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Innovative Product Design Based on Translating Customer's Feelings-Case Study of Foldable Hat Insert

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ABSTRACT

A do-it-yourself foldable hat insert has been introduced as an alternative channel for supporting customers to stay safe in daily outdoor activities. After obtaining results from self-administered questionnaires, the majority of respondents expressed satisfaction with wearing baseball caps for outdoor activities. This high level of motivation could show a strong personal relationship between baseball-cap design and customer viewpoint. The key components of the proposed design were considered to be the spline-shaped design with shell attached to baseball cap and inner shell attached to the head. ABS and ethylene vinyl acetate – EVA were selected ergonomically for creating the shell and inner shell, respectively. For quickly translating customer perceptions into a conceptual design, the principles of product design and development (PDD), reverse engineering (RE), and rapid Prototyping (RP) were integrated. In order to study about falling objects and their force on the foldable hat insert, the situation was simulated virtually via finite element analysis (FEA) where the mass of the object, height of human, and drop height were assigned according to the real-world application. The standard value of 26,000 N/m^2 was applied as the key reference to predict mild diffuse axonal injuries (mDAI) for loss of consciousness for a few seconds to a few minutes. The simulation results that the surface area of an insert with EVA foam material in direct contact with the head did not exceed the standard value for Von Mises Stress, and this could make wearers feel comfortable with soft-and-flexible material while minimizing the risk for head injury.

Keywords: Conceptual design; Foldable hat insert; Product design and development; Reverse Engineering; Rapid prototyping; Splines model

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1. Introduction

In today's world, pedestrians are regarded as an extremely vulnerable and high-risk group of road users since they are unprotected. Heads are one of the most frequently injured body parts and may lead to disability or even death. Therefore, preventing head injuries has become a critical issue and it is fundamental to understand the mechanisms of these injuries [1]. Safety helmets can prevent and protect against serious head and brain injuries in the event of an accident [2]. However, the helmet could constitute a health hazard to the users. Constant handling and use of helmets by different individuals could create a prime breeding ground for many microorganisms such as bacteria and mildew, and a possible transmission of pathogenic microorganisms as well as communicable diseases among users [3]. In addition, generally, the safety helmet is formed of a metal material or a plastic material, which is inconvenient to carry due to its size and weight, and is bulky and occupies a large space in storage [4].

Generally, helmets are used to protect the head of a wearer. They are used in various construction work sites. The safety is provided by metal or plastic material, which is inconvenient to carry due to its size and weight, and is bulky and occupies a large space in storage [4]. In addition, the use of the helmet may cause the user to feel a sort of oppression and/or to smell some unpleasant odor due to perspiration; for such reasons, many users do not use it [5].

These factors have led to the proposed research where several options for making the helmet-like product can be revealed and suggested for supporting different types of hats. The users can use this type of insert while performing activities in everyday life to prevent head injuries.

2. Materials and Methods

Presented in this section are the background of the research for understanding customer requirements, perceptions, and key considerations of helmet-like design. The existing products in the market are also mentioned and discussed.

2.1 Customer requirements and perception

People need the product that can prevent their head from injury but they do not want to wear the safety helmet in their daily life because it is not trendy and the helmet can cause bad smell to users. Therefore, the helmet that can adapt with every type of hat with a sweat absorber would be a solution for the user, which can prevent their head from minor accidents.

Referring to the normal method, people are unprotected while walking on the street, which can cause injuries, especially head injury. Head injury can be caused by accident from traffic, industrialization, falls and ballistic trauma. Some people wear the hat in everyday life but do not have the protector that can prevent their head from accident.

At this stage, the researchers tried to apply the classic number, which was 100 to represent the "Population size" where the "Sample size" should be considered as 80 that was needed to have a confidence level of 95% when the real value was within ±5% of the measured/surveyed value. Fortunately, after launching a set of questionnaires to the target customers, 94 responses were obtained, the main question was considered as "What types of hats do you have and use in daily life?". The answers are presented in Table 1.

The most popular design of hat is the "baseball cap", which led the design team to create a new product corresponding to the existing characteristics of a hat that customers may like. The reasons given for baseball caps being very popular were their neutral look, ease to match any outfit, compatibility with all body types, and the variety of styles available.

Table 1. Types of hats selected and used in daily life.

Type of hat	Design	No. of respondents
Baseball hat		55
Bucket hat		16
Panama hat		9
Beanie hat		5
Beach hat		4
Others		5

2.2 Existing products – baseball cap style

Many styles and patterns of the existing products (i.e., bump cap inserts for baseball caps) are available in the online marketplaces such as Amazon, Alibaba or E-bay. Most of them are formed as a single-plate style. An insert is permanently attached to the internal curve-area of the cap. Plastics and rubber are the key materials, which are both made from the same families of polymers. Moreover, the polymers are mixed with a complex blend of materials known as additives. For rubbers, they are elastomers, and these are polymers with an elastic property. One of the greatest advantages of polymer materials is their flexibility and low stiffness. The key functions of existing products are observed and compared properly, since they might be useful in the design stage.

Currently, when people would like to extract, reveal, and compare some facts or details of existing products, searching for data from different websites via a "Search Engine" has become a vital channel with "easy-to-access" and "take a quick look" concepts. In order to understand "what they want", the designers should act like them and think like them. The activity of "take a quick look" via search engine can reveal some hidden issues to be explored in a systematic way.

Classifying the existing products by using customer behavior can allow the designers to understand more about what they find from the websites; and whether or not data obtained from different sources might provide a group of related products under the same brand name manufactured by a company. However, the price of product from different websites might be different.

Therefore, the researchers tried to think like customers and started to search the product of interest under the constraints and keywords such as: "*safety caps*, *bump caps and inserts*, *bump baseball caps*, *helmet caps/hats*, *impact-resistant caps*, *safety helmet bump baseball caps/hats*, and *impact-resistant hats*".

Presented in Figs. 1 and 2 are the baseball cap products providing support or bump inserts to protect against the impact of moving objects on the head. The main design consists of two parts: shell and inner shell. However, the helmet with bump insert cannot be applied to prevent the impact of falling objects, this style can only support the wearer to prevent the impact of moving objects on the head.

Fig. 1. The baseball cap with head support - Air ventilation provided on the cap [6].

Fig. 2. The baseball cap with ABS Shell and EVA Inner shell [7].

Before using this helmet, double-checking is recommended; if it has started to malfunction and finally breaks down or is damaged, the user has to replace it immediately. For effective protection, the impact hood should be worn to keep the cap forward all the time, and adjusted to the head size of the wearer. The paddings inside the hat, which are normally soft and flexible, should be adjusted easily by the safety device on the rear of the hat – in the case of safety hat. The main concern is checking the position of the helmet to make sure it is comfortable to wear and the curvature surfaces of the paddings are matched to the structure of the user's head. In general, the life of this helmet is affected by many factors (e.g., changes in temperature, in contact with chemical products, direct exposure to sunlight or misuse).

2.2.1 Products from Amazon

Table 2. Universal bump cap insert styles for baseball caps – from Amazon.

No.	Product	Functions
1	 by FENICAL [8]	• **Material :** Hard ABS, soft PP foam • **Flexible :** No • **Cover the whole head :** Yes • **Ventilate :** Yes • **Fit to any hat :** No • **Weight :** 89.868 g. • **Absorb sweat :** No • **Price :** $10.99
2	 by Ergodyne [9]	• **Material :** Polypropylene, Foam Pad • **Flexible :** Yes • **Cover the whole head :** Yes • **Ventilate :** Breathable - Yes • **Fit to any hat :** Yes • **Weight :** 45.36 g. • **Absorb sweat :** No • **Price :** $5.41
3	 by MOHEEN Store [10]	• **Material :** ABS plastic shell with foam padding • **Flexible :** N/A • **Cover the whole head :** Yes • **Ventilate :** Yes • **Fit to any hat :** No • **Weight :** 141.748 g. • **Absorb sweat :** No • **Price :** $19.99

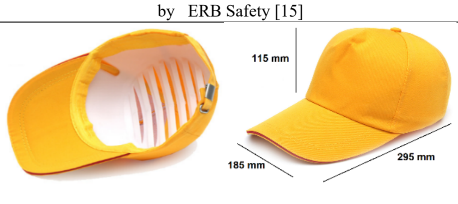
2.2.2 Products from Alibaba

Table 3. Universal bump cap insert styles from Alibaba.

No.	Product	Functions
1	 by Top Safety Workwear [11]	• **Material :** ABS shell insert/ EVA cushion sponge • **Flexible :** No • **Cover the whole head :** Yes • **Ventilate :** No • **Fit to any hat :** No • **Weight :** 210 g. • **Absorb sweat :** No • **Price :** $16.56
2	 by Deltaplus [12]	• **Material :** *Shell* - polyester cotton fabric/ *Inner shell* - TPE • **Flexible :** No • **Cover the whole head :** Yes • **Ventilate :** No • **Fit to any hat :** No / but the ergonomic bump stand fits all head shapes. • **Weight :** N/A • **Absorb sweat :** No • **Price :** $21.99
3	 by LJMY Store [13]	• **Material :** High-density polyethylene (HDPE), Foam Pad • **Flexible :** No • **Cover the whole head :** Yes • **Ventilate :** Yes • **Fit to any hat :** No • **Weight :** N/A • **Absorb sweat :** No • **Price :** $16.37

2.2.3 Products from E-bay

Table 4. Universal bump cap insert styles from E-bay.

