The Choose an item. has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.



APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Mechanical Engineering Technology (Maintenance Technology) with Honours.



DEDICATION

I am dedicating this thesis to my parents Zawiyah Binti Suleiman and Mazlan Bin Mohamad who give their full support through my ups and downs and also to my siblings Muhammad Shafiq Ashraf Bin Mazlan, NurFarah Hanis Binti Mazlan, Humaira Asyikin Binti Mazlan that always there helps builds my motivation up and cheer me up when i felt lost. Also, a big thanks to my project supervisor Ts. Dr. Ahmad Fuad Bin Ab. Ghani and Ir Mohd Azhar Bin Shah Rizam for the guidance throughout completing this thesis and to all other UteM lecturers. Without their dedication in teaching. I wouldn't reach until this far. Lastly, to my all good friends, classmates and teammates through bittersweet four years' journey. Thank you, I appreciate all the support and good vibe through the process. ل مليسيا ملاك ويبونه سيتي نيكنيك

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ABSTRACT

Analytical Hierarchy process is one of the most complete decisions-based methods since it allows you to hierarchically construct the problem and examine a mix of quantitative andqualitative factors. The Analytical Hierarchy Method is described in detail in this paper (AHP). The paper also investigates the issue of maintenance of HVAC system by using a quantitative method known as the Analytic Hierarchy Process (AHP) for offshore platform, focusing on electrical component, mechanical component, and alternatives types of maintenance such as Preventive Maintenance (PM), Predictive Maintenance (PDM) and Corrective Maintenance (CM). The authors look at a case study of compressor maintenance selection using the AHP process, as well as an overview of compressor testing to see how the answers correlate and compare to other multi-criteria decision analysis tools (MCDM).



Keyword: Semi hermetic compressor, AHP method

ABSTRAK

Proses Hierarki Analitik ialah salah satu kaedah berasaskan keputusan yang paling lengkap kerana ia membolehkan anda membina masalah secara hierarki dan memeriksa gabungan faktor kuantitatif dan kualitatif. Kaedah Hierarki Analitik diterangkan secara terperinci dalam kertas ini (AHP). Kertas kerja ini juga menyiasat isu penyelenggaraan sistem HVAC dengan menggunakan kaedah kuantitatif yang dikenali sebagai Proses Hierarki Analitik (AHP) untuk platform luar pesisir, memfokuskan kepada komponen elektrik, komponen mekanikal, dan jenis penyelenggaraan alternatif seperti Penyelenggaraan Pencegahan (PM), Penyelenggaraan Ramalan (PDM) dan Penyelenggaraan Pembetulan (CM). Penulis melihat kajian kes pemilihan penyelenggaraan pemampat menggunakan proses AHP, serta gambaran keseluruhan ujian pemampat untuk melihat cara jawapan berkait dan dibandingkan dengan alat analisis keputusan berbilang kriteria (MCDM) yang lain.



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LIST OF SYMBOLS AND ABBREVIATIONS

D,d	-	Diameter
HVAC	-	Heat Ventilation Air Conditioning
AHP	-	Analytical Hierarchy Process
IAQ	-	Indoor Air Quality

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CHAPTER 1

INTRODUCTION

1.1 Background

The oil and gas sector may be divided into two categories: upstream and downstream. Upstream systems include exploration and production (E&P) systems. The goal of (E&P) is to locate reservoirs and drill oil and gas wells. While downstream refining and processing of crude oil into finished product before to delivery to the consumer (M. Jones, 2018). Both upstream and downstream operators in Malaysian oil blocks are run by Shell, Petronas, ExxonMobil, and others, to mention a few, and are located in offshore blocks far from shore. Production facilities known as "Platforms" are constructed with complicated types of equipment to extract oil from reservoirs, while residential accommodations are mostly accessible on the mother platform to accommodate personnel. Aside from that, the satellite platform is unmanned, and the worker travels to work from the mother platform by boat every day. HVAC is an abbreviation for heating, ventilation, and air conditioning, and it refers to the equipment, distribution network, and terminals that are used collectively or individually to supply fresh filtered air, heating, cooling, and humidity management in a structure (Roger W.Haines, 2010). HVAC is definitely used in the oil and gas industry, notably on production platforms, satellite platforms, and a variety of crude oil boats delivering crude oil to onshore processing units. Each customer has a unique HVAC system. ExxonMobil, for example, has around 380 systems in total for its platform. As a result, maintenance of each unit and system is required till the end of the lifecycle. This is critical since the cost of the new HVAC system 10 is considerably high as compared to onshore HVAC systems owing to safety requirements compliance (ATEX, IECX). HVAC structure developed for an offshore platform particularly to meet the needs of offshore environments, which are governed by tight laws and standards (DNV). According to (Walter Grondzik, 2007), the primary purpose of an HVAC system is to preserve human comfort and health or to provide a set of environmental conditions for a product process in a conditioned area. The importance of an HVAC system on an offshore platform is to maintain safety by providing pressurisation in the room enclosure while cooling for worker comfort and preventing electrical equipment from malfunctioning due to excessive heat produced.

The problems of managing offshore platform assets have intensified in recent years as a result of the high cost of operation caused by the volatility of the oil price. When facilities get older, maintenance costs rise and more complicated solutions are required; also, replacement of existing parts may become obsolete owing to new technologies created. The incorrect selection of maintenance type for specific equipment contributed to the unexpected failure of HVAC equipment, as the maintenance option entered into the CMMS system was not accurate enough to prevent failure from occurring. A few research on HVAC maintenance utilising AHP have been undertaken. (M. Bevilacquaa, 2000) introduced and applied the AHP approach for maintenance strategy selection in an Italian oil refinery processing plant, incorporating an essential selection of the maintenance policy, applicability, economic aspects and safety, expenses, and so on. While (Stefano Ierace, 2009) accessed the most popular maintenance strategies in the selection of maintenance systems using the AHP decision-making evaluation methodology and evaluated them based on two companies, and demonstrated the relationships between the infrastructural and structural decision categories. This encourages me to employ the AHP approach for oil and gas platform HVAC maintenance. The impact on cost reduction for the HVAC system in the oil and gas platform is critical while preserving 11 system efficiency and lifetime. Especially amid the low-oil-price situation, which necessitates an appropriate maintenance expenditure. Because of developing technology, the necessity of asset maintenance is getting more complex. The department of maintenance also encountered difficulty in maintaining equipment efficiency owing to a lack of people and experience, and equipment frequently failed prematurely. Failure to regulate the possibility of dependability might result in greater catastrophe to the oil platform, as there are more aged platforms in Malaysia's oilfield. These are the difficulties that, if successfully met, will contribute to the long-term viability of Malaysia's oil and gas sector. The current study of this work is to create the maintenance hierarchy and further examine the AHP approach for better maintenance selection, which could be used to assess the most appropriate maintenance type for specific difficulties such as the high rate of HVAC compressor damages.

Maintenance has existed since the building of physical constructions such as ships and machinery. In general, maintenance is described as the combination of all technical and administrative procedures, including monitoring and action, undertaken to keep or restore the machine to a state in which it can perform a needed function. Effective maintenance eventually tries to discover appropriate actions that can keep machine performance at an acceptable level and extend the equipment's life cycle (Thor, Ding, & Kamaruddin, 2013). There is a critical need for industries to select an appropriate maintenance plan to avoid the negative impacts of disruptions. Because of the data collection phase, numerous, conflicting criteria, and decisionmakers from various fields, as well as a variety of components and functions that must be addressed in a systematic manner, choosing an optimal maintenance strategy for a system is a complex and multidimensional decision-making problem (Shafiee, 2015). Maintenance should be well planned in terms of investment, planning, and control. Maintenance strategies should be chosen in accordance with the organization's global and operational objectives when planning maintenance. However, the maintenance environment is very dynamic, with frequent technology changes, and so maintenance plans must adapt to

new possibilities and practices. Maintenance selection selections that have a high influence on technology should be handled in a technologically rational manner (Zaim, Turkyılmaz, Acar, Al-Turki, & Demirel, 2012). The industrial industry, selecting a maintenance plan is critical. This is due to the fact that maintenance costs in industry may be fairly high. According to research, the three best maintenance strategies for HVAC systems are corrective maintenance, predictive maintenance, and preventive maintenance (Madu & Madu, 2002).

Phase 1 of the analysis is to calculate the pairwise comparison between each level to find out the relative intensity of the main criteria and sub-criteria.

Phase 2 focuses on deriving the relative weight as this step is important for determining each criterion and sub-criteria of the hierarchical tree.

In phase 3 to validate the model consistency ratio will be analyzed and a conclusion will be made once the consistency ratio has been finalized.

1.2 Problem Statement

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Maintenance programmed of the HVAC system at the oil and gas platform was done according to normal practice (Preventive maintenance, Corrective maintenance, and RiskBased inspection). These are standard options for the maintenance department to operate a maintenance program. With the numerous studies on AHP analysis able to select precise maintenance strategies. The study of AHP application for comparative evaluation of different CMMS has shown promising result in integrating with maintenance software as well this method can be easily applied in different industrial contexts to provide the right choice of maintenance type for specific needs and to avoid an implementation without providing the expected benefits (D. Meira, 2021). However, oil and gas maintenance managers are questioning the effectiveness of the development of maintenance strategy based on analytical approachable to increase the effectiveness of maintenance program, especially on oil and gas industry. A recent study of AHP application on the suitability of maintenance contractor in turnaround maintenance (TAM) at to prevent loss and better safety orientation to prequalify a contractor due to incident of reoccurring plant loss (Laith A. Hadidi, 2015). This study aims to introduce a model of maintenance strategy using ''Analytic Hierarchical Process (AHP) method to justify the success of the application of HVAC equipment maintenance at the offshore platform. This model will able to help the clients & service contractors to identify the maintenance criticality for HVAC equipment's for the oil and gas sector thus reducing trial and error technique.

1.3 Research Objective

The main aim of this research is defined as follow:

- a) To study and introduce the best HVAC component maintenance selection using AHP method for HVAC systems in Semi Hermetic Compressor.
- b) To apply the AHP method for critical decision-making in the actual HVAC maintenance case study.
- c) To evaluate and validate the case study and recommend the best maintenance approach for minimizing cost & downtime of the system breakdown.

1.4 Scope of Research

The scope of this research are as follows:

- A case study on a Semi Hermetic Compressor in oil and gas
- Mainly focused on the brainstorming to AHP method to be applied to the case study maintenance report by Hvac Experts Sdn.Bhd.

• The decision-making success criteria is by using AHP method compared Preventive maintenance, Corrective maintenance, Predictive maintenance and which are the most effective method for selected HVAC equipment maintenance type and reliability.



CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Heating, ventilation, and air conditioning are abbreviated as HVAC. The letter "R" for refrigeration is occasionally added, resulting in "HVACR." The technique of managing the temperature of a constrained space to satisfy the demands of the people or goods within it is referred to as HVAC. HVAC systems are in charge of not just heating and cooling, but also maintaining indoor air quality (IAQ). In the winter, the air is heated, and in the summer, the air is cooled. In HVAC systems, thermodynamics, fluid mechanics, and heat transfer are all used. These fields are all used in different HVAC components. IAQ (Indoor Air Quality) is a air quality inside a building or structure as it relates to the health and safety of its occupants is referred to as indoor air quality. IAQ is affected by gas inclusion or contamination, as well as uncontrolled mass and energy transmission. Heating, cooling, and air conditioning systems are used in a range of applications, including houses, buildings, industry, automobiles, aquariums, and more. The use of HVAC systems is becoming increasingly widespread, and more study is being done in this area. At the same time that the field of application expands, the HVAC sector grows. A heating and cooling system, as well as indoor temperature management, is essentially a collection of many pieces of equipment that are all linked together. HVAC systems use mechanical and electrical components to provide comfort to building/space occupants or to maintain items, products, or anything else placed in space.

HVAC cooling systems can be integrated with HVAC heating systems or installed independently, depending on the HVAC design. HVAC systems keep machinery running on a large scale by managing the temperature of the space/hall/room where they are installed. HVAC water chillers have become vital in any industry for a multitude of reasons. In the background of the HVAC system, a water chiller produces chilled water, which is then circulated throughout the building or area and up to cooling coils in air handling units. Blowers circulate air across cooling coils, which is then disseminated throughout the room or building for comfort or to preserve goods/items, as required by HVAC design. Supply ducts give air, whereas return ducts collect air in air handling systems. Chilled water and cooling water pumps supply energy to keep the chilled and cooling water moving. HVAC Valves are also installed at various points in the pipe to facilitate HVAC system maintenance and management. An HVAC heat pump, a hot water generator, or a furnace can all be used to heat the air. Certain industrial chillers can also be used as heaters in the winter. Heated coils take the place of cooling coils in the heating mode. The cost of an HVAC system, as well as the cost of heating and cooling an area or environment, varies based on the use.



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Figure 1 Basic sytem HVAC

HVAC systems, which stand for heating, ventilation, and air conditioning, are one of the most important systems on an oil platform. Positive pressure in the living quarters and negative pressure in the battery room are maintained by the ventilation systems on the oil platform. Negative pressure is essential to limit any gas leaks that may occur in the living area. While positive pressure must be maintained at a specified level to prevent harmful gases from entering the living area from the outside. Humans in the quarters require constant fresh air, which is provided by ventilation. For the purpose of heating, which is commonly required at oil platforms located in cold climate countries. There are normally two basic types of air conditioning in oil platforms direct expansion and chilled water, with capacities ranging from 1 HP to 180 HP to accommodate the needs of an HVAC system. Air conditioning is critical to provide comfort to the people on board and in some countries such as the Middle East, it is also important to some electric and electronic systems such as the control panel. And, in most cases, HVAC units are operated in parallel or in main standby mode.

Main HVAC systems which normally under maintenance program are listed below:-UNIVERSITI TEKNIKAL MALAYSIA MELAKA

- Air Handling Unit (AHU) The Air Handling Unit (AHU) is a device that circulates air. The central unit to which the AHU is attached is the HVAC. AHU is just a part of HVAC, and it also provides fresh air and pressurization to the room.
- 2) Air-Cooled Condensing Unit (ACCU) A direct dry cooling system in which steam is condensed within air-cooled finned tubes is known as an air-cooled condenser (ACCU). The ACCU operates at a pressure similar to a vacuum since the steam from the turbine is low pressure, and non-condensable gases are continuously collected by an air evacuation device.

- 3) HVAC Filter Coalescer Coalescing is a process for separating liquid aerosols and droplets from gas using filter media, and coalescing filters are designed to extract submicron oil, water, and other liquid droplets from airflows.
- 4) HVAC Control Panel HVAC control panels for offshore platforms are devices that handle the temperature and air in a given environment and are designed to meet ATEX or IEC specifications.
- 5) ACSU FCU Unit A fan coil unit (FCU) or (ACSU) is a system that heats or cools a room without the use of ductwork by using a coil and a fan. Indoor air passes through the coil, which heats or cools it before returning it to the room.
- 6) ACSU Unit Only one indoor unit is connected to the outdoor compressor in a single split air conditioner. Multiple indoor devices are connected to the outdoor system in multi-split air conditioners. Single split air conditioners can only impact air conditioning in single rooms if they fail.
- 7) Fire Damper The fire damper maintains the integrity of the current barrier, preventing a fire from spreading until temperatures exceed the barrier's fire rating mark. Its main purpose is to keep the fire from spreading from one side of a fire-rated barrier to the other.
- 8) Chiller & Freezer Chillers only cool liquids at temperatures ranging from 7 to -1 degrees Celsius. Anything stored in an enclosed space can be cooled to -20 to -35 degrees Celsius in a freezer. The refrigerator absorbs heat from the same source as the freezer, but only to a temperature of 3 to 5 degrees Celsius.

2.2 Basic refrigerant sytem cycle

A refrigeration cycle's goal is to absorb and reject heat. The refrigeration cycle, also known as a heat pump cycle, is a means of transporting heat away from a cooling area. This is accomplished by altering the pressure of the operating refrigerant using a compression and expansion cycle.



Compressor

The compressor is the air conditioner's beating heart. Refrigerant that is low-pressure and low-temperature enters the compressor as a low-pressure, low-temperature gas and departs as a high-pressure, high-temperature gas. A split air conditioning system is the most common type of central air conditioning system found in most homes. The compressor is housed in the outside unit. Its job is to circulate and apply energy to the refrigerant required for heat exchange via the coils of the indoor and outdoor units. The compressor is powered by a motor that is similar in design to a cylinder and piston motor. The gaseous refrigerant is compressed by the compressor, which raises its temperature and converts it to a highpressure gas. Due to the high pressure, the refrigerant is driven along a tube to the outdoor coil, where it releases its heat and condenses into a liquid.

Condenser

The condenser, commonly known as the condenser coil, is one of two types of heat exchangers in a simple refrigeration loop. From the compressor, this component gets vaporized, high-temperature, high-pressure refrigerant. The heated refrigerant vapor gas vapor is cooled in the condenser until it condenses into a saturated liquid state. A condenser (or AC condenser) is the part of an air conditioner or heat pump that releases or absorbs heat depending on the season. Both split air conditioner and heat pump condensers have the same basic components. The condenser cabinet houses the condenser coil, a compressor, a fan, and various controls. The condenser coil could be made of copper tubing with aluminum fins or all aluminum tubing to transfer heat quickly. The condenser fan is a crucial component that helps with heat transfer by pumping air across the coil. The compressor is the system's heart since it compresses the refrigerant and pumps it to a coil as a hot gas. The hot gas is pushed straight to the evaporator coil in heat pumps to provide heat.

Expansion valve

These components come in a number of styles. Fixed orifices, thermostatic or thermal expansion valves, and more sophisticated electronic expansion valves are all common. The job of the expansion device in a system, regardless of configuration, is to induce a pressure decrease when the refrigerant leaves the condenser. Some of the refrigerant will boil quickly as a result of the pressure reduction, resulting in a two-phase mixture. Flashing is a quick phase change that helps the evaporator, the next piece of equipment in the circuit, perform

its function. Thermal expansion valves are occasionally referred to as "metering devices," but this word can also refer to any other device, such as a capillary tube or a pressurecontrolled valve, that releases liquid refrigerant into the low-pressure portion but is unaffected by temperature.

Evaporator

The evaporator is the second heat exchanger in a traditional refrigeration circuit, and it, like the condenser, is named after its principal purpose. It serves as the "business end" of a refrigeration cycle because it does what we expect air conditioning to do: absorb heat. The air is cooled by the refrigerant absorbing heat from the place in question when it enters the evaporator as a low-temperature, low-pressure liquid and a fan blows air through the evaporator's fins. After that, the refrigerant is returned to the compressor, where the cycle repeats all over again.

2.3 Research gap RSITI TEKNIKAL MALAYSIA MELAKA

This study examines a review of a study in the maintenance field of HVAC components support systems in general, with the study focusing on HVAC maintenance reports at a specific firm, the findings of which can be used as a reference and applied to other businesses. Maintenance workers in the sector frequently struggle to prioritise maintenance needs in order to develop an effective strategy. The AHP methodology is one of the methods used to prioritise the issue. The AHP method is used to track the impact of each failure mode in the reciprocating compressor until the root cause is identified, allowing the appropriate remedial action to be determined.

Authors	Year	Study Method	Topics/Focus	Description	Gap
Riaz Khan,	2019	Asset Life	Safety-Critical	The articles	No specific
A. B.		Extension	Equipment (SCE)	summarize of	approach to
(n.d.).		(ALE)		maintenance of	identify the
				aging oil and gas	right method of
				facilities to study	maintenance
				the effects and	for specific
	MALAI	SIA		current practice	equipment
	No. 1	STEL 24		of maintenance	
	11 TEK	>		management	
Iorge	2012	АНР	Maintenance	Emphasize on	The
Moreno-	بيا ملاك	Method	ی نیر planning	maintenance	importance of
Trejo	UNIVERS	ITI TEKNI	KAL MALAYSI	planning shall be	having a
				developed during	specific
				FEED study by	approach of
				using challenges	maintenance
				of maintenance	and with the
				of subsea	result can be
				production	further study to
				platforms	feed the
					maintenance
					strategy during

					the design
					stage
Erick Lima	2019	AHP	Industrial	AHP qualitative	A study doesn't
			Maintenance 4.0	study model	recommend a
				ranked the	suitable type of
				probability	maintenance to
				failure events in	overcome the
				a similar to	failure of the
				Bayesian	equipment.
	NALA)	SIA MO		Network model	
	HALL REAL	LAKA		generated by the	
	II II			K2 algorithm	
	AINO				
C. Nzukam	2017	DMDA	Maintenance of	Stoppage	The method
		- 0	non-residential 🤤	characteristics,	optimized the
	UNIVERS	ITI TEKNI	buildings LAYS	system RUL	usage of the
				(Remaining	system and
				Useful Life), and	delayed the
				component	maintenance
				criticalities to	program and
				prepare early	focusing much
				maintenance	more critical
				interventions for	equipment for
				a multi-	maintenance

				component	priority
				system	without
					mentioning the
					type of
					maintenance
					approach.
Cheong	2014	SPSS	Maintenance	Investigation of	The actual case
Peng Au-	MALAY	SIA	Management for	the maintenance	study with
Yong	A. C.	CLARK	HVAC System in	characteristics of	experiments
	E E	2	office buildings	HVAC systems	and analysis
	Y.a.			that affect	shall be further
	abl (occupant	investigated
	يا ملات	_ل مىيس	ي بيھيد	satisfaction, and	with the
	UNIVERS	ITI TEKNI	KAL MALAYSI	then create a	important
				relationship	maintenance
				between the	characteristics.
				characteristics	
				and occupant	
				satisfaction	
				through	
				questionnaire	
				surveys and	
				interviews	

D.Meira, I. C.	2021 با مارك UNIVERS	AHP	CMMS تي تيڪيد KAL MALAYSI	The promisingresult showed inintegrating withmaintenancesoftware as wellthis method canbe easily appliedin differentindustrialcontexts toprovide the rightchoice ofmaintenance typefor specific needsand to avoid animplementationwithoutproviding the	Oil and gas maintenance managers are questioning the effectiveness of the development of anaintenance strategy based on an analytical approach.
Laith A.Hadidi, M. A.	2015	AHP	TAM	AHP application on the suitability of maintenance contractor in turnaround	A study showing success for TAM. However,

				maintenance	further study
				(TAM) to	required for the
				prevent loss and	implementation
				better safety	of AHP in the
				orientation to	Offshore
				prequalify a	industry
				contractor due to	
				incident of	
				reoccurring plant	
	ALA	SIA		loss	
	S"	ALC .			
M.	2000	AHP	Reliability	Presented and	Other
Bevilacqua,			Engineering &	application of the	characterized
M. B.	ou AINO		System Safety	AHP technique	of important
	سا ملاك	J, ahm	ة, تكند	for maintenance	properties shall
	"			strategy selection	be considered
	UNIVERS	ILLEAN	NAL MALATSI	in an Italian oil	for a different
				refinery	case study such
				processing plant,	as technology,
					safety, costs.
Stefano	2009	АНР	Maintenance	Accessed	To recommend
Sterano	2007	7.111	Wantenance	necessea	To recommend
Ierace, S. C				maintenance	a specific type
				strategies using	of maintenance
				the AHP	and pairwise
		decision-making	analysis		
--	--	------------------	----------------		
		evaluation	between the		
		methodology in	type of		
		the selection of	maintenance		
		maintenance	(CM, PM, etc.)		
		systems.	and		
			alternatives.		

 Table 1 : List of potential research gap in the area of maintenance and MCDM method

2.4 Type of compressor

2.4.1 Scroll compressor

Scroll compressors are positive displacement compressors used in household and commercial air conditioning, refrigeration, and heat pump applications. These compressors have a mechanical compressing element that accepts gas on the perimeter and releases it in the center. This element is made up of two identical spiral-shaped metallic pieces (scrolls). One scroll remains stationary, while the other moves in an orbital pattern, causing gas to migrate from the scroll's periphery to its interior. Throughout the migration, the gas chambers' capacity is gradually reduced. As a result, the gas's pressure and temperature increase. The main irreversibility in scroll compressors is commonly thought to be leakage between chambers with different pressures. Heat transfer within the compressor has an impact on thermodynamic efficiency. The temperature profile throughout the scroll wraps and the gas temperature inside the suction pockets (suction temperature), which is higher than the input temperature due to refrigerant contact with heated compressor parts, are critical for heat transfer characterization. Many authors have developed models to predict

suction temperature in scroll compressors, which are typically used in conjunction with numerical compression simulations.

When it comes to heat transmission during the compression process, the gas temperature increase and scroll temperature profile may be focused on. According to most studies, a linear temperature profile in relation to the scroll involute angle is a reasonable assumption.



When differential models are employed to simulate the compression process, the suction temperature is a critical starting condition, with the scroll temperature profile serving as the required boundary condition. In this study, a steady state one-dimensional model was used to estimate heat conduction and temperature distribution in the scrolls. The conduction model was integrated with a thermodynamic model of the compression process developed by Pereira and a simplified thermal model developed by (Diniz et al.). As a result, the simulation was ran multiple times, allowing for a full thermodynamic description of the compressor.

2.4.2 Screw compressor

Oil is used to lubricate the majority of screw compressors. There are two types: semi hermetic and open drive. In the former, the motor is contained inside the compressor housing, whereas in the latter, the motor is housed outside the compressor housing, necessitating the installation of a shaft seal. There are only two moving elements in a screw compressor: two intermeshing helical rotors. A male lobe functions as a rolling piston, and a female flute serves as a cylinder, in the rotors. Because rotary screw compression is a continual positive-displacement process, there are no spikes in the system. Screw compressors require little maintenance because the rotors move slowly and are well lubricated with cooling oil. Fortunately, the majority of the oil can be easily extracted from the gas using screw compressors.



Figure 4 Screw compressor

2.4.3 Semi Hermetic Compressor

The motor and compressor housing are housed in a two-piece shell on semi hermetic compressors. The covers are bolted together and can be removed for cleaning. Due to the bolts and O-rings required to connect the covers, semi hermetic compressors are usually more expensive than hermetic compressors. The ease with which this compressor can fail or be maintained is its greatest advantage over the hermetic kind. It was designed by a French monk, Abbe Audiffren, and erected by SIngrun in Epinal, France, in 1905.



To meet system distribution requirements, semi-hermetic compressors increase gas pressure and transport it via a pipe system. From low pressure to high pressure, the refrigerant is delivered in a steadily decreasing volume. Its mechanical working principle began when an electric motor was turned on, causing the compressor crankshaft to revolve. The compressor pump features a piston that provides a low-pressure rear between the piston top and the cylinder head during the down stroke. Gas rushes into the low-pressure compartment through the suction valve's entry. During the piston upstroke, the suction valve closes, forcing the exhaust valve to open due to increased pressure. The gas is compressed and forced through the discharge, or high pressure, side of the system. When the semi-hermetic compressor piston reaches the top of the cylinder, the discharge valve closes. The suction valve opens when the piston begins to descend, drawing in gas to finish the cycle. Furthermore, a screw compressor has no suction or pressure valves, only a non-return valve to ensure that no refrigerant flows back when the compressor is switched off. Screw compressors may achieve high compression ratios because the oil absorbs compression and friction heat as well as providing lubrication and sealing during the process. Oil cooling in a screw compressor is consequently critical, and can be accomplished either through refrigerant injection into the compressor or through a separate oil cooling system. In oil coolers, BPHEs are extensively used.



