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# Enhancing Motorcycle Riding Safety through Smart Helmet Design Using the Quality Function Deployment (QFD) Approach

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## Abstrak

*Sepeda motor mendominasi transportasi harian di Indonesia, yang berkontribusi terhadap tingginya jumlah kecelakaan lalu lintas yang melibatkan pengendara motor. Meskipun terdapat peraturan yang mewajibkan penggunaan helm, cedera kepala masih sering terjadi, terutama akibat penggunaan tali dagu helm yang tidak terpasang dengan benar. Penelitian ini berfokus pada pengembangan helm pintar yang menekankan kualitas keselamatan melalui penerapan mekanisme pengunci tali dagu otomatis dengan pendekatan manajemen kualitas. Metode Quality Function Deployment (QFD) digunakan untuk secara sistematis menerjemahkan kebutuhan dan harapan pengguna ke dalam spesifikasi desain teknis yang relevan. Data primer diperoleh melalui penyebaran kuesioner untuk mengidentifikasi suara pelanggan (voice of customer) terkait aspek keselamatan, kenyamanan, kemudahan penggunaan, preferensi desain, dan pertimbangan harga. Kualitas data dijamin melalui uji validitas dan reliabilitas sebelum dilakukan analisis. Hasil penelitian menunjukkan bahwa fitur yang berorientasi pada keselamatan, khususnya sistem pengunci tali dagu otomatis dan alarm peringatan, merupakan faktor paling penting dalam meningkatkan kualitas keselamatan berkendara. Desain helm pintar yang diusulkan berhasil menggabungkan fitur keselamatan utama dengan kenyamanan pengguna dan kemudahan penggunaan. Penelitian ini menegaskan bahwa metode QFD merupakan pendekatan yang tepat untuk mengembangkan produk yang berfokus pada pengguna dan keselamatan, serta memberikan wawasan praktis bagi pengembangan helm pintar dalam bidang teknik industri.*

***Kata kunci:*** *Quality Function Deployment; Helm Pintar; Kualitas Keselamatan Berkendara; Peningkatan Kualitas; Teknik Industri*

## Abstract

Motorcycles dominate daily transportation in Indonesia, which contributes to a substantial number of traffic accidents involving motorcyclists. Despite regulations requiring helmet use, head injuries continue to occur frequently, largely due to improper fastening of helmet chin straps. This research focuses on the development of a smart helmet that emphasizes safety quality through the implementation of an automatic chin strap locking mechanism using a quality management perspective. The Quality Function Deployment (QFD) method is employed to systematically convert user expectations into relevant technical design specifications. Primary data were obtained through questionnaires to identify the voice of customer concerning safety, comfort, usability, design preferences, and price considerations. Data quality was ensured through validity and reliability testing prior to analysis. The findings reveal that safety-oriented features, especially the automatic chin strap locking system and warning alarm, represent the most critical factors in enhancing riding safety quality. The proposed smart helmet design successfully combines key safety features with user comfort and ease of use. This study confirms that QFD is a suitable approach for developing user-centered, safety-focused products and offers practical insights for smart helmet design within the industrial engineering field.

**Keywords:** Quality Function Deployment; Smart Helmet; Riding Safety Quality; Quality Improvement; Industrial Engineering

## INTRODUCTION

Motorcycles are the most widely used mode of transportation in Indonesia, resulting in a relatively high risk of traffic accidents involving motorcyclists. One of the primary efforts to reduce the severity of injuries in such accidents is the use of helmets as head protection devices (Dhere et al., 2025). The Indonesian government has mandated helmet use through Law Number 14 of 1992 (Musa & Olajide, 2025). However, despite this regulation, the incidence of head injuries among motorcycle accident victims remains high. Data from the National Standardization Agency of Indonesia (BSN) indicate that approximately 88% of two-wheeled vehicle accident victims suffer head injuries due to the use of helmets that do not comply with established safety standards (Bhoomika et al., 2025).