No.	Product	Functions
1	 by peshalidistribution_online [14]	• **Material :** Polypropylene, Foam Pad • **Flexible :** Yes • **Cover the whole head :** Yes • **Ventilate :** Good Breathability • **Fit to any hat :** Yes • **Weight :** N/A • **Absorb sweat :** No • **Price :** $15.41
2	 by ERB Safety [15]	• **Material :** Polycarbonate resin • **Flexible :** No • **Cover the whole head :** N/A • **Ventilate :** Yes • **Fit to any hat :** No • **Weight :** 176.9 g. • **Absorb sweat :** No • **Price :** $5.99
3	 by Hanzhexuan [16]	• **Material :** Cotton and ABS • **Flexible :** No • **Cover the whole head :** N/A • **Ventilate :** Yes • **Fit to any hat :** No • **Weight :** 200 g. • **Absorb sweat :** No • **Price :** $10.75

2.2.4 Conclusion about types of bump cap inserts

Table 5. Five types of bump cap inserts – Material-based design platform.

Type	Insert Material	Products	Price
A	Foam Pad	 by FENICAL [8]	$10.99
		 by Ergodyne [9]	$5.41
		 by MOHEEN Store [10]	$19.99
		 by LJMY Store [13]	$16.37
		 by peshalidistribution_online [14]	$15.41
B	EVA cushion sponge	 by Top Safety Workwear [11]	$16.56
C	Thermoplastic Elastomer (TPE)	 by Deltaplus [12]	$21.99
D	Polycarbonate resin	 by ERB Safety [15]	$5.99
E	ABS	 by Hanzhexuan [16]	$10.75

2.3 Key consideration for design stage

After reviewing various designs of safety helmets, the key consideration is shown through "*bump cap hat inserts*". An alternative channel of a bump cap insert is considered as universal design where the material applied should provide lightweight, durable, breathable, and flexible characteristics. Presented in Fig. 3 is the flexible hat insert that is lightweight and easy-to-use forming space to let the user adjust the shape of insert to fit the curvature area of a baseball cap. This insert style offers a comfortable layer of high quality, high density foam plus an added tough, flexible hard-shell layer to help combat against bumps, bruises, cuts and abrasions. Moreover, this insert works well in the trucker style or roomier caps and hats. This insert can be trimmed to fit smaller sized heads.

Fig. 3. Flexible bump cap hat insert [17].

The expected design platform and product characteristics of "*bump cap hat insert*" can be explained as follows:

1. Provides an ergonomically shaped hard shell with integrated shock-absorbing elements to ensure safety and optimal comfort.
2. Adjustable fastening and soft foam insert cushions should be considered to help protect the head. Air ventilation holes or slots in the sides of the bump hat insert to optimize comfort for user should be added properly.
3. Removable inner shell should be made of ABS or EVA material to make users feel comfortable when wearing with secure protection.

2.4 Customer survey

For identifying the customer's behavior, requirement and perceptions towards the helmet insert, a set of questionnaires, which consists of *Customer's behavior on health-problem*, and *Physical design of hat* issues, was distributed to 250 respondents. However, only 154 respondents answered and returned the results to the team.

In the initial design stage, the researchers did not have much information on the subject, but the number of target customers was assumed to be around 250 people who might purchase hat or head protection item; this gave us maximum variability and a bright direction to obtain the survey results. From this following Eq. (2.1) [18], the value of the sample was obtained

$$\text{Sample size}, n = N \times \left(\frac{\dfrac{(Z)^2 \times p \times q}{e^2}}{(N-1) + \dfrac{(Z)^2 \times p \times q}{e^2}} \right), \tag{2.1}$$

where

- *n* the minimum size that is needed to estimate the true population proportion with the required margin of error and confidence level.
- *N* is population.
- *Z* is critical value of the normal distribution at the required confidence level .
- *e* is the desired level of precision (the margin of error, or confidence interval).
- *P* is the estimated proportion of the population, which has the attribute to the question (i.e., sample proportion).
- *q* is $1 - p$.

Therefore, in this study, N = 250 people, p = 0.5, and the researchers wanted

95% confidence, and at least 5 percent—plus or minus—precision. A 95% confidence level gave Z values of 1.96, per the normal tables; therefore, the sample size (n) should be

$$n = 250 \times \left(\frac{\frac{(1.96)^2 \times 0.5 \times (1-0.5)}{0.5^2}}{(250-1) + \frac{(1.96)^2 \times 0.5 \times (1-0.5)}{0.5^2}} \right),$$

$$n = 152.$$

In conclusion, the summarized parameters of this calculation can be expressed as:

- *Population Size* (*N*): 250

The total number of people whose opinion or behavior our sample will represent.

- *Confidence Level* (%): 95

The probability that our sample accurately reflects the attitudes of the population. The industry standard is 95%.

- *Margin of Error* or *e* (%): 5

The range (measured as a percentage) that the population's responses may deviate from our sample's.

- *Sample proportion* (*p*): 0.5

The estimated proportion of the population, which has the attribute to the question (i.e., sample proportion).

Therefore, "Sample size" should be "152". From this calculation, we found that a random sample of 152 respondents in our target population should be enough to give us the confidence levels we needed.

In practice, around 250 sets of the questionnaires were given to the target customers. In this initial stage of concept development, 154 respondents responded; these data were recorded and translated into the conceptual model of helmet and baseball cap insert.

2.4.1 Phase 1: Customer behavior on health-problem

After collecting some ideas about customer behavior on health-problem, to create the drafted design of the new helmet-like platform, three main activities were established: *data collection*, *data analysis*, *and discussion results and conclusion*.

1. Data Collection

In order to create the helmet-like product, a market survey was conducted by using a data collection method. A questionnaire was selected as the method for data collection. Questions were created and distributed into two parts to determine the important issues such as the most important health concern, cause of pain, and customer's behavior. Moreover, identifying or extracting customer opinions and requirements from questionnaires was the key activity required since some answers could be interpreted and used as the key factors and parameters for drafting a design directly and effectively. Samples of the questionnaires are illustrated below.

2. Data Analysis

There were 154 questionnaire participants who took part in answering via a Google form.

The first part of the questionnaire contains basic questions about the participant characteristics. From the questionnaire results; 19.6% were between 23-45 years old, 19% were above 45 years old, and 16.3% were 7-18 years old. Most of the participants were university students. For this group, the average income per month was below 9,000 baht (~29.4%).

Most of the participants identified their biggest health-concerned problem as head (43.8%), back (38.6%), and hand and finger (17.6%), respectively. Since the participant's most health-concerned problem – person perception was considered in "head issue", the next part was constructed to reveal the causes of head problem.

For the *second part* of the questionnaire, the results (Table 6) show customer perception where the most common causes of head injury were shown in "outdoor activities" (94%), the next one was considered in "motor vehicle accidents" (61.2%), the third place was mentioned as "object falls" (31.3%), and the last place was about "the violence" (6%).

The next set of questions was about "*What is your favorite outdoor experience?*". From Table 7, the top three participants' favorite outdoor activities were "running and walking" (73.1%), "biking" (49.3%), and "picnic" (29.9%). The key factors that most participants' valued if choosing helmet-like product were considered as safety, followed by weight, durability, portability, design and color, respectively.

The hat style most used by participants was identified as "the baseball cap". At that time, 89.6% of respondents thought that applying foldable hat insert was more convenient than wearing the helmet. Some 85.1% of respondents said that doing this might help to prevent their head injury where the size of hat insert should be considered as a large-scale platform. And lastly, 92.5% of respondents showed positive willingness to pay for "foldable hat insert" if it was available in the market. Thus, the researched platform has been focused on this guideline to adapt the inspiration of this model, a helmet, in which its main function is for protection in the daily hat.

Finally, the decision of product design and development emphasizes the area of "*foldable hat inserts*" to support and prevent the head injury where the participants seem to be open-minded and willing to try our product.

Table 6. People perception in the main cause of head injury.

Perception in the main cause of head injury (Top 4 answers)	No. of Respondents	%
Outdoor activity	144	94
Motor vehicle accidents	94	61.2
Object falls	48	31.3
Violence	9	6

Table 7. People experience about outdoor activity.

Outdoor activity (Top 3 answers)	No. of Respondents	%
Running and Walking	112	73.1
Biking	75	49.3
Picnic	46	29.9

3. Discussion of questionnaire results and conclusion

The results obtained from the questionnaire indicate that the most health-concerned problem is on "head", and type of hat that most people have and use in daily life is "the baseball cap". A majority of the respondents want the large size of hat insert, foldable, lightweight, durability, portable, and with good design and color. However, our team discussed that we will continue with a design of foldable hat insert that can help prevent the head from injury. In addition to the questionnaire results, our team decided to add additional functions to the primary model to create a new design that will be more convenient for the users.

2.4.2 Phase 2: Physical design of hat

In order to translate the requirements of the target customers into the foldable hat insert design, the factors affecting the hat insert are considered and classified into three main groups; *the dimension of hat insert*, *mechanism*, and *material for each part*.

1. Dimension of Hat Insert

According to the research objective, the existing product designs are to be developed to support the customer's health in daily outdoor activities. The design of the foldable hat insert has to be fitted perfectly with both the head of the customer and the hats available in the market. Also, the size of the product should cover many head sizes.

2. Mechanism

To reduce the risk of chance for head injuries, the foldable hat insert must be made from suitable material to absorb the force and other physical effects applied, be lightweight, portable and easier to fold than the common head supporting gadgets available in the market.

3. Material for each part

This research applies the knowledge about materials for selecting the most suitable material for each individual part with the lowest cost possible. Material properties and quality will be considered as well.

3. Results

After translating customer behaviors and requirements from the self-administered questionnaires, the draft design was constructed. The key theme of this developed design was raised by seeking a gap in the market where there is no helmet-like product introduced as the functional-design platform, along with DIY concepts, which required zero-background. These led to our research for creating an alternative design with an easy-to-access concept for supporting helmet-like product, which is the foldable hat insert.