Figure 6 Copeland Semi hermetic compressor

Semi hermetic compressor common faults:

- i. Oil leakage causes insufficient lubrication.
- ii. Inadequate oil in the system.
- iii. Slugging oil happen in the compressor.
- iv. Overheated compressor.

v. Due to contaminant inside system degrade valve and seal.

2.4.4 Hermetic Compressor

Compressors that are hermetically sealed and inaccessible are known as hermetic compressors. The motor and compressor housing are held together by a casing. The steel shell is welded to establish a hermetic seal against the environment. Because the shell is welded, it is more difficult to access the welded shell in order to perform maintenance work. If the motor or compressor is damaged, the compressor must be discarded for maintenance purposes. Semi-hermetic compressors, on the other hand, feature a metal casing with covers that allow the user to access any damaged or malfunctioning pieces, such as pump components or the motor. The size of the hermetic and semi hermetic compressors can be used to distinguish them. The hermetic compressor is smaller than the semi hermetic compressor. Due to its size, the cost of maintenance and repair for hermetic is higher. Both compressors are widely utilized in a variety of industries, including home refrigeration, small commercial refrigeration, and air conditioning systems.



Figure 7 Hermetic compressor

Advantages of hermetic compressor:

- Due to it sealed mechanical process it protected the system from pollution.
- Dust particles unable to enter and contaminate the lubricant.
- Simple design and small in size.

2.5 Reciprocating compressor (Hermetic) characteristic

A hermetic or sealed compressor is one in which both the compressor and the motor are enclosed in a single welded steel casing for small compression while cast iron of the body compressor for high compression required. With the motor inside the refrigeration circuit, the motor and compressor are directly connected on the same shaft. And if a larger cooling capacity is required, this sort of compressor is typically used on the Offshore platform. It's usually placed in pairs and runs in duty and standby mode in that order.

Name	Function	Failure Mode	Effect
Body of compressor	The body of the	The body	The compressor will
	compressor is built	compressor part can	increase in
	of high-strength	be damaged due to	temperature and
	metals that can	lack of lubrication at	produce rattling
	sustain highpressure	the surface. Then	sound until the
	compression and last	will cause the	compressor severely
	for a long time. It	compressor to	damage before it
	also houses the	overheating	ends its life.
	essential		
	components that		
MALAY	allow it to function		
See.	as a compressor.	_	
Piston	Internal combustion	Worn pistons rings	This wears down the
	engines rely on	and cylinder,	rings, piston and
100	pistons as a key	damage and also	cylinder causing
TAINO -	component. It turns	liquid slugging	blow-by, leaky
سا ملاك	heat energy into	happens when the oil	valves and metal
	mechanical power	in the compressor	debris in the oil.
UNIVERS	through KNIKAL a	head heats up to the	Punch hole top of
	reciprocating	point where it loses	piston will occurdue
	motion. When the	its capacity to	to overheat and other
	engine produces	lubricate effectively.	effect such as worn
	power, it goes up		pistons scored
	and down inside the		cylinder walls &
	cylinder. The		wear on wrist pin.
	piston's job is to stop		
	gases from		
	expanding and		
	sending them to the		
	crankshaft.		

Connecting rod	The connecting rod	Liquid Slugging	Connecting rods
	joins the piston to		break & crankshaft
	the crankshaft,		break
	converting the		
	crankshaft's rotating		
	action into the		
	piston's		
	reciprocating		
	motion.		
Gasket, Piston	Components	Usually the failure	Then due to
Rings, Shaft Seals	guarantee that the	mode that will occur	inadequate
	compressor does not	in this part is wear &	lubrication effecting
	leak refrigerant, oil,	tear and because of	discharge valve
AL MALAY	or air.	that failure mode	failed, gasket plate
	K. R.	will cause to	blown effect pin
TEK	P	inadequate	hole to wear. Also
E		lubrication to the	cause discolored
Saning.		system.	pistons and worn
she (110-10		pistons because of
سيا مالات	مىيس	بوہر سیبی بیھ	the friction between
UNIVERS	ITI TEKNIKAL M	ALAYSIA MELA	the parts.

Cross Head	A crosshead is a		
	mechanism used to		
	alleviate sideways		
	pressure on the		
	piston in long		
	reciprocating		
	engines and		
	reciprocating		
	compressors as part		
	of the slider-crank		
	couplings. The		
	crosshead also		
ALAY	allows the		
At MAR	connecting rod to		
	move freely outside		
	of the cylinder.		
E			
Crankshaft	the reciprocating	If the crankcase oil	The overheating in
Crankshaft	the reciprocating compressor's main	If the crankcase oil level is low due to	The overheating in crankcase affect the
Crankshaft	the reciprocating compressor's main shaft The electric	If the crankcase oil level is low due to lack of oil in the	The overheating in crankcase affect the crankshaft working
Crankshaft	thereciprocatingcompressor'smainshaftTheelectricmotorisconnected	If the crankcase oil level is low due to lack of oil in the crankcase to	The overheating in crankcase affect the crankshaft working continuously results
Crankshaft	the reciprocating compressor's main shaft The electric motor is connected to one side of the	If the crankcase oil level is low due to lack of oil in the crankcase to adequately lubricate	The overheating in crankcase affect the crankshaft working continuously results to damage
Crankshaft	the reciprocating compressor's main shaft The electric motor is connected to one side of the crankshaft, while the	If the crankcase oil level is low due to lack of oil in the crankcase to adequately lubricate the running gear.	The overheating in crankcase affect the crankshaft working continuously results to damage component.
Crankshaft	the reciprocating compressor's main shaft The electric motor is connected to one side of the crankshaft, while the connecting rod is	If the crankcase oil level is low due to lack of oil in the crankcase to adequately lubricate the running gear. Then, overheat will	The overheating in crankcase affect the crankshaft working continuously results to damage component.
Crankshaft	the reciprocating compressor's main shaft The electric motor is connected to one side of the crankshaft, while the connecting rod is connected to the	If the crankcase oil level is low due to lack of oil in the crankcase to adequately lubricate the running gear. Then, overheat will occur.	The overheating in crankcase affect the crankshaft working continuously results to damage component.
Crankshaft	the reciprocating compressor's main shaft The electric motor is connected to one side of the crankshaft, while the connecting rod is connected to the other.	If the crankcase oil level is low due to lack of oil in the crankcase to adequately lubricate the running gear. Then, overheat will occur.	The overheating in crankcase affect the crankshaft working continuously results to damage component.
Crankshaft	the reciprocating compressor's main shaft The electric motor is connected to one side of the crankshaft, while the connecting rod is connected to the other.	If the crankcase oil level is low due to lack of oil in the crankcase to adequately lubricate the running gear. Then, overheat will occur. Many motors fail to	The overheating in crankcase affect the crankshaft working continuously results to damage component.
Crankshaft	the reciprocating compressor's main shaft The electric motor is connected to one side of the crankshaft, while the connecting rod is connected to the other.	If the crankcase oil level is low due to lack of oil in the crankcase to adequately lubricate the running gear. Then, overheat will occur. Many motors fail to function due to	The overheating in crankcase affect the crankshaft working continuously results to damage component. The whole winding gets overheats and
Crankshaft	the reciprocating compressor's main shaft The electric motor is connected to one side of the crankshaft, while the connecting rod is connected to the other. The power is usually supplied by an electric motor,	If the crankcase oil level is low due to lack of oil in the crankcase to adequately lubricate the running gear. Then, overheat will occur. Many motors fail to function due to mechanical failure.	The overheating in crankcase affect the crankshaft working continuously results to damage component. The whole winding gets overheats and burn, also causing
Crankshaft	the reciprocating compressor's main shaft The electric motor is connected to one side of the crankshaft, while the connecting rod is connected to the other. The power is usually supplied by an electric motor, which is constructed	If the crankcase oil level is low due to lack of oil in the crankcase to adequately lubricate the running gear. Then, overheat will occur. Many motors fail to function due to mechanical failure. Shorting windings	The overheating in crankcase affect the crankshaft working continuously results to damage component. The whole winding gets overheats and burn, also causing voltage unbalance
Crankshaft	the reciprocating compressor's main shaft The electric motor is connected to one side of the crankshaft, while the connecting rod is connected to the other. The power is usually supplied by an electric motor, which is constructed using either star or	If the crankcase oil level is low due to lack of oil in the crankcase to adequately lubricate the running gear. Then, overheat will occur. Many motors fail to function due to mechanical failure. Shorting windings and overheating	The overheating in crankcase affect the crankshaft working continuously results to damage component. The whole winding gets overheats and burn, also causing voltage unbalance affects to electrical
Crankshaft	the reciprocating compressor's main shaft The electric motor is connected to one side of the crankshaft, while the connecting rod is connected to the other. The power is usually supplied by an electric motor, which is constructed using either star or delta winding	If the crankcase oil level is low due to lack of oil in the crankcase to adequately lubricate the running gear. Then, overheat will occur. Many motors fail to function due to mechanical failure. Shorting windings and overheating happens due to	The overheating in crankcase affect the crankshaft working continuously results to damage component. The whole winding gets overheats and burn, also causing voltage unbalance affects to electrical damages and

		components that are	
		not working.	
Oil Sump	Oil pumps maintain	At the oil pumps part	Low level of oil
	the running gear	leaking will happen	reading due to oil
	elements adequately	if the cover is not	leaking then will
	lubricated in order to	tightly closed. And	cause to low
	prevent premature	cause of oil losses.	refrigerant velocity
	damage to the		as there not enough
	cylinder and other		lubricants moving
	sections of the		into the parts, such
	commercial		as broken fan belts,
	compressor.		failed fan motors,
at MALAI	ALA ALE		dirty coil and
200	L. R. K.		unloaded
12	P		compressor
ILIE			operation.
\$3AININ			
Bearings	Pistons, rotors,	If the bearing	When bearing fails
-/~~~~	scrolls, and	damage it will cause	to achieve its
UNIVERS	impellers all have	contaminants	performance
	shafts that need to be	present in the oil of	requirements it
	supported. These	the compressor that	causes bearing
	components are	will damaging.	damage as the
	critical because they	Another failure	bearing failed to
	can sustain the	mode that will occur	function and
	varying loads that	is overload as the	prevents proper
	occur during	bearing is continue	lubrication (affect to
	compressor	to working	short winding & fail
	operation and	excessive	motor) to the system
	prevent metal-to-	temperatures.	causing totally
	metal contact		system to
	between the rolling		breakdown.

	elements and		
	stationary castings,		
	which reduces		
	friction-related		
	wear.		
Discharge Valve	The discharge valve	Due to high	Cause high
	directs the high-	discharge	compression ratio
	pressure refrigerant	temperature will	effect evaporator
	to the discharge line,	cause to discolored	coil problem,
	which leads to the	valve and low	improper pressure
	condenser.	suction pressure,	
		because the oil loses	
Nº MALAI	ALA ALA	its capacity.	
and the second se	L. R. W.		
Suction Valve	Through the suction	The failure mode	Unable to lubricate
III S	piping and valve, the	that will occur is	properly lead to
S'AININ	refrigerant is pulled	wear and slugging	Suction valve break,
shi	into the compressor.	because when the oil	and dented valves.
ين مرد	and a second	becomes too hot, it	Next, from leaky
UNIVERS	ITI TEKNIKAL M	loses its capacity to	valve it will affect to
		lubricate adequately.	high discharge
		Also, cause leaky	pressures &
		valves.	temperature.

 Table 2 : Main components of reciprocating compressor (Hermetic)

2.6 **Operating Requirements**

Reciprocating compressors are designed to work continuously for long periods of time, up to a year, without requiring major maintenance if properly maintained. Oil should be changed at least once a year, and compressor parameters should be inspected solely on a regular basis to ensure that the compressor is still in good working order.

2.6.1 Continuous Duty

When selecting equipment for continuous operation, consistency, efficiency, and dependability are all critical variables to consider. Before valve and seal wear becomes too severe to handle, reciprocating compressors can only run for roughly a year. When equipment is not maintained on a regular basis, the chances of failure grow.

2.6.2 Intermittent Duty

Although reciprocating compressors are tolerant of duty variations, recycling control is typically employed to manage flow changes because they are positive displacement machines. Some machines include unloading mechanisms, which can be complicated and result in localized high temperatures. Reciprocating compressors may be set up fast if thorough checks are performed and, most importantly, there is no liquid in the compressor or suction system.

2.6.3 Emergency Duty

When process deposits (salts, oxides) are exposed to damp air under poor ventilation conditions, the corrosion is the most severe. If there is a failure that inhibits a normal procedure clean out, this can happen. After that, the system is opened for examination and left opens while components and resources are procured. This can be avoided by performing 40 adequate cleaning and venting activities after the inspection, as well as applying the appropriate chemicals. Clean lubricating oil without contamination should be used in the crankcase and cross-head areas, which should be totally isolated from the process. There should be little risk of corrosion, however. Moisture from the refrigerant system could occur and mixing with the compressor oil. Therefore, the oil become acidic becomes enemy of the inner parts of compressor.

2.7 Application of Semi hermetic and Hermetic compressor

2.7.1 Application for Refrigeration in Residential Building

Hermetic compressors are used in both household refrigeration and small business refrigeration and air conditioning systems. In Beijing, for example, using charcoal to heat up during the winter is not environmentally friendly. As a result, in Beijing, using an air source heat pump to heat residential buildings is deemed environmentally friendly and encouraged (Wang et al., 2011). As the working principle of the system, which consists of a primary refrigerant circle, would give a huge amount of heat to the building while keeping the same operational conditions, the type of compressor employed in the building is the hermetic compressor type. As stated in the journal, the bypass refrigerant may be utilized to raise the density of refrigerant at the inlet of the hermetic compressor used in the refrigeration cycle. Refrigeration and air-conditioning equipment suited to supermarkets and other commercial industrial applications, as well as major air conditioning project systems such as shopping malls, utilize semi hermetic compressors. They are the preferred compressor system for

larger machines because these compressors may provide a more cost-effective solution. According to Saengsikhiao & Taweekun, a study on energy efficiency enhancement options for supermarket freezers was presented in 2021. The installation of a digital semi-hermetic compressor can adapt its duty cycle to fit the current load while neither sucking or compressing the refrigerant in the unloaded situation, resulting in a 50% reduction in compressor energy usage, according to the journal.

As Thailand's household sector has been listed as one of the country that has secondhighest energy usage rate. The use of semi hermetic compressor helps to cut expenses and conserve energy while ensuring that energy saving measures doesn't effect it maintenance costs. As the researcher's is proposed a low E glass door for open refrigerators and digital semi-hermetic compressor to fix the speed of semi hermetic compressor as an energy efficient enhancement option. From both cases, the application of both hermetic compressors used in residential building require for energy efficiency and has been proposed with various ways to enhance it, at the same time maintain the maintenance

costs.

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2.7.2 Application for Refrigeration in Offshore Platform

The semi hermetic compressor is then used in the HVAC oil and gas platform living cabin. Cooling plant, which consists of four basic components such as a compressor, condenser, expansion valve, and evaporator, is one of the applications that has been used of an air conditioning system (HVAC) on offshore platforms. The application is determined by the type of offshore installation of the equipment, including whether it is water-cooled or air-cooled. It will be difficult to maintain a comfortable indoor environment without a cooling plant when cooling is required. While in the living cabin, the use of semi-hermetic and hermetic compressors improves and provides personal comforts by providing electrical warming and cooling (Heinen & Hopman). Similarly, Prof. Dr. – Ing.A. Hafner et al. note in their book (Refrigeration units in marine vessels, 2011) that refrigeration on passenger and cargo ships has a wide range of chilling capacity, principally to provide comfort to passengers and crew via air conditioning and to preserve food. The interiors of the oil and gas living cabin platform resemble a blend of a hotel and a workplace, and many rigs house and employ over 200 people. Cabins are shared with a minimum of two persons per room, and the kitchen and facilities are shared with other cabins.

2.8 Maintenance HVAC ITI TEKNIKAL MALAYSIA MELAKA

As the systems have grown larger and more involved in larger temperature control applications, the methods for recognizing and eliminating performance concerns have improved. As a result, FMEA is one strategy for preventing recurrent failures.

The building owner, engineer, technicians, or contractor in charge suggests that the HVAC system be serviced once a year, and the pump should be serviced every six months to keep it in good operating order. The heating, ventilation, and air conditioning (HVAC) system will work smoothly and efficiently for a long period if it is maintained on a regular basis. The HVAC system ensures

that the home's environment is both comfortable and clean. Its job is to make sure the indoor air quality is acceptable.

2.8.1 Importance of Maintenance

The number of variables to consider when making maintenance management decisions is also notable. It's crucial to look into how the maintenance staff communicates their maintenance goals. Even though maintenance is carried out on the offshore platform. However, when the maintenance department's maintenance schedule fails to determine the priority of maintenance alternatives for each piece of equipment, the same challenges arise (Lee, H.H.Y, et al., 2009). Machine and equipment maintenance is necessary to keep them in top working order. As a result, in a well-functioning production system, plant maintenance is a vital and unavoidable service job (Jain. M, 2010). Maintenance has been shown to be critical in ensuring that equipment lasts as long as possible, especially on offshore platforms where maintenance costs are higher than onshore due to harsh surroundings and a higher risk of equipment failure.

2.8.2 Type of Maintenance

Planned maintenance and unscheduled maintenance are the two types of maintenance strategies. Preventive maintenance, predictive maintenance, corrective maintenance, and proactive maintenance are all examples of planned maintenance in the subject of maintenance management. Unplanned maintenance is often referred to as reactive maintenance. Breakdown maintenance is preventative maintenance in the event of unforeseen problems, which results in high maintenance expenses.



Figure 8 Type of Maintenance

2.8.3 Generation of Maintenance

To date, there has been three distant generation of maintenance. The first is characterized by a focus on repair tasks, the second focuses on improving maintenance planning and scheduling, and the third by a focus on predicting preventing, and avoiding the consequences of equipment failures. (John Moubray). The fourth generation of maintenance will focus on failure elimination rather than prediction or prevention.



Figure 9 Distance generation of maintenance

Preventive Maintenance

A maintenance used to detect and correct the problem before the problem occur. Typically carried out in the form of routine inspections which are normally performed between an interval of time such as twice a year. This preventive maintenance is carried out by look for any symptoms of wear and tear, inspect any potential failure and replace any broken components right away. These activities will keep the component from critical failure. Also, this maintenance may avoid unexpected downtime before any issue develop. Goals of preventive maintenance:-

- Keeps equipment in good condition to prevent large problems
- Extends the useful life of the equipment
- Finds small problems before they become big ones
- Is an excellent training tool for technicians
- Helps eliminate rework/scrap and reduces process variability.
- Keeps equipment safer
- Parts stocking levels can be optimized
- Greatly reduces unplanned downtime

Breakdown Maintenance

Breakdown maintenance is performed on a piece of equipment that has broken down, has a malfunction, or cannot be operated in any other way. The purpose of breakdown maintenance is to restore functionality to anything that has broken down. Preventive maintenance, on the other hand, is done to keep something going.

Predictive maintenance

Predictive maintenance is a subset of condition-based maintenance in which systems are constantly monitored on a regular basis, allowing maintenance staff to perform timely actions such machine modification, repair, or overhaul. Direct monitoring of mechanical condition and other indicators is used in predictive maintenance to calculate the true mean time to failure during the machine's life lifetime. Steps before establishing predictive maintenance:-

- Analysis of the needs and history of equipment
- Any records available on downtimes, failures in facilities, losses (efficiency and energy), possible control fines, and protection on site
- Description and idea development as well as case development for PdM
- Education and buy-in big players
- Fulfill the inventory of the equipment and evaluate the current requirements
- Equipment for initial execution of the program
- System information dependent on different structures and/or parts
- Assess any current repair prevention or prediction
- Decide which structures to incorporate and when to audit
- State the criticality of the program and set the PdM frequency and program form
- Assessing expected capabilities and allocating positions and obligations for staff
- Organize and integrate the software in the programming method
- Education and procurement of processes and repairs

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Corrective Maintenance

Corrective maintenance is a type of HVAC maintenance in which a fault is identified and replaced as soon as possible. It varies from preventive maintenance in that it is based on the state of the equipment. Corrective maintenance is what most maintenance managers rely on to fulfil daily maintenance duties, according to (Nik Myeda et al., 2011). Because corrective maintenance issues are discovered on time, CM reduces emergency repairs and enhances employee safety. Corrective maintenance can be costly since a failure of one item might cause extensive damage to other components of the structure, and a failure of one item can occur at an inconvenient time. The benefits of corrective maintenance show as below:-

- Reduced anticipated as well as unexpected downtime
- Reduced costs for reactive repair methods
- Reduction of net maintenance costs
- Enhanced productivity of personnel while the repair team will concentrate on other activities

Proactive Maintenance

According to (Jabar, 2015), proactive maintenance is a type of maintenance that discovers issues at their cause. It has the ability to boost production capacity while also extending the equipment's lifespan. Proactive maintenance differs from preventive and predictive maintenance. By employing a high level of competence in terms of operational precision, proactive maintenance aims to extend the useable life of equipment until it reaches the wear-out stage.

2.8.4 Risk Assessment on Maintenance strategy of a compressor.

Risk assessment is a term used to describe the whole process or method to identifying hazards and risk factors that have the potential to cause harm (hazard identification). Analyze and evaluate the danger posed by that threat (risk analysis, and risk evaluation).

2.8.5 Objectives of Risk Assessment

- Identifies and evaluates risk.
- Reduce and eliminate harmful threats
- Support efficient use of resources
- Better communication with an organization

2.8.6 Steps in the Risk Assessment Process

- Identify the hazards
- Determine who might be harmed
- Evaluate the risks and take precautions
- Record the findings v. Review assessment

The risk analysis process aids the organization's effective and efficient operation by identifying hazards that demand management's attention. They'll have to prioritize risk management activities based on their ability to benefit the company. If the refrigeration system's compressor overheats, the problem can only be remedied by upgrading the refrigeration system's design and maintenance. The problem cannot be solved fundamentally by replacing a new compressor.



LIKELIHOOD (L)	EXAMPLE	RATING
Most likely	The most likely result of the hazard	5
Possible	Has a good chance of occurring and is not unusual	4
Conceivable	Might be occur at sometimes in future	3
Remote	Has not been known to occur after many years	2
inconceivable	Is practically impossible and has never occurred	1

 Table 3 : Likelihood of occurence

SEVERITYAYSIA	EXAMPLE	RATING
Catastrophie	Numerous fatalities, irrecoverable	5
KIII	property damage and productivity	
Fatal	Approximately one single fatality major	4
II A	property damage if hazard is realized	
Serious Salaro	Non-fatal injury, permanent disability	3
Minor	Disabling but not permanent injury	2
Negligible Marine	Minor abrasions, bruiser, cuts, first aid	1
	type injury	0

Table 4 : Severity of hazard

Likelihood	Severity (S)				
(L)	1	2	3	4	5
5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5

Table 5 : Risk matrix

Risk	Description Action	
15–25	High	A high risk requires immediate action to control the hazard as detailed in the hierarchy on the risk assessment form including date for completion.
5 – 12	Medium A medium risk requires a planned approace controlling the hazard and applies tempore measure if required. Actions taken must documented on the risk assessment form including date for completion.	
1 - 4	Low	A risk identified as low may be considered as acceptable and further reduction may not be necessary. However, if the risk can be resolved quickly and efficiently, control measures should be implemented and recorded.

Table 6 : Priority based on the range

2.6.6 High and low-pressure requirements of HVAC compressors for the specific type of gasses (R22, R407C & R410) commonly used at the platform.

There is a difference of requirement for HVAC compressor for the specific type of gasses such as R22, R407C, and R410. For R22, the low pressure is 60-70psi while high pressure is between 250-300psi. R407C requires 75-80psi at low pressure and 275-300psi at high pressure. Lastly for gas R410a, the low pressure is at 120-130psi, and for high-pressure 450-500psi. If the requirement of the compressor is not followed such as refrigerant overcharge or refrigerant undercharge, it may cause some result that can be creating risk. Some of the risks are:-

1. Compressor motor overheating.

This may prevent the compressor from starting or cause the circuit breaker to trip prematurely. Left unchecked, the motor will eventually burn out and fail to run at all.

2. Loss of cooling capacity

The system is no longer able to maintain the humidity and temperature at the required levels.

3. Flooded condenser

Condenser flooded with liquid refrigerant, which will reduce its capacity; besides causing excessive sub-cooling at the condenser outlet, this condition may cause the compressor to short cycle on the high-pressure cut-out.

4. Liquid refrigerant enters the suction line

Commonly referred to as "liquid slugging", this is a dangerous condition potentially leading to compressor damage.

To ensure that undercharge and overcharge occur, proper maintenance must be done. The condition of the HVAC system must be observed timely within the maintenance schedule. Proper charging of the refrigerant must be done to ensure that the overcharge and undercharge of refrigerant occur.

2.8.7 Oil Acidity Impact on HVAC Compressors and Type of Compressors Oil Used.

2.8.8 Type of Analysis Used for Measuring Oil Acidity

• HVAC Acidic Refrigerant

According to the HVAC 2018 Annual Review Report, lightning is always the most common stated risk to HVAC systems in home-owners' claims year after year and is also the most common misdiagnosed cause of loss. Acidic refrigerant in the system is a sign that is sometimes misunderstood as lightning damage. In contrast to the widespread perception of contractors, lightning in the coolant circuit of an HVAC system cannot create acid. Rather, this symptom is produced by one of three conditions: wear and tear, inadequate repair or maintenance of the system. Because this widespread misunderstanding is frequently mentioned as a lightning damage indication, adjusters must grasp why it isn't.

• Factors Cause the Acidic Refrigerant

When humidity, excess heat, pollutants or other impurities are submitted to the coolant circuit, it produces an airborne chemical reaction. This is caused by age (usual wear and tear), maintenance failure or incorrect system repair. Leaks in copper coils containing the refrigerant can occur as a system age and provide an entrance point for external pollutants. The compressor components can also be disintegrated owing to ageing and contamination in the refrigerant may be introduced. The ensuing chemical reaction generates acid as soon as impurities or moisture reach the refrigerant belt. Acid coolant can also develop if a blocked coil or malfunctioning condenser fan overheats our system. The absence of ventilation causes excessive heat to speed the formation of acid in the coolant. Finally, if a compressor is bruising because the acidic refrigerant is there and eventually is replacing it,

acid can be reintroduced in a new Compressor (but a line set isn't completely flushed or a new filter drier is not fitted).

