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ORIGINAL ARTICLE

Applying TRIZ to Design and Develop Roof Shield for Two-Wheeled Motorcycle

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ABSTRACT – Online purchasing and food delivery have shown an increase in demand during the pandemic COVID-19. In Malaysia, the most preferred mode of transportation for food delivery is motorcycle. However, the hot weather and rain affect the delivery time. This paper presents the effort to design and develop a roof shield for a motorcycle to tackle the problem of delivery during uncertain weather conditions. A survey was conducted around Pekan and Kuantan, Pahang districts, encompassing a total of 100 respondents, including riders and customers. From respondents' feedback, the design requirements for the roof shield were derived. Two conceptual designs were sketched based on the TRIZ approach and evaluated using the scoring test matrix. The roof shield is designed so that it is height adjustable and expandable to fit different brands of motorcycles, which have slightly different dimensions. Furthermore, the rotatable roof is developed to improve riding, especially during cornering. The fabricated roof was assembled on the AVETA DY90 and DEMAK EX90 motorcycles. Twenty random riders were chosen to test the roofed motorcycle on the road. The feedback collected from them showed overall satisfaction with the roof shield installed on the motorcycle. They believed that the roof can protect them from the sun's rays and light rain thereby increasing delivery performance. The suggestion by the rider to further improve the roof is being considered for future design.

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INTRODUCTION

By the end of the first quarter of 2019, almost every nation across the globe was shocked by the transmission of the COVID-19 virus. The uncertainty around the mutation of new variants in the ensuing months has affected both the economy and the general health of the public. Despite the scare and negative economic effects, demand for food delivery has emerged to be a preferred method for people to continue with their 'eating out experience' whilst minimizing human interaction. In Malaysia, the most common mode of food transportation is by motorcycles, as it's the most economical and efficient means. However, as the number of motorists increases, it is reported that more than half of the total number of road accidents are associated with motorists. Both riding attitudes and uncertain weather conditions contribute to the factors attributing the statistics. Nevertheless, to fulfil customer satisfaction and maintain the hygiene of the ordered food, the riders usually have no choice but to continue delivering. This could be dangerous to the riders, especially during poor weather such as rain and extreme sun ray. The former affects the eyesight whereas the later leads to fatigue.

Malaysia is geographically located closer to the equator, making the climate only have dry, hot, humid, and rainy weather throughout the year. A heat index that exceeds 27 degrees Celsius will cause different categories of illness and even death [1]. According to the Ministry of Health Malaysia (MOH), there have been 200 cases, including two deaths, caused by the extreme hot weather that was recorded in 2016 [2]. In this case, riding a motorcycle under prolonged exposure in a hot environment for a long time is very dangerous, especially in Malaysia, which has recorded the highest ambient temperature of 37 degrees Celsius [3]. The extreme hot temperature not only raises the risk of health problems such as tiredness, heat exhaustion or even heat stroke [4], but the severity may lead to fatal road accidents. In even light rain, wearing a raincoat is the most preferable way for the riders to continue riding the motorcycle. However, it is difficult to keep the wet raincoat after use [5]. In the worst case, riders prefer to wear a helmet without any protective suit while riding the motorcycle [6].

Even after the impact of the pandemic COVID-19, the recovery of the economy does not reduce the number of motorcycle riders. This is due to the fact that the catering industries must change and combine their business models with the logistic field to form the food delivery online services to maintain productivity and adapt to the new health regulations and hygiene rules [7]. According to the findings of a survey conducted by the Bumiputera Agenda Steering unit (TERAJU) [8], more than 65 000 people changed jobs in the food delivery industries during the COVID-19 pandemic. Most of them preferred to use motorcycles over other transport. The reason is to avoid being tremendously congested due to a shortage of public transport and parking facilities [9]. The most attractive thing about using motorcycles is their affordable cost in terms of fuel consumption and maintenance. Besides that, motorcycles are available free of charge for parking space.