3.1 Expected requirements from the questionnaires

From the questionnaire results, a new prototype design is chosen to be more ergonomic and trendier than the existing products. We compared and adapted the advantages from the existing products, with additional functions that could be added to the primary model, with a proper engineering point of view. The design of the foldable hat insert and prototypes are decided to be spline-structure characteristics where the hat design that most people likely use is a baseball cap. The design of the foldable hat insert is concerned about injury prevention and convenience. The key concepts of this new model are focused on *foldable*, *portable size*, and *easy to use*.

3.2 Concept of "3F's approach" for the foldable hat insert

The research of interest for this foldable hat insert prototype is the functional use of the foldable hat insert. To emphasize its functional use, the two main components details and functions will be mentioned in this section. The foldable hat insert embodies the 3F's approach, *form*, *fit*, and *function* as shown below.

3.2.1 Form

The foldable hat insert will follow the baseball cap design, which should have a circumference of 56 cm. [19] and sellion to the top of head of 10.85 cm. [20], as shown in Fig. 4. However, concerned with difficulties in creating a 3D CAD model, we decided to make the value a little more flexible by focusing only on the circumference size of 56 cm., which will give the height of 8.9 cm. This generates very small differences. Moreover, this change could also reduce tightness between ears and the model, which leads to more comfort and area for air ventilation. The design should be dark color (less sensitive to dust and environment), lightweight, and foldable. The designed materials to be used are polypropylene (PP) and foam.

According to "effect of helmet liner systems and impact directions on severity of head injuries sustained in ballistic impacts: a finite element (FE) study" (2016) [21], the helmet liner is better in a form of foam pads because it helps to reduce impact force. It also suggested that more padding inserts of smaller size may offer better protection. Apart from this, the overall thickness of the helmet should be at least about 0.3 inch or 8 mm. Usually, it should not exceed 0.6 inch or 15 mm. [22].

For the supportive item as foam inside helmet, the thicker foam is better; since this might give the user's head more room and milliseconds to stop. If the foam is 15-mm thick, it obviously has to stop the user in half the distance of a 30-mm thick foam. According to the basic laws of physics, this results in more force to the brain if the stopping distance is shorter. The less dense foam can be better as well, since it can crush in a lesser impact; however, it has to be thicker in order to avoid crushing down and "bottoming out" in a harder impact.

If the helmet is very thick, the outer circumference of the head is in effect extended. If the helmet then does not skid on the crash surface, that will wrench the head more, contributing to strain on the neck and possibly to rotational forces on the brain. In short, there are always tradeoffs, and a super-thick helmet will probably not be optimal. It will also fail on consumer acceptance.

In some designs of helmets, the foams are crushable; however, they cannot be recovered or reused when the wearers crash the bike helmet and, with the material property plus the usual expanded polystyrene foam, the foam is deformed and trashed. Construction and property of helmets are suitable to be used as long as the outer shell of a helmet that is designed to spread out the force from an impact across the entire shell, minimizing the blow, is not cracked and the suspension is not damaged.

However, different types of helmets seem indistinguishable to most consumers where the wearers cannot test the impact protection unless they have a special testing room and are willing to destroy the helmet, which is quite expensive. For this reason, the manufacturers decide to use the standards as the references to choose the performance levels.

Moreover, a relevant safety standard for head or concussion (i.e., a traumatic brain injury that affects your brain function) protection exists and this standard criterion should be considered in the design stage. The head protection (i.e., protective helmets or hard hats) has to accomplish each of the following: *absorb the shock of a blow*, *resist penetration by objects*, and *be water-resistant and slow-burning properties*.

There are three main features that head protection must include: *clear instructions explaining proper adjustment and replacement*, *a hard-outer shell*, and *shock-absorbing lining with a headband and suspension straps that suspend the shell between 2.54 and 3.18 centimeters away from the head*.

All protective headgear must meet ANSI Standard Z89.1-1986 or provide an equal level of protection.

There are three different classifications of hard hats, each with their own level of protection.

Type 1: Class G (listed as Class A in ANSI Z89.1-1986). This provides resistance to impact and penetration and voltage protection up to 2,200 volts.

Type 2: Class E (listed as Class B in ANSI Z89.1-1986). This provides protection from impact and penetration along with voltage and burn protection of up to 20,000 volts.

Type 3: Class C (not ANSI approved). This class of hard hats is designed to provide lightweight comfort and protection against minimal impacts. This is known as a "*bump hat*". These hard hats protect workers from bumping their heads on low overhead clearances, but are not designed to protect against falling or flying objects or electrical hazards.

Each hard hat should contain a label inside the shell that states the class, ANSI designation, and manufacturer of the hat [23-27]. Finally, for the proposed design of head protection, the researchers have tried to identify and make decisions on the shape, size, and materials used. A polypropylene plate with 0.8-mm thickness should be selected to make foldable inserts where the thickness of foam paddings will fall in the range of 7 to 14 mm. Hence, the lowest and middle thickness of 7 and 10 mm are selected to study throughout this research.

Fig. 4. The baseball cap size

3.2.2 Fit

A well-fitting baseball cap should sit comfortably above the ears with the bill resting in the middle of the forehead. The crown of the baseball cap should top the user's head, leaving a little space between the head and the cap [28]. The foldable hat insert consists of two main parts, which are *foldable plate* and *paddings* (Fig. 5), and it should fit the user's head and the selected hat perfectly after assembly.

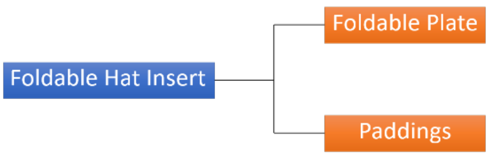


Fig. 5. Flow diagram about the structure of foldable hat insert

3.2.3 Function

The function of the foldable hat insert is to protect the head from a minor injury, absorb force when crashed, and be convenient to use. This function could be measured by the deformation of the material (foam) after a load is applied.

3.3 Conceptual design

For supporting the conceptual design stage, the key concepts and constraints to design helmet or supportive device for protecting head have been taken into consideration. According to the answers from questionnaires and interviews, riding a bicycle is one of the favorite outdoor activities where the target customers can extract and explain about the safety devices and supportive items very well. These could convey and imply some benefits and clear perceptions about using bicycle-safety equipment to a new design platform of helmet inserts. Therefore, the current helmet standards – bicycle standards are applied as the references for the design process of this proposed approach.

Typically, in order to ensure a minimum level of performance of the helmet for a range of criteria that affect safety, the cycle helmets are tested. The following statements are taken into consideration [29]:

- *Construction requirements:* the materials applied for making helmet or supportive head item do not affect the skin of the wearer, and the other way around, the sweat and hair and skin products do not affect the materials of the helmet.
- *Impact requirements:* the minimum level of energy absorption at multiple points or areas on the helmet should be in a range of environmental conditions.
- *Retention system requirements:* the stability of the helmet on the head and the strength of the straps are required.
- *Coverage:* a certain area of the head is covered by the helmet.
- *Vision:* the helmet does not unnecessarily impede the vision of the wearer.

From the aforementioned bicycle-helmet standards and constraints, plus the customer requirements, the proposed helmet inserts have been developed where the drafted form, fit, and function are expressed in tangible formats; the "*bump cap insert*" is the key consideration.

Moreover, the emphasized specific requirements of a new design are clearly explained in five components, which are:

1. *Flexible design:* The bump cap insert should provide a horizontal and vertical two-way design flexibly for effectively protecting wearers from any impact of danger while moving or doing some activities.

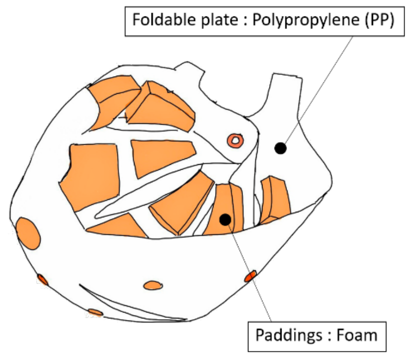
2. *Adjustable height:* The height of the bump cap insert can be trimmed easily by scissors for fitting in the different shapes and sizes of hats.

3. *Solid material - shell:* The cap insert should be made from durable, lightweight and flexible material, which is not easy to break.

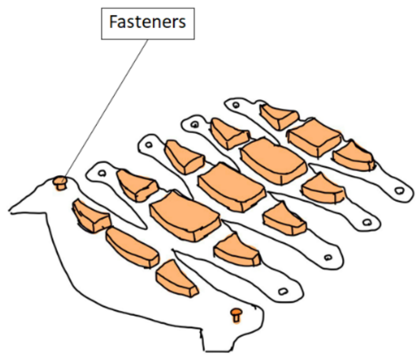
4. *Inner-shell material:* This is about padding in the bump cap insert, which should provide better protection for user's head. The material for padding should not absorb strange smells.

5. *Good breathability:* While wearing the helmet insert, the wearer should feel comfortable. The design of the helmet insert should provide good breathability where the physical properties and structures ensure continuous airflow. The main point for this constraint is not only to protect the wearer from danger but also to provide a wearable condition.

Fig. 6 presents the sketched design of a new product proposed in this research. At one end of the foldable plate, the fastener will be assembled on both sides where the plate folds inwards to converge at two points that are then held in place with an integrated fastener.



(a)



(b)

Fig. 6. Sketched design of the helmet and baseball cap insert: (a) Forming helmet insert as hat pattern, (b) Expanding the foldable hat insert

3.4 System-level design

Since a baseball cap or hat was selected as a key shape consideration. The structure of a bump cap insert or an inner case should properly fit and match the fabric texture and material used for forming a profile of baseball cap. An insert should contain lightweight waterproof material and be impact resistant.

