

Design and Development of a Foldable Triangular Emergency Hazard Light to Enhance Safety of Powered Two-Wheel Motorcycles

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ABSTRACT

Motorcycle roadside emergencies can expose riders to increased risk when a stationary motorcycle is insufficiently visible to approaching road users, particularly under nighttime and low-visibility conditions. Conventional reflective warning triangles provide passive visibility but may offer limited conspicuity as observation distance increases. This study aimed to develop a foldable triangular emergency hazard light for powered two-wheelers (PTWs) motorcycles, integrating active LED illumination, reflective materials, rechargeable energy storage, solar charging, and a compact folding configuration. A design and development methodology was adopted, comprising a user requirement survey, conceptual design, Pugh concept selection, prototype fabrication, and experimental visibility evaluation. The survey involved 164 Malaysian motorcycle riders, of whom 65% reported frequent nighttime or low-visibility riding and 59% had experienced a roadside emergency or motorcycle breakdown. Three conceptual designs were evaluated using the Pugh method, with Design C achieving the highest net score of 4 and subsequently selected for prototype fabrication. A total 150 motorcycles riders participated in the recognition performance experiment. The prototype was compared with a conventional warning triangle at 50, 75, and 100 m on straight and curved road sections under daytime, nighttime with street lighting, and nighttime without street lighting conditions. On straight roads, the prototype achieved visibility scores of 10, 10, and 9 at 50, 75, and 100 m, respectively, under nighttime conditions without street lighting, compared with 4, 2, and 1 for the conventional triangle. On curved roads, the prototype achieved 3, 7, and 9, compared with 4, 3, and 1, respectively. The findings demonstrate that the developed prototype provides improved visibility, particularly under nighttime conditions, while maintaining portability through its foldable configuration.

Keywords: Emergency hazard light; motorcycle safety; visibility; LED warning system; prototype development.

INTRODUCTION

Motorcycles are a popular means of transport, particularly for daily travel in urban and developing regions, because they are affordable, economical and maneuverable. The increasing popularity of powered two-wheelers (PTWs) has raised concerns about road safety, as motorcyclists have limited physical protection and are more exposed to surrounding traffic hazards than occupants of passenger vehicles. Recent studies suggest that motorbike crashes are influenced by a combination of rider characteristics, riding behaviour, road conditions, crash circumstances, and other interacting risk factors (Fang et al., 2026; Ferko et al., 2025; Islam & Li, 2026). Another important safety consideration is motorcycle conspicuity. The ability of other road users to detect and correctly interpret the presence of a motorcycle can affect their response to

potential conflicts. Previous research has shown that the conspicuity of motorcycles is affected by the visual environment, the visual appearance of the motorcycle, the lighting configuration and the attention of other road users (Bowo et al., 2025; Gershon et al., 2012; Williams & Hoffmann, 1979; Wulf et al., 1989). Furthermore, studies of motorcycle detection systems showed the need to improve drivers' capability to recognise motorcycles in the surrounding traffic (Kassim et al., 2021). These results suggest that motorcycle safety is determined not only by rider behaviour and infrastructure improvements but also by applicable countermeasures that improve the visibility and detectability of motorcycles.

The visibility of motorcycles has been extensively studied using means of lighting and visual enhancement techniques. Research has shown that daytime running lights and other lighting combinations increase the probability of motorcycle detection by other road users (Farmer & Williams, 2002; Haferkemper et al., 2010; Smither & Torrez, 2010). Gershon and Shinar (2013) showed that an alternating-blinking lighting system can improve motorcycle conspicuity for attention and search, while Pinto et al. (2014) reported that the configuration of the front lighting affects visual conspicuity. Detection distance is also important, as a warning device that is recognizable from a greater distance may provide approaching drivers with more time to respond. A greater distance may give approaching drivers more time to respond. Specifically, Khalid et al. (2020) investigated motorcycle conspicuity in relation to detection distance. Wells et al. (2004) found a relationship between motorcycle rider conspicuity and injury severity in crashes. Recent reviews have continued to identify conspicuity as an important component of motorcycle safety and have emphasized the need for interventions that enhance motorcycle visibility across different traffic and environmental conditions (Bowo et al., 2025; Khalid et al., 2021). However, most of the existing literature focuses on motorcycle detection under normal riding conditions. The visibility of a stopped motorcycle due to a breakdown or roadside emergency has received less attention, as the motorcycle may have a smaller visual profile and may require an independent warning device.