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To date, several researchers and automotive industries are attempting to challenge the delivery issue due to weather by equipping a motorcycle with a roof. However, in Malaysia, the use of roof shield is not yet unacceptable, possibly due to a lack of attractiveness, instability, lack of self-confidence (of the riders), unavailability in the market, and unaffordable cost, although it could benefit both the customer and the riders by reducing the time taken to deliver food during poor weather. For instance, Jusoh et al. (2020) [10] proposed a portable motorcycle roof, however, the roof design not only has flaws in terms of stability and strength but the frontal plastic cover may also become vision disturbance to the riders. Therefore, better improvements to the existing design in the market could possibly change the perception of the user towards the roofed motorcycle.

TRIZ, defined as Teoriya Resheniya Izobreatatelskikh Zadatch, translated to English as Theory of Inventive Problems, is one of the powerful methods widely used in generating ideas for problem solving. The method can be applied in a wider situation, including product development. In TRIZ, a so-called 40 inventive principles can be used to trigger inventive issues and possible solutions in any system by evaluating the contradiction problem. Mishra et al [11] applied the TRIZ method to improve the design of computer keyboards. They claimed that the TRIZ method led to the creation of various aspects of improvement in terms of efficiency, size reduction, and other new attractive designs. In addition, Ellen et al [12] employed the TRIZ method and manage to trigger 48 additional concepts for three new airbag designs. In another study, Jung et al [13] applied the TRIZ method with Root Conflict Analysis (RCA+) to find the potential solution for logistics improvement. They claimed that the TRIZ with RCA+ method is not only suitable in the area of engineering design problems but also can be employed to the logistics field.

The purpose of this work is to identify and determine the desired needs of the riders and customers regarding the possibility of equipping the motorcycles with a roof. Using the results from the survey, the roof shield is designed, fabricated, and installed on the motorcycle. The techniques of TRIZ are utilized to help in generating the conceptual design of the roof shield.

METHODS

Design Requirement through Questionaire and Interview

The difficulties due to weather problems faced by riders during delivery were identified. Before the conceptual design of the roof shield was being developed, the data was collected by means of a survey through a questionnaire and an interview to understand the desired needs and problems faced by the riders. The survey was conducted during a movement control order (MCO), thus, using the online medium of Google Form. However, after MCO was retracted, the interview was carried out by meeting the respondent face-to-face. The survey targeted two groups of respondents: food delivery customers and food delivery riders. For this case, two sets of questions were prepared and distributed to the respondents. Each group of respondents is required to answer a total of ten (10) questions, which includes multiple choice, rating scale questions, and image choice questions. The interview session was conducted at Kuantan, Pahang, and Sabak Bernam, Selangor.

Based on the results and findings obtained through the survey, ten design requirements that must be considered when developing the roof shield were identified (see Table 1). A description of each requirement was also provided. The potential solution based on the 40 inventive principles proposed by TRIZ was employed during idea generation of conceptual design.

Table 1. Summary of design requirement obtained from the survey

No	Crucial criteria	Descriptions
1	Portable	It measures the overall weight of the product and its capability of being disassembled.
2	Cost	Includes production costs, manufacturing costs, labor costs, materials and other expenses.
3	Strength	The ability to withstand the impact of weathers such as wind, rain water, and working load.
4	Durability	The ability to use for an extended period of time, exposure to various environments, and other factors.
5	Safety	The safety ranking of the product designs for users without the risk of injury.
6	Functionality	The improvement and innovation of the quality, performance, services, and value from the existing products.
7	Simplicity	The complexity of the structure or mechanism used for product installation, handling, operation, and assembly.
8	Attractiveness	The product's attractiveness scales to reach the buyers, including shape and appearance characteristics
9	Storage	The ability to keep or store more goods or food that being delivered
10	Maintenance	It measures the convenient of replacement or repair of the product.

