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Concept Development in a Walking Assistive Device:
Offset Handle With a Small Base Area

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ABSTRACT

The design of a walking assistive device with a single stick, offset handle, and small base area platform has been introduced in this study as an alternative channel for supporting senior adults to walk by themselves with confidence while maintaining good posture. The stick can follow the rhythm of walking step, and the users can control it easily. To provide cost-effective design structure while preserving customer requirements, product design and development (PDD) with the assistance of finite element analysis (FEA) is applied in this study for simulating the load distribution on the area of interest. The perceptions from potential users expressed that "strong and stiff with light weight" were the main considerations for making a walking device. Aluminum material was suggested to be the reference for developing a walking cane. The concept of "usefulness of product" was applied as the guideline to help and support the design team for selecting the right design parameters of a walking cane based on the data obtained from the survey and customer perceptions.

KEYWORDS

Customer Perception, House of Quality, Product Design, Quality Function Deployment, Usefulness of Products, Walking Device

INTRODUCTION

Currently, the number of people aged 60 and older in Thailand stands at about 13 million, accounting for 20% of the population. Within the next 15 years, approximately 30.2 percent of Thai people will become senior citizens. This will cause many changes in this country including in the manufacturing section. For supporting "*senior citizens*", manufacturers have tried to emphasize and focus more on developing and producing the alternative products with applying the concept of "universal design" where "accessibility and simplicity" are the key components. Social care and support guide of activities for senior adults with limited mobility will become an essential issue where "health-related products" have been introduced in various fields and categories. However, cost of manufacturing and selling price for those products are high since the specific materials applied and easy-to-use functions are involved. Moreover, common health problems for elders include loss of vision, hearing loss, upper

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and lower body pain, heart disease, diabetes and osteoarthritis. In addition, the senior adults are more likely to experience several conditions at the same time. According to the World Health Organization (WHO), around 28–35% of people 65 years or older fall annually. The number of fallers increases approximately to 32–42% in persons 70 years or older (World Health Organization, 2014). With the rapid increase in the aged population, the global market for elder care assistive devices is continuously growing. However, in Thailand, this is still in the initial stage where the industries cannot provide a right product to satisfy customer requirements. This problem is considered as one of health-related product problems, and it results in a mismatch with the growing demand of the market when focusing on product quality or product category. Particularly, the companies have some concerns about spending a lot of money for supporting the initial research and development process of elderly products. As the result, the obtained design with trial-and-error concept cannot satisfy the target users. In the near future, it is essential to focus on "customer-oriented" concept by creating products based on customer needs. For the business owner to compete with competitors, providing and offering the right products to the customers at the right time, right place and at the right price are very important and necessary (Rianmora et al., 2020, Rianmora & Werawatganon, 2021). Moreover, two factors have been identified as the key important issues for designers and manufacturers to launch a new product to the market: "*know where it is going by having a clear vision*"; and "*follow a structured new product development process*" (Tsimiklis *et al*., 2015).

Recently, from the reports, age is one of the key risk factors for falls – the senior adults are increasingly at risk of falling and consequent injuries, and they might be searching treatment for their injuries in hospital emergency rooms or health care institutions. In the older persons, the frequent falls can imply and lead to serious health consequences, since a fall might be considered as the first key indication of an undetected illness. Every year, around 2.5 million, people ages 65 and older (this is higher than any other age group) are treated in emergency departments because of falls, according to the disability and instability to maintain the posture during standing, walking or slowly moving from one place to another. This critical situation starts to a rapid increase in the number of patients (very old people) who, again, go to the emergency room for a fall issue within one year. The most falls occur in the house where the dangerous zones include area that contains a floor covering of thick woven material or animal skin as rugs and slippery bathroom floors (Vann & Bass, 2016). Unintentional falls are a leading cause of a major contributor to disability in the senior citizens. Even if an injury is not life threatening, falls have long-term consequence. Therefore, falling has become the main reason for pain, disability, loss of self-caring ability and premature death. The loss of muscle strength, physical frailty, hearing, and visual deterioration in addition to environmental hazards in the home are a major cause of reported falls. The walking assistive devices have been introduced as the key tool for helping senior adults to walk properly with confidence in everyday life – when the senior adults perform daily activities and move around. Various types of the walking assistive device are available in the current markets such as cane, crutches, walkers, walker cane hybrid or the combinations among the devices. As the aforementioned assistive devices, the stick-shaped-like form is selected as the reference design for creating the proposed model of the walking assistive device. Furthermore, the walking stick can effectively prevent senior adults from falling (West, Bhat, Stevens, & Bergen, 2015). The most difficult part of design stage is about how to express and translate customer needs to be product characteristics with technical functions properly. The users or target customers decide to buy a new product by applying their personal perceptions, feelings, and experiences obtained from the influencers and/or salespeople (Aziz & Lokman, 2011; Sarkar & Chakrabarti, 2011; Rianmora *et al.*, 2020). Thus, a product that provides good-looking form and shape with extra features or fashionable characteristics will be sold out first. However, for a health-related product, ergonomics and physical properties of the product of interest are the key addressed issues and need to be considered first.

After reviewing some articles about walking assistive devices for senior adults; some hidden issues were mentioned and discussed. However, many senior adults who might benefit from using

mobility aids (i.e., walking assistive devices) do not or will not use them due to some reasons. *Firstly*, the device is large, and it is difficult to carry around. *Secondly*, some of the walking aids are heavy. *Thirdly*, a handle used to hold the walking aid is not comfortable when using for a long period. *Finally*, older adults' self-perceptions of aging and being older can influence well-being and quality of life; however, using walking aid makes they look older than their age, and they feel awkward about it. From these perceptions, the researchers have tried to propose an alternative design direction with easy-to-use concept to develop a health-related product that can prevent the senior citizens from fall accidents. Product design and development (PDD) has been applied as the key tool in this research to extract the hidden issues and help to reveal which type of walking cane should be selected for preventing dangerous accident while walking.

2. RELATED WORKS

2.1 Target Customer

Falling has become the main reason for pain, disability, loss of self-caring ability and premature death. The loss of muscle strength, physical frailty, hearing, and visual deterioration in addition to environmental hazards in the home are the main reasons of falls. As aforementioned about the assistive devices, the stick-shaped-like form is selected as the reference design for creating the proposed model of the walking assistive device. Furthermore, the walking stick can effectively prevent seniors from falling (West *et al*., 2015). To accomplish the proposed design of a walking assistive device, some related works have been studied and discussed where descriptions of existing models of walking aids will be mentioned and presented.

2.2 Market Survey on the Existing Products

Some hidden issues are found during selecting the assistive device, especially, the difference between "cane" and "stick". For the brief story of the fundamental difference between a walking stick and a cane, "the function" provided by each type will be used as the "key consideration". For, "*walking sticks*", they are a temporary device primarily used for stability and balance when climbing or walking on rough terrains or a stretch of land, especially regarding its physical features. Whereas, for "walking canes", they are mobility aids designed to take the pressure off a painful joint on a long-term basis (Rowe, 2020).

2.2.1 Common Types of a Walking Device

Recently, there are many types of canes that are available in the market, a function or design that is confusing makes it difficult for people to know exactly how to apply, select and define which one is suitable for senior adults. Some common types of canes are classified into six main types (Figure 1 and Table 1). Some are about "a single stick design", whereas some of these may be combined as shown in the "quad canes" which have a functional grip with a 4-leg base area.

The key points for supporting the design of walking device are "single-stick" and "4-leg" platforms. From Figure 5, "single-stick" style is applied in *C-Cane*, *functional grip cane*, *offset handle*, and *folding walking*. Whereas the concept of "4-leg" platform is applied in *quad walker*, and *hemi walker*.

2.2.2 Popular Walking "Cane and Stick" From Commercial Websites

However, from the customer perceptions, words "cane" and "stick" are not much different and they do believe that those two devices can save and maintain their stability during doing some activities without asking for help. From this point, the designers have tried to launch the walking aids with the specific "cane-and-stick" keyword to their product characteristic; and/or sometimes, they decide to apply "stick" for representing the "cane" function. Table 2 to 4 present the popular types of "walking

Figure 1. Types of canes (California Mobility, 2021)

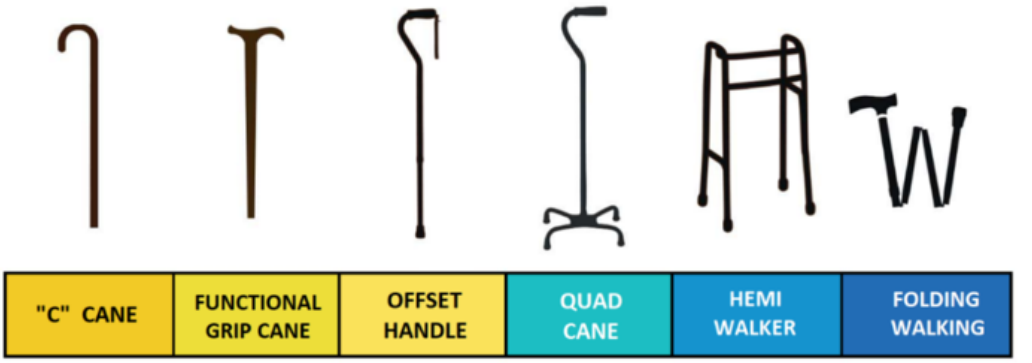


Table 1. Common types of a walking device (California Mobility, 2021)

Type	Features	Pros	Cons
"C" Cane	• This is one of the most basic types of walking cane. • It is a single-tip straight cane with a curved (C-shaped) handle. • It helps balance simply by increasing your base of support. • Minor assistance with balancing or keeping weight off one leg is required.	• Provides some support • Widely available	• Not suitable for people requiring more than light support • Do not stand alone
Functional Grip Cane	• It is a straight single-tip cane with a straight handle (perpendicular to the main shaft or stick). • The straight handle allows for better grip and control than a curved one does. • Ideal for people who need a bit more assistance with balance.	• Easy to grip • Provides more support than a "C" cane • Widely available • Often foldable for easy storage • Often have adjustable height	• Most do not stand alone • Not as supportive as a quad cane
Offset Handle Cane	• The design of this walking cane ensures the user's weight is centered such that it bears mainly on the strongest part of the cane. • It is suitable for those who need to put partial weight on their cane.	• Improved weight distribution • Provides more support than a standard functional grip cane	• Still not as supportive as a quad cane • Most do not stand alone
Quad Cane	• Rather than a single tip, this has four supports at the bottom, forming a rectangular base of varying sizes. • It typically comes with an offset handle and is suitable for those requiring a lot of support. • It can bear more weight than a single tip cane and reduces the chances of slipping.	• Provides the most support • It can stand alone instead of having to be leaned against something when not in use.	• Can be more cumbersome and difficult to maneuver than a single-tip cane • Typically, cannot fold for storage
Hemi Walker	• This type of cane is closer to a walker than the others. • It is often used by those transitioning to or from a walker.	• Provides the most support • It has an even larger base than a quad cane.	• More cumbersome; Difficult to use on stairs
Folding Cane	• A folding cane is a regular cane — usually a functional grip cane — that can be folded. When folded, it might be carried by a wrist strap or placed in a bag.	• Light weight • Ideal for on-the-go • Typically have adjustable height	• May not be as sturdy as other canes

Table 2. Small base and adjustable walking cane (Single-stick concept)

No.	Image	Key Components	Features	Price (THB/USD*)
1	 **Deluxe Light weight Adjustable Walking Cane** https://amzn.to/3nrbR9d	• **Name:** Duro-Med • Light weight adjustable cane, easily adjust with button • Strong slip resistant with a rubber tip, help to prevent slips and falls • Weight capacity up to 250 pounds (113 kg) • Soft foam handle with strap • Push button for length adjustment	• **Shaft material:** Aluminum • **Size:** 0.88 x 0.88 x 38 inches (2.3 x 2.3 x 76 cm.) • **Weight:** 0.75 pounds (340 grams) • **Color:** Black • Anodized aluminum tubing offers strong, durable support. • This cane has a metal reinforced slip-resistant rubber tip **Key point:** • Curve top (offset handgrip) is made with soft foam fits with user hand. • Adjustable height from 30 to 39 inches (76 – 99 cm.)	380 / 11.28
2	 **NOVA Heavy Duty Walking Cane with Offset Handle** https://amzn.to/3nrio3m	• **Name:** NOVA Medical Products • Durable plastic handgrip with carrying strip • Light weight & adjustable walking cane • Heavy duty with weight capacity up to 500 pounds (226 kg) • Anti-rattle lock adjustment and prevents cane rattle • Long-lasting slip resistant rubber tip	• **Shaft material:** Aluminum • **Size:** 6.75 x 2 x 29.5 inches (17 x 5 x 75 cm.) • **Weight:** 1.1 pounds (500 grams) • **Color:** Black • Handle with offset design provides good support for user wrist • Smooth plastic handgrip **Key point:** Adjustable height from 30 to 39 inches (76 – 99 cm.)	600 / 17.82

*Based on exchange rate on December 22, 2021 - 1 USD = 33.677 THB.

aids" from the commercial websites. Most of the designs are reported as "cane and stick" styles. Three main categories are mentioned and discussed: *small base with adjustable height walking stick, foldable walking stick,* and *quad walking cane*.

