

# Innovative Advanced Material Solutions for Integrated Safety Helmets in Mining

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**Keywords:** Mining, Personal Protective Equipment, Safety Helmet, Visor, Earplug, Innovative Design, FMEA, Occupational Safety, SDGs.

**Abstract.** This research focuses on the development of a 3-in-1 personal protective equipment (PPE) design, which includes a safety helmet, visor, and earplugs, specifically aimed at mining applications. The objective of this study is to identify and address unique safety risks in mining environments, such as impact hazards, high noise levels, and particle exposure. The research methodology involves ergonomic dan analysis HIRADC (Hazard Identification, Risk Assessment, and Determining Control) to identify potential failures and risks in the design. Additionally, field surveys and interviews with stakeholders, including miners and safety experts, were conducted to understand the needs and challenges faced on-site. The results yield a 3-in-1 PPE design that integrates safety, functionality, and comfort, focusing on comprehensive impact protection, incorporating a scratch-resistant visor and adjustable earplugs. Performance evaluation was carried out through simulation testing and field prototypes. Overall, this design development aims to enhance the effectiveness of worker protection in mining environments while considering ergonomic aspects for user comfort. Furthermore, this research contributes positively to the innovation of PPE in the mining sector, aligning with Sustainable Development Goals (SDGs) related to industry, innovation, and infrastructure (SDG 9), by creating more efficient and safe solutions to protect workers from potential risks in high-risk workplaces.

## Introduction

The use of Personal Protective Equipment (PPE) is mandatory for all operators in the mining area as a preventive measure against accidents. PPE is divided into two categories: Mandatory PPE, which includes hard hats and safety shoes to protect against common hazards, and Optimal PPE, which encompasses additional equipment such as dust masks, goggles, and Full Body Harnesses for specific hazardous situations. The innovative design of the Safety Helmet contributes to Sustainable Development Goal 9 by enhancing user protection and comfort, as well as supporting the development of sustainable industry and infrastructure.

## Literature References

### Anthropometry

An anthropometer is an application of ergonomic principles in measuring human body dimensions, which is essential for determining product sizes such as helmets. Considering the anthropometric differences among ethnic groups in Indonesia, this study focuses on adults from Aceh, who have a high rate of motorcycle accidents and head injuries, in order to adjust helmet sizes for more frequent use and to reduce the risk of fatal injuries. Ergonomics prioritizes products, services, and work systems that are more human-centered, adapting to the dynamic needs of individuals. A lack of attention to ergonomics can lead to work-related injuries, decreased productivity, and product failures. Anthropometer aids in tailoring product designs to human body characteristics, enhancing

productivity, and reducing musculoskeletal disorders. In helmet design, safety is a primary factor. The strength of a helmet is influenced by the materials used, while its shape plays a role in both strength and aesthetics. Paying attention to accurate dimensions enhances comfort and the overall design of the helmet.

### HSE (Health and Safety)

Some mining locations experience inconsistencies in air temperature, leading to issues in the coal industry, such as the persistent detection of coal dust and methane gas due to suboptimal ventilation systems. Coal dust contains chemicals that can cause respiratory disturbances, influenced by various factors such as respiratory mechanisms, anatomy, breath physics, immunological responses, and the physical and chemical characteristics of the dust. Occupational health and safety (OHS) is a top priority, and companies continue to strive to ensure ethical measures that support worker health (Aisah Amini & Susilawati, 2023).

### SDG

Goal 9 aims to build resilient infrastructure, support sustainable industrialization, and promote innovation. Economic and social growth, as well as climate change mitigation, depend on investment in infrastructure and technology. The COVID-19 pandemic exacerbated the decline of the global manufacturing sector, which had previously been triggered by tariffs and trade tensions, leading to inflation, rising energy prices, and supply chain disruptions. Less developed countries in Asia have shown progress, while efforts in Africa need to be accelerated to achieve the 2030 targets. Enhancing research and industrial technological capabilities in developing countries through increased R&D workforce and funding is essential by 2030.