Concept Scoring

Concept scoring concentrates on the desired needs of customers by narrowing down all the design concepts and finding out the potential design with the evaluation and analysis from the set of selection criteria. Ten design requirements gathered from the respondents or questionnaire were used to construct the concept screening for every proposed conceptual design. Every design requirement was given a weightage, in which the value depends on the level of importance of each requirement. A rating of 1 to 5 for every design requirement was given to each conceptual design according to Table 2. A higher rating value corresponds to a 'better' design and a lower rating corresponds to a 'worse' design. Once the rating was given, the score of each parameter was calculated according to the formula in Eq. (1):

$$\text{Score} = \frac{Rate}{Total\ Rating\ (5)} \times Total\ Weighted\ Score \tag{1}$$

Table 2. Definition of rating score

Relative Performance	Rating
Much worse than	1
Worse than	2
Same as	3
Better than	4
Much better than	5

Idea Generation using TRIZ

The procedure of idea generation using TRIZ for roof shield has been reported by the author recently (Bin et al., 2021) [14]. The application of the TRIZ method with function analysis and (CECA) leads to 28 inventive principles that were applied to improve the design of roofed motorcycles. Furthermore, 17 potential solutions were triggered from the total of 40 inventive principles of TRIZ. The proposed solution that was related to the triggered inventive principles was brainstormed and followed by the improvement of the roof shield. Using the same procedure (as reported in the author's published paper [14]), two additional concept designs were proposed as discussed in the next section of this paper.

RESULTS AND DISCUSSION

Survey and Questionaire: Feedback from Riders

The responses have been successfully collected from 100 respondents, which include 55 riders and 45 customers. Late delivery (43.6% of respondents), poor quality of the food being delivered (41.8% of respondents) and dangerous driving are the three major problems that are frequently mistaken by the riders. The respondents confirmed the reason of these three problems are due to the weather (about 69.1% of respondents), time delay of food preparation (about 67.3%), and traffic congestion (about 34.5%). Based on the survey, 58.2% of riders think that poor weather had a substantial impact on their delivery performance. To overcome the poor weather of rain, 96.3% of riders prefer to wear a raincoat. Surprisingly, 0% of riders are willing to use the current available roof product available from the market. Besides, the results revealed that 70.6% of respondents believed that the current available designs (of motorcycle's roof) are not stable, 11.8% stated it will increase the dangerous risks during riding and 29.4% of them thought the roof can cause decreasing in motorcycle's speed.

Survey and Questionaire: Feedback from Customer

Poor weather, such as rain, not only affects the riders but also delays the arrival time for food delivery. From the data obtained, 77.3% of customers felt that they needed to wait a longer time during a rainy day, which causes them to be unsatisfied. This shows that the arrival time is an important factor for food delivery services. Furthermore, another problem faced by the customers is the poor food quality. The feedback from customers shows that the possible causes of the occurrence of those problems are the uncertain weather and long travel distances. Moreover, 53.3% of customers have less confidence in the current market designs (of roofs). They stated that the design is unable to help riders encounter weather problems.

Conceptual Design of Roof Shield

First concept design

Based on No. 3 inventive principle "Local Quantity" and No. 17 "Another Dimension" of TRIZ, the storage box in the first design concept is divided into two layers. The purpose of the multi-layers design is to keep the roof components in the first layer storage (box no. 1), whereas the second layer (box no. 2) is to keep the food or parcel. Furthermore, the roof top is made using fabric and has a 'measuring tape' mechanism (Principle 13: The other way round; Principle 15: Dynamization; Principle 28: Mechanical System) which can provide the function of either being stored or pulled out to connect with the windscreen if necessary (Principle 7: Nested Dolls). With the idea of "inventive principle #10: Prior Action", the first concept design is added with an electrical actuator lifting device which can adjust the desired height of the top roof according to the dimensions of the user or rider. In addition, the first design is also equipped with back seat support as an aesthetic value. The use of curve shape design at windscreen, which derived from inventive principle "#12: Curvatures", not only improves the overall appearance of the roofed motorcycle but also improves its aerodynamics performance. Lastly, it is important to define the inventive principles for the material selection of the components that can affect the performance of the motorcycle (Principle 8: Anti-weight). Therefore, a fabric roof and a polycarbonate or acrylic plastic windshield are proposed.

