Alternative Design of a Stacking-Bag Assistive Device for Facilitating Loading and Unloading of Objects – A Case Study on Sago Bags

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Abstract— **This study presents an alternative design for handling sago bags, focusing on creating a user-friendly platform for loading and unloading. Sago is packed in canvas bags of varying loads (15 kg, 25 kg, and 30 kg), which poses challenges due to its non-uniform distribution and can lead to stability issues during transport. The study proposes an assistive device made of durable, tough, and resistant materials such as HDPE, PP, ABS, and Polyester, offering a balance between hardness and solidity. The device's standardized size allows for easy connection and application with the forklift lever, with a simple design for easy maintenance and part replacement. The elastic properties of polymer materials enable deformation during heavy load handling, crucial for shock absorption in a stacking-like building style. Rubberized shoulder straps enhance grip and durability. The device can be folded into a compact size (109 cm × 30 cm × 10 cm) for easy stacking and storage. The handle features a rubber grip for comfort, and the side belt is made of 1.5 mm thick polyester, designed to accommodate 50% and 100% capacity. The base, 1 mm thick, is constructed from polypropylene (PP) and measures 109 × 120 cm, ensuring a robust and efficient solution.**

Index Terms— **Transportation, Pallet, P-Sling, Design and Development, Material Handling System, and Storage System**

I. Introduction

Tapioca pearls, also known as sago, are versatile ingredients used in various culinary creations, such as boba tea, sago cantaloupe, and sago vada. Made from tapioca starch, these pearls are rich in carbohydrates and calories. In tapioca pearl manufacturing, tapioca starch undergoes granulation to form spheres of different sizes, which are then meticulously sorted. Subsequently, the pearls undergo roasting and drying processes [1].

When storing tapioca pearls, use food-grade, airtight containers to maintain freshness and prevent contamination. Ensure the containers are durable and resistant to tearing, especially during transport. Store them in cool, dry places to prevent moisture absorption, which can affect their texture and quality. Properly label containers with packing and expiration dates to use the product within its shelf life. Implementing these practices optimizes the handling and storage of sago bags, improving efficiency, organization, and preservation. Securely pack and stack bags to ensure stability during transport, preventing shifting or damage. Maintain uniform weight distribution and prevent deformations by properly distributing sago within bags. Store bags in dry, well-ventilated areas to prevent moisture buildup, reducing the risk of spoilage or mold growth. Use appropriate handling equipment, like forklifts or pallet jacks, to minimize physical strain and potential bag damage. Select durable materials for bags and handling equipment to withstand transportation and storage rigors. Implement efficient storage and retrieval systems to streamline operations and minimize handling time. Regularly inspect bags for damage or deterioration, addressing issues promptly to prevent further damage. Provide training to personnel involved in handling and storing sago bags to ensure proper procedures are followed, reducing the risk of accidents or damage [2]-[7].

After conducting direct interviews with business owners, it became evident that in real-world applications, several factors require attention to ensure the efficiency, organization, and preservation of sago bags in a factory storage setting.

- *Racking System:* Implement a sturdy and well-organized racking system that allows for easy stacking and retrieval of sago bags. Adjustable shelving can accommodate bags of varying sizes, optimizing the use of vertical space. However, the cost of organizing items is perceived as high due to the materials used in their construction.

- *Categorization and Labeling:* Clearly label different sections or shelves for specific types or grades of sago bags. This makes it easier for workers to locate and retrieve the required bags quickly. Accurate details like instruction plates, manufacturing dates, and parameters need to be carefully prepared; otherwise, wrong information might confuse users.
- *Ventilation:* Ensure proper ventilation within the storage area to prevent moisture buildup. Sago bags are sensitive to humidity, and maintaining optimal conditions helps in preserving the quality of the product. High humidity or excess moisture can lead to the growth of fungi or infections later.
- *Palletization:* If applicable, consider palletizing the sago bags. Pallets provide stability, ease of handling with forklifts, and allow for proper airflow around the bags. Inserting the forklift levers into the designated slots of the pallet requires skill and stability to move items effectively.
- *Inventory Management System:* Implement a digital inventory management system to keep track of the quantity, production date, and other relevant information for each batch of sago bags. This enhances traceability and helps in managing stock levels efficiently.
- *Safety Measures:* Incorporate safety measures to prevent damage to the sago bags during storage. This may include using corner protectors, implementing guidelines for stacking height, and providing a designated area for loading and unloading.
- *Regular Inspections:* Schedule regular inspections of the storage area to identify and address any issues promptly. This proactive approach helps in maintaining the quality of the sago bags and ensures a smooth storage process.
- *Employee Training:* Train warehouse staff on proper handling procedures to minimize the risk of damage to the sago bags during storage and retrieval.
- *Climate Control:* If feasible, consider implementing climate control measures to regulate temperature and humidity, especially in areas prone to extreme weather conditions.
- *Quality Control Checks:* Conduct periodic quality control checks on stored sago bags to identify any signs of deterioration or damage. Prompt action can prevent the spread of issues and maintain the overall quality of the stored products.