The visibility problem in a roadside emergency differs from that encountered during normal motorcycle operation. A motorcycle parked at the roadside may not provide sufficient visual information to approaching road users, particularly at night or in areas with limited street lighting. Standard emergency warning triangles mainly rely on the reflected or retro-reflected light of approaching vehicles. Their effectiveness could be affected by factors such as lighting conditions, distance of observation, road geometry and the ability of an oncoming driver to identify the warning device. Earlier research on motorcycle conspicuity has shown that visual detection can vary widely depending on environmental and visual conditions (de Craen et al., 2014; Gershon et al., 2012; Shaheed et al., 2015). This problem is more acute for low capacity. PTWs with capacities below 150 cc have limited storage space, making it less convenient to carry and deploy conventional emergency equipment. A suitable warning device must therefore be highly visible but also compact, light, portable, easy to deploy and robust enough for roadside use. Active LED illumination can be added to provide an independent light source. Reflective material can augment the visual warning function. Rechargeable energy storage and solar charging can also improve operational flexibility by decreasing dependence on an external power source. Previous studies have examined solar-powered warning and alarm systems to improve their energy autonomy and practicality (Ehiaguina et al., 2023). Therefore, there is a need to combine visibility enhancement, portability, foldability, and independent power supply into an emergency warning device for motorcycles.

Hence, the present research work aims to design and develop a foldable triangular emergency hazard light for powered two-wheeled motorcycles with engines below 150 cc to enhance the motorcycle's visibility during a roadside emergency. The proposed device combines active illumination through LEDs, reflective material, rechargeable battery storage, solar charging and a foldable mechanical structure. The design and development approach adopted in the study comprises four principal stages, namely user requirement identification, conceptual design development and selection, prototype fabrication and experimental performance evaluation. A survey of 164 Malaysian motorcycle riders was carried out to identify riding conditions and past roadside emergencies experienced and features that are sought for an emergency warning device. Three alternative concepts were then developed using computer-aided design and evaluated using the Pugh Concept Selection Method based on size, stability, cost, ease of use, lightweight construction, durability, and comfort. The highest-ranked concept was fabricated into a functional

prototype and tested against a conventional reflective warning triangle at observation distances of 50, 75 and 100 m on straight and curved road sections under daytime, nighttime with street lighting and nighttime without street lighting conditions. Therefore, this work explores the potential of an active, foldable warning system that improves visibility while meeting the practical needs of PTW users with limited capacity.

METHODOLOGY

Literature Review and Hypothesis Development

This study adopts a design-and-development methodology to develop a foldable triangular emergency hazard light for powered two-wheel (PTW) motorcycles. The research process consists of several sequential stages, beginning with the Introduction and Literature Review, followed by a user requirement survey, conceptual design development, product and electrical circuit design, prototype fabrication, and performance testing. The overall research process and decision-making sequence are illustrated in Figure 1. The methodology incorporates an iterative process to ensure that the proposed design meets the identified requirements. The conceptual design and electrical circuit are evaluated before fabrication. If the design is not acceptable, modifications are made and the design process is repeated. Once an acceptable design is obtained, the prototype is fabricated and tested. If the test results are unsatisfactory, further modifications and fabrication are conducted before repeating the testing process. The results are then analyzed and discussed to establish the performance of the developed emergency hazard light.