The attractiveness of the first concept design is due to its unique mechanism, i.e., measuring tape-like mechanism. The assembly design strategy with elastic fabric allowed the product to be used by keeping or pulling the fabric out of the first storage box. Lightweight fabric tends to decrease the overall weight of the roof shield. The fabric also offers several advantages, such as color options, ease of sizing, and an affordable price. The adjustment height of the roof is controlled by the electrical actuator and is stored in the second storage box. However, the designs also include some limitations. More space in the storage box is required to keep the electronic devices. Besides that, inadequate strength of the fabric may result in being unable to withstand the high impact of forces during strong wind and heavy rain. Due to the uniqueness of the design, i.e., measuring tape-like mechanism, this may lead to a problem with future maintenance. Since the roof shield is provided with electronic devices, therefore, it is compulsory to provide a variety of safety rules, electrical protective devices, and precautions to prevent the risk of electrical shock and damage due to the penetration of water into the electrical components.

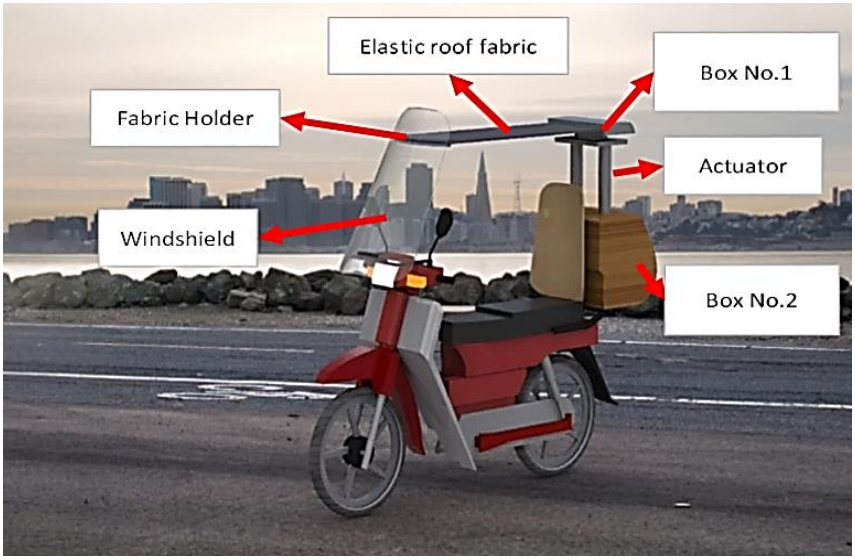


Figure 1. First design concept of roof shield

Second concept design

It is important to define the inventive principles for the material selection of the components (Principle 8: Anti-weight), which can affect the overall performance of the roofed motorcycle. Therefore, a polycarbonate or acrylic plastic windshield is proposed for the second design. In order to increase the aerodynamic performance of the roofed motorcycle, the windshield is recommended to be designed with a curvature shape (Principle 14: Curvature). Apart from that, the roofed motorcycle is designed so that it is portable (inventive principles #1-Segmentation). To meet the user demand, several inventive principles of TRIZ (Principle 13: The other way around, Principle 15: Dynamization and Principle 28: Mechanical System) are introduced in which the roof is height adjustable and expandable in length using the levelling feet and sliding rail, respectively. Based on the inventive principle #2 (Taking out), the electrical device is not recommended for this concept design to avoid the potential hazard risks of electricity shocks and complexity due to a huge number of connection wires. The back frame support, which is constructed into two layers (Principle 6 Universality), is designed to allow the users to place a storage box and the other parts such as roof and windshield components.