Once these aspects have been addressed, the engineering team can establish an efficient and organized product storage system for sago bags in a factory storage environment.

II. Research Background

To achieve the objective of this study, which focuses on identifying an effective approach for managing loads during transportation and organizing stacked sago bags, various factors will be considered. These include the types of sago available in the industry, waste management, user-friendliness, ergonomic considerations, relevant research findings from similar case studies, and the overall performance within the context of the sago bag supply chain.

A. Food waste and Sustainability

In recent years, there has been a heightened focus on food waste at local, national, and international levels, driven by concerns about the environment, social implications, economic impacts, and climate change effects. Statistics reveal that roughly one-third of the world's food, equivalent to about 1.3 billion tons annually, goes to waste [8]. This significant level of food wastage poses profound consequences, contributing to environmental, economic, and social challenges, including food insecurity and the exacerbation of global warming [9]. The growing awareness of the environmental impact of food-processing waste has prompted a need to explore using this waste for livestock feed, considering its feasibility, safety, and sustainability. This research addresses the urgent issue of reducing food waste and enhancing sustainability by repurposing waste as livestock feed, highlighting the potential to convert waste into a valuable resource in agriculture. Additionally, food waste, rich in carbohydrates, proteins, and lipids, offers significant potential for biotransformation into valuable compounds. This underscores the opportunity for sustainable bioconversion methods, including the use of immobilized enzymes, to convert food waste into high-value products. Such approaches align with the broader goals of the bioeconomy, addressing environmental challenges and leveraging economic opportunities associated with food waste [10], [11].

B. Tapioca Pearl in Food Industries

Tapioca pearls or sago, are extensively used in bubble tea, desserts, and snacks, showcasing their versatility in the food industry [12]-[16]. These pearls, appreciated for their unique texture and flavor-absorbing capabilities, are popular in diverse culinary applications. Sago is derived from wet tapioca starch, obtained after extracting excess water in sedimentation tanks. Marketed as small globules or pearls, sago is valued for its easy digestibility, high carbohydrate content, and a size range from 2 to 4.5 mm [17], [18]. Its consumption offers a rapid energy boost, making it particularly beneficial for swift patient recovery. When cooked, sago undergoes a transformation from an opaque white to a translucent, soft, and spongy consistency [19]. However, caution is advised due to its high heat sensitivity; frying may cause sago to become sticky and gluey, making separation nearly impossible.

C. Sago Byproducts: Exploring Tapioca's Secondary Outputs

Numerous case studies and examples illustrate the creation of innovative food products from substandard or byproduct materials. A notable instance is the utilization of tapioca byproducts to produce bio-sugar [20]. Their research delves into the enzymatic saccharification of tapioca processing waste, resulting in biosugar generation through immobilization technology. By addressing the conversion of processing waste into valuable biosugars, this study exemplifies the potential for sustainable use of agricultural byproducts. Enzymatic processes present a promising pathway for enhancing the value of waste materials, contributing to resource efficiency. Emerging food processing technologies can significantly contribute to transforming defective tapioca pearls into desirable products. Introducing an innovative sensor that uses purple sweet potato tapioca pearls to monitor shrimp freshness is intriguing [21]. The tapioca pearls are a key component in creating a pH sensor for this purpose. This creative use of tapioca pearls in developing a freshness monitoring sensor demonstrates the adaptability of traditional ingredients for modern food quality assessment.

D. Forces Applied on Vertically Stacked Sago Bags

This section will discuss the forces exerted on vertically stacked sago bags, with all data sourced and summarized from manufacturers in the sago field. The key considerations can be articulated through the following statements.

