STRATEGIC DECISION MAKING IN INVESTMENT FOR PRODUCTION FACILITY DEVELOPMENT AT PT. PINDAD

FINAL PROJECT

**In partial fulfilment of the requirements
for the master's degree
from Institut Teknologi Bandung**

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ABSTRACT

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Strategic investment is essential in the defense industry to overcome production capacity limitations and remain competitive in the global market (Lu & Asghar, 2020). PT Pindad, a state-owned enterprise, faces challenges due to aging machinery in its weapons production line, with many units operating for over 30 years. To address this, the government has allocated IDR 450 billion through State Capital Participation (PMN) to support a modernization and automation program aimed at increasing production capacity from 54,000 to 75,000 units per year by 2029. This research aims to support strategic investment decision-making using a Multi-Criteria Decision Analysis (MCDA) approach (Rezaei, 2015), applying Kepner-Tregoe Decision Analysis and the Analytic Hierarchy Process (AHP). Data were gathered through in-depth interviews with key internal stakeholders and internal document reviews Nine main evaluation criteria were identified, such as efficiency, technology, cost, sustainability and more. The results of the analysis show that there are 8 machines and equipment that are prioritized such as modern CNC, automated inspection systems, collaborative robots and others are the main investment options to improve efficiency and competitiveness. The study provides practical recommendations to guide PT Pindad's modernization roadmap and academic contributions to the application of structured decision-making in strategic industries. This systematic approach offers a reference for managing large-scale investment decisions in state-owned and defense-related enterprises.

Keywords: strategic decision-making, defense industry investment, production facility modernization, MCDA, AHP, industrial automation

ABSTRAK

PENGAMBILAN KEPUTUSAN STRATEGIS DALAM INVESTASI PENGEMBANGAN FASILITAS PRODUKSI DI PT. PINDAD

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Investasi strategis sangat penting bagi industri pertahanan dalam menghadapi tantangan kapasitas produksi dan daya saing global. PT Pindad, sebagai BUMN strategis, menghadapi keterbatasan pada fasilitas produksi senjata akibat penggunaan mesin usang yang berusia lebih dari 30 tahun. Pemerintah telah mengalokasikan PMN sebesar Rp 450 miliar untuk mendukung program modernisasi dan otomatisasi lini produksi, yang ditargetkan meningkatkan kapasitas dari 54.000 menjadi 75.000 unit per tahun pada 2029. Penelitian ini bertujuan untuk membantu pengambilan keputusan investasi melalui pendekatan Multi-Criteria Decision Making (MCDM), menggunakan metode Kepner-Tregoe dan Analytic Hierarchy Process (AHP). Data dikumpulkan melalui wawancara mendalam dengan manajemen dan analisis dokumen internal perusahaan. Sembilan kriteria utama evaluasi diidentifikasi, seperti efisiensi, teknologi, biaya, keberlanjutan dan lainnya. Hasil analisis menunjukkan bahwa terdapat 8 mesin dan peralatan yang di prioritaskan seperti CNC modern, sistem inspeksi otomatis, robot kolaboratif dan lainnya menjadi pilihan investasi utama untuk meningkatkan efisiensi dan daya saing. Penelitian ini memberikan kontribusi praktis dalam mendukung roadmap modernisasi PT Pindad dan juga kontribusi akademik dalam penerapan metode keputusan strategis di sektor industri pertahanan. Pendekatan sistematis ini diharapkan dapat menjadi acuan bagi pengambilan keputusan investasi berskala besar di lingkungan BUMN dan industri strategis lainnya.

Kata kunci: pengambilan keputusan strategis, investasi industri pertahanan, modernisasi fasilitas produksi, MCDA, AHP, otomatisasi industri

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This final project is wholeheartedly dedicated to
my beloved parents,
for their unwavering love, prayers, and endless support;
my wife "Nada Annisa Nastiti" and my daughter "Harlea Saviera Adara",
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Bandung, May 2025

Rangga Randika Munggaran

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LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviation	Full Term	Page of Initial Usage
AHP	Analytic Hierarchy Process	14
AI	Artificial Intelligence	23
AGV	Automated Guided Vehicle	42
AS/RS	Automated Storage and Retrieval System	43
CNC	Computer Numerical Control	1
CR	Consistency Ratio	56
DMG	Deckel Maho Gildemeister (machine tool manufacturer)	33
IoT	Internet of Things	23
KT	Kepner-Tregoe	11
MCDA	Multi-Criteria Decision Analysis	12
MEF	Minimum Essential Force	5
OEE	Overall Equipment Effectiveness	20
PMN	Penyertaan Modal Negara (State Capital Participation)	6
ROI	Return on Investment	25
SA	Situation Appraisal	11
SMART	Simple Multi-Attribute Rating Technique	13
TCO	Total Cost of Ownership	26

Symbol	Description	Page of Initial Usage
Wi	Weight of main criterion *i* in AHP	56
Wj	Weight of sub-criterion *j* under criterion *i*	56
λmax	Maximum eigenvalue in pairwise matrix	57
CI	Consistency Index	57
CR	Consistency Ratio	57
Uij	Score of alternative *i* under sub-criterion *j*	59
Si	Global score of alternative *i*	60
$\sum$	Summation symbol (used in scoring formula)	59
n	Total number of criteria or alternatives	56

Chapter I Introduction

I.1 Background

In an increasingly competitive global era, the defense industry plays a very strategic role in maintaining the stability and sovereignty of a country. Indonesia, as the world's largest archipelagic country with a very strategic geographical position in the Southeast Asian region, has a major challenge in ensuring that its defense industry is able to meet domestic needs while competing at the global level (Goverment of Indonesia, 2020). One of the main actors in this ecosystem is PT Pindad, a state-owned company responsible for producing defense products such as weapons, munitions, combat vehicles, and various other defense equipment. With a vision to become one of the 100 largest defense companies in the world, PT Pindad is committed to continuing to innovate and develop its production capacity (Pindad, 2023).

PT Pindad is a company that plays a strategic role in supporting national defense and security policies. As a defense industry, PT Pindad not only provides the main equipment for the Indonesian National Army (TNI) and the Indonesian National Police (POLRI), but also contributes to strengthening the independence of the domestic industry (Pindad, 2025). This role is in line with the *Minimum Essential Force (MEF)* policy which is an integral part of the 2020-2024 National Medium-Term Development Plan (Goverment of Indonesia, 2020).

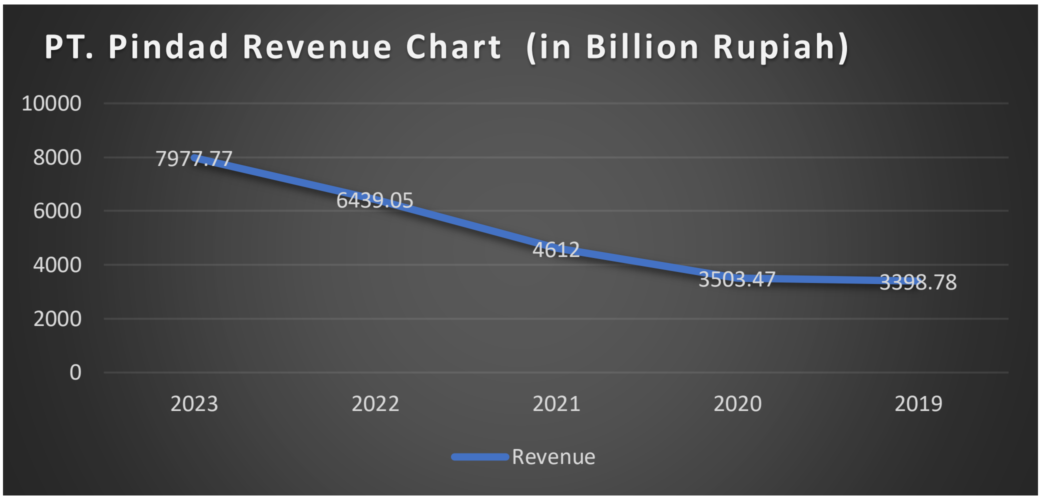

Figure 1.1 Pindad Revenue Chart

Source : Annual report PT. Pindad 2023

From the chart above, it shows that there is a significant increase in net sales which indicates that the interest from the market in the products made by Pindad is very good. With this, Pindad needs to respond with readiness to meet market needs which are likely to continue to increase. However, PT Pindad faces major challenges from various sides. From the internal side, the current condition of production facilities is no longer adequate to meet modern needs. Most weapons production machines have been in operation for more than 30 years in the weapons division, making them not only less efficient but also expensive to operate. The technology used in these machines is not able to support the automation of the production process that is needed in the industrial era 4.0 (Alkaraan et al., 2022) . This condition has led to limited production capacity, which is currently only able to reach 54,000 units per year. In addition, obsolete machines are often the main cause of limited production capacity and high operating costs.

This modernization is seen as very important considering the urgent need to increase the Domestic Component Level (TKDN) in PT Pindad's products. Currently, TKDN for weapons products is at 72.53%, and with this investment, it is expected to increase to 73.25% by 2029 (Pindad, 2025). This increase will not only reduce dependence on imported components but also support the development of local industries, create new jobs, and have a multiplier effect on the national economy.

In addition, one of the main factors affecting arms sales is market competition. Manufacturers must be able to offer products with the latest technology that is better and of high quality to maintain market share and meet customer demands. To achieve production targets, meet the needs of weapons, and ensure product quality that continues to increase every year, PT Pindad needs to ensure that the capacity and quality of weapons production are at an optimal level.

This increase in production capacity must be supported by modern and efficient production machines and facilities. With investment in advanced equipment and good production process management, PT Pindad is expected to increase production capacity, produce high-quality products, ensure smooth production processes and reduce production costs to produce products at competitive prices and be able to compete in the global market.

On the industrial side, it is necessary to strengthen manufacturing capabilities, capacity, and ecosystems, especially in the revenue portfolio of land-based defense products, which has significant business growth potential. If facilities and technology are not rejuvenated, PT Pindad risks facing threats from competitors, both at the regional and global levels. These threats include lagging behind in the production process, inability to compete in technology and production costs, and decreased customer confidence due to potential delays in delivery and deterioration in product quality.

Therefore, the rejuvenation program and strengthening of production facilities are crucial to ensure that PT Pindad continues to master the latest technology. Thus, the company can meet the production target according to the contract received, while maintaining good product quality assurance. This step will also strengthen PT Pindad's position in the global defense market competition.

The social impact of this investment is no less significant. In addition to creating new jobs, the program will support upskilling of the local workforce through training and technology transfer. This project is also expected to make a significant contribution to the economic growth of the community around the location of the production facility through increasing local economic activities (Alkaraan et al., 2023). From a strategic perspective, this investment will strengthen PT Pindad's position in the defense industry ecosystem and support the achievement of the TNI's Minimum Essential Force (MEF), which currently only reaches 66%.

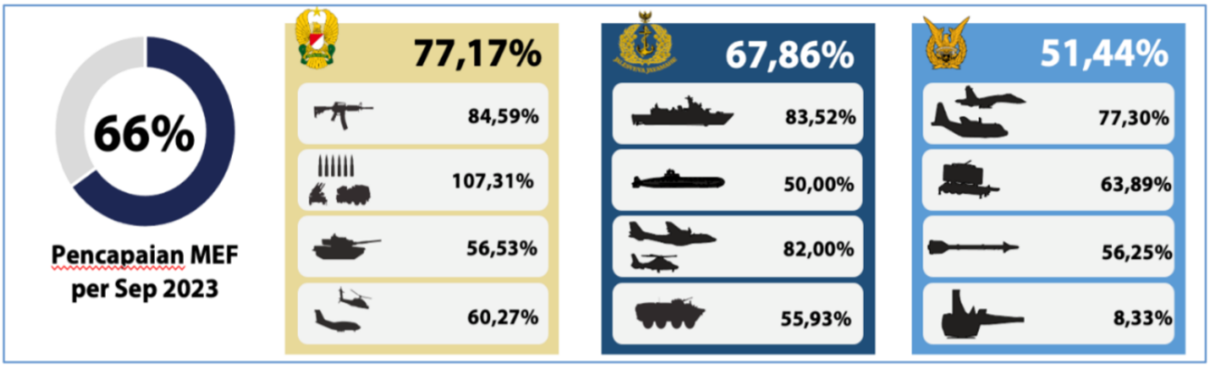

Figure 1.2 MEF Achievements as of September 2023

Source: FGD Defense and Security Policy and Alpalhankam Procurement Policy, 2023

Defense and security development is directed to increase strength in the face of defense threats and global threats as well as a sense of security and peace within the framework of the Indonesian nation and state. High-risk defense is one of Indonesia's visions to achieve a Golden

Indonesia 2045 which is directly related to the defense industry. PT Pindad as a state-owned defense industry has challenges to:

1. Realizing defense equipment with modern technology;
2. Creating an advanced and healthy defense industry;
3. To be the main player in the global supply chain.

Therefore, PT Pindad plans to use this PMN as an accelerator for building defense and security product business line capabilities. The Modernization & Automation Program of Weapon Production Line and Revitalization of Defense Product Support Manufacturing Line was chosen by PT Pindad to realize the dominance of domestic demand and be in line with the national *alpalhankam (alat peralatan pertahanan dan keamanan)* modernization strategy (Pindad, 2025). This development is expected to be able to answer the challenges of the defense business in the future.

However, with the large and complex scale of investment, decision-making related to PMN fund allocation requires a careful and systematic approach. For this reason, this study uses the Kepner-Tregoe Decision Analysis method to evaluate various investment options based on relevant criteria such as cost efficiency, strategic impact, and economic benefits. In addition, the Multi-Criteria Decision Making (MCDM) tool will be used to determine the best alternatives for the implementation of this investment. The use of MCDM in this study allows PT Pindad to objectively compare and evaluate various investment alternatives, resulting in recommendations based on data and measurable analysis. The research is expected to provide optimal and applicable solutions to ensure the success of PT Pindad's investment implementation.

This research has high relevance, both from an academic and practical perspective. From an academic perspective, this research contributes to the development of strategic decision-making in the defense manufacturing sector. From a practical point of view, the results of this research are expected to provide recommendations that can be implemented by PT Pindad to ensure the success of the modernization and revitalization program of production facilities. Furthermore, the study also provides a comprehensive picture of how strategic investments in the defense sector can have far-reaching positive impacts, not only for companies but also for the economy and society as a whole.

Thus, this research is not only an effort to answer the challenges faced by PT Pindad but also an important step in supporting the strengthening of the national defense industry that is sustainable and globally competitive.

I.2 Company Profile

PT Pindad (Persero) is a state-owned company (BUMN) in Indonesia engaged in manufacturing and services, with the main focus on the production of main equipment for defense and security purposes. Established in 1983, PT Pindad has a mission to support Indonesia's independence in the defense sector while contributing to the development of the national industry through innovative and high-quality products (Pindad, 2023).

Figure 1.2 PT Pindad Logo

PT Pindad conducts business activities in two main sectors:

- **Defense and Security**
  Production of weapons, ammunition, tactical vehicles, and combat vehicles for military and law enforcement needs. Some of its flagship products include the Anoa combat vehicle, SS2, and small to large caliber ammunition.
- **Commercial Industry**
  It includes the production of industrial equipment such as generators, machinery for agriculture, as well as other metal and manufacturing products used in various civil sectors.

I.2.1 Vision

To become the leading defense and security equipment manufacturer in Asia by 2026, as well as support the independence of Indonesia's defense industry.

I.2.2 Mission

- Developing technologies and innovations to support national defense and security needs.

- Producing competitive industrial products in the global market.
- Improving human resource competencies through training and development of cutting-edge technology.
- Contribute to national economic development through the export of defense products.
- PT Pindad is a tangible proof of the ability of the Indonesian nation to create superior products that are competitive in the global market. With the foundation of innovation, technology, and national spirit, Pindad continues to move forward as a symbol of the independence of Indonesia's defense industry.

PT Pindad (Persero) is a state-owned strategic industry responsible for supplying defense and security equipment, primarily for the Indonesian National Armed Forces (TNI). The company's vision to become a leading defense manufacturer in Asia by 2026 aligns with national objectives for defense independence, as stipulated in RPJMN 2020–2024.

I.2.3 Organizational Structure and Business Units

PT Pindad's organizational structure is designed to support the achievement of the company's vision and mission, which is to become the leading defense equipment manufacturer in Asia by 2026 and support the independence of the national defense industry. The following is an overview of the organizational structure implemented:

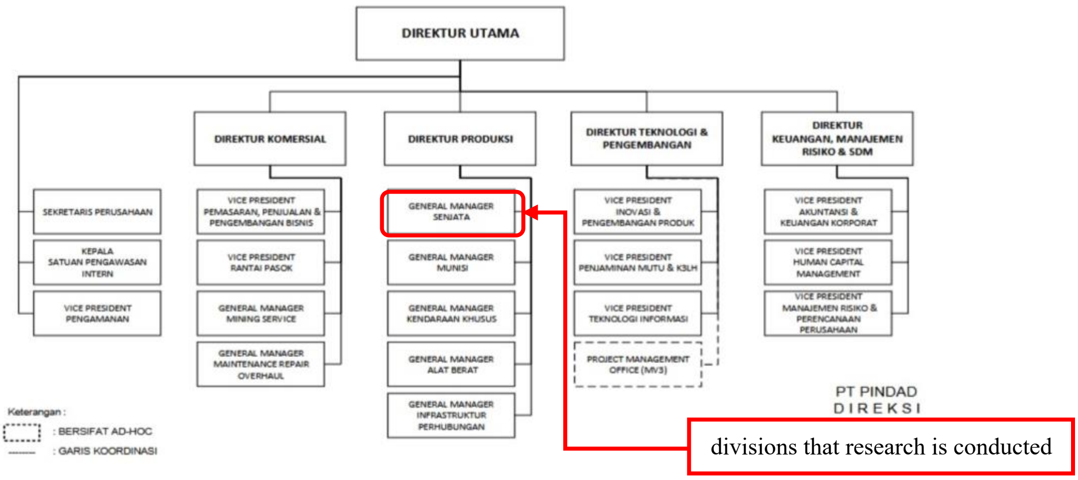

Figure 1.3 Organizational Structure of PT Pindad

I.3 Business Issue

This research aims to identify and overcome the decision-making faced by PT Pindad in choosing automation technology that suits the needs of weapon production. The following are some analyses of conditions from various perspectives.

Externally, demand for domestic defense products shows an increasing trend. Based on data from the TNI's Defense Equipment Needs Plan for the 2025-2029 period, the market potential for weapons, munitions, and combat vehicle products is estimated to reach Rp 140.9 trillion. Of this amount, the Army (*TNI AD*) is the largest orderer with a need of Rp 114.9 trillion. In detail, the needs of the *TNI AD* include special vehicles worth Rp 60.1 trillion, weapons worth Rp 32.7 trillion, and munitions worth Rp 22.1 trillion. In addition, requests also come from the Indonesian Navy, Air Force, and Indonesian National Police (*POLRI*), which need various types of weapons and munitions to support their operations. The following are the market potentials for munitions, special vehicles, and weapons products for 2025-2029:

Table 1.1 Market Potential 2025-2029

NO	DESCRIPTION	Market Potential 2025-2029	Average per Year
1	**MABES TNI**		
	Ammunitions	IDR 1,221,831,258,893	IDR 244,366,251,779
2	**TNI AL**		
	Ammunitions	IDR 1,369,015,528,584	IDR 273,803,105,717
	Special Vehicles	IDR 6,177,578,844,962	IDR 1,235,515,768,992
	Weapons	IDR 1,383,275,895,901	IDR 276,655,179,180
3	**TNI AU**		
	Ammunitions	IDR 1,190,953,373,079	IDR 238,190,674,616
	Special Vehicles	IDR 248,900,000,000	IDR 49,780,000,000
	Weapons	IDR 2,616,429,457,793	IDR 523,285,891,559
4	**TNI AD**		
	Ammunitions	IDR 22,105,671,887,955	IDR 4,421,134,377,591
	Special Vehicles	IDR 60,167,764,278,647	IDR 12,033,552,855,729
	Weapons	IDR 32,710,833,161,048	IDR 6,542,166,632,210
5	**POLRI**		
	Ammunitions	IDR 631,926,118,000	IDR 126,385,223,600
	Weapons	IDR 11,091,030,180,000	IDR 2,218,206,036,000
	TOTAL	**IDR 140,915,209,984,862**	**IDR 28,183,041,996,972**

Source: Daftar Rencana Kebutuhan Pinjaman Luar Negeri (PLN) 2025-2029, Rencana Kebutuhan Anggaran TNI AU Tahun 2025-2029, Rekapitulasi Rencana Kebutuhan Alpalhankam TNI AD Jangka Panjang 2025-2029 Per Produk, Usulan Anggaran Polri Tahun 2025-2029

When grouped by PT Pindad product users, it can be seen that the TNI AD has a high dominance of Rp 114.9 trillion with the most need for special vehicle products followed by the need for the National Police worth Rp 11.7 trillion dominated by the need for weapons products. For the needs of the Indonesian Navy worth Rp 8.9 trillion dominated by special vehicle products, for the needs of the Indonesian Air Force worth Rp 4.1 trillion dominated by weapon products, while the needs of the TNI Headquarters for munition products worth Rp 1.2 trillion. More specifically, the market opportunities for Weapons based on the PLN *Renbut* 2025 - 2029 are as follows:

Table 1.2 Products from Potential Contract TNI Requirement Plan

No		Products From Potential Contract TNI Requirement Plan	Pindad Products	Value (USD)	Value (RP)
1		**Sniper Rifles**			
	a	Caliber 7.62 mm	Sniper Multi Kaliber	$ 4,747,500	IDR 75,791,463,750
	b	Caliber 12.7 mm	Sniper Multi Kaliber	$ 3,927,600	IDR 62,702,170,200
2		**Anti-Tank Weapons**	SLT	$ 19,950,000	IDR 318,491,775,000
3		**Marine Weapons**			
	a	40 mm Grenade Launcher Weapon (AGL & MGL)	Agl Kaliber 40 Mm	$ 2,795,000	IDR 44,620,777,500
	b	40 mm SPG (Marine) Weapon	Agl Kaliber 40 Mm	$ 1,701,000	IDR 27,155,614,500
	c	5.56 mm underwater gun (Passusla)	SS Amphibious (Eksisting)	$ 17,064,000	IDR 272,418,228,000
	d	9 mm Sub-Machine Gun	New Smg 9 Mm	$ 2,700,000	IDR 43,104,150,000
	e	Portable Air Defence Missile System & Munition	Rudal & Guided Rocket	$ 11,850,000	IDR 189,179,325,000
		Total		**$ 64,735,100**	**IDR 1,033,463,503,950**

Based on *PLN Renbut* 2025 – 2029, the total arms market opportunity is Rp 1.03 trillion for the TNI. It is hoped that PT Pindad can get market opportunities in the 2025-2029 PLN Target. In addition to the *PLN Renbut,* the TNI strategic plan also usually conducts a budget for the purchase of defense equipment through the *PDN Renbut* for procurement for 5 years, with the details of the 2025-2029 *Renbut PDN* as follows with a total weapons market opportunity of Rp 4.70 trillion for the TNI.

Table 1.3 Potential Products from TNI Renbut Contract

No	**Potential Products from TNI Renbut Contract**	**Value (RP)**
1	Assault Rifle	830.975.762.265
2	Pistol	51.662.629.320
3	Sniper Rifle	45.660.562.290

No	Potential Products from TNI Renbut Contract	Value (RP)
4	Machine Gun	3.016.732.332.980
5	Anti-Tank Gun	759.393.480.716
	Total	**4.704.424.767.571**

The government has contributed through State Capital Participation *(PMN)* for the 2025 fiscal year, has provided financial support of Rp 450 billion for the modernization and automation program of weapons production lines as well as the revitalization of manufacturing lines supporting defense products. The investment includes the purchase of modern machines that are expected to increase weapons production capacity from 54,000 to 75,000 units per year by 2029. In addition, this program also supports the improvement of the Domestic Component Level *(TKDN),* the efficiency of the production process, and the import substitution of strategic components.

I.3.1 Gap (What, When, Where, and to What Extent)

The production machines owned are old. More than 70% of machines are over 20 years old, with many reaching 30 years old, resulting in capacity and efficiency limitations. The technology used no longer meets the needs of modern production processes, including automation capabilities. Obstacles in achieving the target of increasing production capacity from 54,000 to 75,000 shoots per year by 2029. This condition also affects PT Pindad's ability to meet domestic demand, seize opportunities and compete with international producers.