The main characteristic of a bump insert is to provide extra head protection from any bruises and other minor head injuries. In order to create a main frame of bump cap insert easily and quickly, physical characteristics with descriptions were identified (Table 8) and applied. Doing this could also minimize time spent on recreating a 3D model in the detailed design stage – the next stage. The specific adjective words are applied as the key points for the detailed design stage and these can support the designers or manufacturers to easily understand and extract what target customer wants for a safety helmet or hat to protect the head; since all words were extracted previously in "*translation customer's feelings*" stage.

These revealed adjective words concern physical shape, function, and size of a new design of the insert for supporting fashionable baseball hats. The main application of the insert is less concerned with color or aesthetics. Therefore, color and extra-decorated items have not be taken into consideration for the design of hat insert.

Table 8. Product characteristics and definitions.

Product Characteristics	Definitions
Small	Hat insert has a relatively small size.
Soft material	Elastic material. Example epoxy resin, EVA foam.
Hard material	High strength material. Example ABS, PP plastic.
Ergonomic	Hat insert has been designed based on working conditions, especially done in order to improve effectiveness.
Light	Hat insert contains light weight.
Protective	Hat insert is capable of protecting the user.
Portable	Hat insert is easy to carry
Simple	Hat insert is easy to understand or use
DIY	Hat insert is easy to apply with zero-background experiences

3.5 Material considerations

In making the foldable hat insert, different parts of the product required different materials. The two main characteristics for this product are being foldable and protective (force absorbable). Therefore, three materials selected for these purposes are Polypropylene (PP) Homopolymer, Flexible Epoxy Resin and Ethylene Vinyl Acetate (EVA) foam. For the foldable plate, two materials are considered and tested to compare the results obtained from both materials.

3.5.1 Polypropylene (PP) homopolymer

Polypropylene has a high softening or glass-transition point, high resistance to flexing stress, low water absorption, lightweight, dimensional stability, high impact strength and a non-toxicity property [30]. The properties of PP are shown below in Table 9.

Table 9. Properties of Polypropylene Homopolymer.

Property	Unit	Value
Poisson's Ratio	-	0.42
Density	kg/m^3	904 – 908
Linear Thermal Expansion Coefficient	cm/cm K	8 – 10 x 10^{-5}
Thermal Conductivity (Solid)	W/m K	0.17 – 0.22
Tensile Strength at Yield	N/mm^2	37
Elongation at Yield	%	28
Charpy Notched Impact Strength (At 23°C)	MJ/mm^2	6
Flexural Modulus (1% Secant)	Mpa	1600

Note: Data for Poisson's ratio, density, linear thermal expansion coefficient and thermal conductivity from INEOS Olefins & Polymers USA (2014) [31], and for tensile strength at yield, elongation at yield, charpy notched impact strength and flexural modulus from Mizuya Corporation Co., Ltd. (2019).

3.5.2 Flexible epoxy resin

The flexible epoxy resin is known to be excellent in chemical resistance and viscous consistency. The processing times and curing times are quite fast and short. Moreover, it has very high tensile, compressive, flexural strength and does not tear up easily. However, the material properties obtained from casting will depend on the casting process and its mixing ratio. For the padding, the material should be Ethylene-vinyl acetate (EVA) foam. It is a closed cell foam made from ethylene-vinyl acetate and blended copolymers, which shows a high level of chemical cross-linking and semi-rigid foam with a fine uniform cell structure, low-water absorption and chemical resistance. It is frequently used in applications with high impact and vibration absorption. Compared to polyethylene foams, EVA foam is softer, more resilient and flexible, and has greater recovery characteristics after compression [32-33]. The properties of EVA are shown below in Table 10.

Table 10. Properties of Ethylene-vinyl acetate (EVA) foam.

Property	Unit	Value
Poisson's Ratio	-	0.48
Young Modulus	Mpa	10
Density	kg/m^3	30
Yield Strength	N/m^2	750,000
Compression Strength	N/m^2	78,000
Tensile Strength	N/m^2	780,000

Note*:* Data for Poisson's ratio from Dias et al. (2018) [34], for young modulus from Cambridge University Engineering Department (2003) [35], and for density, yield strength, compression strength and tensile strength from Nanoshel [36].

3.6 Detailed design

The 3D CAD model of the foldable hat insert has been made. SolidWorks, a computer-aided design (CAD) program, has been selected as a tool to create a 3D spline model of the product. The foldable plate is designed to be folded and inserted into the selected hat. After the plate is folded, the circumference should be 56 cm. This foldable plate will attach to the paddings and the hat; the virtual design model is illustrated in Fig. 7. Moreover, after adjusting the size of the foldable plate to match and fit with the human head, the PP was cut into suitable size manually as shown in Fig. 8, the cut foldable plate from *polypropylene* (PP).

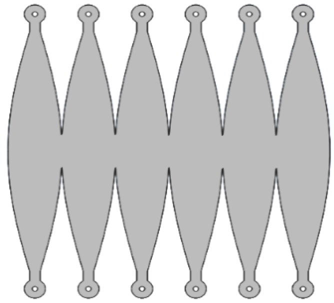


Fig. 7. The foldable plate in foldable hat insert – virtual design form.

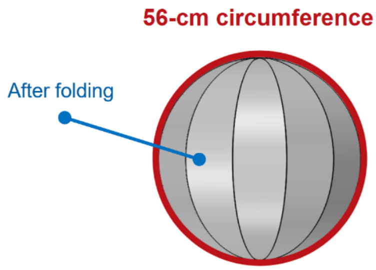


Fig. 8. Foldable plate made from Polypropylene.

For applying flexible epoxy resin material to make a foldable plate, in the first step, the CNC router machine was used to cut the acrylic plate that was used as a mold cavity for creating the silicone rubber mold to cast the flexible epoxy resin plate. Then, the flexible epoxy resin ingredient was prepared. In general, the flexible epoxy resin consists of Type A (resin) and Type B (hardener) as shown in Fig. 9. Material type A and type B were mixed by using the ratio 100:60. Finally, the flexible epoxy resin was poured into the mold. After that, demolding at the end of the cure time, with careful twisting, was required for removing the resin from the mold. The finished work (jelly-like structure) is shown in Fig. 10. After finishing the foldable plate, the second part of a helmet insert was "paddings".

Fig. 9. Flexible Epoxy Resin.

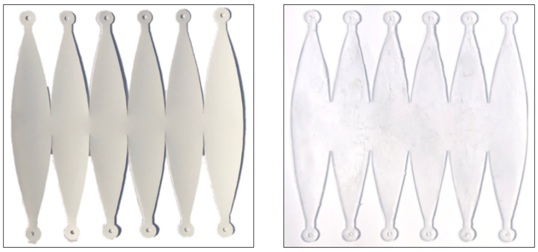


Fig. 10. Foldable plate made from Flexible Epoxy Resin.

In this study, *Ethylene Vinyl Acetate* (EVA) forms were cut according to the drawing dimension of the designed part. The finished parts of paddings with *Ethylene Vinyl Acetate* (EVA) forms are shown in Fig. 11.

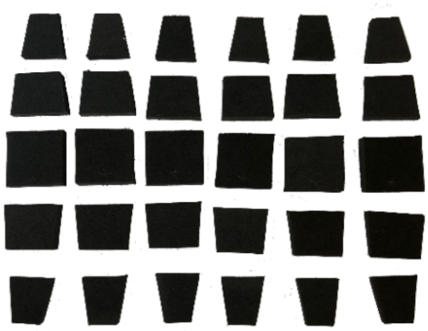


Fig. 11. Padding part made from EVA foam.

The required numbers of each padding style were different; 12 pieces each for block 1 and 2, and 6 pieces for block 3 (Fig. 2).

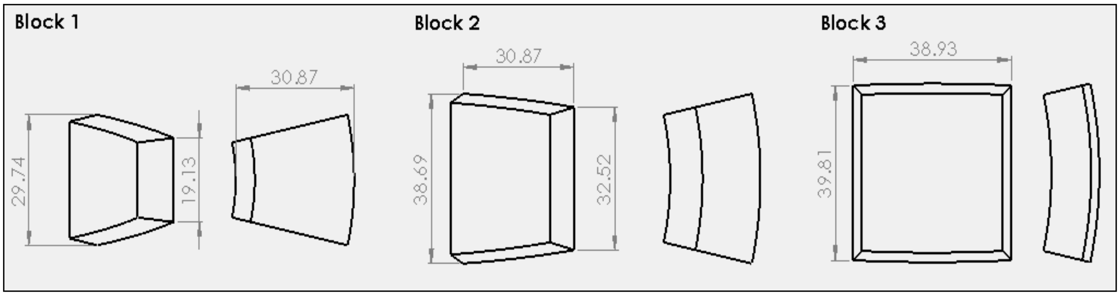


Fig. 12. Dimensions of paddings.

3.7 Testing the physical feelings-hat insert

A study was conducted to determine the effectiveness of different materials. The first design of the foldable hat insert consisted of a foldable plate, which was made from Polypropylene (PP), whereas the padding parts were made from Ethylene Vinyl Acetate (EVA) (Fig. 13).

The second design consisted of a foldable plate, which was made from flexible epoxy resin. The padding parts were made from Ethylene Vinyl Acetate (EVA) (Fig. 14).

For both types, the sizes are identical and the fasteners are also assembled in the same locations. Moreover, to extract feelings while wearing the two designs of hat, forty potential users were asked to wear the hat for 10 minutes for each design, and to perform some fundamental movements as outdoor activities, i.e., walking, catching, or throwing things.