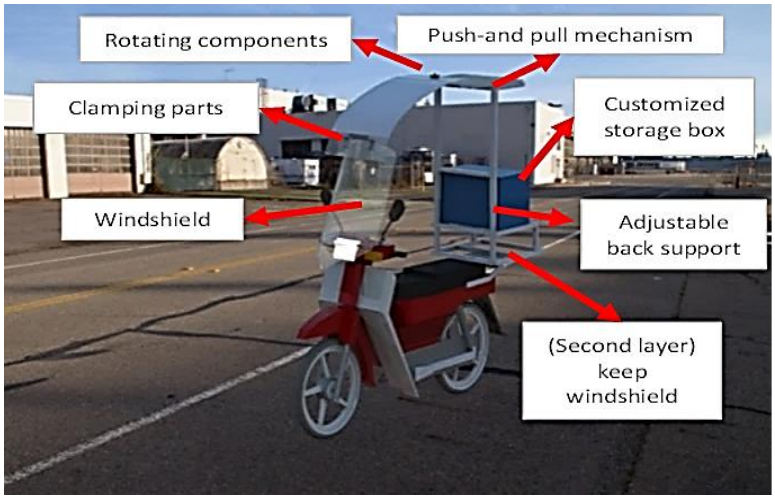


Figure 2. Second design concept of roof shield

Comparison between the two concept designs, it is showed that the second design is more practical and involves two types of adjustable systems to control the height and length of the roof shield. The adjustable parts offer convertible and portable support, which can be either installed on the motorcycle or taken out when the roof shield is not in use. In order to tackle the weather problems, the back support has been constructed with the good mechanical strength properties of the aluminium frame. The back support's "*T*" shape design not only provides reinforcement to the roof shield but also allows for ease fabrication work with lower machining costs. Regarding the prices, the maintenance and repairs for the second design are relatively cheaper and the parts are convenient to disassemble. The ready-to-use storage bag can be purchased from the market and placed on the back support. In addition, the roof shield is designed with fully mechanical-controlled mechanisms.

Table 3 shows the evaluation of every design concept based on the 10 design criteria gathered from the survey. The rating for each criterion is carefully given based on critical brainstorming. Clearly, design concept 2 gives a better score with 79 marks out of 100, compared to design concept 1 with 47 marks. Therefore, design concept 2 is proceeding to the next stage of the fabrication process.

Table 3. Concept scoring result

Selection Criteria	Weight (%)	Design Concept 1		Design Concept 2	
		Rating	Score	Rating	Score
Portable	5	3	3	5	5
Cost	5	4	4	4	4
Strength	10	3	6	3	6
Durability	10	3	6	3	6
Safety	15	2	6	4	12
Functionality	15	3	9	5	15
Simplicity	10	3	6	2	4
Attractiveness	15	3	9	4	12
Storage	10	2	4	5	10
Maintenance	5	3	3	5	5
Total Score	100		47		79
Rank			2		1
Continue?			No		Yes

Fabrication Works

This section deals with the strategy of the development of the roofed motorcycle. The fabrication process is divided into three main parts, namely back support, windshield, and roof top. The detailed components of each part are described in the following section of this paper. For better view, the fabricated part is positioned next to the CAD drawing (using Solidworks software).