Motorcycle helmet safety standards are regulated by several institutions, including the Department of Transportation (DOT), the Japanese Industrial Standard (JIS), and the Indonesian National Standard (SNI) (Jennings et al., 2025). According to SNI 1811-2007, a standard helmet must consist of three main components: a strong and smooth outer shell, an impact-absorbing liner, and a retention system or chin strap that ensures the helmet remains securely fastened to the rider’s head during a collision (Boopathy et al., 2020). In practice, however, many riders continue to use non-standard helmets or fail to properly fasten the chin strap due to comfort considerations, design preferences, and a lack of safety awareness.

Technological advancements have encouraged innovation in helmet design through the development of smart helmets. These helmets are equipped with technology-based features such as sensors, communication systems, and entertainment functions aimed at enhancing user comfort and attractiveness (Prasetya & Syamsudin, 2025). This trend aligns with the growing consumer demand for products that not only provide safety but also support modern lifestyles. Nevertheless, most existing smart helmet developments tend to prioritize accessory features and convenience, while the helmet’s primary function as a protective device has not been fully optimized.

One critical issue that remains insufficiently addressed in smart helmet development is the chin strap locking system. In certain accident scenarios, particularly when riders are thrown from or roll during a crash, an inadequate locking mechanism may cause the helmet to detach before the main impact occurs, thereby significantly increasing the risk of fatal head injuries. This condition indicates that the presence of smart features does not necessarily correlate with improved safety performance if not supported by a reliable and user-friendly retention system.

Furthermore, data from Statistics Indonesia (BPS) show that motorcycle sales increase by approximately six million units annually. This growth reflects a substantial market potential for innovative helmet development. Consumers increasingly prefer helmets with attractive designs and additional features, creating opportunities for smart helmet products that are not only lifestyle-oriented but also capable of delivering tangible improvements in riding safety.

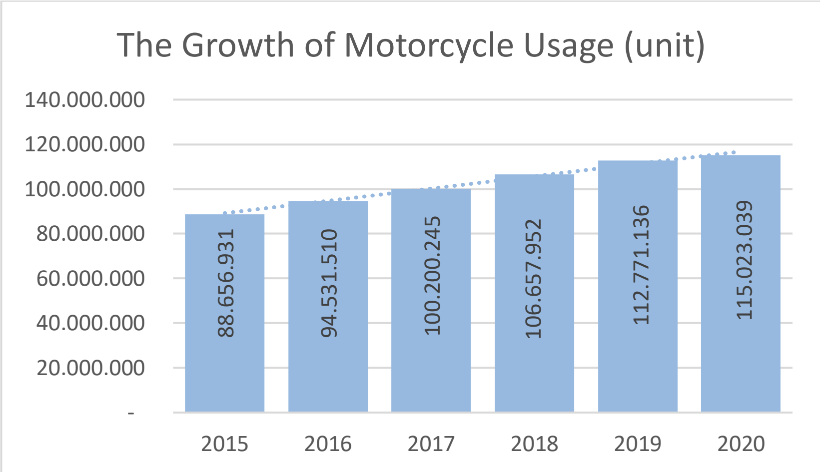


**Figure 1.** Development of the Number of Motorcycles Data by BPS (units)

The research gap in this study arises from the limited number of investigations that specifically focus on the integration of a smart lock belt system as a primary safety feature in smart helmet design. Most existing studies and product developments emphasize the incorporation of sensors, communication systems, or entertainment features, while giving insufficient attention to the effectiveness of helmet retention mechanisms in preventing helmet detachment during traffic accidents (Siddhi et al., 2025). As a result, the core protective function of smart helmets has not been optimally addressed.

Based on this background, the present study aims to evaluate the role of smart helmet features, with particular emphasis on the smart lock belt system, in enhancing rider safety and safety awareness. The findings of this study are expected to contribute scientifically to the development of smart helmet designs that are more safety-oriented and to serve as a reference for future research and product development in motorcycle helmet safety.

## RESEARCH METHODOLOGY

### Research Prosedure

This study adopts a design engineering approach based on quality management principles to develop a smart helmet design oriented toward improving riding safety performance. The research procedure is conducted systematically through several structured stages.