When vertically stacking sago bags, various forces come into play, influencing the stack's stability and integrity. The primary force is *gravity*, with each bag exerting a downward force on the one below, accumulating as the stack grows. Friction between adjacent bags contributes to lateral stability, preventing horizontal shifts. *Compression forces* result from the weight of the entire stack pressing down, necessitating consideration of compressive strength. Internal shear forces may occur due to uneven loading or shifting contents. *Dynamic forces*, stemming from handling and transportation, can impact the stack, emphasizing the need for reinforcement. *Environmental factors*, such as moisture and temperature, affect bag material properties. The structural design and strength of the bags are pivotal, and the stacking configuration influences force distribution. Understanding and managing these forces is critical for preventing collapse, ensuring safe handling and storage, and preserving the quality of both the sago bags and their contents. Regular assessments and adjustments in stacking practices may be necessary based on specific bag characteristics and usage conditions.

Detailed discussions on each type of force will be provided in the subsequent section.

III. Research Concepts

To investigate alternative designs for creating a supporting device or method to transport stacked sago bags with varying weights (15, 25, and 30 kg), it is essential to consider the concepts and fundamental principles of force distribution, as well as the design and properties of both 'P-Sling and Pallet'. Additionally, customer satisfaction and analysis should be taken into account.

A. Eight Types of Forces

When sago bags are vertically stacked, eight types of forces come into play, impacting the stability and integrity of the stack. The details of key considerations and discussions regarding the forces applied to vertically stacked sago bags are explained in the following statements.

- *Gravity*

  Downward Force: The primary force acting on the stacked sago bags is gravity. Each bag exerts a downward force on the bag below it, accumulating as the stack grows taller. The force applied depends on the weight of the individual bags and the number of bags in the stack.

- *Friction*

  Lateral Force: Friction between adjacent bags plays a role in maintaining the stability of the stack. Adequate friction prevents bags from sliding or shifting horizontally, contributing to the overall structural integrity of the stack.

- *Compression*

  Vertical Force: As more bags are added to the stack, the lower bags experience compressive forces. This compression is a result of the weight of the entire stack pressing down on the bags at the bottom. It is important to consider the compressive strength of the bags and the potential for deformation.

- *Shear Forces*

  Internal Forces: Shear forces within the bags may occur due to uneven loading or shifting of contents. Properly securing the bags and evenly distributing the load helps minimize shear forces and prevents internal structural damage [22].

- *Dynamic Forces*

  Impact Forces: During handling or transportation, dynamic forces may be applied to the stack. These forces can result from sudden starts, stops, or vibrations. Strengthening the bags and optimizing the stacking pattern can mitigate the impact of dynamic forces.

- *Environmental Factors*

  Moisture and Temperature: Environmental conditions, such as moisture and temperature fluctuations, can affect the bags' material properties.

Wet or weakened bags may alter the forces involved, emphasizing the importance of proper storage conditions.

- *Structural Design*

Bag Strength: The design and strength of the sago bags significantly influence the forces they can withstand. Using bags with adequate structural integrity is essential for maintaining stability when stacked vertically.

- *Stacking Configuration*

Alignment and Symmetry: The arrangement and symmetry of the stack impact the distribution of forces. A well-aligned and symmetrical stack helps evenly distribute the load, minimizing the risk of uneven forces [23].

Fig. 1 illustrates the load applied to the heavy bag during manual carrying for stacking purposes. The force distribution results in the deformation of the sago bag shape and may cause fatigue in workers.

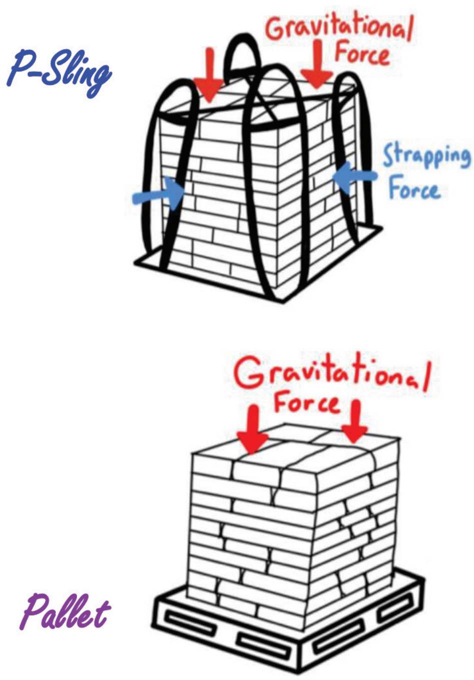


Fig. 1. The load applied to the heavy bag during carrying by forklift.