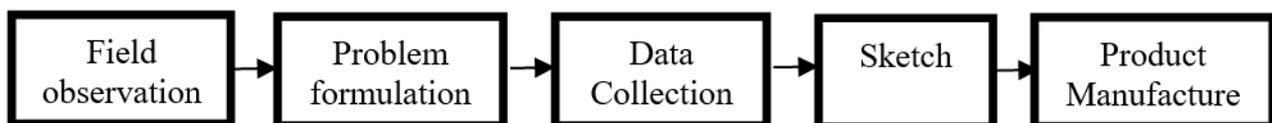
### Material Science

Industrial safety helmets protect the head from falling objects by absorbing mechanical energy. The number of brain injuries among construction workers increases each year; however, wearing the appropriate helmet can significantly reduce this risk. Current helmets are often insufficiently strong due to material packaging issues and pressure distribution. This study aims to enhance helmet stiffness through design modifications using finite element analysis in ABAQUS. Natural fibers and ABS are recommended as helmet materials. The helmet is modeled in CATIA V5 and analyzed using ABAQUS. The analysis results indicate that the redesigned helmet is stiffer compared to conventional helmets (Cavas-Martínez et al., n.d.).

### Methodology Design

#### Flowchart

To achieve the objectives outlined in the introduction, the stages of the system design/methodology utilized can be described as follows:



**Fig. 1.** Flowchart.

- **Field Observation:** In this step, field observations were conducted at one of the mining companies in Indonesia to identify intensive activities around the mining area. The author noted the safety measures in place, including the use of helmets, eye protection, and gloves by the workers.
- **Problem Formulation:** Identifying the issues and articulating them into key points.
- **Data Collection:** Data collection was carried out through a field survey and semi-structured interviews. A purposive sampling technique was employed to ensure that the respondents had

direct experience with mining operations and safety practices. A total of 30 miners and 5 occupational safety experts were selected as participants. The questionnaire consisted of both closed-ended and open-ended questions, aimed at assessing PPE usage, ergonomic comfort, and compliance. Interview data was used to validate and enrich the survey findings. The survey responses were analyzed using descriptive statistical methods (frequency distribution and percentage), while qualitative interview data were examined through thematic coding to identify recurring safety concerns and design requirements.

- **Product Sketch Ideas:** At this stage, the author will create rough sketches of the product as a basis for 3D modeling. During this phase, the author will also refine the sketches, clarifying and illustrating the product details.
- **Product Manufacturing:** The product manufacturing stage begins with determining ergonomic dimensions, where designers consider the size and shape of the product to meet user needs and comfort. Subsequently, 3D rendering modeling processes are utilized to create realistic digital visual representations of the product, allowing designers and manufacturers to visualize and evaluate the design more accurately before producing a physical prototype. In addition to 3D rendering and mechanical testing, simulation-based analysis was conducted to evaluate the structural integrity and ergonomic performance of the proposed helmet design. Finite Element Method (FEM) simulations were employed to assess stress distribution, impact resistance, and potential weak points under mining-related conditions. Furthermore, digital human modeling was utilized to examine ergonomic fit and comfort, ensuring that the helmet design accommodates diverse anthropometric profiles of Indonesian workers. These simulation steps complement physical validation by providing predictive insights into safety performance prior to prototype manufacturing. Finally, another critical stage involves reviewing the potential hazards associated with the product, including the risk of injuries or other dangers that may arise from its use.

These steps help ensure that the produced product is safe to use and complies with the established quality standards.

## Results and Discussion

### Material Science

The selection of materials for the safety helmet is based on commonly used materials according to the ANSI/ISE Z89.1-2014 standard, Type I, Class G and E. Helmets can be made from various materials, ranging from simple to composite options, such as polymers, plastics, fiberglass, or metals. The design includes a robust outer shell and an internal suspension system to absorb impacts. Examples include single-material injection, such as High-Density Polyethylene (HDPE) and ABS, or composite materials like expanded polystyrene shells with Polycarbonate (PC) sheets bonded within molds.