The need for modernization has been urgent since the last few years, especially with production targets that continue to increase every year. The critical momentum is in 2025, where the implementation of State Capital Participation (*PMN*) of Rp 450 billion will begin. Without the right strategic decisions, PT Pindad risks facing capacity stagnation and loss of competitiveness.

The main focus is on the weapons production line at PT Pindad's production facility in Bandung. This area includes assembly lines, conventional machinery, as well as packing and storage facilities, all of which require technological updates to achieve optimal efficiency. Delays in modernization could impact domestic supply chains, supporting industries, and PT Pindad's ability to meet international market demands.

The limitations of these old machines not only affect production volumes but also long production cycle affect to operating costs, which makes product prices less competitive than global manufacturers. The risk of losing contracts with domestic strategic customers such as the TNI and the National Police, which will hamper the target of contributing to national defense independence.

In facing this challenge, PT Pindad has designed an ambitious investment strategy by utilizing the 2025 State Capital Participation (*PMN*). An investment of Rp 450 billion is planned to support two main programs, namely the modernization and automation of weapons production lines and the revitalization of manufacturing lines Defense Product Supporters. The first program aims to increase production capacity from 54,000 units to 75,000 units per year by 2029, At the same time, it improves operational efficiency and product quality through the application of automation technology. The second program will focus on updating forging, casting, heat treatment, and CNC lines, which not only supports the production of defense products but also opens up opportunities for diversification into other industrial sectors such as railways and mining.

Based on the analysis of the above conditions, the following Rich Picture describes the strategic decision-making process involving various stakeholders in designing investment solutions to increase production capacity and support the independence of the national defense industry.

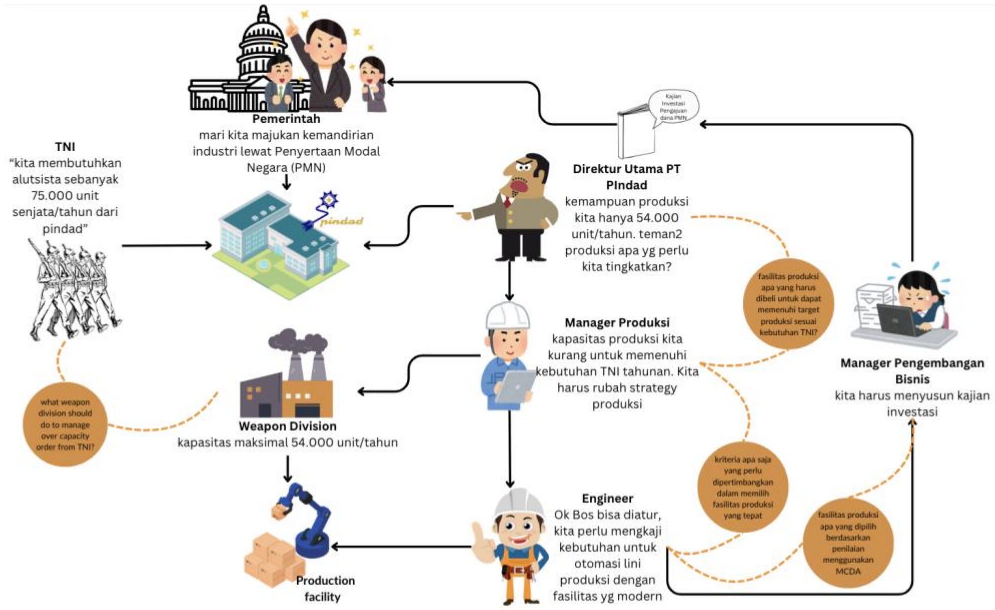

Figure 1.4 Rich Picture

The rich picture above illustrates the strategic decision-making process at PT Pindad in answering the challenge of fulfilling the annual demand of the Indonesian National Army (TNI) of 75,000 units of weapons. The production capacity of PT Pindad's weapons division is currently limited to 54,000 units per year, creating a capacity gap that necessitates investment in production facilities.

The process began with the government's initiative to increase industrial independence through funding mechanisms such as State Capital Participation *(PMN)*. The directive was conveyed to PT Pindad's Board of Directors, who identified production deficiencies and encouraged discussions among key stakeholders to determine the necessary production ramp-up. Production managers highlight the need to realign production strategies to meet targets, while business development managers prepare investment studies to identify suitable production facilities.

Simultaneously, engineering teams evaluate requirements to automate production lines using modern facilities to bridge capacity gaps. The decision-making process involves a multi-criteria decision analysis (MCDA) to select the optimal production facility, ensuring alignment with the TNI's long-term strategic needs and objectives.

This illustration highlights the interconnected role of government policies, corporate strategies, and operational execution in overcoming production capacity constraints. It underscores the importance of structured investment planning and decision-making to achieve organizational goals in a resource-constrained environment.

I.4 Research Questions and Objectives

The following are the research questions and research objectives of the research conducted.

I.4.1 Research Questions

1. What are the criteria that must be considered in the strategic investment decision for the modernization and automation of PT Pindad's production facilities?
2. How can each criterion be measured and analyzed to determine the optimal investment priorities using the MCDA approach?
3. How does the MCDA evaluation result in prioritized investment decisions for production facility development in the Weapons Division of PT Pindad ?

I.4.2 Research Objectives

1. Identify and establish relevant criteria in strategic investment decision-making for the modernization and automation of production facilities at PT Pindad with the aim of determining factors influencing investment decisions, including increased production capacity, cost reduction, and increased competitiveness in the defense industry.
2. Calculate and analyze the weight of each predetermined criterion using the Multi-Criteria Decision Analysis (MCDA) technique, with the aim of providing clear priority in selecting the optimal investment alternative for the modernization of production facilities at PT Pindad.
3. Evaluate the results of MCDA's analysis in the context of PT Pindad's strategic objectives, ensuring that the resulting investment decisions are in line with the company's long-term objectives, including increased competitiveness, cost reduction, production capacity, as well as broader objectives related to Indonesia's national defense policy.

I.5 Research Scope and Limitation

This research has several scopes and limitations.

I.5.1 Scope of the Research

The research will limit its focus to strategic investment decisions related to the modernization and automation of the weapons production facility at PT Pindad. The main focus of the research is on the development of weapons production facilities that will increase production capacity, reduce costs, and increase competitiveness in the defense industry. This study will identify and analyze the criteria used in making investment decisions in the weapon division, using the Multi-Criteria Decision Analysis (MCDA) methodology to calculate and prioritize optimal investment alternatives. This study will also evaluate the results of the MCDA analysis in the context of PT Pindad’s strategic goals and Indonesia’s national defense goals.

I.5.2 Limitation of the Research

1. The study will only include investments that will be made in PT Pindad’s weapons division, not in any other division (e.g., the vehicle or other equipment division).
2. This research relies on data that can be accessed from PT Pindad and public information related to national defense policy. Some sensitive data relating to technical or financial aspects may not be fully available to the public.
3. This study focuses more on investment decisions and does not discuss in depth the technical or operational implementation of the modernization of production facilities that have already been carried out.
4. Furthermore, this study focuses solely on determining the most suitable machine alternative using the Analytic Hierarchy Process (AHP), and does not include the Potential Problem Analysis (PPA) component of the Kepner-Tregoe framework. Referring to the Kepner-Tregoe model, PPA is more relevant for anticipating implementation risks after a decision has been made. Since this research only aims to assist in the selection process, PPA is considered beyond the current scope and timing of this study.

I.6 Brief Writing Structure

Below are five chapters of this research, as follows:

1. Chapter 1: Introduction

   Presents the background of the study, an overview of PT Pindad, the formulation of the problem, the research questions and objectives, as well as the scope and limitations of the study.
2. Chapter 2: Literature Review

   Discusses the *Literature Review*, focusing on relevant theories related to decision analysis and the Multi-Criteria Decision Analysis (MCDA) framework
3. Chapter 3: Research Methodology

   Outlines the *Research Methodology*, including the research design, data collection methods, and the techniques used for data analysis.
4. Chapter 4: Data Analysis and Results

   Presents the *Data Analysis and Results*, emphasizing the evaluation of investment criteria and the resulting investment prioritization based on the applied MCDA method.
5. Chapter 5: Conclusion and Recommendations

   Provides the *Conclusion and Recommendations*, summarizing the key findings, offering practical recommendations, and outlining the limitations and suggestions for future research.

Chapter II Literature Review

II.1 Theoretical Foundation

This section presents the theoretical foundations used to support research in understanding the strategic decision-making process in investment. The selection of the right theory is essential to provide a structured approach in evaluating complex investment alternatives, particularly in the development of manufacturing production facilities.

II.1.1 Kepner Tregoe

Kepner Tregoe (KT) knowns a systematic approach to problem solving and decision making. This method was found by Charles H. Kepner and Benjamin B. Tregoe in 1950 for their research on decision-making in solving the Strategic Air Command when they worked for the RAND Corporation. In 1958 they founded Kepner Tregoe Inc., a consulting company and multinational management services as they continued to develop the application of process thinking and analysis for critical business (Diputra, 2024; Kepner & Tregoe, 2013).

The KT method has been utilized for decision making based on criteria to minimize or even to avoid losses. The methodology of the KT method is collecting the information, evaluating the current condition and the results to be achieved. The Kepner-Tregoe process can be applied universally, regardless of the cultural setting or the content that applies to it (Snarskii et al., 2019).

The method is named KT Problem Solving and Decision Making (PSDM). Based on KT, PSDM are consisting of the four distinction processes whereas in each process will design to address a certain type of current business situation that is Situation Appraisal (SA), Problem Analysis (PA), Decision Analysis (DA), Potential Problem Analysis (PPA). The KT PSDM that is applied in this final project will be focused on applicable worksheets during analyze process (Vordermark II, 2019).

II.1.2 Situation Appraisal (SA)

It is a process based on the first thought when faced with a problem. Its purpose is to clarify the conditions of the current situation, sort and prioritize the information obtained, break down complex situations and make components that can be managed and maintain control over of the events. The assessment of the situation consists of evaluative techniques that lead to the use of appropriate analytical techniques (Kepner & Tregoe, 2013). Situation appraisal will help to select the best possible of the techniques of Problem Analysis (PA), Decision Analysis (DA) and Potential Problem Analysis (PPA), as shown at figure below.

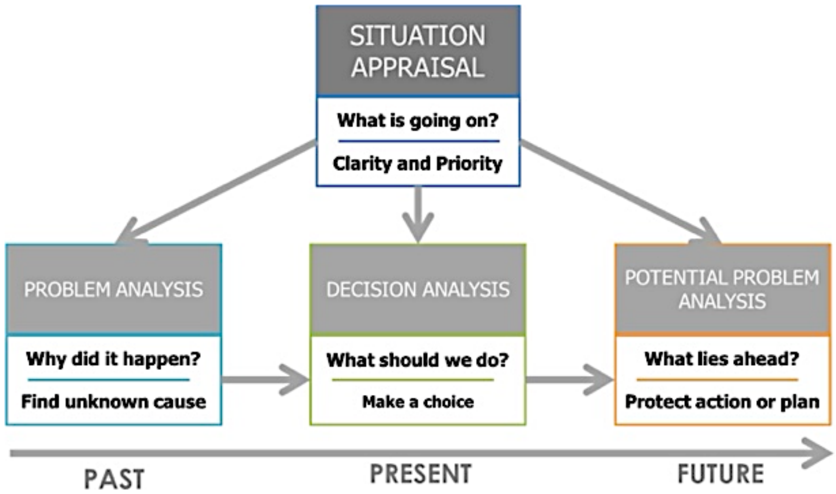

Figure 2.1 Kepner Tregoe Framework

At this stage, the outline of the problem is evaluated, overlapping and confusing problems will be sorted into workable parts, the priority is determined and the steps for solution of the problems are selected. Situation appraisal is consisting these activities:

- Define threats and opportunities,
- Separate and clarify the problem,
- Consider seriousness, urgency and growth,
- Determine the required analysis,
- Determine help needed

The Priority is determined by considering criteria of the timing, the trend and the impact of each problem. The time is determined how urgent the problem is, the deadline is one of the things that must be considered related to the urgency.

Trends are about potential problems that can arise. Impact is a measurement of how serious and severe the consequences of a problem are, which could be affected to (but not limited to) the personnel safety, environment, asset and production. Each criterion of the problem will be evaluated qualitatively and ranked into Low, Medium and High. All the information are collected into Situation Appraisal below and analysis it based on timing, trend, impact and process.

II.1.3 Benchmarking Theory

Benchmarking is defined as the process of comparing one's business operations and performance metrics to industry bests or best practices from other companies (Camp, 1989). It involves the systematic identification, understanding, and adaptation of outstanding practices from other organizations to improve one's own performance. Benchmarking can be applied to various operational areas, including production processes, technology adoption, and investment strategies.

In the context of investment decision-making, benchmarking serves as a valuable strategic tool to identify performance gaps and guide capital allocation. By understanding how leading competitors operate—particularly in areas such as automation, quality standards, and modernization strategies—organizations can better justify their investment priorities and establish realistic performance targets. According to Watson (1993), benchmarking not only reveals operational deficiencies but also stimulates innovation and continuous improvement by exposing companies to new ideas and approaches.

In this study, benchmarking is used to compare PT Pindad's current production capability with that of internationally recognized defense manufacturers, such as FN Herstal (Belgium) and SNT Motiv (South Korea). This comparison provides strategic context for the modernization initiative and supports the criteria formulation in the AHP-based investment decision model.

II.1.4 Decision Analysis (DA)

Decision analysis of Kepner Tregoe (KT) techniques is the methodology to select the best solution from the alternatives that are proposed. In this stage will directly answer the question and will be considered as problem solving (Kepner & Tregoe, 2013). They are eight stages or steps in this process to make decision, there are

- Preparing the conclusion statement,
- Define the purpose,
- Define the level and weighting,
- Listing the alternative,
- Alternative evaluation,
- Select the highest alternative,
- Evaluate the alternative to the potential negative consequences and
- Select the preferred alternative.

II.1.5 Interview in Research

According to the basis of the theoretical and the implementation of practical, there are interviews than most person conduct. Basically, the definition of interview is a type of qualitative research that entails asking open-ended questions to respondents in order to discuss and to have brainstorming with them and collect data on a subject. In most situations, the interviewer is a subject matter expert who uses a well planned and executed set of questions and responses to get insight into respondent attitudes (Gudkova, 2018). When it comes to gathering information, interviews are comparable to focus groups and surveys, but they operate differently focus groups are limited to a small group of 3-5 people, whereas surveys are quantitative (Tusting, 2022). Interviews are done with a sample of a population, and the conversational tone is an important aspect (Georgescu & Anastasiu, 2022).

Figure 2.2 Type of Interview in Research
(Source: Question Pro)

II.1.6 Strategic Decision Making.

Strategic decision-making is a critical process in management that enables organizations to formulate and execute effective strategies to achieve long- term goals and attain competitive advantage (Bazerman & Moore, 2013). It involves a comprehensive evaluation of the external and internal environment, and the selection of the most appropriate course of action based on careful analysis, Strategic decision making involves several important steps, including:

- The organization's leader or management team must identify and understand the organization's long-term goals. These goals should be clear and closely linked to the company's vision and mission.
- They must conduct a thorough analysis of the external environment, including markets, competitors, industry trends, and social, economic, and political changes that may affect the organization.
- Conduct an internal analysis to understand the strengths, weaknesses, resources, and capabilities possessed by the company. This analysis may involve evaluating the company's financial performance, organizational structure, corporate culture, and key competencies.
- The organization's leader or management team will consider the various strategic action alternatives available. This involves assessing each alternative based on relevant criteria, such as potential benefits, risks,

compatibility with the company's vision and mission, and availability of resources.

- the organization's leader or management team will make a strategic decision by selecting the most appropriate course of action based on the analysis and evaluation that has been conducted. These decisions should be based on accurate and detailed information, as well as in-depth knowledge of the business environment and internal conditions of the company.
- Strategic decision-making also involves continuous monitoring and evaluation of the decisions taken.

II.1.7 Analytic Hierarchy Process.

AHP is a decision support model developed by Thomas L. Saaty. This decision support model will decompose complex multi-factor or multi- criteria problems into a hierarchy, according to R. W. Saaty (1987) a hierarchy is defined as a representation of a complex problem in a multi-level structure where the first level is the goal, followed by the level of factors, criteria, sub criteria, and so on down to the last level of alternatives (Galo, 2017).

There are three main principles in problem solving in AHP according to Saaty, namely: Decomposition, Comparative Judgement, and Logical Concistency. Broadly speaking, the AHP procedure includes the following stages (T. L. Saaty, 2001; Zuraidi et al., 2018)

Strategic decision-making in investment for the development of a production facility at PT Pindad can benefit significantly from structured methodologies such as the Analytic Hierarchy Process (AHP). The AHP, devised by Thomas Saaty, provides a framework designed to assist decision-makers with complex multi-criteria decisions, allowing them to systematically evaluate both qualitative and quantitative aspects of their options (Antony & Joseph, 2017). This reinforces the relevance of AHP not only as a theoretical model but also as a practical tool suitable for addressing real-world investment complexities in strategic industries like defense manufacturing (Karasan et al., 2018).

- **Decomposition.**

  Problem Decomposition is a step where a goal that has been set is then systematically broken down into structures that compose a series of systems until the goal can be achieved rationally. In other words, an intact goal is decomposed (solved) into its constituent elements.
- **Assessment / weighting.**

  Conduct a pairwise comparison assessment (weighting) on each hierarchy based on its relative importance.
- **Matrix Compilation and Consistency Test.**

  Preparation of a pairwise matrix to normalize the weight of the level of importance on each element in its respective hierarchy. At this stage the analysis can be done manually or by using a computer program such as Expert Choice.

II.2 Conceptual Framework

Conceptual frameworks build the diagram to shows all the concept and models, supported by literature/books/policies and other relevance references to support the problem solver process, this conceptual framework is different with research design (Putro, 2023). Developing the conceptual framework to understand the business issues is the key preliminary steps in the research process.

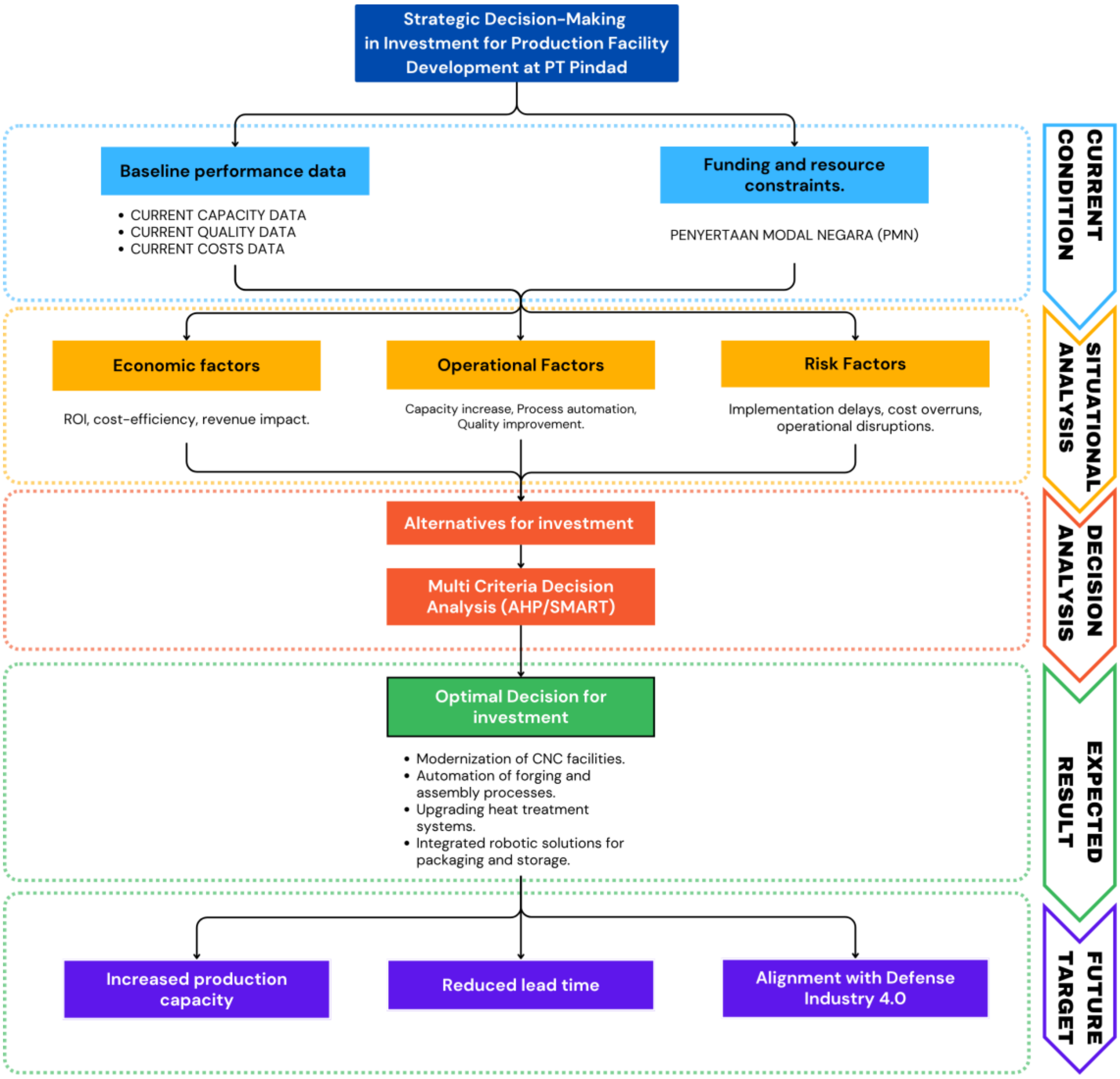

Figure 2.3 Conceptual Frameworks

Here is the explanation from the picture of conceptual framework above:

- **Current Condition**

  The framework begins by analyzing PT Pindad's internal data, while considering funding constraints, such as reliance on *Penyertaan Modal Negara* (PMN). This establishes a clear understanding of operational limitations and opportunities for improvement.

- **Situational Analysis**

  Economic factors like ROI and cost efficiency, operational factors such as capacity growth and quality improvement, and risk factors like delays and cost overruns are assessed. This ensures a comprehensive evaluation of both potential benefits and challenges.

- **Decision-Making Process**

  Investment alternatives are evaluated using tools like AHP or SMART to prioritize options based on strategic alignment and feasibility. These methods ensure objective, data-driven decision-making.

- **Expected Results**

  The optimal investments include modernizing CNC facilities, automating processes, upgrading heat treatment systems, and integrating robotics. These initiatives aim to enhance efficiency, improve quality, and strengthen competitiveness, aligning with long-term strategic goals.

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Chapter III Research Methodology

III.1 Research Design

Research methodology is the main principle that will guide research. This becomes a common approach in conducting research on the author's topic and determining what research methods the author will use. The research methodology is different from the research method because the research method is a tool that the author uses to collect author data (Dawson, 2009).

The research design chosen for this study is a mixed method approach. This approach integrates qualitative and quantitative research methods to gain a comprehensive and holistic understanding of the decision-making process at PT Pindad regarding the investment of production facilities (Antony & Joseph, 2017). By utilizing mixed-method designs, researchers can combine the power of qualitative and quantitative data collection and analysis techniques, providing a richer and more robust investigation of the research problem.

The purpose of this study is to get the best option for the selection of production facilities using a strategic approach, if the wrong choice of production facilities will have an impact on inefficiencies in investment, so that it will have an impact on production capacity and costs, we will determine a strategy to overcome the problem. Here is the design for this study.