2.2.3 The References of Walking Devices Used for Creating a New Design

After classifying types of walking assistive devices for senior adults from the existing articles and researches; four main considerations were grouped and analyzed for being used as the guidelines to create a new product: *crane or stick*, *offset handle*, *crutches*, and *walker* (Table 5).

2.3 Product Design and Development

Product design and development (PDD) is a process of creating new product to be introduced toward customers where voice of customer such as customer's requirements, expectations, and buying behaviors are the main parameters to be considered (Ulrich & Eppinger, 2020). Moreover, PDD has been studied and applied as the main tool for developing a new product. PDD consists of five main stages (Figure 2): *conceptual development*, *system-level design*, *detailed design*, *testing and refinement*, and *production ramp-up*.

Concept development is the most important stage in product development. Concept development includes identifying customer needs, establishing target specification, and concept generation. To complete activities in this stage, a market survey has been conducted by using a set of questionnaires. Result from the questionnaire will reveal needs of customers. A concept is a description of "form-

Table 3. Foldable walking aids (4-leg concept)

No.	Image	Key Components	Features	Price (THB/USD*)
1	 **Folding Cane with T Handle** https://amzn.to/2LmVZav	• **Name:** HurryCane • Steadi-Grip technology for base part which increases friction with the ground for both indoor and outdoor use • The cane can stand on its own • Weight capacity: 350 pounds (158 kg) • Silicone handle grip	• **Shaft material:** Aluminum • **Size:** 4.75 x 3.75 x 15 inches (12 x 9.5 x 38 cm.) • **Weight:** 1 pounds (450 grams) • **Color:** Black • Adjustable height from 30.5 to 37.5 inches (77 – 95 cm.) • Base size 3.5-inch (9 cm) • Folded size 13.7 inch (35 cm) • Ergonomic design handle • Foldable walking cane	1200 / 35.63
2	 **HONEYBULL Walking Cane/ Free Standing, Foldable, Pivot tip** https://amzn.to/2XtccxB	• **Name:** HONEYBULL • Reliable walking cane. • Free Standing cane with quad tips base allows the cane to stand on its own • Pivot tip design to maximize ground contact on rubber base • Ergonomic handle that does not slip out of your hand and it can provide comfort to user when using for a long time	• **Shaft material:** Aluminum • **Size:** 6.75 x 2 x 29.5 inches (17 x 5 x 75 cm.) • **Weight:** 1.1 pounds (500 grams) • **Color:** Black • Adjustable height from 30 to 37 inches (76 – 93 cm.) • Foldable design • Light weight	600 / 17.82

*Based on exchange rate on December 22, 2021 - 1 USD = 33.677 THB.

fit-function" of a product and is usually included with a set of specifications, and analysis of existing products that are currently available in the market (Rianmora, Padnoi, Rattanopas, & Yantabutr, 2019).

System-level design phase includes deconstruction of the product into sublevels and into individual component where the engineers and designers develop the product architecture in detail. Reverse Engineering (RE) technique can be applied in this stage, to create a CAD model from the existing object by using a small amount of time. (Yao, 2004) Geometric dimension of the product is an expected result from this phase.

Table 4. Quad walking cane (4-leg concept)

No.	Image	Key Components	Features	Price (THB/USD*)
1	 **Hugo Adjustable Quad Cane** https://amzn.to/2LsqImI	• **Name:** Drive Medical • Quad Canes with four tips • Offset design handle that provides additional stability and support • Flared rubber tips for stability and traction • Weight capacity: 300 pounds (136 kg) • Locking bolt height adjustment with one button	• **Shaft material:** Aluminum • **Size:** 8 x 6 x 29 inches (20 x 15 x 74 cm.) • **Weight:** 2.1 pounds (950 grams) • **Color:** Black • Adjustable height from 29 to 38 inches (73 – 96 cm.) • Handle available in foam grip or vinyl	670 / 19.89
2	 **NOVA Heavy Duty Quad Cane** https://amzn.to/3qhBefu	• **Name:** NOVA Medical Products • Four legs design with skid resistant rubber tips which provides increase traction • Durable plastic handle and offset design reduces impact on user wrist • Anti-rattle lock features • One-push button height adjustment • Weight capacity: 500 pounds (226 kg)	• **Shaft material:** Aluminum • **Size:** 10 x 14 x 30 inches (25 x 35 x 76 cm.) • **Weight:** 3.5 pounds (1580 grams) • **Color:** Black • Adjustable height from 27 to 376 inches (68 – 91 cm.) • Durable quad cane provides optimal support, stability and balance for a walking cane.	1000 / 29.69

*Based on exchange rate on December 22, 2021 - 1 USD = 33.677 THB.

Detailed design phase includes specification of the physical appearance and materials of all parts in the product and the identification of all standard parts from suppliers. The output of this phase is full detail for the product such as the drawings or computer files describing the geometry of each part and its production requirement, the specifications of parts and raw materials, and manufacturing operation required to produce and assembly of the product (Wang, Yang, Hu, Huo, & Feng, 2021) (Zhang & Yu, 2016).

Testing and refinement phase involves creation of prototypes (pre-production version product) In general, prototypes are normally manufacture with the same material and same design with the actual production. Rapid Prototyping (RP) technologies offer fast and simple nontraditional methods for making 3D models (Salonitis & Zarban, 2015) (Le, Paris, & Mandil, 2017). Prototypes are tested to determine whether the product satisfies customer needs and will work as designed (Rianmora & Werawatganon, 2019).

Table 5. Four main references of the walking device used for this study

Type of Walking aids	Level of Support	Support Area	Feature
Cane  **Stick**  **Offset handle** 	Low	• Lower arm • Keeping balance • Fall prevention	• Wide base • Adjustable height • Foldable cane • The simplest form of walking aid is a cane or walking stick. • It pass-on body weight to the ground. • Body weight of the user transfers from the user's hand and wrist, which is the contact point. • However, a cane can take less weight off the lower body, and it creates significant pressure on the user's wrist. • Assistive canes are useful for people who have balancing problems and who are at risk of falling. • Offset handle design centers the user's weight over the strongest part of the cane • Ergonomically designed to provide comfort and support for partial weight-bearing users • Push-button, height-adjustable to find the perfect height • Secured with a locking ring to provide quiet, rattle-free use and added safety 250-lb. (113 kg) weight capacity
Crutches 	Medium	• Support upper body weight for leg injury case • Can support more weight	• Forearm crutch • Axillary crutch • A crutch is one of mobility assistive devices that transfers weight to the ground to help reduce load on the user's leg. • It is often used by people who cannot use their legs because of injury. • The crutch transfers user weight to the ground through a cylindrical shaft. • Crutch has two points of contact with the arm, at the hand and below the armpit. • This device can support higher weight load compared with a walking stick.
Walker 	High	• Provide highest stability • The height of walking is around the waist of the user.	• Wheels at front legs • Walking frame with 4 wheels • Walker or walking frame is a device that provides more support and stability to a user while walking. • The basic design consists of a frame made of light weight material. • Optional, the front two legs of the walker may have wheels attached to improve mobility.

Figure 2. The process of Product Design and Development (Ulrich & Eppinger, 2020)

Production ramp up phase where the product is manufactured in actual manufacturing process. It is a final stage before the product launch to customers. Normally, customers expected to see desired products that they want to purchase when they visit a store. Inspecting and experiencing products before buying the product are main reasons for visiting retail stores (Chitturi, 2009).

Consumer needs have been taken into consideration during the product development process to ensure that the product characteristics match with customer needs in terms of physical appearance and function. From the manufacturer's point of view, normally a product will develop, and produce based on the manufacturer's ideal. This process is called "product-in concept", which indicates that the company develops and manufactures a product by considering only their own point of view, without including consumer demand. In contrast, with 'market-in concept" where producers focus on needs of customers and produce products based on consumer requirements (Nagamachi, 1995) (Nagamachi, 1996). The products developed from a customer-oriented viewpoint trend to result in high satisfaction because customers are interested in products that match their requirements (Adiyanto & Agung Jatmiko, 2019).

2.4 3F Concept

According to the customer perceptions on the walking aids, "cane" or "stick" style is the key design, which is applied as the key reference since its function, and structure is quite simple with less maintenance requirement. Thus, for supporting "*Form, Fit, and Function*" concept, the average height, posture, and physical characteristic of the target customer are taken into consideration. They are applied for creating a new design proposed in this study. The phrase *form-fit-function* (FFF) approach can describe the characteristics of a part in manufacturing aspect. Form-fit-function can be defined as:

2.4.1 Form

From the consideration of "Form" in design phase, these following topics are applied: *shape, size, dimensions*, or *other parameters*, which characterize the physical look of the item. Ideal walking stick height should be equal to the length of the user wrist to the ground. For determining the right size of a walking cane to support senior adults, the distance from the wrist joint to the floor is measured while the user is standing straight and wearing walking shoes. Then, rounding down to nearest size or ordering a custom size is recommended as shown in Figure 3 (Catherine, 2014). Moreover, for easily conveying the information about how to select the suitable length of a walking device in senior society, explaining via words with short description is required as shown in Figure 4 (California Mobility, 2021). However, in engineering and designing activity, scale and dimension are the key tools for creating physical shape and size to support remodifying process during 3D model generation. Therefore, the guidelines for selecting suitable length of walking stick for different people, which are classified as four main groups (Art walking sticks, 2020; Dimensions.com, 2021): *x-small, small, medium,* and *large* with numbers are mentioned and referred (Figure 5).

Figure 3. Key position for measuring proper length of a walking cane – Choose by measurement

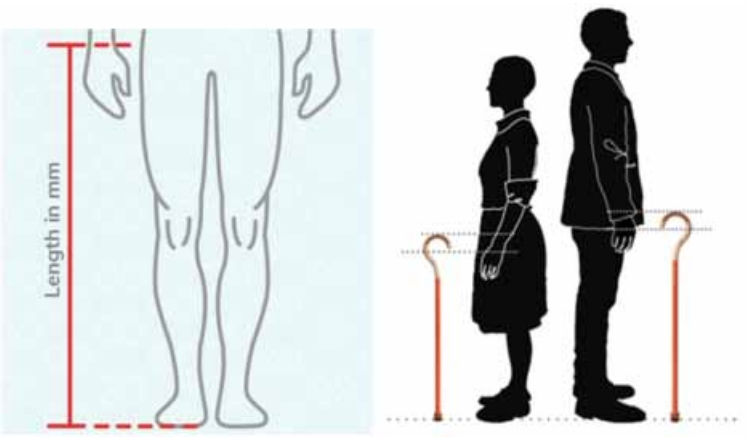


Figure 4. The summarized details for sizing a walking cane (California Mobility, 2021)