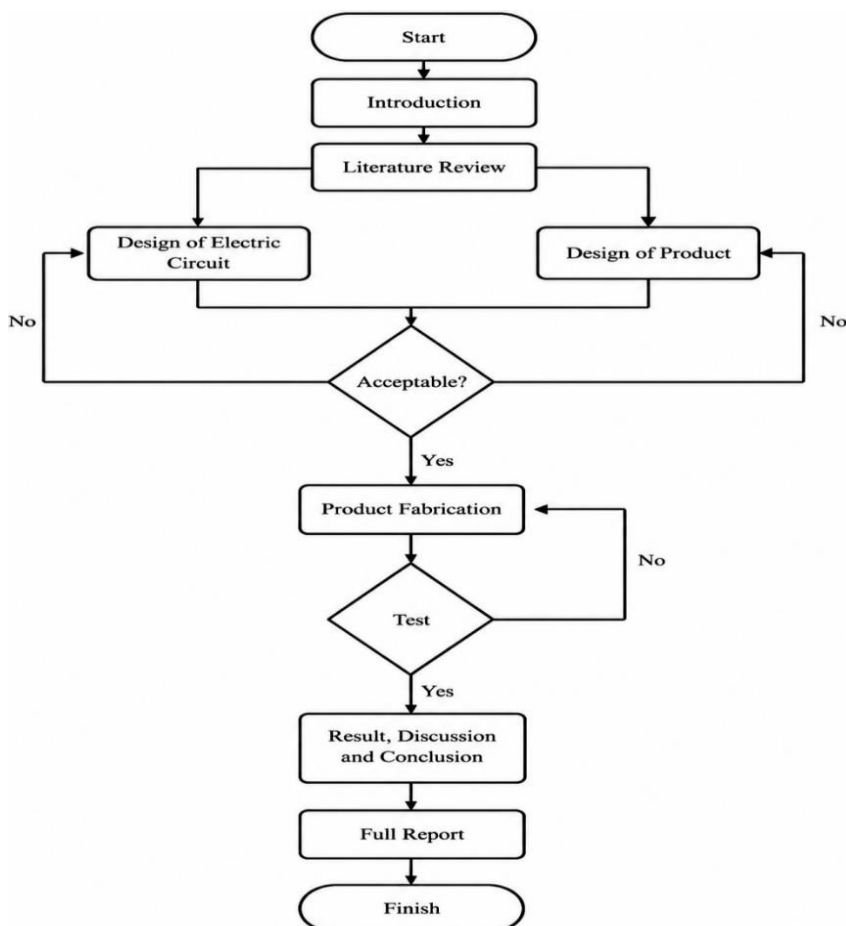


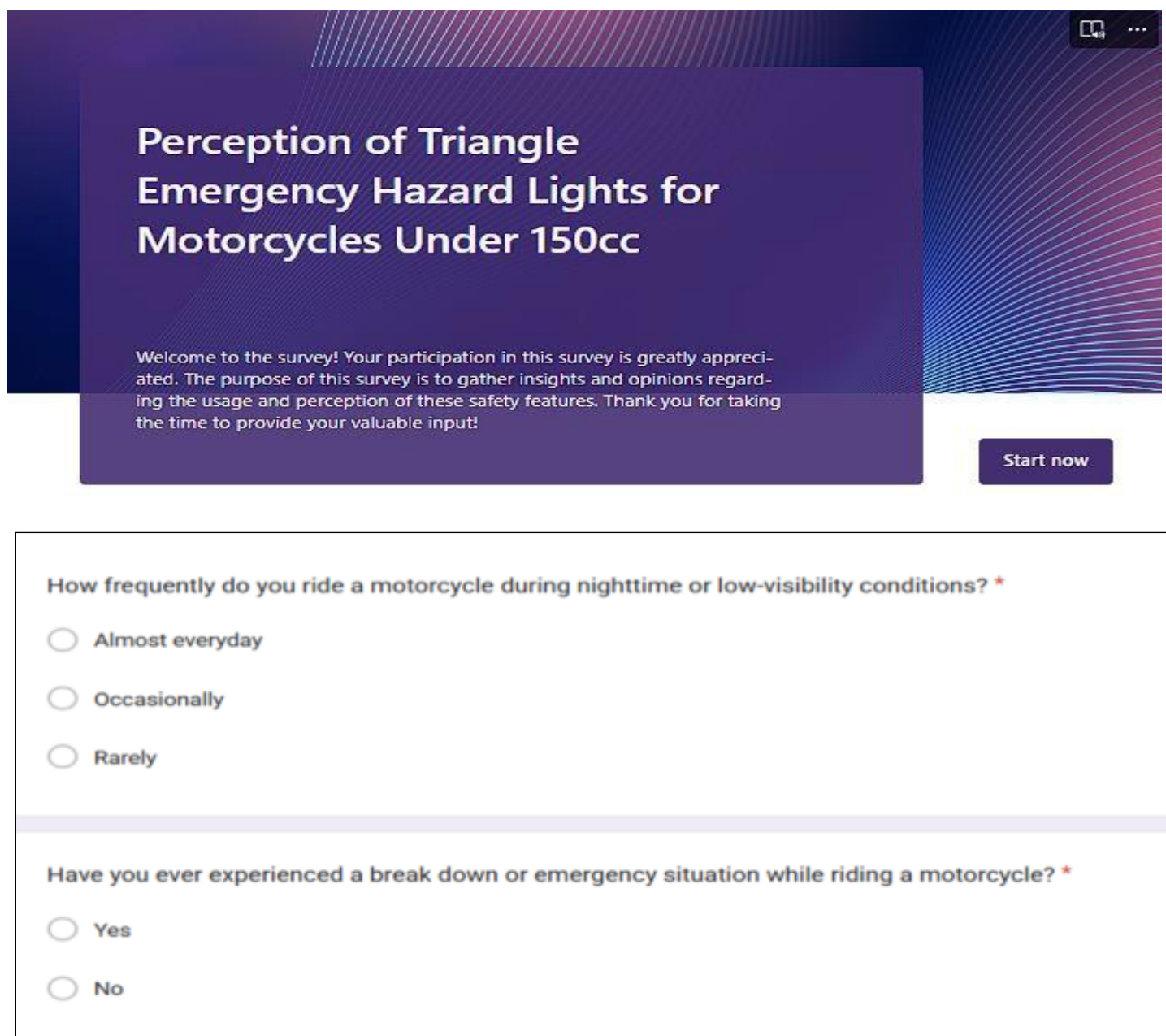
Figure 1 Methodology Flowchart For The Design And Development Of The Foldable Triangular Emergency Hazard Light

User Requirement Survey

A structured questionnaire survey was conducted to identify motorcycle users' requirements and preferences for the development of the proposed emergency hazard light. The survey was administered to

164 motorcycle riders and was designed to gather information on motorcycle usage, riding conditions, experience with roadside emergencies or breakdowns, and preferred characteristics of an emergency warning device. The survey responses were used as the primary input for establishing the product requirements prior to the conceptual design stage.