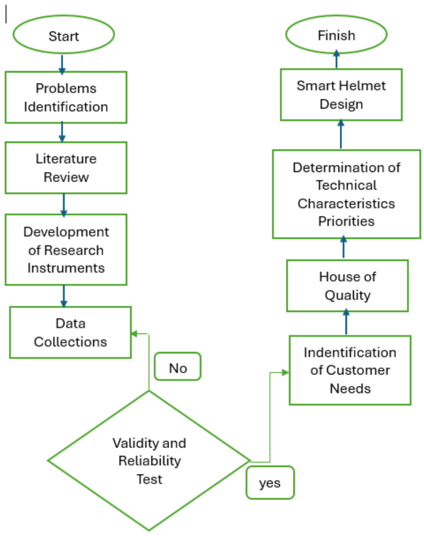


**Figure 2.** The Research Stage

## Method and Collecting Data

This study employs a descriptive and analytical research method using a quantitative approach. The data utilized in this research consist of both primary and secondary data sources.

**a. Primary Data**

Primary data were collected through questionnaires distributed to motorcycle users. The questionnaire was designed to capture user needs and perceptions regarding helmet safety quality, encompassing safety performance, comfort, ease of use, design, and price aspects. Respondents' evaluations were measured using a five-point Likert scale to assess the level of importance of each need attribute.

**b. Secondary Data**

Secondary data were obtained through a literature review encompassing textbooks, scientific journals, helmet safety standards, and other supporting sources relevant to the research topic. The questionnaire results were utilized as the voice of customer in the smart helmet design process and served as the basis for constructing the Quality Function Deployment (QFD) matrix.

## Research Data Test

To ensure the quality of the data used in this study, the following data validation tests were conducted:

**a. Validity Testing**

The correlation of item scores with total scores was used to evaluate the Validity of the exam. "Spears Rank" is the idea of performing an "$r_{arithmetic}$ ($r_{xy}$) with $r_{table}$" test. If the $r_{arithmetic} > r_{table}$ process instrument series is deemed "legitimate," it is also expected that the next process can be employed for this activity if the $r_{arithmetic}$ rtable is deemed "inValid" (Utami & Rasmanna, 2023)

$$r_{xy} = \frac{n\Sigma x_i y_i - (\Sigma x_i)(\Sigma y_i)}{\sqrt{(n\Sigma x_i^2 - (x_i)^2)(n\Sigma y_i^2 - (y_i)^2)}} \quad (1)$$

**b. Reliability Testing**

Cronbach's alpha, a measure of value that has a range of zero – one this measurement concept is done so that the size is appropriate and consistent (Utami & Rasmanna, 2023).

$$r_i = \frac{k}{(k-1)} \{1 - \frac{\Sigma s_i^2}{s_t^2}\} \quad (2)$$

The results of the validity and reliability tests served as the basis for confirming that the voice of customer data were appropriate for use in constructing the QFD matrix and in the smart helmet design process.

## RESULTS AND DISCUSSION

### 1. Respondent Characteristics

Data collection was conducted among motorcycle users who routinely wear helmets during their daily riding activities. The respondents represented diverse age groups and motorcycle usage frequencies, allowing the data to reflect general helmet user requirements. Most respondents reported using half-face helmets due to comfort and ease of use; however, they acknowledged that safety aspects are often not adequately considered, particularly with regard to chin strap fastening. These findings indicate a gap between safety awareness and actual user behavior, which serves as an important basis for the development of a quality management–based smart helmet design.

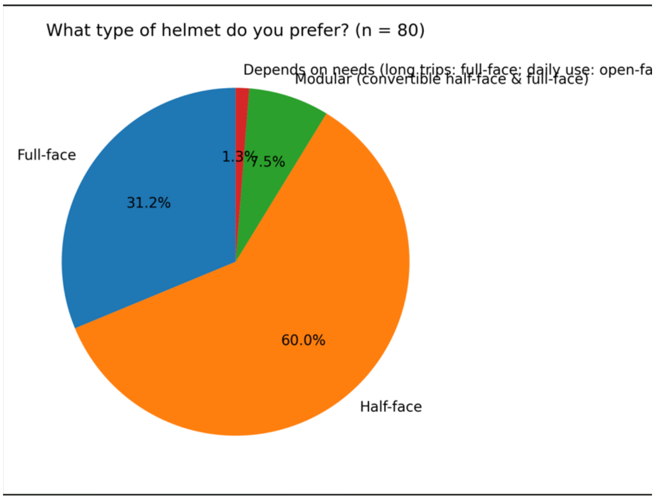


**Figure 3.** Preferred Helmet Model Chart

## 2. Identification of User Needs (Voice of Customer)

Based on the questionnaire results, several key helmet user requirements were identified that are directly related to riding safety quality. These requirements include helmet safety performance, wearing comfort, ease of chin strap fastening, ergonomic design, lightweight structure, and affordable pricing.