Moreover, human labor is required for putting the sago bag to the 'P-Sling' or 'Pallet' one by one where the weight of the bag is varied in the range 15 kg, 25 kg, and 30 kg [24].

The proper ways to support worker's health during carrying heavy bag, these are the tips. When lowering the bag, it is important to follow these steps to ensure safety and proper handling (Fig. 2):

1. Avoid unloading the bag directly from the shoulder to floor level.
2. Use an intermediate platform or seek assistance from a co-worker.
3. Stand close to the platform.
4. Place one foot in front of the platform.
5. Bend hips and knees while keeping the back straight.
6. Gently ease the bag off the shoulder and place it upright on the platform.
7. Pull the bag slightly over the edge of the platform.
8. Stand close to the platform with the bag touching the chest.
9. Clasp the bag against the body with one hand, while the other hand holds the bottom of the bag.
10. Step back.
11. Bend hips and knees, maintaining a straight back.
12. Carefully ease the bag onto the floor.

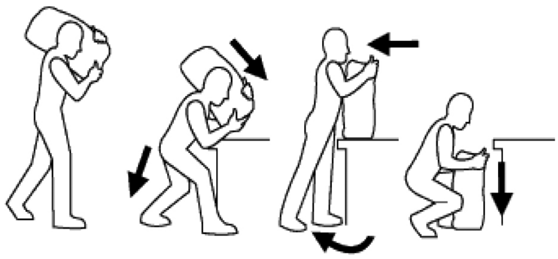


Fig. 2. Carrying Platform for Ensuring Safety and Proper Handling [25]

Understanding and carefully managing these forces are crucial for preventing stack collapse, ensuring the safety of handling and storage, and preserving the quality of the sago bags and their contents. Regular assessments and adjustments in stacking practices may be necessary based on the specific characteristics of the sago bags and the conditions of use.

B. Requirements for 'P-Sling' to Carry Stacking Sago Bags

Through interviews with target customers who have encountered issues with managing sago-stacked bags, some express the need for 'P-Sling' for carrying, while others prefer 'Pallet' for its rigid base. To address the pros and cons of each carrying method, it is crucial to uncover and analyze the specific requirements for both. The findings can illuminate a promising direction in the design stage for creating an alternative platform for carrying heavy loads.

For the first method, 'P-Sling', what customers require and expect from P-Sling to carry sago bags with varying weights (15 to 30 kg each) that are subsequently stacked up vertically includes:

- *Load Capacity*

Ensuring the P-Sling can effectively and safely handle sago bags ranging from 15 to 30 kg.

- *Durability*

Expecting robust construction and materials to withstand the weight and potential stresses during lifting and stacking.

- *Adjustability*

  Capability to accommodate different bag weights with adjustable features for versatile use.
- *Secure Fastening*

  Reliable mechanisms for securing bags during lifting and preventing any unintended shifts.
- *Ease of Use*

  Design features that facilitate easy and efficient loading, unloading, and stacking of sago bags.
- *Safety Measures*

  Implementation of safety features to prevent accidents or damages during handling.
- *Compatibility*

  Compatibility with the specific dimensions and characteristics of sago bags for optimal performance.
- *Longevity*

  Long-lasting performance and resistance to wear and tear for extended use.
- *Stacking Stability*

  Ensuring that the P-Sling contributes to the stability of vertically stacked sago bags.
- *User-Friendly Design*

  A design that considers the ease of use and ergonomics for operators involved in the handling process.