After ten minutes, the interview session was started and the wearers were asked about their feelings and satisfaction while wearing each style of the developed insert. The results were concluded as:

3.7.1. For the first design platform

Its structure could not fit wearer's heads during doing some activities, since the curvature surfaces of the main shell that was made from PP material could not be deformed to properly attach the profile of the head. A hat with a PP shell was slightly loose; around 45% of the wearers mentioned that they kept on losing the hat, even if the EVA inner pads was flexible enough to make the wearer feel comfortable. The good points of this design were being "lightweight" and easy-to-carry – mentioned by 70% of wearers.

3.7.2 For the second design platform

During doing some activities, around 25% of wearers faced the problem of losing the hat – this was less than the first design. Six wearers (~15%) reported that wearing this hat caused hair loss. Around 55% of wearers complained about the hat being quite heavy and difficult to carry – this might be from epoxy resin characteristic. The good point of this design platform was shown through the shell that was made from soft and flexible jelly-like material. This condition made well-deforming curvature direction to support any platform of wear's head, it was not too tight.

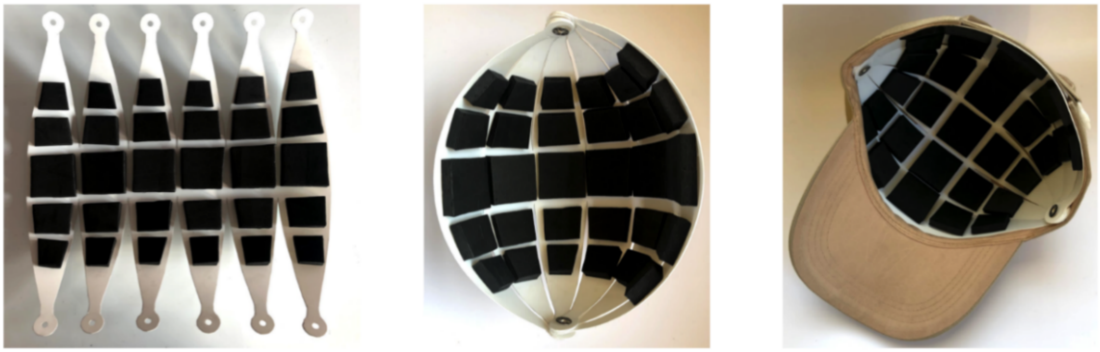


Fig. 13. The first design of foldable hat insert design: PP and EVA.

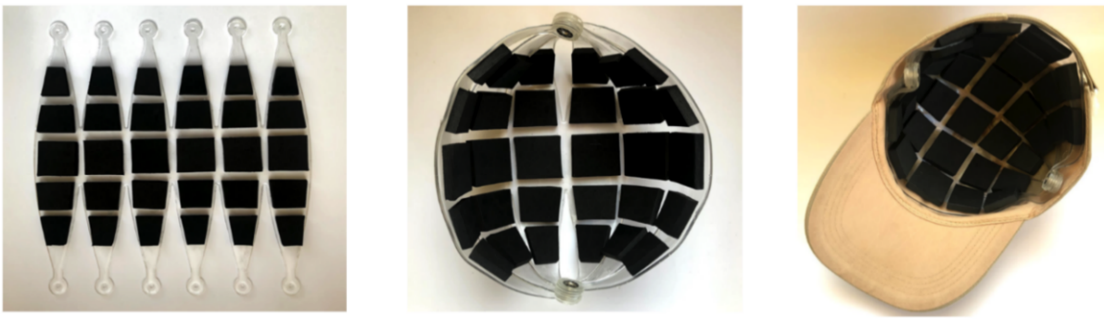


Fig. 14. The second design of foldable hat insert design: Flexible epoxy resin and EVA.

The paddings (Fig. 15) are designed to support the user's head and make the user feel comfortable and soft when wearing the hat. These paddings allow reduction of the contact between the user's head and the foldable plate where the air can flow through. Moreover, the force directly exerted to the head will be lower. There are 3 paddings used in this research; they were lined on each plate strip as shown in Fig. 16.

After combining all components, the 3D virtual model of the foldable hat insert was created as shown in Fig. 17, and this model was ready for fabricating layer by layer in rapid prototyping (RP) process.

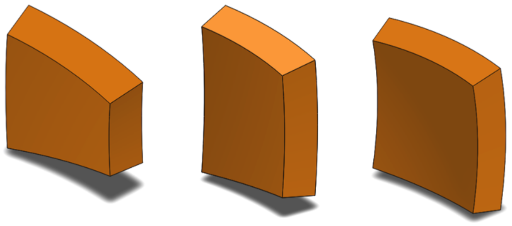


Fig. 15. Paddings used in foldable hat insert.

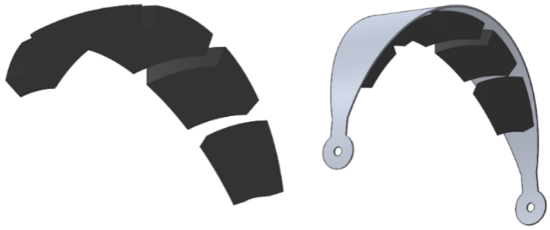


Fig. 16. The paddings when lined on each plate strip.

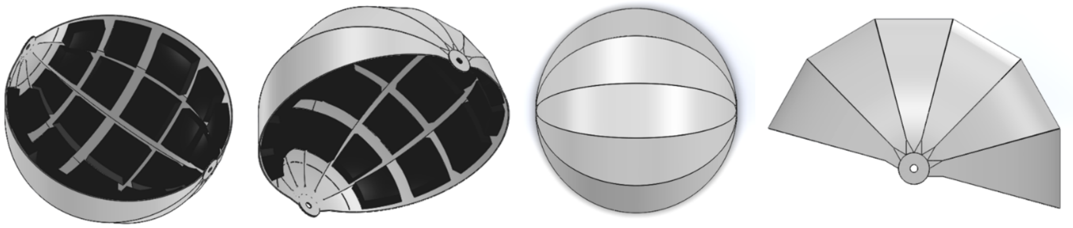


Fig. 17. 3D spline model of foldable hat insert.

3.8 Finite element analysis (FEA)

Recently, the concept of finite element analysis (FEA) has been applied for supporting health-related issues and applications [37, 38]. Those important and interesting techniques were considered and extracted to assist in using FEA in this study. After the design of the foldable hat insert is finalized, a simulation is done by using Solidworks to test impact force when the force is applied to the foldable hat insert. This simulation is tested with the Polypropylene plate and Ethylene Vinyl Acetate (EVA) paddings whose material properties were mentioned previously in Tables 9-10. Actually, both should have a non-linear property.

However, the linear assumption was made with average value of the material properties. This was because of varying the actual data of PP plate and EVA greatly according to the manufacturing process involved, as well as the mixing ratios. The fixed geometry is added on EVA foams surface where the head will be contacted with and the immovable fixed is added where the fasteners will be assembled as shown in Figs. 18(a) and 18(b). The model shown in Fig. 19(a) is a FEA model of a foldable hat insert consisting of 6,389 elements with 14,298 nodes. The foldable hat insert was impacted with the falling object on the top surface of the model as shown in Fig. 19(b).

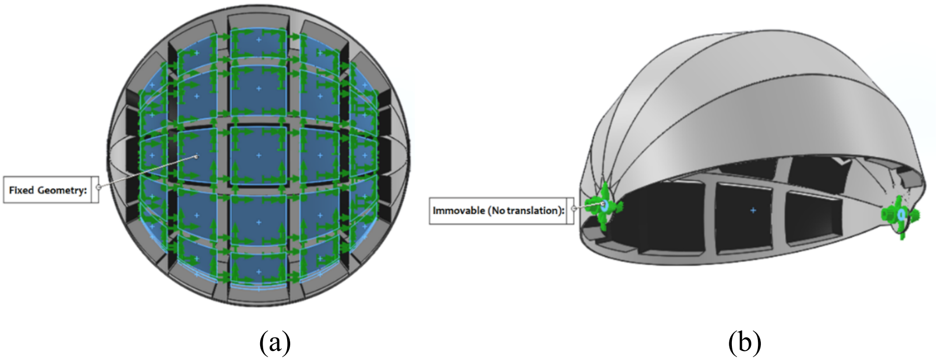


Fig. 18. 3D form of (a) fixed Geometry on EVA foam surface, (b) immovable fixed.

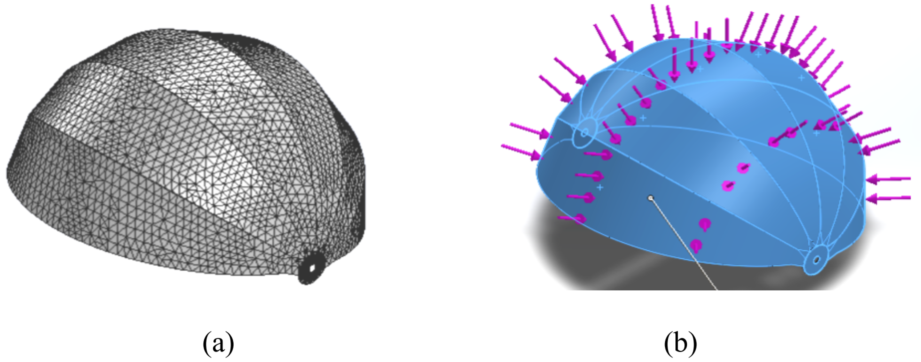


Fig. 19. FEA simulation form of (a) foldable hat insert model – mesh form, (b) total force applied to the top surface.

In order to study falling objects and the force they cause, the *mass of the object*, *height of the human*, and *drop height* are the key components. The drop height is considered as the vertical distance between the drop zone and the object.