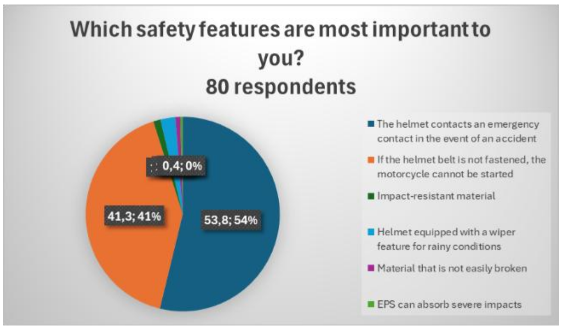


**Figure 4.** Important Safety Feature Chart

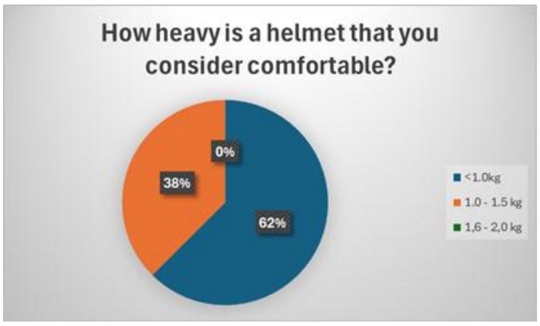


**Figure 5**. Desired Helmet Weight Chart

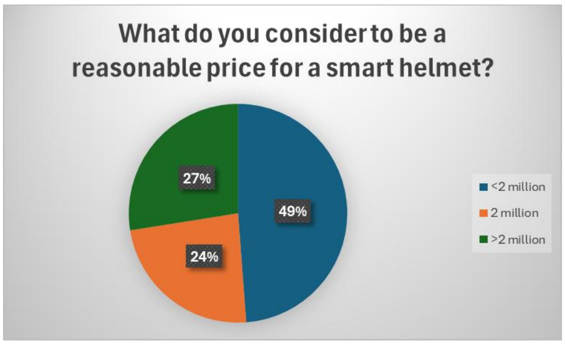


**Figure 6.** Desired Helmet Price

The importance level analysis indicates that safety attributes are ranked as the highest priority compared to other attributes. Respondents consistently stated that helmets which are both safe and easy to use are more likely to improve compliance with proper helmet usage. The ease of chin strap fastening emerged as one of the dominant user requirements, as negligence in securing the strap frequently occurs due to time constraints or discomfort associated with conventional locking systems.

These findings suggest that improvements in riding safety quality cannot rely solely on technical product standards, but must also consider user experience and user perception of helmets as safety-oriented products.

**3. Results of Data Validity and Reliability Tests**

**Tabel 1.** Questionnaire Validity Test Results

| Item Code | User Requirement Statement | r-Count | r-Table | Remarks |
|---|---|---|---|---|
| X1 | The helmet provides adequate head protection | 0,721 | 0,312 | Valid |
| X2 | The helmet chin strap locking system is easy to use | 0,748 | 0,312 | Valid |
| X3 | The helmet is comfortable for long-term use | 0,694 | 0,312 | Valid |
| X4 | The helmet design is ergonomic and fits properly | 0,662 | 0,312 | Valid |
| X5 | The helmet has a lightweight structure | 0,635 | 0,312 | Valid |
| X6 | The chin strap locking system improves safety | 0,781 | 0,312 | Valid |
| X7 | The helmet usage reminder alarm is beneficial | 0,756 | 0,312 | Valid |
| X8 | The helmet is easy to use while riding | 0,689 | 0,312 | Valid |
| X9 | The helmet material feels strong and safe | 0,703 | 0,312 | Valid |
| X10 | The helmet price is appropriate for its quality | 0,641 | 0,312 | Valid |

The validity test results indicate that all statement items have correlation coefficient values (r-count) exceeding the r-table value of 0.312 at a 5% significance level; therefore, all items are considered valid.

