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Analysis on Characteristic Need for Motorcycle Helmet Structures via Product Development Process and FEA

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ABSTRACT

A motorcycle helmet is an essential of safety equipment that shields the head from impact. The goal of the research is to determine whether an existing motorcycle helmet can withstand impacts and to suggest a new design with a greater safety factor. The performance of the motorcycle helmet was identified in this study using Finite Element Analysis (FEA) based on the impact situation. Additionally, by analysing the criteria for material selection specifications and developing design ideas based on user requirements, Quality Function Deployment (QFD) and Theory of Inventive Problem Solving (TRIZ) approaches. The material used in Finite Element Analysis (FEA) for the motorcycle helmet shell is Acrylonitrile butadiene styrene with Polycarbonate (ABS+PC) and Expanded Polystyrene (EPS). Displacement, equivalent stress, and strain are taken into account as output parameters. Based on the findings, it is clear that a motorcycle helmet with a liner is necessary and that it has a substantial impact on FEA. By using the new design helmet structures, it is anticipated that the performance and protection of the helmet will increase by 56.26%, protecting the rider from serious injuries.

1. Introduction

A helmet is a sort of protective gear worn to protect the head from injuries. More specifically, a head shield aids the skull in keeping the human brain secure. Sometimes protective helmets with a decorative or symbolic design are worn, such as a soldier's head protector. The Assyrian army first used helmets in 900 BC [1], when they wore heavy cowhide or bronze helmets to protect their heads from arrow, sword, and limit protest strikes. Fighters continue to wear head coverings, which are now usually made of lightweight plastic materials [2]. In civilian life, helmets are used for many activities, especially for hazardous works, extreme sports, and transportations. But the goal remains the same to protect the head from having any injuries. For the hazardous works, a safety helmet

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which known as a part of the Personal Protective Equipment (PPE) has been produced to minimize serious head injuries at the workplace by the impact of the falling object or collision with fixed sharp and hard objects and crushing by moving large objects. While for extreme sports, they have their safety helmet. No helmet will prevent concussions. Recently, injuries still exist among sports players despite wearing helmets even suffered a concussion during his team's first game of the season. But at least, comfort could be provided by the memory foam's layer and the brain bleeds or skull fractures might be prevented by the hard inner shell [3,4].

Furthermore, in transportation, everyone has been aware of the importance of a helmet instead the law of the road has long been enforcing an obligation of wearing a helmet [5]. With the lack of physical protection, the rate of fatality might be increased among injuries during a crash [6]. Therefore, in Malaysia all motorcycle riders are required to always wear helmets when operating their vehicles on the road as a result of the country's regulations regarding traffic safety. In Malaysia, motorcyclists make up the largest group of fatalities on the roads, with the majority succumbing to head injuries despite the compulsory safety helmet laws in the country [6]. Only 54.4% of motorcycle riders in Malaysia comply with the law requiring helmet use, while 21.4% don't [7]. This is a relatively low compliance rate. Malaysia has outlawed the use of half-shell motorcycle helmets. All motorcycle helmets sold in Malaysia must be certified in accordance with Malaysian Standards (MS), according to laws put in place by the Malaysian government. The Malaysian government has consistently prioritised the safety of motorbike riders by creating high-quality goods. However, each product has a usage-based upper bound on how successful it can be. Therefore, scientists and inventors are constantly working to create new models that will be more effective than current helmets. Currently, there are six types of motorcycle helmets intended for motorcycle rider [8]. The six types are Full Face Helmet, Modular Helmet, Open Face Helmet, Half Helmet, Off-road Helmet, and Dual Sport Helmet, as shown in Figure 1.