The aim of the proposed design is to create the insert to support everyday cap (i.e., baseball-style cap) where the capability of this developed insert is limited only for absorbing some forces/impacts - the action of one object coming forcibly into contact with another, which contribute to the area of interest.

In order to study this, the real-world situations are simulated to observe the Von Mises Stress value. A statistical analysis of different intra-cerebral parameters shows that *Von Mises Stress* is the most suitable parameter to predict mild diffuse axonal injuries (mDAI) for loss of consciousness for a few seconds to a few minutes. Tolerance limits for a 50th percentile risk of injury used in FEA simulation have been established at 26 kPa or 26,000 N/m^2 [39].

Simply saying that "the value of *Von Mises Stress* obtained from FEA is less than 26 kPa or 26,000 N/m^2" answers the question and fulfils the expectation of the design stage where the developed insert can support the wearer from some impacts of the falling object.

Moreover, while wearing the developed insert, a person will feel comfortable and safe when walking since the insert is not too thick and it is fitted to the curvature surface of the wearer's head. Thus, this developed insert can reduce impact from the falling object.

In order to apply the FEA technique, the constraints are required and assigned as:

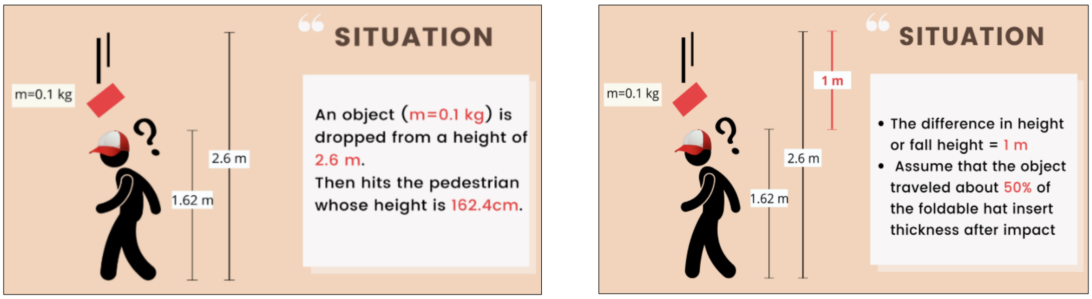
- *Object mass:* it is assumed and assigned as 0.1 kg (i.e., a ball whose mass is 100 g is dropped from a height of 2.6 m from the 2nd floor building).
- *Dropping height:* it is around 2.6 m (i.e., the 2nd floor of a building).
- *Height of pedestrian:* it is assigned as 162.4 cm. This value is considered from the average height of males and females in various world countries [40]. For Thai people, the average male height is 167.5 cm (5' 5.9"), and the average female height: 157.3 cm (5' 1.9"). Thus, the 162.4-cm height is calculated by applying the average height of males and females.

$$\text{Assigned height} = \left(\frac{167.5 + 157.3}{2}\right) = 162.4 \text{ cm.}$$

Situation: An object of mass (0.1 kg) is dropped from a height of 2.6 meters and hits a pedestrian (i.e., a person walking along a road or in a developed area) whose height is 162.4 cm.

This makes the difference in height or fall height equals to 1 meter while assuming that the object traveled about 50% of the foldable hat insert thickness after impact. Using a handy worksheet from *Georgia State University's Physics Department* [41] we can calculate the average impact force theoretically.

Since the EVA foams are varied into 2 thicknesses, which are 7 mm and 10 mm, two models will be simulated separately. Three types of results are obtained for each model, which are the Von Mises Stress, displacement, and strain. Illustrated in Fig. 20 are the graphical platforms of the situation to easily clarify the statements provided.



(a) (b)

Fig. 20. Graphical image for situation: (a) Statement – Part 1, and (b) Statement – Part 2.

3.8.1 FEA result with 7-mm EVA paddings

Fig. 21 presents the platform for calculating impact force from a falling object [41]. Since the object traveled about 50% of the foldable hat insert thickness after impact, the distance traveled after impact (d) was considered as 3.5 mm, which resulted in the average impact of 280 N. The Von Mises Stress, displacement, and strain results from running *Solidworks* simulation for model with 7-mm. EVA paddings are shown in Fig. 22.

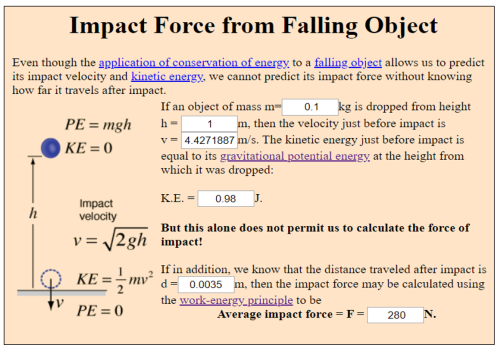


Fig. 21. impact force from falling object calculator, EVA 7-mm. thickness.

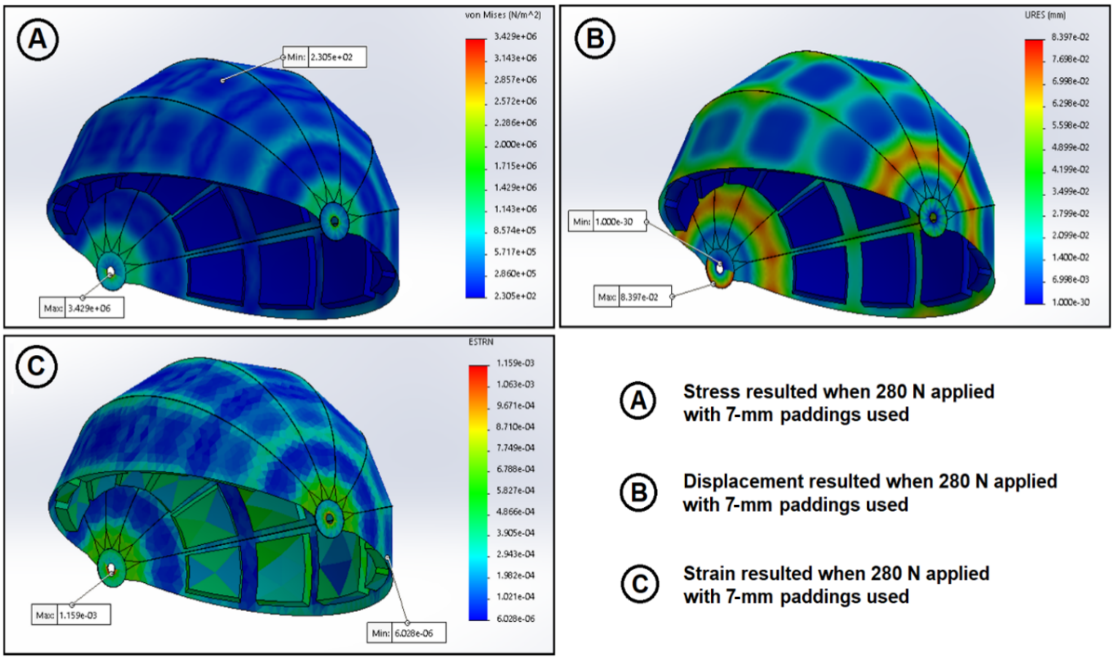


Fig. 22. FEA Simulation for model with 7-mm EVA paddings.

3.8.2 FEA result with 10-mm EVA paddings

Illustrated in Fig. 23 is the platform for identifying the impact force from a falling object [41]. Since the object traveled about 50% of the foldable hat insert thickness after impact, the distance traveled after impact (d) was considered as 5 mm., which resulted in the average impact of 196 N. The *Von Mises Stress*, *displacement*, and *strain* results from running *Solidworks* Simulation for model with 10-mm EVA paddings are shown in Fig. 24.

The simulation results present the *Von Mises Stress*, *displacement*, and *strain* values in which the maximum values obtained for both EVA paddings of 7 mm and 10 mm are summarized in Table 11.

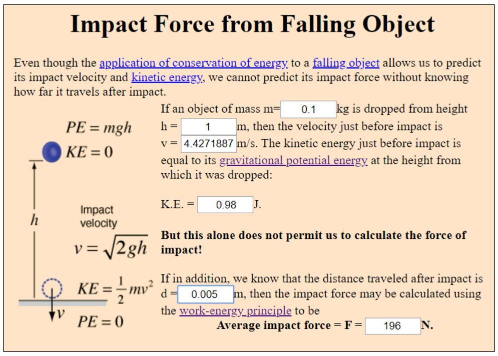


Fig. 23. impact force from falling object calculator, EVA 10 mm.

