Safety Helmet Innovation Design Using New Product Development (NPD) Approach

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DOI: https://doi.org/10.47772/IJRISS.2026.100600068

Received: 20 May 2026; Accepted: 25 May 2026; Published: 17 June 2026

ABSTRACT

This study addresses the critical issue of worker safety in hazardous environments, particularly construction sites, by embedding an IoT-integrated smart safety helmet equipped with GPS tracking and gas detection capabilities. Despite existing safety regulations, accidents persist due to the lack of real-time monitoring of environmental hazards and worker location, reflecting the limitations of conventional helmets that provide only passive protection. The primary objective is to generate variety of an ideas a smart helmet that enhances safety through continuous monitoring and timely alerts. The study adopts a part of structured methodology based on the New Product Development (NPD) approach, beginning with a literature review to identifies user needs, emphasizing real-time tracking and gas detection knowledge. This is followed by idea generation, concept development and design refinement. This study is valuable because it focuses on real user needs and actual safety challenges in the workplace, helping to generate a range of practical and creative design ideas for smart safety technologies. By using a structured approach, it guides the development of ideas in an organized way while still allowing room for innovation, such as incorporating features like real-time tracking and hazard detection. The integration of modern technologies like IoT further supports the development of more intelligent and responsive safety solutions. Moreover, the process of filtering and refining ideas ensures that the final designs are not only innovative but also realistic, user-friendly, and effective in improving workplace safety.

Keywords: New Product Development (NPD), Safety Helmet, IoT, GPS, Design

INTRODUCTION

Worker safety in construction environments has become an increasingly critical concern due to the high risk of accidents and hazardous working conditions. Safety helmets, as a fundamental component of personal protective equipment (PPE), are designed to protect workers from head injuries caused by falling objects and accidental impacts (Sandhya et al., 2022). However, despite their importance, improper usage and non-compliance remain prevalent issues, significantly reducing their effectiveness (Hayat et al., 2022). Construction sites are inherently dynamic and complex, where both physical and psychological factors influence the safety and well-being of workers throughout the project lifecycle (Syed et al., 2020). Globally, workplace accidents continue to rise, with over two million workers reportedly affected by occupational injuries annually, and approximately 25% of these incidents involving critical body parts such as the head, eyes, and limbs (Syed et al., 2020). These statistics highlight the limitations of conventional safety measures and the urgent need for more proactive and intelligent safety solutions.

Recent advancements in wearable technologies and the Internet of Things (IoT) have enabled the development of smart helmets that integrate sensors and communication systems to monitor workers and environmental conditions in real time. Such systems allow data to be transmitted to centralized platforms for continuous supervision, facilitating timely interventions (Herrera-Santos et al., 2021). Smart helmets have been explored across various industries to enhance productivity, safety monitoring, and hazard detection, incorporating features such as activity tracking, gas detection, and remote supervision (Lee et al., 2022). Nevertheless, existing solutions often emphasize either location tracking or environmental sensing, with limited integration of both functionalities into a single, cost-effective and reliable system suitable for construction environments. To address this gap, the study aims to generate a wide range of design ideas for smart occupational safety technologies that respond to real-world user needs and workplace hazards. It adopts a structured methodology based on the New Product Development (NPD) framework, incorporating stages such as literature review, user needs assessment, idea generation, concept development, and design refinement. The novelty of this study lies in its systematic and user centered approach to exploring multiple innovative concepts particularly those integrating technologies like IoT, real-time monitoring, and hazard detection while ensuring that the proposed ideas are both practical and relevant for enhancing workplace safety.

METHODOLOGY

New product development is a systematic process in which each product journey differs depending on the organization and industry context. However, it can generally be categorized into several key stages as shown in Figure 1. The process begins with the user needs assessment. The initial findings were obtained through a questionnaire survey distributed to the community using Google Forms. A total of 53 respondents completed the survey, and the summarized results are presented in Figure 2. The most important requirement identified by the respondents was lightweight design, with 53.2% of respondents selecting this criterion. This was followed by helmet sizing at 44.7%, safety at 42.6%, and functionality, which recorded the lowest percentage at 14.9%.