C. Requirements for 'Pallet' to Carry Stacking Sago Bags

In the case of the second method, 'Pallet', customer expectations and requirements for the effective use of Pallet" to transport vertically stacked sago bags with varying weights (15 to 30 kg each) involve:

- *Load Capacity*

  Adequate strength and load-bearing capacity to support the weight of stacked sago bags.
- *Durability*

  Long-lasting and robust construction to withstand the rigors of handling and transportation.
- *Dimensional Compatibility*

  Proper sizing to accommodate the dimensions of sago bags for secure stacking.
- *Stability*

  Ensuring stability during stacking and transportation to prevent tilting or collapsing.
- *Material Selection*

  The critical decision-making process of choosing materials suitable for the storage and transportation conditions of sago bags. Although wood and plastic are widely favored for pallet construction due to their popularity, it is essential to acknowledge that they may have inferior strength when compared to metal, which is typically crafted on-demand or in customized styles.
- *Ease of Handling*

  Design features that facilitate easy loading, unloading, and movement of stacked bags.
- *Stacking Uniformity*

  Providing a uniform surface to ensure even stacking of sago bags.
- *Compatibility with Handling Equipment*

  Integration with handling equipment like forklifts for efficient transportation.
- *Environmental Considerations*

  Resistance to environmental factors such as moisture, ensuring durability over time.
- *Cost-Effectiveness*

  Balancing performance with cost considerations for practical and economic use.

D. The Overall Sequences Required for Creating Analternative Design of a Stacking-Bag Assistive Device

To establish a systematic platform for the proposed research, four main topics (sequences) (Fig. 3) are necessary to accomplish the task. The subsequent section will provide detailed information on each of these topics. The design process begins with a thorough Customer Satisfaction Analysis, aimed at understanding customer needs and translating them into essential engineering design factors.

The design process begins with a thorough Customer Satisfaction Analysis, aimed at understanding customer needs and translating them into essential engineering design factors. This analysis lays the foundation for the Conceptual Design, which involves drafting the desired product design. The next step, System Level Design, classifies the drafted design into main and sub-components, ensuring a structured approach. Detailed Design follows, specifying key findings and requirements for each component based on customer needs. This process ensures that customer requirements are systematically analyzed to align with functional requirements. Finally, the Testing and Refinement stage, illustrated through case studies, focuses on considering material properties required for components like the 'Pallet' and 'P-Sling', ensuring the product meets quality standards and customer expectations.

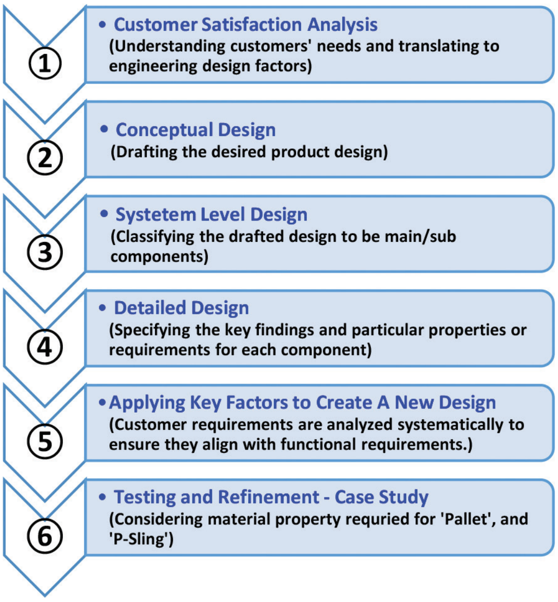


Fig.3. The summarized flowchart for the overall sequences of the research

IV. Customer Satisfaction Analysis

In this study, the chosen technique for considering and extracting customers' requirements to design and assess their satisfaction is Quality Function Deployment (QFD). Quality Function Deployment (QFD) is a systematic product development methodology that originated in Japan. It serves as a tool to translate customer needs and expectations into specific engineering characteristics and actions throughout the product design and manufacturing process. QFD involves cross-functional collaboration, ensuring that the entire organization aligns with customer requirements. It utilizes matrices known as "houses of quality" to visually represent relationships between customer needs, engineering characteristics, and various stages of product development. The aim is to enhance customer satisfaction and product quality by integrating the voice of the customer into every phase of the design and production lifecycle [26]-[28].

The key objective: Optimizing sago-stacking bag holder/carrier solutions for varied weights (15, 25, and 30 kg) through "Pallet and P-sling styles".

The key tools: To establish design guidelines for effectively holding and carrying sago-stacking bags with varying weights (15, 25, and 30 kg) through both "Pallet and P-sling styles", the following approach is recommended:

Approach I: Customer's Requirement Exploration

Step 1: Define the target user group.

Step 2: Identify customer needs through questionnaires, interviews, and experiments.

Step 3: Conduct a competitive analysis of competitor products from the customer's perspective.