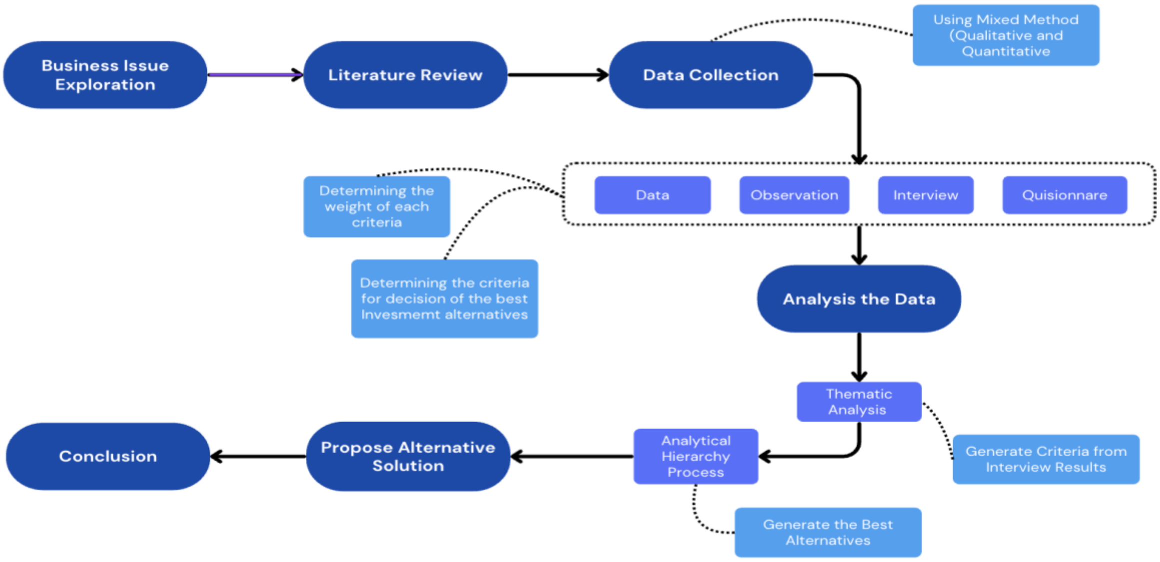


Figure 3.1 Research Design

III.1.1 Research Design Explanation

Below is the composition of the research design in this study, as follows:

(1) Business Issue

In the early stages, the research begins with the identification of business problems. The issue that became the focus was how to make strategic decisions related to investment in production facilities to increase capacity from 54,000 units to 75,000 units. The purpose of this stage is to define a clear research question and objectives, as well as define the scope of the study.

(2) Literature Review

Conduct literature reviews to understand theories, concepts, and previous studies that are relevant to strategic decision-making and investment in production facilities. Reference sources include academic journals, books, industry reports, and relevant best practice standards. The results of the literature review were used to develop a conceptual framework and determine the evaluation criteria for alternative solutions.

(3) Collection Data

This stage involves collecting data from various sources to support the analysis of the problem. The data collected will be used to support quantitative and qualitative analysis (Bryman, 2012).

(4) Analysis the Data

The data collected is analyzed to evaluate alternative investment solutions. The results of the analysis are used to evaluate the advantages and disadvantages of each alternative solution.

(5) Propose Alternative Solution

Based on the results of the analysis, several alternative strategic solutions are proposed. Each alternative is evaluated based on criteria such as cost, benefit, risk, sustainability, and flexibility. Optimal investment recommendations are made by considering the company's needs and existing constraints.

(6) Conclusion

The final stage of the research is to summarize the main findings and provide strategic recommendations. This conclusion includes the practical implications of investment decisions, lessons to be learned, and guidance for the implementation of the proposed decisions. The closing also includes suggestions for further research that may be needed in the future.

III.2 Data Collection Method

This research will employ two methods for data collection. The first method involves conducting semi-structured interviews, a qualitative approach that offers flexibility and depth in gathering participant insights (Saunders et al., 2012). Researchers will hold one-on-one interviews with selected decision-makers at PT PINDAD, guided by a set of open-ended questions aligned with the research objectives. The semi-structured format allows interviewers to delve deeper into specific topics and gain more comprehensive insights. The interviews will focus on the following key areas:

1. Decision-making criteria: Participants will be asked to outline the specific criteria they use to evaluate investment options. They will also provide explanations for the significance of each criterion and its role in the organization's investment decisions.
2. Criteria weighting: Decision-makers will discuss how they assign weights to various criteria using the Multi-Criteria Decision-Making (MCDM) method. The interviews will explore the factors that influence their decisions regarding weight allocation.

The second method utilized in this research is Document Analysis. Alongside the interviews, the researcher will conduct a detailed examination of pertinent documents, reports, and internal memos associated with the decision-making process and prior investment activities of the production facility. These documents may include investment proposals, financial evaluations, strategic plans, and records related to the application of the MCDM method.

Document analysis will serve as a complementary tool to the interview data, offering additional information and context. This method will provide valuable insights into the decision-making process, the criteria and attributes considered in previous investments, and the outcomes of past decisions. By corroborating and triangulating the findings from interviews, this approach will enhance the overall credibility and validity of the study.

III.2.1 Interview Protokol

In conducting this research, a set of interview questions has been designed to explore various aspects relevant to the research problem. Interviewees will be asked to provide insights into the planned development and modernization of the weapons production line at PT Pindad, including the ideal values for each of these factors. The interview questions used in this study are as follows:

(1) Section 1 – Introduction

1. Can you tell us about your current position and responsibilities?
2. Have you ever been involved in the selection or use of the machine before?

(2) Section 2 – Criteria Assessment

(a) Performance & efficiency

1. How important is the production capacity when choosing a cnc machine? (scales 1–10)
2. How much does cycle time affect efficiency?
3. How important is precision and consistency in your production?

(b) Automation & technology

4. What do you think is the role of automation in cnc machining?
5. Are IoT and AI important considerations?

6. How does the readiness of the machine for industrial 4.0 systems affect your decision?

(c) Flexibility & scalability

7. Are multi-functional features such as turning & milling important?

8. How important is scalability in fickle production?

(d) Reliability & maintenance

9. How much impact does downtime have on the production process?

10. Is predictive maintenance an important feature?

(e) Cost & investment

11. Which is more of a priority: the initial price or the long-term operational costs?

12. How long is the roi considered ideal in your opinion?

(f) Compliance & safety

13. How important is certification like iso or ce?

14. How does the company prioritize operator safety?

(g) Ergonomics & health

15. How much does ergonomic design affect operator comfort?

16. How is the impact of machines on worker health assessed?

(h) Supply chain & availability

17. How important is lead time?

18. Is supply chain risk a major consideration?

(i) Environmental & sustainability

19. How much influence does energy efficiency have on investment decisions?

20. Is sustainability an important factor in your company?

(3) Section 3 – Conclusion

21. Is there anything else you would like to add regarding the selection of CNC machines?

III.2.2 Informant

In order to collect rich and diverse data related to this research, a careful selection of sources has been carried out to provide a clear picture of the decision to select production facilities and the influencing factors. The list of interviewees is designed to ensure comprehensive and in-depth coverage of the research questions asked:

1. Junior Manager of Automation, Engineering Department, Weapon Division
2. Manager of Engineering Department, Weapon Division
3. General Manager of the Weapons Division

III.3 Situational Analysis

Situational analysis was carried out to define the actual conditions that are the basis for the use of decision-making methods in this study. This step is in line with the Kepner-Tregoe approach, where the first stage is a situation appraisal to identify problems, challenges, and decision needs.

III.3.1 Context of the Problem

PT Pindad's weapons production unit is currently facing serious challenges in the form of limited production capacity and lagging machine technology. Most machines are more than 20 years old, with decreased levels of efficiency and accuracy. This condition hinders the achievement of the target of increasing production from 54,000 to 75,000 units per year by 2029, as well as efforts to increase the domestic content level (TKDN).

This target cannot be achieved without strategic investment in the modernization of production lines. Current machines have high levels of downtime, intensive maintenance requirements, and are not compatible with automation technology or modern manufacturing digital systems.

III.3.2 The Complexity of Investment Decisions

In practice, the investment decision-making process at PT Pindad has tended to be intuitive and has not used a systematic analysis framework. Strategic decisions such as the selection of new production machines are often based on individual experience, managerial preferences, or poorly documented short-term considerations. The disadvantages of this approach are low objectivity, potential for personal bias, and difficulty in re-evaluating decisions that have been taken, especially when involving many stakeholders with different interests.

Therefore, this study proposes the use of the Analytic Hierarchy Process (AHP) method as a more structured approach. AHP enables the decision-making process to be more transparent and measurable by converting qualitative assessments into quantitative data through paired comparison techniques. Each criterion in the evaluation can be weighted based on stakeholder priorities, resulting in a more rational and accountable final decision. Thus, AHP not only helps to address weaknesses in existing processes, but also increases accountability and accuracy in strategic decision-making in defense industry environments such as PT Pindad.

Investment decisions on the production line are complex because they involve various criteria that affect each other, such as:

1. Production capacity and efficiency
2. Automation and technology compatibility
3. Investment and operational costs
4. Reliability and maintenance
5. Compliance with safety and ergonomic standards
6. Support for environmental sustainability and supply chain management

A variety of alternative machines and technologies are available, but they have their own advantages and disadvantages. There is no single dominant option in all criteria, so a systematic approach is needed that can evaluate all aspects in a structured and objective manner.

This situation encourages the need for multi-criteria decision-making methods, such as the Analytic Hierarchy Process (AHP), to produce the most optimal decisions (R. W. Saaty, 1987; Vaidya & Kumar, 2006) and are in line with PT Pindad's strategic goals

III.4 Data Analysis Method

The following is an explanation of the data analysis method carried out in this study:

III.4.1 Criteria Development Process

The criteria used in this study were developed through a combination of internal documentation, academic literature, and in-depth interviews. Internally, PT Pindad's engineering and production departments have established certain parameters and strategic goals that guide investment decisions such as improving efficiency, increasing automation, and enhancing sustainability. These internal priorities served as the foundation for the criteria formulation.

To ensure academic rigor and alignment with best practices, the initial criteria were cross-validated and expanded through a literature review of scholarly journals focusing on investment decision-making, industrial automation, and defense manufacturing. The researcher also conducted semi-structured interviews with three key stakeholders to contextualize and refine the criteria. The resulting nine main criteria reflect both the organizational needs and the theoretical constructs commonly adopted in Multi-Criteria Decision Analysis (MCDA) literature.

The process ensured that the criteria were not only relevant to the company's strategic direction but also supported by established academic frameworks, making them suitable for use within the AHP methodology.

III.4.2 Qualitative Data Analysis: Thematic Analysis

For this thesis focusing on decision-making processes at PT PINDAD, the thematic analysis will be tailored to extract actionable insights relevant to organizational and investment contexts. The process will include the following customized steps:

1. Transcription

   Interview recordings will be transcribed into written text to ensure accurate representation of participants' responses.
2. Preliminary Review

The transcripts will be reviewed to understand the overall context and identify initial points of interest related to investment decision-making and criteria.

3. Focused Coding

   The data will be segmented into key ideas or concepts relevant to PT PINDAD's investment decisions, such as criteria prioritization, risk considerations, and external influences. Codes will directly align with research objectives like evaluating the AHP method's applicability (Kepner & Tregoe, 2013).

4. Theme Development

   Codes will be grouped into broader themes, such as "criteria for investment evaluation," "external influences on decision-making," and "perceived benefits of the AHP method." These themes will reflect PT PINDAD's specific decision-making challenges and practices.

5. Contextual Analysis

   The themes will be examined in the context of PT PINDAD's organizational goals, industry constraints, and external regulatory environments to provide a deeper understanding of the decision-making process.

6. Synthesis and Reporting

   The themes will be synthesized into a narrative that explains PT PINDAD's decision-making dynamics, focusing on practical implications and strategic recommendations for improving investment evaluation methods.

7. Validation and Stakeholder Feedback

   The findings will be validated by consulting stakeholders at PT PINDAD to ensure alignment with organizational practices and enhance credibility.

III.4.3 Quantitative Data Analysis

The following are the steps taken in analyzing quantitative data:

1. Calculating Weighted Utility Scores

Using Equation from the AHP method's linear utility function model, the weighted utility scores for each investment option at PT PINDAD will be calculated. This involves multiplying the attribute weights (Wj) by the utility values (Uij) provided by the decision-makers for each investment option and attribute. The sum of these products will yield the overall utility score for each investment option (Padilla-Garrido et al., 2014).

2. Ranking Investment Options

   The investment options will be ranked based on their utility scores, with higher scores indicating a stronger preference for investment. The option with the highest utility score will be recommended as the top priority for implementation.

3. Descriptive Statistics

   Descriptive statistics will be applied to analyze Likert-scale responses from the questionnaires. This will include calculating measures such as mean, median, and standard deviation to summarize the decision-makers' perceptions of the AHP method's transparency, reliability, and practicality in PT PINDAD's investment decisions.

4. Integration of Qualitative and Quantitative Findings

   To achieve a comprehensive understanding of PT PINDAD's decision-making processes and evaluate the effectiveness of the AHP method, the qualitative and quantitative findings will be integrated. This triangulation of data sources will validate and complement the findings, resulting in a deeper and more nuanced perspective on the research objectives.

Chapter IV Data Analysis and Results

The investment in modernization and automation of production facilities is a strategic step for PT Pindad in increasing production capacity and efficiency, in line with the company's target to meet domestic and international market demands. This chapter aims to analyze data obtained through various research methods, including stakeholder interviews, internal document analysis, and quantitative evaluation using Multi-Criteria Decision Analysis (MCDA).

The analysis in this chapter will begin with a mapping of current production conditions, including the main obstacles faced in achieving the arms production target. Furthermore, an evaluation will be carried out on various possible investment alternatives, taking into account aspects of cost, production capacity, energy efficiency, and its impact on PT Pindad's competitiveness in the defense industry.

To determine the most optimal investment, this study uses the MCDA method, which allows the comparison of various alternatives based on predetermined criteria. In addition, this chapter also presents a simulation of production layout improvements that aim to improve material flow efficiency and reduce production cycle time.

IV.1 In-Depth Interview Results

To strengthen the results of quantitative evaluation in the selection of CNC machine investment using the AHP methods, the researcher conducted in-depth interviews with three internal resource persons at PT Pindad who have strategic positions in decision-making. The three respondents came from technical, operational, and managerial backgrounds, namely:

1. **LMS .** – Junior Manager of Automation, Weapons Division
2. **HRY.** – Manager of Engineering Department, Weapons Division
3. **AFS.** – General Manager of the Weapons Division

In this section the researcher will explain the research results obtained during the research process in accordance with the research framework.

Table 4.1 Interview Results

No	Questions	Answers		
		LMS	**HRY**	**AFS**
	PART 1 – INTRODUCTION			
1	Can you tell us about your current position and responsibilities?	I am responsible for the smooth production process in the light weapons line. My focus is on ensuring that every process runs efficiently, meets quality standards, and meets production targets. I am also involved in the evaluation of production equipment needs, including the procurement of new machines.	I lead an engineering team that designs the manufacturing process and selects the right technology to support production innovation. One of my main responsibilities is to evaluate the technical specifications of the machines to be used.	As General Manager, I am strategically responsible for the overall management of the weapons division, including production, development, and technology investment. I was instrumental in major decision-making, including the investment of machinery and the direction of modernization of the production line.
2	Have you ever been involved in the selection or use of the machine before?	Yes, I was involved in the technical evaluation team several times when the company was going to buy a new CNC machine. Usually I give input in terms of production speed and ease of operation.	I am very often involved, especially in the technical evaluation stage of machine specifications. I also interact directly with vendors to ensure that the machines we choose can be integrated into existing systems.	I am more involved in the final stages of decision-making, especially in evaluating the impact of investments on long-term business strategies. But I also follow developments from the beginning to ensure alignment between operational needs and the direction of the company.
	SECTION 2 – CRITERIA ASSESSMENT			
	Performance & Efficiency			

No	Questions	Answers		
		LMS	**HRY**	**AFS**
3	How important is production capacity when choosing a CNC machine?	I give it a 9. Production capacity is at the core of our work. If the machine is unable to handle the volume, it will immediately have an impact on production delays.	I give it an 8. Capacity is important, but it must be balanced with other technical aspects such as precision and flexibility.	I give it a 9. The machine with large capacity will support the company's long-term production target.
4	How much does cycle time affect efficiency?	Very big. The cycle time determines how quickly we can complete a batch. If it takes too long, we can lose time and production potential.	Cycle time is a direct indicator of process efficiency. We typically take cycle time into account as a key part of productivity analysis.	From a management perspective, cycle time has a direct impact on costs and capacity. So we consider that a crucial factor.
5	How important is precision and consistency in your production?	I give it a 10. Absolute precision, especially for weapons products. The fault tolerance is very small.	Precision and consistency are the foundation of quality. I personally wouldn't recommend a machine without clear precision data.	Defense products demand high accuracy. Consistency greatly determines the level of defects and acceptance of the product.
	Automation & Technology			
6	What role do you think automation in CNC machining is?	Automation goes a long way in reducing human error and increasing the speed of work.	I see automation also helps in keeping quality consistent. Especially for repetitive processes.	An investment in an automated machine is also an investment in long-term efficiency. We can reduce our reliance on manual labor.
7	Are IoT and AI an important consideration?	I'm still learning about this, but if you can notify the engine condition automatically, it would be very helpful.	Important, especially for preventive and predictive maintenance. With IoT, we can monitor real-time data.	In our strategic direction towards industry 4.0, the integration of IoT and AI is highly regarded.
8	How does the readiness of the machine for Industry 4.0 systems affect your decisions?	If the machine is ready for system integration, it is definitely a plus.	I consider it mandatory. An incompatible machine will add to the integration cost.	I see it as part of the digital transformation we are pursuing. An unprepared machine will become a burden in the future.

No	Questions	Answers		
		LMS	HRY	AFS
	Flexibility & Scalability			
9	Are multi-functional features like turning & milling important?	Very important. The multi-function machine reduces the need to move processes and saves setup time.	That is one of the main considerations from the technical side. Machines that can perform more than one process are highly efficient in terms of footprint and production logistics.	I see the multi-function feature as a way to reduce bottlenecks and speed up throughput. It also saves you long-term investments.
10	How important is scalability in fickle production?	Production here is often volatile, so machines need to be flexible to handle batch variations without the need for a lot of reconfiguration.	Scalability is important to anticipate a surge in demand. The machine must be able to work in a variety of capacities.	We design investments based on medium-term growth. Scalable machines are highly regarded by us.
	Reliability & Maintenance			
11	How much does downtime impact the production process?	Downtime is a nightmare. If one machine shuts down, it can affect the entire production flow.	We measure OEE, and downtime instantly lowers the overall efficiency value.	From a business perspective, downtime means potential delivery delays and penalties. We strongly avoid this.
12	Is predictive maintenance an important feature?	Very helpful. We don't have to wait for a broken engine to act.	This feature is very relevant. With the data from the sensors, we can predict which components will be damaged and when they need to be replaced.	This is part of the digital transformation that we are promoting. Modern machines must be able to talk to management systems.
	Cost & Investment			
13	Which is more of a priority: initial price or long-term operational costs?	From an operational perspective, long-term costs are much more important. Cheap but often broken	I always encourage teams to not just look at the initial price. Sometimes machines with higher prices are actually more	From the management side, we prioritize the total cost of ownership. Upfront price is important, but operational

No	Questions	Answers		
		LMS	HRY	AFS
		machines actually make it difficult for us.	economical because they are energy-efficient and rarely damaged.	efficiency and sustained ROI are key determinants.
14	How long is ROI considered ideal in your opinion?	If the ROI can be achieved in 3 to 5 years, I think it is very good.	Ideally no more than 5 years. But for a very strategic machine, up to 7 years is still reasonable as long as the contribution is large.	We target ROI in the range of 4-6 years, depending on the value of the investment and its impact on capacity building and competitiveness.
	Compliance & Safety			
15	How important are certifications like ISO or CE?	Certifications such as ISO and CE are important to ensure the machine is up to standard. It also makes it easier during production audits and documentation.	I will not approve the purchase of a machine without basic certifications such as CE. It is a guarantee that the design and functionality are in accordance with safety standards.	In terms of company policy, we do require certification as part of the vendor selection process.
16	How does a company prioritize operator safety?	Operator safety is our daily priority. The machine must have a guard, emergency sensors, and be easy to operate.	We are on board from the very beginning of the redesign process to ensure a safe and ergonomic work area.	PT Pindad is committed to K3, and every procurement of new equipment must meet the safety aspect as an absolute requirement.
	Ergonomics & Health			
17	How much does ergonomic design affect operator comfort?	The ergonomic design greatly helps operators in working longer hours without fatigue. Especially if you have to operate the machine for hours.	Machines that are not ergonomic often lead to human error. We cannot ignore the interface design and operating position.	From a management perspective, operator productivity will be better if they work comfortably and safely. Ergonomics is an investment in HR as well.

No	Questions	Answers		
		LMS	**HRY**	**AFS**
18	How is the impact of machines on worker health assessed?	Machines with high vibrations or extreme noise can cause fatigue and long-term health problems. So this must be a concern from the beginning.	We always evaluate in terms of vibration, sound, and potential danger of dust or metal particles. It can all be minimized with good design and features.	Worker health has a direct impact on attendance and productivity. Modern machines must support a healthy working environment.
	Supply Chain & Availability			
19	How important is lead time (machine procurement time)?	Lead time is very important because it affects the production plan. The sooner the machine comes, the sooner we can start production.	We are often faced with projects with tight deadlines, so lead time is one of the key parameters when evaluating vendors.	From a strategic perspective, lead times that are too long can hinder the government's annual investment target and procurement schedule.
20	Is supply chain risk a major consideration?	If parts are hard to come by, production can stop for a long time. That is a big problem on the field.	We see the availability of spare parts and local technician services as an absolute requirement. Supply chain risks must be mitigated from the start.	In the context of defense, we cannot depend on unstable foreign supplies. Supply chain is a strategic issue.
	Environmental & Sustainability			
21	How much influence does energy efficiency have on investment decisions?	Energy efficiency can save daily electricity costs, especially if the machine is operating continuously. That is definitely an added value.	We are starting to see energy consumption as a technical evaluation factor. The more economical, the better it is for the long run.	We also want to align with the national sustainability agenda. More energy-efficient machines automatically come in priority.
22	Is sustainability an important factor in your company?	Yes, even though it is not yet a top priority, we are starting to be directed to pay attention to environmental impacts.	Sustainability is not only about the environment, but also long-term efficiency. We're moving in that direction.	Sustainability is part of the company's roadmap towards a green industry. New machines must support that.
	PART 3 – CONCLUSION			

No	Questions	Answers		
		LMS	HRY	AFS
23	Is there anything else you would like to add regarding the selection of CNC machines?	I hope that the selection process of the machine takes into account the real conditions of the field. Sometimes it looks good on paper, but when used, it is difficult to operate or complicated to maintain. The most important thing is that the machine really supports the smooth running of daily production.	I emphasized the importance of integrating future technologies, such as IoT and predictive maintenance. The machines we buy now must be relevant and ready to use for the next 10–15 years. In addition, operator training must also be part of the investment process.	This investment decision is not just about buying machines, but about building the foundation of a more competitive production system. We have to look at it from various aspects: technical, operational, financial, and strategic. The chosen machine must accelerate PT Pindad's transformation towards a modern and globally competitive manufacturing industry.

The interview is conducted in a structured manner based on a question guide that includes the dimensions of investment evaluation, such as engine performance, automation, reliability, cost, as well as external factors and sustainability.

IV.1.1 Thematic Analysis Process

The interview data analysis process was carried out using **the Thematic Analysis** approach (Braun & Clarke, 2006) which consists of seven steps:

1. **Transcription**

   All conversations from the three speakers are transcribed into verbatim written text to ensure the accuracy of the response representation.

2. **Preliminary Review**

   Researchers thoroughly reread the transcript to understand the general context and identify early patterns that emerged, especially regarding engine investment decisions.

3. **Focused Coding**

   The data is broken down into chunks of meaning (code) such as *"high precision"*, *"TCO is more important than the initial price"*, *"critical lead time"*, and so on. This code is directly associated with the research objective.

4. **Theme Development**

   Codes that have a meaning-related relationship are grouped into broader themes, such as *"key criteria for investment evaluation"*, *"external risks"*, and *"strategic alignment"*.

5. **Contextual Analysis**

   The theme formed was analyzed by considering the condition of PT Pindad as a strategic SOE in the defense sector, which has unique industry characteristics and a strict regulatory environment.

6. **Synthesis and Reporting**

   The final results are presented in the form of a thematic narrative explaining how investment decisions were made, accompanied by representative quotes from respondents.

7. **Validation of Findings**

   The results of the analysis will be returned to the respondent's representative for verification (member checking) to ensure that the findings have reflected actual practices in the organization.

IV.1.2 Findings from Thematic Analysis

Table 4.2 Thematic Analysis

Theme	Description
Investment Evaluation Criteria	The three dominant criteria that come up repeatedly in interviews are precision, downtime, and production capacity. Precision is considered critical for the defense industry as it concerns the safety and performance of weapons.
Operational & Supply Chain Risks	Respondents emphasized the importance of procurement lead time, access to parts, and availability of local technicians as important factors in operational risk evaluation.
Sustainability & Technology Efficiency	There is a growing focus on Machinery features that support energy efficiency, IoT, and long-term predictive maintenance .
Organizational Strategic Alignment	Machines are seen not only as a means of production, but as part of PT Pindad's transformation roadmap towards industry 4.0 and increasing global competitiveness.