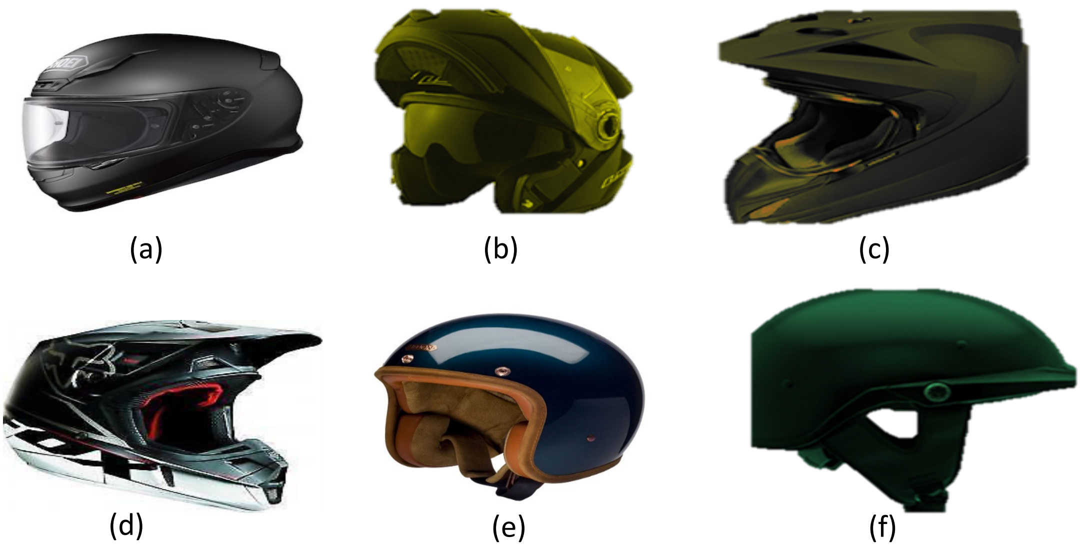


Fig. 1. Type of helmet; (a) Full face, (b) Modular, (c) Dual Sport, (d) Off road, (e) Open face, (f) Half

The head region, which is the most vital portion of the body, is fitted and protected by the construction and design of a motorcycle helmet [9]. The shell of the helmet, which is made of tough thermoplastic to guard against head punctures, the liner, which deflects excess force from the shell [10] the padding, which provides comfort for the motorcycle rider, and the visor, which shields the eyes from foreign objects [11] make up the structure of the helmet, as shown in Figure 2.