Approach II. Customer's Priorities and Engineering Characteristics (ECs) Evaluation

Step 1: Prioritize customer expectations related to the sago carrying method through "Pallet or P-sling", focusing on factors like ergonomic comfort, strain prevention, and ensuring a secure and gentle grip during the lifting and transportation process.

Step 2: Consider additional factors, including lightweight design, with careful attention based on priority ratings.

Step 3: Evaluate engineering characteristics (ECs) with the highest relative weight, focusing on material type, error rate during carrying (failure rate), shape of the entire frame of stacked bags during transportation, and cost of both 'Pallet' and 'P-sling'. Additionally, consider user perceptions and experiences by applying their '5 senses', incorporating sensory feedback such as touch, sight, hearing, smell, and taste, to enhance the overall design and usability of the sago carrying method.

Step 4: Distinguish between ECs requiring experimentation (material type, shape, and size) and those derived through questionnaires or reasoning (surface area, holder construction, and function).

The key considerations of this approach are about when considering carrying by forklift, ergonomic comfort is indeed a relevant factor. While forklift operators may not directly carry the loads manually, their comfort and well-being play a crucial role in ensuring efficient and safe material handling. This involves aspects such as providing a comfortable seat and ergonomic controls for the operator, minimizing vibrations and shocks during operation, optimizing visibility to reduce strained body positions, designing a spacious and accessible cabin, implementing noise reduction measures, and, if applicable, offering climate control features for comfort during varying weather conditions. Ensuring ergonomic considerations in these areas contributes to increased productivity, safety, and overall job satisfaction for forklift operators.

Approach III: Design and Development Considerations

Step 1: Account for user preferences, storage positions, and specific needs or discomfort in the sago-stacking bag holder/carrier design.

Step 2: Encourage users to try different holders/carriers or seek professional advice for personalized solutions.

Step 3: Address concerns about time consumption and potential price increases by presenting an alternative approach.

Step 4: Suggest that target users rely on searching information about the product of interest to compare the pros and cons of relevant products available in the market. Utilize commercial or social platforms for acquiring information to make informed decisions.

This systematic approach ensures that the design process for sago-stacking bag holder/carrier solutions considers customer expectations, aligns with engineering characteristics, and offers diverse options catering to individual preferences and needs.

V. Conceptual Design Stage

To propose an appropriate assistive platform for stacking sago bags, examining the components and design features of both 'P-Sling' and 'Pallet' is essential. The design team has systematically extracted key design requirements from both handling styles. The subsequent sub-sections provide detailed insights into the components and design features.

A. The Components and Design Features of P-Sling

The P-Sling, designed for efficient handling of sago-stacking bags, typically comprises sturdy yet flexible materials. Its components include adjustable straps that can securely hold bags of various sizes and weights, allowing for versatility in accommodating different loads. The straps are often made from durable materials to ensure strength and longevity. The design incorporates ergonomic considerations, featuring padded sections or handles for comfortable gripping during lifting and carrying. Additionally, P-Sling may incorporate reinforced stitching or load-bearing points to enhance its overall durability and reliability in supporting heavy loads. To ensure ease of use, the P-Sling design may include quick-release mechanisms or adjustable buckles, enabling swift and secure attachment and detachment of bags. This user-friendly design contributes to efficient loading and unloading processes. Illustated in Fig. 4 is the design of the 'P-Sling'.

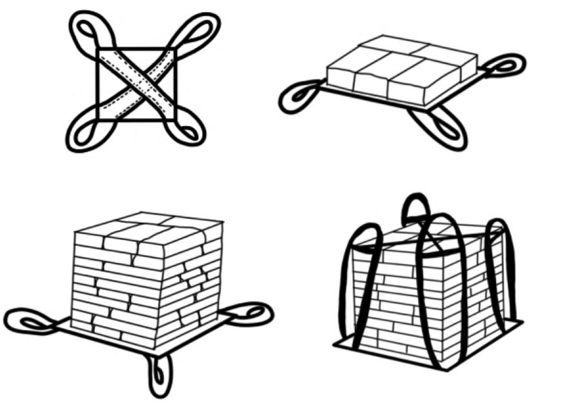


Fig.4. The components and design features of 'P-Sling' available in the market

The key points: The P-Sling is engineered with a focus on durability, versatility, and user comfort, making it a practical and efficient tool for handling sago-stacking bags of varying weights and sizes.