Back support

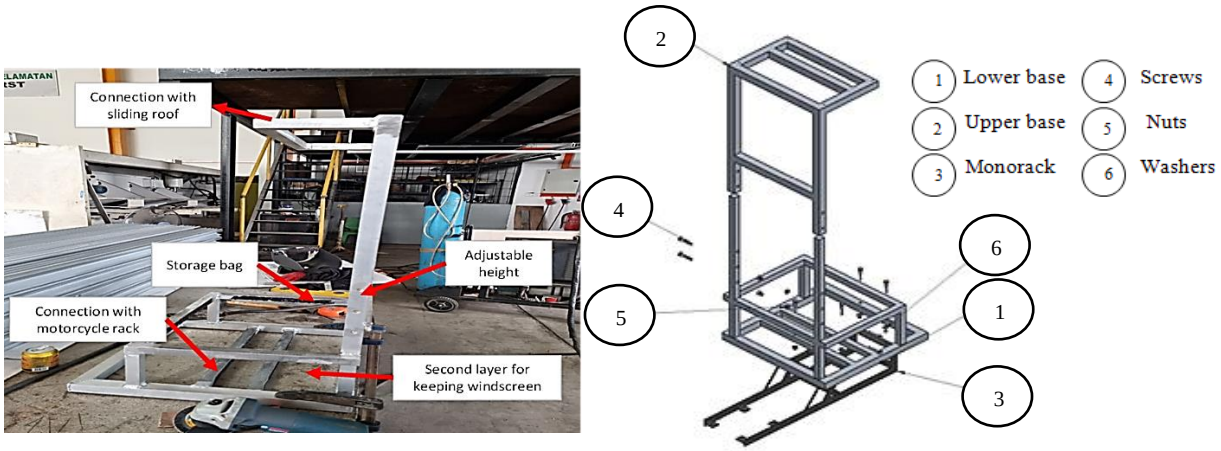
Figure 3 illustrates the accomplished fabrication of back support together with the CAD model. The material used for the construction of the back support is aluminium square hollow due to its strong environmental resistances, rigidity, and anti-rusting properties. The 3 mm thick aluminium sections are welded with full penetration welding to ensure complete fusion and a stronger weld for every joint connection. The height adjustable of the roof works by inserting the screws into the drilled holes on each side of its legs. This type of levelling allows changing the height in small increments depending on the height of the user or rider. The round-metal filler with lubricant of grease is used to smooth the holes of the square hollow sections. Lastly, the surface grinding comes into the final stage to remove sharp corners and excessive layers on the weld surface.

Windshield

Figure 4 shows the accomplished assembly of windshield components and the CAD model. Fabricating the frontal windshield with aerodynamic features is challenging. Therefore, this part has been purchased from the market. However, the bought windshield has a narrow width and does not fulfill the initial plan of the design concept. Therefore, several modifications have been made to the existing windshield by adding a 3 mm thick polycarbonate board on each side to widen the coverage area of the windshield. This provides a bigger protective area for the riders or users.