Acid Number (AN) is the non-aqueous solution measurement of the concentration of acid. The level of potassium hydroxide (KOH) needed to neutralize the acid in one gram of the oil sample is calculated. The default measuring unit is mg KOH/g. The absolute acid level of the oil sample does not reflect AN. Both organic acids and powerful inorganic acids are detected in the measurement of AN. Multiple causes may cause a change in the acid content of oil. The rise can be caused with acid impurities, incorrect oil, losses of alkaline reserves and by-products of oxidation. Table 1 provides a list of detectable common acids. In calculating the RUL of oil, understanding the level of additive depletion is critical. Certain additions are mildly acidic and can increase the initial AN of the oil. With the age of the lubricant, these additives will diminish, lessening their acidity. A specific AN trend is produced during lubricant ageing by the common wear additive, zinc dialkyl dithiophosphate (ZDDP). At the same time it may be polluted with acidic components and the acid level in the oil increases. In identifying what the AN signifies, the combined impacts of additive depletion, acidic contamination and other an acidificate processes provide a difficulty. The fundamental components of the AN during lubricant ageing are displayed in Figure 1. The antioxidant compounds are lost throughout an induction phase; once these additives have been depleted, base oil oxidizes when stress is enough. This growth may be observed by trending the AN.

• Type of Compressor Oil (Organic Vs. Inorganic Refrigerant Acids)

Depending on the type of chemical reaction, the acid generated will be either organic or inorganic in nature. The type of refrigerant, oil composition, and the type of contaminant all influence this reaction. While both types of acids are destructive to compressors, the types of damage they cause are very different. One factor in determining the composition of the acid produced is the combination of refrigerant and oil. Hydrochlorofluorocarbon (HCFC) systems, such as those that contain the refrigerant R-22, typically use mineral oil to lubricate the systems. When moisture or contaminants enter these systems, the refrigerant breaks down, because the natural lubricating oil is more stable than its accompanying refrigerant. This results in the creation of an inorganic acid. Such acids result in abnormally high temperatures in the motor windings and/or discharge area of the compressor. These high temperatures break down the windings and lead to the loss of electrical resistance of the compressor, or a compressor burnout.

• Acid Number (AN)

Acid Number (AN) is the measure of acid concentration in a non-aqueous solution. It is determined by the amount of potassium hydroxide (KOH) base required to neutralize the acid in one gram of an oil sample. The standard unit of measure is mg KOH/g. AN does not represent the absolute acid concentration of the oil sample. The AN measurement detects both weak organic acids and strong inorganic acids. A change in the acid concentration of oil can originate from multiple sources. Acidic contaminants, wrong oil, alkaline-reserve depletion, and oxidation by-products can cause an increase in acid concentration. Table 1 lists common acids that can be detected

Understanding the extent of additive depletion is key in determining the RUL of oil. Some additives are weakly acidic and can elevate the oil's initial AN. As the lubricant ages, these additives deplete, thereby reducing the acidity created by the additives. The common anti-wear additive, zinc dialkyl dithiophosphate (ZDDP), produces a certain AN trend during lubricant aging. Concurrently, the oil is possibly being contaminated with acidic constituents, increasing the acid content in the oil. The combined effects of additive depletion, acidic contamination, and other acidic-affecting events create a challenge in determining what the AN represents Figure 1 shows the underlying components that affect the AN during lubricant aging. It can be seen that during an induction period the antioxidant additives are depleting; once these additives are depleted, the base oil begins to oxidize if the stressing conditions are sufficiently high. By trending the AN, this increase can be detected.

Acid Type	Source	Lube Application			
Organic (1)	Oil oxidation product	All severe lubrication environments			
Hydrochloric (2)	Freon refrigerant breakdown	Chillers			
Hydrofloric (2)	Freon refrigerant breakdown	Chillers			
Sulfuric (3)	Diesel fuel and water H ₂ S contamination AW and EP breakdown	Diesel engines NG compressors Hydraulic systems			
Nitric (4)	Nitration and nitric oxides	Gas engines Gasoline engines			
Phosphorie (5)	Phosphate ester degradation by-products Phosphate sume environment	Mobile equipment, especially hydraulics			
Confirming tests: (1) FIIR oxidation (4) FFIR nitration	Confirming tests: (1) FTIR oxidation (2) Vacuous thinning (3) FTIR sulfation (4) FTIR nitration (5) Elemental analysis - phosphorus				
Figure 10 Type of acid					
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2.8.9 Caused of severe vibration on HVAC Compressors and impact as well as mitigation action.

HVAC systems involve plenty of moving components, it is normal to have some vibration and noise, even in a correctly installed and well-maintained system. However, excessive vibration and noise indicate that an installation should be serviced, and they can also lead to other performance issues. Vibration and noise are normally addressed together because they are closely related. The second is often a consequence of the first. Some property owners only focus on noise and use plenty of soundproofing, but this is not the best approach because it does not solve the underlying issue.

Here are some common sounds that an HVAC system can make:

1. Banging:-

Banging is usually a sure sign that there's a loose or broken part a connecting rod, piston pin, or crankshaft inside the air conditioning compressor.

2. Clicking:-

The clicking of electrical components at start-up and shutdown is a normal part of the system's operation, but constant or ongoing clicking is not typical. It could be a sign of a defective control or a failing thermostat.

3. Buzzing:-

A buzzing noise from the outside unit could mean, it had loose parts, debris in either the indoor or outdoor unit, the outdoor fan motor is loose or about to fail, fan blades are loose or out of balance, the copper lines from outside to inside are rubbing against something.

2.8.7 The special design of explosion-proof HVAC compressors for the specific area of Zone 1 and Zone 2 (onshore production area) and risk of not following (ATEX/ICEX Standards)

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Air conditioners are not made to explode. Yet, few cases of HVAC system explosion were failed in past years. The explosion-proof of HVAC systems is essential in hazardous areas in offshore production areas such as the oil and gas industry. As the explosion-proof heating, ventilation, and air conditioning systems are designed by a skilled engineer to ensure safety. This system is very durable and reliable in use. Since it is an offshore used compressor, so its anti-corrosion ability is enhanced. This is purposely to increase the machine's life working time and prevent unexpected shut down of the machine. As the explosion-proof is the internal sparks or explosion that occurs in the casing which causes a larger blast. This could damage the compressor, especially internal components. Therefore, it is important to minimize the explosion of the compressor. Besides, some standards can be referred to reduce the explosion occurs.

2.8.8 Effect of High Suction and Discharge Temperature of HVAC Compressors Along With It Cause and Mitigation

• High return gas temperature

The evaporating temperature is used to calculate the return gas temperature. To prevent fluids from returning to the compressor, a return superheat temperature of 20°C is generally necessary. The superheat degree will be considerably over 20°C if the return gas pipe is not adequately insulated. The suction and discharge temperatures will be higher if the return gas temperature is higher. The temperature of the return gas will rise by 1°C to 1.3°C

Burned valve reeds Reed

Valves are a form of check valve that restricts fluid flow to a single direction and opens and closes as the pressure on each face changes. Flexible metal or composite materials are frequently used in modern versions (fiberglass or carbon fiber).

• High compression ratio

The compression ratio has a significant impact on discharge temperature. The higher the compression ratio, the higher the discharge temperature. Reducing the compression ratio, as well as raising the suction pressure and lowering the discharge pressure, can considerably lower the discharge temperature. Evaporating pressure and suction line resistance determine suction pressure. The suction pressure may be efficiently raised by raising the evaporation temperature, and the compression ratio can be swiftly lowered, lowering the discharge temperature. The temperature difference can be increased by lowering the evaporation temperature, but the compressor cooling capacity is lowered, so the freezing speed is not guaranteed. Besides, the lower the evaporation temperature, the lower the refrigeration coefficient; yet, since the load has grown, the power consumption will rise if the operating duration is extended

• Stator spot burns from metal debris

The unequal voltage between phases due to uneven loads on the power source, a faulty connection at the motor terminal, or a high resistance contact can cause thermal deterioration of insulation in one phase of the stator winding.

2.8.9 Study of caused compressor motor damage and how to perform the inspection on motor winding to check its reliability

Compressor failure is usually characterized by some excessive discharged temperatures, and some of the parameters are recommended to measure first when compressors show signs of distress. It is important to know these causes to prevent such failures and troubleshoot the problems. If there is any troubleshooting towards compressor failure, a replacement compressor will suffer the same problem. Compressor motor failure can be caused by a variety of electrical or mechanical conditions. All compressor manufacturers do spot teardown analysis on returned compressors. Occasionally, a compressor manufacturer will teardown all returned compressors, for some time, to analyze them and determine the cause or causes of failure. This is expensive, but the information gathered helps the manufacturer to improve the product, the manufacturing process, and the literature regarding installation and maintenance. Here are some of simplify and explanation causes that are mostly found in the causes of compressor motor damaged. Which are:

- Slugging: Broken component, break connection rods, even crankshaft.
- Flood back: The continuous return of liquid refrigerant.
- Loss or lack of lubrication: Not enough oil in the crankcase.
- Electrical problem: Unbalance of current towards the compressor system.
- Contamination: The debris or any slight dirty substance affecting flow system 6.
- **Overheating**: Increase of temperature of the compressor system.

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• Flooded start: Oil in the crankcase-absorbing refrigerant during the mix cycle.

To conclude the finding of the causes of the compressor motor damage, the technician must pay attention to symptoms such as higher than normal discharge temperatures, low amp draw, and higher than normal suction pressures. Also, report any malfunctioning parts of the compressor or towards the system itself to ensure the safety of the manufacturer and the engineer who works with the compressor that they are using. While taking notes and record all the malfunction in a general input data that stored safely for future references. The engineer or the maintenance team who is in charge of the system must be also be recorded to ensure all the possibilities of unknowing the causes of the system can be resolve due to their action of using the system itself performing an inspection on the motor winding.

Electric motor inspection testing is an important part of establishing the condition of the motor and beginning the troubleshooting process. There are several different tests involved, and basic knowledge of what the tests are can help understand the repair data received back from the electric company that handles electrical maintenance. The most critical motor inspection tests include the following:

- Winding phase-to-phase resistance: To detect any large differences in resistance that exist between the winding.
- **Insulation resistance (IR) to the ground**: Resistance measured between each motor winding and frame.
- **DC hi-pot**: Stress test for insulation and requires the use of DC hi-pot tester.
- Surge comparison: Detect insulation weaknesses and short. Incorrect internal connection.
- **Polarization index**: Act as insulation resistance to ground test.
- AC and DC voltage drop (DC motors): DC motor repair to identify shorted.

These tests should be performed by experienced technicians using the methods and voltages prescribed by EASA (Electrical Apparatus Service Association) and IEEE (Institute of Electrical and Electronics Engineers) standards. In addition, all phase-to-phase resistance tests and IR tests must be passed before performing the high voltage DC hi-pot and surge comparison tests. Note that electric motor inspection test values are compared between the initial inspection test data and the final test data to ensure that improvements were made as a result of the repair or re-manufacturing process. To conclude the study of performing an inspection on motor winding is thorough takes electric motor inspection testing with seriousness. Carefully documented the results of each test performed and keep the data onto a safe and secured data collection for future references. If the result showing poorly, perform an additional cleaning and check for any components that are needed for the test or the coil itself including the armature rewind. Repair any broken component of the motor winding.

Keeping motors running is critical in a vast number of industries. Knowing the condition of the windings is one important part of ensuring motors' proper.

2.8.10 One of the enemies of HVAC is moisture. Why it can cause compressor's damage in the long term duration.

Air conditioners cool homes by removing heat and moisture from the air. When humidity levels are excessive, they need to work a lot harder. If the equipment doesn't have sufficient cooling capacity, it may be unable to cope with extreme humidity. As a result, the home may never feel truly comfortable. A few common signs of high indoor humidity include:

- Moist, clammy air: In fact, your skin may feel clammy when you're inside your home.
- Foggy windows: This happens because the humidity is vaporized water in the air. When it becomes bottled up in your home, it may fog up the windows.
- A musty odor: Excessive humidity causes dampness around the home and can eventually lead to this unpleasant problem.

2.8.11 Safety devices are used to protect the compressor from premature failure.

• High Pressure Cut Out

High pressure can be caused by a variety of factors, including overcharging, a loss of cooling water, a high ambient temperature, air, or other incompressible gases in the system, and an obstruction in the compressor's discharge line. A high-pressure cut-out is provided to protect the compressor from high pressure and subsequent failure. It takes a pressure tapping from the discharge line and stops the compressor when it detects an overpressure. The HP cut-out is not automatically resettable and must be reset by the operator. This is because high

pressure is a serious fault that must be investigated and corrected before the system can be restarted.

• Low Pressure Cut Out

A low-pressure cut-out is provided to protect the compressor from low pressure in the system and to prevent air from entering the system if a vacuum is generated in the lines. When the solenoids cut off the air conditioner compartments and there is no return gas, the low pressure cut out is activated. When the solenoid of the air conditioner compartments opens, the return gas enters the compressor's inlet and the suction pressure rises, and the compressor's low pressure switch cuts in

Low Oil Pressure Cut Out

The oil is pumped under pressure by an attached oil pump, which supplies lubricant to the bearings. Any problem with the lube oil pressure can jeopardize the bearings, so a tapping from the pump outlet is taken and fed to the oil pressure switch. Any pressure drop will activate the cut-out, causing the compressor to stop.

• Oil Separator

Since oil is miscible with the air conditioner and frequently exits the compressor with it, it can enter the evaporator and reduce heat transfer. An oil separator is used to prevent oil from entering the evaporator and forming a layer or causing the obstruction. It consists primarily of baffle plates that separate the oil from the refrigerant and return it to the compressor. Afloat valve is provided to prevent the refrigerant from being short-circuited.
2.8.12 Undersize and Oversize Selection of HVAC Compressors and Its Implication to the System As Well As Cooling Rate Effect.

Airflow issues in HVAC systems can also be caused by incorrect size and design. To maintain the required temperature and humidity levels, an HVAC unit that is too small for a building, for example, may have to run for longer periods or cycle on and off more frequently. This will result in higher energy costs and a shorter lifespan for many components, including the compressor. Most airflow-related issues in HVAC systems are simple and affordable to resolve. Neglecting them, on the other hand, may result in decreased system efficiency, which appears as:

• Inadequate cooling

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The temperature surrounding the coil might drop below the freezing point due to a faulty component that obstructs airflow to the evaporator. When ice forms on the coil, it prevents heat transfer between the air and the refrigerant. As a result, to effectively cool the building, the system must work harder and longer.

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• Inadequate heating

Decreased airflow through the central heating system can cause the heat exchanger to overheat and fail to meet the pre-set limit. The high-limit control switch will turn off the burner as a safety precaution, allowing the heat exchanger to cool. If this happens frequently enough, the HVAC unit will be unable to produce the necessary heat to keep the building at the proper temperature. Higher operating and repair expenses will result from an inefficient HVAC system.

2.8.13 The risk of charging inappropriate refrigerant to the HVAC compressor system for example compressor designed for R22 gas is mistakenly injected with R407C.

• Low-Side Air Conditioner Compressor Motor Pressure

This is the pressure in the refrigerant suction line of the air conditioner (low side pressure during compressor operation), and it will be low, generally less than 100 psi. During operation, refrigerant from the cooling (evaporator) coil in this line returns to the compressor. The compressor might pull a real vacuum on the line if the suction line was connected directly to a sealed vacuum test gauge. The low side of an air conditioning system is always found inside the cooled space, or inside an air handler that transports air through the cooled space. The compressor allows liquid refrigerant to be discharged into the cooling coil on the "low side" of the air conditioning system by lowering the pressure in the cooling coil, where the change in refrigerant state from liquid to gas absorbs heat and brings the cooling coil to the proper operating temperature. The low-pressure and low-temperature side of a refrigeration system is known as the low side. This is usually the interior air handler, which is positioned inside the room to be cooled and is responsible for getting indoor air to working temperature

• High-Side Air Conditioner Compressor Pressure

The pressure of the compressed refrigerant gas as it leaves the compressor motor is known as output (high side pressure during operation). In other words, refrigerant gas returns to the compressor through the cooling coil's suction line (which is cooling building air). Inside the compressor motor, the low-pressure refrigerant gas is compressed into a highpressure refrigerant gas. This high-temperature refrigerant gas is subsequently cooled to form a refrigerant liquid, which is then returned to the air handler and evaporator coil to chill the building air. The compressor, condensing coil, and fan unit utilized to cool the condensing coil of an air conditioning system are positioned outside of the conditioned or refrigerated room and will be submerged in the air at the ambient outside temperature, say 72 °F. The high side of a refrigeration system is constantly above ambient temperature and operates at a greater (refrigerant) pressure. As a result, in a cooling system, it will be placed outside to transfer heat to the outside air. When in heating mode, a heat pump intended to pump heat into a building will, of course, invert these functions. If the compressor's requirements are not followed, such as refrigerant overcharge or refrigerant undercharge, it may result in a risky situation. Some of the risks are: -

- 1. Flooded condenser: Flooded condenser reduces capacity; in addition to generating excessive sub-cooling at the condenser output, this situation may cause the compressor to short cycle on the high-pressure cut-out.
- 2. Loss of cooling capacity: The system is no longer capable of maintaining the appropriate humidity and temperature conditions. AYSIA MELAKA

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- **3. Compressor motor overheating:** The compressor may not start or the circuit breaker may trip prematurely as a result of this. If left alone, the motor will ultimately burn out and stop working.
- **4. Liquid refrigerant enters the suction line:** Also known as "liquid slugging," this is a hazardous situation that can result in compressor damages.

Finally, undercharging or overcharging refrigerant gas might destroy an HVAC system. If this problem is not resolved immediately, the HVAC system may be put in jeopardy. Proper maintenance and assembly are required to guarantee that the danger is minimized.

2.9 Analytical Hierarchy Process

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making (MCDM) process that aids decision-makers faced with several contradictory and subjective criteria. Many intangibles influence decisions, and they must be balanced. To do so, they must be measured alongside tangibles, the measures of which must also be appraised in terms of how well they fulfil the decision maker's objectives. One of the main reasons for AHP's success is that the first two stages do not demand sophisticated understanding of mathematics or decision analysis from the decision maker. It is a theory of measurement that uses pairwise comparisons to establish priority scales and relies on the opinions of experienced professionals. These scales are used to calculate the relative value of intangibles. The comparisons are done using an absolute judgement scale that indicates how much more one element dominates another in terms of a specific feature. The judgement may be inconsistent, and the AHP is concerned about how to measure inconsistency and change judgments when possible to achieve better consistency. By multiplying the derived priority scales by the priority of their parent nodes and adding for all such nodes, the final priority scales are created. Psychologists are of the opinion that it is easier and more accurate to express one's opinion on only two alternatives than simultaneously on all the alternatives at any given time.

In an industrial setting, everyone is essentially a decision maker. Everything we do, whether consciously or unconsciously, stems from a decision. The data we collect is used to help us comprehend events so that we can make sound judgments and make decisions about them. In most cases, not all accessible data is helpful in increasing our understanding and judgement. If we solely make decisions based on intuition, we are prone to feel that any type of knowledge is beneficial, and that the more there is, the better. However, this is not always the case.

AHP was evolved to optimize decision making when one is faced with a mix of qualitative, quantitative, and sometimes conflicting factors that are taken into consideration. It has been very effective in making complicated decisions. Profound decision-making involves weighing all the factors that are significant. Present Day decision making has been inherently complex when many factors have to be weighed against competing priorities. One of the modern tools developed in the last 30 years used to assess, prioritize, rank, and evaluate decision choices is the Analytic Hierarchy Process. It uses matrix algebra to sort out factors to arrive at a mathematically optimal solution. The outputs include ratio scales and consistency indices derived by computing Eigen values and eigenvectors. Based on the values of these indices, a decision is termed as logically correct or incorrect.



CHAPTER 3

METHODOLOGY

3.1 Introduction

In this study, structure integrity is assessed through the identification of Analytical hierarchy process (AHP) in HVAC systems in order to reduce energy consumption, increase system reliability, and discover system defects, as well as provide optimum maintenance practice for the system. It's critical to keep the HVAC support system in good working order so that it can last longer and continue to provide excellent service. This is possible if you combine it with excellent maintenance. One strategy for preventing systematic mistake is the Analytical Hierarchy Process (AHP). The method's early detection of the system's problem has made it popular to use because it detects the problem earlier in the design phase. The Analytical Hierarchy Process (AHP) method was developed for semi-hermetic compressors used in Malaysian oil and gas offshore to determine the optimal maintenance strategy for extending compressor life. The AHP Method is used in this thesis to assign risk severity, occurrence, and detection ratings to the compressor listed. To conduct the research, an analysis table was constructed based on a maintenance report from a company in the oil and gas industry. The AHP Method techniques assist in defining, priorities, and selecting the appropriate maintenance strategy for semi hermetic compressors in order to achieve high system reliability.

3.2 Project Flowchart



Figure 11 An overview of the AHP method

3.3 Proposed Methodology

Step 1 – Define the problem for Semi Hermetic compressor

Data was gathered for the study by reading maintenance records produced by the maintenance service. Observation of failure mode occur in the maintenance report data then are conclude into the FMEA table and are categorized by the type of sub-system. Then each of failure mode are listed and assigned by their severity, Occurrence and detection rating lastly the RPN number are calculate.



Figure 12 Maintenance repor

Step 2 – FMEA table

The compressors condition was investigated based on gathering data in industrial report for semi hermetic compressor. It includes all compressors, whether they are new, old, or still under warranty. All of the compressors were affected by the failure. After all of the data has been obtained, an FMEA worksheet paper is created by inserting the data onto the paper. In the worksheet, the required details about failed components and prospective failure were noted and analysed further.

Step 3 – Pareto Analysis

Based on the result that we obtain from the FMEA table, Analyze the failure mode versus RPN number through the Pareto graph and Pie Chart for clear description of the Failure Modes and Effects Analysis of the semi hermetic compressor. This technique helps to identify the top portion of cause that need to be addressed to resolve the majority of problems. Refer to Pareto as 80/20 rule, under the assumption that in all situations 20% of causes determine 80% of problems. This ratio is merely a convinient rule of thumb and is not, nor should it be considered, an immutable law of nature.

Step 4 - Construction of the Hierarchy Tree

Before moving forwards a "Hierarchical Decision Tree" for the HVAC compressor to select the best maintenance approach developed and shown as below figure. The Hierarchy Tree contains 4 core levels from the top level of the first row stated Level 1 determines the goal or aim which is the maintenance approach for the compressor. While level 2 and level 3 are the criteria and sub-criteria associated with the maintenance approach and to the bottom of level 4 are the alternatives of the maintenance strategy to be achieved.



Step 5 – Pair-wise Comparison matrix

The Hierarchy has been completed and the next move is to establish the relative intensity of importance between the main criteria and sub-criteria by comparing both in the form of pairs. It's a crucial step before moving forward of conducting the analysis. Referring to the below figure the intensity of a nine-point scale is used to measure the relative importance of the items in each set of the hierarchy comparison with their corresponding group members. No ''Right'' or ''Wrong'' chose during comparing the items. However, when choosing between two items, should be noted of which preference are more important over another item on the same level of the hierarchy. While another aspect is to assign a numerical value to quantify the judgment on a scale of 1 to 9.

Judgment scores in and towards consistency measure in AHP which no 2,4,6,8 represent the intermediate values.



The pairwise judgments are later written in a decision matrix based on theoretical knowledge of AHP analysis. The following equation shows an algebraic representation of a comparison matrix.

$$\mathbf{A} = \begin{bmatrix} \mathbf{a}_{11} & \mathbf{a}_{12} & \cdots & \mathbf{a}_{1n} \\ \mathbf{a}_{21} & \mathbf{a}_{22} & \cdots & \mathbf{a}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \mathbf{a}_{n1} & \mathbf{a}_{n2} & \cdots & \mathbf{a}_{nn} \end{bmatrix}.$$

The decisions or relative value of alternatives are represented as a matrix in the above matrix "A," where "n" is the number of items being evaluated. The entries of matrix "A," i.e. aij, are relative decisions between the two alternatives I and j, with the ith row corresponding to the jth column of "A." Equations depict the attributes as follows:



Where the relative weight of the alternative I is shown

Step 6 - Deriving Relative Weights

This move necessitates the calculation of relative weights for each of the decision hierarchy's criteria and sub-criteria. Many methods for estimating relative weights from a comparison matrix have been developed by researchers. Relative weights are usually calculated using eigenvector and logarithmic methods. As a pioneer of AHP, Saaty (1991) proposed the eigenvector form, which is derived. "A" in an equation can be represented as below.

С	A_1	A ₂	A ₃	 A _n
A ₁	w_1/w_1	w_1/w_2	w_1/w_3	 w_1/w_n
A_2	w_2/w_1	w_2/w_2	w_2/w_3	 w_2/w_n
	w_3/w_1	w_3/w_2	w_3/w_3	 w_3/w_n
A ₃				
'				,
A _n	w_n/w_1	w_n/w_2	w_n/w_3	 w_n/w_n

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The goal is to find eigenvalues "," where is the number of eigenvalues.

 $w=\left(w_1,w_2,w_3,\ldots,w_n\right),$

Despite the existence of several other methods, the geometric mean is thought to be the best option for generating the eigenvector. It's worked out by multiplying each row of the matrix above. Take the nth root of the multiplication since there are "n" entries. Finally, the normalized roots are calculated by calculating the sum and then dividing it by the total result.