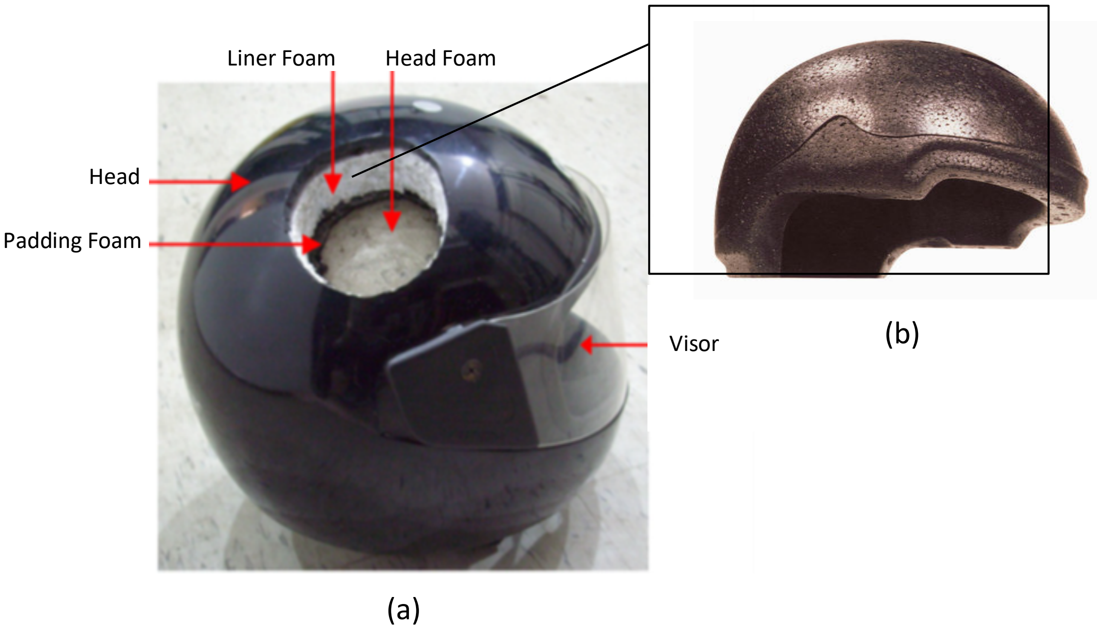


Fig. 2. A typical helmet; (a) Helmet structures, (b) Helmet liner

In this study, the innovative and systematic theories of Quality Function Deployment (QFD) and Theory of Inventive Problem Solving (TRIZ) have been applied to support the decision-making process in order to identify the solution to the design process. Quality function deployment is a way of product development that is committed to converting client needs into product and service development activities [12]. Previous studies on the subject mentioned combining TRIZ with other theories, such as axiomatic design (AD) [13]. Zhang *et al.,* [17] employed the Integration Model of E, HOQ, and TRIZ as three theoretical examples. The goal of the reach study is to incorporate all of the theoretical benefits for innovative design. In addition, as reported by Xie *et al.,* [18] the House of Quality (HOQ), a key tool of QFD, has been combined with TRIZ to support product fuzzy front-end demand decision-making, technical feature decision-making, and technical conflict decision-making research. Furthermore, from this research the Finite Element Analysis was used to evaluate the performance and behaviour of helmet, in term of impact collision. The effectiveness of analysis as an embodiment design process, where the outcomes revealed the behaviour condition based on the predicted condition, was mentioned in a review on finite element analysis (FEA) [14,15]. As a result, in this study, a preliminary analysis of the essential needs for helmet constructions was used to prioritise safety over an existing helmet. The QFD and TRIZ quantitative basis models were utilised to build the helmet, with FEA employed to portray the behaviour condition as a sampling of collisions.

2.0 Methodology

2.1 Conceptual Innovative Design of Helmet using QFD and TRIZ

In order to improve the performance of existing products, the combination of QFD and TRIZ is required. User demand data was gathered through questionnaire surveys and assessed in accordance with design specifications. There are several steps in the research process on the association between QFD and TRIZ model:

Step 1: Conduct a questionnaire survey according to the criterion of helmet. Based on the data obtained from the customer requirements, the percentage of each attribute were observed, with mean scores and rating.

Step 2: Use Quality Function Deployment (QFD) method to provide a series of technical requirements that specify a suitable design that responds to customer requirements [3]. The House of Quality (HOQ) technique is used to examine the important ranking for helmets based on customer demand. The correlation matrix of engineering characteristic (EC) and customer requirement (CR) was identified using the HOQ approach. The correlation represented whether there was a strong or weak relationship between the two criteria.

Step 3: The conflict is resolved using the TRIZ theory, which is based on the HOQ criteria. Any contradiction was solved, with related to the 40 invention principles. The needs for the invention were determined by combining customer needs and technical characteristics. As shown in Figure 3 flow chart of conceptual innovative design.