Figure 1: New Product Development Process Involved

Table 1 presents the analysis of the different functional criteria and provides valuable insights into the design priorities. The lightweight feature achieved the highest average rating of 5.0, indicating that it is considered a highly critical design requirement. Other criteria that received relatively high ratings include sizing (4.2), safety (4.0), and modularity (3.8), suggesting that the proposed design is expected to be practical, safe, and adaptable. In contrast, functionality and aesthetics received lower average ratings of 1.4 and 2.6, respectively, indicating that these aspects were given less emphasis in the current design evaluation but still possess potential for further improvement. Overall, these findings highlight that lightweight characteristics, safety, and modularity are the primary priorities in the design process, while aesthetics and functionality are considered secondary factors. The results of this assessment are useful for refining the design to ensure that it effectively meets the intended objectives.

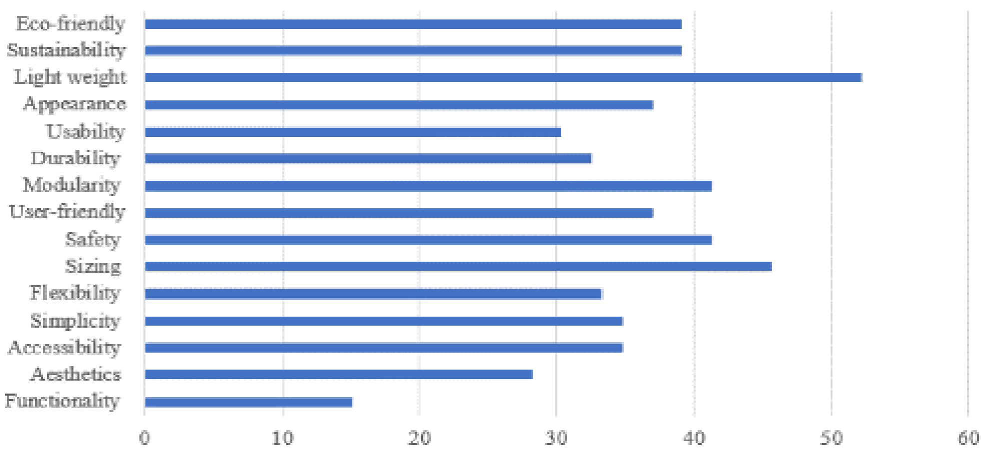

Figure 2: User need assessment

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

Table 1: Percentage and average of the functional

No	Function	Percentage (%)	Average
1	Functionality	14.9	1.4
2	Aesthetics	27.7	2.6
3	Accessibility	34	3.2
4	Simplicity	34	3.2
5	Flexibility	32.6	3
6	Sizing	44.7	4.2
7	Safety	42.6	4
8	User-friendly	36.2	3.4
9	Modularity	40.4	3.8
10	Durability	31.9	3
11	Usability	29.8	2.8
12	Appearance	36.2	3.4
13	Light weight	53.2	5
14	Sustainability	38.3	3.6
15	Eco-friendly	38.3	3.6

Idea generation involves identifying new product opportunities or improving existing products through brainstorming activities, market trend analysis, product research, and an in-depth understanding of customer needs and problems to develop innovative solutions. Sources of product ideas may originate internally from departments such as Marketing, Sales, Engineering, and Customer Support, or externally through competitor analysis and customer feedback, which provide valuable insights into consumer expectations and market demands.

A morphological chart is a design tool used to break a product into its main functions and list different solution options for each function. These options are then combined to create various design concepts, helping designers explore multiple alternatives systematically and choose the most suitable one as shown in Table 2 below.

Table 2: Morphological chart for safety helmet innovation design

No	Type	Type 1	Type 2	Type 3
1	Battery			

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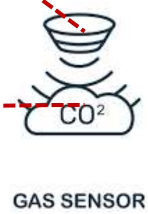
2	Material	 HDPE	 ABS (Arcylonitrile Butadiene Styrene)	 Carbon fiber
3	Shell			
4	Type of features	 Mobile apps	 Wearable device	 Web
5	Sensor	 GPS tracking		 Hard impact detection sensor
6	Electrical Component cover			

From Table 2 above, there are two types of safety helmets that can be use according to the morphological chart. This approach allows the investigation and combination of several options for the product's components or features and detailed shown in Table 3 below. Type 1 is well suited for applications in hazardous environments that require real-time environmental monitoring, as it prioritizes portability, advanced safety monitoring, and user convenience. Its features include a lithium-ion battery, HDPE material, a multi-layer shell, mobile application integration, GPS tracking, and a carbon monoxide (CO) gas sensor. On the other hand, Type 2 utilizes a nickel-metal hydride battery, ABS material, a single-layer shell, a web interface, GPS tracking, and a hard impact detection sensor. It emphasizes mechanical safety and durability, making it more suitable for harsh environments where impact resistance and physical robustness are essential. Based on the comparison, Type 1 has been selected as the preferred option.