Step 7- Checking the Consistency Ratio

The "Consistency Ratio" (CR) is a critical component of AHP. The allowable value of consistency ratio is closely linked to the best decision-making in pairwise contrast. This move serves as a starting point for observing the decision matrix's consistency and inconsistency. For pairwise comparisons, cardinal and ordinal consistency checks are usually used. If a is greater than b and b is greater than c, then a must be greater than c, according to ordinal consistency. Cardinal consistency, on the other hand, notes that a stronger relationship between the factors to be evaluated is necessary. If a is two times more important than b and b is three times more important than c, a should be six times more

important than c in this situation. An index was created to test the accuracy of weights to determine the consistency ratio. In this case, the appropriate CR range should be less than or equal to 0.10. However, a re-evaluation of the pairwise comparison is needed. Calculation of consistency:

 $V_{max} =$

Consistency Index (C.I) = $\frac{(V_{max}-n)}{n-1}$ =

Where n is the number of compared elements

Consistency Index (C.I) =

Consistency Ratio = $\frac{(Consistency Index, C.I)}{(Random Index, RI)} = \frac{(0)}{(0)} =$

Consistency Ratio (CR) = 0 < 0.10 (Consistent)

	61				/	1 ¹				
n	1 -	20 4	3.10	4	5	6	اسيح	ريبو.8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Step 8 - Synthesizing Results

On all hierarchy stages, the final step begins with the summation of relative values for each set of alternatives. These values are added together to determine each alternative's total score or requirements weight. As a result of this additional function, the normalized local priority vectors are obtained. The final goals are now synthesized by combining the results of local priorities. The aggregation process begins at the bottom of the hierarchy and works its way up to the highest-level target. It's worth noting that the number of all alternative weights and their related importance equals 1.00. A simplified arithmetical formulation for aggregation of requirements weights at different levels of hierarchy is shown in the following equation:



3.3.1 Parameters

3.3.1.1 FMEA parameter

Probability of failure	Possible failure rates	Ranking				
	. 1 . 2	10				
Very high: failure is almost	>1 in 2	10				
inevitable	1 in 2	0				
	1 111 5	7				
High: repeated failures	1 in 8	8				
	1 in 20	7				
Moderate: Occasional	1 in 80	6				
failures	110					
EKIIIK	1 in 400	5				
	1 in 2000	4				
Low: Relatively few	1 in 15,000	3				
failures المسالك	تر تنکنک	levin, mar				
44 F	U 1 in 150,000 C	2				
UNIVERSITI	TEKNIKAL MALAYSI	A MELAKA				
Remote: Failure is unlikely	< 1 in 1,500,000	1				

 Table 8 : Typical occurence evaluation criteria

Effect	Criteria: severity of effect	Ranking
Hazardous-without	Very high severity ranking when a potential failure	10
warning	mode affects safe operation and/or involves	
	noncompliance with regulations without warning	
Hazardous- with	Very high severity ranking when a potential failure	9
warning	mode affects safe operation and/or involves	
	noncompliance with regulations with warning	
Very high	Product/item inoperable with loss of primary function	8
High	Product/item operable, but a reduced level of	7
	performance. Customer dissatisfied	
Moderate	Product/item operable, but may cause rework/repair	6
	and/ or damage to equipment	
Low	Product/item operable, but may cause slight	5
E BARR	inconvenience to related operations	
Very low	Product/item operable, but possesses some defects	4
ملاك	(aesthethic and otherwise) noticeable to most	
UNIVE	customersEKNIKAL MALAYSIA MELAKA	
Minor	Product/item operable, but may possess some defects	3
	noticeable by discriminating customers	
Very minor	Product/item operable, but is in incompliance with	2
	company policy	
None	No effect	1

 Table 9 : Typical severity evaluation criteria

Detection	Criteria: Likelihood of detection by design	Ranking
	control	
Absolute	Design control will not and/ or can not detect	10
uncertainly	a potential cause/mechanism and subsequent	
	failure mode, or there is no design control	
Very remote	Very remote chance the design control will	9
	detect a potential cause/mechanism and	
	subsequent failure mode	
Remote	Remote chance the design control will detect	8
	a potential cause/mechanism and subsequent	
	failure mode	
Very low	Very low chance the design control will	7
	detect a potential cause/mechanism and	
AL M	subsequent failure mode	
Low	Low chance the design control will detect a	6
TE	potential cause/mechanism and subsequent	
Her	failure mode	
Moderate Moderate	Moderate chance the design control will	5
5Me	detect a potential cause/mechanism and	Inial
	subsequent failure mode	7.2
Moderately high	Moderately high chance the design control	AKA ⁴
	will detect a potential cause/mechanism and	
	subsequent failure mode	
High	High chance the design control will detect a	3
	potential cause/mechanism and subsequent	
	failure mode	
Very high	Very high chance the design control will	2
	detect a potential cause/mechanism and	
	subsequent failure mode	
Almost certain	Design control will almost certainly detect a	1
	potential cause/mechanism and subsequent	
	failure mode	

Table 10 : Typical detection evaluation criteria

3.3.1.2 AHP parameter

	Definition	Intensity of Importance
	Equal Important	1
	Equal to Moderate Importance	2
	Moderate Importance	3
	Moderate to Strong Importance	4
Ser. B	Strong Importance	5
TEKII	Strong to Very Strong Importance	6
TISTA .	Very Strong	
للك	Very Strong to Extreme Importance	اونيوبر ۽سيتي
UNIV	ERS Extreme Importance ALA	YSIA MELAKA 9

 Table 11 : AHP numeric scale

3.3.2 Equipment

The Super Decisions educational software, which was built by the method's originator. The Foundation is a private 501(c)(3) organization dedicated to educate individuals around the world in order to help them make better reasonable decisions. The Foundation supports advanced decision-making teaching, research, and software development using the AHP. Human judgement is utilized to measure intangibles utilizing the Analytic Hierarchical Process (AHP). The AHP synthesis approaches are the most potent for combining judgement

and data to rank options and forecast outcomes. Rather of prescribing a "right" answer, these strategies assist decision-makers in identifying the optimal solution for their objective and understanding of the problem. It provides a complete and rational framework for constructing a decision problem, expressing and measuring its aspects, linking them to broader goals, and assessing potential solutions.



3.4 Limitation of Proposed Methodology MALAYSIA MELAKA

- 1. The AHP Method are made based on the obtained data from Super Decision software.
- All the AHP Method for semi hermetic compressor are made only on Super Decision software.

3.5 Summary

Finally, decision-making demands a broader and more complex understanding of the environment than the use of a single technique. It is assumed that a portfolio decision is the result of negotiations, human factors, and strategic analysis, in which methods such as AHP aid and direct job execution for better analysis results when compared to other MCDM will be able to reduce error and provide strong evidence in strategy selection.



CHAPTER 4

RESULT AND DISCUSSION

In Chapter 4, we have investigated the most important criteria and considerations for semi hermetic compressor maintenance strategy while generalizing our ahp-based approach from industrial maintenance report. In this report also, we generate FMEA table, pareto analysis and analytical hierarchy process to define the weight of priority for each component in semi hermetic compressor.



4.1 Company A case study

4.1.1 FMEA table of company A semi hermetic compressor

N 0	Proces s input	Item fault	Compon ent	Failure mode	Failure effects	Severity	Failure cause	Occurrence	Current controls	Detection	RP N
1	Electri	Stator and rotor fault	Winding	Melting	shortage	9	Overheating of the start windings and rapid failure	1	Replace new compressor	2	18
			Rotor	Corrod e, scratch and damage	Weaken rotor over time and decrease rotor power	9	Makes the noisy sound	2	Replace new motor	1	18
2	Electri cal	Compress or crankcase damage	Compres sor crankcas e heater	Leakag e and damage	Refrigerant entering the crankcase	3	will then be vaporized and driven back into the suction line	5 K	Replace/repair use tape	2	30

3	Mecha nical	Oil Sight glass dirty	Oil sight glass	Dirty	Compressor oil does not return back	3	Insufficient compressor oil	7	Clean internal oil sight glass	5	105
4			Piston head	Damag e	Have the nocking debris off suction valve plate	8	Faulty cylinder head components	2	Replace new compressor	1	16
	Mecha nical	Piston fault	Piston ring (oil & compress ion)	Wear	Flood back in system, with extreme refrigerant overcharge and or oil separators	8	High pressure ratio and very high refrigerant charge	2	Replace new compressor	1	16
			Bore piston body	Very Deep scratch/ damage	Suction valve debris at bore piston body	6	Excessive rocking of the piston	2	Repolish bore body/Replacepiston newcompressor	2	24
			Piston and rod assembly	Wear and damage	Inadequate lubrication	8	Overheating and poor oil return due to low charge or low flowrate	2	Replace new piston and rod assembly	2	32
5	Mecha nical	Crankshaf t fault	Cranksha ft	Scratch	Debris in crankshaft	9	Compressor system failed	1	Change new compressor crankshaft	1	9
			Cranksha ft	Missing	Compressor cannot run	7	Compressor system failed	1	Replace new crankshaft	1	7

			Cranksha ft	Dirty	Crankshaft wear	6	Defective lubrication on journals	1	Clean crankshaft	3	18
			Terminal box assembly	Damag e	Shortage of refrigerant	7	A short circuit occurs	3	Suggest changing new terminal box	2	42
6	Electri cal	Terminal fault	Terminal plate assembly	Corrod e	Refrigerant circuit clogging	7	Liquid refrigerant flood back	2	Change new terminal plate	2	28
			Terminal	Corrod e	Drain power out of compressor	6	Compressor system cannot run properly and current trip on terminal	3	Clean terminal	2	36
7	Mecha nical	Cylinder head fault	Cylinder head- Centre bank	Corrod e and scratch		7	Compressor overheating	2	Clean cylinder head- centre bank corroded	1	14
			Cylinder head- side bank	Corrod e and scratch	Piston ring damage	8	Drop in compressor performance	1	Clean the corroded	1	7

											1
8	Mecha nical	Internal relief valve fault	Internal relief valve	Corrod e	Damage to other part of system	7	Maximum operating pressure of the compressor failure	3	Clean internal relief valve	3	63
9	Mecha nical	Bottom cover fault	Bottom cover	Dirty/c orroded	Loss of reinforcement area and damage in the surrounding concrete	4	Bottom cover gasket can eventually fail due to friction or constant exposure to heat	3	Clean bottom cover	1	12
1 0	Mecha nical	Pump and bearing fault	Pump end bearing head assembly	Corrod e	Contamination	8	Mechanical damage in system	1	Change new pump end bearing head assembly	2	16
			Bearing sleeve	Corrosi on	Damage to bearing	6	Chemical and electrochemical reactions between the surface	2	Suggest replacing a new one	2	24
1 1	Mecha nical	Oil pump fault	Oil pump	Dirty		7	Poor performance	4	Clean oil pump	3	84
1 2	Mecha nical	Valve plate wear	Valve plate	Wear	Debris in cylinder	8	Mechanical damage to piston and valves	3	Change new valve plate	4	96
			1			1	1				715

Table 12: FMEA table of company A

4.1.2 Pareto analysis

NO.	Forms of fault or	RPN	Relative	Cumulative	
	failures		Number	frequency	
				(%)	
1	Terminal fault	106	15.00%	15.00%	
2	Oil sight glass dirty	105	15.00%	30.00%	
3	Valve plate wear	96	13.00%	43.00%	
4	Piston fault	88	12.00%	55.00%	
5	Oil pump fault	bil pump fault 84 12.00%		67.00%	
6	Internal relief valve fault	63	9.00%	76.00%	
7	Pump and bearing fault	40	6.00%	82.00%	
8	Stator and rotor fault	36	5.00%	87.00%	
9	Crankshaft fault	34	5.00%	92.00%	
10	Compressor crankcase				
	heater damage	30	4.00%	96.00%	
11	Cylinder head fault	21	3.00%	99.00%	
12	Bottom cover fault	12	1.00%	100.00%	
	UNIVERSITI TEKN	Total: 715	YSIA MEL	AKA	
		Table 1.4			

The fault of failure were sorted from highest to lowest frequency, and the relative frequency for each was determined (table). For example, terminal fault was 106 out of 715 fault of failures, and so the relative frequency for size out of specification was:

106/715 x 100 = 15%

An optional final step is to calculate cumulative relative frequency. Cumulative relative frequency helps the user to readily see the combined effect of the vital few problems. For example, you could see that the top six problems were responsible for nearly 80 percent of the problem overall. To calculate cumulative relative frequency, add the relative frequency for each category of fault of failure to the sum of all preceding relative frequencies. For

example the were 106 occurence of terminal fault or 15 percent (relative frequency) of the total. There were same occurence with oil sight glass dirty fault. Oil sight glass diry, was therefore responsible for 15 percent of the total. terminal fault and oil sight glass dirty combined (cumulative relative frequency) were responsible for 30 percent of the total. size out terminal fault, oil sight glass dirty, valve plate wear, piston fault, oil pump fault and internal relief valve fault combined were responsible for 76 percent of the total. The cumulative relative frequency for the least frequent category bottom cover fault, in this example should be 100 percent. (Table) shows the terminal fault arranged in descending order of frequency and with relative frequency and cumulative relative frequency calculated.





Figure 1.0 Pareto analysis of failure mode occur on Semi Hermetic Compressor

To carry out this analysis, a failure mode effect analysis (FMEA) table was created based on Petronas Carigali Sdn Bhd maintenance reports. The analysis focused on component in HVAC which is semi hermetic compressor of refrigeration systems. This inquiry allowed for a through evaluation of the primary failure modes for semi- hermetic compressors while they were in used in oil and gas industry.

The results of the analysis shown in Pareto Chart and Pie Chart by using pareto analysis method. Pareto Analysis is a statistical technique in decision making that is used for the selection of a limited number of tasks that produce significant overall effect. Pareto Analysis use pareto principle also know as the 80/20 rule mean the idea that by doing 20% of the work generate 80% of the benefit of doing the whole job.

(Figure) is the pareto chart for the data in (table). The left vertical axis indicates the number (frequency) of each type of fault of failure for component. Always plot fault of failure in descending order of frequency, with the most frequent at the left vertical axis. The right axis indicates cumulative frequency.

The pareto chart make it easy to see that terminal fault, oil sight glass dirty, valve plate wear, piston fault, oil pump fault and internal releif valve are the major fault of failure. Maintenance strategy that focus on these failure will give the biggest bang for the buck.



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When constructing the criteria hierarchy, we draw on a ealier version of the hierarchy that was utilised for multi-criteria decision making in (figure) The starting criteria for this semi hermetic compressor hierarchy are based on industry reports from two oil and gas companies. We go through various processes to build the hierarchy. Most essential, when creating the hierarchy chart, make a list of all the electrical and mechanical failures in the compressor.

The goal of the decision hierarchy is to select the best maintenance policy. We maintain the general structure for the hierarchy, because it was found to be clear and understandable. The hierarchy starts with goals and eneath these two top level criteria, the hierarchy is structured into twelve sub-criteria and the alternatives is three best maintenance strategy for semi hermetic compressor. The goals into electrical component and mechanical component was well-received. Therefore, we keep this top level of criteria in the hierarchy. Electrical component focusses on the maintenance for electrical part, while mechanical focusses on the mechanical part in semi hermetic compressor.



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In this result, an analytical hierarchy method was used with super decision software to generate the outcomes and data based on failure mode effect and analysis and pareto analysis. We findings a semi hermetic compressor that have twelve components can fail and potentially harm the refrigerant system based on the data we obtained. We employ an analytical hierarchy process numeric scale rating to evaluate which is more significant. Each component is evaluated using an analytical hierarchy process numeric scale, and the results must be entered into the super decision programme.

Goal

Normalization of the pairwise calculation matrix

Goal	Electrical	Mechanical component		
	component			
Electrical	1	3		
component				
Mechanical component	0.3333	1		

Goal	Electrical	Mechanical	Weight
WALAYSI,	component	component	
Electrical	0.75	0.75	0.75
component	AKA		
Mechanical component	0.25	0.25	0.25
1111 1111			
Wn -			

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Goal	Electrical	Mechanical		
	component	component		
Criteria weight	0.25	0.75	Weight sum	
			value	
Electrical	0.25	0.25	0.5	2
component				
Mechanical	0.75	0.75	1.5	2
component				

Calculation of consistency:

$$V_{max} = \frac{(2+2)}{2} = 2$$
Consistency Index (C.I) = $\frac{(V_{max} - n)}{n-1} = \frac{(2-2)}{2-1} = 0$
Where n is the number of compared elements
Consistency Index (C.I) = 0
Consistency Ratio = $\frac{(Consistency Index, C.I)}{(Random Index, RI)} = \frac{(0)}{(0)} = 0$

Consistency Ratio (CR) = 0 < 0.10 (Consistent)

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Main criteria (electrical component)

Main criteria	Compressor	Stator and motor	Terminal fault
(Electrical	crankcase damage	fault	
component)			
Compressor	1	0.166	0.333
crankcase damage			
Stator and rotor	6	1	2
fault			
Terminal fault	3	0.5	1
L MAL	AYSIA 44		

Pair-wise comparison matrix of the criteria concerning the Main Criteria.

Normalization of the pairwise calculation matrix

Main criteria	Compressor	Stator and	Terminal	Weight
(Electrical	crankcase	motor fault	fault	
component)	damage			
500	2 alumita 12		aug mar	
Compressor	. 0.1	0.1	0.1	0.1
crankcase	ERSITI TEKNI	KAL MALAYS	IA MELAKA	
damage				
Stator and	0.6	0.6	0.6	0.6
rotor fault				
Terminal fault	0.3	0.3	0.3	0.3

Weight	0.1	0.6	0.3		
Main	Compressor	Stator and	Terminal	Weighted	
criteria	crankcase	motor fault	fault	sum value	
(Electrical	damage				
component)					
Compresso	0.1	0.1	0.1	0.3	3
r crankcase					
damage					
Stator and	0.6	0.6	0.6	1.2	3
rotor fault					
Terminal	0.3	0.3	0.3	0.9	3
fault	WALAYSIA	Ale.			

Calculation of consistency:

$$V_{max} = \frac{3+3+3}{3} = 3$$
Consistency Index (C.I) = $\frac{(V_{max}-n)}{n-1}$

tency Index (C.I) = $\frac{(V_{max} - n)}{n-1} = \frac{(3-3)}{3-1} = 0$ UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Where n is the number of compared elements

Consistency Index (C.I) = 0

Consistency Ratio = $\frac{(Consistency \, Index \, , C.I)}{(Random \, Index \, , RI)} = \frac{(0)}{(0.58)} = 0$

Consistency Ratio (CR) = 0 < 0.10 (Consistent)

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Main criteria (Mechanical Compressor)

Main	er	æ		е	-	ass	lt	l ult	e
Criteria	cov llt	shaf lt	ider faul	'nal valv	ump lt	t glå ty	fau	and g fau	plat ar
(Mechanical	tom fau	ank fau	ylir ead	inter lief	il p fau	sigh dir	ston	ump ırinş	alve we:
Component)	Bot	C	े व	l re	0	Oil	Pi	P	V.
Bottom	1	0.2	0.5	3	1	2	0.25	1	0.333
cover fault									
Crankshaft	5	1	3	8	6	7	1	4	2
fault									
Cylinder	2	0.333	1	5	3	4	2	1	1
head fault	101	YSI							
Internal	0.333	0.125	0.2	1	0.5	1	0.142	0.25	0.166
relief valve	7		E.		L .				
fault 🖁									
Oil pump	1	0.166	0.333	2	1	17	0.2	0.5	0.25
fault	**AINO								
Oil sight 🚽	0.5	0.142	0.25	1.4	1	1	0.166	0.333	0.2
glass dirty		1.1	0	-	-1	S.	13.	2	
Piston fault	NIV4ER	SI‡I T	0.5	KÆL I	AA5_A	(S64 N	IELA	KA ³	1
Pump and	1	0.25	1	4	2	3	0.333	1	0.5
bearing									
fault									
Valve plate	3	0.5	1	6	5	1	2	1	1
wear									
Sum	17.833	3.716	7.783	37	24.5	26	7.091	12.083	6.449

Pair-wise comparison matrix of the criteria concerning the Main Criteria
Main			t	e				P 0		
Criteria	fault	£	faul	valv	ult	SSI	t	uring	/ear	
(Mechanic	ver	shaf lt	lead	elief ult	ıp fa	it gl: ty	fau	l bea	ite w	ght
al	n co	ank fau	ler h	al re fau	und	sigh dir	ston	and fau	e pla	Wei
Compone	ottor	C	lind	tern	Oil	Oil	Pi	duu	'alvo	
nt)	B(Cy	Int				Pı		
Bottom	0.056	0.053	0.064	0.081	0.040	0.076	0.035	0.082	0.051	0.059
cover fault										
Crankshaf	0.280	0.269	0.385	0.216	0.244	0.269	0.141	0.331	0.310	0.269
t fault										
Cylinder	0.112	0.089	0.128	0.135	0.122	0.153	0.282	0.082	0.155	0.144
head fault		MALA	YSIA .							
Internal	0.018	0.033	0.025	0.027	0.020	0.038	0.020	0.020	0.025	0.025
relief	KW			KA						
valve fault	TE									
Oil pump	0.056	0.044	0.042	0.054	0.040	0.038	0.028	0.041	0.038	0.042
fault		Ann								
Oil sight	0.028	0.038	0.032	0.027	0.040	0.038	0.023	0.027	0.031	0.031
glass dirty		4	ang particular and a second se	<u> </u>		- Q	. V			
Piston	0.224	0.269	0.064	0.189	0.204	0.230	0.141	0.248	0.155	0.188
fault										
Pump and	0.056	0.067	0.128	0.108	0.081	0.115	0.046	0.082	0.077	0.083
bearing										
fault										
Valve	0.168	0.134	0.128	0.162	0.204	0.038	0.282	0.082	0.155	0.155
plate wear										

Weight	0.059	0.269	0.144	0.025	0.042	0.031	0.188	0.083	0.155		
Main Criteria (Mechanical Component)	Bottom cover fault	Crankshaft fault	Cylinder head fault	Internal relief valve fault	Oil pump fault	Oil sight glass dirty	Piston fault	Pump and bearing	Valve plate wear	Weight sum	
Bottom cover fault	0.059	0.053	0.072	0.075	0.042	0.062	0.047	0.083	0.051	0.544	9.22
Crankshaft fault	0.295	0.269	0.432	0.2	0.252	0.217	0.188	0.332	0.31	2.495	9.275
Cylinder head fault	0.118	0.089	0.144	0.125	0.126	0.124	0.376	0.083	0.155	1.34	9.305
Internal relief valve fault	0.019	0.033	0.028	0.025	0.021	0.031	0.026	0.02	0.025	0.228	9.12
Oil pump fault	0.059	0.044	0.047	0.05	0.042	0.031	0.037	0.041	0.038	0.389	9.261
Oil sight glass dirty	0.029	0.038	0.036	0.025	0.042	0.031	0.031	0.027	0.031	0.29	9.354
Piston fault	0.236	0.269	0.072	0.175	0.21	0.186	0.188	0.249	0.155	1.74	9.255
Pump and bearing fault	0.059	0.067	0.144	0.1	0.084	0.093	0.062	0.083	0.077	0.769	9.265
Valve plate wear	0.177	0.134	0.144	0.15	0.21	0.031	0.376	0.083	0.155	1.46	9.419

$$V_{max} = \frac{(9.220 + 9.275 + 9.305 + 9.12 + 9.261 + 9.354 + 9.255 + 9.265 + 9.419)}{9} = 9.274$$

UNIVERSITI TEKNIKAL MALAYSIA MELAKA Consistency Index (C.I) = $\frac{(V_{max}-n)}{n-1} = \frac{(9.274-9)}{9-1} = 0.034$

Where n is the number of compared elements

Consistency Index (C.I) = 0.034

Consistency Ratio = $\frac{(Consistency \, Index \, ,C.I)}{(Random \, Index \, ,RI)} = \frac{(0.034)}{(1.45)} = 0.023$

Consistency Ratio (CR) = 0.023 < 0.10 (Consistent)

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Sub criteria to Alternatives (Electrical) Stator and rotor

Stator and Rotor	Corrective	Predictive	Preventive
	Maintenance	Maintenance	Maintenance
Corrective	1	3	0.5
Maintenance			
Predictive	0.333	1	0.2
Maintenance			
Preventive	2	5	1
Maintenance			

Pair-wise comparison matrix of the criteria concerning the sub criteria to alternatives:

Stator and	Corrective	Predictive	Preventive	Weight
Rotor	Maintenance	Maintenance	Maintenance	
Corrective	0.3	0.333	0.294	0.309
Maintenance	Samn .			
Predictive	0.1	0.111	0.117	0.109
Maintenance	ل میسیا مار	- in the	يتور سيبي م	91
Preventive	IVER ^{0.6} TI TEI	0.555	AYSIA.588	0.581
Maintenance				

Weight	0.309	0.109	0.581		
Stator and	Corrective	Predictive	Preventive	Weight	
rotor	Maintenance	Maintenance	Maintenance	sum	
				value	
Corrective	0.309	0.327	0.290	0.926	2.996
Maintenance					
Predictive	0.102	0.109	0.116	0.327	3
Maintenance					
Preventive	0.618	0.545	0.581	1.744	3.001
Maintenance					

 $V_{max} = \frac{(2.996 + 3 + 3.001)}{3} = 2.999$

Consistency Index (C.I) = $\frac{(V_{max} - n)}{n-1} = \frac{(2.999 - 3)}{3-1} = 0.0005$

Where n is the number of compared elements

Consistency Index (C.I) = 0.0005

Consistency Ratio = $\frac{(Consistency \, Index \, ,C.I)}{(Random \, Index \, ,RI)} = \frac{(0.0005)}{(0.58)} = 0.00086$

Consistency Ratio (CR) = 0.00086 < 0.10 (Consistent)

n	1	2	3	45	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49
		So.								•
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			1							
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Compressor Crankcase

Compressor	Corrective	Predictive	Preventive
crankcase damage	Maintenance	Maintenance	Maintenance
Corrective	1	3	0.5
Maintenance			
Predictive	0.333	1	0.2
Maintenance			
Preventive	2	5	1
Maintenance			
Sum	3.333	9	1.7

Pair-wise comparison matrix of the criteria concerning the sub criteria to alternatives:

Compressor	Corrective 🗧	Predictive	Preventive	Weight
crankcase 🗒	Maintenance	Maintenance	Maintenance	
damage 💈			JIVI	
Corrective	⁴⁴ /4n 0.3	0.333	0.294	0.309
Maintenance	J. ahund al	تنكنك	ونوم سنخ	
Predictive	· 0.1 · ·	0.111	0.117	0.109
Maintenance	IVERSITI TEK	NIKAL MALAY	SIA MELAKA	
Preventive	0.6	0.555	0.588	0.581
Maintenance				

Weight	0.309	0.109	0.581]	
Compressor	Corrective	Predictive	Preventive	Weight	
crankcase	Maintenance	Maintenance	Maintenance	sum	
damage				value	
Corrective	0.309	0.327	0.290	0.926	2.996
Maintenance					
Predictive	0.102	0.109	0.116	0.327	3
Maintenance					

Preventive	0.618	0.545	0.581	1.744	3.001
Maintenance					

$$V_{max} = \frac{(2.996 + 3 + 3.001)}{3} = 2.999$$

Consistency Index (C.I) = $\frac{(V_{max}-n)}{n-1} = \frac{(2.999-3)}{3-1} = 0.0005$

Where n is the number of compared elements

Consistency Index (C.I) = 0.0005

Consistency Datio -	(Consistency Index ,C.I)	(0.0005) _ 0 (0006	
	(Random Index ,RI)	- (0.58) $-$ 0.0	10080	
E C				
Consistency Ratio (C	$(\mathbf{R}) = 0.00086 < 0.10$	(Consistent)		

Consistency Ratio (CR) = 0.00086 < 0.10 (Consistent)

n	1	2 2 11	3	4	5	6	7	8	9	10
RI	0	9	0.58	0.9 <	1.12	1.24	1.32	1.41	1.45	1.49
			45 45	0			Q	0		

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Terminal Fault

Terminal fault	Corrective	Predictive	Preventive	
	Maintenance	Maintenance	Maintenance	
Corrective	1	3	0.5	
Maintenance				
Predictive	0.333	1	0.2	
Maintenance				
Preventive	2	5	1	
Maintenance				

Pair-wise comparison matrix of the criteria concerning the sub criteria to alternatives:

Terminal fault	Corrective	Predictive	Preventive	Weight
LINE AND A	Maintenance	Maintenance	Maintenance	
Corrective	0.3	0.333	0.294	0.309
Maintenance				
Predictive	⁴ /4n 0.1	0.111	0.117	0.109
Maintenance	J. alunda J	تنكنك	ونوم ست	
Preventive	* 0.6*	0.555	0.588	0.581
Maintenance N	IVERSITI TEK	NIKAL MALA	SIA MELAKA	

Weight	0.309	0.109	0.581]	
Terminal	Corrective	Predictive	Preventive	Weight	
fault	Maintenance	Maintenance	Maintenance	sum	
				value	
Corrective	0.309	0.327	0.290	0.926	2.996
Maintenance					
Predictive	0.102	0.109	0.116	0.327	3
Maintenance					
Preventive	0.618	0.545	0.581	1.744	3.001
Maintenance					

 $V_{max} = \frac{(2.996 + 3 + 3.001)}{3} = 2.999$

Consistency Index (C.I) = $\frac{(V_{max}-n)}{n-1} = \frac{(2.999-3)}{3-1} = 0.0005$