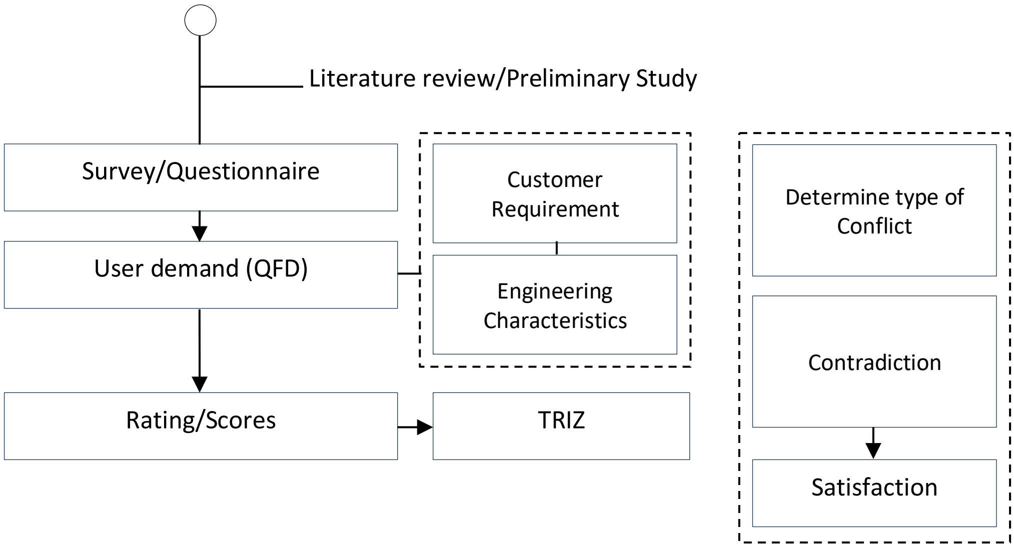


Fig. 3. Flow chart of conceptual innovative design

2.2 CAD & CAE

In this study, SolidWorks software was used to simulate the representative of motorcycle helmet structures, using material form ABS, with PC shell and EPS foam for the liner. The simulation test based on certain plain at a constant gravitational force, distance, direction and high [3]. Tables 1 and 2 indicate the mechanical and parameter values used in the simulation process.

Table 1
Mechanical properties of material

Properties	Value
Density	$1.03gcm^{-3}$
Young's Modulus	2.0×10^9 Nm^2
Poisson's Ratio	0.37

Table 2
Parameter of material

Material	ABS+PC
Liner material	EPS
Shell thickness (mm)	1
Liner thickness (mm)	25
Gravity (m/s^2)	9.81
Drop height (m)	3

3. Results and Discussion
3.1 Importance of the Current Product Performance

The importance of the current product performance and the identification of consumer requirements were investigated in the major analysis of the data collected from the conducted survey. The average ratings for the current product as determined by customer requirements are displayed in Table 3, with simplified of customer requirement in order to establish the amount of relevance information. Using the data, Quality Function Deployment (QFD) was created based on customer demand and supported criteria, as shown in Table 4.

Table 3
Mean scores for the product importance rating & simplified of customer requirement (customer level importance)

Requirements	Score, x						Mean, μ
	Q3	Q4	Q5	Q6	Q7	Q8	
Soft Internal fitting	5	4	4	0	5	5	3.8
Tough external design	4	3	2	5	0	4	3.0
Easy to carry	3	2	5	4	1	2	3.8
Not burden the head and neck	3	4	4	4	5	1	3.5
Note reduce user's vision	2	3	3	0	0	0	1.3
Ventilation factor	2	3	2	0	1	0	1.3
Attractive looking	2	2	1	0	0	1	1.0

No.	Requirements	Importance	Importance Rating
1	Soft Internal fitting	3.8	6
2	Tough external design	3.0	5
3	Easy to carry	3.8	4
4	Not burden the head and neck	3.5	6
5	Note reduce user's vision	1.3	1
6	Ventilation factor	1.3	1
7	Attractive looking	1.0	1

Table 4
Customer portion of QFD

No.	Technical Requirement	Competitive Evaluation			Quality Planning				
	Customer Requirement	Importance	Brand Review	Competitor	Target New Model (C)	Improvement ratio (D)	Strength (E)	Actual Weight	Relative Weight, %
1	Soft internal fitting	6	4	3	6	1.5	1.5	13.5	26
2	Tough external design	5	3	3	5	1.7	1.5	12.8	24.6
3	Easy to carry	4	2	2	4	2	1.2	9.6	18.5
4	Not burden the head and neck	6	4	2	6	1.5	1.5	13.5	26
5	Not reduce user's vision	1	1	1	1	1	1	1	1.9
6	Ventilation Factor	1	1	2	1	1	1.2	1.2	2.3
7	Attractive looking	1	3	1	1	0.3	1.2	0.4	0.8
								52	100

Next, the main objective is to create a collection of technical specifications that specify an appropriate design and fits with client requirements [4]. Table 5 demonstrates how the technical component interprets the customer requirements, with different of grouping. The grouping represents a helmet component. Additionally, the action plan and decision-making are ranked with the highest relative weight according to the needs of the customer. As a result, Table 6 provides an overview of related principles for each customer need using TRIZ method, whereby the designers are compelled to reframe issues in terms of contradictions and find solutions in line with the rules of technological progress [5].