The questionnaire was organized into several components covering the respondents' background, motorcycle riding conditions, previous roadside emergency experience, and user requirements for an emergency warning device. The respondents were asked to indicate their experience with nighttime or low-visibility riding and whether they had previously experienced a motorcycle breakdown or roadside emergency. In addition, the questionnaire assessed the importance of selected product characteristics, including visibility, portability, compactness, ease of use, lightweight construction, durability, affordability, weather resistance, and energy efficiency. Figure 2 shows the survey carried out for data collection.



The figure displays a survey form titled "Perception of Triangle Emergency Hazard Lights for Motorcycles Under 150cc". The form includes a welcome message and two questions with radio button options.

Perception of Triangle Emergency Hazard Lights for Motorcycles Under 150cc

Welcome to the survey! Your participation in this survey is greatly appreciated. The purpose of this survey is to gather insights and opinions regarding the usage and perception of these safety features. Thank you for taking the time to provide your valuable input!

Start now

How frequently do you ride a motorcycle during nighttime or low-visibility conditions? *

- ☐ Almost everyday
- ☐ Occasionally
- ☐ Rarely

Have you ever experienced a break down or emergency situation while riding a motorcycle? *

- ☐ Yes
- ☐ No

Figure 2 Survey form for data collections

The survey findings were subsequently translated into design requirements for the conceptual design process. In particular, the requirements for high visibility, portability, compactness, lightweight

construction, ease of use, durability, weather resistance, affordability, and energy efficiency were considered during the development and evaluation of the alternative concepts. The relationship between the survey findings and the resulting design requirements is presented in Table 1.

Table 1 User requirements and corresponding design considerations

No.	User requirement	Design consideration
1	Visibility	LED illumination and reflective material
2	Portability	Foldable structure
3	Compactness	Reduced dimensions during storage
4	Ease of use	Simple deployment and operation
5	Lightweight construction	Appropriate lightweight materials
6	Durability	Robust structural design
7	Affordability	Cost-effective component selection
8	Weather resistance	Protection of structural and electrical components
9	Energy efficiency	Rechargeable battery and solar charging

Design Concept and Selection Method

Following the identification of the user requirements, three alternative conceptual designs were developed using computer-aided design (CAD). The conceptual development focused on striking an appropriate balance between the functional requirements of the emergency hazard light and the practical needs of motorcycle users. In particular, the concepts were developed by considering differences in mounting configuration, portability, and storage capacity, while maintaining the fundamental triangular configuration required for an emergency warning device. The three conceptual designs are presented in Figure 3.

Three concepts were subsequently evaluated using Pugh Concept Selection Method. This method was applied to systematically compare the alternative concepts against a common set of design criteria. The evaluation criteria comprised size, stability, cost, ease of use, lightweight construction, durability, and comfort. Each concept was compared based on its relative performance against the selected criteria using positive (+), neutral (0), and negative (–) ratings. The resulting scores were then used to determine the relative suitability of each conceptual design for further development.

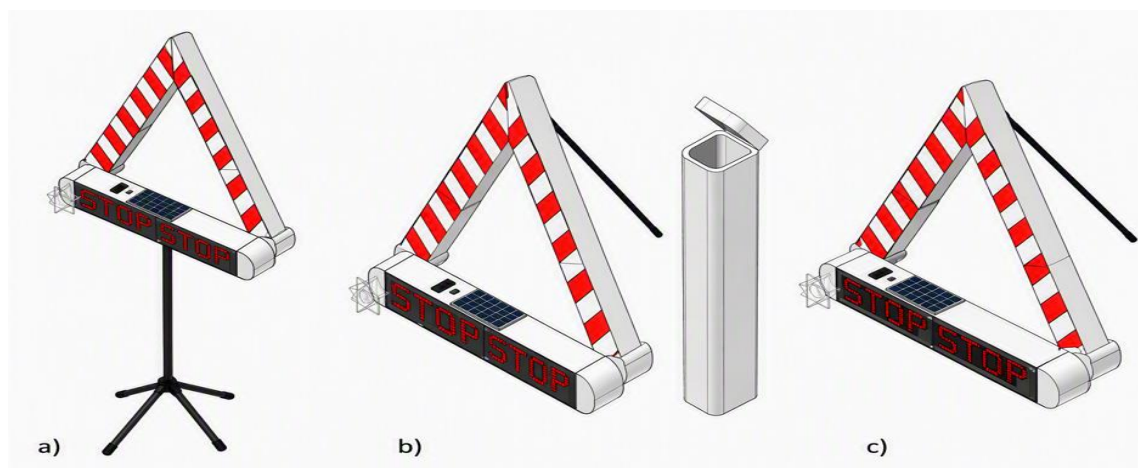


Figure 3 Conceptual designs of the triangular emergency hazard light: Design A, Design B, and Design C