**Tabel 2.** Questionnaire Reliability Test Results (Source: Processed Data)

| Variable | Number of Item | Cronbach's Alpha | Criteria |
|---|---|---|---|
| Customer Needs (VoC) | 10 | **0,842** | Reliable |

Furthermore, the reliability test produced a Cronbach's Alpha value of 0.842, indicating that the research instrument demonstrates a high level of reliability. Therefore, the obtained voice of customer data are considered suitable for use in the Quality Function Deployment (QFD) analysis.

**4. Development of the Quality Function Deployment (QFD) Matrix**

The subsequent stage involves the application of the Quality Function Deployment (QFD) method to translate user requirements into technical product characteristics (Laetitia et al., 2021). The House of Quality matrix is constructed by establishing relationships between customer requirements and the technical characteristics of the smart helmet.

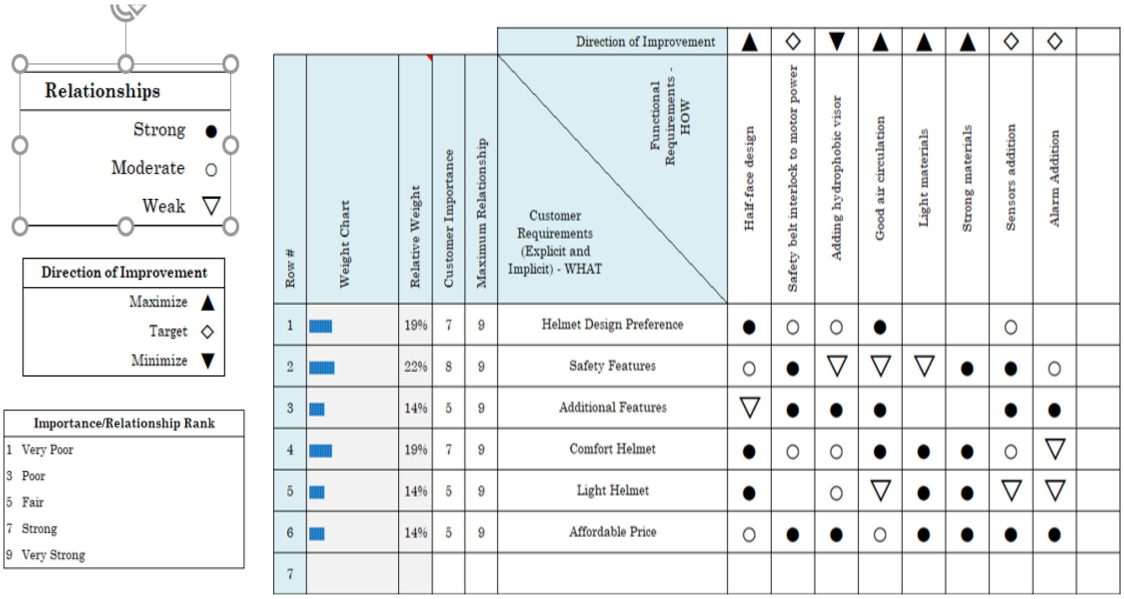


**Figure 7.** QFD – Relationship Matrix

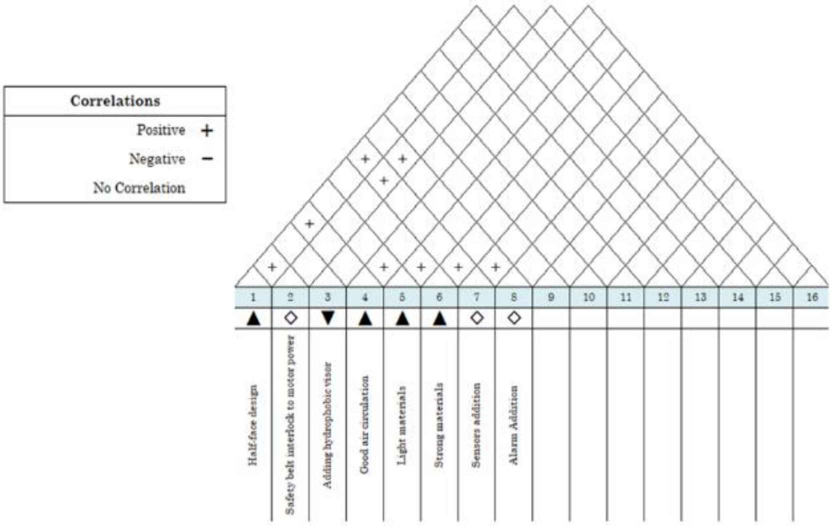


**Figure 8.** QFD – Technical Correlation

The QFD analysis results indicate that several technical characteristics contribute significantly to fulfilling user requirements. The automatic chin strap locking system and the reminder alarm are identified as the highest-priority features, as they exhibit strong relationships with safety and ease-of-use requirements. In addition, other technical characteristics, such as helmet material selection, ventilation system design, and helmet weight, also play important roles in enhancing user comfort.

The relationship analysis within the QFD matrix demonstrates that improving a single technical characteristic can simultaneously influence multiple user requirements (Sutapa et al., 2025). This finding confirms that a quality management–based QFD approach is effective in identifying and prioritizing key focus areas in safety-oriented product design.

## 5. Prioritization of Technical Characteristics

Based on the priority weight calculations in the QFD matrix, a hierarchy of technical development priorities for the smart helmet was established. The automatic chin strap locking system was identified as the top priority, as it has the highest importance value and directly influences riding safety quality.

The next prioritized technical characteristic is the helmet usage reminder alarm, which functions to alert users when the chin strap is not properly secured. This feature is designed to proactively enhance user compliance without compromising comfort.

In addition, the selection of strong yet lightweight helmet materials and an ergonomic design are considered supporting priorities. The combination of these technical characteristics indicates that riding safety quality results from the integration of technical performance, ergonomic considerations, and ease of use.