Table 5
Customer Requirement Translation Worksheet

Customer Requirement	Technical Requirement		Grouping
Soft internal fitting	1. Weight 2. Area	3. Adaptability 4. Design	1. Liner foam 2. Comfort Padding
Tough external design	1. Durability 2. Weight 3. Area	4. Strength 5. Design	1. Outer shell 2. Visor/shield
Easy to carry	1. Weight 2. Area	3. Convenience	1. Outer shell 2. Comfort padding 3. Retention system
Not burden the head and neck	1. Weight 2. Adaptability	3. Stability	1. Outer shell 2. Comfort padding 3. Retention system
Not Reduce user’s vision	1. Area 2. Adaptability		1. Visor/shield
Ventilation Factor	1. Convenience 2. Adaptability		1. Outer shell
Attractive looking	1. Color 2. Design		1. Outer shell

Table 6
Product improvement plan by QFD and TRIZ

Rank	Customer Requirement	Performance		TRIZ design principle solutions
1	Soft internal fitting	Adaptability	Shape complexity	10, 25, 35, 40
1	Not burden the head and neck	Stability	Less manufacturability	11, 40, 10, 25
2	Tough external design	Durability	More amount of substance	10, 35, 15, 27
3	Easy to carry	Weight	Device complexity	15, 40, 10, 25

3.2 Preliminary Study on Behaviour of Helmet Using Simulation

In this study, there are elements that are considered based on the product development process. Due to the consumers' safety and comfort, liners are one of the components that should be taken into consideration. Therefore, the model of an open face helmet without a liner was utilised as a simulation research example to assess the effect on the shell. The helmet's outer shell is constructed of polycarbonate and acrylonitrile butadiene styrene (ABS+PC). According to previous research study, there are five different area of the helmet that is crucial to study when doing the drop test is the top side, back side, front side, left side, and right side [5]. As a result, all areas in this study were assessed based on the stress, strain, and displacement. Because of the motorcycle helmet's shape and design, the maximum and lowest amount of stresses happened at various points differently. As shown in Table 7, the open-face motorcycle helmet was dropped, showing the base stress estimation ranging from the lowest 3.217 KN/m^2 to the highest 273.640 KN/m^2. The motorcycle helmet shell is in a critical condition to break, as indicated by the red colour contour region, whereas the blue area shows the least stressed area and is safe from fracture [3]. The motorcycle helmet without a liner exhibits a stress reaction at the top and back, as shown in Figure 4.

Table 7
Data collected from open face helmet without liner

Area	Stress, (KN/m^2)		Displacement, (mm)		Strain	
	Min	Max	Min	Max	Min	Max
Top	11.059	200.155	0.0267	2.402	4.087e^{-6}	0.007
Back	9.501	251.993	0.0202	2.357	4.823e^{-6}	0.008
Front	3.217	232.640	1.329	2.353	1.168e^{-6}	0.007
Right	11.707	273.640	0.0204	2.356	7.012e^{-6}	0.008
Left	13.369	271.860	0.0221	2.354	4.999e^{-6}	0.008

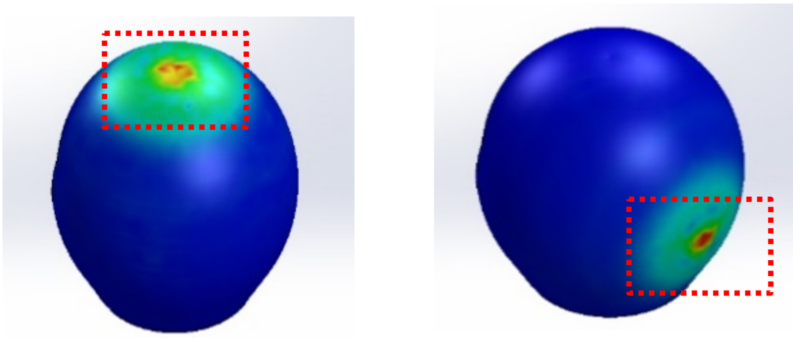

(a) (b)