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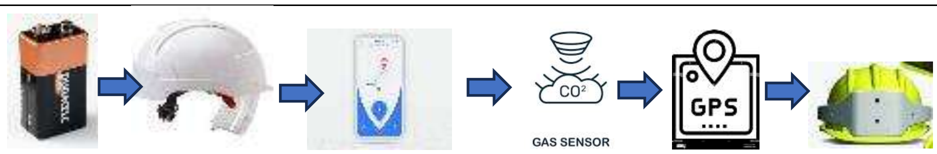
Table 3: Two (2) option derived from morphological chart

Type	**Functional / fitting**
Type 1	
Type 2	

Concept development is the process of turning an initial idea into a clear and detailed product concept by defining its features, functions, and target users. It also involves creating and comparing different alternatives to select the most suitable design for further development. At this stage, multiple alternative concepts are often created and evaluated to determine which one best meets user needs, technical feasibility, and market requirements.

Four concept designs for the safety helmet have been developed, each specifically designed to address the needs of employees working in hazardous environments. These concepts prioritize real-time environmental monitoring, user comfort, and safety. They aim to enhance overall worker protection, improve situational awareness, and provide timely alerts through the integration of advanced features such as GPS tracking, environmental sensors, and mobile application connectivity. Each design incorporates modern technologies, including gas sensors for detecting hazardous substances, durable shell materials for impact resistance, and user-friendly interfaces for quick access to critical information. Collectively, these four designs emphasize both comfort and functionality for workers in high-risk environments, representing a significant advancement in industrial and construction safety as illustrated in Figure 3.

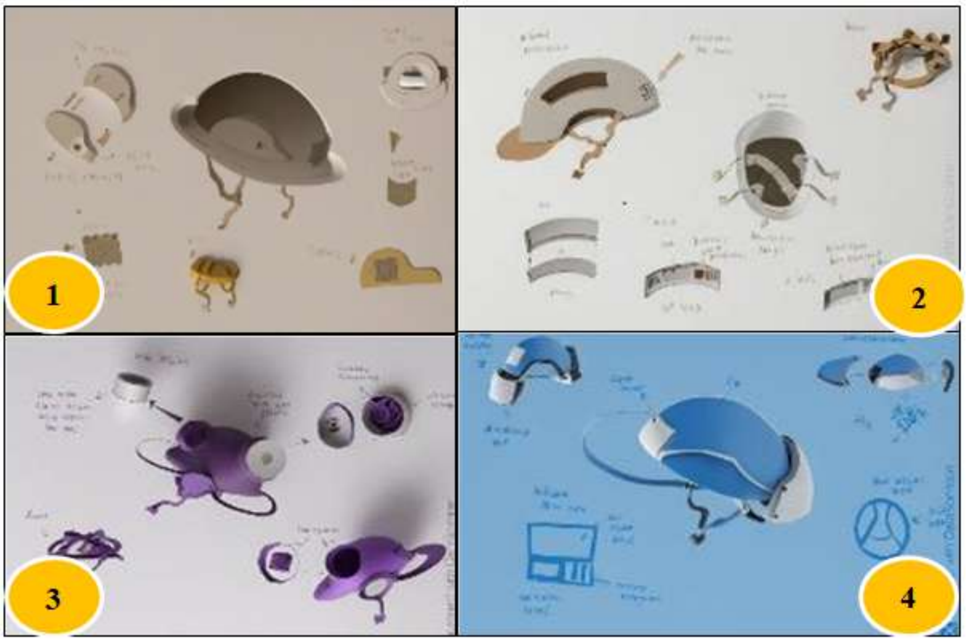


Figure 3: Four (4) concept for safety helmet innovation design

The Pugh rating is a decision-making tool used to select the best concept design by comparing multiple alternatives against a set of customer requirements. It is used to evaluate each of the four concepts against each criterion. Each concept is rated based on its performance in relation to the design requirements. The ratings value is shown in Figure 4.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