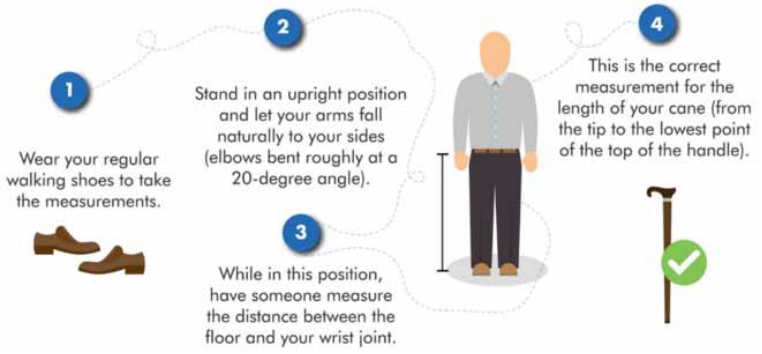
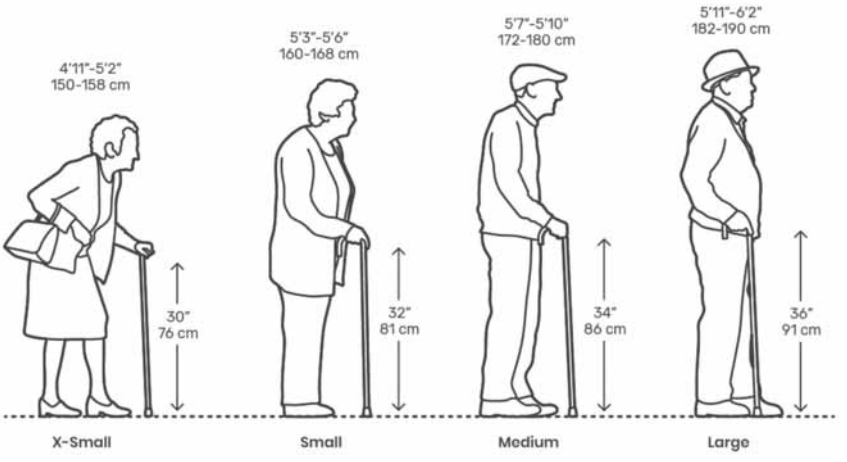


Figure 5. Walking stick height – Choose by height



2.4.2 Fit

"Fit" description can be expressed as the parameters and abilities that provide and make a compartment of new design to be ready for integrating or combining with other components appropriately within an assembling or setting tolerances and requirements. In this study, "handle part" of a walking device is applied as the key tool for "Fitting" concept since this part is used for supporting the force and contacting directly to the user's palm. Recently, many types of handles are available with different materials and shapes. Wood, rubber, and plastic are common materials for the handle part. Shaft is usually made of metal or wood. Tip part is located at the bottom part of the walking stick, which provides the grip. It is made of rubber to provide support and increase friction to prevent slip. Types of walking stick handles are shown in Figure 6. The key design for this "handle" is formed in "curvature surface and shape" with less groove presented. Since the groove (i.e., it is shaped as the finger-like curve) might make the users feel uncomfortable during holding and grabbing for a long time when the forces and moment are applied vertically to the walking cane (i.e., around 1/3 of body weight) during walking (Gomez et al., 2018).

2.4.3 Function

The definition of "function" can be mentioned as the operation of the item or the actions it is intended to perform. For a walking cane design, the activity performed by the target users is the key consideration. Angles and dimensions of the cane mentioned and referred to in many researches (Figure 7) with

Figure 6. Types of walking stick handles

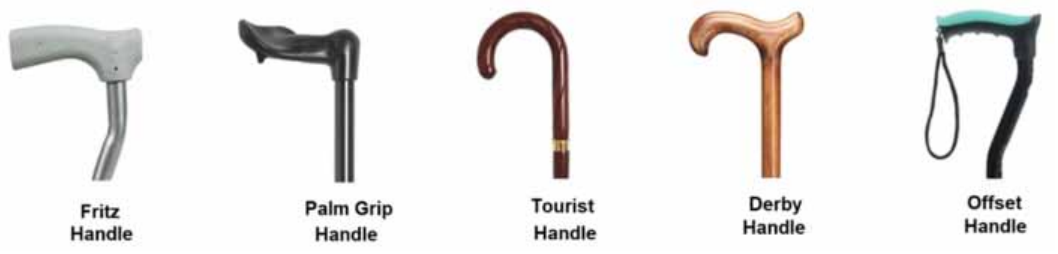
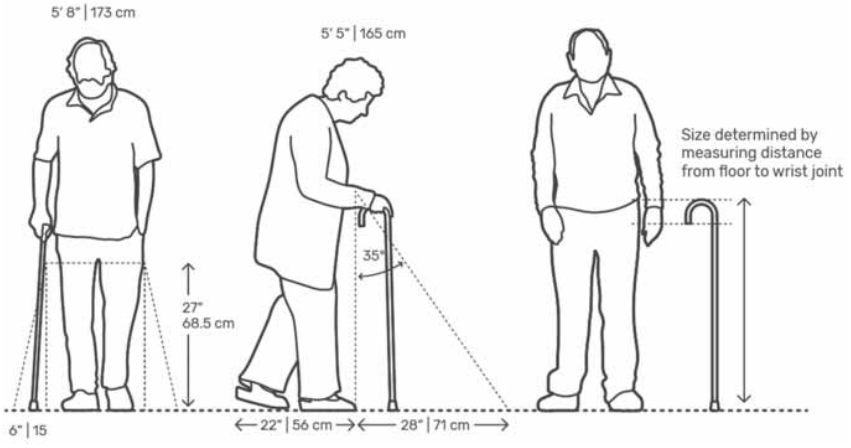


Figure 7. Measuring a walking cane (Art walking sticks, 2020)



respect to the height of the users are implied about the proper space that should be provided during walking or standing without causing any dangerous situations (Art walking sticks, 2020). The stick should be followed the rhythm of walking step, the user can control it easily.

2.5 Usefulness of Products

The knowledge gained from "usefulness of products" can provide some guidelines about which component(s) of the existing product(s) should be considered and selected to be modified and used as the reference(s) for a new design and development. Usefulness can be defined as effective concept, which describes an item or the new technology for helping someone to do something with appropriateness and socially valuable. The actual use of a product is the key consideration for "Usefulness (U)" calculation (Sarkar & Chakrabarti, 2011).

2.5.1 Important Level

The "importance of use" can be described as the impact of a product on people or user live. The product, which has more impact to society, should have higher value of usefulness. Level of importance of products depends on how much a product has impact on user life. Some items are essential to human life, but some are not. Five levels of importance of use have been identified (Table 6).

In addition to Table 6, the level of importance of products can be changed according to the constraint required in that period. When new technology or new invention, which makes some products, becomes more important comparing to itself in the past, that thing is referred as "high level"; for example, "internet and banking transactions". In the past, banking transaction can only be done at local branch of the bank comparing to the present where customers can perform banking transactions such as transfer money, pay bills and card-less cash withdrawal can be done by using mobile banking application on smartphone with internet connection.

Table 6. Level of importance of products (Sarkar & Chakrabarti, 2011)

Code	Points in a scale of 5	Level of importance	Type of importance	Product examples
A	5 (>4.0 - 5.0)	Extreme	• Life-saving drugs, life support systems • Patient life support system • Medical equipment, medicine	Mechanical ventilator, defibrillator, heart/lung bypass machine (Oxygen cylinder, pacemakers)
B	4 (>3.0 - 4.0)	Very high	• Essential for daily activities • Compulsory daily activities	Water, Taking food, Using restroom
C	3 (>2.0 - 3.0)	High	• Accommodation • Social communication • Banking transactions	House, clothes, internet, computer, smartphone, EDC machine, Pen, Belt, Spectacles, Shoes
D	2 (>1.0 - 2.0)	Medium	• Household appliances • Machines for daily needs	Air conditioning system, refrigerator, washing machine
E	1 (0.0 - 1.0)	Low	• Recreation activities • Entertainment systems • Recreation systems	Television, Comics, Books, Computer games, Bowling, Go-carting

2.5.2 Popularity of Use

If a product has been used by many people, that product should considered as more useful that other that are used by less people. It defines as rate of popularity within certain time.

2.5.3 Usage Duration

Usage duration is one of the factors, which affect on product usefulness. A product that has been used for a long period is considered more useful compared with other. Normally, the usage duration can be expressed in unit of hour per day.

2.5.4 Assessing Product Usefulness

Usefulness (U) = Important level (L) x Popularity of use (R) x Usage frequency (F) x Usage duration (D) (1)

The unit should be the same for all factors in the equation such as day, month or year. For seasonal product such as sweater or swimsuit that product demand changes significantly over seasonal period, then a large unit time such as a year should be considered. For products that demand does not fluctuate over the period, any unit of time can be selected for the calculation. Product importance level is associated with Maslow's hierarchy (Figure 8). According to Maslow, human needs have been classified into five types.

Most products intent to satisfy physiological and safety needs of users, which are basic needs of for human life. In this study, walking assistive device has been considered as product with high level of importance for senior citizen and it is considered as one of "Basic needs" products. It can prevent and reduce the risk of accidents while walking.

2.6 Quality Function Deployment (QFD)

In order to translate the voice of the customer into the tangible requirement, the concepts of Quality Function Deployment (QFD) and House of Quality (HoQ) have been applied (Figure 9). To satisfy the customer requirements, QFD will analyze the customer expectation to match with the engineering point of view. The suitable methods for translating the customer need into a product design or customer-driven design process are raised first (Lia, Xie, & Tan, 2004). This method is considered as the importance of product development and innovation process. Recently, the concept of QFD is

Figure 8. Maslow's Hierarchy of Needs (McLeod, 2020)

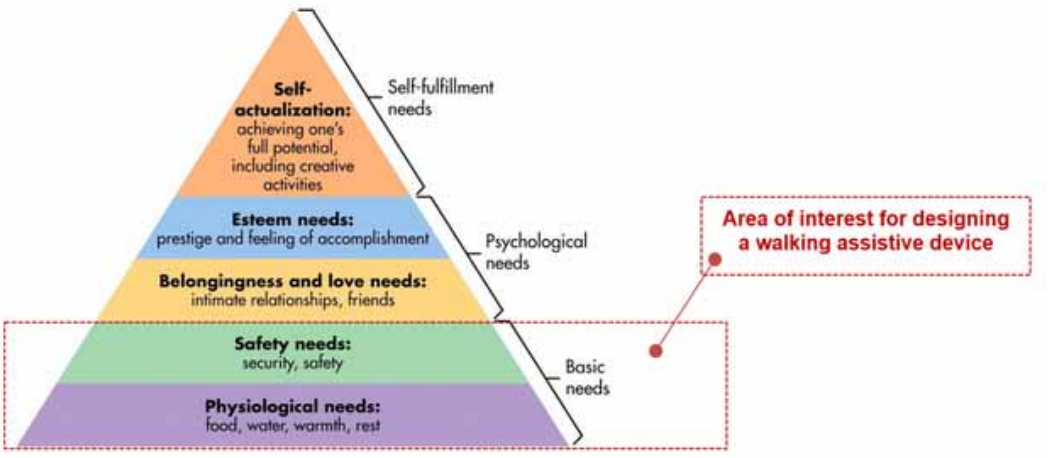
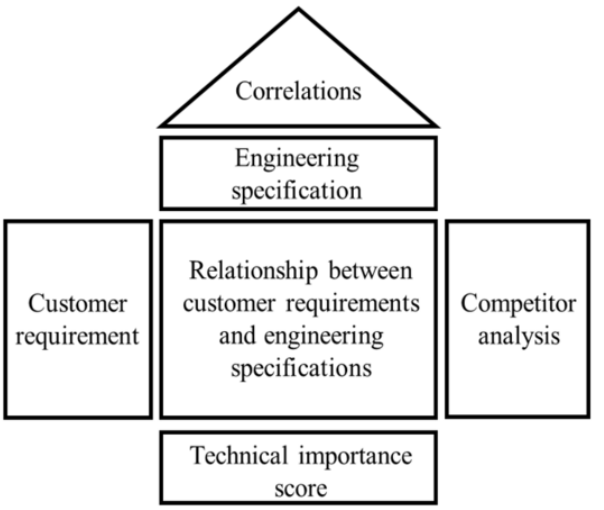


Figure 9. House of Quality



very meaningful to give the appropriate engineering elements at each stage of engineering design, production process and development, and prototype evaluation. Completing the HoQ starts with the question: *What do customers want?*, and their requirements are called as "*customer needs*". These are phrases, which are used by customers to describe products and product characteristics.

This research focus on concepts of product design and development (PDD), concept development has been applied for determining the relationship between customer perception and engineering design where walking assistive devices are used as the case study by focusing in the early stages of PDD. For concept development stage, the customer's requirement must be identified from the survey. To know the customer's attitude on product, this research provide a set of questionnaires to collect the data that the people have ever had the experience on products. Those data will be applied for creating the guideline to create a prototype that satisfies the customer's requirement.