B. The Components and Design Features of a Pallet

Pallet is designed for the efficient handling of sago-stacking bags, encompass several key aspects. Pallets are typically crafted from materials like *wood, plastic,* or *metal*, ensuring robustness and sufficient load-bearing capacity.

Their size and dimensions vary to accommodate diverse bag sizes and weights, while the inclusion of deckboards and stringers ensures even weight distribution and stability during transportation and storage. *Load-bearing capacity* is a crucial consideration, with pallets engineered to support specific weight limits without compromising structural integrity. *Durability and longevity* are inherent in pallet design, achieved through material choices and construction techniques such as heat or chemical treatment. Accessibility from all four sides facilitates ease of handling with forklifts or pallet jacks. *Stackability* is a notable feature, optimizing storage space in warehouses and during transportation. Some designs may also incorporate safety features like anti-slip surfaces or rounded edges to enhance workplace safety during handling operations.

The key points: Pallets are thoughtfully designed to provide durability, standardization, and operational efficiency in the handling and storage of sago-stacking bags within a supply chain context. Illustated in Fig. 5 is the design of the 'Pallet'.

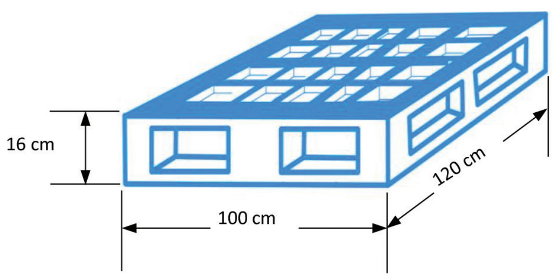


Fig.5. The components and design features of 'Pallet' available in the market

C. Design Analysis

The use of soft containers as 'P-sling' design can help reduce labor costs, provided that the enterprise has [29]:

- Devices for loading (unloading) containers.
- Loading devices for supplying containers for loading (unloading) and transportation means.
- Temporary storage sites and warehouses for filled containers.

All the benefits of soft containers can be realized if the container is appropriately chosen based on the type of cargo and if handling rules are adhered to. When selecting soft containers, various factors are taken into account, depending on the properties of the transported cargo, logistical chain, and customer requirements. Therefore, it is recommended to consult the technical services of the manufacturer when choosing the type of soft container.

Illustrated in Fig. 6 are the Dos and Don'ts for applying soft containers.

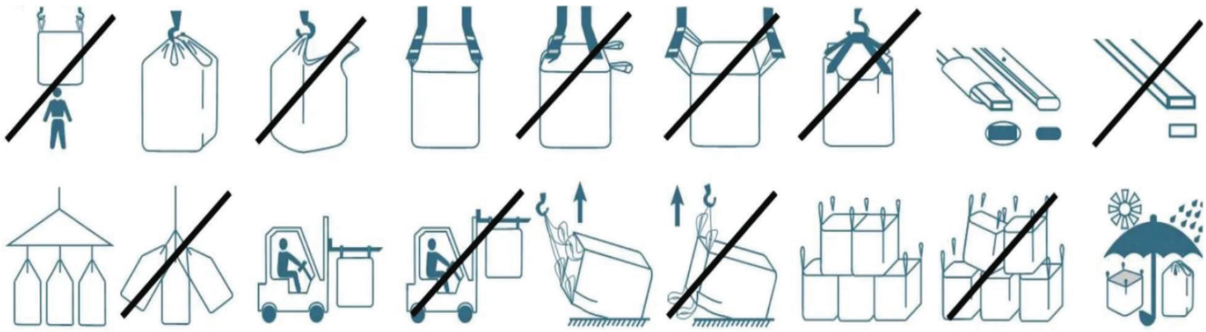


Fig. 6. The Dos and Don'ts for applying soft containers [29]. Instructions for use - Big bag user manual.

However, choosing 'P-Sling' as a solution for managing stacked items, which is itself easy to store with minimal space requirements, comes with certain limitations outlined in the standard soft container guidelines. It is specified that soft materials such as 'P-Sling' cannot be employed for the following materials:

- Liquids (special containers are designated for them)
- Substances containing concentrated corrosive acids and alkalis.
- Substances of hazard class I (explosive, strong poisons)
- Radioactive materials
- Materials with temperatures exceeding 120°C
- Lump and piece materials with a size larger than 250 mm with sharp edges

D. Pros and Cons of P-Sling and Pallet

The design team carefully weighs the pros and cons of this style as a pivotal consideration for design and development purposes. The durability of P-Sling and Plastic Pallets can vary based on factors such as material quality, usage conditions, and maintenance.