Design A, Design B, and Design C achieved different performance levels across the selected criteria. Based on the Pugh concept selection, the highest score was ranked first and selected for subsequent prototype development. The design was selected for its overall balance of the specified design requirements, particularly its suitability in terms of size, cost, ease of use, lightweight construction, and comfort. The original methodology confirms that the final design was subsequently used to fabricate the prototype. The selected concept incorporated a foldable configuration to facilitate storage in the limited space available on a motorcycle while retaining the required emergency-warning functions. The design was further developed to accommodate the integration of LED lighting, battery storage, solar charging, and reflective elements. This integration allowed the selected concept to progress from a preliminary CAD model to a functional prototype while maintaining the portability and compactness requirements established during the user requirement stage. The selected concept was therefore carried forward to the material selection and prototype manufacturing stage.

Prototype Fabrication

Following the analysis using the Pugh Concept Selection Method, a functional prototype of the foldable triangular emergency hazard light was fabricated. The prototype was developed using an additive manufacturing approach to produce the main structural components, followed by the integration of the electrical and visual components required for emergency warning operation. The fabrication process was carried out in accordance with the selected conceptual configuration, while maintaining the device's intended foldable structure and portability. The fabricated prototype incorporated LED modules, reflective tape, a lithium-ion battery, a solar panel, a printed circuit board (PCB), and a USB Type-C charging interface. The LED modules provided active illumination to enhance the visual warning function, while the reflective tape provided a passive visual warning when exposed to external illumination. The lithium-ion battery supplied power to the lighting system, while the solar panel and USB Type-C interface provided alternative charging options. The PCB was used to integrate and control the electrical components within the prototype.

The prototype consisted of three main functional elements: the mechanical structure, visual warning system, and energy system. The mechanical structure provided the triangular warning form and folding mechanism, allowing the device to be deployed during an emergency and folded for storage when not in use. The visual warning system combined active LED illumination with reflective surfaces, while the energy system supported the device's operation and charging. The integration of these components was intended to produce a compact, portable emergency warning device suitable for PTW motorcycles. The completed prototype was inspected in both deployed and folded configurations to confirm the intended operating and storage arrangements. The deployed configuration was subsequently used for the visibility evaluation. The prototype fabrication and component integration are illustrated in Figure 4.

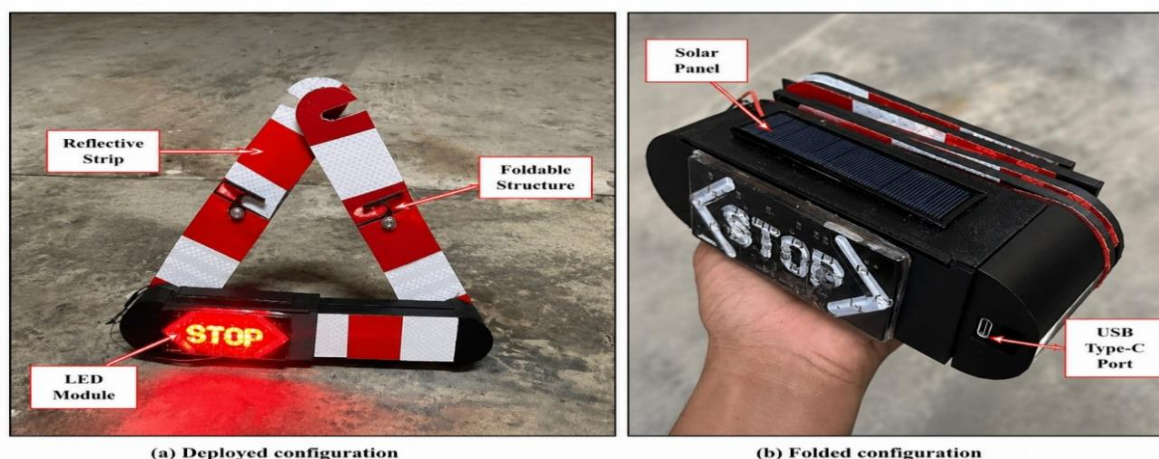


Figure 4 Foldable triangle emergency hazard light prototype

Experimental Testing and Evaluation

The fabricated prototype was evaluated experimentally to determine its visibility performance under different road and lighting conditions. The evaluation was conducted by comparing the developed foldable emergency hazard light with a conventional reflective warning triangle, as shown in Figure 5. The comparison was intended to determine whether integrating active LED illumination with a reflective material could improve the visibility of a stationary motorcycle during roadside emergencies.