Fig. 4. Stress reaction on helmet without liner; (a) top side, (b) back side

Next, the investigation is based on strain phenomenon. According to Figure 5, the red colour contour produces the highest reading value of 0.007, the blue colour contour region generates the lowest strain reading at the top side of the helmet, which is at 4.087e^{-6}, while the back of the helmet has the lowest strain effect, which is 4.823 e^{-6}, and the red colour contour produces the highest reading value of 0.008. The displacement of the left side of the helmet, for instance, in Figure 6, reveals that the minimum displacement is 0.0221mm and the highest displacement is 2.354mm.

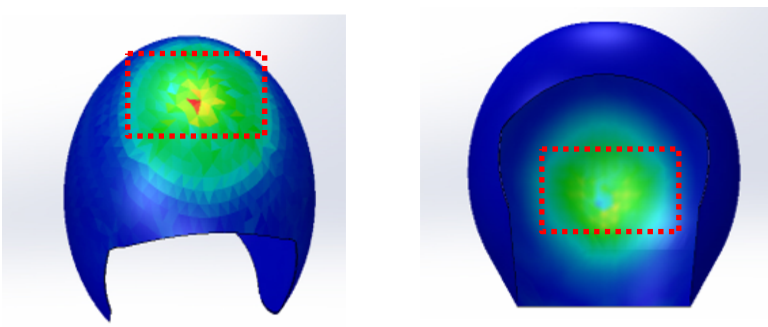

(a) (b)

Fig. 5. Strain reaction on helmet without liner; (a) top side, (b) back side

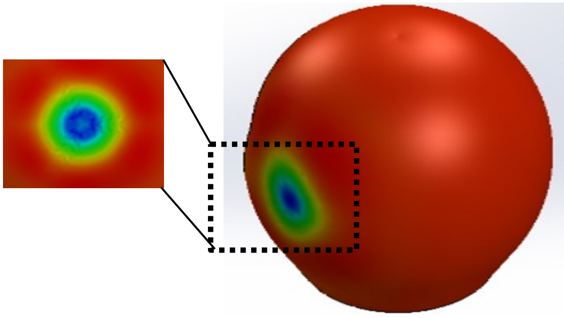


Fig. 6. Probe location taken at the different colour contour for displacement phenomenon at right side of helmet without liner

Additionally, the open face helmet with liner was examined based on the same conditions as the open face helmet without liner in order to explore the usefulness of liner as a component in helmet structure. The liner component is made from expanded polystyrene (EPS) foam. On the top side of the motorcycle helmet, the reading of stress is at a minimum of 0.375 KN/m^2, and the maximum reading is taken at 463.049 KN/m^2. On the back side of the helmet, the minimum stress is shown in the blue contour region at 0.110 KN/m^2, as shown in Figure 7.

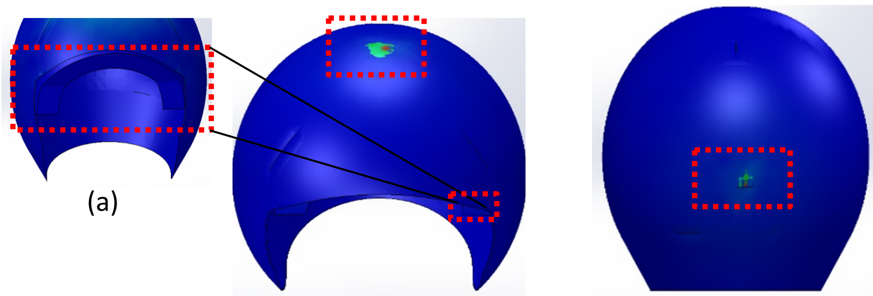
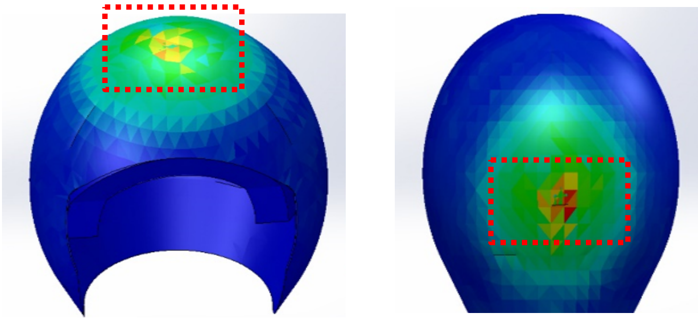