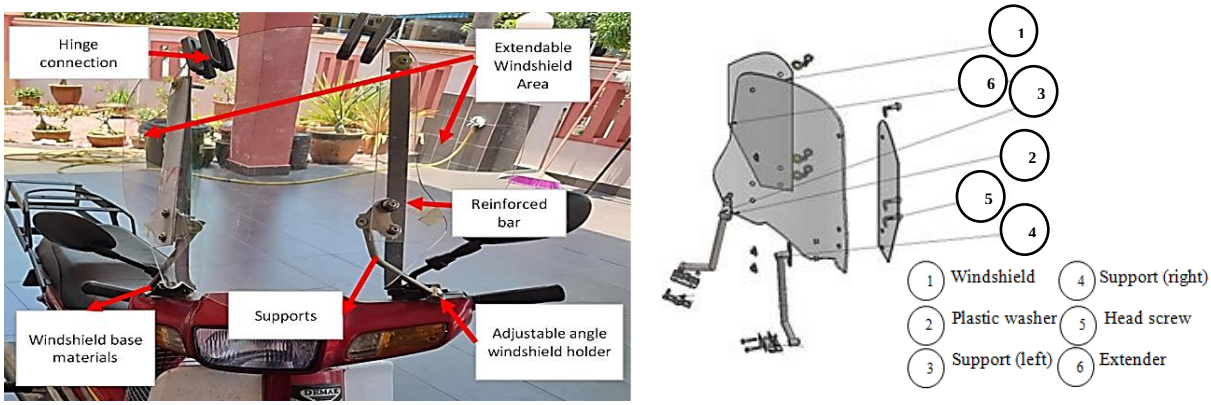
Roof Top

The roof top of the motorcycle provides protection to the rider from the exposure of extreme weather. Figure 5 and Figure 6 illustrate the fabricated roof top components and CAD model, respectively. The roof top consists of two sliding tracks and a ball bearing to allow the length adjustment in the horizontal direction. The sliding tracks allowed for length extensions ranging from 50 cm to 100 cm. Besides that, small screws are used along with the washers to prevent damage to the polycarbonate sheet. In order to prevent the backflow of the rainwater, a 430 mm long L-shaped bar was placed at one end of the slider (see Figure 5). In addition, a circular PVC pipe with a horizontal cut is inserted into the *L*-shaped bar to avoid any scratches on the polycarbonate roof top. Since the windshield is directly connected to the handle of the motorcycle, the ball and socket joint is designed to connect between the windshield and the top roof. The purpose of this joint is to unconstraint the handle while driving, especially during cornering. Furthermore, all edges of the upper fairing are wrapped with rubber to protect the rider from the sharp corners. At the same time, the wrapping of rubber also tends to increase attractiveness and acts as a protective layer from the scratches and leaking of rainwater.



(a) (b)

Figure 3. Back support components: (a) physical/fabricated and (b) schematic



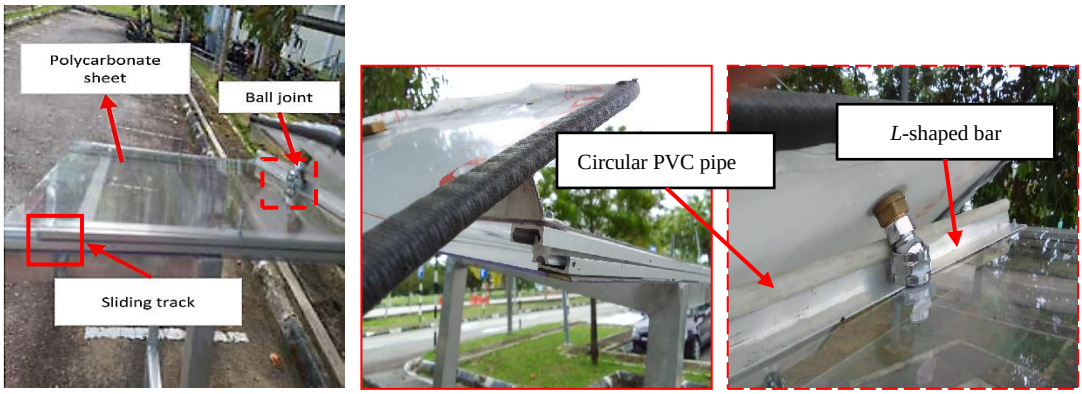
(a) (b)

Figure 4. Windshield components: (a) physical/fabricated and (b) schematic

Fabrication Works and User/Rider Feedback

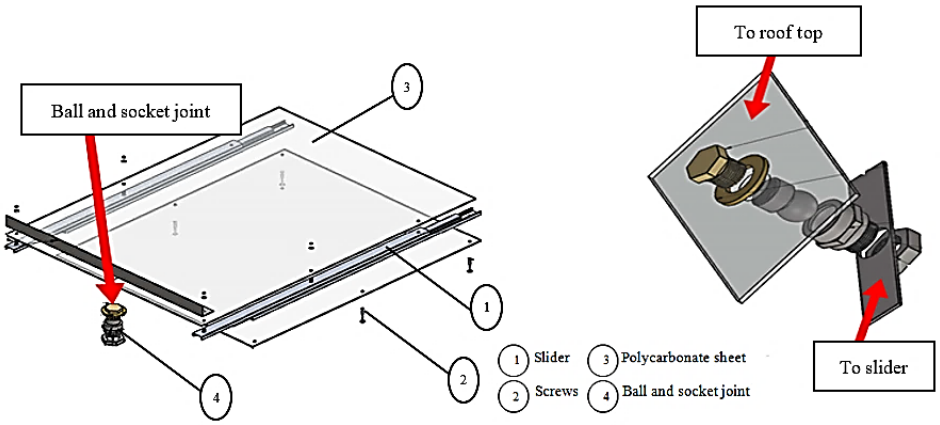
The fabricated roof has been successfully assembled on the two motorcycle brands, AVETA DY90 and DEMAK EX90, as shown in Figure 7. With both motorcycles having slightly different sizes in length, with slider mechanisms of roof, it can be fitted to the motorcycles. Beyond that, the roof can also be adjusted in terms of its height to fit the riders or users. For the actual road riding experience and feedback, a total of 20 riders/users are randomly chosen. Approximately 90% of the participants show a positive impression towards the roofed motorcycle. However, the other 10% believed that the appearance of the roofed motorcycle could be further improved. Out of 10% of the unsatisfied users, 5% feel that the instability of the motorcycle is the factor that leads to the uncomfortable condition.