Where n is the number of compared elements

Consistency Index (C.I) = 0.0005

Consistency Ratio = $\frac{(Consistency \, Index \, , C.I)}{(Random \, Index \, , RI)} = \frac{(0.0005)}{(0.58)} = 0.00086$

Consistency Ratio (CR) = 0.00086 < 0.10 (Consistent)

n	1	2	3	4 5	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49
		E.								
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Sub criteria to Alternatives

Oil Sight Glass

Pair-wise comparison matrix of the criteria concerning the sub criteria to alternatives:

Oil Sight Glass	Corrective	Predictive	Preventive	
	Maintenance	Maintenance	Maintenance	
Corrective	1	2	0.5	
Maintenance				
Predictive	0.5	1	0.25	
Maintenance				
Preventive	2	4	1	
Maintenance				

WALAYS/4

Oil Sight Glass	Corrective 🏅	Predictive	Preventive	Weight
I TE	Maintenance	Maintenance	Maintenance	
Corrective	0.285	0.285	0.285	0.285
Maintenance	Alun			
Predictive	کے ما0.142 مار	0.142	و سو0.142 سن	0.142
Maintenance	0		· · · · · · ·	
Preventive	VERSIT TEK	NIKALAY	SIA MELAKA	0.571
Maintenance				

Weight	0.285	0.142	0.571		
Oil Sight	Corrective	Predictive	Preventive	Weight	
Glass	Maintenance	Maintenance	Maintenance	sum	
				value	
Corrective	0.285	0.284	0.285	0.854	2.996
Maintenance					
Predictive	0.142	0.142	0.142	0.426	3
Maintenance					

Preventive	0.57	0.568	0.571	1.709	2.992
Maintenance					

$$V_{max} = \frac{(2.996 + 3 + 2.992)}{3} = 2.996$$

Consistency Index (C.I) = $\frac{(V_{max} - n)}{n-1} = \frac{(2.996 - 3)}{3-1} = 0.002$

Where n is the number of compared elements

Consistency Index (C.I) = 0.002

Consistency Ratio = $\frac{(Consistency \, Index \, , C.I)}{(Random \, Index \, , RI)} = \frac{(0.002)}{(0.58)} = 0.0034$ Consistency Ratio (CR) = 0.0034 < 0.10 (Consistent)

n	1	2 ^{*4/40}	3	4	5	6	7	8	9	10
RI	0	املاك	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49
			et et	0	**		2. 0			

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Piston Fault

Table 1: Pair-w	vise comparison	matrix	of the	criteria	concerning	the sub	criteria	to
alternatives:								

Piston fault	Corrective	Predictive	Preventive
	Maintenance	Maintenance	Maintenance
Corrective	1	0.5	0.25
Maintenance			
Predictive	2	1	0.5
Maintenance			
Preventive	4	2	1
Maintenance			

 Table 2: Normalization of the pairwise calculation matrix

Piston fault	Corrective	Predictive	Preventive	Weight
Kully	Maintenance	Maintenance	Maintenance	
Corrective	0.1429	0.1429	0.1429	0.1429
Maintenance				
Predictive	^v 1/mn 0.2857	0.2857	0.2857	0.2857
Maintenance	La lunda L	in Single	اونية م سية	
Preventive	0.5714	0.5714	0.5714	0.5714
Maintenance N	VERSITI TEKN	IKAL MALAY	SIA MELAKA	

Weight	0.1429	0.2857	0.5714		
Piston fault	Piston fault Corrective		Preventive	Weight	
	Maintenance	Maintenance	Maintenance	sum	
				value	
Corrective	0.1429	0.1429	0.1429	0.4287	3
Maintenance					
Predictive	0.2858	0.2857	0.2857	0.8572	3.0004
Maintenance					
Preventive	0.5716	0.5714	0.5714	1.7144	3.0004
Maintenance					

 $V_{max} = \frac{(3+3.0004+3.0004)}{3} = 3.0003$

Consistency Index (C.I) = $\frac{(V_{max} - n)}{n-1} = \frac{(3.0003 - 3)}{3-1} = 0.0003$

Where n is the number of compared elements

Consistency Index (C.I) = 0.0003

Consistency Ratio = $\frac{(Consistency \, Index \, ,C.I)}{(Random \, Index \, ,RI)} = \frac{(0.0003)}{(0.58)} = 0.003$

Consistency Ratio (CR) = 0.003 < 0.10 (Consistent)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49
		To.								
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		2)	·	=ں مد			يتى ا	يوم	191	
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Valve plate wear

Doin wigo	amananican	moting of the	amitamia	aanaamina	the auh	amitania ta	altarmativage
Pair-wise ('onnoarison		• сгнегія	concerning	the sub	сгнегія то	anernanves:
	comparison		o er reer ra	concerning		criteria to	

Valve plate wear	Corrective Maintenance	Predictive Maintenance	Preventive Maintenance
Corrective	1	3	0.333
Maintenance			
Predictive	0.333	1	0.166
Maintenance			
Preventive	3	6	1
Maintenance			

Normalization of the pairwise calculation matrix

Valve plate wear	Corrective	Predictive	Preventive	Weight
a de la companya de	Maintenance	Maintenance	Maintenance	
Corrective	0.230	0.3	0.222	0.250
Maintenance				
Predictive	0.076	0.1	0.110	0.095
Maintenance	Alun -			
Preventive 2	ڪ م.692 ما	0.6	0.667	0.653
Maintenance				

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Weight	0.250	0.095	0.653		
Valve plate	Corrective	Predictive	Preventive	Weight	
wear	Maintenance	Maintenance	Maintenance	sum	
				value	
Corrective	0.250	0.285	0.217	0.752	3.008
Maintenance					
Predictive	0.083	0.095	0.108	0.286	3.010
Maintenance					
Preventive	0.75	0.57	0.653	1.973	3.021
Maintenance					

 $V_{max} = \frac{(3.008 + 3.010 + 3.021)}{3} = 3.013$

Consistency Index (C.I) = $\frac{(V_{max}-n)}{n-1} = \frac{(3.013-3)}{3-1} = 0.0065$

Where n is the number of compared elements

Consistency Index (C.I) = 0.0065

Consistency Ratio = $\frac{(Consistency \, Index \, ,C.I)}{(Random \, Index \, ,RI)} = \frac{(0.0065)}{(0.58)} = 0.011$

Consistency Ratio (CR) = 0.011 < 0.10 (Consistent)

n	1	2	3	4 5	5	6	7	8	9	10
RI	0	-0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49
		6								
		831	Wn							
		shi	(1		<u> </u>				
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Crankshaft fault

Crankshaft fault	Corrective	Predictive	Preventive
	Maintenance	Maintenance	Maintenance
Corrective	1	0.5	0.166
Maintenance			
Predictive	2	1	0.333
Maintenance			
Preventive	6	3	1
Maintenance			

Pair-wise comparison matrix of the criteria concerning the sub criteria to alternatives:

Crankshaft fault	Corrective	Predictive	Preventive	Weight
E.	Maintenance	Maintenance	Maintenance	
Corrective	0.111	0.111	0.110	0.111
Maintenance				
Predictive	0.222	0.222	0.222	0.222
Maintenance		/		
Preventive	0.666	0.666	0.666	0.666
Maintenance	VERSITI TEKN	IKAL MALAYS	A MELAKA	

Weight	0.111	0.222	0.666		
Crankshaft	Corrective	Predictive	Preventive	Weight	
fault	Maintenance	Maintenance	Maintenance	sum	
				value	
Corrective	0.111	0.111	0.110	0.332	2.99
Maintenance					0
Predictive	0.222	0.222	0.221	0.665	2.99
Maintenance					5
Preventive	0.666	0.666	0.666	1.998	3
Maintenance					

 $V_{max} = \frac{(2.990 + 2.995 + 3)}{3} = 2.995$

Consistency Index (C.I) = $\frac{(V_{max}-n)}{n-1} = \frac{(2.995-3)}{3-1} = 0.0025$

Where n is the number of compared elements

Consistency Index (C.I) = 0.0025

Consistency Ratio = $\frac{(Consistency \, Index \, , C.I)}{(Random \, Index \, , RI)} = \frac{(0.0025)}{(0.58)} = 0.0043$

Consistency Ratio (CR) = 0.0079 < 0.10 (Consistent)

n	1	2	3	4 5	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49
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Cylinder Head

Pair-wise comparison matrix of the criteria co	oncerning the sub criteria to alternatives:
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Cylinder Head	Corrective	Predictive	Preventive
	Maintenance	Maintenance	Maintenance
Corrective	1	3	0.333
Maintenance			
Predictive	0.333	1	0.125
Maintenance			
Preventive	3	8	1
Maintenance			

 Table 2: Normalization of the pairwise calculation matrix

Cylinder Head	Corrective	Predictive	Preventive	Weight
EK11	Maintenance	Maintenance	Maintenance	
Corrective	0.230	0.25	0.228	0.236
Maintenance	200			
Predictive	0.076	0.083	0.085	0.081
Maintenance	کل ملیسیا ما	يتكنيك	اونيۇم سىتى	
Preventive	0.692	0.666	0.685	0.681
Maintenance	VERSITI TEKI	NIKAL MALAY	SIA MELAKA	

Weight	0.236	0.081	0.681		
Cylinder	Corrective	Predictive	Preventive	Weight	
Head	Maintenance	Maintenance	Maintenance	sum	
				value	
Corrective	0.236	0.243	0.226	0.705	2.98
Maintenance					
Predictive	0.078	0.081	0.085	0.244	3.012
Maintenance					
Preventive	0.708	0.648	0.681	2.037	2.991
Maintenance					

 $V_{max} = \frac{(2.98 + 3.012 + 2.991)}{3} = 2.994$

Consistency Index (C.I) = $\frac{(V_{max} - n)}{n-1} = \frac{(2.994 - 3)}{3-1} = 0.003$

Where n is the number of compared elements

Consistency Index (C.I) = 0.003

Consistency Ratio = $\frac{(Consistency \, Index \, ,C.I)}{(Random \, Index \, ,RI)} = \frac{(0.003)}{(0.58)} = 0.0051$

Consistency Ratio (CR) = 0.0051 < 0.10 (Consistent)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49
		411	Nn							

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Internal Relief valve

Internal Relief	Corrective	Predictive	Preventive
Valve	Maintenance	Maintenance	Maintenance
Corrective	1	2	0.333
Maintenance			
Predictive	0.5	1	0.2
Maintenance			
Preventive	3	5	1
Maintenance			

Pair-wise comparison matrix of the criteria concerning the sub criteria to alternatives:

Internal Relief	Corrective	Predictive	Preventive	Weight
Valve 🖉	Maintenance	Maintenance	Maintenance	
Corrective	0.222	0.25	0.217	0.229
Maintenance				
Predictive	0.111	0.125	0.13	0.122
Maintenance	~~an			
Preventive 2	کل م0.666 یا ما	0.625	ويه 0.652 سيخ	0.647
Maintenance				
Maintenance	VERSITI TEKI	IKAL MALAY	SIA MELAKA	

Weight	0.229	0.122	0.647		
Internal	Corrective	Predictive	Preventive	Weight	
Relief Valve	Maintenance	Maintenance	Maintenance	sum	
				value	
Corrective	0.229	0.244	0.215	0.688	3.004
Maintenance					
Predictive	0.114	0.122	0.129	0.365	2.991
Maintenance					
Preventive	0.687	0.61	0.647	1.944	3.004
Maintenance					

 $V_{max} = \frac{(3.004 + 2.991 + 3.004)}{3} = 2.999$

Consistency Index (C.I) = $\frac{(V_{max}-n)}{n-1} = \frac{(2.999-3)}{3-1} = 0.0005$

Where n is the number of compared elements

Consistency Index (C.I) = 0.0005

Consistency Ratio = $\frac{(Consistency \, Index \, , C.I)}{(Random \, Index \, , RI)} = \frac{(0.0005)}{(0.58)} = 0.0008$

Consistency Ratio (CR) = 0.0008 < 0.10 (Consistent)

n	1	2	3	4 5	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49
		6								
		831	Wn							
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Bottom Cover

Table 1: Pair-wise	comparison	matrix	of the	criteria	concerning	the sub	criteria	to
alternatives:								

Bottom Cover	Corrective	Predictive	Preventive
	Maintenance	Maintenance	Maintenance
Corrective	1	4	2
Maintenance			
Predictive	0.25	1	0.5
Maintenance			
Preventive	0.5	2	1
Maintenance			

 Table 2: Normalization of the pairwise calculation matrix

Bottom Cover	Corrective	Predictive	Preventive	Weight
1 1	Maintenance	Maintenance	Maintenance	
Corrective	0.571	0.571	0.571	0.571
Maintenance	Alun .			
Predictive	کے ملکسا ما	0.142	0.142	0.142
Maintenance	0		7. V	
Preventive	VER 0.285 TEKI	IKA 0.285 LAY	SIA N0.285 KA	0.285
Maintenance				

Weight	0.571	0.142	0.285		
Bottom	Corrective	Predictive	Preventive	Weight	
Cover	Maintenance	Maintenance	Maintenance	sum	
				value	
Corrective	0.571	0.568	0.57	1.709	2.992
Maintenance					
Predictive	0.142	0.142	0.142	0.426	3
Maintenance					
Preventive	0.285	0.284	0.285	0.854	2.996
Maintenance					

 $V_{max} = \frac{(2.992 + 3 + 2.996)}{3} = 2.996$

Consistency Index (C.I) = $\frac{(V_{max} - n)}{n-1} = \frac{(2.996 - 3)}{3-1} = 0.002$

Where n is the number of compared elements

Consistency Index (C.I) = 0.002

Consistency Ratio = $\frac{(Consistency \, Index \, ,C.I)}{(Random \, Index \, ,RI)} = \frac{(0.002)}{(0.58)} = 0.0034$

Consistency Ratio (CR) = 0.0034 < 0.10 (Consistent)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49
		VER	Win				-			
		shi	(1.12						
		للالت	•	=ں م		-4	سيبي (يور	191	
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Pump and Bearing

Pump and bearing	Corrective	Predictive	Preventive
	Maintenance	Maintenance	Maintenance
Corrective	1	0.5	0.25
Maintenance			
Predictive	2	1	0.5
Maintenance			
Preventive	4	2	1
Maintenance			

Pair-wise comparison matrix of the criteria concerning the sub criteria to alternatives:

Pump and	Corrective	Predictive	Preventive	Weight
bearing	Maintenance	Maintenance	Maintenance	
Corrective	0.142	0.142	0.142	0.142
Maintenance				
Predictive	0.285	0.285	0.285	0.285
Maintenance	10 June 15		In the main	
Preventive	0.571	0.571	9	0.571
Maintenance N	VERSITI TEKI	IKAL MALAY	SIA MELAKA	

Weight	0.142	0.285	0.571]	
Pump and	Corrective	Predictive	Preventive	Weight	
bearing	Maintenance	Maintenance	Maintenance	sum	
				value	
Corrective	0.142	0.142	0.142	0.428	3
Maintenance					
Predictive	0.285	0.285	0.285	0.857	3
Maintenance					
Preventive	0.571	0.571	0.571	1.714	3
Maintenance					

$$V_{max} = \frac{(3+3+3)}{3} = 3$$

Consistency Index (C.I) = $\frac{(V_{max} - n)}{n-1} = \frac{(3-3)}{3-1} = 0$

Where n is the number of compared elements

Consistency Index (C.I) = 0

Consistency Ratio = $\frac{(Consistency \, Index \, , C.I)}{(Random \, Index \, , RI)} = \frac{(0)}{(0.58)} = 0$

Consistency Ratio (CR) = 0 < 0.10 (Consistent)



Oil Pump Fault

Oil Pump Fault	Corrective	Predictive	Preventive
	Maintenance	Maintenance	Maintenance
Corrective	1	0.5	0.2
Maintenance			
Predictive	2	1	0.333
Maintenance			
Preventive	5	3	1
Maintenance			

Normalization of the pairwise calculation matrix

Oil Pump Fault	Corrective	Predictive	Preventive	Weight
S.	Maintenance	Maintenance	Maintenance	
Corrective	0.125	0.111	0.130	0.122
Maintenance				
Predictive	0.25	0.222	0.217	0.229
Maintenance	Ainn .			
Preventive	0.625	0.666	0.652	0.647
Maintenance	0		2. 0	

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Weight	0.122	0.229	0.647		
Oil Pump	Corrective	Predictive	Preventive	Weight	
Fault	Maintenance	Maintenance	Maintenance	sum	
				value	
Corrective	0.122	0.114	0.129	0.365	3.016
Maintenance					
Predictive	0.244	0.229	0.215	0.688	3.004
Maintenance					
Preventive	0.61	0.687	0.647	1.944	3.004
Maintenance					

 $V_{max} = \frac{(3.016 + 3.004 + 3.004)}{3} = 3.008$

Consistency Index (C.I) = $\frac{(V_{max} - n)}{n-1} = \frac{(3.008 - 3)}{3-1} = 0.004$

Where n is the number of compared elements

Consistency Index (C.I) = 0.004

Consistency Ratio = $\frac{(Consistency \, Index \, ,C.I)}{(Random \, Index \, ,RI)} = \frac{(0.004)}{(0.58)} = 0.0068$

Consistency Ratio (CR) = 0.0068 < 0.10 (Consistent)



4.1.3.1 Sensitivity Analysis

In order to determine the stability of the method, as well as its results, we performed a sensitivity analysis on the result of our analysis. By analysing the behaviour or the variability of the result, we want to see if the judgement used to evaluate among the different investment alternatives would vary within a range of two notches (either up or down) of the risk scale score assigned to them during the analysis.

formation Panel	Network	Judgments	Ratings	
et: 0	1 Choose		3 Results	
lode: luster:	Node Chutter		0.11004110	
ttachments	Choose Node	Normal	Inconsistency: 0.02587	Hybrid
lodel Structure	Mechanical Com~ -	⊴ Bottom co~		0.059
	Cluster: Criteria	Crankshaf~		0.269
reate/Edit Details	Choose Cluster	Cvlinder ~		0.1449
how Priorities	Sub criteria -	Internal ~		0.025
lake/Show Connections	۲	Oil pump ~		0.042
	MALAYSIA	Oil sight~		0.031
	SY .	Piston fa~		0.188
	7	Pump end ~		0.083
2		Valve pla~		0.1554
F				1
1	a ==			
	<u>२</u> . ==		Completed Comparison	
	1/1/0 Restore		Convite clinkoard	

Figure 17: Super decision result

a.

We performed our sensitivity analysis with the help of Super decision software. This software -originally design to perform a decision tree evaluation process, also do a judgment and find the priorities weight to make a multi criteria decision making.

- au g



Figure 18: Sensitivity analysis chart company A

Electrical	I AND A	Criteria		
component	Corrective	Predictive	Preventive	weight
Lies	Maintenance	Maintenance	Maintenance	
Stator and Rotor	0.309	0.109	0.581	0.6
fault 4	کل ملیسیا ما	ة, تىكنىد	اونتومرست	
Compressor	0.309	0.109	0.581	0.1
Crankcase	VERSITI TEKN	IKAL MALAYS	A MELAKA	
Heater				
Terminal Fault	0.309	0.109	0.581	0.3

Table 13: Sensitivity analysis for electrical component company A

The table illustrates some electrical component result data about maintenance strategy for semi hermetic compressor. It allows comparisons between the corrective maintenance, predictive maintenance, and preventive maintenance. The stator and rotor have a higher weight than the other two components, with a value of 0.6, according to the table. The terminal with the second highest value is 0.3, while the terminal with the lowest value is the crankcase compressor, which has a value of 0.1.

The prominence of preventive maintenance is striking. Based on the data obtained, most electrical component maintenance favours to preventive maintenance. For the second-best option, corrective maintenance is ahead in terms of score value, while predictive maintenance has the lowest score value, which is 0.109. As we can see from the graph, of the three electrical components evaluated for maintenance, preventive always has the highest trend compared to the other two strategies, namely corrective maintenance and predictive maintenance.

Overall, preventive maintenance is the best solution to overcome the problem of damage that occurs. According to (Hilber, Miranda, Matos, & Bertling, 2007), preventive maintenance is the best maintenance strategy for electrical components because it can reduce the maintenance budget without reducing compressor performance. said. It will considerably reduce the cost of preventative maintenance and can optimize the usage of electrical components in the compressor.





Figure 19: Sensitivity analysis chart for mechanical component

Mechanical	N	Criteria		
component	Corrective	Predictive	Preventive	weight
KUIN	Maintenance	Maintenance	Maintenance	
Oil Sight Glass	0.285	0.142	0.571	0.031
Piston Fault	0.142	0.285	0.571	0.188
Valve Plate 🖌 wear	فل مايكنياً مالا	0.095	ويومر 0.654 سيتي	0.155
Crankshaft	IVER6111 TEK	NIKA0.222ALAY	SIA 10.6664KA	0.269
Fault				
Cylinder Head	0.236	0.081	0.681	0.144
Internal Relief	0.229	0.122	0.648	0.025
Valve				
Bottom Cover	0.571	0.285	0.142	0.059
Pump and	0.142	0.285	0.571	0.083
Bearing				
Oil Pump fault	0.122	0.229	0.648	0.042

Table 14: Sensitivity analysis for mechanical component Company A

According to the chart, nine mechanical component faults arise in semi hermetic compressors based on industry reports reviewed. All mechanical faults with these components can lead to larger difficulties in the compressor system. For mechanical components, crankshaft fault has the greatest weight value of 0.269, followed by piston fault, which has a weight of 0.188. Furthermore, the valve plate ranks third with a score of 0.155. Among the other nine components, these three have the highest weight value. This diagram depicts the three major mechanical pillars of the semi hermetic compressor.

According to the graph pattern, The prominence of preventive maintenance is striking. Based on the data obtained, most mechanical component maintenance favours to preventive maintenance. For the second-best option, corrective maintenance is ahead in terms of score value, while predictive maintenance has the lowest score value. As we can see from the graph, of the mechanical components evaluated for maintenance, preventive always has the highest trend compared to the other two strategies, namely corrective maintenance and predictive maintenance. From (Abramson & Magee, 1999) preventive always can benefits such as reduced maintenance costs, extended equipment life, improved occupant comfort and morale, improved indoor air quality, and reduced CFC emissions.



Figure 20: Sensitivity analysis chart for all component

All sensitivities for all components are combined in the graph provided. According to the graph, both mechanical and electrical components are more prone to preventative maintenance. The majority of the components were appropriate for preventative maintenance. Preventive maintenance is the best choice of maintenance for a semi hermetic compressor out of the three options. Corrective maintenance is less expensive to maintain than preventive maintenance, however without preventive maintenance, the refrigeration system in an HVAC system cannot operate at full capacity due to a shortage of failure parts. It is not appropriate to do predictive maintenance in an HVAC system based on data since it would increase maintenance costs. Most oil and gas companies want to ensure that their HVAC systems are operating at peak efficiency while trying to minimize maintenance costs.

N. A.	2		
Mechanical	Corrective	Predictive	Preventive
component	Maintenance	Maintenance	Maintenance
Oil Sight Glass	0.285	0.142	0.571
Piston Fault	0.142	0.285	0.571
Valve Plate wear	0.249	0.095	0.654
Crankshaft Fault /	ERSITI0.111KNIKA	L MA10.22251A ME	LAKA0.666
Cylinder Head	0.236	0.081	0.681
Internal Relief	0.229	0.122	0.648
Valve			
Bottom Cover	0.571	0.285	0.142
Pump and Bearing	0.142	0.285	0.571
Oil Pump fault	0.122	0.229	0.648
Stator and Rotor	0.309	0.109	0.581
fault			
Compressor	0.309	0.109	0.581
Crankcase Heater			
Terminal Fault	0.309	0.109	0.581

4.2 Company B case study

4.2.1 FMEA table of company B semi hermetic compressor

FMEA table of company B semi hermetic compressor

N	Proce	Item fault	Compo	Failure mode	Failure effects	tv	Failure cause	enc	Current controls	on	RP N
•	input	laun	Kuller		S. F. A.K.	Severi		Occurre		Detecti	1
			Termin al plate shortag e	Compressor trip	Low pressure in compressor	7	High voltages can also damage the motor causing the compressor to overheat	2	Rectify and Top-up freon R22	3	28
1	Electr ical	Termin al fault	Termin al Gasket	Gasket worn out	Major leaking at gasket terminal box compressor	6	Compressor system cannot run properly and current trip on terminal	3	Fabricate and fix new gasket and RTV with terminal box	2	36
			Termin al plate	Terminal plate worn out	Leaking at terminal plate	5	A short circuit occurs	2	Change new terminal plate	3	30

2 Electr ical	Compr essor breakd own	Compre ssor	Compressor tripped	Compressor worn out	8	Compressor totally grounded	1	Change new compressor	1	8
3 Mech anical	Discha rge valve fault	Dischar ge valve	Leaking on gasket and broken	Discharge main valve gasket broken	6	Low suction and high head	5	Fabricated new gasket for discharge valve	1	30
		Dischar ge valve	Discharge valve leaking	High compression ratio	5	Higher than normal suction pressures with low discharge pressures	4	Change new discharge valve	2	40
		Dischar ge valve	Wear	High compression ratio	6	Low suction and high head	3	Change new discharge valve	3	54
		12	ليسبيا ما	يكل ما	• 4	ىسىتى تېك	1	اونيو		
4 Mech	Suctio	Suction	Damage	Contamination	8	Mechanical damage	3	Replace new suction	2	48
anical	n valve damag e	Valve	VERSITI	TEKNIKA		in system SIA M	EL	valve		
Total 274								274		

Table 15: FMEA table case company B

4.2.2 Pareto analysis

NO.	Forms of fault or failures	RPN	Relative	Cumulative		
			Number (%)	relative		
				number		
				(%)		
1	Discharge valve fault	124	45%	45%		
2	Terminal fault	94	34%	79%		
3	Suction valve fault	48	18%	97%		
4	Compressor breakdown	8	3%	100%		
		Total=274				

Table 16: Form of fault or failure company B

The fault of failure were sorted from highest to lowest frequency, and the relative frequency for each was determined table 19. For example, discharge valve fault was 124 out of 274 fault of failures, and so the relative frequency for size out of specification was:

124/274 x 100 = 45%

An optional final step is to calculate cumulative relative frequency. Cumulative relative frequency helps the user to readily see the combined effect of the vital few problems. For example, you could see that the top two probems were responsible for nearly 80 percent of the problem overall. To calculate cumulative relative frequency, add the relative frequency for each category of fault of failure to the sum of all preceding relative frequencies. For example the were 124 occurence of discharge valve fault or 45 percent relative frequency of the total. Then the occurence terminal fault was the second highest number in rpn. Terminal fault, was therefore responsible for 34 percent of the total. Discharge valve fault and terminal fault combined cumulative relative frequency were responsible for 79 percent of the total. The cumulative relative frequency for the least frequent category compressor breakdown, in this table should be 100 percent. Table 19 shows the discharge valve fault arranged in descending order of frequency and with relative frequency and cumulative relative frequency calculated.