3. RESEARCH CONCEPTS

The specific requirements for creating the walking assistive device are illustrated in Figure 10. These requirements will be applied as the guidelines for selecting the appropriate cane where the key factors are mentioned and addressed: *Height of user*, *Size of cane/stick*, *Type of cane/stick*, and *Type of handle*. These key factors are applied for supporting the conceptual design of a fall prevention walking assistive device where six main stages (Figure 11) have been taken into consideration. The details of each consideration will be presented in the sub-section.

1. **Creating target group:** Target customers for this product include senior citizens who are 55-85 years and older and people who have problem when moving.
2. **Identifying needs of the customers:** This stage is applied to identify the customer needs and the customer perceptions on walking assistive devices. Self-administered questionnaire has been selected as the method of gathering customers' opinions and their perspectives on the product of interest. Moreover, the common concerns that might cause senior adults to avoid a cane even if they do need one are listed and included into the set of questions. The common concerns are (Stachowiak, & Apetauerova, 2020): *feeling self-conscious, embarrassed or less competent in front of others*, *a sense that a cane represents losing freedom and fear that a cane means that*

Figure 10. The specific requirements for creating the walking assistive device

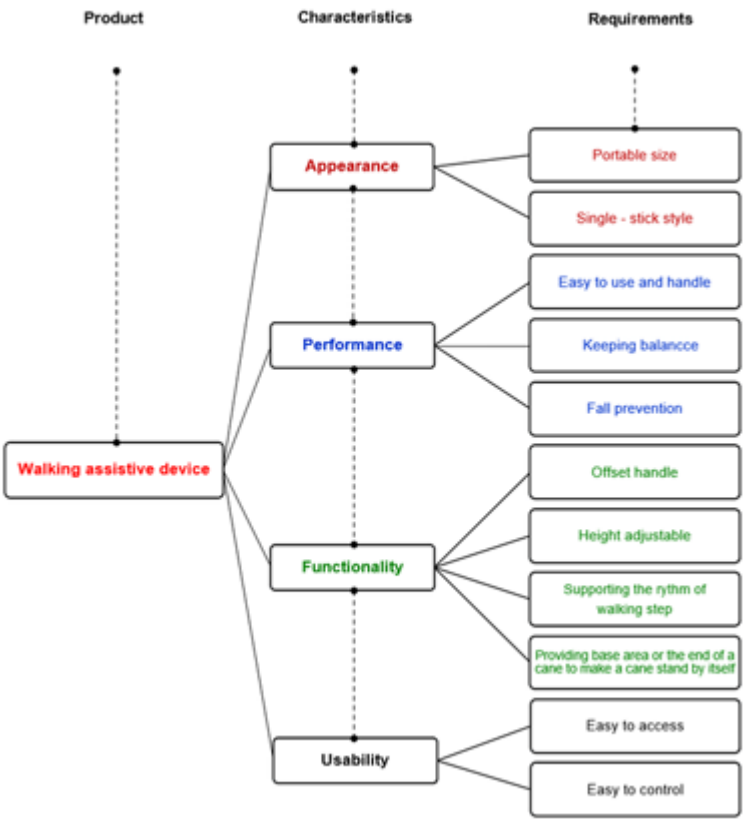
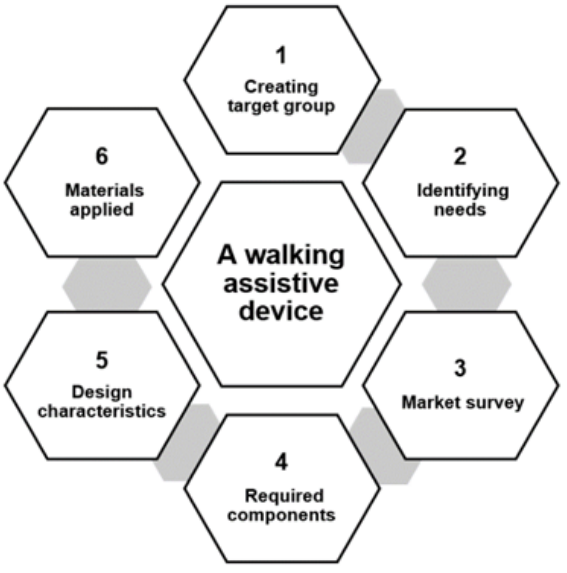


Figure 11. Six stages required for accomplishing the proposed research



the health condition is declining, and *associating a cane with being old and concern that relying on a cane will weaken the muscles.*

3. **Market survey of existing product:** A market survey is a key tool used for gathering information about the existing or potential customers in a certain market or population. In this study, a walking assistive device has been classified into 3 main types, which are walking canes, crutches, and walking frames. The target customers or the potential users will be asked to fill the form and answer some questions: *the normal ways to use a walking device*, *problems found during using device*, *the specific requirements such as shape, color, size or price*, and weight of the material applied. The top score of the design selection will be considered as the reference for supporting the proposed design.
4. **Components of walking device:** A walking cane has been introduced as a simple and easy-to-use platform for the users who would like to use this every day without asking for help or user guide. The main frame of this device consists of three main components, which are *handle*, *shaft*, and *tip* (Figure 12). Handle part has different materials and shapes. Wood, rubber, and plastic are common materials for the handle part. Shaft is usually made of metal or wood. Tip part located at the bottom part of the walking stick, which is contact point with the ground. Tips usually made with elastic rubber to provide support and increase friction to prevent slip. However, from Figure 12, two hidden issues have been found at the neck of the cane and the base area or 4-leg style (i.e., it is about the tip on the end of a cane that grips the floor much like the tread on car tires grips the road). Since these two issues might have a direct effect on the rhythm of walking step, and this might cause an accident.
5. **Design characteristic:** Design of walking assistive devices must be able to support the user's weight and contain additional features. A draft design of a walking cane consists of ergonomic handles that fit with the user's hand and wrist of the user should be in a neutral position to reduce risk of injuries. Light weight material is applied to reduce weight and still provide strength to support the user's weight. The proper height of walking can vary depending on the height of the user. Thus,

Figure 12. Components of a walking device – Single stick with 4 legs

adjustable height is another important feature that is included in the draft design. In addition, the last feature is anti-slip rubber at the bottom part, which increases friction to prevent slip.

6. **Materials applied:** The materials that provide "light weight" and "durable" are suitable for supporting the postural stability in maintaining a good posture. The specific properties of polymer, aluminum, stainless steel or copper, which might be suitable for making a walking device, are researched and selected as the input parameters for stress-strain simulation in finite element analysis (FEA) platform.

3.1 Addressed Issues on Customer's Perceptions and Requirements

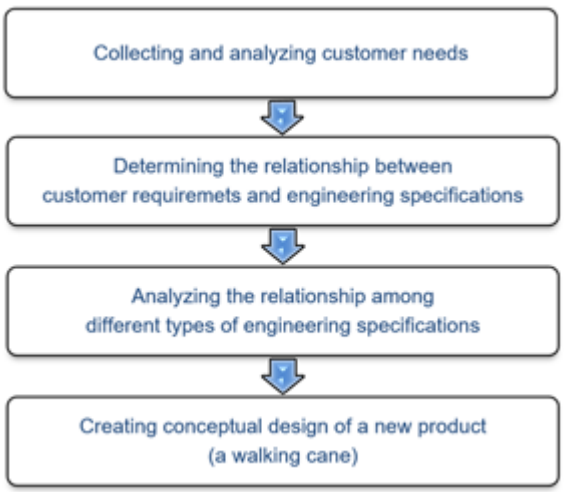
Customer perceptions can help developers to understand more about the actual needs of customer and what characteristics of a new or improved product should be. In the early stages of product design and development, the lists of questions were created and included in the questionnaires. The questions are focused on how target customers think about their perspectives toward walking assistive devices that are available on the market. To accomplish the proposed design for a walking device, four main steps are required (Figure 13).

3.1.1 Problems Found During Using Walking Devices (The Existing Products)

Before starting to create some questions for identifying an alternative design of a walking device where shape, size, and function are the key components. Two main problems were extracted and reviewed from the real users who commented about their feelings during using the existing products:

1. **Uncomfortable touch points:** Around the handle area, when the force (weight) and pressure put on a small space of hand, especially around the palm. The wrist position should be in a neutral position to reduce risk of injuries. Moreover, providing too much curvature surfaces on the small space of the handle of walking device makes direct effects to the fatigue and pain abound the finger and palm of the user.
2. **Heavy weight and large size:** Many walking canes have significant weight. This is difficult to carry around during walking, and this disadvantage is the main reason that makes the senior adults or the users are not willing to use a product.

Figure 13. Guideline for creating customer-oriented product



3.1.2 Set of the Questions

Questionnaire consists of a set of questions for gathering information from respondents. The first part of questionnaire includes questions about general information of questionnaire respondents such as gender, age, occupation and income. In the second part, respondents were asked about their attitude and opinion about walking assistive devices. The questionnaire was created by using an online survey platform. The expected target group of this questionnaire is senior citizens and people who have experience of using any kind of walking assistive devices. For example, the main questions raised for identifying about customer's attitude toward walking assistive devices are listed below:

Question 1: Have you ever use any kind of walking assistive devices before?
Question 2: Do you have any friends or family members who use walking assistive device?
Question 3: Which type of walking assistive device is mostly seen?
Question 4: In your opinion, do you think that walking assistive devices are important to you?
Question 5: Are you willing to use walking assistive device?
Question 6: Do you have a plan to buy those devices in the future?
Question 7: What factors are important to you if you want to buy those devices?
Question 8: How much are you willing to pay for a walking assistive device?

From this question set, the results indicated that there were six characteristics of walking stick that the target users required: *Light weight, Portable, Additional smart feature such as GPS tracking, fall detection, Attractive design, Product quality,* and *Reasonable price*.

3.2 Extracting Customer's Perceptions and Requirements

3.2.1 Results Obtained From the Survey

The total number of respondents was 96 people. The obtained results implied about "the customers' perceptions" on a walking assistive device. The answers can be classified into five topics.

1. The most common and standard type of walking aid.

The "a simple walking stick" or "canes are perhaps the most common and standard type of walking aid that is often seen in public and a senior is likely to use. The second and the third place of the result were shown through "a walking stick with wide base" and "a walking stick with small base" respectively (Figure 14). Table 7 represents about the summarized "*common types of walking assistive device with details*"; these data obtained from 96-senior citizens. Once the question raised, 25% of 96 potential users could express their perceptions on the specific characteristic of "*a simple stick type*" within a few seconds.

2. Interesting design of a walking device.

From the results illustrated in Figure 15, 60% of respondents did not have any experiences on using the walking assistive devices. Around 68% of respondents tried to express their perception like this way; a walking assistive device that was an important tool for elders and using this could reduce the risk of falling. Moreover, 7% of respondents did not want to use a walking assistive device because, in their own opinion and perception, using a walking device might them look older.