### Material(s)

Name	Polyethylene, High Density	
General	Mass Density	0,952 q/cm <sup>3</sup>
	Yield Strength	20,67 MPa
	Ultimate Tensile Strength	13,78 MPa
Stress	Young's Modulus	0,911 GPa
	Poisson's Ratio	0,392 ul
	Shear Modulus	0,327227 GPa
Part Name(s)	HELME 3.1.ipt	

Fig. 2. Material (S).

### HDPE (High Density Polyethylene)

High-Density Polyethylene (HDPE) is a polymer chain derived from ethylene or petroleum through a catalytic process. The selection of HDPE over other materials is due to its ease of molding and joining, as well as its superior tensile strength compared to Acrylonitrile Butadiene Styrene (ABS). HDPE is resistant to solvents and has a high density-to-strength ratio, making it an ideal plastic for reusable and recyclable materials.

The use of HDPE material will be employed in the shell of the safety helmet. This serves the following purposes:

1. Comfort

HDPE is commonly used in safety helmet materials. This is due to its lightweight nature, making it more comfortable for prolonged use. This can be an important factor in work environments that require helmet usage throughout the day.

2. Chemical Resistance

HDPE has good chemical resistance properties due to its densely packed molecular structure. As a result, HDPE tends to be less reactive to various types of chemicals.

3. Extreme Temperatures

HDPE exhibits good tolerance to extreme temperatures, both high and low. This makes it suitable for use in work environments with varying temperature conditions.

4. Energy Absorption

HDPE has excellent energy absorption properties, meaning that upon impact or collision, this material can absorb a significant portion of the energy, reducing the impact felt by the user's head.

5. Electrical Insulation

HDPE has good electrical insulation properties, which can protect users from electrical hazards in the workplace or relevant environments.

### 3D Model Design

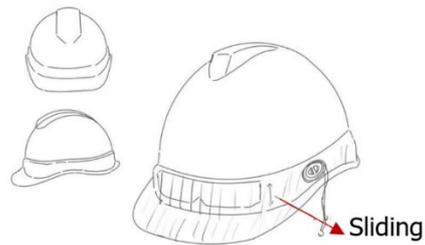
The authors utilize Quality Function Deployment (QFD) to help identify and translate customer needs for miners into clear and measurable technical specifications. Below is the QFD that has been created

**Table 1.** Tabel QFD to identify and translate customer needs for miners.

Quality Function Deployment													
Project title: Safety Helmet 3 in 1							Correlation:						
Project leader:	Date:						<table border="1"> <tr> <td>+</td> <td>.</td> <td>-</td> <td></td> </tr> <tr> <td>Positive</td> <td>No correlation</td> <td>Negative</td> <td></td> </tr> </table>				+	.	-
+	.	-											
Positive	No correlation	Negative											
Desired direction of improvement (↑, 0, ↓)		Functional Requirements (How's)					Relationships:						
Customer Requirements - (What's)		Helmet protection	Noise reduction	Eye protection	Comfort and fit	Integration and Compactability	Competitive evaluation (1: low, 5: high)						
Customer importance rating						Weighted Score	3M	MSA	CAT				
1	5	Safety protection head	9	0	0	1	0	50	5	5	5		
2	4	Reduce noises	0	9	0	1	0	40	1	1	1		
3	4	Clear Visibility	0	0	9	1	0	40	1	5	5		
4	5	Comfortable to wear	1	1	1	9	0	60	4	4	4		
5	5	Adjustability	0	0	0	3	9	60	5	5	5		
6	5	Efficiency	0	0	0	0	9	45	1	4	3		
Technical importance score		50	41	41	73	90	295						
importance %		17%	14%	14%	25%	31%	100%						
Priorities rank		3	4	4	2	1							
Current performance		0	0	0	0	0							
Target		Safety protection	Noise canceller	Eye protector	Comfortable	Compact							
Benchmark		C1:Very Safety Protection	1:Not Noise Cancele	C1:Not eye protect	C1:Comfortable	C1:Not Compact							
		C2: Very Safety Protection	2:Not Noise Cancele	C2: Eye protect	C2:Comfortable	C2: Compact							
		C3: Very Safety Protection	3: Not Noise Cancele	C3: Eye Protect	C3: Comfortable	C3: Compact							
Difficulty		1	2	5	4	5	1: very easy, 5: very difficult						
Priority to improve		1	2	3	4	5	1: low, 5: high						