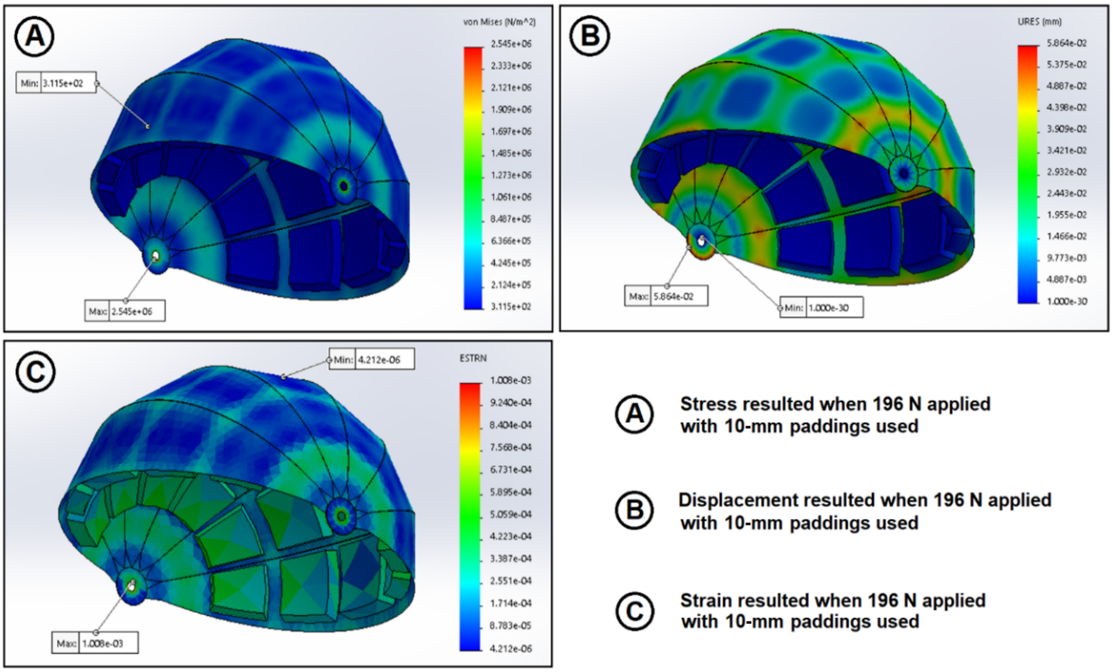


Fig. 24. FEA Simulation for model with 10-mm EVA paddings.

Table 11. Maximum values obtained from the simulation of EVA of 7-mm and 10-mm surfaces.

Result Type	Surfaces	
	EVA 7-mm	EVA 10-mm
Von Mises Stress	3.429×10^{6} N/m^2	2.545×10^{6} N/m^2
Resultant Displacement	8.397×10^{-2} mm	5.864×10^{-2} mm
Equivalent Strain	1.159×10^{-3}	1.008×10^{-3}

When this standard value was compared to the one obtained from Solidworks simulation model, it was found that the tested model exceeded the standard Von Mises Stress value. However, when the team reconsidered the results, they noticed that the maximum value only occurred in the area where the fastener was assembled (i.e., the left and the right joining areas); this was at the side of the hat. This stress did not apply pressure to the wearer.

Zooming the surface area of EVA foam that contacted directly to the head could clearly show that the Von Mises Stress did not exceed 10^4 N/m^2 or this obtained value did not exceed the standard value of 26,000 N/m^2 (26 kPa) for both sizes of EVA foam. Moreover, from Fig. 25, the maximum value of stress found was shown as 3.239 kPa; 3,239 N/m^2. Therefore, the force from the falling object (impact) was considered with only 3,239 N/m^2 that was hit the wear's head; forces applied 8 times less than the standard value (26 kPa) that could make the people lose their consciousness for a few seconds to a few minutes.

For Von Mises Stress on EVA 10-mm surfaces (Fig. 26), the the maximum value of stress found was shown as 3.320 kPa; 3,320 N/m^2.

In conclusion, the shock absorption ability of the insert developed in this study can be expressed via the value of Von Mises Stress that is less than 26 kPa or 26,000 N/m^2.

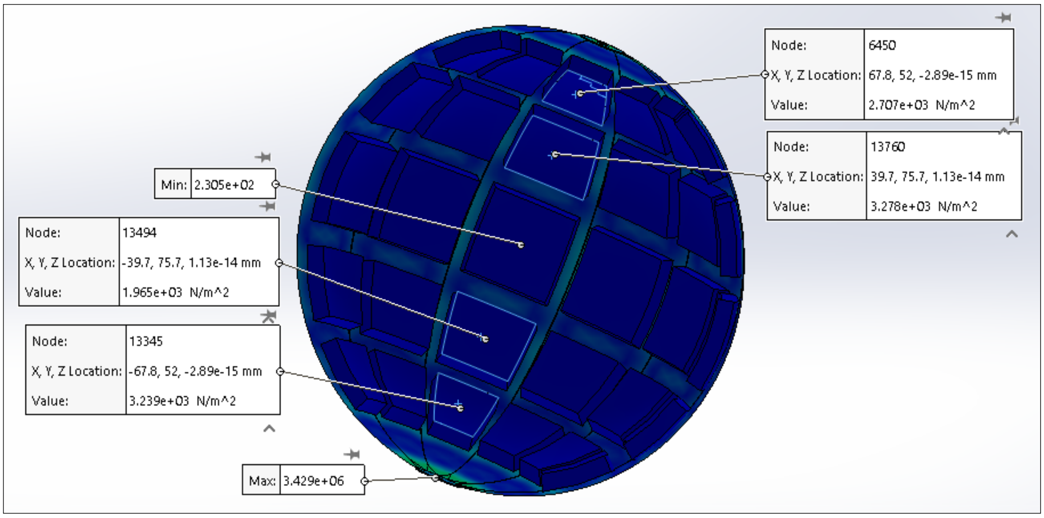


Fig. 25. Von Mises Stress on EVA 7-mm surfaces.

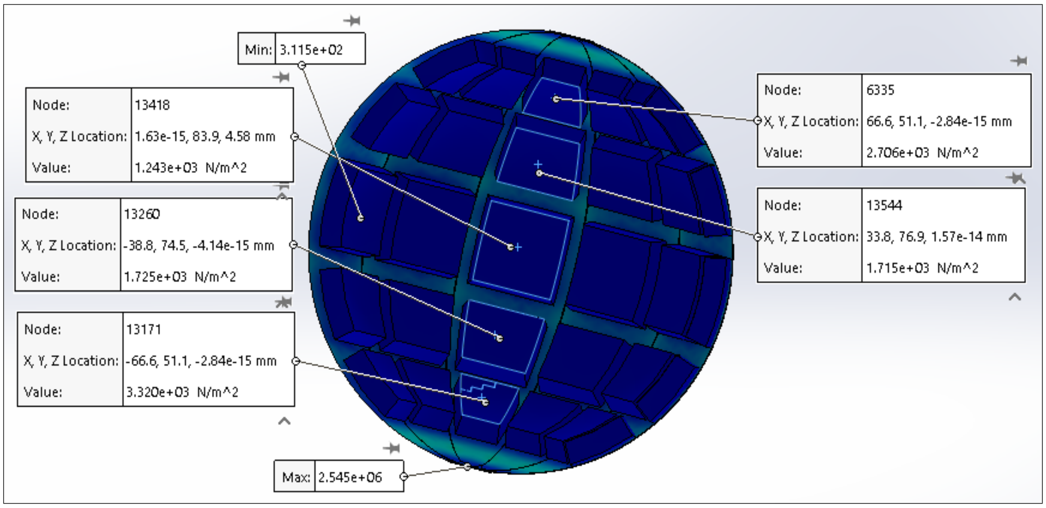


Fig. 26. Von Mises Stress on EVA 10-mm surfaces.

3.9 Prototyping

After a 3D spline model of the foldable hat insert was created, a Rapid prototyping (RP) method was used to create the first prototype by using a 3D printer. The set of paddings of the foldable hat inserts was printed out by using an XYZ da Vinci 1.0A – 3D printer. For the software part, the Simplify3D software was selected for creating the prototype since it produces better quality compared to other programs (Fig. 27).

However, in this prototyping process and the limitation of this printer type, ABS plastic was applied as the printing material instead of EVA; as a result, only the correct geometric shapes of the designed hat inserts were revealed and checked. This might have a direct effect on user's feeling when applying these inserts to the baseball cap, since ABS is a lightweight, tough, rigid thermoplastic that has high impact and high mechanical strength compared to EVA ones.

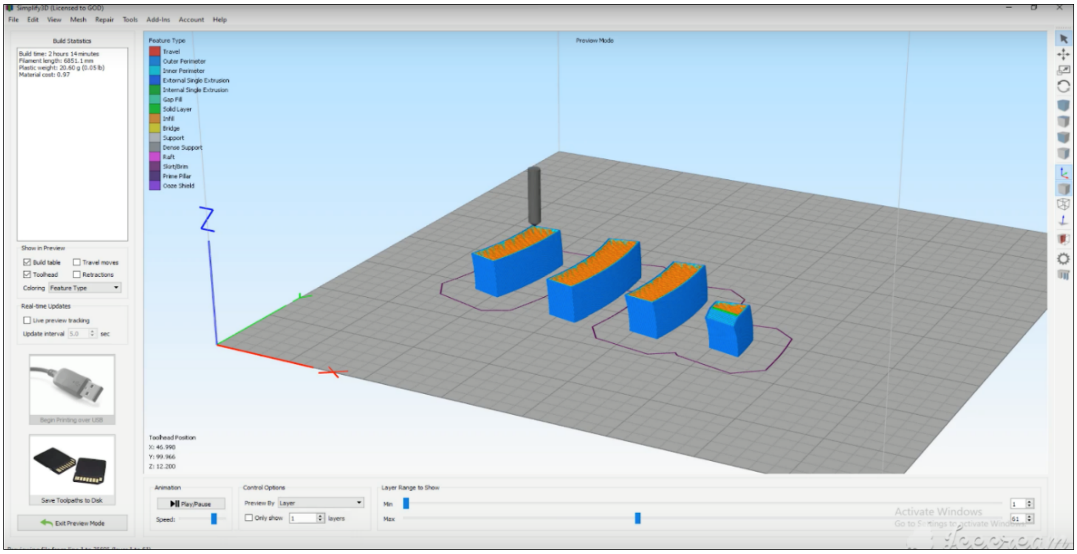


Fig. 27. The Simplify3D software.

After completing the assembly process, there was a problem about the size of the hat that does not fit the user's head properly. In order to improve the prototype of padding, the thickness of the padding part needs to be reduced with taking force applied capacity in account. The prototype of the padding set is shown in Fig. 28. The first prototype of the foldable hat insert is introduced when the fabricated paddings are assembled with the baseball cap (Fig. 29).