3. Acceptable price of a walking device.

Table 7. Summarized details of the most common and standard types of walking assistive device

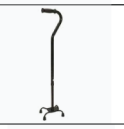
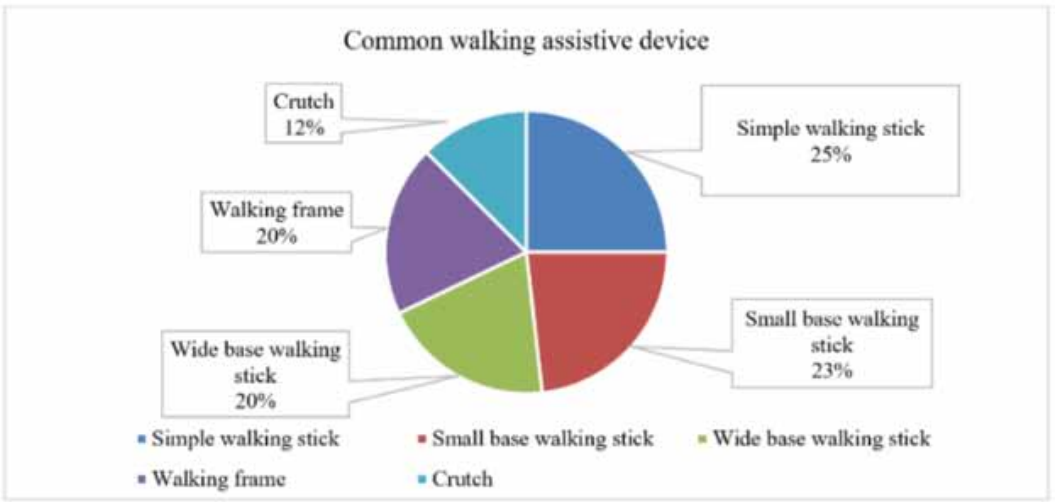
No.	Type	Picture	Description	Percentage of Response
1	Simple walking stick with C-shaped handle		Traditional design walking sticks that user cannot adjust the length. **Key design:** Simple C-shaped handle design. A handle is made with same material as a shaft.	25%
2	Small-base walking stick		Small base walking stick, which has extra contact area, compare with simple walking stick. **Key design:** Adjustable length. Special design/ ergonomics handle	23%
3	Wide-base walking stick with offset handle		Wide-base walking stick with multiple tips (3 or more tips) **Key design:** Adjustable length. Add-on material at offset handle	20%
4	Walking frame		The height of walking is around the waist of the user. **Key design:** A frame made of light weight material	20%
5	Aluminum crutches		A cylindrical shaft with two points of contact with the arm, at the hand and below the armpit. The saddle grips naturally and is well-ventilated for continuous air circulation. **Key design:** Ergonomic handgrips contour to the hand, maintain a natural wrist angle and evenly distribute load across the palm.	12%

Figure 14. The most common and standard type of walking aid



For the price of a walking device, the target users would like to purchase the one that provides "cheaper" price where "medium-to-high quality" can be maintained. The range of the price was shown as "500 – 1000 Baht" (around 14.85 – 29.69 USD) (Figure 16). The interesting idea obtained from this issue was about "the acceptable price range". Since the respondents who answered this

Figure 15. Percentage of respondent that willing to use a walking assistive device

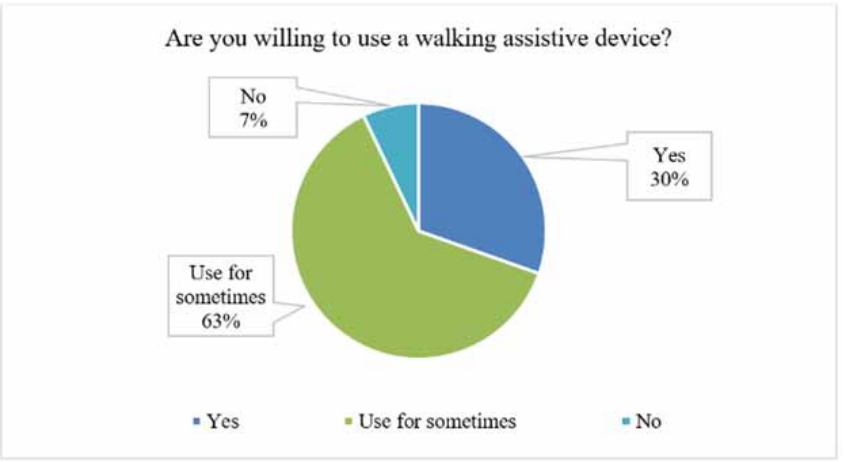
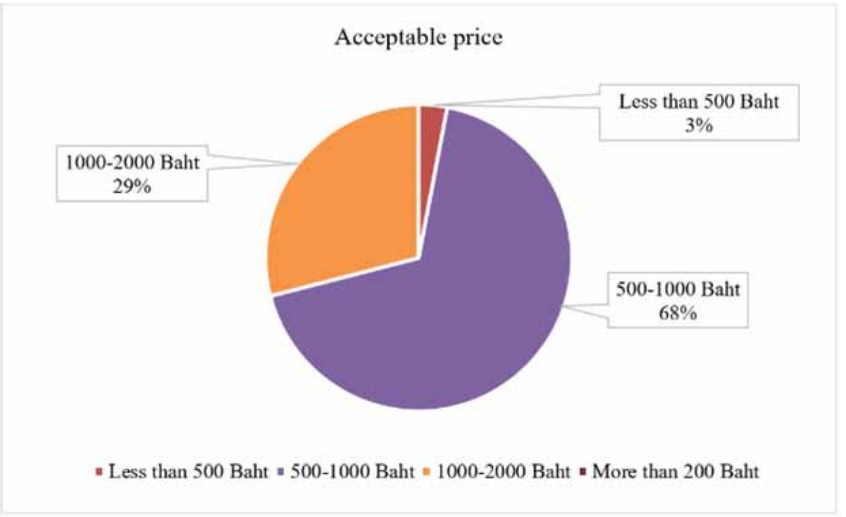


Figure 16. Acceptable price of walking assistive device

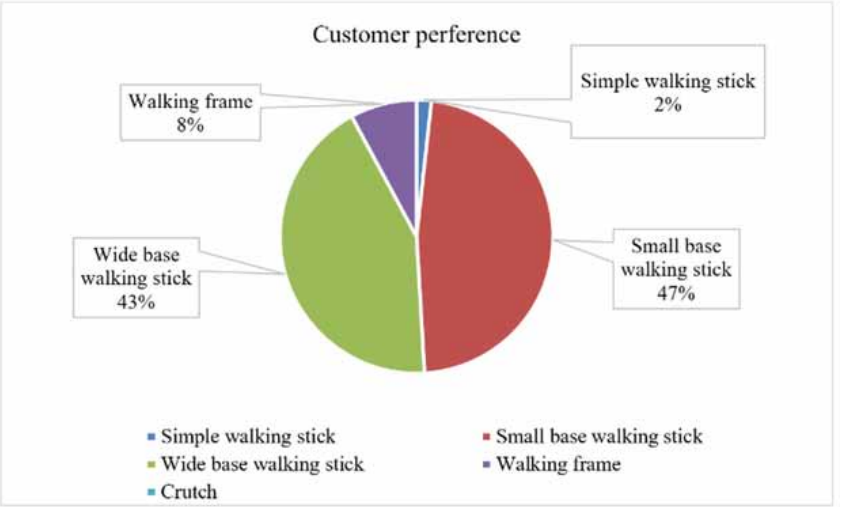


set of questions were “the retirement group”. There are many types of retirement funds initiated by the government to target different groups in the Thai population (Ratanabanchuen, 2019). Some senior citizens expressed their feelings via the most concern issue that is about “financial plan”. It is quite hard to have a good financial plan if they do not really know what life is going to look like in retirement. Some decided to stay within assisted living retirement communities, since it is very easy to share correlating information and stories with the group of the people who have the same age and perception.

4. Customer preference on walking assistive device.

Illustrated in Figure 17 are the results obtained from the questionnaires where four types of assistive device are the main consideration. The results presented that “a walking stick with small

Figure 17. Customer preference on walking assistive device



base and adjustable height" (47%) is the most popular design. Smaller base, in the users' perceptions, is easily handled and flexible to keep walking along the path; that might contain uneven surfaces, until they reach the destination. With the light weight stick and easy-to-use structure, the respondents might consider and make decision to purchase in the future. The second place of the design (43%) as shown through "a walking stick with wide base and adjustable height", since the target users would like to apply a device that provides a lot of space and friction on the base area to support them during moving and walking.

3.2.2 Summarized Data Obtained From the Questionnaire

Presented in Table 8 are the summarized results obtained from the survey where the top five issues of customers' attitudes and opinions were extracted. These issues include *acceptable price*, *the importance of walking mobility aids for senior adults*, *respondents who are willing to use the device*, *customer preference for walking assistive device,* and *mostly seen walking mobility aids.*

3.3 Translate Customer Needs to Engineering Design

The quality function deployment (QFD), in this study, is used as the key tool for assisting researchers to identify the important engineering factors or attributes of an alternative design of walking assistive devices. Engineering specifications of a walking assistive device are created and classified by the

Table 8. The summarized results: top 5 issues of customers' attitudes and opinions

Issue	Percentage of Response
Acceptable price in the range of 500 to 1000 baht	68%
Walking assistive device is an important tool for senior adults	68%
Respondents who are willing to use a walking assistive device	63%
Customer preference on walking assistive device: small base walking stick	47%
Mostly seen walking mobility aids: *Simple walking stick*	25%

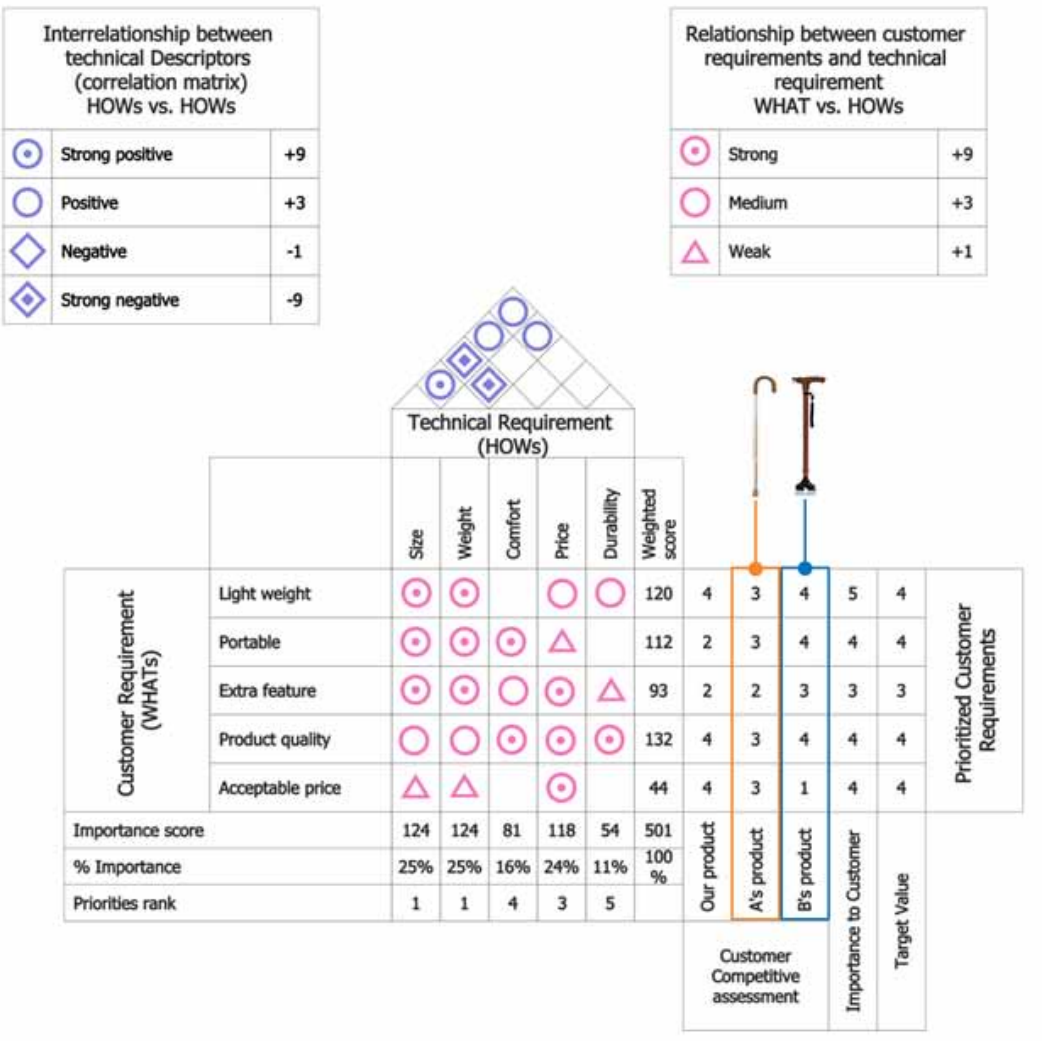
researchers' viewpoints; however, some small areas of product characteristics might be shown as subjective design platform.

3.3.1 House of Quality (HoQ)

House of quality (HoQ) method is applied to identify the relationship between customer requirements and engineering requirements. In general, to complete the construction of HOQ, a team should start with asking the question as "*What do customers want?*". The lists of translated answers were listed in to the first row (engineering attributes) and the first column (customer requirements) of the house (Figure 18).

In HoQ diagram, the relationships between customer requirements (Whats) and engineering specifications (Hows) are represented as four-scale levels; number 9, 3, 1 and none. The meaning of each scale level can be expressed as:

Figure 18. House of quality with relationship matrix between customer requirement and design characteristics



- 9 represents *strong relationship*
- 3 represents *moderate relationship*
- 1 represents *weak relationship*
- None represents *no relationship*

For "*customer requirements*", the results obtained from the questionnaire can be applied as the guidelines for helping design team to understand the direction and trend of a new product; in this study, walking assistive device should be created with *light weight* and *portable platform*, *additional features with attractive design*, *high product quality*, and *acceptable price*.