Rating	Description
1	For worse than the baseline
2	For equal to the baseline
3	For better than the baseline

Figure 4: Rating value

From the Table 4, the best concept design is Concept 2, as it achieved the highest total score overall. Concept 3 was a close second. Both concepts demonstrate a strong balance of functionality, user-friendliness, and ergonomics in relation to the critical design criteria. Concepts 1 and 4 scored lower, indicating that they are still viable but require further refinement in key areas. Therefore, Concept 2 has been selected as the final concept.

Table 4: Pugh rating

				Concept			
No	**Function**	**AVG.**	**Weight**	**1**	**2**	**3**	**4**
1	Functionality	1.4	3	2	2	2	2
2	Aesthetics	2.6	3	1	3	3	2
3	Accessibility	3.2	2	2	2	2	2
4	Simplicity	3.2	1	3	3	1	1
5	Flexibility	3	1	2	2	3	2
6	Sizing	4.2	2	1	2	2	2
7	Safety	4	2	2	2	2	2
8	User-friendly	3.4	2	2	3	2	1
9	Modularity	3.8	1	1	1	2	2
10	Durability	3	3	1	2	2	1
11	Usability	2.8	2	2	2	2	2
12	Appearance	3.4	1	1	3	3	2
13	Ergonomics	5	3	2	2	2	1
14	Sustainability (ease to manufacturing)	3.6	3	3	2	1	2
15	Cost efficiency	3.6	3	2	1	1	1
				25	**31**	29	24

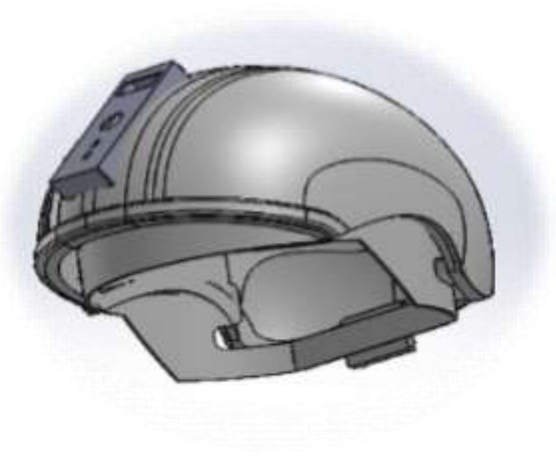
Design refinement using 3D modeling for visualization is an iterative design improvement process in which digital three-dimensional models are continuously developed, analyzed, and modified to enhance the overall

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

quality and performance of a product before prototype fabrication and final production. Through the use of 3D computer-aided design (CAD) software, designers are able to visualize the product in a realistic and detailed manner, allowing comprehensive evaluation of the product's form, dimensions, functionality, ergonomics, structural arrangement, assembly process, and manufacturability.

This process enables designers to identify potential design weaknesses, component interferences, dimensional inaccuracies, and usability issues at an early stage of product development, thereby reducing the risk of costly errors during fabrication and production. Design refinement also supports the optimization of material selection, product aesthetics, weight distribution, structural stability, maintenance accessibility, and user interaction to ensure the product meets both technical specifications and customer requirements.

In addition, 3D modeling visualization facilitates effective communication and collaboration among designers, engineers, manufacturers, and stakeholders by providing a clear graphical representation of the proposed product. Various modifications and improvements can be implemented efficiently through repeated evaluation and simulation processes without the need for immediate physical prototyping. Consequently, design refinement using 3D modeling contributes significantly to reducing product development time, minimizing production cost, improving product reliability and manufacturability, and increasing overall user satisfaction before the final product is approved for manufacturing and commercialization.