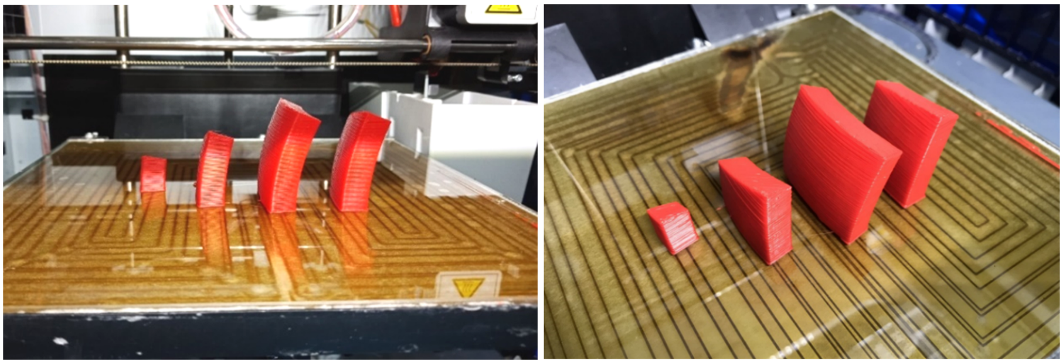


Fig. 28. Padding parts printed by *XYZ da Vinci 1.0A*-3D printer.

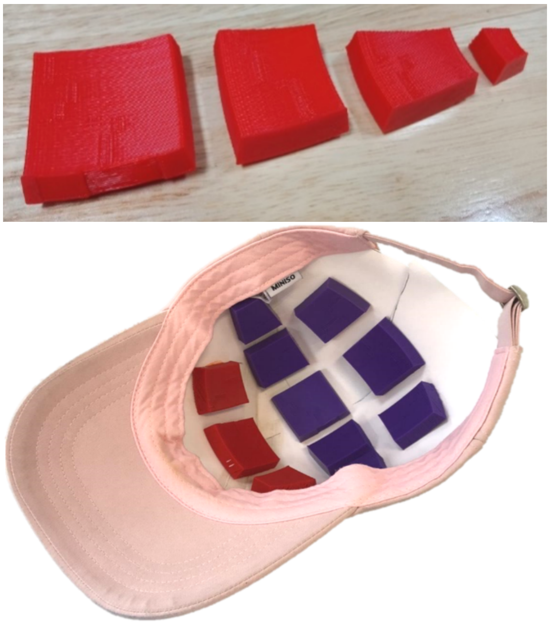


Fig. 29. The fabricated prototype of paddings and the foldable hat insert when assembled with the baseball cap.

4. Discussion

In this study, the customer feeling has been used as the key consideration to create the prototype of foldable hat insert. Head injury, such as from falling objects, can happen to pedestrians and people who usually perform outdoor activities. The foldable hat insert is an equipment that can help to reduce risk of this problem and is very portable to carry. The user can use this developed equipment with zero-background experience.

The self-administered questionnaires were used for collecting data in order to obtain the customer's requirements. The 3D spline model is created based on the concept of ergonomics. The main problem of the traditional design was its bulky size and weight, which is inconvenient and requires a large space. In addition, use of the helmet may cause the user to feel a sort of oppression and/or to smell some unpleasant odor due to perspiration. For such reasons, many users do not use it.

After the 3D spline model of the foldable hat insert was created, a 3D printer was used to create the first prototype. The padding parts of the foldable hat inserts were printed out using a 3D-printing RP process where ABS plastic was the main raw material. Since each part was printed out separately, an assembly process was required to get the complete prototype.

4.1 Guidelines of the proposed research

Moreover, some concepts of product and development have been studied and applied in this study for assisting the design stage of this study [42, 43]. The expected results of this research are a spline model of foldable hat insert and prototypes based on the design of the spline model. The overall steps and guidelines of the proposed research are shown in Fig. 30. Five main concepts are applied: product design and development (PDD), ergonomics, reverse engineering (RE), rapid prototyping (RP), and finite element analysis (FEA).

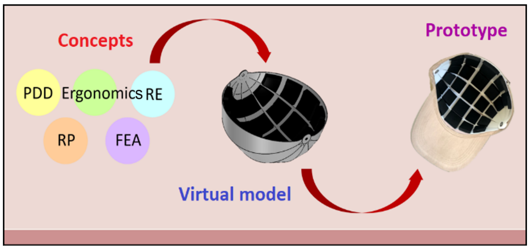


Fig. 30. Overall guidelines for making a hat insert.

A market survey was conducted using questionnaires as the method for data collection in order to obtain the customer requirements such as the main cause of injuries, suitable size, and function of the foldable hat insert. After the final design of the product was created using the collected data, the properties of materials were considered. Different parts of the product require different materials.

The most suitable materials are *Polypropylene (PP)* and *Flexible Epoxy*

Resin for the plate part and *Ethylene Vinyl Acetate (EVA) foam* for the padding parts.

The FEA model has been used to simulate the impact force of the foldable hat insert to see the Von Mises stress value, displacement and strain. Von Mises stress is used as an indicator to predict minor head injury. The tolerance for a 50th-percentile risk of injuries is at 26,000 N/m^2 in which the simulation results from current study are not exceeded this standard value. Nevertheless, the finite element results obtained from running a simulation at this stage might not be completely done. Therefore, it seems to be too soon to conclude whether our final model works or not. This study has to be revised, modified and developed in a further study. However, this could be used as a guideline or proof of concept on the product background, product design and for developing the extra gadget, foldable hat insert, for anyone who has an idea to make the product that is useful to others. In conclusion, for developing a new design of product, three main phases are required (Fig. 31).

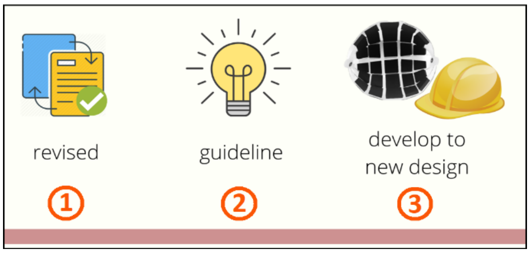


Fig. 31. Three main phases required for creating a new product

4.2 Limitations and difficulties

The limitations and difficulties of this research are summarized in the following statements. The machines available in our laboratory are not capable of making the final model. Thus, most parts of the model have to be made manually, which can cause errors. The casted flexible epoxy resin plate could not determine its mechanical properties due to the lack of a testing machine. This led to no simulation for the model with foldable plate made from flexible epoxy resin and padding parts made from EVA foam.

Another problem with simulation by FEA is the data of constraints for some materials cannot be found in the software library or on the internet. Some materials used have nonlinear elastic properties. However, currently within this study, the nonlinear simulation could not run successfully. The specification of the applied computer cannot deliver various patterns of the calculation with many constaints, and it takes a long time to run the complete set of simulations.

4.3 Research contributions

The contributions of this research are summarized as follows:

4.3.1 Supporting Pedestrians

Over the next two to four years, traffic across the city is likely to move slower from the impact of the widespread construction work to expand the city's skytrain network. There are many risk factors for pedestrian fatalities, walking through or around the skytrain construction areas is the biggest factor. Some small particles (e.g., cement construction materials, polymers, metals or woods), coincidently and diversely, may fall and they can cause serious head injuries. This proposed approach has been introduced for an alternative channel to select the appropriate foldable hat-insert to protect head.

4.3.2 Supporting Sports

For personal protective equipment or sports injury prevention, applying the proposed materials to assist the existing protective equipment (e.g., for football and baseball; *shin/elbow/upper arm guards*, *hand/wrist guard for runners*, and *chest protector/shin guards/a helmet with a face mask for catchers*) can protect the players effectively. The user can feel comfortable applying the proposed light-weight and thin-layer protective plates where the shapes of the plates can be deformed and flexible enough to fit the body parts.

4.3.3 Supporting DIY indoor activities

During the COVID-19 pandemic, many people are working from home; they might need some activities to do with their families, creating new idea on protective equipment, such as applying the guidelines of hat-insert item proposed in this research to the mask shield or other protective items for kids, can help them stay relaxed and encouraged.

4.4 Recommendations for the future study

Furthermore, the prototype will be applied to the real experimental test, modified and revised in order to get a better design of the foldable hat insert. For the simulation test, testing more on non-linear and impact by using other programs, such as *ANSYS*, *Comsol*, or *Abaqus*, is required to make sure that the quality of the foldable hat insert obtained reaches the standard.

For the final model, launching a new set of *Google Forms* questionnaire is required to gauge the customers' satisfaction on the model design where both the physical shape and characteristics are taken into consideration. The clean-and-clear pictures of overall design and the video that demonstrates how the foldable hat insert works should also be attached to the questionnaire to let the respondents experience the model as if they have a real product in their hands.

5. Conclusion

The research aimed to present the new alternative design of protective equipment or helmet-like product. The design was evaluated to determine whether it can fit perfectly with the user's head and the available hat or not. The finite element analysis was applied to analyze the impact force on the model. Moreover, the prototype design refinement will take place in upcoming events as we render a material 3D model and animate the foldable hat insert demonstration. After a 3D spline model of the foldable hat insert was created, a 3D printer was used to create the first prototype. The paddings of the foldable hat insert were printed out layer by layer by using 3D-printing RP process where the ABS plastic was the main raw material. Since each part was printed out separately, the assembly process was required and performed to get the complete prototype. In this research, product design and development (PDD), ergonomics design, reverse engineering (RE), rapid prototyping (RP) and finite element analysis (FEA) have been used as the key tools to obtain optimal design and prototype of the product.

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