For "*engineering attributes*", the top five specifications were selected after brainstorming among team members: *size, weight, comfortable, price*, and *durability*. Those specifications are represented in terms of manufacturer point of view relating to product design and product characteristics.

For "*HoQ*", the interrelationships between engineering attributes or factors are classified as five levels with symbols; *strong positive correlation* (+), *positive correlation* (+), *strong negative correlation* (-), negative correlation (-), and *no correlation between those factors* (no symbol, blank space).

For "*example*", to put the symbol into the matrix provided on the roof area of the house, the correlation between a pair of factors is analyzed by considering the meaning and description of each. The first pair of factors is "*size*" and "*weight*" of the product. The meaning of "size" is definitely matched to the "weight" since when the size of a walking device is large, the weight is considered relatively high.

Therefore, the correlation between "size" and "weight" was analyzed to be "strong positive correlation", the + symbol was put into the correlating matrix as shown at the first parallelogram-shaped area.

In contrast, for the second pair of factors; "comfort" and "weight", when the weight of a walking device is increased, a user may feel not comfortable to carry and hold. This indicated as "*strong negative correlation* (-)".

4. APPLYING THE USEFULNESS CONCEPT

The key point for applying the usefulness concept in this study is about identifying the direction of the leg or base-area design platform of a walking cane model whether the smaller base area with combined plate and legs is interesting enough for being used as the master model in this study. Since the classic style of single stick with no base area has been popularly applied by senior adults recently, and it has been recorded as the master model of a walking assistive device that is compact and cheap from the customers' perceptions. However, with this single-stick design platform, the cane cannot stand by itself. The base area is required for solving this issue where the concept of "*Quad Cane*" with 4-leg base area and offset handle has been taken into consideration. Figure 19 presents the key references applied in this section for identifying the usefulness of existing designs of a walking cane:

- **Collecting data:** From the users' perceptions, walking canes can usually hold the body weight, and reduce the risk of falling and seriously hurting themselves. Canes come in a variety of shapes and sizes, and from Figure 24, around 20% of 96 users mentioned about some advantages of "offset handle" that is shown in Reference 3 over the traditional C-shaped handle cane (Reference 1) and the groove-handle or functional grip cane (Reference 2). Since when they start using and grabbing this handle style, the canes work to improve their balance and stability. However, with four-legged base area as presented in Reference 3, the direction of cane and body structure plus movement (i.e., the motion of arm, wrist, and legs) cannot be synced together simultaneously during walking.

Figure 19. Key components for supporting the design stage

- **Key concept obtained:** The design of "offset handle" has been considered and recorded as the main design for the handle part of the cane.
- **Weak point found:** For the large-base design platform, it contains 4 legs is not suitable for supporting the rhythm of walking step, and, sometimes, the users cannot control it.
- **Suggestion:** The alternative designs of the base area illustrated in "Reference 1 and 2" should be taken into consideration and compared where the concept of "usefulness (U)" is applied. For the handle design, Reference 3 – offset handle style should be chosen according to the comments from the target users. Moreover, it would be better to apply some techniques to check whether the suggested design platforms are suitable for developing a walking assistive device.

4.1 Calculating "Usefulness (U)"

Applying "usefulness (U)" calculation in this study can help to minimize time spent for identifying the trend of cane styles that are suitable for senior adults who have faced with the way to select the appropriate design where the shape of handle and the base area are the key issues. For supporting this "U" calculation, three main sections are introduced:

- **Background of this study:** According to the concept of "usefulness" mentioned earlier in Section 2.5, in this study, a walking device is considered as "a safety need" referring to the Maslow's hierarchy of needs, and the important level from Table 6 was considered as "very high" level. For senior citizens, it is extremely important and essential for daily activities. The considerations were applied to the designs of walking cane mentioned in Table 7 where the data were obtained and translated from the target users.
- **Obtained data from the questionnaires:** The total number of target users is 96. On each type of walking device, according to Table 7, the percentage of respondents was analyzed and applied as the key point for identifying the importance level. Since the importance level of "a walking device" was considered in the "Category B – Very high level; the maximum scale of this level is 4. Moreover, this level can be translated into any number ranging from 3.1 to 4 (>3.0 - 4.0).

- **Analysis:** 25% of 96 people (around 24 people - the maximum number of respondents) believe that "a simple walking stick" (Reference 1) is easy and less maintenance cost and it is considered as the most common and standard type of walking aid. The scale of importance of "a simple walking stick" should be considered as the "3.1" points from "4" since the C-shaped handle design is less comfortable than "a small base walking stick" (Reference 2). The scale of importance should be assigned with a value that is higher than "3.1" since the design of Reference 2 – Functional grip crane with small base area provides more comfortable feeling during walking than Reference 1 where the cane can stand by itself.

4.1.1 Usefulness Calculation for "Reference 1 (Design A): A Simple Walking Stick"

According to the previous section, the scale of importance of "a simple walking stick" (Figure 20) is assigned as "3.1", and the time spent for walking with a simple walking stick is "around 3 hours". From the customers' experiences, they said that it is not comfortable for grabbing *semi-circular shaped handle (C-shaped design)* for a long time. It is not a "continuous usage" type. The rate of use is identified as 3 hours per day or 24 hours (3/24).

Therefore, applying *Eq. 1* can determine *Usefulness (U) of Design A*:

Usefulness (U) = Important level (L) x Popularity of use (R) x Usage frequency (F)
x Usage duration (D)
= (3.1/5) × (24/96) × (3/24)
= 0.019

4.1.2 Usefulness Calculation for "Reference 2 (Design B): A Small Base Walking Stick"

In order to consider the assessing the usefulness of Reference 2: "a small base walking stick" (Figure 21) called as "Design B", which was the second place of popularity selected by 96 potential users (around 23%). Around 22 people have some experience on "a small base walking stick – Reference 2", comparing to C-shaped handle (Reference 1 - Design A), all of them feel more comfortable during walking with this device. Therefore "3.90" is selected as the point for representing the important level of Reference 2 (Design B). Moreover, time spent forusing this type of cane was considered around 3 hours per day.

Therefore, applying *Eq. 1* can determine *Usefulness (U) of Design B*:

Usefulness (U) = Important level (L) x Popularity of use (R) x Usage frequency (F)
x Usage duration (D)
= (3.9/5) × (22/96) × (3/24)
= 0.022

Figure 20. A simple walking stick

Design A: Simple walking stick

1. *Importance of use (L)*: **Very high (Code B) = 3.1/5 (3.1 scale from the maximum – 5 scale)**
2. *Rate of popularity for use (R)*: **24/96** (ratio of number of target users who have experiences on the simple walking cane/total number of people who could potentially use it)
3. *Rate of use (F × D)*: **3/24** (ratio of number of hours of use/total number of hours in a day)

Figure 21. A Small base walking stick

Design B: Small base walking stick

1. *Importance of use (L)*: **Very high (Code B) = 3.9/5 (3.9 scale from the maximum – 5 scale; this handle style is more comfortable than Ref.1 – C-shaped cane.)**
2. *Rate of popularity for use (R)*: **22/96** (ratio of number of target users who have experiences on the small base walking stick /total number of people who could potentially use it)
3. *Rate of use (F × D)*: **3/24** (ratio of number of hours of use/total number of hours in a day)

4.2 Discussion – Assessment of Usefulness of a Product

After obtaining the guidelines for designing "base area" of a cane from the calculation of "U", the discussion activity has been raised where four main areas are taken into consideration:

- **Analysis:** To distinguish among very similar products with the same level of importance, in this case, the importance level of a walking device is "Very high" or 4 (>3.0 – 4.0) scale. Assigning intermediate points to the "level of importance" could be beneficial. For instance, there is a higher popularity and easy-to-use involved in applying "a small base walking stick" (Reference 2 – Design B) compared to that in "a simple walking stick" (Reference 1 – Design A) one. Thus, this can assume that the importance of "a simple design" (Reference 1 – Design A) in our lives or the specified community is less than that of "a small base walking stick" (Reference 2 – Design B).
- **Selecting value:** If "a simple walking cane" (Reference 1 – Design A) and "a small base walking stick" (Reference 2 – Design B) are compared (both with a "very high level of importance"), "a small base walking stick" (Reference 2 – Design B) could be assigned a higher level of importance (say 3.9) than "a simple walking stick" (Reference 1 – Design A) (say 3.1), since the users feel more comfortable during applying the "Reference 2 – Design B" device where the cane can stand by itself. However, this could also be based on user preferences, and the perspective of a team. Using various methods such as user survey or research articles can support the way to make decision.
- **Suggestions:** For the given conditions, Reference 2 – Design B" (A small base walking stick) is more useful than "Reference 1 – Design A" (A simple walking stick) within the specified community. However, "Time spent" for using a product is the key component for this comparison, since the number of popularities was not different much where the importance level was considered to be the same, which is "Very High" range – >3 to 4 points.
- **Findings:** For the conclusion of this phase, the researchers could obtain the guideline about assessing the ratio of usefulness of these products as usefulness of "Reference 1 – Design A" (A simple walking stick): usefulness of "Reference 2 – Design B" (A small base walking stick) = 1: 1.16. The concept of small base area of "Reference 2 – Design B" should be applied in the proposed design of walking assistive device where the "offset-handle platform" is selected for making the handle part area.

5. CONCEPTUAL DESIGN OF A NEW PRODUCT

According to the previous concept and usefulness consideration, the guidelines for creating a walking assistive device have been introduced. For stick-shape form of walking assistive device consists of

various components. The components of walking stick or cane were classified into three main parts: *handle*, *shaft*, and *tip (or the base area)*.

5.1 The Key Considerations and the Guidelines for Selecting Cane

The key considerations, which are the conceptual design with guidelines for a new design, were considered as these following parts.

5.1.1 Part 1: Handle of a Walking Cane

Conceptual design: It should support all sizes of palm with less curvature surfaces as finger-shaped groove (Figure 22-a) since the size and space between fingers of different people are varied. Making fixed finger groove might force the user to hold and grab the handle like "jig and fixture" during moving. Finally, the user will feel so pain and fatigue. The semi-circular shape design like the handle of an umbrella (Figure 22-b) is quite difficult to hold and grab since too much curve around the palm area will make the users feel hurt and not comfortable. It is notice that, for the main body of the cane, the different colors of stick mean different materials applied (Figure 22).

Guideline for a new design: The "universal design" concept with straight-line tube formed in parallel to the floor is the choice. Moreover, the rubber or plastic tips can be applied on the end of a walking stick. Since the rubber tips on the ends of canes grip the floor much like the way that tread on tires grip the road. The good rubber tip should be in a good shape where it can be bent and moved properly; otherwise, buying a new one from medical supply store is recommended.

5.1.2 Part 2: Angle-Bent Bar

Conceptual design: After analyzing the direct comments and experiences of the users, one of the critical problems found during using a walking stick or cane are shown through the broken part between handle and stick. Traditionally, the neck is made by 90-degree corner to the handle (Figure 23).

Guideline for a new design: The "angle-shaped stick" concept is applied for preventing the broken problem around the neck of a walking stick; connecting area between handle and body of

Figure 22. Handle styles of a walking cane and stick

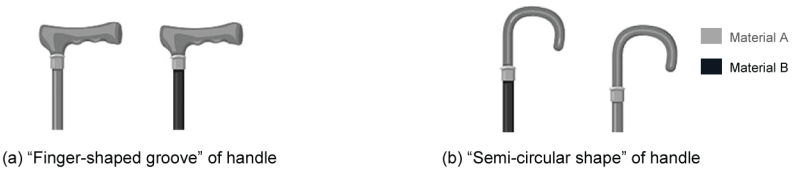


Figure 23. The connecting area between handle and vertical stick of a cane

a cane. Any degree of angle can be chosen, it depends upon the originality of the manufacturer's viewpoint, in this study, "160-degree stick" around neck area is selected. Since this value is not too much straight like "180-degree design", which means "straight or vertical stick" as presented in the traditional form of a walking cane.