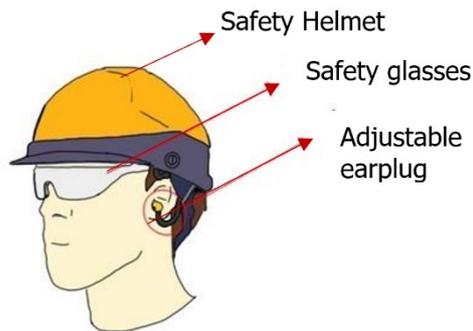
Here is a Design Sketch of the Concept of the 3 in 1 Safety Helmet:

1. Sketch Raw



**Fig. 3.** Sketch Raw

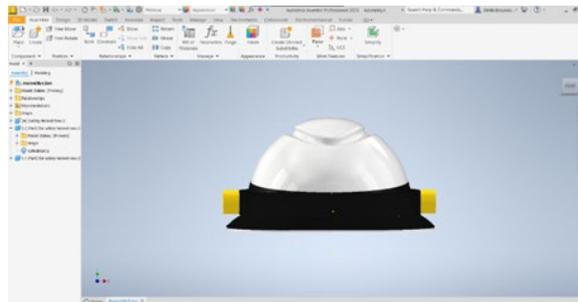
2. Final Sketch



**Fig. 4.** Final Sketch

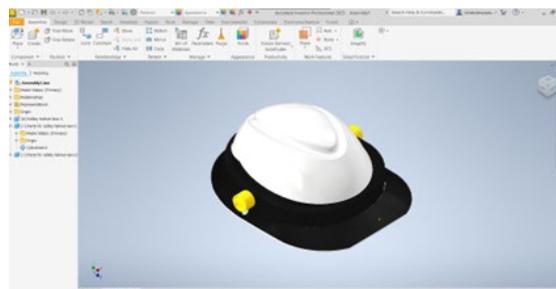
The following is the overall 3D model of the 3-in-1 safety helmet product created using Inventor software:

1. Front View Render



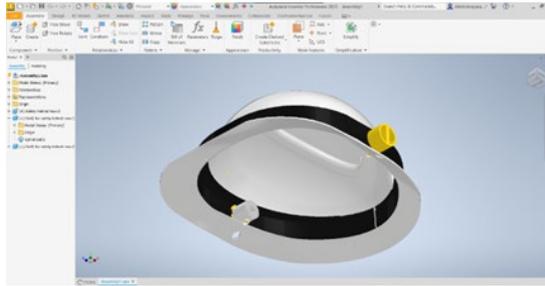
**Fig. 5.** Front View Render

2. Top Side View Render



**Fig. 6.** Top Side View Render

### 3. Bottom Side View Render



**Fig. 7.** Bottom Side View Render

### Stress Analysis

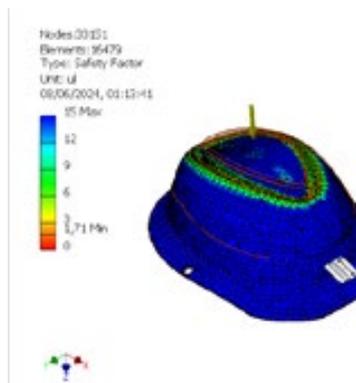
#### a. Von misses stress



**Fig. 8.** Von misses stress

Based on the obtained results, it is known that the minimum von Mises stress value of the safety helmet shell frame occurs at the upper indentation of the shell, which is measured at 0.03 MPa. In contrast, the maximum value on the safety helmet shell is recorded at 12,11MPa

#### b. Safety Factor



**Fig. 9.** Safety Factor

Based on the obtained results, the minimum safety factor value of the safety helmet shell occurs at the upper indentation of the shell, with a range of  $6 < x < 9$ . In contrast, the maximum value on the safety helmet shell is recorded at 15.

c. Displacement

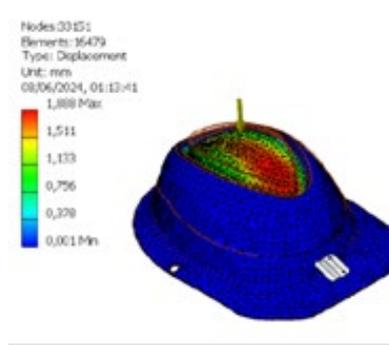


Fig. 10. Displacement

Based on the obtained results, the minimum displacement value of the safety helmet shell occurs at the upper indentation of the shell, measuring 0.001 mm. In contrast, the maximum value on the safety helmet shell is recorded at 1.888 mm.