IV.1.3 Representative Quotes

The following quotes provide a first-hand overview of respondents' perceptions of each theme:

1. **Precision:** "Absolute precision, especially for weapon products. The tolerance for error is very small." – *LMS*
2. **Downtime:** "Downtime is a nightmare. If one machine dies, it can affect the entire production flow." – *HRT*
3. **Total Cost of Ownership (TCO):** "We prioritize the total cost of ownership. The initial price is important, but operational efficiency and ROI are the main determinants." – *AFS*
4. **IoT & Industry 4.0:** "We are moving towards industry 4.0, so automation is the foundation." – *AFS*
5. **Supply Chain Risk:** "If parts are hard to come by, production can be halted for a long time. That is a big problem in the field." – *LMS*

IV.1.4 Implications for the AHP Model

The results of the interviews showed that the criteria structure used in the AHP models was appropriate and relevant to practice in the field. Emerging themes such as *precision, downtime, ROI, and IoT readiness* directly support the weighting and modeling of pre-formulated decisions.

Nevertheless, interviews also open up opportunities to expand criteria such as sustainability and strategic alignment, which can be considered in advanced models or the development of more complex frameworks.

IV.2 Situational Analysis Results

The situational analysis in this chapter aims to translate the results of the identification of the company's internal and external conditions into a strong basis for investment decision-making. Using the Kepner-Tregoe approach, situational appraisal is conducted to comprehensively understand the urgency and complexity of the situation faced by PT Pindad.

IV.2.1 Findings from Situational Analysis

Based on primary and secondary data collected from PT Pindad's weapons production unit, it can be concluded that several key points are as follows:

1. **Current condition of the machine:** Most machines are more than two decades old, resulting in decreased precision, increased downtime, and high maintenance costs.
2. **Strategic production target:** PT Pindad targets to increase production capacity from 54,000 to 75,000 units per year by 2029, which is impossible to achieve without modernization of production lines.
3. **Pressure for technology integration:** The demands of automation, IoT readiness, and industry 4.0 readiness are the main requirements for modernization.
4. **Government support commitment:** The existence of PMN of IDR 450 billion to support the transformation of manufacturing facilities.
5. **Risk of delayed decisions:** If investments are not made on time, companies risk losing large contracts and losing competitiveness nationally.

IV.2.2 Implications for Decision Making Models

These findings are derived from a series of interviews conducted with key stakeholders at PT Pindad. Based on the insights gathered, nine key evaluation dimensions were formulated to comprehensively represent the critical aspects influencing strategic decision-making in production facility development (Appendix B). Nine main criterias are arranged to represent all aspects that are critical to PT Pindad:

1. Performance & Efficiency
2. Automation & Technology
3. Reliability & Maintenance
4. Flexibility & Scalability
5. Costs & Investments
6. Compliance & Security
7. Ergonomics & Health
8. Supply Chain & Availability
9. Environment & Sustainability

All of these dimensions are then evaluated pairwise to obtain their respective priority weights. This assessment is carried out by considering the company's strategic objectives, the urgency of investment, and the relationship of dimensions with the success of modernization (Cioca et al., 2021).

The results of this situational analysis strengthen the need to use multi-criteria-based decision-making methods and become the foundation in determining the best machine alternatives to be analyzed at the next stage.

IV.3 Competitor Benchmarking Analysis

To strengthen the rationale behind PT Pindad’s investment in machinery, this study incorporates a competitor benchmarking analysis. By comparing the company’s current manufacturing conditions with those of leading global defense manufacturers, the study highlights the strategic gap that must be addressed to maintain competitiveness and operational efficiency.

Two benchmark companies are selected:

- **FN Herstal** (Belgium): A globally recognized leader in the development, industrialization, and production of small arms and integrated weapon systems. FN Herstal operates under ISO 9001, EN/AS 9100, and ISO 14001 certifications, and maintains multiple modernized production facilities across Europe and the United States.
- **SNT Motiv** (South Korea): A leading defense and automotive manufacturer certified under ISO 9001, ISO 14001, ISO 45001, and IATF 16949, with strong emphasis on automated production, export competitiveness, and ESG integration.

Table 4.3 Strategic Comparison: PT Pindad vs FN Herstal & SNT Motiv

Criteria	PT Pindad	FN Herstal (Belgium)	SNT Motiv (South Korea)
Automation Level	Low (manual setup, limited integration)	High (robotic CNC, digital control systems)	High (automated manufacturing, integrated QC systems)
Quality Certifications	ISO 9001	ISO 9001, EN/AS 9100, ISO 14001	ISO 9001, ISO 14001, ISO 45001, IATF 16949
Environmental Management	Not certified	ISO 14001 certified	ISO 14001 certified, ESG practices implemented
Factory Network	Centralized (Bandung only)	6 global sites (Belgium, USA, Finland, UK)	Domestic HQ with large-scale export capability
Investment Strategy	Reactive and short-term	Proactive, guided by Middle-Term Planning	Strategic and long-term, aligned with R&D and market needs
Product Scope	Small arms, ammunition, light weapon systems	Small arms, integrated weapon systems, software, training tools	Defense products and automotive components with advanced QC

This comparative analysis clearly shows that PT Pindad is significantly behind its global peers in several key areas: automation, standardization, and production scalability. While FN Herstal and SNT Motiv have adopted proactive investment strategies and operate with highly automated and certified systems, PT Pindad still relies on aging, manually operated equipment.

Therefore, the investment decision modeled in this study is not only necessary for addressing current production inefficiencies, but also crucial for enabling PT Pindad to close the strategic gap and meet long-term competitiveness targets. This benchmarking reinforces the decision model developed through AHP by contextualizing the investment within industry best practices.

IV.4 Internal Document Review

The following is an internal document review conducted to obtain complete, comprehensive information and can support this research to obtain good and accurate results.

IV.4.1 Overview of PT Pindad’s Production Facility

PT Pindad's production facilities, especially in the weapons division, are the backbone in meeting the needs of the main equipment of the national defense system (*Alutsista*). Currently, PT Pindad's weapons production line has a maximum capacity of 54,000 units per year, with various types of firearms produced for the needs of the Indonesian National Army (TNI), the National Police of the Republic of Indonesia (Polri), and the export market.

However, in the face of increasing demands and demands of modern technology, today's production facilities face several key challenges, including capacity limitations, outdated machine technology, and inefficiencies in material flow.

The following is the location of the storage of the machines in the existing area of each line with the building layout plan as shown in the figure below.

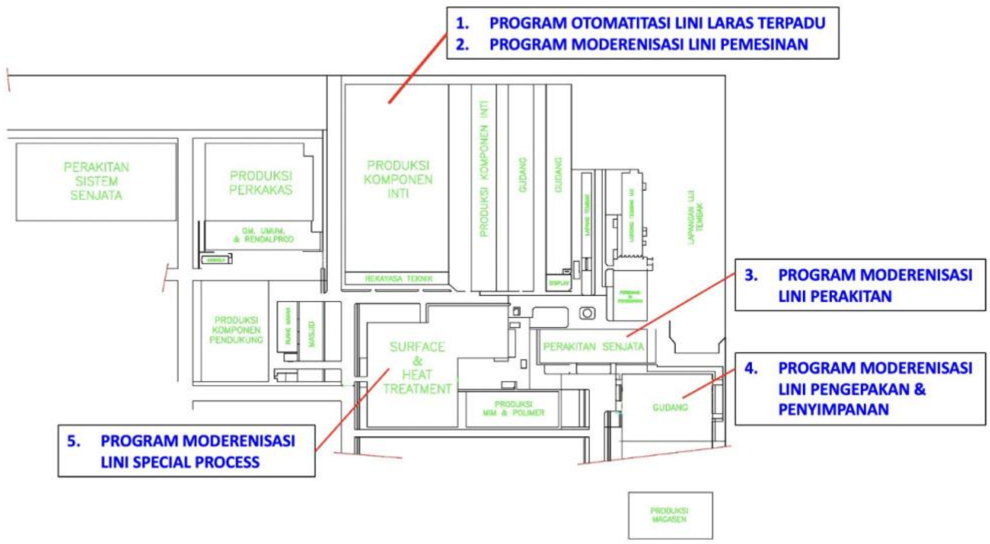


Figure 4.1 Layout Plan of the Production Facility of the Weapons Division

- **Integrated Barrel Production Line**

  Location : Main Component Production Department

  Item : Production Machinery, Handling, Product Measurement

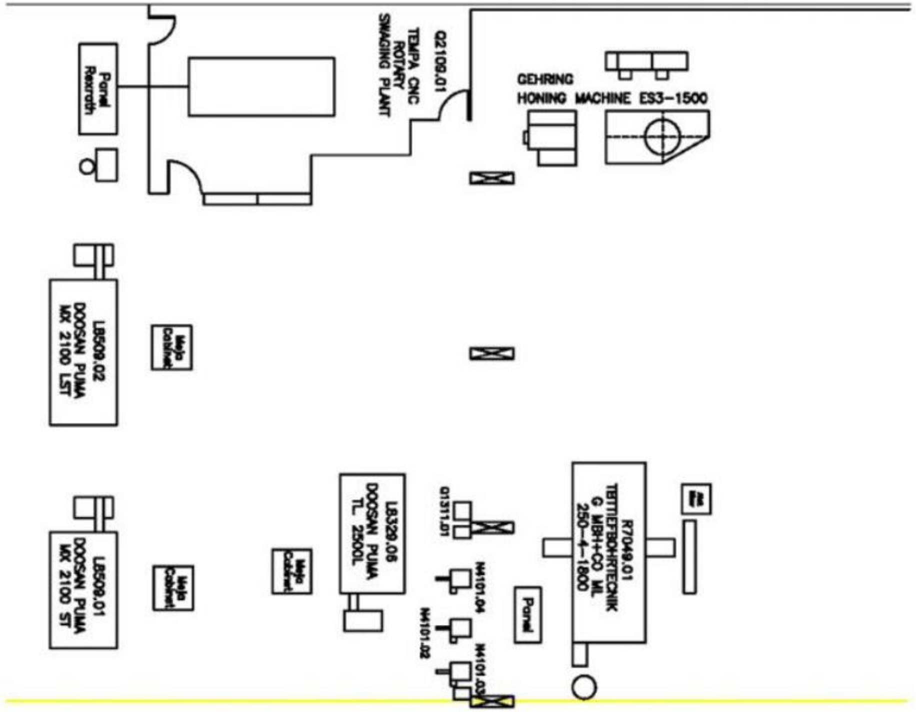


Figure 4.2 Current Condition of Integrated Barrel Production Line

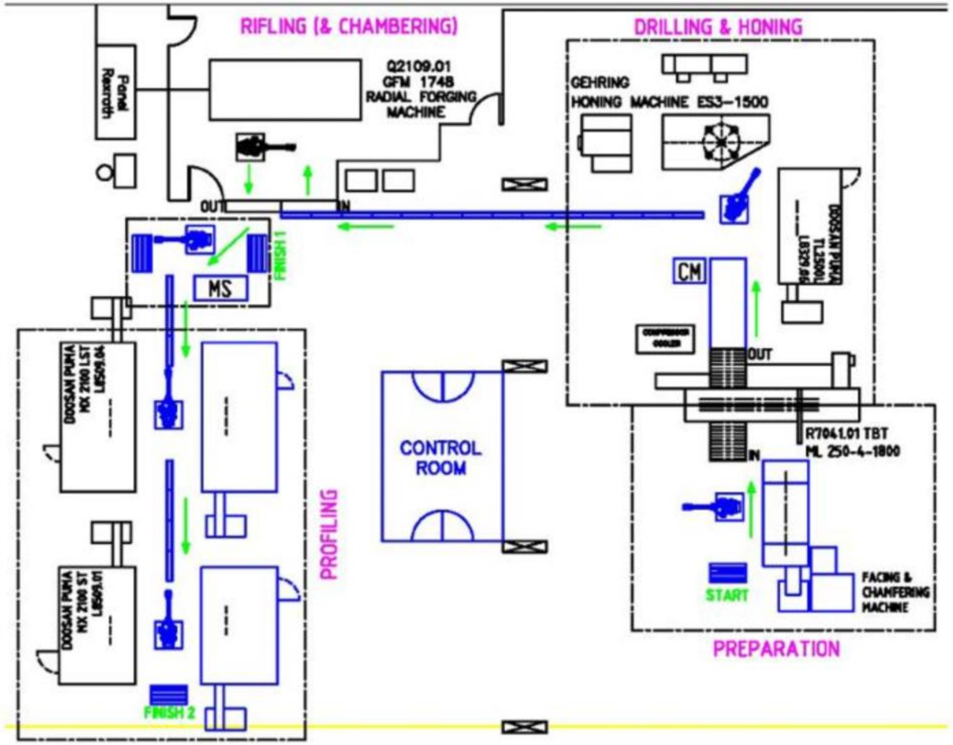


Figure 4.3 Investment Plan on Integrated Barrel Production Line

- **CNC Milling Machining Line**

  Location : Main Component Production Department

  Item : CNC Milling

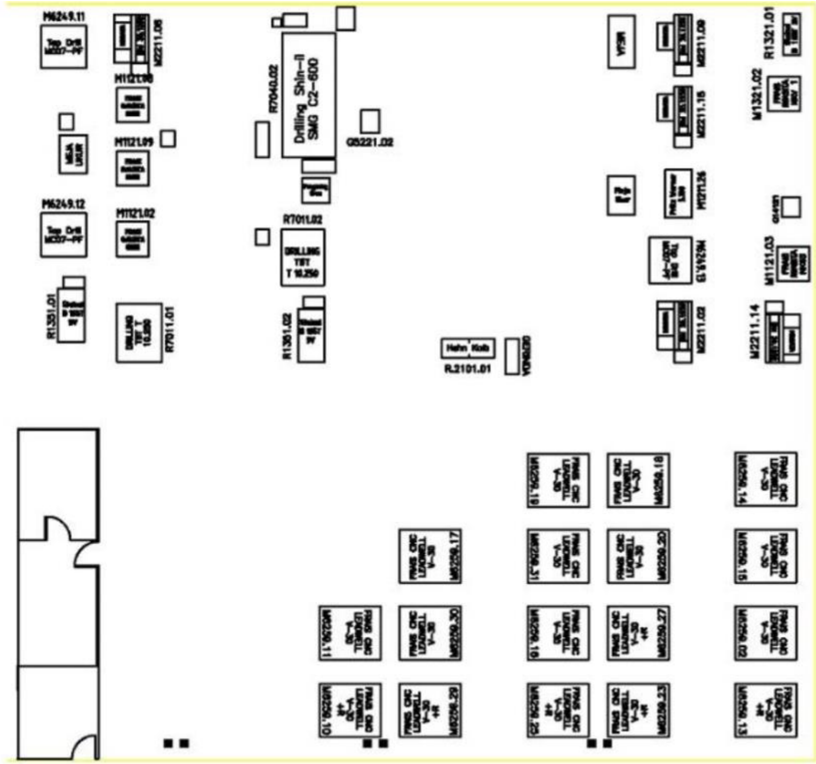


Figure 4.4 Current Condition of CNC Milling Machining line

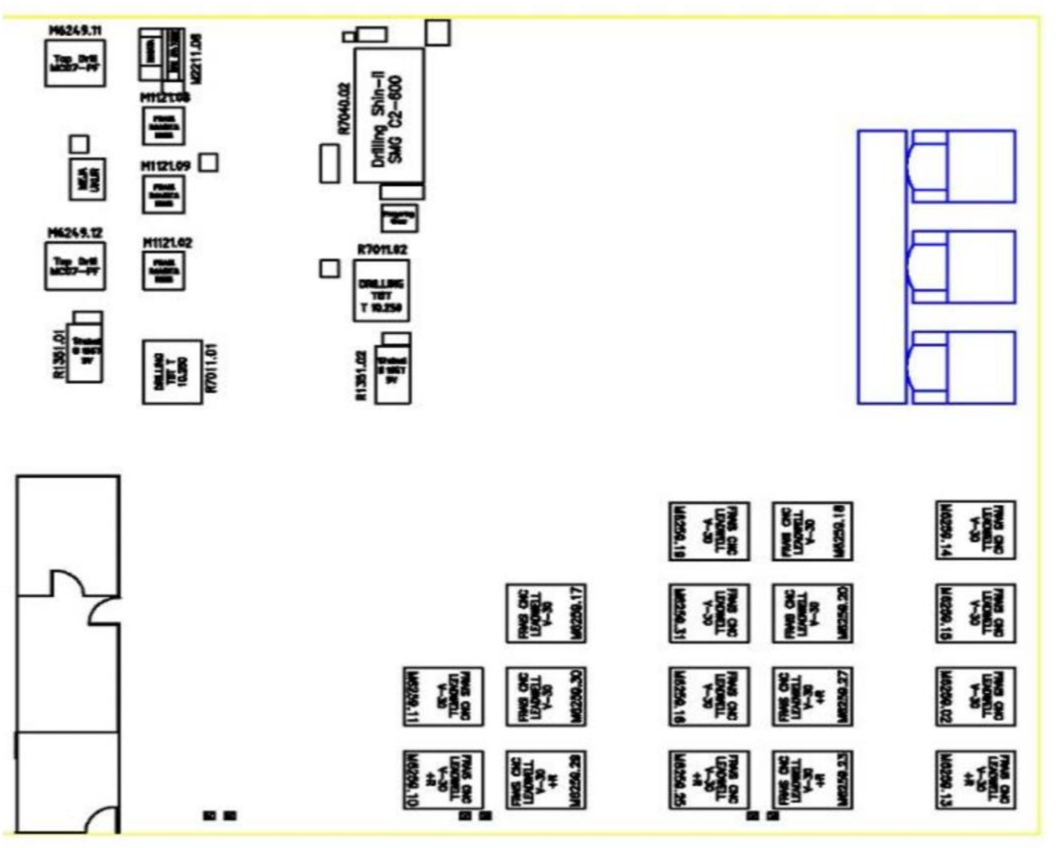


Figure 4.5 Investment Plan on CNC Milling Machining Line

- **CNC Turning Machining Line**

  Location : Main Component Production Department

  Item : CNC Turning

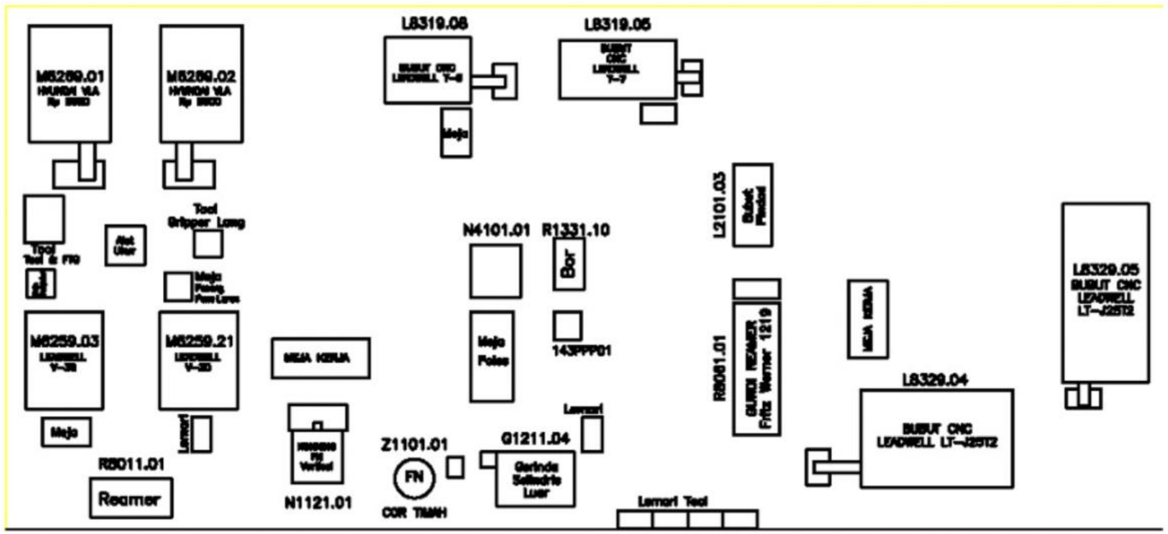


Figure 4.6 Current Condition of CNC Turning Machining line

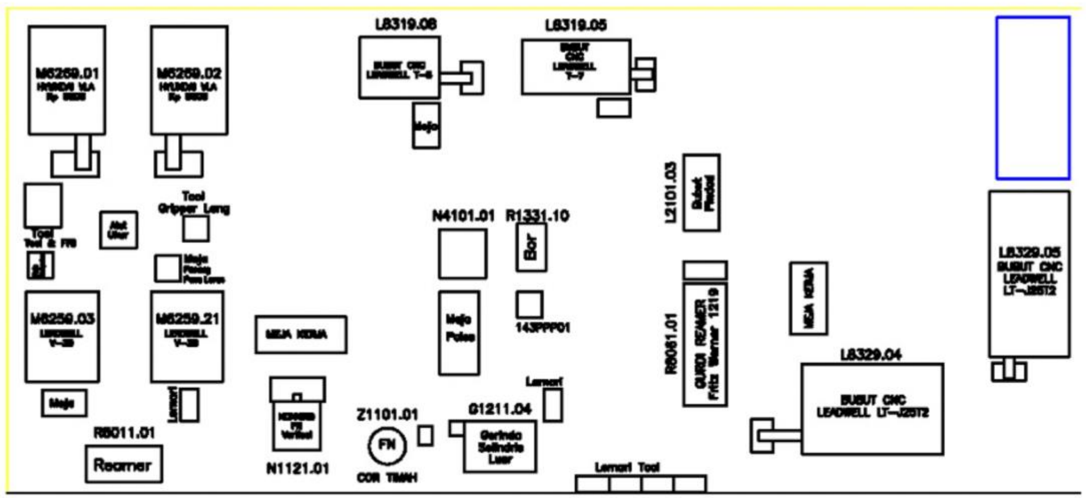


Figure 4.7 Investment Plan on CNC Turning Machining Line

- **Weapon Assembly Line**

  Location : Weapons Assembly Department

  Item : Special Work Machinery & Equipment, Weapon Component Storage and Weapon Washing