Figure 21: Pareto analysis of failure mode occur for company B

Figure 19 is the pareto chart for the data that we obtain. The left vertical axis indicates the number frequency of each type of fault of failure for component. Always plot fault of failure in descending order of frequency, with the most frequent at the left vertical axis. The right axis indicates cumulative frequency.

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The pareto chart make it easy to see that discharge valve fault and terminal fault are the most highest rpn fault of failure. Maintenance strategy that focus on these failure will give the biggest bang for the buck.




4.2.3 Result of analytical hierarchy process



GOAL

Pair-wise comparison matrix of the criteria respect to the goal

Goal	Electrical component	Mechanical component		
Electrical	1	4		
component				
Mechanical component	0.25	1		

Normalization of the pairwise calculation matrix

Goal	Electrical component	Mechanical	Weight	
M	ALAYSIA	component		
Electrical component	0.8	0.8	0.8	
Mechanical component			0.2	

Weight 실	ل مليه.0يا ملا	0.2	يىۋىرسىتى ت	او
Goal	Electrical	Mechanical	Weight sum	× 4
UN	component	component	value	(A
Electrical	0.8	0.8	1.6	2
component				
Mechanical	0.2	0.2	0.4	2
component				

Calculation of consistency:

$$V_{max} = \frac{(2+2)}{2} = 2$$

Consistency Index (C.I) =
$$\frac{(V_{max} - n)}{n-1} = \frac{(2-2)}{2-1} = 0$$

Where n is the number of compared elements

Consistency Index (C.I) = 0

Consistency Ratio = $\frac{(Consistency Index, C.I)}{(Random Index, RI)} = \frac{(0)}{(0)} =$

Consistency Ratio (CR) = 0 < 0.10 (Consistent)

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49



Main criteria (Electrical component)

Electrical component	Compressor breakdown	Terminal fault
Compressor breakdown	1	0.5
Terminal fault	2	1

Pair-wise comparison matrix of the criteria concerning the Main Criteria.

Normalization of the pairwise calculation matrix

component breakdown	Electrical	Compressor	Terminal fault	Weight	
Compressor 0.333 0.333 0.333 breakdown 0.666 0.666 0.666 fault 0.666 0.666 0.666	component	breakdown			
Terminal 0.666 0.666 0.666 fault 0.666 0.666 0.666	Compressor breakdown	0.333	0.333	0.333	
74.7	Terminal fault	0.666	0.666	0.666	

Weight 🕘	0.333.	0.666	ىبۇم سىتى ت	9
Electrical	Compressor	Terminal	Weight sum	
component	breakdown		YSI valueLA	(A
Compressor	0.333	0.333	0.666	2
breakdown				
Terminal	0.666	0.666	1.332	2
fault				

Calculation of consistency:

 $V_{max} = \frac{(3.0037 + 3.0091 + 3.0145)}{3} = 3.0091$

Consistency Index (C.I) = $\frac{(V_{max} - n)}{n-1} = \frac{(3.0091 - 3)}{3-1} = 0.0091$

Where n is the number of compared elements

Consistency Index (C.I) = 0.0091

Consistency Ratio = $\frac{(Consistency \, Index \, ,C.I)}{(Random \, Index \, ,RI)} = \frac{(0.0091)}{(0.58)} = 0.0157$

Consistency Ratio (CR) = 0.0157 < 0.10 (Consistent)

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49



Main criteria (Mechanical Component)

Mechanical component	Discharge valve fault	Suction valve fault		
Discharge valve fault	1	0.5		
Suction valve fault	2	1		

Pair-wise comparison matrix of the criteria concerning the Main Criteria

Normalization of the pairwise calculation matrix

Mechanical component	Discharge valve fault	Suction valve fault	Weight	
Discharge valve fault	0.333	0.333	0.333	
Suction valve fault	0.666	0.666	0.666	
"Nn				

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Weight	0.333	0.666	Weight	
Mechanical component	Discharge valve	Suction valve	sum value	
	fault	fault	vuite	
Discharge valve fault	0.333	0.333	0.666	2
Suction valve fault	0.666	0.666	1.222	2

 $V_{max} = \frac{(2+2)}{2} = 0$

Consistency Index (C.I) = $\frac{(V_{max} - n)}{n-1} = \frac{(2-2)}{2-1} = 0$

Where n is the number of compared elements

Consistency Index (C.I) = 0

Consistency Ratio = $\frac{(Consistency \, Index \, ,C.I)}{(Random \, Index \, ,RI)} = \frac{(0)}{(0.90)} = 0$

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Consistency Ratio (CR) = 0 < 0.10 (Consistent)

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Sub criteria to Alternatives (Electrical)

Compressor breakdown

Pair-wise comparison matrix of the criteria concerning the sub criteria to alternatives:

Compressor	Corrective	Predictive	Preventive
breakdown	Maintenance	Maintenance	Maintenance
Corrective	Corrective 1		0.25
Maintenance			
Predictive	0.333	1	0.142
Maintenance			
Preventive	4	7	1
Maintenance			

Normalization of the pairwise calculation matrix

Compressor	Corrective	Predictive	Preventive	Weight
breakdown 🚆	Maintenance	Maintenance	Maintenance	
Corrective	0.187	0.272	0.179	0.212
Maintenance	Samo -			
Predictive	0.062	0.090	0.102	0.084
Maintenance	متسب ملا)	بوہر سیبی بیا	191
Preventive U	0.750 I TE	6.636 MAL	AYS ^{0.718} IELA	KA 0.701
Maintenance				

Weight	0.212	0.084	0.701		
Compressor	Corrective	Predictive	Preventive	Weight	
breakdown	Maintenance	Maintenance	Maintenance	sum	
				value	
Corrective	0.212	0.252	0.175	0.639	3.014
Maintenance					
Predictive	0.07	0.084	0.099	0.253	3.011
Maintenance					
Preventive	0.848	0.588	0.701	2.137	3.048
Maintenance					

 $V_{max} = \frac{(3.014 + 3.011 + 3.048)}{3} = 3.024$

Consistency Index (C.I) = $\frac{(V_{max} - n)}{n-1} = \frac{(3.024 - 3)}{3-1} = 0.012$

Where n is the number of compared elements

Consistency Index (C.I) = 0.012

Consistency Ratio = $\frac{(Consistency \, Index \, , C.I)}{(Random \, Index \, , RI)} = \frac{(0.012)}{(0.58)} = 0.020$

Consistency Ratio (CR) = 0.020 < 0.10 (Consistent)

		4		NC I	_		-			
n	1	2	3	45	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49
		Ne ba	140							
		للك	ليسيا ه	کل ما	نيد	تيك	مىيتي	ينوم	او	
		UNIV	ERSITI	TEKN	IKAL	MALA	YSIA N	IELAK	A	

Terminal Fault

Terminal fault	Corrective	Predictive	Preventive
	Maintenance	Maintenance	Maintenance
Corrective	1	0.5	0.25
Maintenance			
Predictive	2	1	0.5
Maintenance			
Preventive	4	2	1
Maintenance			

Pair-wise comparison matrix of the criteria concerning the sub criteria to alternatives:

Table 2: Normalization of the pairwise calculation matrix

Terminal fault	Corrective	Predictive	Preventive	Weight
4	Maintenance	Maintenance	Maintenance	
Corrective	0.142	0.142	0.142	0.142
Maintenance	-			
Predictive	0.285	0.285	0.285	0.285
Maintenance	Alun			
Preventive 3	0.571	0.571	0.571	0.571
Maintenance			- G. V.	_

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Weight	0.142	0.285	0.571		
Terminal	Corrective	Predictive	Preventive	Weight	
fault	Maintenance	Maintenance	Maintenance	sum	
				value	
Corrective	0.142	0.142	0.142	0.428	3
Maintenance					
Predictive	0.285	0.285	0.285	0.857	3
Maintenance					
Preventive	0.571	0.571	0.571	1.714	3
Maintenance					

$$V_{max} = \frac{(3+3+3)}{3} = 3$$

Consistency Index (C.I) = $\frac{(V_{max} - n)}{n-1} = \frac{(3-3)}{3-1} = 0$

Where n is the number of compared elements

Consistency Index (C.I) = 0

Consistency Ratio = $\frac{(Consistency \, Index \, , C.I)}{(Random \, Index \, , RI)} = \frac{(0)}{(0.58)} = 0$

Consistency Ratio (CR) = 0 < 0.10 (Consistent)



Discharge valve fault

Discharge valve	Corrective	Predictive	Preventive
fault	Maintenance	Maintenance	Maintenance
Corrective	1	3	1
Maintenance			
Predictive	0.333	1	0.333
Maintenance			
Preventive	1	3	1
Maintenance			

Pair-wise comparison matrix of the criteria concerning the sub criteria to alternatives:

Normalization of the pairwise calculation matrix

Discharge valve	Corrective	Predictive	Preventive	Weight
fault	Maintenance	Maintenance	Maintenance	
Corrective Maintenance	0.428	0.428	0.428	0.428
Predictive Maintenance	0.142	0.142	0.142	0.142
Preventive	فل ما <u>8</u> 0.42 مار VERSITI TEK		اوييو0.428-يىتي مىرم UFL مادى	0.428

Weight	0.428	0.142	0.428		
Discharge	Corrective	Predictive	Preventive	Weight	
valve fault	Maintenance	Maintenance	Maintenance	sum	
				value	
Corrective	0.428	0.426	0.428	1.282	3
Maintenance					
Predictive	0.142	0.142	0.142	0.246	3
Maintenance					
Preventive	0.428	0.426	0.428	1.282	3
Maintenance					

$$V_{max} = \frac{(3+3+3)}{3} = 3$$

Consistency Index (C.I) = $\frac{(V_{max} - n)}{n-1} = \frac{(2.996 - 3)}{3-1} = 0$

Where n is the number of compared elements

Consistency Index (C.I) = 0 Consistency Ratio = $\frac{(Consistency Index, C.I)}{(Random Index, RI)} = \frac{(0)}{(0.58)} = 0$

Consistency Ratio (CR) = 0 < 0.10 (Consistent)



Suction valve fault

Pair-wise comparison matrix of the criteria concerning the sub criteria to alternatives:

Suction valve	Corrective	Predictive	Preventive
fault	Maintenance	Maintenance	Maintenance
Corrective	1	0.5	0.3333
Maintenance			
Predictive	2	1	0.5
Maintenance			
Preventive	3	2	1
Maintenance			

Normalization of the pairwise calculation matrix

Suction valve	Corrective	Predictive	Preventive	Weight
fault	Maintenance	Maintenance	Maintenance	
Corrective	0.166	0.142	0.181	0.163
Maintenance				
Predictive	0.333	0.285	0.272	0.297
Maintenance	مليسيا ملا	کنیک	ىۋىرىسىتى تى	اود
Preventive	0.5	0.571	0.545	0.539
Maintenance	IVERSITI TE	KNIKAL MAL	AYSIA MELA	KA

Weight	0.163	0.297	0.539		
Suction	Corrective	Predictive	Preventive	Weight	
valve fault	Maintenance	Maintenance	Maintenance	sum	
				value	
Corrective	0.163	0.148	0.179	0.492	3.003
Maintenance					
Predictive	0.327	0.297	0.269	0.894	3.009
Maintenance					
Preventive	0.491	0.594	0.53	1.624	3.014
Maintenance					

 $V_{max} = \frac{(3.003 + 3.009 + 3.014)}{3} = 3.0091$

Consistency Index (C.I) = $\frac{(V_{max} - n)}{n-1} = \frac{(3.009 - 3)}{3-1} = 0.009$

Where n is the number of compared elements

Consistency Index (C.I) = 0.009

Consistency Ratio = $\frac{(Consistency \, Index \, ,C.I)}{(Random \, Index \, ,RI)} = \frac{(0.009)}{(0.58)} = 0.015$

Consistency Ratio (CR) = 0.015 < 0.10 (Consistent)

n	1	2	3	45	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49
		E.								
		×311	Nn .							
		shi	(.12						
		مارك		_ں م			سيبي ا	يور	21	
		LIMIN	DOITI	TEKN			VEIA		<u>د ۸</u>	





E	M	laintenance strateg	gy	
Forms of fault or	Corrective	Predictive	Preventive	
failures	maintenance	maintenance	maintenance	Weight
Discharge valve fault	0.428	0.142	ويبر0.428-ي	0.333
Terminal fault	0.142	0.285	0.571	0.666
Suction valve fault	0.163	0.297	0.539	0.666
Compressor breakdown	0.212	0.084	0.701	0.333

Table 17: Sensitivity analysis for ExxonMobil

According to the chart, two mechanical component and 2 electrical faults arise in semi hermetic compressors based on industry reports reviewed. All mechanical and electrical fault with these components can lead to the failure compressor. For mechanical components, suction valve has the greatest weight value of 0.666, followed by discharge valve, which has a weight of 0.333. Then, for electrical component the terminal fault ranks with highest a score of 0.666 and compressor breakdown with weight 0.333.

According to the graph pattern, The prominence of preventive maintenance is striking. Based on the data obtained, most mechanical component maintenance favours to preventive maintenance. For the second-best option, corrective maintenance is ahead in terms of score value, while predictive maintenance has the lowest score value. As we can see from the graph, compressor breakdown has a higher score with 0.701 for preventive maintenance, 0.12 for corrective maintenance and 0.084 for predictive maintenance. After that, for terminal plate and suction valve, preventive maintenance is the priority compare to corrective maintenance and predictive maintenance. For mechanical compressor discharge valve, have a same value for preventive and corrective. Both maintenance can be perform on discharge valve based on the pairwise comparison that we obtain from the result.



4.3 Combine data company A and company B

Ν	Proces	Item	Compon	Failure	Failure effects	V	Failure cause	nc	Current controls	u	RP
0	S	fault	ent	mode		erity		irrei		ctio	Ν
	input					Sev		Occu		Dete	
			Winding	Melting	shortage	9	Overheating of the start	1	Replace new	2	18
					19 C		windings and rapid failure		compressor		
			EKINA		AKA						
1	Electri	Stator and	Rotor	Corrod	Weaken rotor over	9	Makes the noisy sound	2	Replace new motor	1	18
	cal	rotor fault	E	е,	time and decrease						
			193	scratch	rotor power	-					
				and							
			shi	damage	115	• <		•			
2	Electri	Compress	Compres	Leakag	Refrigerant entering	3	will then be vaporized and	5	Replace/repair use tape	2	30
	cal	or	sor	e and	the crankcase		driven back into the suction				
		crankcase	crankcas	damage	TI TEKNIKA		line LAYSIA MELA	K	A		
		damage	e heater								
3	Mecha	Oil Sight	Oil sight	Dirty	Compressor oil does	3	Insufficient compressor oil	7	Clean internal oil sight	5	105
	nical	glass dirty	glass		not return back				glass		

			Piston	Damag	Have the nocking	8	Faulty cylinder head	2	Replace new	1	16
4			head	e	debris off suction		components		compressor		
					valve plate						
	Mecha	Piston	Piston	Wear	Flood back in system,	8	High pressure ratio and very	2	Replace new	1	16
	nical	fault	ring (oil	ALAYS	with extreme		high refrigerant charge		compressor		
			&		refrigerant overcharge		888-		F		
			compress		and or oil separators			-			
			ion		and of on separators						
				N/		6		2			24
			Bore	very	Suction valve debris at	6	Excessive rocking of the piston	2	Repolish bore piston	2	24
			piston	Deep	bore piston body				body/Replace new		
			body	scratch/		1		-	compressor		
				damage							
			Ne	ه (ب	alo Ko	• 4	فرست تد	j.			
			Piston	Wear	Inadequate lubrication	8	Overheating and poor oil return	2	Replace new piston and	2	32
			and rod	and			due to low charge or low		rod assembly		
			assembly	damage	TI TEKNIKA		flowrate YSIA MELA	K.	A		
5	Mecha	Crankshaf	Cranksha	Scratch	Debris in crankshaft	9	Compressor system failed	1	Change new	1	9
	nical	t fault	ft						compressor crankshaft		
5	nical	t fault	ft	Scratch	Debris in cranksnatt	9	Compressor system raned	1	compressor crankshaft	1	9

			Cranksha	Missing	Compressor cannot	7	Compressor system failed	1	Replace new crankshaft	1	7
			ft		run						
			Cranksha	Dirty	Crankshaft wear	6	Defective lubrication on	1	Clean crankshaft	3	18
			ft				journals				
				ALAYS	10						
			2		110						
			and the second s		LAX .						
			Terminal	Damag	Shortage of refrigerant	7	A short circuit occurs	3	Suggest to change new	2	42
			box	e					terminal box		
			assembly			1					
			437			1					
			Terminal	Corrod	Refrigerant circuit	7	Liquid refrigerant flood back	2	Change new terminal	2	28
			plate	е	clogging	• 4		÷	plate		
			assembly		یک سید	-	ور سبی می				
									-		
			Terminal	Corrod	Drain power out of	6	Compressor system cannot run	3	Clean terminal	2	36
6	Electri	Terminal		e	compressor		properly and current trip on				
	cal	fault					terminal				

			Terminal	Compre	Low pressure in	7	High voltages can also damage	2	Rectify and Top-up	3	28
			plate	ssor	compressor		the motor causing the		freon R22		
			shortage	trip			compressor to overheat				
			Terminal	Gasket	Major leaking at	6	Compressor system cannot run	3	Fabricate and fix new	2	36
			Gasket	worn	gasket terminal box		properly and current trip on		gasket and RTV with		
			1	out AY	compressor		terminal		terminal box		
			Terminal	Termin	Leaking at terminal	5	A short circuit occurs	2	Change new terminal	3	30
			plate	al plate	plate				plate		
			EK	worn	P						
			-	out							
			Cylinder	Corrod	Head gasket failure	7	Compressor overheating	2	Clean cylinder head-	1	14
			head-	e and		1		-	centre bank corroded		
			Centre	scratch							
7	Mecha	Cylinder	bank	0	into 15	• 6	المع البيت أن	3.4			
	nical	head fault		4 th			. G. V.	2			
			Cylinder	Corrod	Piston ring damage	8	Drop in compressor	1	Clean the corroded	1	7
			head-	e and	TI TEKNIKA		performance Statistics ELA	K.	A		
			side bank	scratch							

8	Mecha	Internal	Internal	Corrod	Damage to other part	7	Maximum operating pressure	3	Clean internal relief	3	63
	nical	relief	relief	e	of system		of the compressor failure		valve		
		valve	valve								
		fault									
				BALAYS	I/A .						
9	Mecha	Bottom	Bottom	Dirty/c	Loss of reinforcement	4	Bottom cover gasket can	3	Clean bottom cover	1	12
	nical	cover	cover	orroded	area and damage in		eventually fail due to friction				
		fault	EK		the surrounding		or constant exposure to heat				
			-		concrete						
			To.			2					
1	Mecha	Pump and	Pump	Corrod	Contamination	8	Mechanical damage in system	1	Change new pump end	2	16
0	nical	bearing	end	e					bearing head assembly		
		fault	bearing		Ja Ko	• 4	Di tura	3.			
			head				وررشتى ش	2			
			assembly				48				
			Bearing	Corrosi	Damage to bearing	6	Chemical and electrochemical	2	Suggest replacing a	2	24
			sleeve	on			reactions between the surface		new one		
						_					
1	Mecha	Oil pump	Oil pump	Dirty	Clogged	7	Poor performance	4	Clean oil pump	3	84
1	nical	fault									

1	Mecha	Valve	Valve	Wear	Debris in cylinder	8	Mechanical damage to piston	3	Change new valve plate	4	96
2	nical	plate wear	plate				and valves				
1	Mecha	Suction	Suction	Damag	Contamination	8	Mechanical damage in system	3	Replace new suction	2	48
3	nical	valve	Valve	е					valve		
		damage	-	ALLAND	A Ar						
			S.		2						
			3		8						
			e	-							
1	Mecha	Discharge	Discharg	Leakin	Discharge main valve	6	Low suction and high head	5	Fabricated new gasket	1	30
4	nical	valve	e valve	g on	gasket broken				for discharge valve	-	20
-	mear	foult	c varve	goslat	gusket broken				Tor discharge varve		
		Taun		gasket							
			shi	and	11/-	. /		۰.,	1		
			27	broken	no je	~	ور سی ب	23			
			Discharg	Dischar	High compression	5	Higher than normal suction	4	Change new discharge	2	40
			e valve	ge	ratio		pressures with low discharge	10	valve		
			ONIV	valve	TT TERMINA		pressures	LTN.			
				leaking							
				leaking							

			Discharg	Wear	High compression	6	Low suction and high head	3	Change new discharge	3	54		
			e valve		ratio				valve				
1	Electri	Compress	Compres	Compre	Compressor worn out	8	Compressor totally grounded	1	Change new	1	8		
5	cal	or	sor	ssor	1 () () () () () () () () () (compressor				
		breakdow	3	tripped	2								
		n	×.		Ş								
	715												
			1		Table 18: Combi	ne F	MEA table						

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AHP hierarchy tree



Pareto analysis

NO.	Forms of fault or failures	RPN	Relative	Cumulative
			Number	frequency (%)
1	Terminal fault	200	20	20%
2	Discharge valve fault	124	13	33%
3	Oil sight glass dirty	105	11	44%
4	Valve plate wear	96	10	54%
5	Piston fault	88	9	63%
6	Oil pump fault	84	8	71%
7	Internal relief valve fault	63	6	77%
8	Suction valve fault	48	5	82%
9	Pump and bearing fault	40	4	86%
10	Stator and rotor fault	36		90%
11	Crankshaft fault	34	3	93%
12	Compressor crankcase	30	- 3	96%
12	Cylinder head fault	21	ور هي د	0000
15				98%
14	Bottom cover fault	12 MAL	AT STA IMELA	99%
15	Compressor breakdown	8	1	100%
		Total: 989		

 Table 19: Synthesize pareto table



Figure 26: Synthesize pareto chart



Figure 27: Synthesize pie chart

Occurrence

	bottom	Compressor	Compressor	Crankshaft	Cylinder	Discharge	Internal	Oil pump	Oil sight		Pump end	Stator and	Suction	Terminal	Valve plate
Occurence	cover fault	breakdown	crankcase	fault	head fault	valve fault	relief valve	fault	glass dirty	Piston fault	bearing	rotor fault	valve fault	fault	fault
Bottom cover fault	1.00	1.00	0.50	0.33	0.50	0.11	0.17	0.14	0.11	0.13	0.25	0.33	0.25	1.00	0.11
Compressor breakdown	1.00	1.00	0.50	0.33	0.50	0.11	0.17	0.17	0.11	0.14	0.20	0.33	0.25	0.11	0.14
Compressor crankcase heater damage	2.00	2.00	1.00	1.00	1.00	0.13	0.33	0.33	0.17	0.20	0.50	0.50	0.33	0.13	0.17
crankshaft fault	3.00	3.00	1.00	1.00	2.00	0.14	0.50	0.33	0.17	0.25	0.50	1.00	0.50	0.13	0.20
Cylinder head fault	2.00	2.00	1.00	0.50	1.00	0.13	0.25	0.20	0.13	0.17	0.33	0.50	0.33	0.11	0.14
Discharge valve fault	9.00	9.00	8.00	7.00	8.00	1.00	3.00	2.00	1.00	2.00	5.00	6.00	4.00	1.00	2.00
Internal releif valve fault	6.00	6.00	3.00	2.00	4.00	0.33	1.00	1.00	2.00	0.50	2.00	2.00	1.00	0.25	0.50
Oil pump fault	7.00	6.00	3.00	3.00	5.00	0.50	1.00	1.00	0.50	1.00	2.00	3.00	2.00	0.33	0.50
Oil sight glass dirty	9.00	9.00	6.00	6.00	8.00	1.00	0.50	2.00	1.00	2.00	4.00	5.00	1.00	3.00	1.00
Piston fault	8.00	7.00	5.00	4.00	6.00	0.50	2.00	1.00	0.50	1.00	2.00	3.00	2.00	2.00	0.50
Pump end bearing fault	4.00	5.00	2.00	2.00	3.00	0.20	0.50	0.50	0.25	0.50	1.00	2.00	1.00	0.20	0.33
Stator and rotor fault	3.00	3.00	2.00	1.00	2.00	0.17	0.50	0.33	0.20	0.33	0.50	1.00	0.50	0.17	0.25
Suction valve fault	4.00	4.00	3.00	2.00	3.00	0.25	1.00	0.50	1.00	0.50	1.00	2.00	1.00	0.20	0.33
Terminal fault	1.00	9.00	8.00	8.00	9.00	1.00	4.00	3.00	0.33	0.50	5.00	6.00	5.00	1.00	2.00
Valve plate fault	9.00	7.00	6.00	5.00	7.00	0.50	2.00	2.00	1.00	2.00	3.00	4.00	3.00	0.50	1.00
Total	69.00	74.00	50.00	43.17	60.00	6.06	16.92	14.51	8.46	11.22	27.28	36.67	22.17	10.12	9.18

Table: Pair-wise comparison matrix of the sub criteria

	bottom	Compressor	Compressor	Crankshaft	Cylinder	Discharge	Internal	Oil pump	Oil sight		Pump end	Stator and	Suction	Terminal	Valve plate			Eigen
Occurence	cover fault	breakdown	crankcase	fault	head fault	valve fault	relief valve	fault	glass dirty	Piston fault	bearing	rotor fault	valve fault	fault	fault	total	Weight	value
Bottom cover fault	0.014	0.014	0.010	0.008	0.008	0.018	0.010	0.010	0.013	0.011	0.009	0.009	0.011	0.099	0.012	0.257	0.017	1.181
Compressor breakdown	0.014	0.014	0.010	0.008	0.012	0.018	0.010	0.011	0.013	0.013	0.007	0.009	0.011	0.011	0.015	0.177	0.012	0.872
Compressor crankcase heater damage	0.029	0.027	0.020	0.023	0.017	0.021	0.020	0.023	0.020	0.018	0.018	0.014	0.015	0.012	0.018	0.294	0.020	0.980
crankshaft fault	0.043	0.014	0.020	0.023	0.033	0.023	0.030	0.023	0.020	0.022	0.018	0.027	0.023	0.012	0.022	0.354	0.024	1.018
Cylinder head fault	0.029	0.027	0.020	0.012	0.017	0.021	0.015	0.014	0.015	0.015	0.012	0.014	0.015	0.011	0.015	0.250	0.017	1.001
Discharge valve fault	0.130	0.122	0.160	0.162	0.133	0.165	0.177	0.138	0.118	0.178	0.183	0.164	0.180	0.099	0.218	2.328	0.155	0.941
Internal releif valve fault	0.087	0.081	0.060	0.046	0.067	0.055	0.059	0.069	0.236	0.045	0.073	0.055	0.045	0.025	0.054	1.057	0.070	1.192
Oil pump fault	0.101	0.081	0.060	0.070	0.083	0.082	0.059	0.069	0.059	0.089	0.073	0.082	0.090	0.033	0.054	1.087	0.072	1.051
Oil sight glass dirty	0.130	0.122	0.120	0.139	0.133	0.165	0.030	0.138	0.118	0.178	0.147	0.136	0.045	0.296	0.109	2.007	0.134	1.132
Piston fault	0.116	0.095	0.100	0.093	0.100	0.082	0.118	0.069	0.059	0.089	0.073	0.082	0.090	0.198	0.054	1.419	0.095	1.061
Pump end bearing fault	0.058	0.068	0.040	0.046	0.050	0.033	0.030	0.034	0.030	0.045	0.037	0.055	0.045	0.020	0.036	0.625	0.042	1.137
Stator and rotor fault	0.043	0.041	0.040	0.023	0.033	0.027	0.030	0.023	0.024	0.030	0.018	0.027	0.023	0.016	0.027	0.426	0.028	1.040
Suction valve fault	0.058	0.054	0.060	0.046	0.050	0.041	0.059	0.034	0.118	0.045	0.037	0.055	0.045	0.020	0.036	0.758	0.051	1.121
Terminal fault	0.014	0.122	0.160	0.185	0.150	0.165	0.236	0.207	0.039	0.045	0.183	0.164	0.226	0.099	0.218	2.213	0.148	1.493
Valve plate fault	0.500	0.095	0.120	0.116	0.117	0.082	0.118	0.138	0.118	0.178	0.110	0.109	0.135	0.049	0.109	2.095	0.140	1.282