5.1.3 Part 3: Main Body and Base Area of a Walking Stick

Conceptual design: "*a hollow tube with a straight stick*" is the main idea for creating the body of a walking device. This hollow tube is designed with various constraints, *adjustable height*, *light weight*, *less sensitive to temperature changes*, *plain and simple function*, *corrosion resistance*, *easy maintenance*, and *lower chance of accident*. Moreover, for increasing the friction between the device and the floor during walking, the rubber base tip is recommended on the end of a cane. From the customers' perceptions, four types of handle and base area designs have been mentioned and raised as the key issues (Figure 24). However, the critical part of a walking cane design has been shown through "the base area" since the users would like to get smooth and safe feeling where the rhythm of walking step can be synced simultaneously with the posture of hand/arm during moving the cane. Based on the users' experiences, during walking, "wide base area" as "four-legged base area" causes some accidents where the feet of users are obstructed by the extended legs of cane (around the base area); they stumbled over a cane. Illustrated in Figure 25 present the three most popular designs of the base area of a walking cane (i.e., single stick of main body and three styles of base area) recommended by the target users.

5.2 Drafted Design of a New Product

After analyzing the entire parameters obtained from "QFD" process and the conditions mentioned in the previous section, the drafted design of a new walking device is shown in Figure 26. According to the hidden issues (Figure 26(a)), the design of the neck and the base area of a cane are extracted and mentioned in 3D CAD model forms (Figure 26(b)).

Handle (Part 1): applying the "universal design" concept with straight-line tube formed in parallel to the floor. The rubber or plastic tips can be applied on the end of a walking stick.

Figure 24. Four key guidelines for handle and base area designs (Orthopedic, 2016)

Figure 25. Single stick of main body and three styles of base area (JUN-Walking Sticks, 2021)

Neck area (Part 2): applying the "angle-shaped stick" concept for preventing the broken problem around the neck of a walking stick; connecting area between handle and body of a cane. The "160-degree stick" around neck area is selected.

Main body and base areas: applying the "straight stick with hollow tube" concept.

Since some designs of the assistive devices can provide and serve as a decorated platform where the fashion accessory such as colorful stick or handle with extra ordinary handle-curve design is introduced. For self-defense purpose, the durability, stability, and force distributed along the stick are the key considerations, the applications of FEA can be used to support the ways to identify the proper material used. Moreover, the strength of structures of equal cross-sectional area loaded in tension is independent on the shape of the cross-section. The "tensile stress" is the key consideration where it is the stress state caused by an applied load that tends to elongate the material along the axis of the applied load, in other words, the stress caused by pulling the material. For the supportive information to create and select a walking cane, material considerations and load distribution have been mentioned and discussed in the following sub-sections.

5.3 Material Considerations

For the material applied for making a walking stick, the following mechanical properties are mentioned and considered:

- **Strong and stiff:** To support the user's weight without bending or plastically being deformed.
- **Have low weight:** To carry and handle while walking easily without fatigue.
- **Must be sufficiently tough and strong:** A walking stick should not break or deform, if the user drops it or compress it immediately with high force.

From Figure 27, the most required properties in materials for walking assistive device are "low weight" and "stiffness". A Young's modulus and density chart helps researchers to identify which types of material are stiff and light. Those materials located towards the top left of the graph. The

Figure 26. Drafted design of a walking assistive device

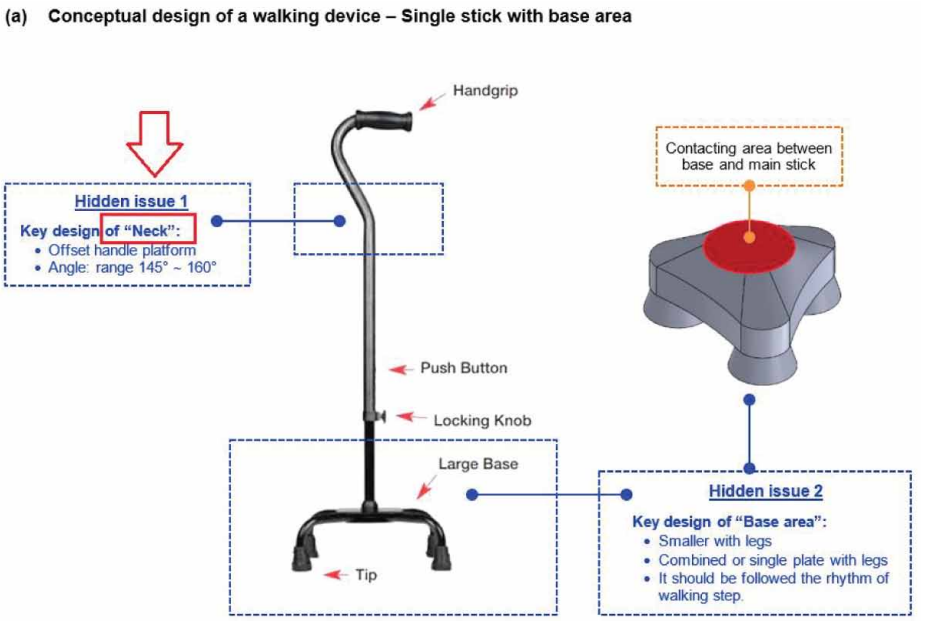
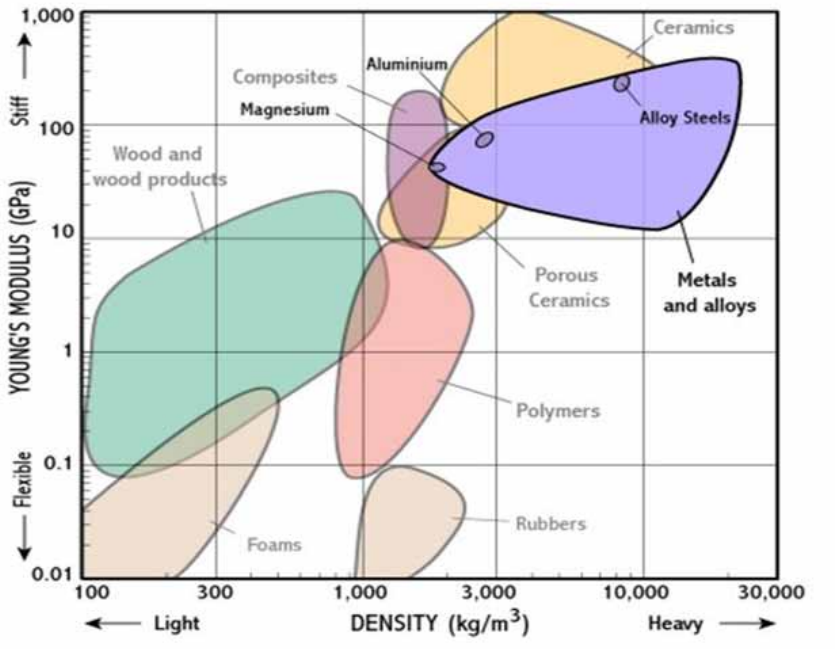


Figure 27. Young's modulus and density graph (Department of Engineering, Univerisity of Cambridge, 2002)



composites material and various types of ceramics have relatively low density and high stiffness. Since "weight" is one of the most important factors for designing a walking cane, the aluminum alloys might be suitable in this study comparing to the alloy steels, which have significant higher density. Walking assistive devices are usually loaded in compression along the length of shaft. Due to the shape, which is long and slender, it is more likely to break by buckling that depends on the stiffness of material, not its strength. "*Buckling*" refers as the sudden change in shape of a structural component under load, such as the bowing of a column under compression. It will bend in the middle, but spring back again if it is still within the elastic stage. The force required to buckle is much less than the load needed to break or yield the material in compression. Moreover, the factors that can cause buckling of material are mentioned as these following statements:

- **Young's modulus:** It is about the stiffness of the material.
- **Cross-sectional shape and the length of a walking stick:** Materials selected should have high Young' modulus.
- **A hollow cross-section tube:** The hollow-shaped cane should have lower weight comparing to the solid cross-section.

In conclusion, for this section, the materials selected should provide light weight and high strength of material for forming hollow-shaped cane. Therefore, "aluminum" material has excellent corrosion resistance to normal environment (Atmospheric Corrosion of Aluminum Alloys, 2014). It has low density with light weight characteristic, which is the suitable characteristic for the shaft part of a walking stick. Scratch resistance and corrosion resistance of aluminum can be improved by using anodizing method. Aluminum alloys with various kind of properties are used in engineering application such as aviation, structure, and some other light weight products. Stiff and light weight designs can be achieved with aluminum alloy compared with steels. The "*1060 aluminum alloy*" is widely used for products, which have universal usage with lower requirement for strength, such as kitchen utensil, outdoor lamp post, electrical part, chemical equipment, billboard, and other decorations. It has strong corrosion resistance properties. Table 9 presents mechanical properties of aluminum alloy.

For aluminum, however, it is quite difficult to determine the exact yield point due to the nonlinear characteristic of material. The offset yield point is considered at the point when strain equals 0.2%. (Ross, 2016). "Yield stress" can be defined as a stress at yield point where the material begins to plastically deform from its original shape. Yield strength of 1060 aluminum alloy is approximately 27.57 MPa. Von Mises stress is applied to predict the yield of materials, under complex loads from uniaxial tensile tests. A material is starting to deform when the von Mises stress reaches yield strength of the material. In this study, 3D CAD model of aluminum tube was created to represent a draft design of walking assistive device. The design was made of aluminum tube with uniform thickness of 2 mm

Table 9. Mechanical properties of 1060 aluminum alloy (SOLIDWORKS, 2016)

Property	Value	Unit
Elastic Modulus	69000	MPa
Poisson's Ratio	0.33	N/A
Shear Modulus	27000	MPa
Mass Density	2700	kg/m^3
Tensile Strength	68.9356	MPa
Compressive Strength	-	MPa
Yield Strength	27.5742	MPa

along the length of the tube. SOLIDWORKS simulation has been applied for this study. Volumetric properties of a draft design aluminum tube are listed below:

- **Mass:** 0.463341 kg
- **Volume:** 0.000171608 m^3
- **Density:** 2700 kg/m^3
- **Weight:** 4.54074 N

5.4 Simulations

For *Finite Element Analysis (FEA)*, aluminum alloy 1060 has been selected for static analysis since this type can be applied as the universal property for supporting different types of applications and products. At the center of the model, gravity force is included in the model simulation. The distributed mass of 75 kg is applied to the handle part area for representing the simulation of the user's weight. Since this value of distributed mass is selected according to the surveys where the maximum weight of the senior adults who can walk by themselves with a walking assistive device is around 75 kg. The results obtained from SOLIDWORK simulation showed that, in some areas of aluminum tube, von Mises stress from the static study is more than yield strength of aluminum alloy, the material is expected to yield or deformed plastically from its original dimension. Figure 28 to 30 presented about the results of FEA simulation. The thermal expansion coefficients of four types of material are shown in Table 10. The thermal expansion coefficient of "Aluminum (Al)" material presents the maximum value comparing to the rest, this means "Al" is quite sensitive to the environment temperature when it changes immediately. In this study, a walking cane is considered for supporting a senior adult who applies a cane during walking for a while or the maximum time spent is in a few hours. The environment during doing some activities is normally performed on the sidewalk, and under the shelter or roof without exposing sunlight or UV directly. These EV conditions might not affect much to the expansion of Al material applied for making a walking cane. Since the price of Al is quite interesting,