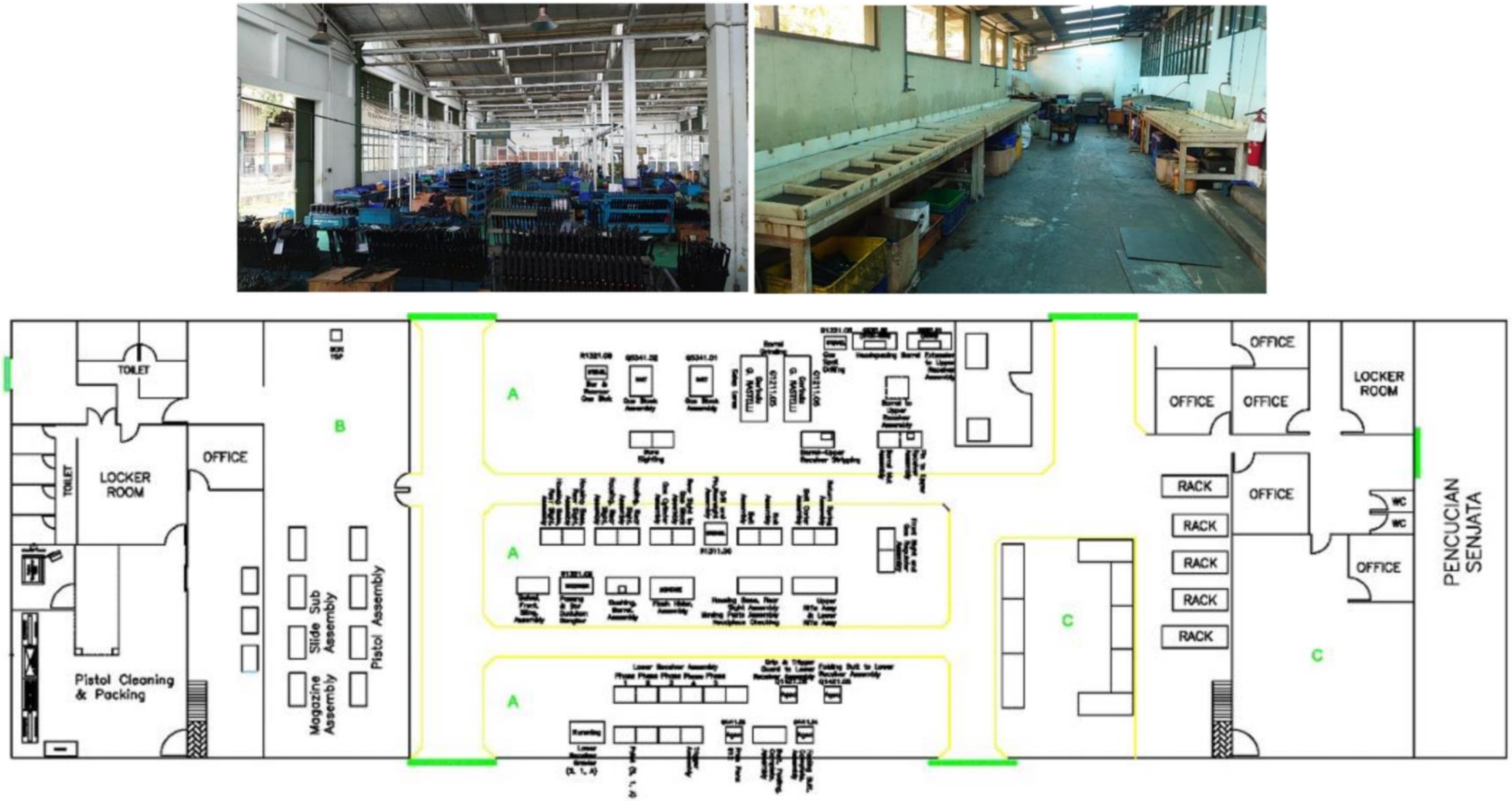


Figure 4.8 Current Condition of the Weapon Assembly Line

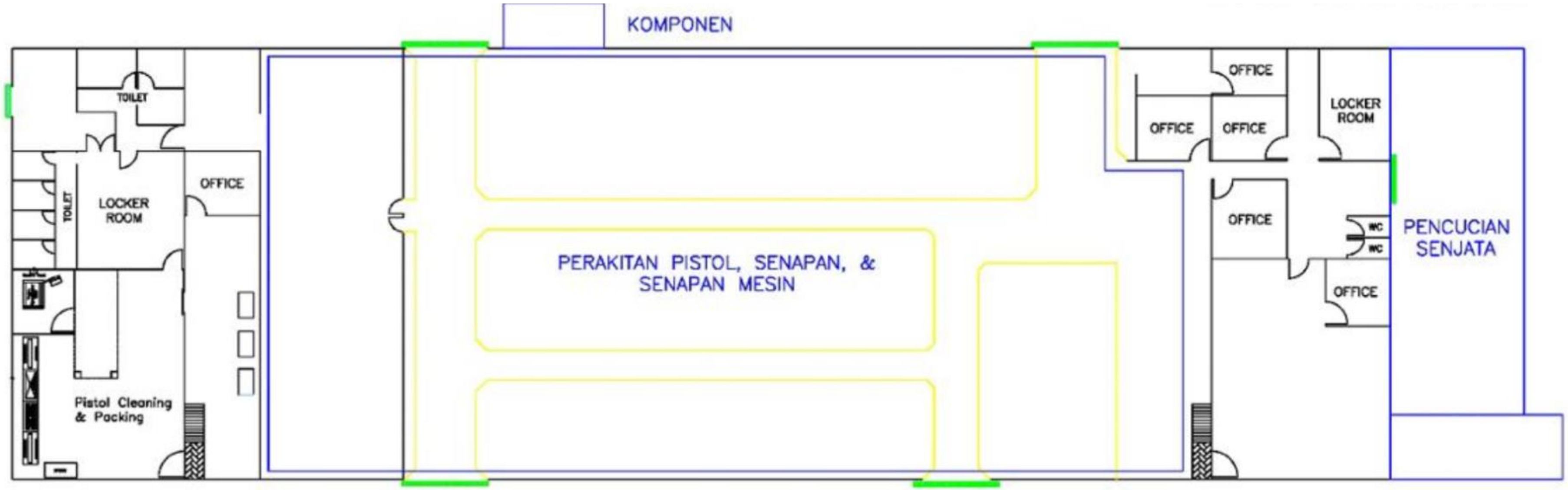


Figure 4.9 Investment Plan on the Arms Assembly Line

IV.4.2 Analysis of Current Production Layout

Based on the conditions described above, the limitations in PT Pindad's production facilities risk causing various strategic impacts To understand more deeply the problems and needs in the production flow, here is an analysis of the current layout of production facilities:

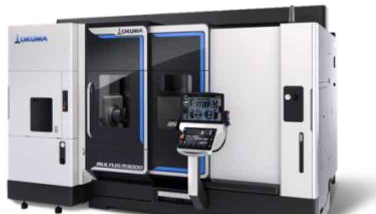
Table 4.4 Urgent Needs for Weapon Division Production Line

No	Production Line	Main Issues	Urgent Solutions	Required Equipment/Machines	Units Needed	Investment Estimate (Rp Billion)	Expected Impact
1	**Integrated Barrel Production**	Old machines, mostly manual process	Replacement with modern machines	Deep Hole Drilling Machine	2 units	86.2	Increased production capacity & barrel quality
		Unbalanced cycle time	Automated inspection & material handling	CNC Lathe for Barrel Profiling	3 units		Reduced production cycle time
		Bottleneck in headspace & profile machining		Automated Inspection System	1 unit		
2	**Machining Line (CNC & CAD/CAM)**	Old CNC machines without multitasking	Modernization of CNC multitasking	CNC 5-Axis Milling	4 units	93.8	Ability to produce new weapon series
		Incompatible with new weapon production (AM1, SM3 A1)	Upgrade to latest CAD/CAM software	CAD/CAM Software	2 licenses		15% increase in energy efficiency
3	**Weapon Assembly Line**	100% manual assembly	Automated assembly with robots	Collaborative Robot	5 units	25.5	20% reduction in lead time
		High risk of human error	Collaborative robots (cobots)	Automated Screw Assembly System	2 units		Improved accuracy & consistency
		Long assembly time	AI & IoT sensors for monitoring	AI & IoT Monitoring Sensor	1 system		
4	**Packaging & Storage Line**	Current capacity: 15,000 units (insufficient)	Automated Warehouse System (AWS)	Automated Storage & Retrieval System (AS/RS)	1 system	17.1	Better stock organization
		No real-time inventory tracking	Increase storage capacity to 50,000 units	RFID & Barcode Tracking System	1 system		90% reduction in stock loss risk
		High risk of storage errors	RFID & barcode tracking system				
5	**Material Handling & Workflow**	Manual material movement	Implementation of AGVs (Automated Guided Vehicles)	AGV System	5 units	27.4	15% reduction in lead time
		High error rate & long waiting time	Robotic handling for inter-workstation distribution	Automated Conveyor System	2 units		Improved production flow efficiency

Here is a list of the machines needed along with their specifications, the appropriate engine options, and the manufacturer or vendor that provided them. These machines are selected based on their technical capabilities, precision, and integration with modern manufacturing systems such as IoT and CAD/CAM. (Lata et al., 2021; Nhu et al., 2024)

The following table summarizes the categories of machinery required for the production process, especially in the manufacturing industry of high-precision weapons and components:

Table 4.5 Required Machines and Suitable Options

No	Machine Category	Suitable Machine Options	Manufacturer/Vendor
1	**CNC 5-Axis Multitasking**	**DMG Mori NTX 2000** 	DMG Mori, Mazak, Okuma
		Mazak Integrex i-200 	
		Okuma Multus U3000 	
2	**Deep Hole Drilling Machine (Weapon Barrels)**	**Tibo T-Series** 	Tibo, BTA Systems, SIG
		BTA Systems BDH-800 	

		Gundrill SIG L55 	
3	**CNC Lathe for Barrel Profiling**	**Okuma LB3000 EX II**  **Doosan Puma GT2600**  **Mazak Quick Turn 250MY** 	Okuma, Doosan, Mazak
4	**Automated Inspection System**	**Hexagon Absolute Arm 7-Axis**  **Zeiss O-Inspect 322** 	Hexagon, Zeiss, Mitutoyo

		Mitutoyo Quick Vision Apex 	
5	**Collaborative Robot (Cobot) for Assembly**	**Universal Robots UR10e** 	Universal Robots, KUKA, Fanuc
		KUKA LBR iiwa 14 R820 	
		Fanuc CRX-10iA 	
6	**Automated Screw Assembly System**	**Weber Vibratory Screw Feeder** 	Weber, Janome, Bosch Rexroth
		Janome JR3000 Series 	

		Bosch Rexroth Smart Screwdriver 	
7	**AGV for Material Handling**	**MiR 250 (Mobile Industrial Robots)** 	MiR, Omron, KUKA
		Omron LD-250 	
		KUKA KMP 600-S 	
8	**Automated Warehouse System (AS/RS)**	**Kardex Remstar Shuttle XP 500** 	Kardex, SSI Schaefer, Daifuku

		SSI Schaefer LogiMat 	
		Daifuku Smart Storage System 	

IV.4.3 Evaluation Criteria for Machine Options

To ensure the selection of the machine that best suits operational needs, an evaluation is carried out based on several key factors. These factors include technical, financial, and long-term strategy aspects so that the investments made provide maximum value. The following is a detailed explanation of each assessment factor (Breaz et al., 2019; Nhu et al., 2024).

(1) Production Performance & Efficiency

The performance of the machine greatly determines the effectiveness of the overall production process. Some of the aspects assessed in this category include:

- **Production Capacity**

  Production capacity indicates how much product a machine can produce in a single work cycle or in a given period of time (per hour, per shift, or per day) (Breaz et al., 2019; Negash et al., 2021). Machines with larger capacities allow for increased production output, but it is necessary to consider whether that capacity is suitable for operational needs.
- **Cycle Time**

Cycle time is the duration required by a machine to complete a single unit of product from start to finish (Breaz et al., 2019). The lower the cycle time, the faster the production process, which means the throughput increases. However, it is important to ensure that speed does not sacrifice quality and precision.

- **Precision & Consistency**

  Machines that have a high level of precision are able to produce products with accurate dimensions and tight tolerances, which are very important in high-tech manufacturing industries such as the manufacture of weapon components. In addition, consistency in production results ensures uniform quality, reduces waste, and improves raw material efficiency (Kundrák et al., 2006).

(2) Automation & Technology Integration

In the era of Industry 4.0, the use of machines that have automation capabilities and integration with intelligent technology has become increasingly important(Alkaraan et al., 2022). Some of the aspects evaluated include:

- **Automation Level**

  Machines with higher levels of automation can reduce reliance on manual process, increase efficiency, and reduce the risk of human error. Automation can be robotic arms systems, automated material feeding systems, or integrated assembly processes.

- **IoT & AI Compatibility**

  The Internet of Things (IoT) allows machines to collect and transmit production data in real-time to a central monitoring system. With the support of Artificial Intelligence (AI), this data can be analyzed to improve operational efficiency, conduct early detection of potential damages, and optimize the use of energy and raw materials (Kalir et al., 2023).

- **Adaptability to Industry 4.0**

  Machines compatible with Industry 4.0 technology have the ability to connect with cloud systems, perform predictive maintenance, and enable data-driven production control(Alkaraan et al., 2023). This increases the company's competitiveness in the long run.

(3) Flexibility & Scalability

A good machine not only meets today's needs but is also able to adapt to future demand changes.

- **Multi-Function Capabilities**

  Machines that have multi-tasking capabilities can perform more than one type of production process, such as turning and milling in a single system. This allows for space efficiency, cost, and increased flexibility in operation.

- **Scalability**

  Scalable machines allow for increased production capacity without the need to make additional investments in the near future. This factor is important to ensure readiness to face surge in market demand.

(4) Reliability & Maintenance

The reliability of the machine determines the continuity of uninterrupted production operations. Evaluation of this aspect includes:

- **Frequency of Downtime & Machine Reliability**

  High downtime can hinder productivity and increase operational costs. Therefore, machines that have a high level of reliability and minimal interference are highly preferred (Negash et al., 2021)

- **Predictive Maintenance Support**

  Predictive maintenance technology allows the system to detect potential failures before they occur, so maintenance can be carried out proactively (Lauro et al., 2014). This helps reduce unexpected repair costs and increases the service life of the machine.

(5) Costs & Investment Considerations

Financial factors are very important in decision-making. The main aspects assessed in this category include:

- **Initial Purchase Cost**

  The price of the machine should be compared to the value of its benefits in the long run. Higher-priced machines may have more advanced features, but it needs to be ensured that they are really needed and provide significant added value.

- **Operating Cost**

  Operational costs include energy consumption, consumables needs, and routine maintenance costs. An energy-efficient machine that has simple maintenance will be more profitable in the long run.

- **Return on Investment (ROI)**

  ROI is calculated by comparing the benefits obtained from the machine with the investment costs incurred. Machines that have a high ROI will generate profits for the company faster.

(6) Regulatory Compliance & Safety Standards

The machine must meet applicable industry standards to ensure compliance with regulations and occupational safety.

- **Certifications & Industry Standards**

  Compliance with standards such as ISO, ASTM, MIL-SPEC, or CE Marking ensures that the machine has met the technical and quality requirements set in the industry.

- **Operator Safety & Work Environment**

  The machine must be equipped with safety features such as automatic sensors, work area guards, and emergency stop systems to prevent work accidents(Breaz et al., 2019).

(7) Ergonomics & Operator Health Impact

Ergonomic factors affect the comfort of the operator in using the machine and reduce the risk of fatigue and injury due to long-term use (Cioca et al., 2021).

- **Ergonomic Design**

  Ergonomically designed machines are easier to operate and can reduce the risk of injury due to unnatural working postures.

- **Impact on Operator Health**

The machine must be designed to minimize exposure to excessive vibration, high noise, or harmful gas emissions that can negatively impact the health of workers.

(8) Supply Chain & Spare Parts Availability

The ease of obtaining spare parts and technical support affects the continuity of the machine's operations in the long run.

- **Procurement Lead Time**

  Machines that have a fast procurement time will also be faster in implementing them in the production line.

- **Supply Chain Risk**

  The availability of spare parts and after-sales service from vendors must be ensured so that the machine can continue to operate without a hitch (Claran Santhiyagu et al., 2025).

(9) Environmental Impact & Sustainability

The sustainability aspect is increasingly a concern in the modern industrial world.

- **Energy Efficiency**

  The machine with low power consumption and energy-saving features will be more environmentally friendly and reduce electricity costs (Kundrák et al., 2006).

- **Material & Process Sustainability**

  Machines that use environmentally friendly raw materials and produce minimal waste are preferred in sustainability-oriented industries (Jiang et al., 2025).

Table 4.6 Selected Attributes Relationship with Pindad Investment

No	Criteria	Attributes	Description
1	**Performance & Production Efficiency**	Production Capacity	Measures the machine's ability to produce a certain output within a given time frame.
		Cycle Time	The time required to complete one full production process.

No	Criteria	Attributes	Description
		Precision & Consistency	Evaluates the machine's accuracy and its ability to maintain consistent output over time.
2	**Automation & Technological Integration**	Level of Automation	Assesses how much the machine reduces manual intervention and enhances efficiency.
		IoT & AI Compatibility	Determines whether the machine supports real-time data analysis and connectivity with smart factory systems.
		Industry 4.0 Adaptability	Evaluates the machine's integration with cloud-based systems, predictive maintenance, and advanced analytics.
3	**Flexibility & Scalability**	Multi-Functionality	The ability of the machine to handle different processes or products.
		Scalability	Whether the machine can accommodate increased production demands in the future.
4	**Reliability & Maintenance**	Downtime & Reliability	Measures the frequency and duration of machine failures or required maintenance.
		Predictive Maintenance Support	Determines if the machine includes features for condition monitoring and preventive maintenance.
5	**Cost & Investment Considerations**	Initial Purchase Cost	The upfront cost of acquiring the machine.
		Operational Costs	Includes power consumption, raw materials, and routine maintenance costs.
		Return on Investment (ROI)	Assesses how quickly the machine generates profit relative to its cost.
6	**Regulatory Compliance & Safety Standards**	Industry Standards Compliance	Checks adherence to certifications such as ISO, ASTM, MIL-SPEC, and CE Marking.

No	Criteria	Attributes	Description
		Operator Safety & Workplace Security	Ensures that the machine has safety features that protect workers from hazards.
7	**Ergonomics & Operator Health**	Ergonomic Design	Evaluates how well the machine is designed for operator comfort and ease of use.
		Health Impact	Assesses the potential risks of repetitive strain injuries or fatigue due to machine operation.
8	**Supply Chain & Availability**	Procurement Lead Time	The time required for machine delivery and installation.
		Supply Chain Risk	Identifies potential challenges in obtaining spare parts and vendor support.
9	**Environmental Impact & Sustainability**	Energy Efficiency	Measures the machine's power consumption and sustainability.
		Eco-Friendliness	Determines whether the machine uses environmentally friendly materials and processes.

IV.4.4 Pairwise Comparison Matrix of Main Criteria

The nine criteria used in the AHP analysis were derived from the thematic synthesis of qualitative interview results as well as internal documentation and academic literature, as previously discussed in Chapter III. Each interviewee provided input regarding the challenges, priorities, and expected outcomes of the machine investment decision. These insights were then coded and categorized into recurring themes such as performance, efficiency, cost, risk, and sustainability.

To ensure both contextual relevance and methodological rigor, these qualitative findings were cross-referenced with industrial investment decision-making frameworks from prior research. The finalized set of criteria used in the AHP pairwise comparison reflects the combination of empirical stakeholder knowledge and established theoretical constructs, which strengthens the objectivity and applicability of the decision-making model.

As part of the strategic decision-making analysis process in investing in the modernization of weapons production facilities at PT Pindad, a series of structured discussions were conducted with resource persons consisting of internal experts from the company. This discussion aims to compile a hierarchy of criteria and sub-criteria and conduct *a pairwise comparison* assessment of each element using the Analytic Hierarchy Process (AHP) approach.

This matrix was compiled based on the results of discussions with three resource persons at PT Pindad, who represented strategic, technical, and operational perspectives. The three have a deep understanding of the need for modernization of weapons production lines, operational challenges, and long-term investment strategic criteria. The results of the discussion are attached in the Appendix B, here is the pairwise comparison matrix :

Table 4.7 Pairwise Comparison Matrix of Main Criteria

Main Criteria	1. Performance & Efficiency	2. Automation & Technology	3. Flexibility & Scalability	4. Reliability & Maintenance	5. Costs & Investment	6. Compliance & Security	7. Ergonomics & Health	8. Supply Chain & Availability	9. Environment & Sustainability
1. Performance & Efficiency	1	1	3	5	5	7	7	7	9
2. Automation & Technology	1	1	3	5	5	5	5	7	9
3. Flexibility & Scalability	1/3	1/3	1	3	3	5	5	5	7
4. Reliability & Maintenance	1/5	1/5	1/3	1	3	3	3	5	5
5. Costs & Investment	1/5	1/5	1/3	1/3	1	3	3	5	5
6. Compliance & Security	1/7	1/5	1/5	1/3	1/3	1	3	3	3
7. Ergonomics & Health	1/7	1/5	1/5	1/9	1/3	1/3	1	3	3
8. Supply Chain & Availability	1/7	1/7	1/5	1/5	1/5	1/3	1/3	1	3
9. Environment & Sustainability	1/9	1/9	1/7	1/5	1/5	1/3	1/3	1/3	1
TOTAL	**3.27**	**3.39**	**8.41**	**15.18**	**18.07**	**25.00**	**27.67**	**36.33**	**45.00**

IV.4.5 Normalization and Weight Calculation of the Main Criteria

After normalization of the above matrix, the global weights (priority vectors) for each dimension are obtained as follows:

Table 4.8 Normalization Weight of Main Criteria

Main Criteria	1. Performance & Efficiency	2. Automation & Technology	3. Flexibility & Scalability	4. Reliability & Maintenance	5. Costs & Investment	6. Compliance & Security	7. Ergonomics & Health	8. Supply Chain & Availability	9. Environment & Sustainability	Avg Weight
1. Performance & Efficiency	0.306	0.295	0.357	0.329	0.277	0.280	0.253	0.193	0.200	**28%**
2. Automation & Technology	0.306	0.295	0.357	0.329	0.277	0.200	0.181	0.193	0.200	**26%**
3. Flexibility & Scalability	0.102	0.098	0.119	0.198	0.166	0.200	0.181	0.138	0.156	**15%**
4. Reliability & Maintenance	0.061	0.059	0.040	0.066	0.166	0.120	0.108	0.138	0.111	**10%**
5. Costs & Investment	0.061	0.059	0.040	0.022	0.055	0.120	0.108	0.138	0.111	**8%**
6. Compliance & Security	0.044	0.059	0.024	0.022	0.018	0.040	0.108	0.083	0.067	**5%**
7. Ergonomics & Health	0.044	0.059	0.024	0.007	0.018	0.013	0.036	0.083	0.067	**4%**
8. Supply Chain & Availability	0.044	0.042	0.024	0.013	0.011	0.013	0.012	0.028	0.067	**3%**
9. Environment & Sustainability	0.034	0.033	0.017	0.013	0.011	0.013	0.012	0.009	0.022	**2%**

IV.4.6 Pairwise Comparison Matrix and Normalization of Each Sub Criteria

A pairwise comparison matrix is used to determine the relative weight of each sub-criterion in a single dimension. Each dimension has 2 to 3 sub-criteria that are compared to each other based on the Saaty scale. This process is carried out to ensure that the assessment is structured, consistent, and representative of the actual conditions faced by PT Pindad.