The visibility evaluation was conducted at three observation distances of 50, 75, and 100 m. Two road configurations, namely straight and curved road sections, were considered to represent different approaching conditions. The tests were further conducted under three lighting conditions: daytime, nighttime with street lighting, and nighttime without street lighting. These conditions were selected to assess the performance of the warning devices under varying levels of ambient illumination.



Figure 5 Triangular emergency hazard light final prototype and standard benchmark model

The recognition performance experiment involved 150 motorcycle riders as participants. Visibility rating was evaluated using a subjective rating scale from 1 to 10 by a panel observer with normal or corrected-to-normal vision as show in Table 2. Observers were positioned at distances of 50 m, 75 m, and 100 m and asked to assess the ease of detecting and recognizing the road sign under different lighting conditions.

Table 2 Visibility rating scale

Scale	Interpretation
1-2	Barely visible
3-4	Visible with considerable difficulty
5-6	Moderately visible
7-8	Clearly visible
9-10	Highly visible and easily recognizable

For each test condition, the developed hazard light and conventional warning triangle were positioned at the roadside at the designated distance from the observation point. The observer assessed the visibility of each warning device from the approaching position. The test procedure was repeated for all combinations of

observation distance, road configuration, and lighting condition. The visibility assessment was recorded systematically to enable comparison between the proposed device and the conventional warning triangle.

The experimental results were subsequently analyzed to determine the effect of warning-device type, observation distance, road geometry, and lighting condition on visibility. Attention was given to the performance of the LED-based warning system under nighttime conditions, where active illumination is expected to provide an advantage over a passive reflective warning triangle. The results obtained from the experimental evaluation were then used to assess the effectiveness of the proposed foldable emergency hazard light and to identify its potential advantages and limitations.

RESULTS AND DISCUSSION

Survey results

The survey was conducted online to examine Malaysian motorcycle riders' perceptions and preferences regarding triangle emergency hazard lights for motorcycles under 150 cc. A total of 164 riders participated voluntarily. The respondents were predominantly male (91%), with 83% aged 18–24 years and 67% having 1–5 years of riding experience. The findings showed that 65% frequently rode at night or under low-visibility conditions, and 59% had experienced a motorcycle breakdown or emergency. Regarding safety perception, 73% believed that emergency triangle hazard lights could improve motorcycle visibility, while 64% would consider using them if they were reasonably priced. These findings support the importance of improving motorcycle conspicuity, particularly under challenging visibility conditions (Bowo et al., 2025; Khalid et al., 2021; Gershon et al., 2012).

Regarding product acceptance and requirements, 81% of respondents indicated that they would use hazard lights under specific riding conditions, while 19% would not. For standardization, 36% supported mandatory use, whereas 59% preferred voluntary use. The main preferred features were compactness (31%), lightweight construction (17%), and ease of use (16%), followed by durability, affordability, portability, and weather resistance. These preferences highlight the need for a practical emergency warning device that combines portability with effective visibility and usability for motorcycle riders (Khalid et al., 2020; Shaheed et al., 2015; Wells et al., 2004).

Concept Selection using Pugh Method

The three conceptual designs shown in Table 3, Design A, Design B and Design C, will be evaluated using the Pugh Concept Selection Method. The criteria used to evaluate the designs include dimensions, stability, cost, usability, lightweight, durability, and comfort. The evaluation results indicated that Design C received the highest net score of 4, followed by Design B with a net score of 2, and Design A with a net score of 0. Therefore, Design C was used for prototype fabrication.

The chosen design was foldable for easy storage in motorcycle compartments while retaining key safety features, such as LED lighting, battery storage, and the ability to charge via solar power. The excellent performance of Design C demonstrates the necessity of considering portability and visibility in motorcycle safety apparatus. Earlier studies have found that rider safety is greatly improved by user-focused motorcycle visibility and safety features, particularly in low-visibility conditions (Haworth, 2021; Khalid et al., 2021). Additionally, recent studies have highlighted the importance of small, highly visible safety devices in improving motorcycle safety and reducing crash risk (Bowo et al., 2025; WHO, 2022).

Table 3 Pugh method selection outcomes for Design A, Design B, and Design C.