NO	PART NAME	DESCRIPTION
1	SHELL	ABS
2	STRAP	ABS
3	INNER STRAP	ABS
4	SENSOR COMPARTMENT	ABS

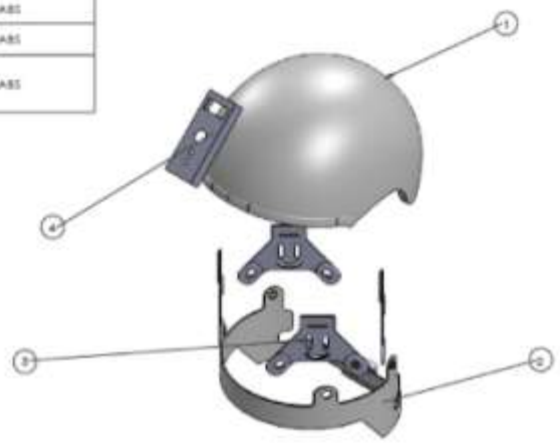


Figure 5: Assembly and exploded view of safety helmet integrated with gas sensor and GPS system

The fully assembled helmet integrates the helmet shell, straps, and sensor compartment into a unified design system, as illustrated in the final configuration. The sensor compartment is specifically designed to securely accommodate the GPS module and gas sensor, ensuring adequate protection while maintaining full functionality, and it includes ventilation features to support effective air sampling and safe housing of electronic components.

The strap system consists of adjustable outer components that enhance stability and fit, while the inner section incorporates a suspension mechanism that improves comfort and impact absorption; additionally, the inner straps are padded to ensure even pressure distribution and enhanced wearability during extended use. The outer shell forms the primary structural framework of the helmet, fabricated from ABS material, and is ergonomically contoured to achieve aerodynamic performance while providing integrated mounting points for the sensor compartment. Overall, the design emphasizes modularity to enhance safety, usability, and functional integration of all components.

DISCUSSION

This study addresses ongoing safety issues in hazardous environments, particularly construction sites, where accidents still occur despite existing safety regulations. A major limitation of conventional helmets is their passive nature, as they do not provide real-time monitoring of environmental hazards or worker location. To address this gap, an IoT-integrated smart safety helmet with GPS tracking and gas detection capabilities is proposed to enhance worker safety through continuous monitoring and timely alerts.

The application of the New Product Development (NPD) approach effectively guided the development process, beginning with a literature review that identified key user needs such as real-time tracking and hazardous gas detection. These requirements informed the idea generation and concept development stages, ensuring that the proposed solutions are aligned with actual workplace safety challenges.

In addition, the design refinement stage played a critical role in evaluating and improving the generated concepts based on feasibility, usability, and functionality. The integration of IoT technology further enhances the system by enabling real-time communication and improved hazard response. Overall, the study demonstrates that a structured and user-centered design approach can produce practical and innovative safety solutions that improve occupational safety performance.

FUTURE RESEARCH RECOMMENDATION

Future research should focus on the development and implementation of a fully functional prototype of the IoT-integrated smart safety helmet to evaluate its real-world performance in construction environments. Further studies are recommended to conduct extensive field testing under various working conditions to assess the reliability, accuracy, and durability of the GPS tracking and gas detection systems. In addition, future work should explore the integration of advanced sensors and artificial intelligence algorithms to enhance predictive capabilities, such as early hazard detection and risk prediction based on environmental and worker behavior data.

Moreover, research should be extended to improve energy efficiency and battery management systems to ensure longer operational time without frequent recharging interruptions. User acceptance studies involving construction workers and safety personnel are also essential to evaluate usability, comfort, and practical adoption in real working scenarios. Finally, future investigations may consider expanding the system into a broader IoT-based workplace safety ecosystem by integrating multiple safety devices and centralized monitoring platforms to further enhance occupational safety management and emergency response effectiveness.

CONCLUSION

In conclusion, this study proposes an IoT-integrated smart safety helmet with GPS tracking and gas detection to enhance worker safety in hazardous construction environments. It addresses the limitations of conventional helmets, which provide only passive protection and lack real-time monitoring of hazards and worker location. Using a structured New Product Development (NPD) approach, the study identified key user needs and developed concepts through systematic idea generation, development, and refinement. The findings indicate that integrating IoT technology into safety helmets can improve real-time hazard detection, monitoring, and response, thereby enhancing overall workplace safety. The structured design process also ensures that the proposed solutions are practical, user-centered, and feasible for implementation in real working conditions.

ACKNOWLEDGMENT

The authors would like to express their sincere gratitude to Universiti Teknikal Malaysia Melaka (UTeM) and Fakulti Teknologi dan Kejuruteraan Industri dan Pembuatan (FTKIP) for providing the facilities, resources, and support necessary to carry out this research.

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