The following is a summary of the pairwise comparison and local priority for each sub-criterion:

(1) Performance & Production Efficiency

The following is a weight calculation of Production Capacity, Cycle Time and Precision:

Pairwise Matrix:

Sub-Criteria	**Capacity**	**Cycle Time**	**Precision**	**λ**	**CI**	**CR**
Production Capacity	1.00	3.00	0.50	3.06	0.03	0.05
Cycle Time	0.33	1.00	0.33	3.02		
Precision & Consistency	2.00	3.00	1.00	3.08		
Total	**3.33**	**7.00**	**1.83**	**3.05**		
				Average λ		

Normalized Matrix:

Sub-Criteria	**Capacity**	**Cycle Time**	**Precision**	**Row Avg (Priority)**
Production Capacity	0.30	0.43	0.27	**33%**
Cycle Time	0.10	0.14	0.18	**14%**
Precision	0.60	0.43	0.55	**52%**

(2) Automation & Technological Integration

The following is a weighted calculation of the Level of Automation, IoT & AI Compability and Industry 4.0 Adaptability:

Pairwise Matrix:

Sub-Criteria	**Level of Automation**	**IoT & AI Compatibility**	**Industry 4.0 Adaptability**	**λ**	**CI**	**CR**
Level of Automation	1.00	3.00	3.00	3.00	0	0
IoT & AI Compatibility	0.33	1.00	1.00	3.00		
Industry 4.0 Adaptability	0.33	1.00	1.00	3.00		
Total	**1.67**	**5.00**	**5.00**	**3.00**		
				Average λ		

Normalized Matrix:

Sub-Criteria	**Level of Automation**	**IoT & AI Compatibility**	**Industry 4.0 Adaptability**	**Row Avg (Priority)**
Level of Automation	0.60	0.60	0.60	**60%**
IoT & AI Compatibility	0.20	0.20	0.20	**20%**
Industry 4.0 Adaptability	0.20	0.20	0.20	**20%**

(3) Flexibility & Scalability

The following is a weighted calculation of Multi-Functionality and Scalability:

Pairwise Matrix:

Sub-Criteria	**Multi-Functionality**	**Scalability**
Multi-Functionality	1.00	2.00
Scalability	0.50	1.00
Total	**1.50**	**3.00**

Normalized Matrix:

Sub-Criteria	**Multi-Functionality**	**Scalability**	**Row Avg (Priority)**
Multi-Functionality	0.67	0.67	**67%**
Scalability	0.33	0.33	**33%**

(4) Reliability & Maintenance

The following is a weight calculation of Downtime & Reliability, Predictive Maintenance:

Pairwise Matrix:

Sub-Criteria	**Downtime & Reliability**	**Predictive Maintenance**
Downtime & Reliability	1.00	3.00
Predictive Maintenance	0.33	1.00
Total	**1.33**	**4.00**

Normalized Matrix:

Sub-Criteria	**Downtime & Reliability**	**Predictive Maintenance**	**Row Avg (Priority)**
Downtime & Reliability	0.75	0.75	**75%**
Predictive Maintenance	0.25	0.25	**25%**

(5) Cost & Investment Considerations

The following is a weighted calculation of the Initial Purchase, Operational Cost and ROI:

Pairwise Matrix:

Sub-Criteria	Initial Purchase	Operational Cost	ROI	λ	CI	CR
Initial Purchase	1.00	0.33	0.33	3.05	0.07	0.12
Operational Cost	3.00	1.00	0.33	3.13		
ROI	3.00	3.00	1.00	3.23		
Total	**7.00**	**4.33**	**1.67**	**3.14**		
				Average λ		

Normalized Matrix:

Sub-Criteria	Initial Purchase	Operational Cost	ROI	**Row Avg (Priority)**
Initial Purchase	0.14	0.08	0.20	**14%**
Operational Cost	0.43	0.23	0.20	**29%**
ROI	0.43	0.69	0.60	**57%**

(6) Regulatory Compliance & Safety Standards

The following is a weight calculation of Compliance and Safety:

Pairwise Matrix:

Sub-Criteria	Ergonomic Design	Health Impact
Ergonomic Design	1.00	0.50
Health Impact	2.00	1.00
Total	**3.00**	**1.50**

Normalized Matrix:

Sub-Criteria	Ergonomic Design	Health Impact	**Row Avg (Priority)**
Ergonomic Design	0.33	0.33	**33%**
Health Impact	0.67	0.67	**67%**

(7) Ergonomics & Operator Health

The following is a weight calculation of Ergonomic design and Health Impact:

Pairwise Matrix:

Sub-Criteria	Lead Time	Supply Chain Risk
Lead Time	1.00	2.00
Supply Chain Risk	0.50	1.00
Total	**1.50**	**3.00**

Normalized Matrix:

Sub-Criteria	Lead Time	Supply Chain Risk	**Row Avg (Priority)**
Lead Time	0.67	0.67	**67%**
Supply Chain Risk	0.33	0.33	**33%**

(8) Supply Chain & Availability

The following is a weighted calculation of Lead Time and Supply Chain Risk:

Pairwise Matrix:

Sub-Criteria	Lead Time	Supply Chain Risk
Lead Time	1.00	2.00
Supply Chain Risk	0.50	1.00
Total	**1.50**	**3.00**

Normalized Matrix:

Sub-Criteria	Lead Time	Supply Chain Risk	**Row Avg (Priority)**
Lead Time	0.67	0.67	**67%**
Supply Chain Risk	0.33	0.33	**33%**

(9) Environmental Impact & Sustainability

The following is a weight calculation of energy efficiency and sustainable production:

Pairwise Matrix:

Sub-Criteria	Energy Efficiency	Sustainable Production
Energy Efficiency	1.00	0.50
Sustainable Production	2.00	1.00
Total	**3.00**	**1.50**

Normalized Matrix:

Sub-Criteria	Energy Efficiency	Sustainable Production	**Row Avg (Priority)**
Energy Efficiency	0.33	0.33	**33%**
Sustainable Production	0.67	0.67	**67%**

IV.4.7 Weight of Criteria

Those 22 evaluation attributes will be grouped into 9 main criteria: *Performance & Efficiency, Automation & Technology, Flexibility & Scalability, Reliability & Maintenance, Cost & Investment, Regulatory Compliance & Safety, Ergonomics & Operator Health, Supply Chain & Availability, and Environmental Impact & Sustainability.*

For each criterion, specific attributes have been assigned to ensure alignment with the machine selection process and overall project evaluation. Finally, the list of attributes and their corresponding weight factors are summarized as follows:

Table 4.9 Final Weight Calculation of Criteria

Main Criteria	**Weight**	**Sub-Criteria**	**Weight**	**Final Weight**
1. Performance & Efficiency	**28%**	Production Capacity	**33%**	**9.23%**
		Cycle Time	**14%**	**3.91%**
		Precision & Consistency	**52%**	**14.52%**
2. Automation & Technology	**26%**	Level of Automation	**60%**	**15.58%**
		IoT & AI Compatibility	**20%**	**5.19%**
		Industry 4.0 Adaptability	**20%**	**5.19%**
3. Flexibility & Scalability	**15%**	Multi-Functionality	**67%**	**10.05%**
		Scalability	**33%**	**5.03%**
4. Reliability & Maintenance	**10%**	Downtime & Reliability	**75%**	**7.24%**
		Predictive Maintenance	**25%**	**2.41%**
5. Costs & Investment	**8%**	Initial Purchase Cost	**14%**	**1.11%**
		Operational Cost	**29%**	**2.27%**
		Return on Investment (ROI)	**57%**	**4.55%**
6. Compliance & Safety	**5%**	Standards Compliance	**33%**	**1.72%**
		Operator Safety	**67%**	**3.44%**
7. Ergonomics & Health	**4%**	Ergonomic Design	**33%**	**1.30%**
		Health Impact	**67%**	**2.60%**
8. Supply Chain & Availability	**3%**	Lead Time / Delivery	**67%**	**1.88%**
		Supply Chain Risk	**33%**	**0.94%**
9. Environment & Sustainability	**2%**	Energy Efficiency	**33%**	**0.61%**
		Sustainable Production	**67%**	**1.22%**
TOTAL	100%			100%

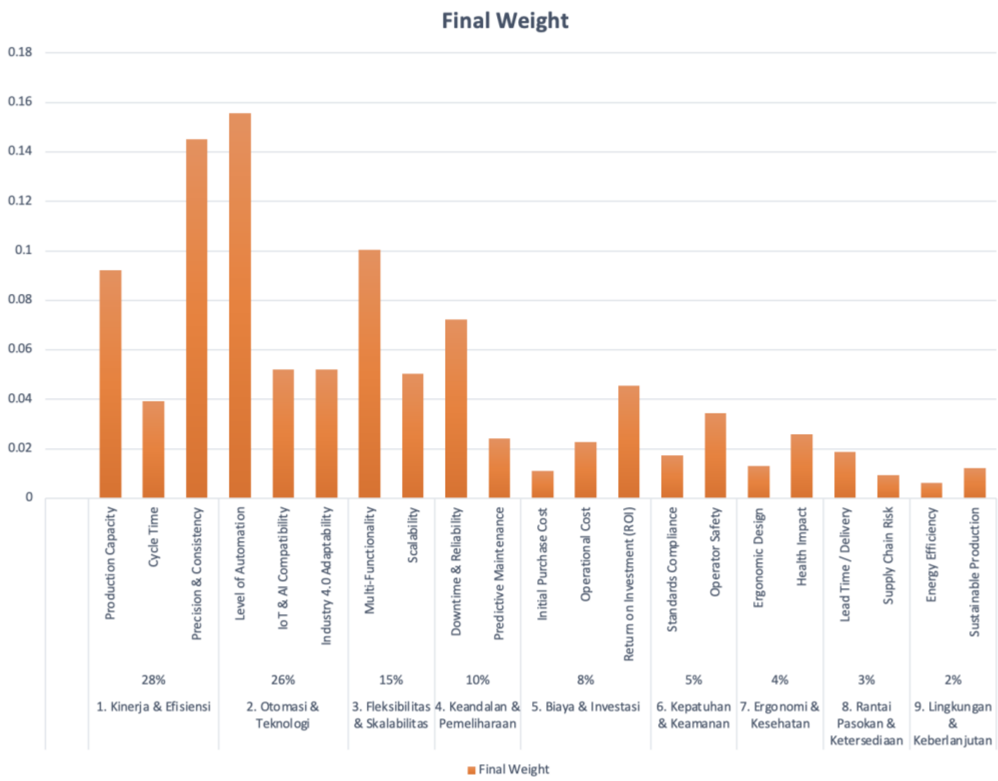


Figure 4.10 Final Weight Chart

The weighting of attributes in the machine selection criteria reflects their relative importance in evaluating investment opportunities, considering factors such as production efficiency, automation capabilities, cost-effectiveness, long-term reliability, and sustainability. Attributes with higher weights represent critical considerations that have a significant impact on manufacturing performance, operational feasibility, and strategic decision-making in the industrial sector.

IV.4.8 Final Scoring and Ranking of Alternatives

After obtaining the global weights of each sub-criterion based on the AHP method, the next step is to evaluate the proposed engine alternatives. Each alternative is scored against each sub-criterion on a scale of 1–10 based on technical assessments and vendor data

Table 4.10 Final Scoring Calculation for CNC 5-Axis Multitasking

Main Criteria	Sub-Criteria	Weight (%)	DMG Mori NTX 2000		Mazak Integrex i-200		Okuma Multus U3000	
			Score	Wighted Score	Score	Wighted Score	Score	Wighted Score
1. Performance & Efficiency	Production Capacity	9.23%	9	0.831	8	0.738	8	0.738
	Cycle Time	3.91%	8	0.313	9	0.352	8	0.313
	Precision & Consistency	14.52%	9	1.306	8	1.161	9	1.306
2. Automation & Technology	Level of Automation	15.58%	8	1.246	8	1.246	8	1.246
	IoT & AI Compatibility	5.19%	8	0.415	8	0.415	9	0.467
	Industry 4.0 Adaptability	5.19%	8	0.415	8	0.415	9	0.467
3. Flexibility & Scalability	Multi-Functionality	10.05%	10	1.005	9	0.905	9	0.905
	Scalability	5.03%	8	0.402	7	0.352	8	0.402
4. Reliability & Maintenance	Downtime & Reliability	7.24%	9	0.652	9	0.652	9	0.652
	Predictive Maintenance	2.41%	8	0.193	7	0.169	9	0.217
5. Costs & Investment	Initial Purchase Cost	1.11%	6	0.067	7	0.078	7	0.078
	Operational Cost	2.27%	8	0.182	7	0.159	8	0.182
	Return on Investment (ROI)	4.55%	8	0.364	8	0.364	8	0.364
6. Compliance & Security	Standards Compliance	1.72%	10	0.172	10	0.172	10	0.172
	Operator Safety	3.44%	9	0.310	9	0.310	9	0.310
7. Ergonomics & Health	Ergonomic Design	1.30%	8	0.104	8	0.104	9	0.117
	Health Impact	2.60%	8	0.208	8	0.208	9	0.234
8. Supply Chain & Availability	Lead Time / Delivery	1.88%	6	0.113	6	0.113	6	0.113
	Supply Chain Risk	0.94%	8	0.075	8	0.075	7	0.066
9. Environment & Sustainability	Energy Efficiency	0.61%	8	0.049	7	0.043	8	0.049
	Sustainable Production	1.22%		0.000		0.000		0.000
		1.0		8.4223		8.0314		8.3982

Table 4.11 Final Scoring Calculation for Deep Hole Drilling Machine (Weapon Barrels)

Main Criteria	Sub-Criteria	Weight (%)	Tibo T-Series		BTA Systems BDH-800		Gundrill SIG L55	
			Score	Wighted Score	Score	Wighted Score	Score	Wighted Score
1. Performance & Efficiency	Production Capacity	9.23%	9	0.831	9	0.831	8	0.738
	Cycle Time	3.91%	8	0.313	8	0.313	7	0.274
	Precision & Consistency	14.52%	9	1.306	8	1.161	9	1.306
2. Automation & Technology	Level of Automation	15.58%	8	1.246	7	1.091	7	1.091
	IoT & AI Compatibility	5.19%	7	0.364	6	0.312	6	0.312
	Industry 4.0 Adaptability	5.19%	7	0.364	6	0.312	6	0.312
3. Flexibility & Scalability	Multi-Functionality	10.05%	8	0.804	7	0.704	7	0.704
	Scalability	5.03%	8	0.402	7	0.352	6	0.302
4. Reliability & Maintenance	Downtime & Reliability	7.24%	9	0.652	8	0.579	8	0.579
	Predictive Maintenance	2.41%	7	0.169	6	0.145	6	0.145
5. Costs & Investment	Initial Purchase Cost	1.11%	7	0.078	7	0.078	7	0.078
	Operational Cost	2.27%	8	0.182	7	0.159	8	0.182
	Return on Investment (ROI)	4.55%	8	0.364	7	0.319	8	0.364
6. Compliance & Security	Standards Compliance	1.72%	10	0.172	9	0.155	9	0.155
	Operator Safety	3.44%	9	0.310	8	0.275	8	0.275
7. Ergonomics & Health	Ergonomic Design	1.30%	8	0.104	7	0.091	7	0.091
	Health Impact	2.60%	8	0.208	7	0.182	7	0.182
8. Supply Chain & Availability	Lead Time / Delivery	1.88%	7	0.131	6	0.113	7	0.131
	Supply Chain Risk	0.94%	8	0.075	7	0.066	7	0.066
9. Environment & Sustainability	Energy Efficiency	0.61%	8	0.049	7	0.043	8	0.049
	Sustainable Production	1.22%	8	0.098	7	0.085	7	0.085
		1.0		8.2208		7.3634		7.4199

Table 4.12 Final Scoring Calculation for CNC Lathe for Barrel Profiling

Main Criteria	Sub-Criteria	Weight (%)	OKUMA LB3000 EX II		DOOSAN PUMA GT2600		MAZAK QUICK TURN 250MY	
			Score	Wighted Score	Score	Wighted Score	Score	Wighted Score
1. Performance & Efficiency	Production Capacity	9.23%	9	0.831	8	0.738	8	0.738
	Cycle Time	3.91%	8	0.313	8	0.313	9	0.352
	Precision & Consistency	14.52%	9	1.306	8	1.161	9	1.306
2. Automation & Technology	Level of Automation	15.58%	8	1.246	7	1.091	9	1.402
	IoT & AI Compatibility	5.19%	7	0.364	6	0.312	9	0.467
	Industry 4.0 Adaptability	5.19%	8	0.415	6	0.312	9	0.467
3. Flexibility & Scalability	Multi-Functionality	10.05%	8	0.804	7	0.704	9	0.905
	Scalability	5.03%	8	0.402	7	0.352	9	0.452
4. Reliability & Maintenance	Downtime & Reliability	7.24%	9	0.652	8	0.579	9	0.652
	Predictive Maintenance	2.41%	8	0.193	6	0.145	9	0.217
5. Costs & Investment	Initial Purchase Cost	1.11%	7	0.078	9	0.100	6	0.067
	Operational Cost	2.27%	8	0.182	8	0.182	7	0.159
	Return on Investment (ROI)	4.55%	8	0.364	8	0.364	8	0.364
6. Compliance & Security	Standards Compliance	1.72%	9	0.155	8	0.138	9	0.155
	Operator Safety	3.44%	9	0.310	8	0.275	9	0.310
7. Ergonomics & Health	Ergonomic Design	1.30%	8	0.104	7	0.091	9	0.117
	Health Impact	2.60%	9	0.234	8	0.208	9	0.234
8. Supply Chain & Availability	Lead Time / Delivery	1.88%	7	0.131	8	0.150	7	0.131
	Supply Chain Risk	0.94%	8	0.075	8	0.075	7	0.066
9. Environment & Sustainability	Energy Efficiency	0.61%	8	0.049	7	0.043	8	0.049
	Sustainable Production	1.22%	7	0.085	7	0.085	8	0.098
		1.0		8.2935		7.4172		8.7088

Table 4.13 Final Scoring Calculation for Automated Inspection System

Main Criteria	Sub-Criteria	Weight (%)	HEXAGON ABSOLUTE ARM 7-Axis		Zeiss O-Inspect 322 (CNC Optical + Tactile CMM)		Mitutoyo Quick Vision Apex (Optical Measuring System)	
			Score	Wighted Score	Score	Wighted Score	Score	Wighted Score
1. Performance & Efficiency	Production Capacity	9.23%	8	0.738	7	0.646	7	0.646
	Cycle Time	3.91%	8	0.313	9	0.352	8	0.313
	Precision & Consistency	14.52%	9	1.306	10	1.452	9	1.306
2. Automation & Technology	Level of Automation	15.58%	6	0.935	9	1.402	9	1.402
	IoT & AI Compatibility	5.19%	7	0.364	7	0.364	7	0.364
	Industry 4.0 Adaptability	5.19%	7	0.364	8	0.415	7	0.364
3. Flexibility & Scalability	Multi-Functionality	10.05%	9	0.905	8	0.804	8	0.804
	Scalability	5.03%	8	0.402	7	0.352	6	0.302
4. Reliability & Maintenance	Downtime & Reliability	7.24%	9	0.652	9	0.652	8	0.579
	Predictive Maintenance	2.41%	6	0.145	6	0.145	6	0.145
5. Costs & Investment	Initial Purchase Cost	1.11%	6	0.067	5	0.056	6	0.067
	Operational Cost	2.27%	8	0.182	8	0.182	8	0.182
	Return on Investment (ROI)	4.55%	8	0.364	8	0.364	8	0.364
6. Compliance & Security	Standards Compliance	1.72%	9	0.155	10	0.172	9	0.155
	Operator Safety	3.44%	9	0.310	9	0.310	9	0.310
7. Ergonomics & Health	Ergonomic Design	1.30%	9	0.117	8	0.104	8	0.104
	Health Impact	2.60%	9	0.234	9	0.234	9	0.234
8. Supply Chain & Availability	Lead Time / Delivery	1.88%	7	0.131	7	0.131	7	0.131
	Supply Chain Risk	0.94%	8	0.075	8	0.075	8	0.075
9. Environment & Sustainability	Energy Efficiency	0.61%	9	0.055	8	0.049	8	0.049

Main Criteria	Sub-Criteria	Weight (%)	HEXAGON ABSOLUTE ARM 7-Axis		Zeiss O-Inspect 322 (CNC Optical + Tactile CMM)		Mitutoyo Quick Vision Apex (Optical Measuring System)	
			Score	Wighted Score	Score	Wighted Score	Score	Wighted Score
	Sustainable Production	1.22%	8	0.098	7	0.085	8	0.098
		1.0		7.9100		8.3454		7.9926

Table 4.14 Final Scoring Calculation for Collaborative Robot (Cobot) for Assembly

Main Criteria	Sub-Criteria	Weight (%)	Universal Robots UR10e		FANUC CRX-10iA		Doosan H-Series H2017	
			Score	Wighted Score	Score	Wighted Score	Score	Wighted Score
1. Performance & Efficiency	Production Capacity	9.23%	8	0.738	9	0.831	10	0.923
	Cycle Time	3.91%	8	0.313	8	0.313	8	0.313
	Precision & Consistency	14.52%	9	1.306	10	1.452	9	1.306
2. Automation & Technology	Level of Automation	15.58%	9	1.402	9	1.402	9	1.402
	IoT & AI Compatibility	5.19%	8	0.415	8	0.415	9	0.467
	Industry 4.0 Adaptability	5.19%	9	0.467	9	0.467	9	0.467
3. Flexibility & Scalability	Multi-Functionality	10.05%	10	1.005	9	0.905	9	0.905
	Scalability	5.03%	8	0.402	7	0.352	8	0.402
4. Reliability & Maintenance	Downtime & Reliability	7.24%	9	0.652	10	0.724	9	0.652
	Predictive Maintenance	2.41%	7	0.169	8	0.193	7	0.169
5. Costs & Investment	Initial Purchase Cost	1.11%	7	0.078	6	0.067	5	0.056
	Operational Cost	2.27%	9	0.205	8	0.182	8	0.182
	Return on Investment (ROI)	4.55%	9	0.410	8	0.364	7	0.319
6. Compliance & Security	Standards Compliance	1.72%	10	0.172	10	0.172	10	0.172
	Operator Safety	3.44%	10	0.344	9	0.310	10	0.344
7. Ergonomics & Health	Ergonomic Design	1.30%	9	0.117	8	0.104	9	0.117
	Health Impact	2.60%	10	0.260	9	0.234	10	0.260
8. Supply Chain & Availability	Lead Time / Delivery	1.88%	9	0.169	7	0.131	6	0.113
	Supply Chain Risk	0.94%	9	0.084	8	0.075	7	0.066
9. Environment & Sustainability	Energy Efficiency	0.61%	9	0.055	8	0.049	9	0.055
	Sustainable Production	1.22%	8	0.098	8	0.098	8	0.098
		1.0		8.8618		8.8393		8.7868

Table 4.15 Final Scoring Calculation for Automated Screw Assembly System

Main Criteria	Sub-Criteria	Weight (%)	Weber Automatic Screwdriving System (SEV-L Series)		eprag Screwdriving System (Minimat-EC Servo)		Kilews SKD-R Screwdriving Robot System	
			Score	Wighted Score	Score	Wighted Score	Score	Wighted Score
1. Performance & Efficiency	Production Capacity	9.23%	9	0.831	8	0.738	7	0.646
	Cycle Time	3.91%	9	0.352	8	0.313	7	0.274
	Precision & Consistency	14.52%	10	1.452	10	1.452	8	1.161
2. Automation & Technology	Level of Automation	15.58%	9	1.402	9	1.402	8	1.246
	IoT & AI Compatibility	5.19%	8	0.415	9	0.467	6	0.312
	Industry 4.0 Adaptability	5.19%	9	0.467	9	0.467	6	0.312
3. Flexibility & Scalability	Multi-Functionality	10.05%	7	0.704	8	0.804	7	0.704
	Scalability	5.03%	9	0.452	9	0.452	8	0.402
4. Reliability & Maintenance	Downtime & Reliability	7.24%	10	0.724	9	0.652	8	0.579
	Predictive Maintenance	2.41%	7	0.169	8	0.193	6	0.145

Main Criteria	Sub-Criteria	Weight (%)	Weber Automatic Screwdriving System (SEV-L Series)		eprag Screwdriving System (Minimat-EC Servo)		Kilews SKD-R Screwdriving Robot System	
			Score	Wighted Score	Score	Wighted Score	Score	Wighted Score
5. Costs & Investment	Initial Purchase Cost	1.11%	6	0.067	6	0.067	9	0.100
	Operational Cost	2.27%	9	0.205	9	0.205	8	0.182
	Return on Investment (ROI)	4.55%	8	0.364	8	0.364	9	0.410
6. Compliance & Security	Standards Compliance	1.72%	10	0.172	10	0.172	8	0.138
	Operator Safety	3.44%	10	0.344	9	0.310	9	0.310
7. Ergonomics & Health	Ergonomic Design	1.30%	9	0.117	9	0.117	8	0.104
	Health Impact	2.60%	10	0.260	10	0.260	9	0.234
8. Supply Chain & Availability	Lead Time / Delivery	1.88%	8	0.150	7	0.131	9	0.169
	Supply Chain Risk	0.94%	8	0.075	7	0.066	9	0.084
9. Environment & Sustainability	Energy Efficiency	0.61%	9	0.055	9	0.055	8	0.049
	Sustainable Production	1.22%	8	0.098	8	0.098	7	0.085
		1.0		8.8748		8.7849		7.6450

Table 4.16 Final Scoring Calculation for AGV for Material Handling

Main Criteria	Sub-Criteria	Weight (%)	MiR250 (Mobile Industrial Robots		Omron LD-250		Hikrobot Forklift AGV (FMR-FA)	
			Score	Wighted Score	Score	Wighted Score	Score	Wighted Score
1. Performance & Efficiency	Production Capacity	9.23%	8	0.738	9	0.831	10	0.923
	Cycle Time	3.91%	9	0.352	8	0.313	7	0.274
	Precision & Consistency	14.52%	8	1.161	8	1.161	7	1.016
2. Automation & Technology	Level of Automation	15.58%	9	1.402	8	1.246	9	1.402
	IoT & AI Compatibility	5.19%	10	0.519	9	0.467	9	0.467
	Industry 4.0 Adaptability	5.19%	9	0.467	8	0.415	7	0.364
3. Flexibility & Scalability	Multi-Functionality	10.05%	9	0.905	8	0.804	7	0.704
	Scalability	5.03%	9	0.452	8	0.402	7	0.352
4. Reliability & Maintenance	Downtime & Reliability	7.24%	10	0.724	9	0.652	9	0.652
	Predictive Maintenance	2.41%	9	0.217	8	0.193	7	0.169
5. Costs & Investment	Initial Purchase Cost	1.11%	6	0.067	7	0.078	7	0.078
	Operational Cost	2.27%	8	0.182	8	0.182	7	0.159
	Return on Investment (ROI)	4.55%	8	0.364	8	0.364	7	0.319
6. Compliance & Security	Standards Compliance	1.72%	10	0.172	10	0.172	9	0.155
	Operator Safety	3.44%	10	0.344	9	0.310	9	0.310
7. Ergonomics & Health	Ergonomic Design	1.30%	9	0.117	8	0.104	7	0.091
	Health Impact	2.60%	10	0.260	9	0.234	10	0.260
8. Supply Chain & Availability	Lead Time / Delivery	1.88%	7	0.131	6	0.113	6	0.113
	Supply Chain Risk	0.94%	8	0.075	8	0.075	7	0.066
9. Environment & Sustainability	Energy Efficiency	0.61%	9	0.055	9	0.055	8	0.049
	Sustainable Production	1.22%	8	0.098	8	0.098	8	0.098
		1.0		8.8038		8.2689		8.0180

Table 4.17 Final Scoring Calculation for Automated Warehouse System (AS/RS)