Selection Criteria	Design A	Design B	Design C
Size	-	0	+

Stability	+	0	0
Cost	-	-	+
Easy To Use	0	+	+
Lightweight	-	+	+
Durability	+	0	-
Comfortability	0	+	+
Sum +	2	3	5
Sum 0	2	3	2
Sum -	2	1	1
Net Score	0	2	4
Rank	3	2	1

Straight Road Visibility Performance Optimization Results

A total of 150 motorcycle riders participated in the recognition performance experiment to assess the effectiveness of the prototype under these varying conditions. Figure 6 presents the visibility efficiency comparison of the proposed emergency light prototype (column graph) against the standard warning triangle benchmark (line graph) in various lighting conditions on a straight roadway. Visibility tests were performed at distances of 50, 75 and 100 meters in day, night with street lighting and night without street lighting. Both devices had similar visibility at 50 meters in daytime conditions, with a score of 10. However, visibility dropped with distance, with the prototype and benchmark scoring 3 and 5, respectively, at 100 meters. The prototype performed better in the night-time environment. For 50, 75, and 100 meters, the prototype scored 10, 9, and 7, while the benchmark scored 8, 6, and 2. The most significant difference was recorded under night-time conditions without street lighting. The marks for the prototype were 10, 10, and 9, while the benchmark was only 4, 2, and 1.

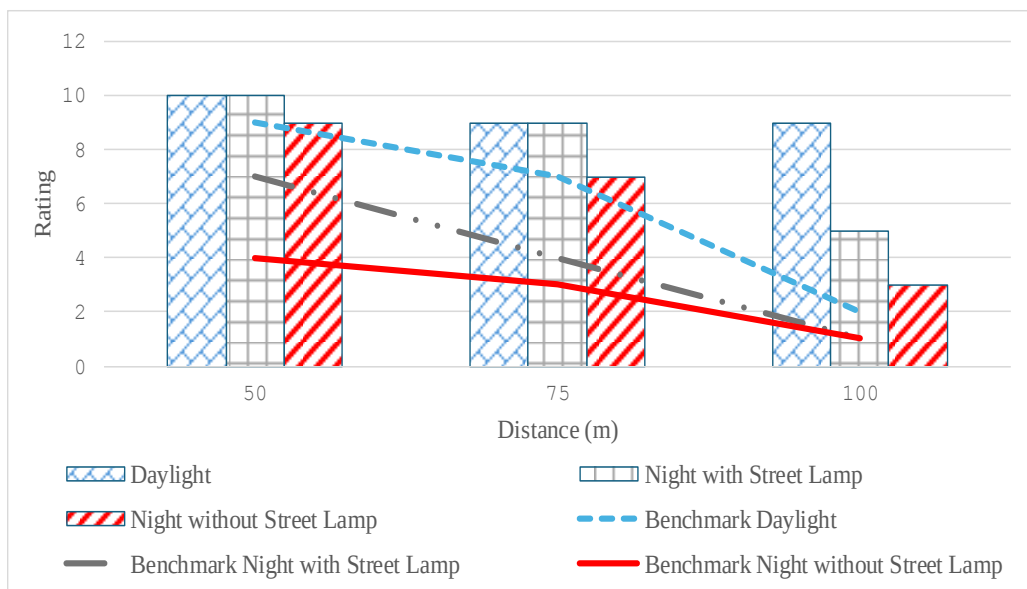


Figure 6 Visibility comparison of the proposed prototype and conventional warning triangle on a straight road under different environmental conditions

As shown in Figure 6, the prototype column graph remained relatively stable, whereas the benchmark line graph became less visible as distance increased. Adding LED lights and reflective parts makes it easier for the rider to see in low light. Similar studies indicate that increased motorcycle visibility substantially improves rider detection and reduces the likelihood of crashes at night (Haworth, 2021; World Health Organization, 2022). Advanced warning systems can also provide earlier detection by approaching motorists, which can reduce the chances of secondary crashes in roadside incidents (Se et al., 2025; Khalid et al., 2020).

Performance in visibility on curved roads

The visibility performance of the proposed emergency light prototype and the benchmark standard warning triangle line graph on curved roads with different weather conditions is shown in Figure 7. The proposed prototype regularly showed improved visibility, especially at night. The prototype achieved scores of 3, 7 and 9 on the visibility scale at 50, 75 and 100 meters away, respectively, with no street lighting, compared to the benchmark warning triangle, which scored 4, 3 and 1, respectively. At 100 m, under night conditions without street lighting, only 20% of participants correctly identified the sign, corresponding to a visibility score of 2.