 Table: Normalization of the pairwise calculation matrix

 $V_{max} = = 16.501$

Consistency Index (C.I) = $\frac{(V_{max} - n)}{n-1} = \frac{(16.501 - 15)}{15-1} = 0.107$

Where n is the number of compared elements

Consistency Index (C.I) = 0.107



Cost

	bottom	Compressor	crankcase	Crankshaft	Cylinder	Discharge	relief valve	Oil pump	Oil sight		bearing	Stator and	Suction	Terminal	Valve
Cost	cover fault	breakdown	heater	fault	head fault	valve fault	fault	fault	glass dirty	Piston fault	fault	rotor fault	valve fault	fault	plate
Bottom cover fault	1.00	0.11	0.33	0.11	0.11	0.50	2.00	0.17	2.00	0.25	0.17	0.11	0.50	0.13	0.20
Compressor breakdown	9.00	1.00	9.00	2.00	3.00	9.00	9.00	5.00	9.00	8.00	6.00	2.00	9.00	4.00	7.00
Compressor crankcase heater	3.00	0.11	1.00	0.14	0.17	2.00	4.00	0.25	5.00	0.50	0.33	0.13	2.00	0.20	0.50
crankshaft fault	9.00	0.50	7.00	1.00	2.00	9.00	9.00	3.00	9.00	6.00	4.00	0.50	8.00	2.00	5.00
Cylinder head fault	9.00	0.33	6.00	0.50	1.00	8.00	9.00	2.00	9.00	5.00	4.00	0.50	7.00	2.00	4.00
Discharge valve fault	2.00	0.11	0.50	0.11	0.13	1.00	2.00	0.17	3.00	0.33	0.20	0.11	0.50	0.14	0.25
Internal releif valve fault	0.50	0.11	0.25	0.11	0.11	0.50	1.00	0.13	2.00	0.20	0.14	0.11	0.33	0.11	0.17
Oil pump fault	6.00	0.20	4.00	0.33	0.50	6.00	8.00	1.00	9.00	3.00	2.00	0.25	5.00	0.50	2.00
Oil sight glass dirty	0.50	0.11	0.20	0.11	0.11	0.33	0.50	0.11	1.00	0.17	0.13	0.11	0.25	0.11	0.14
Piston fault	4.00	0.13	2.00	0.17	0.20	3.00	5.00	0.33	6.00	1.00	0.50	0.14	2.00	0.25	0.50
Pump end bearing fault	5.99	0.17	3.00	0.25	0.25	5.00	7.00	0.50	8.00	2.00	1.00	0.20	4.00	0.50	2.00
Stator and rotor fault	9.00	0.50	8.00	2.00	2.00	9.00	9.00	4.00	9.00	7.00	5.00	1.00	9.00	3.00	6.00
Suction valve fault	2.00	0.11	0.50	0.13	0.14	2.00	3.00	0.20	4.00	0.50	0.25	0.11	1.00	0.17	0.33
Terminal fault	8.00	0.25	5.00	0.50	0.50	7.00	9.00	2.00	9.00	4.00	2.00	0.33	6.00	1.00	3.00
Valve plate fault	5.00	0.14	2.00	0.20	0.25	4.00	6.00	0.50	7.00	2.00	0.50	0.17	3.00	0.33	1.00
Total	73.99	3.88	48.78	7.66	10.47	66.33	83.50	19.35	92.00	39.95	26.22	5.77	57.58	14.44	32.09
	Table: Pair-wise comparison matrix of the sub criteria														

Table: Pair-wise comparison matrix of the sub criteria

	bottom	Compressor	Compressor	Crankshaft	Cylinder	Discharge	Internal	Oil pump	Oil sight		Pump end	Stator and	Suction	Terminal	Valve			Eigen
Occurence	cover fault	breakdown	crankcase	fault	head fault	valve fault	relief valve	fault	glass dirty	Piston fault	bearing	rotor fault	valve fault	fault	plate	total	Weight	value
Bottom cover fault	0.014	0.029	0.007	0.014	0.011	0.008	0.024	0.009	0.022	0.006	0.006	0.019	0.009	0.009	0.006	0.191	0.013	0.943
Compressor breakdown	0.122	0.258	0.184	0.261	0.287	0.136	0.108	0.258	0.098	0.200	0.229	0.347	0.156	0.277	0.218	3.138	0.209	0.812
Compressor crankcase heater	0.041	0.029	0.020	0.019	0.016	0.030	0.048	0.013	0.054	0.013	0.013	0.022	0.035	0.014	0.016	0.380	0.025	1.237
crankshaft fault	0.122	0.129	0.143	0.131	0.191	0.136	0.108	0.155	0.098	0.150	0.153	0.087	0.139	0.139	0.156	2.035	0.136	1.039
Cylinder head fault	0.122	0.086	0.123	0.065	0.096	0.121	0.108	0.103	0.098	0.125	0.153	0.087	0.122	0.139	0.125	1.670	0.111	1.165
Discharge valve fault	0.027	0.029	0.010	0.014	0.012	0.015	0.024	0.009	0.033	0.008	0.008	0.019	0.009	0.010	0.008	0.234	0.016	1.035
Internal releif valve fault	0.007	0.029	0.005	0.014	0.011	0.008	0.012	0.006	0.022	0.005	0.005	0.019	0.006	0.008	0.005	0.162	0.011	0.899
Oil pump fault	0.081	0.052	0.082	0.043	0.048	0.090	0.096	0.052	0.098	0.075	0.076	0.043	0.087	0.035	0.062	1.020	0.068	1.316
Oil sight glass dirty	0.007	0.029	0.004	0.014	0.011	0.005	0.006	0.006	0.011	0.004	0.005	0.019	0.004	0.008	0.004	0.137	0.009	0.838
Piston fault	0.054	0.032	0.041	0.022	0.019	0.045	0.060	0.017	0.065	0.025	0.019	0.025	0.035	0.017	0.016	0.492	0.033	1.310
Pump end bearing fault	0.081	0.043	0.061	0.033	0.024	0.075	0.084	0.026	0.087	0.050	0.038	0.035	0.069	0.035	0.062	0.803	0.054	1.403
Stator and rotor fault	0.122	0.129	0.164	0.261	0.191	0.136	0.108	0.207	0.098	0.175	0.191	0.173	0.156	0.208	0.187	2.505	0.167	0.964
Suction valve fault	0.027	0.029	0.010	0.016	0.014	0.030	0.036	0.010	0.043	0.013	0.010	0.019	0.017	0.011	0.010	0.296	0.020	1.137
Terminal fault	0.108	0.064	0.102	0.065	0.048	0.106	0.108	0.103	0.098	0.100	0.076	0.058	0.104	0.069	0.093	1.304	0.087	1.255
Valve plate fault	0.068	0.037	0.041	0.026	0.024	0.060	0.072	0.026	0.076	0.050	0.019	0.029	0.052	0.023	0.031	0.633	0.042	1.355
Total	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	15.000	1.000	16.709

 Table: Normalization of the pairwise calculation matrix

 $V_{max} = = 16.709$

Consistency Index (C.I) = $\frac{(V_{max} - n)}{n-1} = \frac{(16.709 - 15)}{15-1} = 0.079$

Where n is the number of compared elements

Consistency Index (C.I) = 0.079

Consistency Ratio = $\frac{(Consistency \, Index \, ,C.I)}{(Random \, Index \, ,RI)} = \frac{(0.079)}{(1.59)} = 0.049$

Consistency Ratio (CR) = 0.049 < 0.10 (Consistent)



GOAL

Judgement score for each of the criteria:

- 1. Occurrence is equally as important as cost:
 - Occurrence 1x value
 - Cost 1x value

Pair-wise comparison matrix of the criteria respect to the goal

Goal	Cost	Occurrence
Cost	1	1
Occurrence	1	1
AVE		

Normalization of the pairwise calculation matrix

Goal	Cost	Occurrence	Weight
6			
Cost	0.5	0.5	0.5
Occurrence	كنيك.9 مليسي	ويبومر سيقي ٿيڪ	0.5

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Weight	0.5	0.5		
Goal	Cost	Occurrence	Weight sum	
			value	
Cost	0.5	0.5	1	2
Occurrence	0.5	0.5	1	2

$$V_{max} = \frac{(2+2)}{2} = 2$$

Consistency Index (C.I) = $\frac{(V_{max} - n)}{n-1} = \frac{(2-2)}{2-1} = 0$

Where n is the number of compared elements

Consistency Index (C.I) = 0

Consistency Ratio = $\frac{(Consistency Index, C.I)}{(Random Index, RI)} = \frac{(0)}{(0)} =$

Consistency Ratio (CR) = 0 < 0.10 (Consistent)

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Stator and rotor

Judgement score for each of the criteria:

- 1. Corrective maintenance is moderately more important than Predictive maintenance
 - Predictive Maintenance x value
 - Corrective Maintenance 3x value
- 2. Preventive maintenance is equally to moderately more important than Corrective maintenance.
 - Preventive Maintenance 2x value
 - Corrective Maintenance x value
- 3. Preventive maintenance is strongly more important than Predictive maintenance.
 - Predictive Maintenance x value
 - Preventive Maintenance 5x value

Pair-wise comparison matrix of the criteria concerning the sub criteria to alternatives:

5.60			
Stator and Rotor	Corrective	Predictive	Preventive
shi	Maintenance	Maintenance	Maintenance
Compositivo	Junilo 5	استى يېكى	٥٢
Corrective	· · · · ·		0.5
Maintenance	ERSITI TEKNIKA	L MALAYSIA ME	LAKA
Predictive	0.333	1	0.2
Maintenance			
Proventive	2	5	1
1 I CVCIILIVE	2	5	
Maintenance			

Stator and	Corrective	Predictive	Preventive	Weight
Rotor	Maintenance	Maintenance	Maintenance	
Corrective	0.3	0.333	0.294	0.309
Maintenance				
Predictive	0.1	0.111	0.117	0.109
Maintenance				
Preventive	0.6	0.555	0.588	0.581
Maintenance				

Weight	0.309	0.109	0.581		
Stator and	Corrective	Predictive	Preventive	Weight	
rotor	Maintenance	Maintenance	Maintenance	sum	
				value	
Corrective	0.309	0.327	0.290	0.926	2.996
Maintenance	AINO .				
	shl .	16.6	· · · · · · · ·	1	
Predictive	0.102	0.109	0.116	0.327	3
Maintenance	JNIVERSITI	TEKNIKAL M	ALAYSIA MEL	AKA	
Preventive	0.618	0.545	0.581	1.744	3.001
Maintenance					

$$V_{max} = \frac{(2.996 + 3 + 3.001)}{3} = 2.999$$

Consistency Index (C.I) = $\frac{(V_{max}-n)}{n-1} = \frac{(2.999-3)}{3-1} = 0.0005$ Where n is the number of compared elements

Consistency Index (C.I) = 0.0005
Consistency Ratio =
$$\frac{(Consistency \, Index \, ,C.I)}{(Random \, Index \, ,RI)} = \frac{(0.0005)}{(0.58)} = 0.00086$$

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Consistency Ratio (CR) = 0.00086 < 0.10 (Consistent)



Compressor Crankcase.

Judgement score for each of the criteria:

- 1 Corrective maintenance is moderately more important than Predictive maintenance.
 - Predictive Maintenance x value
 - Corrective Maintenance 3x value
- 2 Preventive maintenance is equally to moderately more important than Corrective maintenance.
 - Preventive Maintenance 2x value
 - Corrective Maintenance x value
- 3 Preventive maintenance is strongly more important than Predictive maintenance.
 - Predictive Maintenance x value
 - Preventive Maintenance 5x value

5.60			
Compressor	Corrective	Predictive	Preventive
crankcase damage	Maintenance	Maintenance	Maintenance
Corrective	· · 10	-3	0.5
Maintenance	ERSITI TEKNIKA	L MALAYSIA ME	LAKA
Predictive	0.333	1	0.2
Maintenance			
Preventive	2	5	1
Maintenance			
Sum	3.333	9	1.7

Compressor	Corrective	Predictive	Preventive	Weight
crankcase	Maintenance	Maintenance	Maintenance	
damage				
Corrective	0.3	0.333	0.294	0.309
Maintenance				
Predictive	0.1	0.111	0.117	0.109
Maintenance				
Preventive	0.6	0.555	0.588	0.581
Maintenance				

Weight	0.309 48/4	0.109	0.581		
Compressor	Corrective	Predictive	Preventive	Weight	
crankcase	Maintenance	Maintenance	Maintenance	sum	
damage	L. S. S. S.			value	
Corrective	0.309	0.327	0.290	0.926	2.996
Maintenance	يسبيا ملاك	کنیکل ما	ۆس سىتى تىھ	اوني	
Predictive	0.102	TEK 0.109	0.116	0.327	3
Maintenance					
Preventive	0.618	0.545	0.581	1.744	3.001
Maintenance					

 $V_{max} = \frac{(2.996 + 3 + 3.001)}{3} = 2.999$

Consistency Index (C.I) = $\frac{(V_{max}-n)}{n-1} = \frac{(2.999-3)}{3-1} = 0.0005$

Where n is the number of compared elements

Consistency Index (C.I) = 0.0005

Consistency Ratio = $\frac{(Consistency \ Index \ ,C.I)}{(Random \ Index \ ,RI)} = \frac{(0.0005)}{(0.58)} = 0.00086$

Consistency Ratio (CR) = 0.00086 < 0.10 (Consistent)

n	1	2	3	45	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49
		*3A)	wn -							-
		للاك	يسياه	کل ما	Zi	يْڪ	ميتي ت	بور.	او	
		UNIV	ERSITI	TEKN	IKAL	MALA	YSIA	MELA	KA	

Terminal Fault

Judgement score for each of the criteria:

- 1. Corrective maintenance is moderately more important than Predictive maintenance.
 - Predictive Maintenance x value
 - Corrective Maintenance 3x value
- 2. Preventive maintenance is equally to moderately more important than Corrective maintenance.
 - Preventive Maintenance 2x value
 - Corrective Maintenance x value
- 3. Preventive maintenance is strongly more important than Predictive maintenance.
 - Predictive Maintenance x value
 - Preventive Maintenance 5x value

5.65			
Terminal fault	Corrective	Predictive	Preventive
ch l	Maintenance	Maintenance	Maintenance
ملاك	Sel Juni	رسىق يىكت	_ او دوم
Corrective	IV		0.5
Maintenance	ERSITI TEKNIKA	L MALAYSIA ME	LAKA
Predictive	0.333	1	0.2
Maintenance			
Preventive	2	5	1
Maintenance			

Normalization	of t	the	pairwise	calculation	matrix
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Terminal fault	Corrective	Predictive	Preventive	Weight
	Maintenance	Maintenance	Maintenance	
Corrective	0.3	0.333	0.294	0.309
Maintenance				
Predictive	0.1	0.111	0.117	0.109
Maintenance				
Preventive	0.6	0.555	0.588	0.581
Maintenance				

Weight	0.309	0.109	0.581		
Terminal	Corrective	Predictive	Preventive	Weight	
fault	Maintenance	Maintenance	Maintenance	sum	
				value	
Corrective	0.309	0.327	0.290	0.926	2.996
Maintenance	shi (. 16 6			
Predictive	0.102	0.109	0.116	0.327	3
Maintenance	JNIVERSITI	TEKNIKAL M	" ALAYSIA MEL	AKA	
Preventive	0.618	0.545	0.581	1.744	3.001
Maintenance					

$$V_{max} = \frac{(2.996 + 3 + 3.001)}{3} = 2.999$$

Consistency Index (C.I) = $\frac{(V_{max} - n)}{n-1} = \frac{(2.999 - 3)}{3-1} = 0.0005$

Where n is the number of compared elements

Consistency Index (C.I) = 0.0005

Consistency Ratio = $\frac{(Consistency \, Index \, , C.I)}{(Random \, Index \, , RI)} = \frac{(0.0005)}{(0.58)} = 0.00086$

Consistency Ratio $(CR) = 0$.00086 < 0.10 ((Consistent)
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n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49



Oil Sight Glass

Judgement score for each of the criteria:

- 1. Corrective maintenance is equally to moderately more important than Predictive maintenance.
 - Predictive Maintenance x value
 - Corrective Maintenance 2x value
- 2. Preventive maintenance is equally to moderately more important than Corrective maintenance.
 - Preventive Maintenance 2x value
 - Corrective Maintenance x value
- 3. Preventive maintenance is moderately to strongly more important than Predictive maintenance.
 - Predictive Maintenance x value
 - Preventive Maintenance 4x value

Oil Sight Glass	Corrective	Predictive	Preventive
UNIV	Maintenance ERSITI TEKNIKA	Maintenance L MALAYSIA ME	Maintenance
Corrective	1	2	0.5
Maintenance			
Predictive	0.5	1	0.25
Maintenance			
Preventive	2	4	1
Maintenance			

Normalization	of	the	pairwise	calculation	matrix
	~		Pair (150	carcaration	

Oil Sight Glass	Corrective	Predictive	Preventive	Weight
	Maintenance	Maintenance	Maintenance	
Corrective	0.285	0.285	0.285	0.285
Maintenance				
Predictive	0.142	0.142	0.142	0.142
Maintenance				
Preventive	0.571	0.571	0.571	0.571
Maintenance				

Weight	0.285	0.142	0.571		
Oil Sight	Corrective	Predictive	Preventive	Weight	
Glass	Maintenance	Maintenance	Maintenance	sum	
			IAN	value	
Corrective	0.285	0.284	0.285	0.854	2.996
Maintenance	Alwn -				
	shl . l	16.6	· · · · · · ·	1	
Predictive	0.142	0.142	0.142	0.426	3
Maintenance	JNIVERSITI	TEKNIKAL M	" ALAYSIA MEL	AKA	
Preventive	0.57	0.568	0.571	1.709	2.992
Maintenance					

 $V_{max} = \frac{(2.996 + 3 + 2.992)}{3} = 2.996$

Consistency Index (C.I) = $\frac{(V_{max} - n)}{n-1} = \frac{(2.996 - 3)}{3-1} = 0.002$

Where n is the number of compared elements

Consistency Index (C.I) = 0.002

Consistency Ratio = $\frac{(Consistency \, Index \, ,C.I)}{(Random \, Index \, ,RI)} = \frac{(0.002)}{(0.58)} = 0.0034$

Consistency Ratio (CR) = 0.0034 < 0.10 (Consistent)

n	1	2	3	45	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49
	I	N. P. V.	Nn .					-		
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		UNIV	ERSITI	TEKN	IKAL	MALA	YSIA	MELA	KA	

Piston Fault

Judgement score for each of the criteria:

- 1. Predictive Maintenance is equally to moderately more important than Corrective Maintenance.
 - Predictive Maintenance 2x value
 - Corrective Maintenance x value
- 2. Preventive Maintenance is moderately to strongly more important than Corrective Maintenance.
 - Preventive Maintenance 4x value
 - Corrective Maintenance x value
- 3. Preventive Maintenance is equally to moderately more important than Predictive Maintenance.
 - Predictive Maintenance 2x value
 - Preventive Maintenance x value

Piston fault	Corrective	Predictive	Preventive
UNIVI	Maintenance ERSITI TEKNIKA	Maintenance L MALAYSIA ME	Maintenance
Corrective	1	0.5	0.25
Maintenance			
Predictive	2	1	0.5
Maintenance			
Preventive	4	2	1
Maintenance			

Piston fault	Corrective	Predictive	Preventive	Weight
	Maintenance	Maintenance	Maintenance	
Corrective	0.1429	0.1429	0.1429	0.1429
Maintenance				
Predictive	0.2857	0.2857	0.2857	0.2857
Maintenance				
Preventive	0.5714	0.5714	0.5714	0.5714
Maintenance				

	ALLA SIA				
Weight	0.1429	0.2857	0.5714		
Piston fault	Corrective	Predictive	Preventive	Weight	
	Maintenance	Maintenance	Maintenance	sum	
	Syaning			value	
Corrective	0.1429	0.1429	0.1429	0.4287	3
Maintenance	يسب مارك	<u>سی</u> م	ومرسيبي نيه	اوير	
Predictive	0.2858	TEK0.2857 L M	0.2857	0.8572	3.0004
Maintenance					
Preventive	0.5716	0.5714	0.5714	1.7144	3.0004
Maintenance					

 $V_{max} = \frac{(3+3.0004+3.0004)}{3} = 3.0003$

Consistency Index (C.I) = $\frac{(V_{max} - n)}{n-1} = \frac{(3.0003 - 3)}{3-1} = 0.0003$

Where n is the number of compared elements

Consistency Index (C.I) = 0.0003

Consistency Ratio = $\frac{(Consistency \, Index \, ,C.I)}{(Random \, Index \, ,RI)} = \frac{(0.0003)}{(0.58)} = 0.003$

Consistency Ratio (CR) = 0.003 < 0.10 (Consistent)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49
		19A)	wn -							_
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		UNIV	ERSITI	TEKN	IKAL	MALA	YSIA	IELA	KA	

Valve plate wear

Judgement score for each of the criteria:

- 1. Corrective maintenance is moderately more important than Predictive maintenance.
 - Predictive Maintenance x value
 - Corrective Maintenance 3x value
- 2. Preventive maintenance is moderately more important than Corrective maintenance.
 - Preventive Maintenance 3x value
 - Corrective Maintenance x value
- 3. Preventive maintenance is strongly to very strongly more important than Predictive maintenance.
 - Predictive Maintenance x value
 - Preventive Maintenance 6x value

Valve plate wear	Corrective	Predictive	Preventive
5Me	Maintenance	Maintenance	Maintenance
Corrective	· · 10	3	0.333
Maintenance	ERSITI TEKNIKA	L MALAYSIA ME	LAKA
Predictive	0.333	1	0.166
Maintenance			
Preventive	3	6	1
Maintenance			

Valve plate wear	Corrective	Predictive	Preventive	Weight
	Maintenance	Maintenance	Maintenance	
Corrective	0.230	0.3	0.222	0.250
Maintenance				
Predictive	0.076	0.1	0.110	0.095
Maintenance				
Preventive	0.692	0.6	0.667	0.653
Maintenance				

Weight	0.250	0.095	0.653		
Valve plate	Corrective	Predictive	Preventive	Weight	
wear	Maintenance	Maintenance	Maintenance	sum	
				value	
Corrective	0.250	0.285	0.217	0.752	3.008
Maintenance	alwn -				
	1.142	15.4	- · · · · · · ·	1	
Predictive	0.083	0.095	0.108	0.286	3.010
Maintenance	JNIVERSITI	TEKNIKAL M	" ALAYSIA MEL	AKA	
Preventive	0.75	0.57	0.653	1.973	3.021
Maintenance					

 $V_{max} = \frac{(3.008 + 3.010 + 3.021)}{3} = 3.013$

Consistency Index (C.I) = $\frac{(V_{max}-n)}{n-1} = \frac{(3.013-3)}{3-1} = 0.0065$

Where n is the number of compared elements

Consistency Index (C.I) = 0.0065

Consistency Ratio = $\frac{(Consistency \, Index \, ,C.I)}{(Random \, Index \, ,RI)} = \frac{(0.0065)}{(0.58)} = 0.011$

Consistency Ratio (CR) = 0.011 < 0.10 (Consistent)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49
		19A)	wn -							_
		للك	يسياه	کل ما	- ښ	يْڪ	مىتى ت	بورم	اوز	
		UNIV	ERSITI	TEKN	IKAL	MALA	YSIA	IELA	KA	

Crankshaft fault

Judgement score for each of the criteria:

- 1. Predictive maintenance is equally to moderately more important than Corrective maintenance.
 - Predictive Maintenance 2x value
 - Corrective Maintenance x value
- 2. Preventive maintenance is strongly to very strongly more important than Corrective maintenance.
 - Preventive Maintenance 6x value
 - Corrective Maintenance x value
- 3. Preventive maintenance is moderately more important than Predictive maintenance.
 - Predictive Maintenance x value
 - Preventive Maintenance 3x value

Crankshaft fault	Corrective	Predictive	Preventive
الاك	Maintenance	Maintenance "	Maintenance
Corrective	ERSITI TEKNIKA	L MAL Q.5 SIA ME	LAKA0.166
Maintenance			
Predictive	2	1	0.333
Maintenance			
Preventive	6	3	1
Maintenance			

Crankshaft fault	Corrective	Predictive	Preventive	Weight
	Maintenance	Maintenance	Maintenance	
Corrective	0.111	0.111	0.110	0.111
Maintenance				
Predictive	0.222	0.222	0.222	0.222
Maintenance				
Preventive	0.666	0.666	0.666	0.666
Maintenance				

Weight	0.111	0.222	0.666		
Crankshaft	Corrective	Predictive	Preventive	Weight	
fault	Maintenance	Maintenance	Maintenance	sum	
				value	
Corrective	0.111	0.111	0.110	0.332	2.990
Maintenance	Alwn -				
	1.112	16.6	· · · ·		
Predictive	0.222	0.222	0.221	0.665	2.995
Maintenance	JNIVERSITI	TEKNIKAL M	" ALAYSIA MEL	AKA	
Preventive	0.666	0.666	0.666	1.998	3
Maintenance					

 $V_{max} = \frac{(2.990 + 2.995 + 3)}{3} = 2.995$

Consistency Index (C.I) = $\frac{(V_{max}-n)}{n-1} = \frac{(2.995-3)}{3-1} = 0.0025$

Where n is the number of compared elements

Consistency Index (C.I) = 0.0025

Consistency Ratio = $\frac{(Consistency \, Index \, , C.I)}{(Random \, Index \, , RI)} = \frac{(0.0025)}{(0.58)} = 0.0043$

Consistency Ratio (CR) = 0.0079 < 0.10 (Consistent)

n	1	2	3	45	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49
		N.C.	in .							
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		UNIV	ERSITI	TEKN	IKAL	MALA	YSIA	IELA	KA	

Cylinder Head

Judgement score for each of the criteria:

- 1. Corrective maintenance is moderately more important than Predictive maintenance.
 - Predictive Maintenance x value
 - Corrective Maintenance 3x value
- 2. Preventive maintenance is moderately more important than Corrective maintenance.
 - Preventive Maintenance 3x value
 - Corrective Maintenance x value
- 3. Preventive maintenance is very strongly to extremely more important than Predictive maintenance.
 - Predictive Maintenance x value
 - Preventive Maintenance 8x value