Main Criteria	Sub-Criteria	Weight (%)	SSI Schäfer Cuby Shuttle System (Germany)		Daifuku Unit Load AS/RS (Japan)		Geek+ RoboShuttle RS8 (China)	
			Score	Wighted Score	Score	Wighted Score	Score	Wighted Score
1. Performance & Efficiency	Production Capacity	9.23%	8	0.738	9	0.831	10	0.923
	Cycle Time	3.91%	9	0.352	8	0.313	7	0.274
	Precision & Consistency	14.52%	8	1.161	8	1.161	7	1.016
2. Automation & Technology	Level of Automation	15.58%	9	1.402	8	1.246	9	1.402
	IoT & AI Compatibility	5.19%	10	0.519	9	0.467	9	0.467
	Industry 4.0 Adaptability	5.19%	9	0.467	8	0.415	7	0.364
3. Flexibility & Scalability	Multi-Functionality	10.05%	9	0.905	8	0.804	7	0.704
	Scalability	5.03%	9	0.452	8	0.402	7	0.352
4. Reliability & Maintenance	Downtime & Reliability	7.24%	10	0.724	9	0.652	9	0.652
	Predictive Maintenance	2.41%	9	0.217	8	0.193	7	0.169
5. Costs & Investment	Initial Purchase Cost	1.11%	6	0.067	7	0.078	7	0.078
	Operational Cost	2.27%	8	0.182	8	0.182	7	0.159
	Return on Investment (ROI)	4.55%	8	0.364	8	0.364	7	0.319
6. Compliance & Security	Standards Compliance	1.72%	10	0.172	10	0.172	9	0.155
	Operator Safety	3.44%	10	0.344	9	0.310	9	0.310
7. Ergonomics & Health	Ergonomic Design	1.30%	9	0.117	8	0.104	7	0.091
	Health Impact	2.60%	10	0.260	9	0.234	10	0.260
8. Supply Chain & Availability	Lead Time / Delivery	1.88%	7	0.131	6	0.113	6	0.113
	Supply Chain Risk	0.94%	8	0.075	8	0.075	7	0.066
9. Environment & Sustainability	Energy Efficiency	0.61%	9	0.055	9	0.055	8	0.049
	Sustainable Production	1.22%	8	0.098	8	0.098	8	0.098
		1.0		8.8038		8.2689		8.0180

IV.4.9 Ranking Results

After adding up the weighted score of each alternative, the following results were obtained:

Table 4.18 Final results of AHP Calculation

No	Machine Category	Suitable Machine Options	Final AHP Score
1	CNC 5-Axis Multitasking	DMG Mori NTX 2000	8.4223
		Mazak Integrex i-200	8.0314
		Okuma Multus U3000	8.3982
2	Deep Hole Drilling Machine (Weapon Barrels)	Tibo T-Series	8.2208
		BTA Systems BDH-800	7.3634
		Gundrill SIG L55	7.4199
3	CNC Lathe for Barrel Profiling	Okuma LB3000 EX II	8.2935
		Doosan Puma GT2600	7.4172
		Mazak Quick Turn 250MY	8.7088
4	Automated Inspection System	Hexagon Absolute Arm 7-Axis	7.9100
		Zeiss O-Inspect 322	8.3454
		Mitutoyo Quick Vision Apex	7.9926

5	Collaborative Robot (Cobot) for Assembly	Universal Robots UR10e	8.8618
		KUKA LBR iiwa 14 R820	8.8393
		Fanuc CRX-10iA	8.7868
6	Automated Screw Assembly System	Weber Vibratory Screw Feeder	8.8748
		Janome JR3000 Series	8.7849
		Bosch Rexroth Smart Screwdriver	7.6450
7	AGV for Material Handling	MiR 250 (Mobile Industrial Robots)	8.8038
		Omron LD-250	8.2689
		KUKA KMP 600-S	8.0180
8	Automated Warehouse System (AS/RS)	Kardex Remstar Shuttle XP 500	8.9092
		SSI Schaefer LogiMat	7.9829
		Daifuku Smart Storage System	8.8255

Based on the ranking results table above, the best alternative decisions can be made for each category, which are as follows:

Machine Category	Best Alternatives
CNC 5 Axis Multi-Tasking	DMG Mori NTX 2000
Deep Hole Drilling	Tibo T-Series
CNC Turning Center	MAZAK QUICK TURN 250MY
CMM (Coordinate Measuring Machines)	Zeiss O-Inspect 322 (CNC Optical + Tactile CMM)
Collaborative Robot (Cobot)	Universal Robots UR10e
Screwdriving Automation	Weber Automatic Screwdriving System (SEV-L Series)
Autonomous Mobile Robot (AMR)	MiR250 (Mobile Industrial Robots)
Warehouse Automation / Shuttle System	SSI Schäfer Cuby Shuttle System (Germany)

IV.4.10 Sensitivity Analysis

Sensitivity analysis was performed to test the extent to which the engine alternative rating results were affected by changes in the weight of the main dimensions in the AHP structure. This process is important to assess the stability and reliability of the resulting decisions, especially in the face of uncertainty or changes in strategic priorities in the future.

The dimensions that are considered to have a major influence on investment decisions, namely "Performance & Efficiency" were tested for sensitivity in the selection of "multifunctional 5-axis CNC machines" with weight variations of ±10% and ±20%. In each scenario, the change in the weight of the tested dimension will be compensated by a proportional adjustment to the weight of the other dimensions so that the total remains 1.

Table 4.19 Sensitivity Analysis Scenario

Scenario	Performance Weight
Original Weight	27.66%
Performance +10%	30.43%
Performance -10%	24.89%
Performance +20%	33.19%
Performance -20%	22.13%

Table 4.20 Sensitivity Analysis Scenario 1 (Performance +10%)

Main Criteria	Weight	Adjusted Weight	Sub-Criteria	Weight	Final Weight	DMG Mori		Mazak Integrex		Okuma Multus	
						Score	Wighted Score	Score	Wighted Score	Score	Wighted Score
1. Performance & Efficiency	27.66%	30.43%	Production Capacity	33%	10.15%	9	0.914	8	0.812	8	0.812
			Cycle Time	14%	4.30%	8	0.344	9	0.387	8	0.344
			Precision & Consistency	52%	15.97%	9	1.437	8	1.277	9	1.437
2. Automation & Technology	25.97%	24.97%	Level of Automation	60%	14.98%	8	1.199	8	1.199	8	1.199
			IoT & AI Compatibility	20%	4.99%	8	0.400	8	0.400	9	0.450
			Industry 4.0 Adaptability	20%	4.99%	8	0.400	8	0.400	9	0.450
3. Flexibility & Scalability	15.08%	14.50%	Multi-Functionality	67%	9.67%	10	0.967	9	0.870	9	0.870
			Scalability	33%	4.83%	8	0.387	7	0.338	8	0.387
4. Reliability & Maintenance	9.65%	9.29%	Downtime & Reliability	75%	6.96%	9	0.627	9	0.627	9	0.627
			Predictive Maintenance	25%	2.32%	8	0.186	7	0.162	9	0.209
5. Costs & Investment	7.94%	7.63%	Initial Purchase Cost	14%	1.07%	6	0.064	7	0.075	7	0.075
			Operational Cost	29%	2.19%	8	0.175	7	0.153	8	0.175
			Return on Investment (ROI)	57%	4.38%	8	0.350	8	0.350	8	0.350
6. Compliance & Safety	5.16%	4.96%	Standards Compliance	33%	1.65%	10	0.165	10	0.165	10	0.165
			Operator Safety	67%	3.31%	9	0.298	9	0.298	9	0.298
7. Ergonomics & Health	3.90%	3.75%	Ergonomic Design	33%	1.25%	8	0.100	8	0.100	9	0.113
			Health Impact	67%	2.50%	8	0.200	8	0.200	9	0.225
8. Supply Chain & Availability	2.82%	2.71%	Lead Time / Delivery	67%	1.81%	6	0.108	6	0.108	6	0.108
			Supply Chain Risk	33%	0.90%	8	0.072	8	0.072	7	0.063
9. Environment & Sustainability	1.83%	1.76%	Energy Efficiency	33%	0.59%	8	0.047	7	0.041	8	0.047
			Sustainable Production	67%	1.17%		0.000		0.000		0.000
TOTAL	100.00%	100.00%			100.00%		8.4390		8.0356		8.4031

Table 4.21 Sensitivity Analysis Scenario 2 (Performance -10%)

Main Criteria	**Weight**	**Adjusted Weight**	**Sub-Criteria**	**Weight**	**Final Weight**	**DMG Mori**		**Mazak Integrex**		**Okuma Multus**	
						Score	**Wighted Score**	**Score**	**Wighted Score**	**Score**	**Wighted Score**
1. Performance & Efficiency	27.66%	24.89%	Production Capacity	33%	8.31%	9	0.748	8	0.665	8	0.665
			Cycle Time	14%	3.52%	8	0.282	9	0.317	8	0.282
			Precision & Consistency	52%	13.06%	9	1.176	8	1.045	9	1.176
2. Automation & Technology	25.97%	26.96%	Level of Automation	60%	16.18%	8	1.294	8	1.294	8	1.294
			IoT & AI Compatibility	20%	5.39%	8	0.431	8	0.431	9	0.485
			Industry 4.0 Adaptability	20%	5.39%	8	0.431	8	0.431	9	0.485
3. Flexibility & Scalability	15.08%	15.65%	Multi-Functionality	67%	10.43%	10	1.043	9	0.939	9	0.939
			Scalability	33%	5.22%	8	0.417	7	0.365	8	0.417
4. Reliability & Maintenance	9.65%	10.02%	Downtime & Reliability	75%	7.52%	9	0.677	9	0.677	9	0.677
			Predictive Maintenance	25%	2.51%	8	0.200	7	0.175	9	0.226
5. Costs & Investment	7.94%	8.24%	Initial Purchase Cost	14%	1.15%	6	0.069	7	0.081	7	0.081
			Operational Cost	29%	2.36%	8	0.189	7	0.165	8	0.189
			Return on Investment (ROI)	57%	4.73%	8	0.378	8	0.378	8	0.378
6. Compliance & Safety	5.16%	5.36%	Standards Compliance	33%	1.79%	10	0.179	10	0.179	10	0.179
			Operator Safety	67%	3.57%	9	0.322	9	0.322	9	0.322
7. Ergonomics & Health	3.90%	4.05%	Ergonomic Design	33%	1.35%	8	0.108	8	0.108	9	0.121
			Health Impact	67%	2.70%	8	0.216	8	0.216	9	0.243
8. Supply Chain & Availability	2.82%	2.92%	Lead Time / Delivery	67%	1.95%	6	0.117	6	0.117	6	0.117
			Supply Chain Risk	33%	0.97%	8	0.078	8	0.078	7	0.068
9. Environment & Sustainability	1.83%	1.90%	Energy Efficiency	33%	0.63%	8	0.051	7	0.044	8	0.051
			Sustainable Production	67%	1.27%		0.000		0.000		0.000
TOTAL	100.00%	100.00%			100.00%		8.4056		8.0271		8.3934

Table 4.22 Sensitivity Analysis Scenario 2 (Performance +20%)

Main Criteria	Weight	Adjusted Weight	Sub-Criteria	Weight	Final Weight	DMG Mori		Mazak Integrex		Okuma Multus	
						Score	Wighted Score	Score	Wighted Score	Score	Wighted Score
1. Performance & Efficiency	27.66%	33.19%	Production Capacity	33%	11.08%	9	0.997	8	0.886	8	0.886
			Cycle Time	14%	4.70%	8	0.376	9	0.423	8	0.376
			Precision & Consistency	52%	17.42%	9	1.568	8	1.393	9	1.568
2. Automation & Technology	25.97%	23.98%	Level of Automation	60%	14.39%	8	1.151	8	1.151	8	1.151
			IoT & AI Compatibility	20%	4.80%	8	0.384	8	0.384	9	0.432
			Industry 4.0 Adaptability	20%	4.80%	8	0.384	8	0.384	9	0.432
3. Flexibility & Scalability	15.08%	13.92%	Multi-Functionality	67%	9.28%	10	0.928	9	0.835	9	0.835
			Scalability	33%	4.64%	8	0.371	7	0.325	8	0.371
4. Reliability & Maintenance	9.65%	8.92%	Downtime & Reliability	75%	6.69%	9	0.602	9	0.602	9	0.602
			Predictive Maintenance	25%	2.23%	8	0.178	7	0.156	9	0.201
5. Costs & Investment	7.94%	7.33%	Initial Purchase Cost	14%	1.03%	6	0.062	7	0.072	7	0.072
			Operational Cost	29%	2.10%	8	0.168	7	0.147	8	0.168
			Return on Investment (ROI)	57%	4.20%	8	0.336	8	0.336	8	0.336
6. Compliance & Safety	5.16%	4.77%	Standards Compliance	33%	1.59%	10	0.159	10	0.159	10	0.159
			Operator Safety	67%	3.18%	9	0.286	9	0.286	9	0.286
7. Ergonomics & Health	3.90%	3.60%	Ergonomic Design	33%	1.20%	8	0.096	8	0.096	9	0.108
			Health Impact	67%	2.40%	8	0.192	8	0.192	9	0.216
8. Supply Chain & Availability	2.82%	2.60%	Lead Time / Delivery	67%	1.73%	6	0.104	6	0.104	6	0.104
			Supply Chain Risk	33%	0.87%	8	0.069	8	0.069	7	0.061
9. Environment & Sustainability	1.83%	1.69%	Energy Efficiency	33%	0.56%	8	0.045	7	0.039	8	0.045
			Sustainable Production	67%	1.13%		0.000		0.000		0.000
TOTAL	100.00%	100.00%			100.00%		8.4557		8.0398		8.4079

Table 4.23 Sensitivity Analysis Scenario 1 (Performance -20%)

Main Criteria	Weight	Adjusted Weight	Sub-Criteria	Weight	Final Weight	DMG Mori		Mazak Integrex		Okuma Multus	
						Score	Wighted Score	Score	Wighted Score	Score	Wighted Score
1. Performance & Efficiency	27.66%	22.13%	Production Capacity	33%	7.38%	9	0.665	8	0.591	8	0.591
			Cycle Time	14%	3.13%	8	0.250	9	0.282	8	0.250
			Precision & Consistency	52%	11.61%	9	1.045	8	0.929	9	1.045
2. Automation & Technology	25.97%	27.95%	Level of Automation	60%	16.77%	8	1.342	8	1.342	8	1.342
			IoT & AI Compatibility	20%	5.59%	8	0.447	8	0.447	9	0.503
			Industry 4.0 Adaptability	20%	5.59%	8	0.447	8	0.447	9	0.503
3. Flexibility & Scalability	15.08%	16.23%	Multi-Functionality	67%	10.82%	10	1.082	9	0.974	9	0.974
			Scalability	33%	5.41%	8	0.433	7	0.379	8	0.433
4. Reliability & Maintenance	9.65%	10.39%	Downtime & Reliability	75%	7.79%	9	0.701	9	0.701	9	0.701
			Predictive Maintenance	25%	2.60%	8	0.208	7	0.182	9	0.234
5. Costs & Investment	7.94%	8.54%	Initial Purchase Cost	14%	1.20%	6	0.072	7	0.084	7	0.084
			Operational Cost	29%	2.45%	8	0.196	7	0.171	8	0.196
			Return on Investment (ROI)	57%	4.90%	8	0.392	8	0.392	8	0.392
6. Compliance & Safety	5.16%	5.56%	Standards Compliance	33%	1.85%	10	0.185	10	0.185	10	0.185
			Operator Safety	67%	3.70%	9	0.333	9	0.333	9	0.333
7. Ergonomics & Health	3.90%	4.20%	Ergonomic Design	33%	1.40%	8	0.112	8	0.112	9	0.126
			Health Impact	67%	2.80%	8	0.224	8	0.224	9	0.252
8. Supply Chain & Availability	2.82%	3.03%	Lead Time / Delivery	67%	2.02%	6	0.121	6	0.121	6	0.121
			Supply Chain Risk	33%	1.01%	8	0.081	8	0.081	7	0.071
9. Environment & Sustainability	1.83%	1.97%	Energy Efficiency	33%	0.66%	8	0.053	7	0.046	8	0.053
			Sustainable Production	67%	1.31%		0.000		0.000		0.000
TOTAL	100.00%	100.00%			100.00%		8.3889		8.0229		8.3885

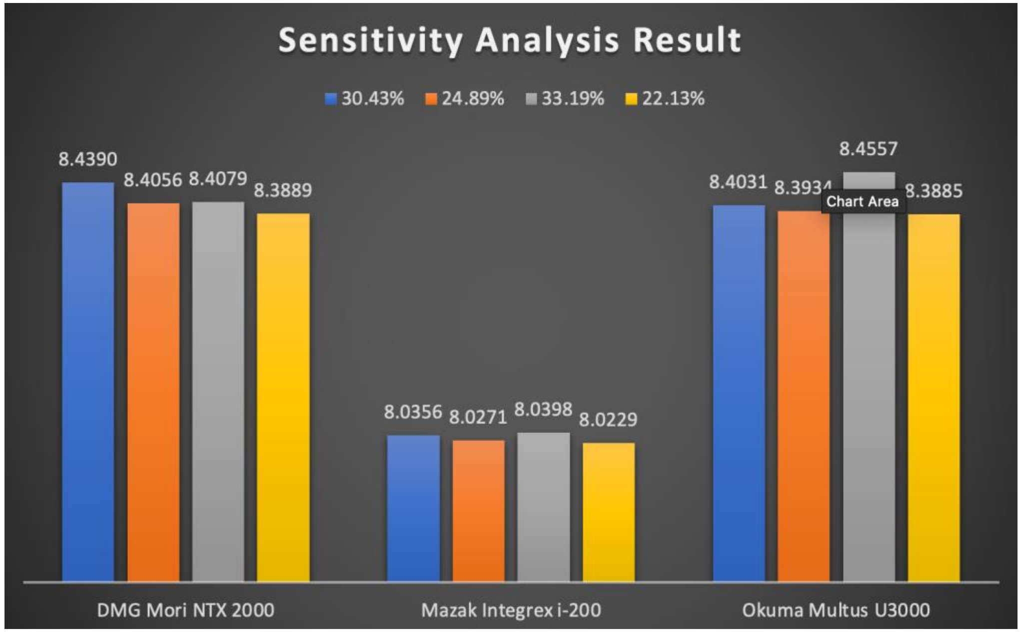


Figure 4.11 Sensitivity Analysis Results

The results show that in most scenarios, DMG Mori' remains the best alternative. However, in extreme scenarios the weight loss of "Performance & Efficiency" is 20%. This shows that decisions are fairly stable, but remain sensitive to significant changes in priorities. Thus, this sensitivity analysis strengthens the validity of the AHP results while providing insight for management in the event of a change in strategic focus in the future.

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Chapter V Conclusion and Recommendation

V.1 Conclusion

This research was initiated in response to the strategic need of PT Pindad (Persero) to modernize its Light Weapons Division through the acquisition of more advanced and reliable production machinery. The study applied the Analytic Hierarchy Process (AHP) to support a multi-criteria decision-making model in the procurement process.

Based on a thematic analysis of expert interviews and literature review, nine primary dimensions were identified: *Performance & Production Efficiency, Automation & Technological Integration, Flexibility & Scalability, Reliability & Maintainability, Cost & Investment, Compliance & Safety, Ergonomics & Health, Supply Chain & Availability,* and *Environmental & Sustainability Factors.*

The AHP method was used to determine the relative importance, with *Performance & Efficiency (27.66%)***,** *Automation & Technology (25.81%)***,** and *Cost & Investment (17.92%)* emerging as the top three priorities. Sub-criteria such as *Precision & Consistency (14.52%)* and *Level of Automation (15.58%)* also played dominant roles in influencing the decision model.

The most appropriate machine alternatives based on the evaluation criteria developed through AHP and expert judgment. Using the Weighted Sum Model (WSM), all machine alternatives across various categories were scored and ranked according to their overall performance against weighted sub-criteria.

The following table summarizes the best-performing alternatives across the eight evaluated machine categories:

Machine Category	**Best Alternatives**
CNC 5 Axis Multi-Tasking	DMG Mori NTX 2000
Deep Hole Drilling	Tibo T-Series
CNC Turning Center	MAZAK QUICK TURN 250MY
CMM (Coordinate Measuring Machines)	Zeiss O-Inspect 322 (CNC Optical + Tactile CMM)

Machine Category	Best Alternatives
Collaborative Robot (Cobot)	Universal Robots UR10e
Screwdriving Automation	Weber Automatic Screwdriving System (SEV-L Series)
Autonomous Mobile Robot (AMR)	MiR250 (Mobile Industrial Robots)
Warehouse Automation / Shuttle System	SSI Schäfer Cuby Shuttle System (Germany)

Each alternative achieved the highest composite score in its respective category, aligning with prioritized dimensions such as precision, automation compatibility, and investment return.

Additionally, sensitivity analysis was conducted by adjusting weights for dominant criteria (e.g., ±10–20% on Efficiency or Automation). The ranking of top alternatives remained stable, indicating a robust decision model and confirming the influence of AHP-derived weights on final decisions. The model thus proves reliable for strategic investment planning in advanced manufacturing technologies.

V.2 Recommendation

Based on the results of the analysis using the AHP methods, supported by insights from internal stakeholders, several recommendations can be drawn to support PT Pindad's decision-making process in machine investment.

First, machines that offer high precision and strong operational reliability should be prioritized. Given the nature of weapon production, accuracy and consistent performance are essential. Machines with efficient cycle times and minimal downtime will significantly improve production output and quality stability.

Second, PT Pindad is encouraged to consider future-oriented technologies such as predictive maintenance and IoT compatibility. These features not only support operational efficiency but also align with the company's digital transformation goals under the Industry 4.0 framework.

Third, investment decisions should move beyond focusing solely on initial purchase price and adopt a total cost of ownership (TCO) perspective. This approach provides a more comprehensive understanding of long-term return on investment and operational cost efficiency.

Fourth, involving cross-functional stakeholders in the evaluation process has proven to provide diverse and balanced perspectives. Therefore, such collaboration should be formalized as part of the company's strategic procurement practices.

Finally, the multi-criteria decision-making approach demonstrated in this study could be extended beyond machine procurement. It is recommended that PT Pindad explore its application in areas such as automation selection, facility modernization, and evaluation of strategic partnerships. This would support more objective, structured, and future-ready investment decisions.

The results of this study provide PT Pindad with a structured, quantitative foundation for making investment decisions regarding CNC machinery replacement. By applying the AHP method, the company can clearly see the prioritized alternatives based on objective criteria, which were derived from both internal needs and stakeholder input.

The final ranking of alternatives can serve as a key input in the capital budgeting process, helping management justify investment decisions in line with operational priorities. Furthermore, this framework can be replicated for future investment evaluations, thereby institutionalizing a more systematic and transparent decision-making process in the Weapons Division and potentially across other divisions of the company.

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APPENDICIES

Appendix A. Interview Results

The results of interviews with the general manager of the weapons division, production manager and engineering engineering manager in the weapons division are directly related to the development process of production facilities in the weapons division. And the result is as follows:

Informasi Responden:

1. Nama: **LMS**
2. Jabatan: **Manager Departemen Produksi Divisi Senjata**

Questions	**Answers**
BAGIAN 1 – PENGANTAR	
Bisa diceritakan posisi dan tanggung jawab Anda saat ini?	Saya bertanggung jawab atas kelancaran proses produksi di departemen produksi. Fokus saya memastikan bahwa setiap proses berjalan aman, efisien, memenuhi standar kualitas, dan sesuai target produksi. Saya juga terlibat dalam evaluasi kebutuhan peralatan produksi, termasuk pengadaan mesin baru.
Apakah Anda pernah terlibat dalam pemilihan atau penggunaan mesin sebelumnya?	Ya, saya beberapa kali terlibat dalam tim evaluasi teknis ketika perusahaan akan membeli mesin CNC baru. Biasanya saya memberi masukan dari sisi kapasitas produksi dan kemudahan operasional.
BAGIAN 2 – PENILAIAN KRITERIA	
Performance & Efficiency	
Seberapa penting kapasitas produksi saat memilih mesin CNC? (Skala 1–10)	Saya beri nilai 9. Kapasitas produksi adalah inti dari pekerjaan di departemen kami. Kalau mesin tidak mampu memenuhi volume produksi, akan langsung berdampak pada keterlambatan produksi.
Seberapa besar pengaruh cycle time terhadap efisiensi?	Sangat besar. Cycle time menentukan seberapa cepat kita bisa menyelesaikan satu lot. Kalau terlalu lama, kita bisa kehilangan waktu dan potensi produksi.
Seberapa penting presisi dan konsistensi dalam produksi Anda?	Saya beri nilai 10. Presisi mutlak, terutama untuk komponen senjata. Toleransi kesalahan sangat kecil karena komponen senjata dituntut untuk mampu tukar dan memiliki akurasi yang baik.
Automation & Technology	
Apa peran otomatisasi dalam mesin CNC menurut Anda?	Otomatisasi sangat membantu mengurangi kesalahan yang berasal dari operator mesin dan meningkatkan kecepatan kerja.