Figure 28. 1060 aluminum alloy static test result

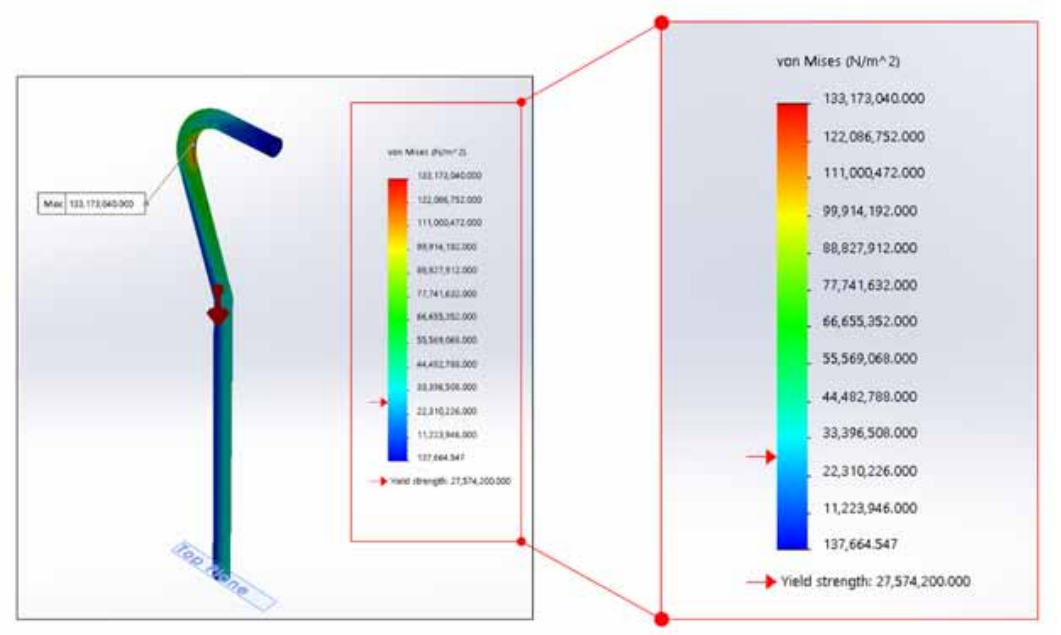


Figure 29. Maximum von Mises stress location

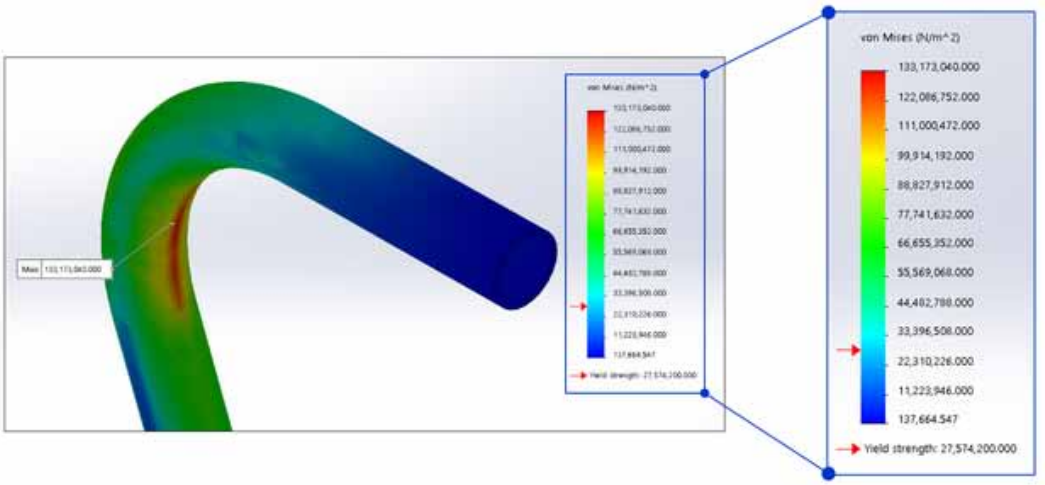


Figure 30. Result of deformed displacement

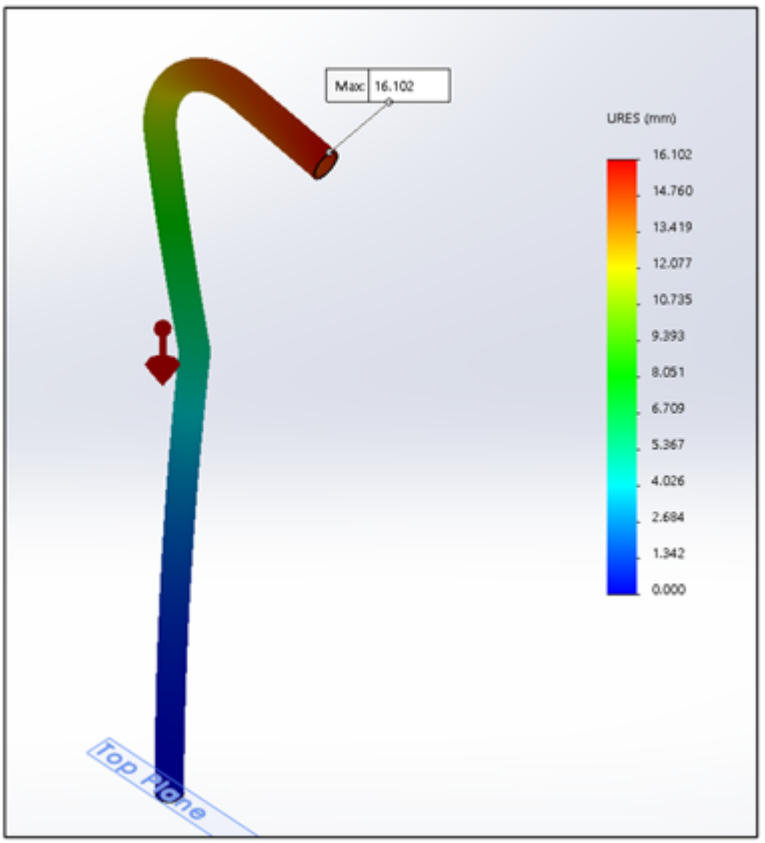


Table 10. Thermal expansion coefficients

Material	Expansion Coefficient
Aluminum	25 x 10^{-6}/ ° C
Copper	16.6 x 10^{-6}/ ° C
Beryllium/copper	9.3 x 10^{-6}/ ° C
Steel	6.7 x 10^{-6}/ ° C

it is cheaper than “Steel” or “Copper”. Moreover, with the same design (hollow-tube shape), “Al” can provide lighter weight comparing to those two. The maximum von Mises stress located at the curve area, which connected to weight load area at the handle. The value of 133 MPa of von Mises stress indicated that there is a high chance that aluminum alloy will be deformed permanently from the original shape under the given weight load. From the simulation, the maximum displacement that can occur is 16.1 mm, which located at the handle part (Figure 30).

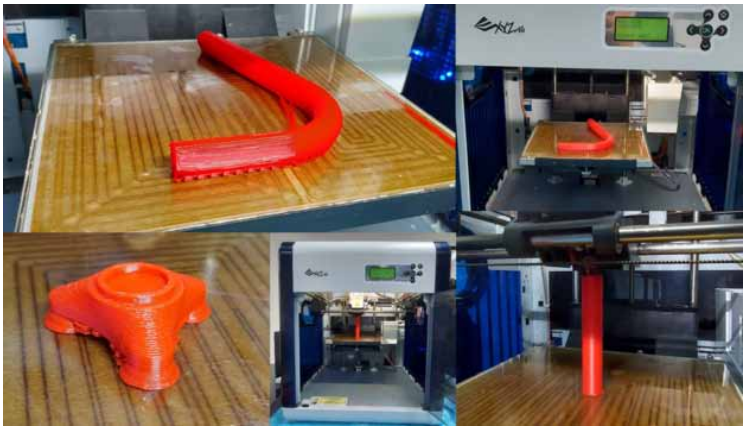
5.5 Prototyping

From the obtained conditions of a walking assistive device, the rapid prototyping process with 3D printing concept has been applied in this study for checking the physical feeling during holding, carrying, and walking with the developed walking cane design. The cane prototype was fabricated by using rapid prototyping (RP) technique – 3D printing process (Figure 31 and 32) where the physical parameters were obtained from the guidelines mentioned in the previous processes.

Due to COVID-19 pandemic, a few ways to approach the developed design follow-ups without irritating prospects, launching pictures of fabricated prototype with different views via online platform to the group of senior adults (20 people) for checking their physical feelings and comments was one of the choices. Moreover, few potential users who have had experiences in science and technology plus engineering background were asked to test and touch the prototype for checking the function during holding and walking. The results from both channels; imaging consideration and real testing platform, the users felt more comfortable to apply this suggested style and function rather than applying the traditional C-shaped cane or four-legged base areas.

Figure 31. Prototype of a walking assistive device

Figure 32. 3D printing machine and fabricated parts



6. DISCUSSION AND CONCLUSION

The objective of this research is to develop an alternative platform for selecting a walking cane to support senior adults where the functional capacity and levels of physical activity in aging are the key factors. To collect richer information about customers' perceptions on a walking cane device and style, the observation or interview method or qualitative approach was performed initially, however it takes time. Therefore, using a survey helps to collect more data quickly. From various experiences and perceptions of target customers on the existing design platforms of walking cane, three main issues were raised, *shape of handle*, *main frame style*, and *base area structure*. These three issues were then extracted and revealed by applying "*Product design and development (PDD)*" – selecting target group and creating a conceptual design, "*Usefulness (U)*" – suggesting the trend of handle and base area designs, and "*Finite element analysis (FEA)*" – checking whether offset handle is good enough for being used. From the team's viewpoint, the large base area and traditional C-shaped handle might not be suitable for supporting senior adults to walk by themselves with confidence and maintaining a good posture with proper friction since the users might not be able to control their rhythm of walking steps with comfort. For the design analysis, quality development function (QFD) was used to translate the voice of customer or customer requirements into engineering design attribute (i.e., the measurable design targets) of a product by using a correlation between parameters. Then, QFD could drive those engineering design attributes from the assembly level down through the sub-assembly (in the system-level design stage), components and sub-components, and the manufacturing process levels. In this study, the results obtained from HoQ indicated that the engineering factors as "*size*" and "*weight*" are the top priority that associated with needs of the customers. For assessment of the usefulness of a product, distinguishing among very similar products with the same level of importance could be identified and studied by using the "usefulness (U)" formula. The guidelines of this calculation could convey the information about "*Which design should be selected?*" for supporting customer requirements. However, the scale of importance of a product ranging from 0 to 5 was assigned by the judgement of the researchers; that was quite subjective.

In conclusion, using various methods such as user surveys or research articles could support the way to make decision. The raw data of design stage were obtained from the market survey of walking assistive devices and the set of questionnaires was launched to the target users, the senior adults. The customer feelings, expectations, and requirements were the main considerations where the universal design and easy-to-use function were the key concepts. In the conceptual design stage, the researchers firstly started to reveal the hidden issues of the walking stick (cane) structure where the main content was focused on the customers' perceptions and influencers or advertisements. Sometimes a high

percentage of walking aids in use might be inappropriate. The main issues were raised, the groove around the handlebar that was not fitted and matched to the user's hand, the straight stick could not maintain the user's posture, and too-narrow-base area of the stick (or too small diameter of a tube) had no friction and made a fairly large number of falls in older adults. For material selection, "*strong and stiff with light weight*" was the motto where an aluminum material was selected for making a main structure of a walking cane stick. The aluminum tube formed into curvature shape around the handle part was analyzed about its physical structure where 75-kg-load distribution was applied in finite element analysis (FEA). For the findings of this study, with the small base area proposed in the concept development stage, the walking cane could stand by itself while providing good rhythm of walking steps – feet and stick could work together simultaneously. The offset handle was designed with 160-degree angle for providing balance with comfort. For the user who has wrist problem and is unable to hold the cane with a firm grip or groove one, the body weight of user can be distributed over the cane's body quickly and directly to reduce pain and gain comfort.

7. LIMITATION AND RECOMMENDATION

The limitation of this study was shown through the *material properties*, *manufacturing process*, *part geometry*, *load distribution*, and *length of the stick*:

- **Material properties:** Aluminum alloy 1060 was the key component for assigning FEA conditions. When the material is changed, the input parameters need to be changed with proper amount and value according to the standard of the program set.
- **For manufacturing process:** This proposed design might be suitable for "extrusion process" where the equal cross-sectional area tube is produced.
- **Part geometry:** A walking stick- or walking cane-like design is the key consideration for developing an alternative design of a walking assistive device. Since the main viewpoint and perception extracted from target customers who are senior adults is shown through "cane-like design" or "simple straight tube as a stick". This reference idea has been transferred to the design stage where the postural stability in maintaining a good posture is the key component.
- **Load distribution:** The assigned load was considered according to the surveys where the maximum weight of the senior adults who can walk by themselves with a walking assistive device is around 75 kg.
- **Length of the stick:** The design was made of aluminum tube with uniform thickness of 2 mm along the length of the tube that is approximately 850 mm.

To develop new design of walking assistive device based on customer needs, the conceptual design of the product should concern with *dimension*, *shape*, *size*, and *material usage for manufacturing process*. Those factors have a strong positive correlation with weight of the product. Finite Element Analysis (FEA) technique has been applied in this study to determine the suitable material for a walking assistive device. However, the results obtained from this study are applied and suitable for being as one of the main guidelines and considerations for the manufacturers or customers to select the proper design and material for making "walking assistive device" with a simple-and-minimal design concept.

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CONFLICT OF INTEREST

The authors of this publication declare there is no conflict of interest.

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