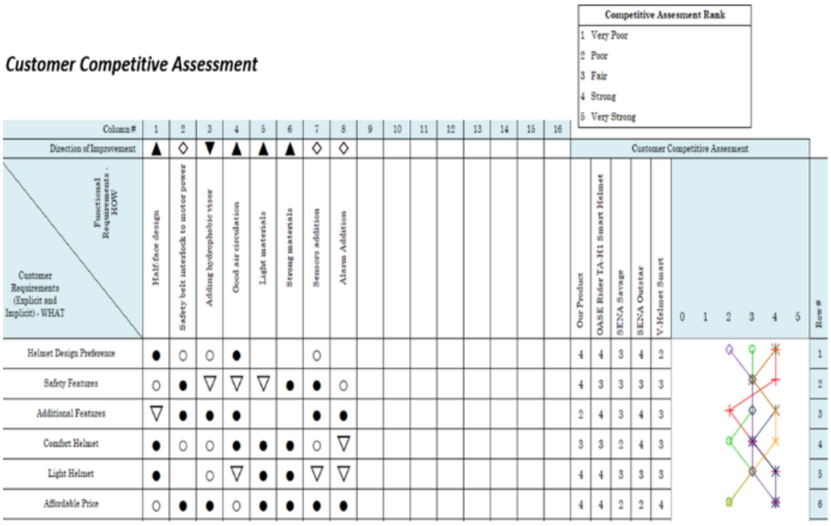


**Figure 10.** QFD - Competitive Assessment

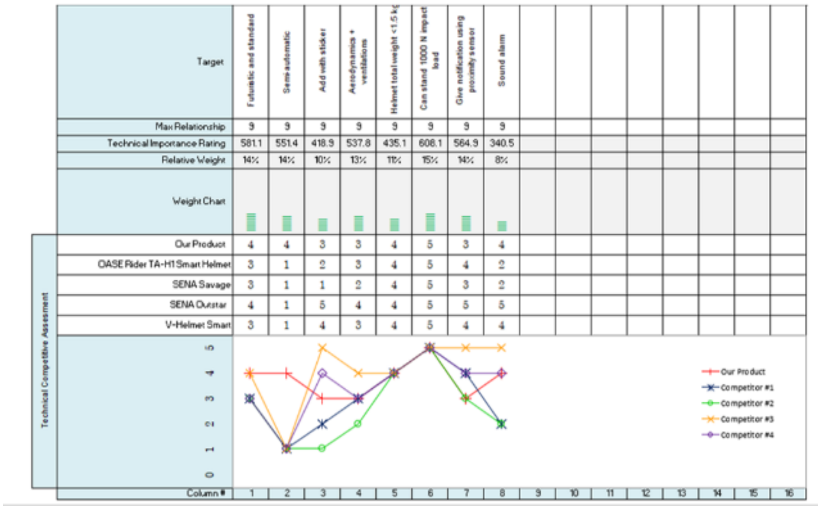


**Figure 11.** QFD – Technical Importance

## 6. Smart Helmet Design Outcomes

Based on the prioritized technical characteristics derived from the QFD analysis, a smart helmet concept was developed with an automatic chin strap locking system as its primary feature. This system is designed to ensure that the helmet functions optimally only when the locking strap is properly secured. A reminder alarm is incorporated as a usage quality control mechanism to support correct helmet use by riders.

The proposed helmet design adopts a half-face configuration, taking into account user comfort and common riding habits. The ventilation system is designed to maintain adequate airflow, ensuring comfort during extended riding durations. Material selection is determined based on considerations of strength, weight, and cost efficiency as part of a comprehensive product quality management approach.

The design outcomes indicate that the developed smart helmet concept effectively addresses key user requirements without increasing usage complexity (Wahyuni et al., 2020). Therefore, the proposed design is expected to contribute to sustained improvements in riding safety quality (Zhao & Chen, 2021).