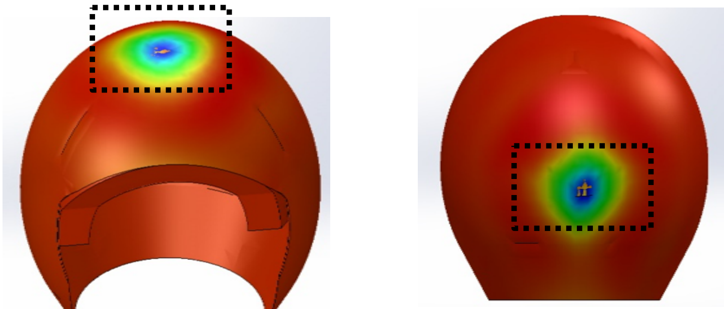
Fig. 7. Open Face helmet with liner on stress condition; (a) liner, (a) top side, (b) back side

According to Figure 8, the strain phenomenon on an open-faced helmet with a liner exhibits a considerable influence, with the lowest value occurring around the blue colour contour region, $3.269e^{-9}$ and the highest value occurring around the red colour contour, 0.011. Moreover, the right side of the open face helmet with liner is tested to observe the strain reaction on it. The red colour contour in Figure 9 determines the strongest strain reaction on the helmet at 0.020mm. The blue contour zone then determines the strain value at the lowest point, which is 2.354mm. The red contour region with the greatest displacement has exceeded the thickness, causing the area to fail, if blue colour contour result is still below thickness, the zone is considered safe [14,16]. As indicated in Table 8, data was gathered for an open face helmet with a liner in all conditions of investigation, with respect to stress, displacement, and strain.



(a) (b)

Fig. 8. Strain reaction on helmet with liner; (a) top side, (b) back side



(a) (b)

Fig. 9. Displacement reaction on helmet with liner; (a) top side, (b) back side

Table 8
Data collected from open face helmet with liner

Area	Stress, (KN/m^2)		Displacement, (mm)		Strain	
	Min	Max	Min	Max	Min	Max
Top	0.375	463.049	0.006	2.339	$3.269e^{-9}$	0.011
Back	0.110	521.377	0.021	2.369	$2.454e^{-11}$	0.014
Front	1.485	279.390	1.531	2.308	$6.626e^{-11}$	0.010
Right	2.095	209.990	0.020	2.354	$7.688e^{-11}$	0.008
Left	3.870	474.479	0.019	2.374	$3.602e^{-10}$	0.013

According to the investigation, the helmet structure has a major impact by using a liner as a structure. As a result, it demonstrates that the liner is one of the components required for helmet structure [15]. Hardness, weight, size, and shape are among the parameters that are taken into account in the previous report. This feature is crucial in assuring the wearer's safety [5].

4. Conclusion

Finally, from this research study, it demonstrates the dependability of the combination of QFD and TRIZ techniques on the product development process. A design need by a customer was effectively recognised by applying the Quality Function Deployment (QFD) method in addition to the criteria selection using the Theory of Inventive Problem Solving (TRIZ) approach. In a summary, simulation studies show that an open face helmet with a liner may withstand more stress, but displacement and strain are higher. The comparable stress is lowered by 58.31% while the displacement is reduced by 17.75%. The strain value in the helmet without a liner is 84.21% higher.

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