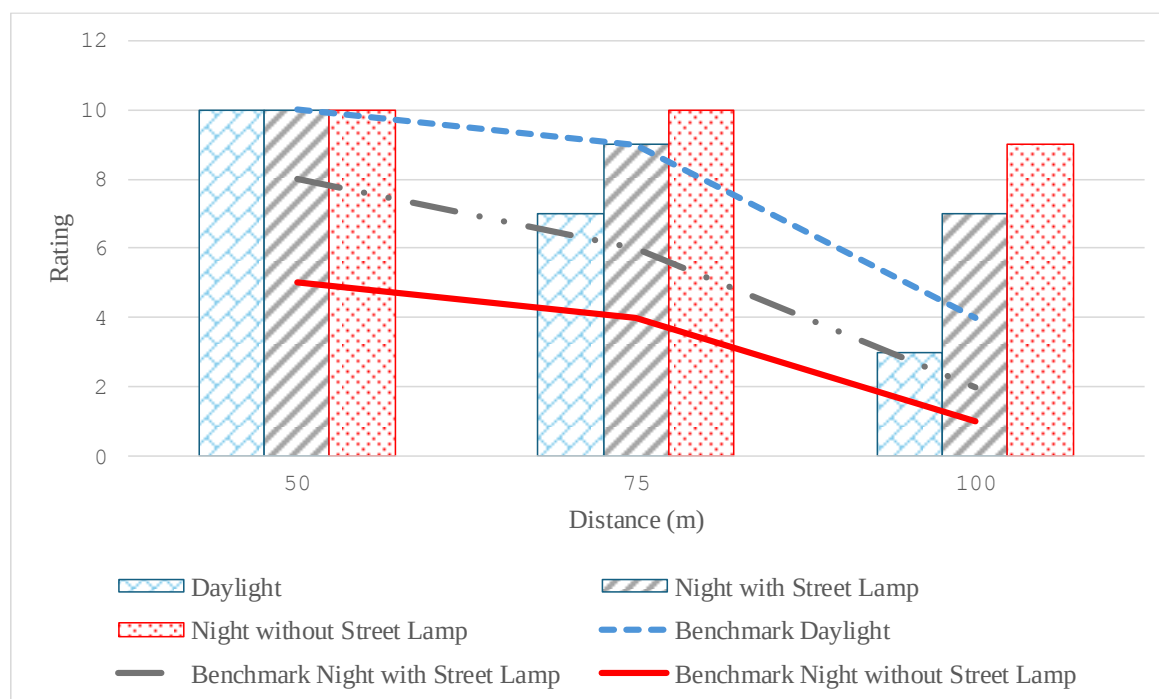


Figure 7 Visibility comparison between the prototype and conventional warning triangle on curved roads under different environmental conditions

The line graph shows a significant reduction in benchmark visibility with increasing distance, whereas the proposed prototype maintains clear visibility, especially at longer distances. This improved performance results from LED lighting and reflective materials that increase the rider's visibility in low-light conditions. Improved visibility allows oncoming drivers to see the subject vehicle earlier and may reduce the risk of additional collisions during roadside emergencies, particularly on winding roads with limited sight distance (Se et al., 2025; World Health Organization, 2022).

Overall Result

The developed emergency hazard light showed better performance than the conventional warning triangle, especially during nighttime and low-visibility conditions. The combination of LED lighting, reflective materials, solar charging capability and a collapsible design greatly increased both portability and visibility. The prototype was visible at up to 100 meters which indicates that it would be able to provide sufficient notice distance to oncoming road users. The findings are in line with recent studies that have highlighted the

importance of motorbike visibility in lowering crash risk and improving road safety (Khalid et al., 2021; Bowo et al., 2025). The World Health Organization has highlighted the importance of visibility enhancement technologies in reducing the worldwide number of fatalities due to motorbike accidents (WHO, 2022). The proposed hazard light as shows in Figure 8 is a practical and economical safety equipment with good potential for PTW motorcycles.



Figure 8 Visibility of proposed prototype at nighttime

Final considerations and Future Works

The research has successfully developed a portable emergency hazard light in the shape of a triangle for power two-wheel (PTW) motorcycles to increase the visibility and safety of the riders during roadside emergencies. A design and development technique was used, which involved an analysis of user requirements, conceptual design, prototype fabrication, and performance evaluation. The three concepts submitted were scored using the Pugh net score, with the highest score of 4 awarded to Design C, which was selected for prototype manufacturing due to its portability, foldable construction and integrated safety measures.

Both straight and curved roadway visibility assessments indicated that the fabricated prototype frequently outperformed the traditional warning triangle, especially in nocturnal conditions without street lighting. The prototype scored a visibility rating of up to 9 at 100 meters, while the baseline warning triangle scored as low as 1. LED lighting and reflective materials greatly improved the visibility of the vehicle in low-light conditions, allowing oncoming drivers to identify it sooner and perhaps decreasing the likelihood of secondary collisions. The proposed hazard light is a practical, portable, and economical solution for enhancing motorcycle safety. Future works should focus on improving weather resistance, optimizing battery life and solar charging efficiency, and carrying out field tests under different traffic and weather conditions to further validate the efficiency of the proposed system.

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