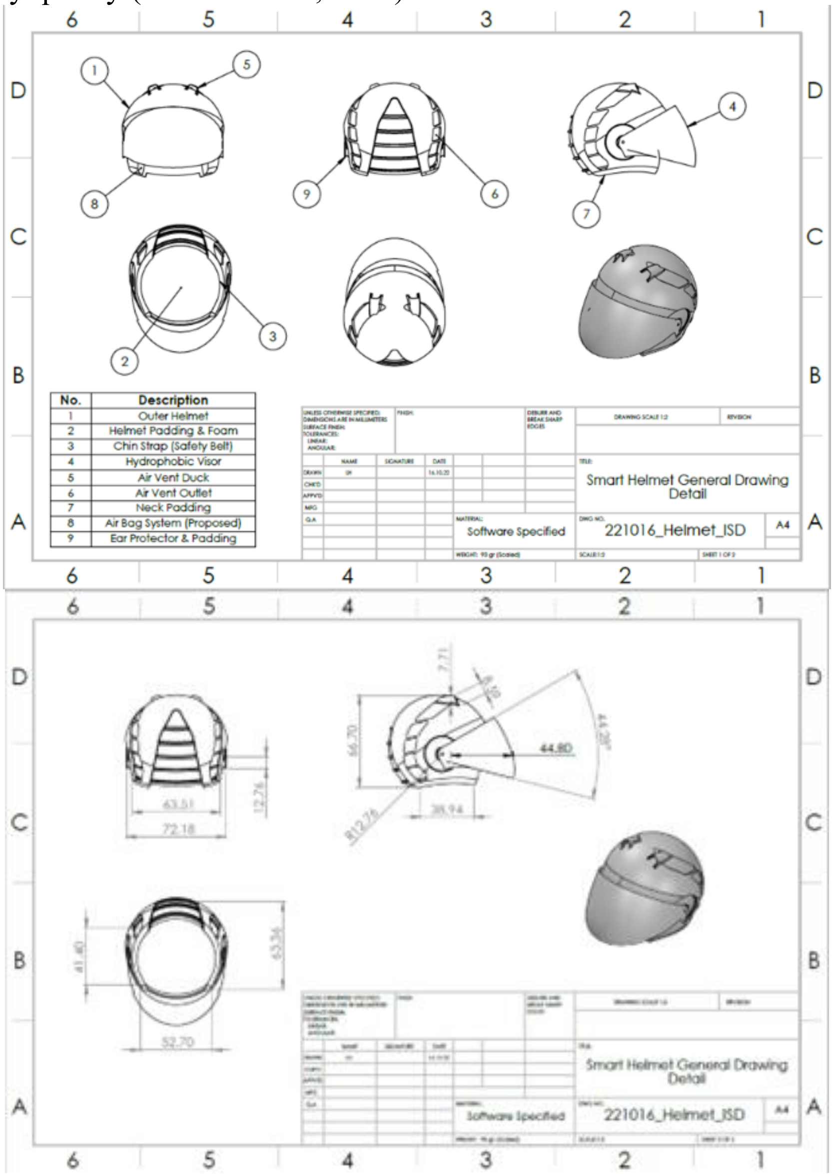


**Figure 12.** Detail Design of Smart Helmet (ANSYS software version 18.1)

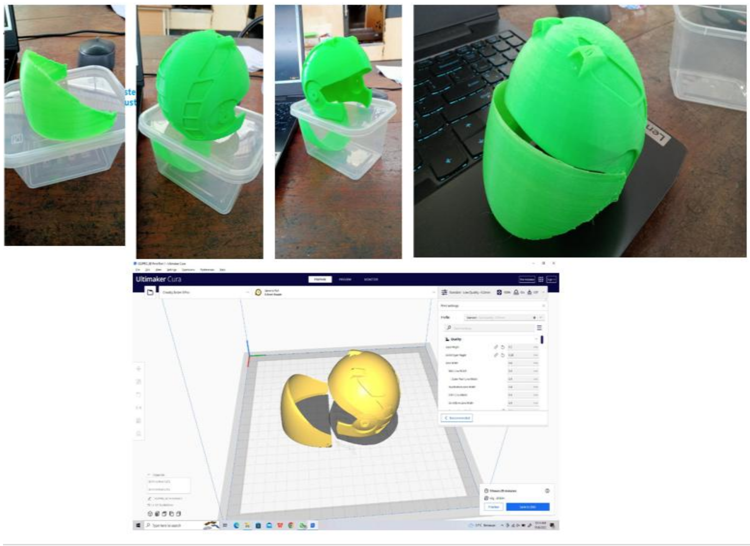

**Figure 13.** 3D printing of helmet

**7. Evaluation of Riding Safety Quality**

The design evaluation was conducted by examining the alignment between user requirements and the product's technical characteristics. The evaluation results indicate that the proposed smart helmet design satisfies most high-priority user requirements, particularly those related to safety and ease of use.

The application of a quality management–based QFD approach enables the identification of critical attributes that significantly influence riding safety quality. Accordingly, the smart helmet design is not solely oriented toward technological innovation, but also toward enhancing the quality of safety-oriented product services for users.

## CLOSING

### Conclusion

This study demonstrates that safety and ease of use are the primary requirements of motorcycle helmet users. The identification of the voice of customer confirms that a reliable and user-friendly chin strap locking system is the most critical attribute for improving riding safety quality.

The research instrument satisfies both validity and reliability criteria, ensuring that the collected data are credible and suitable for supporting the analysis. The application of the Quality Function Deployment (QFD) method is proven to be effective in translating user requirements into technical product characteristics, with the automatic chin strap locking system and reminder alarm emerging as the highest-priority features.

The resulting smart helmet design successfully integrates essential safety features without compromising comfort and usability. As a result, the proposed design has the potential to increase proper helmet usage compliance and reduce the risk of head injuries in motorcycle accidents.

### Suggestions

Future studies are recommended to conduct experimental testing on smart helmet performance, particularly regarding the reliability of the automatic chin strap locking system and its effectiveness under real accident conditions. Product development may also be directed toward integrating additional technologies, such as monitoring systems or application-based connectivity, while maintaining a primary focus on riding safety. Furthermore, research involving a larger and more diverse group of respondents is necessary to ensure that user requirement analyses more accurately represent the broader population of helmet users. From an industrial perspective, the findings of this study may serve as a reference for the development of quality management–based helmet products that are oriented toward user needs and enhanced riding safety.

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