Cylinder Head	Corrective	Predictive	Preventive
she	Maintenance	Maintenance	Maintenance
Corrective	1 Internet		0.333
Maintenance	ERSITI TEKNIKA	L MALAYSIA ME	LAKA
Predictive	0.333	1	0.125
Maintenance			
Preventive	3	8	1
Maintenance			

Cylinder Head	Corrective	Predictive	Preventive	Weight
	Maintenance	Maintenance	Maintenance	
Corrective	0.230	0.25	0.228	0.236
Maintenance				
Predictive	0.076	0.083	0.085	0.081
Maintenance				
Preventive	0.692	0.666	0.685	0.681
Maintenance				

Weight	0.236	0.081	0.681		
Cylinder	Corrective	Predictive	Preventive	Weight	
Head	Maintenance	Maintenance	Maintenance	sum	
			IAN	value	
Corrective	0.236	0.243	0.226	0.705	2.98
Maintenance	Alwn .				
	shl . l	16.6	- · · · · · ·	1	
Predictive	0.078	0.081	0.085	0.244	3.012
Maintenance	JNIVERSITI	TEKNIKAL M	" ALAYSIA MEL	AKA	
Preventive	0.708	0.648	0.681	2.037	2.991
Maintenance					

 $V_{max} = \frac{(2.98 + 3.012 + 2.991)}{3} = 2.994$

Consistency Index (C.I) = $\frac{(V_{max} - n)}{n-1} = \frac{(2.994 - 3)}{3-1} = 0.003$

Where n is the number of compared elements

Consistency Index (C.I) = 0.003

Consistency Ratio = $\frac{(Consistency \, Index \, , C.I)}{(Random \, Index \, , RI)} = \frac{(0.003)}{(0.58)} = 0.0051$

Consistency Ratio (CR) = 0.0051 < 0.10 (Consistent)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49
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		UNIV	ERSITI	TEKN	IKAL	MALA	YSIA	MELA	KA	

Internal Relief valve

Judgement score for each of the criteria:

- 1. Corrective maintenance is equally to moderately more important than Predictive maintenance.
 - Predictive Maintenance x value
 - Corrective Maintenance 2x value
- 2. Preventive maintenance is moderately more important than Corrective maintenance.
 - Preventive Maintenance 3x value
 - Corrective Maintenance x value
- 3. Preventive maintenance is strongly more important than Predictive maintenance.
 - Predictive Maintenance x value
 - Preventive Maintenance 5x value

Internal Relief	Corrective	Predictive	Preventive
Valve	Maintenance	Maintenance	Maintenance
2 Ch	Sunda S	in win in	nava
Corrective	10	-2	0.333
Maintenance	ERSITI TEKNIKA	L MALAYSIA ME	LAKA
Predictive	0.5	1	0.2
Maintenance			
Preventive	3	5	1
Maintenance			

	Normalization	of the	pairwise	calculation	matrix
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Internal Relief	Corrective	Predictive	Preventive	Weight
Valve	Maintenance	Maintenance	Maintenance	
Corrective	0.222	0.25	0.217	0.229
Maintenance				
Predictive	0.111	0.125	0.13	0.122
Maintenance				
Preventive	0.666	0.625	0.652	0.647
Maintenance				

Weight	0.229	0.122	0.647		
Internal	Corrective	Predictive	Preventive	Weight	
Relief Valve	Maintenance	Maintenance	Maintenance	sum	
				value	
Corrective	0.229	0.244	0.215	0.688	3.004
Maintenance	AINO .				
	1.112	15.4		1	
Predictive	0.114	0.122	0.129	0.365	2.991
Maintenance	JNIVERSITI	TEKNIKAL M	" ALAYSIA MEL	AKA	
Preventive	0.687	0.61	0.647	1.944	3.004
Maintenance					

 $V_{max} = \frac{(3.004 + 2.991 + 3.004)}{3} = 2.999$

Consistency Index (C.I) = $\frac{(V_{max}-n)}{n-1} = \frac{(2.999-3)}{3-1} = 0.0005$

Where n is the number of compared elements

Consistency Index (C.I) = 0.0005

Consistency Ratio = $\frac{(Consistency \, Index \, , C.I)}{(Random \, Index \, , RI)} = \frac{(0.0005)}{(0.58)} = 0.0008$

Consistency Ratio (CR) = 0.0008 < 0.10 (Consistent)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49
		A FE	Nn .							
		للاك	• ()	کل ما	- in	<u>_</u>	سيتي ت	يوشر	اوز	
		UNIV	ERSITI	TEKN	IIKAL	MALA	YSIA	MELA	KA	

Bottom Cover

Judgement score for each of the criteria:

- 1. Corrective maintenance is moderately to strongly more important than Predictive maintenance.
 - Predictive Maintenance x value
 - Corrective Maintenance 4x value
- 2. Corrective maintenance is equally to moderately more important than Preventive maintenance.
 - Preventive Maintenance x value
 - Corrective Maintenance 2x value
- 3. Preventive maintenance is equally to moderately more important than Predictive maintenance.
 - Predictive Maintenance x value
 - Preventive Maintenance 2x value

Bottom Cover	Corrective	Predictive	Preventive
UNIV	Maintenance ERSITI TEKNIKA	Maintenance L MALAYSIA ME	Maintenance
Corrective	1	4	2
Maintenance			
Predictive	0.25	1	0.5
Maintenance			
Preventive	0.5	2	1
Maintenance			

Bottom Cover	Corrective	Predictive	Preventive	Weight
	Maintenance	Maintenance	Maintenance	
Corrective	0.571	0.571	0.571	0.571
Maintenance				
Predictive	0.142	0.142	0.142	0.142
Maintenance				
Preventive	0.285	0.285	0.285	0.285
Maintenance				

Weight	0.571	0.142	0.285		
Bottom	Corrective	Predictive	Preventive	Weight	
Cover	Maintenance	Maintenance	Maintenance	sum	
			IAN	value	
Corrective	0.571	0.568	0.57	1.709	2.992
Maintenance	AINO .				
	shl .	16.6	· · · · · · · ·	1	
Predictive	0.142	0.142	0.142	0.426	3
Maintenance	JNIVERSITI	TEKNIKAL M	ALAYSIA MEL	AKA	
Preventive	0.285	0.284	0.285	0.854	2.996
Maintenance					

 $V_{max} = \frac{(2.992 + 3 + 2.996)}{3} = 2.996$

Consistency Index (C.I) = $\frac{(V_{max} - n)}{n-1} = \frac{(2.996 - 3)}{3-1} = 0.002$

Where n is the number of compared elements

Consistency Index (C.I) = 0.002

Consistency Ratio = $\frac{(Consistency \, Index \, ,C.I)}{(Random \, Index \, ,RI)} = \frac{(0.002)}{(0.58)} = 0.0034$

Consistency Ratio (CR) = 0.0034 < 0.10 (Consistent)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49
		A FE	Nn .							
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Pump and Bearing

Judgement score for each of the criteria:

- 1. Predictive Maintenance is equally to moderately more important than Corrective Maintenance.
 - Predictive Maintenance 2x value
 - Corrective Maintenance x value
- 2. Preventive Maintenance is moderately to strongly more important than Corrective Maintenance.
 - Preventive Maintenance 4x value
 - Corrective Maintenance x value
- 3. Preventive Maintenance is equally to moderately more important than Predictive Maintenance.
 - Predictive Maintenance x value
 - Preventive Maintenance 2x value

Pump and bearing	Corrective	Predictive	Preventive
UNIVI	Maintenance ERSITI TEKNIKA	Maintenance L MALAYSIA ME	Maintenance
Corrective	1	0.5	0.25
Maintenance			
Predictive	2	1	0.5
Maintenance			
Preventive	4	2	1
Maintenance			

TNormalization of the pairwise calculation matrix

Pump and	Corrective	Predictive	Preventive	Weight
bearing	Maintenance	Maintenance	Maintenance	
Corrective	0.142	0.142	0.142	0.142
Maintenance				
Predictive	0.285	0.285	0.285	0.285
Maintenance				
Preventive	0.571	0.571	0.571	0.571
Maintenance				

Weight	0.142	0.285	0.571		
Pump and	Corrective	Predictive	Preventive	Weight	
bearing	Maintenance	Maintenance	Maintenance	sum	
			IAN	value	
Corrective	0.142	0.142	0.142	0.428	3
Maintenance	Alwn -				
	shi lala	15.5	1		
Predictive	0.285	0.285	0.285	0.857	3
Maintenance	JNIVERSITI	TEKNIKAL MA	LAYSIA MELA	KA	
Preventive	0.571	0.571	0.571	1.714	3
Maintenance					

$$V_{max} = \frac{(3+3+3)}{3} = 3$$

Consistency Index (C.I) = $\frac{(V_{max} - n)}{n-1} = \frac{(3-3)}{3-1} = 0$

Where n is the number of compared elements

Consistency Index (C.I) = 0

Consistency Ratio = $\frac{(Consistency \, Index \, , C.I)}{(Random \, Index \, , RI)} = \frac{(0)}{(0.58)} = 0$

Consistency Ratio (CR) = 0 < 0.10 (Consistent)

n	1	2	3	4 5	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49
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Oil Pump Fault

Judgement score for each of the criteria:

- 1. Predictive maintenance is equally to moderately more important than Corrective maintenance.
 - Predictive Maintenance 2x value
 - Corrective Maintenance x value
- 2. Preventive maintenance is strongly more important than Corrective maintenance.
 - Preventive Maintenance 5x value
 - Corrective Maintenance x value
- 3. Preventive maintenance is moderately more important than Predictive maintenance.
 - Predictive Maintenance x value
 - Preventive Maintenance 3x value

50			
Oil Pump Fault	Corrective	Predictive	Preventive
she	Maintenance	Maintenance	Maintenance
Corrective	الم میسیا	0.5	0.2
Maintenance	ERSITI TEKNIKA	L MALAYSIA ME	LAKA
Predictive	2	1	0.333
Maintenance			
Preventive	5	3	1
Maintenance			

Oil Pump Fault	Corrective	Predictive	Preventive	Weight
	Maintenance	Maintenance	Maintenance	
Corrective	0.125	0.111	0.130	0.122
Maintenance				
Predictive	0.25	0.222	0.217	0.229
Maintenance				
Preventive	0.625	0.666	0.652	0.647
Maintenance				

Weight	0.122	0.229	0.647		
Oil Pump	Corrective	Predictive	Preventive	Weight	
Fault	Maintenance	Maintenance	Maintenance	sum	
				value	
Corrective	0.122	0.114	0.129	0.365	3.016
Maintenance	Alwn .				
	shl.	16:6	- · · · · · ·	1.1	
Predictive	0.244	0.229	0.215	0.688	3.004
Maintenance	JNIVERSITI	TEKNIKAL M	ALAYSIA MEL	AKA	
Preventive	0.61	0.687	0.647	1.944	3.004
Maintenance					

 $V_{max} = \frac{(3.016 + 3.004 + 3.004)}{3} = 3.008$

Consistency Index (C.I) = $\frac{(V_{max} - n)}{n-1} = \frac{(3.008 - 3)}{3-1} = 0.004$

Where n is the number of compared elements

Consistency Index (C.I) = 0.004

Consistency Ratio = $\frac{(Consistency \, Index \, ,C.I)}{(Random \, Index \, ,RI)} = \frac{(0.004)}{(0.58)} = 0.0068$

Consistency Ratio (CR) = 0.0068 < 0.10 (Consistent)

n	1	2	3	45	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49
	·	***A.	Win .							
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Compressor trip

Judgement score for each of the criteria:

- 1. Corrective maintenance is moderately more important than predictive maintenance:
 - Corrective Maintenance 3x value
 - Predictive Maintenance x value
- 2. Preventive Maintenance is moderately to strongly more important than corrective maintenance:
 - Preventive Maintenance 4x value
 - Corrective Maintenance x value
- 3. Preventive Maintenance is very strongly more important than predictive maintenance.
 - Predictive Maintenance x value
 - Preventive Maintenance 7x value

Compressor trip	Corrective	Predictive	Preventive
shi	Maintenance	Maintenance	Maintenance
Corrective	ا میسیا		0.25
Maintenance	ERSITI TEKNIKA	L MALAYSIA ME	LAKA
Predictive	0.333	1	0.142
Maintenance			
Preventive	4	7	1
Maintenance			

Compressor trip	Corrective	Predictive	Preventive	Weight
	Maintenance	Maintenance	Maintenance	
Corrective	0.187	0.272	0.179	0.212
Maintenance				
Predictive	0.062	0.090	0.102	0.084
Maintenance				
Preventive	0.750	0.636	0.718	0.701
Maintenance				

Weight	0.212	0.084	0.701		
Compressor	Corrective	Predictive	Preventive	Weight	
trip	Maintenance	Maintenance	Maintenance	sum	
			IEN	value	
Corrective	0.212	0.252	0.175	0.639	3.014
Maintenance	ليسبأ ملاك	ڪنيڪل م	نىرسىتى تىد	اوني	
Predictive	0.07	0.084	0.099	0.253	3.011
Maintenance	INIVERSITI	TEKNIKAL MA	LAYSIA MEL	AKA	
Preventive	0.848	0.588	0.701	2.137	3.048
Maintenance					
Calculation of consistency:

 $V_{max} = \frac{(3.014 + 3.011 + 3.048)}{3} = 3.024$

Consistency Index (C.I) = $\frac{(V_{max} - n)}{n-1} = \frac{(3.024 - 3)}{3-1} = 0.012$

Where n is the number of compared elements

Consistency Index (C.I) = 0.012

Consistency Ratio = $\frac{(Consistency \, Index \, , C.I)}{(Random \, Index \, , RI)} = \frac{(0.012)}{(0.58)} = 0.020$

Consistency Ratio (CR) = 0.020 < 0.10 (Consistent)

n	1	2	3	4 5	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49
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Discharge valve fault

Judgement score for each of the criteria:

- 1. Corrective Maintenance is moderately more important than Predictive Maintenance:
 - Predictive Maintenance x value
 - Corrective Maintenance 3x value
- 2. Corrective Maintenance is equally as important as Preventive Maintenance:
 - Preventive Maintenance 1x value
 - Corrective Maintenance 1x value
- 3. Preventive Maintenance is moderately more important than Predictive Maintenance:
 - Predictive Maintenance 1x value
 - Preventive Maintenance 3x value

Pair-wise comparison matrix of the criteria concerning the sub criteria to alternatives:

Discharge valve	Corrective	Predictive	Preventive
fault	Maintenance	Maintenance	Maintenance
Corrective Maintenance	كل لمليسياً	رسيتي ٽيڪني	¹ اونيۆ~
Predictive	ERSITI _{0.333} KNIKA	L MALAYSIA ME	LAKA _{0.333}
Maintenance			
Preventive Maintenance	1	3	1

Normalization of the pairwise calculation matrix

Discharge valve	Corrective	Predictive	Preventive	Weight
fault	Maintenance	Maintenance	Maintenance	
Corrective	0.428	0.428	0.428	0.428
Maintenance				
Predictive	0.142	0.142	0.142	0.142
Maintenance				
Preventive	0.428	0.428	0.428	0.428
Maintenance				

Weight	0.428	0.142	0.428		
Discharge	Corrective	Predictive	Preventive	Weight	
valve fault	Maintenance	Maintenance	Maintenance	sum	
			IAN	value	
Corrective	0.428	0.426	0.428	1.282	3
Maintenance	ann				
	shl.	16.6	- 1	1.1	
Predictive	0.142	0.142	0.142	0.246	3
Maintenance	JNIVERSITI	TEKNIKAL MA	LAYSIA MELA	KA	
Preventive	0.428	0.426	0.428	1.282	3
Maintenance					

Calculation of consistency:

$$V_{max} = \frac{(3+3+3)}{3} = 3$$

Consistency Index (C.I) = $\frac{(V_{max} - n)}{n-1} = \frac{(2.996 - 3)}{3-1} = 0$

Where n is the number of compared elements

Consistency Index (C.I) = 0

Consistency Ratio = $\frac{(Consistency \, Index \, , C.I)}{(Random \, Index \, , RI)} = \frac{(0)}{(0.58)} = 0$

Consistency Ratio (CR) = 0 < 0.10 (Consistent)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49
		LISS ST			V		5	IV		
		Malunda KS: Si in maine								
			** **				5.	103.	-	
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Suction valve fault

Judgement score for each of the criteria:

- 1. Predictive Maintenance is equally to moderately more important than corrective maintenance:
 - Predictive Maintenance 2x value
 - Corrective Maintenance x value
- 2. Preventive Maintenance is moderately more important than Corrective Maintenance:
 - Preventive Maintenance 3x value
 - Corrective Maintenance x value
- 3. Preventive maintenance is equally to moderately more important than predictive maintenance:
 - Predictive Maintenance x value
 - Preventive Maintenance 2x value

Pair-wise comparison matrix of the criteria concerning the sub criteria to alternatives:

Suction valve fault	Corrective	Predictive	Preventive
للاك	Maintenance	Maintenance	Maintenance
Corrective	ERSITI TEKNIKA	L MAL 0.5 SIA ME	LAK 0.3333
Maintenance			
Predictive	2	1	0.5
Maintenance			
Preventive	3	2	1
Maintenance			

Normalization of the pairwise calculation matrix

Suction valve	Corrective	Predictive	Preventive	Weight
fault	Maintenance	Maintenance	Maintenance	
Corrective	0.166	0.142	0.181	0.163
Maintenance				
Predictive	0.333	0.285	0.272	0.297
Maintenance				
Preventive	0.5	0.571	0.545	0.539
Maintenance				

Weight	0.163 sia	0.297	0.539		
Suction	Corrective	Predictive	Preventive	Weight	
valve fault	Maintenance	Maintenance	Maintenance	sum	
	No.		IEN	value	
Corrective	0.163	0.148	0.179	0.492	3.003
Maintenance	ليسيا ملاك	کنیکل م	یرسیتی تید	اونيو	
Predictive	0.327	0.297	0.269	0.894	3.009
Maintenance	INIVERSITI	TEKNIKAL M/	ALAYSIA MEL	AKA	
Preventive	0.491	0.594	0.53	1.624	3.014
Maintenance					

Calculation of consistency:

 $V_{max} = \frac{(3.003 + 3.009 + 3.014)}{3} = 3.0091$

Consistency Index (C.I) = $\frac{(V_{max} - n)}{n-1} = \frac{(3.009 - 3)}{3-1} = 0.009$

Where n is the number of compared elements

Consistency Index (C.I) = 0.009

Consistency Ratio = $\frac{(Consistency Index, C.I)}{(Random Index, RI)} = \frac{(0.009)}{(0.58)} = 0.015$

Consistency Ratio (CR) = 0.015 < 0.10 (Consistent)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49
		19A)	wn -							_
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Compressor spare part cost

Semi Hermetic Compressor parts	Cost (RM)
(Company A)	
1. Stator and rotor	RM 4880.00
2. Compressor crankcase	RM 561.00
3. Oil sight glass	RM 937.00
4. Piston assembly	RM4375.00
5. Valve plate	RM 3920.00
6. Crankshaft	RM 26355.00
7. Terminal plate	RM 5235.00
8. Cylinder head	RM 3596.00
9. Internal relief valve	RM 518.00
10. Bottom cover	RM 2160.00
11. Pump end bearing	RM 3577.00
12. Oil pump	RM 2106.00

Cost (RM)		
RM 57.00		
RM 5235.00		
RM 50 000.00		
RM 628.00		

Acquisition Cost

Acquisition cost is consists of fixed (CFA) and replacement cost. Fixed cost is the initial cost of equipment while replacement cost (CRA) is the purchased cost of sub components when the equipment is failed. The acquisition cost can be defined using Equation:

Caq = Cfa + Cra

Semi Hermetic Compressor parts (Petronas)	Acquisition Cost (RM)
1. Stator and rotor	RM 50000.00 + RM 4880.00 = RM 54880.00
2. Compressor crankcase	RM 50000.00 + RM 561.00 = RM 50561.00
3. Oil sight glass	RM 50000.00 + RM 937.00 =RM 50937.00
4. Piston assembly	RM 50000.00 + RM 4375.00 =RM54375.00
5. Valve plate assembly	RM 50000.00 + RM 3920.00 =RM 53920.00
6. Crankshaft	RM 50000.00 + RM 26355.00

	=RM 76255.00
7. Terminal plate	RM 500000.00 + RM 5235.00 =RM 55235.00
8. Cylinder head	RM 50000.00 + RM 3596.00 =rm 53596.00
9. Internal relief valve	RM 50000.00 + RM 518.00 =RM 50518.00
10. Bottom cover	RM 50000.00 + RM 2160.00 =RM 52160.00
11. Pump end bearing	RM 50000.00 + RM 3577.00 =RM 53577.00
12. Oil pump	RM 50000.00 + RM 2106.00 =RM 52106.00
13. Stator and rotor	RM 50000.00 + RM 4880.00 =RM 54880.00

	JIEW
Semi Hermetic Compressor parts	Acquisition cost (RM)
(ExxonMobil)	
5Malula IS	· Contraction
1. Mounting	RM 50000.00 + RM 782.00
	=RM 50782.00
UNIVERSITI TEKNIKA	L MALAYSIA MELAKA
2. Pressure switch	RM 50000.00 + RM 217.00
	=RM 50217.00
3. Discharge valve	RM 50000.00 + RM 57.00
	=RM 50057.00
4. Terminal plate	RM 50000.00 + RM 5235.00
	=RM 55235.00
5. Semi Hermetic Compressor	RM 50000.00 + RM 50000.00
	RM 100000.00
6. Evaporator	RM 50000.00 + RM 3145.00
	=RM 63145.00
7. TXV	RM 50000.00 + RM 678.00
	=RM 50678.00

8. Discharge service valve	RM 50000.00 + RM 628.00 =RM 50628.00
9. Capacitor	RM 50000.00 + RM 139.00 =RM 50139.00

Maintenance selection weight.

NO.	Sub criteria component	Corrective	Predictive	Preventive	
		maintenance	maintenance	maintenance	
1	Terminal fault	0.571	0.142	0.285	
2	Discharge valve fault	0.428	0.142	0.428	
3	Oil sight glass dirty	0.285	0.142	0.571	
4	Valve plate wear	0.249	0.095	0.654	
5	Piston fault	0.142	0.285	0.571	
6	Oil pump fault	0.122	0.229	0.648	
7	Internal relief valve fault	0.229	0.122	0.648	
8	Suction valve fault	0.163	0.296	0.539	
9	Pump and bearing fault	0.142 AL	AYSI0.285ELA	KA 0.571	
10	Stator and rotor				
	fault	0.309	0.109	0.581	
11	Crankshaft fault	0.111	0.222	0.666	
12	Compressor crankcase	0.309			
	heater damage		0.109	0.581	
13	Cylinder head fault	0.236	0.081	0.681	
14	Bottom cover fault	0.571	0.142	0.285	
15	Compressor breakdown	0.210	0.084	0.704	

Table 20:Sub criteria selection weight

Maintenance strategy	Total weight	Ranking
1. Corrective maintenance	0.245	2
2. Predictive maintenance	0.153	3
3. Preventive maintenance	0.601	1



CHAPTER 5

CONCLUSION

In this final chapter we draw conclusions on the aim of this thesis and the three key challenges that underpin the research. Thereafter we elaborate on the road ahead and provide directions for further research.

This research paper aims to show how a typical problem of maintenance strategy selection can be simplified by using a decision making tools. Using the advantages and facilities of AHP methods helps to control the factor which influences to achieve the goal of company. In this paper review of various researches suggest that large scope of applicability of AHP methods. Comparative study of alternatives can help to understand the condition of problem and also at the time of decision making i.e. to fulfill questionnaire part for data collection. Selection of any criteria is also a challenging task but it can be well estimated by review of various research studies at different conditions in different companies. It can be concluded at the end of this research paper that for the general problem of maintenance strategy selection above steps can be taken in the account and along with this sensitivity analysis can also be implemented so that influence in output can be measured by changing the criteria.

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The three maintenance strategies considered for selection in the semi hermetic for compressor are, corrective maintenance, predictive maintenance and preventive maintenance. With case study and analysis from the industry report, weight of the three maintenance strategies were determined. The result show that preventive maintenance is the most preferred strategy to employ in semi hermetic compressor for refrigeration system HVAC. The advantages of the AHP method model developed in this case study is a feedback mechanism that links maintenance strategy to initiators of maintenance. The model is structured system for group decision making, thus it can be used as a training material to enhance and minimize cost for maintenance program. Recomendation:

- 1. For future research, we suggest that other multi criteria decision making approaches such as TOPSIS and ELECTRE with or without fuzzy methods be used, and to be compared as justification for semi hermetic compressor selection maintenance strategy.
- 2. Proposed stable and easy to use multi criteria decision making-based framework will be helpful in various industrial applications to fulfill analytical needs.
- 3. AHP method still can be improved by providing unique software to avoid making mistakes while doing the calculations.





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APPENDICES

SUPER DECISSION SOFTWARE

Combine company A and B



🚱 New synthesis for: Mai	n Network: Synthesize.sdmo	d	
			Here are the overall synthesized priorities for the alternatives. You synthesized from the network Main Network: Synthesize.sdmod
Name corrective maintenance predictive maintenance preventive maintenance	Graphic	Ideals Normals Raw 0.408255 0.245447 0.081816 0.255057 0.153343 0.051114 1.000000 0.601210 0.204033	
	AL	AYSIA	
Okay Copy Values	Set in	MEL	
	NAT AT AND	AKA	UTeM
	باملاك	کل ملیسب	اونيۇم سىتى تيكنىڭ
	UNIVER	SITI TEKN	IIKAL MALAYSIA MELAKA

🔞 Main	Network: Synthesize.sdmoc	l: Priorities	- 1	j X
Here are the priorities.				
lcon	Name		Normalized by Cluster	Limiting ^
No Icon	corrective maintenance		0.24545	0.081816
No Icon	predictive maintenance		0.15334	0.051114
No Icon	preventive maintenance		0.60121	0.200403
No Icon	Cost		0.50000	0.166667
No Icon	Occurence		0.50000	0.166667
No Icon	Goal		0.00000	0.000000
No Icon	bottom cover fault		0.01544	0.005146
No Icon	compressor breakdown		0.11332	0.037773
No Icon	compressor crankcase heater damage		0.02146	0.007153
No Icon	crankshaft fault	2.	0.08186	0.027286
No Icon	cylinder head fault	Ý.	0.06479	0.021596
No Icon	discharge valve fault	2	0.08418	0.028060
No Icon	internal relief valve fault		0.04022	0.013406
No Icon	Oil pump fault		0.06912	0.023041
No Icon	Oil sight glass dirty	n Ka	0.07262	0.024206
No Icon	Piston fault	· · ·	0.06400	0.021335
No Icon	Pump end bearing fault	reknika	LIMALO.04612IA N	0.015380 A
No Icon	stator and rotor fault		0.10011	0.033369
No Icon	suction valve fault		0.03422	0.011408
No Icon	terminal fault		0.11542	0.038473
No Icon	Valve plate wear		0.07711	0.025704