About 95% of the respondents agreed that the application of roofed motorcycles is able to protect the riders from the exposure of bad weather in the case of rainy and extreme sun rays. Furthermore, 80 percent of the delivery riders anticipated that these roofed motorcycles would increase their delivery performances. The appearance, uniqueness, functionality, and ease of assembling and disassembling are among the aspects that attract riders to use the roofed motorcycle. However, slightly dissatisfied, was expressed by the rider involving the steering stiffness of the motorcycle. Due to the application of weight load (of the roof) on the steering of the motorcycle, some riders are worried about the handling of the motorcycle even though the steering is able to rotate while riding or during cornering. From other feedback, some of the riders claimed that the steering stiffness is a tiny problem that can be adapted easily. Nonetheless, this roofed motorcycle has shown high market potential based on the feedback received from most of the riders. There are a few suggestions proposed by the respondents to enhance the roof design, such as employing bearings for better handling during cornering, permanent fitting of the windshield for stability, providing a lock for the roof top (at the slider), and tinting windshield. Figure 8 shows the road-testing experiences of the riders. The road testing has been conducted in various conditions, such as single rider, rider with passenger, rain, and also during cornering.



(a) (b) (c)

Figure 5. Fabricated roof top: (a) sliding track and ball joint, (b) close-up of sliding track and (c) L-shaped bar



(a) (b)

Figure 6. Detailed of roof top components: (a) sliding track and (b) ball joint

(a) (b)

Figure 7. Roof assembly on two different motorcycle brand: (a) AVETA DY90 and (b) DEMAK EX90

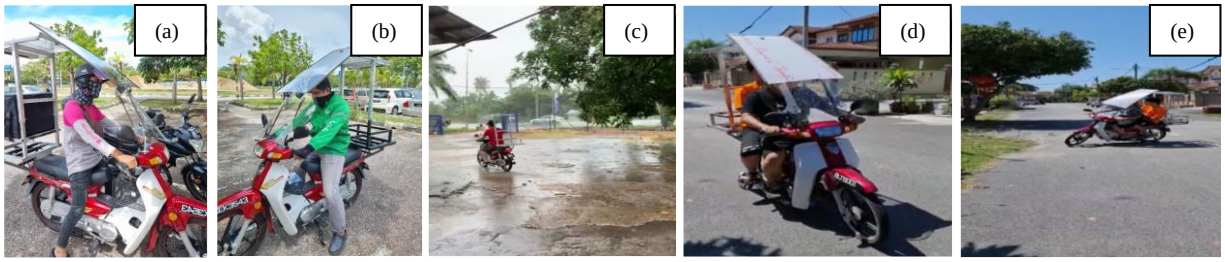


Figure 8. Road testing: (a) rider 1, (b) rider 2 (c) during raining, (d) with rider and passenger and (e) during cornering

CONCLUSION

The design, fabrication, and testing of the new roof for the two-wheeled motorcycle have been performed. Several conclusions can be drawn as follows:

1. Based on the respondents' feedback, 10 design requirements have been identified and are tabulated in Table 1. The new design concept for a motorcycle's roof is proposed using the inventive principle of TRIZ based on the design requirements.
2. The roof with unique functions such as height adjustable, slider (for length adjustment) and rotating ball and socket joint appears to offer advantages over existing products in the market.
3. Most of the riders or users were satisfied with the fabricated roof and believed that the roof could increase their job performance in terms of delivery time during poor weather (light rain and extreme sun ray).
4. Based on the feedback from riders/users, several improvements to the components that affect cornering can still be made.

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