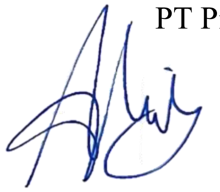
Apakah IoT dan AI menjadi pertimbangan penting?	Saya masih belajar mengenai ini, tapi jika bisa memberi notifikasi kondisi mesin secara otomatis, tentu sangat membantu.
Bagaimana kesiapan mesin terhadap sistem Industri 4.0 memengaruhi keputusan Anda?	Kalau mesinnya sudah siap untuk integrasi sistem, jelas jadi nilai plus.
Flexibility & Scalability	
Apakah fitur multi-fungsi seperti turning & milling penting?	Sangat penting. Mesin multi-fungsi mengurangi kebutuhan pindah proses dan menghemat waktu setup.
Seberapa penting skalabilitas dalam produksi yang berubah-ubah?	Produksi di sini sering fluktuatif, jadi mesin harus fleksibel untuk menangani variasi lot tanpa perlu banyak konfigurasi ulang.
Reliability & Maintenance	
Seberapa berdampak downtime terhadap proses produksi?	Downtime adalah hal buruk dalam produksi. Kalau satu mesin mati, bisa berpengaruh ke seluruh alur produksi.
Apakah predictive maintenance menjadi fitur penting?	Sangat membantu. Kami tidak perlu menunggu mesin rusak baru bertindak.
Cost & Investment	
Mana yang lebih prioritas: harga awal atau biaya operasional jangka panjang?	Kalau dari sisi operasional, biaya jangka panjang jauh lebih penting. Mesin murah tapi sering rusak justru menyulitkan kami.
Berapa lama ROI yang dianggap ideal menurut Anda?	Kalau ROI bisa dicapai dalam 3 sampai 5 tahun, saya anggap itu sudah sangat baik.
Compliance & Safety	
Seberapa penting sertifikasi seperti ISO atau CE?	Sertifikasi seperti ISO dan CE penting untuk memastikan mesin sudah sesuai standar. Ini juga mempermudah saat audit dan dokumentasi produksi.
Bagaimana perusahaan memprioritaskan keselamatan operator?	Keselamatan operator adalah prioritas kami. Mesin harus memiliki fitur yang mengurangi resiko kecelakaan kerja, sensor darurat, dan mudah dioperasikan.
Ergonomics & Health	
Seberapa besar pengaruh desain ergonomis terhadap kenyamanan operator?	Desain ergonomis tentunya dapat membantu operator dalam bekerja lebih lama tanpa kelelahan. Apalagi kalau harus mengoperasikan mesin selama berjam-jam.
Bagaimana dampak mesin terhadap kesehatan pekerja dinilai?	Mesin dengan getaran tinggi atau kebisingan ekstrem bisa menyebabkan kelelahan dan masalah kesehatan jangka panjang. Jadi ini harus jadi perhatian sejak awal.
Supply Chain & Availability	

Seberapa penting lead time (waktu pengadaan mesin)?	Lead time sangat penting karena berpengaruh ke rencana produksi. Semakin cepat mesin datang, semakin cepat kami bisa setup mesin dan mulai produksi.
Apakah risiko supply chain menjadi pertimbangan utama?	Kalau suku cadang sulit didapat, produksi bisa terhenti lama. Itu jadi masalah besar di lapangan.
Environmental & Sustainability	
Seberapa besar pengaruh efisiensi energi terhadap keputusan investasi?	Efisiensi energi bisa menghemat biaya listrik harian, apalagi mesin beroperasi terus-menerus. Itu pasti jadi nilai tambah.
Apakah keberlanjutan menjadi faktor penting di perusahaan Anda?	Ya, meskipun belum jadi prioritas utama, kami mulai diarahkan untuk memperhatikan dampak lingkungan.
BAGIAN 3 – PENUTUP	
Apakah ada hal lain yang ingin Anda tambahkan terkait pertimbangan pemilihan mesin CNC?	Saya berharap proses pemilihan mesin mempertimbangkan kondisi lapangan secara nyata. Kadang di atas kertas kelihatan bagus, tapi ketika digunakan, justru sulit dioperasikan atau perawatannya rumit. Yang terpenting adalah mesin tersebut benar-benar mendukung kelancaran produksi sehari-hari.

Pernyataan: bahwa dokumen di atas benar-benar merupakan ringkasan dari hasil wawancara yang dilakukan oleh peneliti terhadap saya, dan saya memberikan izin untuk dipublikasikan.

Manager Departemen Produksi Divisi Senjata

PT Pindad



LMS

Informasi Responden:

1. Nama: **HRY**
2. Jabatan: **Manager Departemen Rekayasa Teknik Divisi Senjata**

Questions	**Answers**
BAGIAN 1 – PENGANTAR	
Bisa diceritakan posisi dan tanggung jawab Anda saat ini?	Saya memimpin tim teknik yang merancang proses manufaktur dan memilih teknologi yang tepat untuk mendukung inovasi produksi. Salah satu tanggung jawab utama saya adalah mengevaluasi spesifikasi teknis dari mesin-mesin yang akan digunakan.

Apakah Anda pernah terlibat dalam pemilihan atau penggunaan mesin sebelumnya?	Saya sangat sering terlibat, terutama dalam tahap evaluasi teknis spesifikasi mesin. Saya juga berinteraksi langsung dengan vendor untuk memastikan bahwa mesin yang kami pilih dapat diintegrasikan ke sistem yang ada.
BAGIAN 2 – PENILAIAN KRITERIA	
Performance & Efficiency	
Seberapa penting kapasitas produksi saat memilih mesin CNC? (Skala 1–10)	Saya beri nilai 8. Kapasitas penting, tapi harus seimbang dengan aspek teknis lain seperti presisi dan fleksibel.
Seberapa besar pengaruh cycle time terhadap efisiensi?	Cycle time adalah indikator langsung dari efisiensi proses. Kami biasanya memperhitungkan waktu siklus sebagai bagian utama dari analisis produktivitas.
Seberapa penting presisi dan konsistensi dalam produksi Anda?	Presisi dan konsistensi adalah fondasi kualitas. Saya pribadi tidak akan merekomendasikan mesin tanpa data presisi yang jelas.
Automation & Technology	
Apa peran otomatisasi dalam mesin CNC menurut Anda?	Saya lihat otomatisasi juga membantu dalam menjaga kualitas konsisten. Apalagi untuk proses berulang.
Apakah IoT dan AI menjadi pertimbangan penting?	Penting, terutama untuk preventive dan predictive maintenance. Dengan IoT, kita bisa pantau data real-time.
Bagaimana kesiapan mesin terhadap sistem Industri 4.0 memengaruhi keputusan Anda?	Saya anggap itu wajib. Mesin yang tidak compatible akan menambah biaya integrasi.
Flexibility & Scalability	
Apakah fitur multi-fungsi seperti turning & milling penting?	Itu jadi salah satu pertimbangan utama dari sisi teknik. Mesin yang bisa melakukan lebih dari satu proses sangat efisien dalam hal footprint dan logistik produksi.
Seberapa penting skalabilitas dalam produksi yang berubah-ubah?	Skalabilitas penting untuk mengantisipasi lonjakan permintaan. Mesin harus bisa bekerja dalam berbagai kapasitas.
Reliability & Maintenance	
Seberapa berdampak downtime terhadap proses produksi?	Kami mengukur OEE, dan downtime langsung menurunkan nilai efisiensi keseluruhan.
Apakah predictive maintenance menjadi fitur penting?	Fitur ini sangat relevan. Dengan data dari sensor, kami bisa prediksi komponen mana yang akan rusak dan kapan harus diganti.
Cost & Investment	
Mana yang lebih prioritas: harga awal atau biaya operasional jangka panjang?	Saya selalu mendorong tim untuk tidak hanya melihat harga awal. Terkadang mesin dengan harga lebih tinggi justru lebih hemat karena hemat energi dan jarang rusak.
Berapa lama ROI yang dianggap ideal menurut Anda?	Idealnya tidak lebih dari 5 tahun. Tapi untuk mesin yang sangat strategis, sampai 7 tahun pun masih wajar selama kontribusinya besar.

Compliance & Safety	
Seberapa penting sertifikasi seperti ISO atau CE?	Saya tidak akan menyetujui pembelian mesin tanpa sertifikasi dasar seperti CE. Itu menjadi jaminan bahwa desain dan fungsionalitasnya sesuai standar keselamatan.
Bagaimana perusahaan memprioritaskan keselamatan operator?	Kami ikut serta sejak proses desain ulang tata letak untuk memastikan area kerja aman dan ergonomis.
Ergonomics & Health	
Seberapa besar pengaruh desain ergonomis terhadap kenyamanan operator?	Mesin yang tidak ergonomis sering kali memicu kesalahan manusia. Kita tidak bisa abaikan desain antarmuka dan posisi pengoperasian.
Bagaimana dampak mesin terhadap kesehatan pekerja dinilai?	Kami selalu evaluasi dari sisi getaran, suara, dan potensi bahaya debu atau partikel logam. Itu semua bisa diminimalkan dengan fitur yang baik.
Supply Chain & Availability	
Seberapa penting lead time (waktu pengadaan mesin)?	Kami sering dihadapkan pada proyek dengan tenggat ketat, jadi lead time menjadi salah satu parameter utama saat evaluasi vendor.
Apakah risiko supply chain menjadi pertimbangan utama?	Kami melihat ketersediaan suku cadang dan layanan teknisi lokal sebagai syarat mutlak. Risiko supply chain harus dimitigasi sejak awal.
Environmental & Sustainability	
Seberapa besar pengaruh efisiensi energi terhadap keputusan investasi?	Kami mulai melihat konsumsi energi sebagai faktor evaluasi teknis. Semakin hemat, semakin baik untuk jangka panjang.
Apakah keberlanjutan menjadi faktor penting di perusahaan Anda?	Keberlanjutan tidak hanya soal lingkungan, tapi juga efisiensi jangka panjang. Kami sedang bergerak ke arah sana.
BAGIAN 3 – PENUTUP	
Apakah ada hal lain yang ingin Anda tambahkan terkait pertimbangan pemilihan mesin CNC?	Saya menekankan pentingnya mengintegrasikan teknologi masa depan, seperti IoT dan predictive maintenance. Mesin yang kita beli sekarang harus relevan dan siap digunakan untuk 10–15 tahun ke depan. Selain itu, pelatihan operator juga harus jadi bagian dari proses investasi.

Pernyataan: bahwa dokumen di atas benar-benar merupakan ringkasan dari hasil wawancara yang dilakukan oleh peneliti terhadap saya, dan saya memberikan izin untuk dipublikasikan.

Manager Departemen Produksi Divisi Senjata

PT Pindad

Informasi Responden:

1. Nama: **AFS**
2. Jabatan: **General Manager Divisi Senjata**

iQuestions	Answers
BAGIAN 1 – PENGANTAR	
Bisa diceritakan posisi dan tanggung jawab Anda saat ini?	Sebagai General Manager, saya bertanggung jawab secara strategis atas keseluruhan pengelolaan divisi senjata, termasuk produksi, pengembangan, dan investasi teknologi. Saya berperan dalam pengambilan keputusan besar, termasuk investasi mesin dan arah modernisasi lini produksi.
Apakah Anda pernah terlibat dalam pemilihan atau penggunaan mesin sebelumnya?	Saya lebih banyak terlibat dalam tahap akhir pengambilan keputusan, terutama dalam mengevaluasi dampak investasi terhadap strategi bisnis jangka panjang. Tapi saya juga mengikuti perkembangan dari awal untuk memastikan keselarasan antara kebutuhan operasional dan arah perusahaan.
BAGIAN 2 – PENILAIAN KRITERIA	
Performance & Efficiency	
Seberapa penting kapasitas produksi saat memilih mesin CNC? (Skala 1–10)	Saya beri nilai 9. Mesin dengan kapasitas besar akan mendukung target produksi jangka panjang perusahaan.
Seberapa besar pengaruh cycle time terhadap efisiensi?	Dari sudut pandang manajemen, cycle time berdampak langsung pada biaya dan kapasitas. Jadi kami anggap itu faktor krusial.
Seberapa penting presisi dan konsistensi dalam produksi Anda?	Produk pertahanan menuntut akurasi tinggi. Konsistensi sangat menentukan tingkat cacat dan penerimaan produk.
Automation & Technology	
Apa peran otomatisasi dalam mesin CNC menurut Anda?	Investasi ke mesin otomatis juga merupakan investasi ke efisiensi jangka panjang. Kita bisa mengurangi ketergantungan pada tenaga kerja manual.
Apakah IoT dan AI menjadi pertimbangan penting?	Dalam arah strategis kami ke industri 4.0, integrasi IoT dan AI sangat diperhitungkan.
Bagaimana kesiapan mesin terhadap sistem Industri 4.0 memengaruhi keputusan Anda?	Saya melihatnya sebagai bagian dari transformasi digital yang kami kejar. Mesin yang tidak siap akan menjadi beban di masa depan.
Flexibility & Scalability	

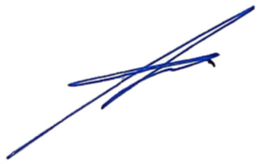
Apakah fitur multi-fungsi seperti turning & milling penting?	Saya melihat fitur multi-fungsi sebagai cara mengurangi bottleneck dan mempercepat throughput. Itu juga menghemat investasi jangka panjang.
Seberapa penting skalabilitas dalam produksi yang berubah-ubah?	Kami merancang investasi berdasarkan pertumbuhan jangka menengah. Mesin yang scalable sangat kami pertimbangkan.
Reliability & Maintenance	
Seberapa berdampak downtime terhadap proses produksi?	Dari sisi bisnis, downtime berarti potensi keterlambatan pengiriman dan penalti. Ini sangat kami hindari.
Apakah predictive maintenance menjadi fitur penting?	Ini menjadi bagian dari transformasi digital yang kami dorong. Mesin modern harus mampu berbicara dengan sistem manajemen.
Cost & Investment	
Mana yang lebih prioritas: harga awal atau biaya operasional jangka panjang?	Dari sisi manajemen, kami mengutamakan total cost of ownership. Harga awal penting, tapi efisiensi operasional dan ROI yang berkelanjutan jadi penentu utama.
Berapa lama ROI yang dianggap ideal menurut Anda?	Kami targetkan ROI dalam rentang 4–6 tahun, tergantung nilai investasi dan dampaknya terhadap peningkatan kapasitas serta daya saing.
Compliance & Safety	
Seberapa penting sertifikasi seperti ISO atau CE?	Dari sisi kebijakan perusahaan, kami memang mensyaratkan sertifikasi sebagai bagian dari proses seleksi vendor.
Bagaimana perusahaan memprioritaskan keselamatan operator?	PT Pindad berkomitmen terhadap K3, dan setiap pengadaan peralatan baru harus memenuhi aspek safety sebagai syarat mutlak.
Ergonomics & Health	
Seberapa besar pengaruh desain ergonomis terhadap kenyamanan operator?	Dari perspektif manajemen, produktivitas operator akan lebih baik kalau mereka bekerja dengan nyaman dan aman. Ergonomi adalah investasi dalam SDM juga.
Bagaimana dampak mesin terhadap kesehatan pekerja dinilai?	Kesehatan pekerja berdampak langsung pada kehadiran dan produktivitas. Mesin modern harus mendukung lingkungan kerja yang sehat.
Supply Chain & Availability	
Seberapa penting lead time (waktu pengadaan mesin)?	Dari sisi strategis, lead time yang terlalu panjang bisa menghambat target investasi tahunan dan jadwal pengadaan pemerintah.
Apakah risiko supply chain menjadi pertimbangan utama?	Dalam konteks pertahanan, kami tidak bisa tergantung pada pasokan luar negeri yang tidak stabil. Supply chain adalah isu strategis.
Environmental & Sustainability	

Seberapa besar pengaruh efisiensi energi terhadap keputusan investasi?	Kami juga ingin selaras dengan agenda keberlanjutan nasional. Mesin yang lebih hemat energi otomatis masuk prioritas.
Apakah keberlanjutan menjadi faktor penting di perusahaan Anda?	Sustainability adalah bagian dari roadmap perusahaan menuju industri hijau. Mesin-mesin baru harus mendukung itu.
BAGIAN 3 – PENUTUP	
Apakah ada hal lain yang ingin Anda tambahkan terkait pertimbangan pemilihan mesin CNC?	Keputusan investasi ini bukan hanya soal membeli mesin, tapi tentang membangun fondasi sistem produksi yang lebih kompetitif. Kita harus melihat dari berbagai aspek: teknis, operasional, finansial, dan strategis. Mesin yang dipilih harus mempercepat transformasi PT Pindad menuju industri manufaktur yang modern dan berdaya saing global.

Pernyataan: bahwa dokumen di atas benar-benar merupakan ringkasan dari hasil wawancara yang dilakukan oleh peneliti terhadap saya, dan saya memberikan izin untuk dipublikasikan.

General Manager Divisi Senjata

PT Pindad



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Appendix B. Pairwise Comparison of Main Criteria

Main Criteria	Pairwise Numerical Rating 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Main Criteria
Performance & Efficiency	9 8 7 6 5 4 3 2 **1** 2 3 4 5 6 7 8 9	Automation & Technology
Performance & Efficiency	9 8 7 6 5 4 **3** 2 1 2 3 4 5 6 7 8 9	Flexibility & Scalability
Performance & Efficiency	9 8 7 6 **5** 4 3 2 1 2 3 4 5 6 7 8 9	Reliability & Maintenance
Performance & Efficiency	9 8 7 6 **5** 4 3 2 1 2 3 4 5 6 7 8 9	Costs & Investment
Performance & Efficiency	9 8 **7** 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Compliance & Security
Performance & Efficiency	9 8 **7** 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Ergonomics & Health
Performance & Efficiency	9 8 **7** 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Supply Chain & Availability
Performance & Efficiency	**9** 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Environment & Sustainability
Automation & Technology	9 8 7 6 5 4 **3** 2 1 2 3 4 5 6 7 8 9	Flexibility & Scalability
Automation & Technology	9 8 7 6 **5** 4 3 2 1 2 3 4 5 6 7 8 9	Reliability & Maintenance
Automation & Technology	9 8 7 6 **5** 4 3 2 1 2 3 4 5 6 7 8 9	Costs & Investment
Automation & Technology	9 8 7 6 **5** 4 3 2 1 2 3 4 5 6 7 8 9	Compliance & Security
Automation & Technology	9 8 7 6 **5** 4 3 2 1 2 3 4 5 6 7 8 9	Ergonomics & Health
Automation & Technology	9 8 **7** 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Supply Chain & Availability
Automation & Technology	**9** 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Environment & Sustainability
Flexibility & Scalability	9 8 7 6 5 4 **3** 2 1 2 3 4 5 6 7 8 9	Reliability & Maintenance
Flexibility & Scalability	9 8 7 6 5 4 **3** 2 1 2 3 4 5 6 7 8 9	Costs & Investment
Flexibility & Scalability	9 8 7 6 **5** 4 3 2 1 2 3 4 5 6 7 8 9	Compliance & Security
Flexibility & Scalability	9 8 7 6 **5** 4 3 2 1 2 3 4 5 6 7 8 9	Ergonomics & Health
Flexibility & Scalability	9 8 7 6 **5** 4 3 2 1 2 3 4 5 6 7 8 9	Supply Chain & Availability
Flexibility & Scalability	9 8 **7** 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Environment & Sustainability
Reliability & Maintenance	9 8 7 6 5 4 **3** 2 1 2 3 4 5 6 7 8 9	Costs & Investment
Reliability & Maintenance	9 8 7 6 5 4 **3** 2 1 2 3 4 5 6 7 8 9	Compliance & Security
Reliability & Maintenance	9 8 7 6 5 4 **3** 2 1 2 3 4 5 6 7 8 9	Ergonomics & Health
Reliability & Maintenance	9 8 7 6 **5** 4 3 2 1 2 3 4 5 6 7 8 9	Supply Chain & Availability
Reliability & Maintenance	9 8 7 6 **5** 4 3 2 1 2 3 4 5 6 7 8 9	Environment & Sustainability
Costs & Investment	9 8 7 6 5 4 **3** 2 1 2 3 4 5 6 7 8 9	Compliance & Security
Costs & Investment	9 8 7 6 5 4 **3** 2 1 2 3 4 5 6 7 8 9	Ergonomics & Health
Costs & Investment	9 8 7 6 **5** 4 3 2 1 2 3 4 5 6 7 8 9	Supply Chain & Availability
Costs & Investment	9 8 7 6 **5** 4 3 2 1 2 3 4 5 6 7 8 9	Environment & Sustainability
Compliance & Security	9 8 7 6 5 4 **3** 2 1 2 3 4 5 6 7 8 9	Ergonomics & Health
Compliance & Security	9 8 7 6 5 4 **3** 2 1 2 3 4 5 6 7 8 9	Supply Chain & Availability
Compliance & Security	9 8 7 6 5 4 **3** 2 1 2 3 4 5 6 7 8 9	Environment & Sustainability
Ergonomics & Health	9 8 7 6 5 4 **3** 2 1 2 3 4 5 6 7 8 9	Supply Chain & Availability
Ergonomics & Health	9 8 7 6 5 4 **3** 2 1 2 3 4 5 6 7 8 9	Environment & Sustainability
Supply Chain & Availability	9 8 7 6 5 4 **3** 2 1 2 3 4 5 6 7 8 9	Environment & Sustainability

Performance & Production Efficiency

Sub Criteria	Pairwise Numerical Rating 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Sub Criteria
Production Capacity	9 8 7 6 5 4 **3** 2 1 2 3 4 5 6 7 8 9	Cycle Time
Production Capacity	9 8 7 6 5 4 3 2 1 **2** 3 4 5 6 7 8 9	Precision & Consistency
Cycle Time	9 8 7 6 5 4 3 2 1 2 **3** 4 5 6 7 8 9	Precision & Consistency

Automation & Technological Integration

Sub Criteria	Pairwise Numerical Rating 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Sub Criteria
Level of Automation	9 8 7 6 5 4 **3** 2 1 2 3 4 5 6 7 8 9	IoT & AI Compatibility
Level of Automation	9 8 7 6 5 4 **3** 2 1 2 3 4 5 6 7 8 9	Industry 4.0 Adaptability
IoT & AI Compatibility	9 8 7 6 5 4 3 2 **1** 2 3 4 5 6 7 8 9	Industry 4.0 Adaptability

Flexibility & Scalability

Sub Criteria	Pairwise Numerical Rating 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Sub Criteria
Multi-Functionality	9 8 7 6 5 4 3 **2** 1 2 3 4 5 6 7 8 9	Scalability

Reliability & Maintenance

Sub Criteria	Pairwise Numerical Rating 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Sub Criteria
Downtime & Reliability	9 8 7 6 5 4 **3** 2 1 2 3 4 5 6 7 8 9	Predictive Maintenance

Cost & Investment Considerations

Sub Criteria	Pairwise Numerical Rating 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Sub Criteria
Initial Purchase Cost	9 8 7 6 5 4 3 2 1 2 **3** 4 5 6 7 8 9	Operational Cost
Initial Purchase Cost	9 8 7 6 5 4 3 2 1 2 **3** 4 5 6 7 8 9	Return on Investment (ROI)
Operational Cost	9 8 7 6 5 4 3 2 1 2 **3** 4 5 6 7 8 9	Return on Investment (ROI)

Regulatory Compliance & Safety Standards

Sub Criteria	Pairwise Numerical Rating 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Sub Criteria
Standards Compliance	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Operator Safety

Ergonomics & Operator Health

Sub Criteria	Pairwise Numerical Rating 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Sub Criteria
Ergonomic Design	9 8 7 6 5 4 3 2 1 **2** 3 4 5 6 7 8 9	Health Impact

Supply Chain & Availability

Sub Criteria	Pairwise Numerical Rating 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Sub Criteria
Lead Time / Delivery	9 8 7 6 5 4 3 **2** 1 2 3 4 5 6 7 8 9	Supply Chain Risk

Environmental Impact & Sustainability

Sub Criteria	Pairwise Numerical Rating 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Sub Criteria
Energy Efficiency	9 8 7 6 5 4 3 2 1 **2** 3 4 5 6 7 8 9	Sustainable Production

Appendix C. Hierarchy AHP