HIRADC

The following is the HIRADC table that the author has created, reviewed in relation to the use of the 3-in-1 safety helmet in the mining area:

Table 2. HIRADC for the 3-in-1 Safety Helmet in the Mining Area.

Name of product: Safety Helmet 3 in 1

Routine No / Non-Routine	Activity/ Product/ Services	N/Ab/Ac/E	Hazard now	Hazard	Potential Incident	Applicable regulations	Existing controls	Consequence	Probability	Risk Rating	Acceptable?
1	Receiving Product	Ab	A1-1	hand cut while opening the packaging	Cut wound	Indonesian National Standard (SNI)	Be careful when opening the packaging	2	2	4	Y
2		Ab	A1-2	eye injury from small particles	Eye injury	Indonesian National Standard (SNI)	Using safety glasses	3	1	3	Y
3		Ab					Carry out work by following applicable SOPs	3	1	3	Y
4	Product Storage	Ab	A2-1	Items fall from storage shelves	Potentially damaged product	Indonesian National Standard (SNI)	Take with Care	2	2	4	Y
5		Ab			Head or body injury			2	2	4	Y
6	Product Usage	Ab	A3-1	falling heavy objects	Serious head injury user	Indonesian National Standard (SNI)	Tighten the helmet so it doesn't come off	2	1	2	Y
7		Ab	A3-2	Dust/small particles get into the eyes	Eye irritation or injury	Indonesian National Standard (SNI)	Wearing glasses according to SOP standards	3	1	3	Y
8		Ab	A3-3	Exposure to loud noises	Hearing loss in users	Indonesian National Standard (SNI)	Wearing glasses according to SOP standards	3	1	3	Y
9		Ab	A3-4	Helmet not properly worn while riding	Serious head injury during an accident	Indonesian National Standard (SNI)	PPE inspection before driving	2	2	4	Y
10		Air condition	A3-5	Glass broken by sharp object	Serious eye injury	Indonesian National Standard (SNI)	Conduct training on the use of PPE and activities in the area before going directly into the field.	3	1	3	Y
11	Product maintenance and replacement	Ab	A4-1	Exposure to chemicals when cleaning products	Skin or eye irritation	Indonesian National Standard (SNI)	Use PPE and follow SOP when cleaning products	2	2	4	Y
12		Ab	A4-2	Pinched/cut when replacing components	cut/bruise	Indonesian National Standard (SNI)	Use PPE and follow SOP when changing products	2	2	4	Y

Conclusion

This study developed an innovative 3-in-1 safety helmet that integrates safety glasses and earplugs, employing an ergonomic approach and HIRADC analysis. The proposed design enhances occupational safety while aligning with SDG 9 by promoting sustainable industrial practices. Specifically designed for Indonesian mining workers, the helmet reduces risks, ensures ergonomic comfort, and improves compliance by consolidating PPE into a single integrated unit.

Future development should address thermal comfort through passive ventilation or advanced heat-dissipating materials, as well as reinforcement of training and compliance via structured workshops and hands-on simulations. Continuous improvement may also be achieved through user feedback integration and the use of advanced materials to optimize both safety and ergonomics.

To strengthen validation, future studies will include user trials and simulation-based testing to compare the proposed helmet with conventional PPE in terms of comfort, preparation time, safety compliance, and overall user acceptance. Nevertheless, this study is limited to a conceptual design and preliminary validation stage. Field implementation and testing in actual mining operations are recommended to comprehensively assess usability, ergonomic comfort, and regulatory compliance of the proposed design.

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