- *P-Sling Durability*

P-Slings are often made from durable materials like woven fabric or synthetic materials. Durability can be influenced by the material thickness, stitching quality, and load capacity. Regular inspection and proper maintenance contribute to extended durability.

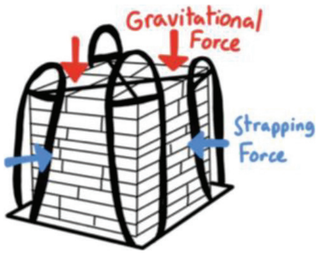
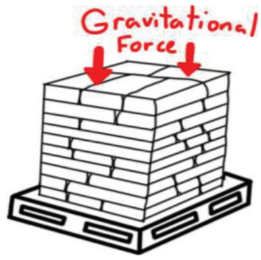
- *Plastic Pallet Durability*

Plastic pallets are known for their durability and resistance to weather, chemicals, and pests. Durability is affected by the type of plastic used (e.g., HDPE, PP), design, and load-bearing capacity. Plastic pallets are generally resistant to rotting, molding, and other environmental factors.

- *Comparing the Two*

P-Slings are lightweight and flexible but may be more prone to wear and tear, especially when subjected to sharp objects or rough handling. Plastic pallets are sturdy and robust, suitable for heavier loads, and provide better protection against external elements. However, there is a high chance of collapse. The key points: To consider the specific use case, load requirements, and environmental conditions when choosing between P-Sling and Plastic Pallets for stacking and transporting sago bags. Regular maintenance and adherence to usage guidelines contribute significantly to the longevity of both options. Furthermore, the comparison between 'P-Sling' and 'Pallet' is detailed in Table I.

TABLE I
THE SUMMARIZED COMPARISON BETWEEN "P-SLING AND PALLET"

Addressed Issues		P-Sling	Plastic Pallet
Model design			
Cost (THB)		200 ($5.63)*	1000 ($28.17)*
Weight (kg)		~ 1.55	~14
Size (WxLxH)		1.09 m x1.2 m x 1.43 m	1 m x 1.2 m x 0.16 m
Capacity	(25-kg bag)	50 bags	50 bags
	(30-kg bag)	45 bags	45 bags
	(15-kg bag)	80 bags	80 bags
Key points		Simple to transport and count / Convenient storage / Equipped with handles / Stability with full capacity during transportation / Still requires manual positioning of the sling handle into the forklift lever even with full capacity	Accessible and easy to pick up with a forklift / Easy counting and organization of stacked products in storage / Requires storage space / Base area with gaps or meshes are prone to fracturing over prolonged use
The material used for constructing		Woven fabric or Synthetic	HDPE, PP, or ABS
Durability		Better	Worse / Easy to Break

*Exchange rate - 02 January 2024 - 34.4143 THB per 1 USD [30]. Exchange Rates. Retrieved from https://www.bot.or.th/en/statistics/exchange-rate.html)

E. *Key Components for Design*

Sago or tapioca pearls, versatile ingredients found in a variety of foods and beverages, are crafted from tapioca starch, derived from the cassava root. Known for their spherical shape and diameters ranging from 1 to 10mm, sago pearls offer flexibility to suit different preferences. While typically white, they can be found in various colors. Sago boasts a firm texture and the ability to absorb water. When boiled, their color transforms to transparency, and the texture becomes soft and springy. Commonly used in dishes like sago cantaloupe, sago vada, and sago pudding, the drying process involves sago with a moisture content around 37% entering a rotary drum dryer. It progresses across the drum's length, from drum number 1 (located on top) down to drum number 5 (at the bottom), covering a total drying length of 30 meters. The drying time is approximately 2 hours, subject to variations based on the initial moisture content and drying temperature.

To explore the fundamental concept of the sago-making process, the essential steps for accomplishing the task are succinctly outlined in Fig. 7. The obtained information can guide the design team in developing a deeper understanding of the behavior of sago prior to the initial design stage. Furthermore, specific criteria are established for creating an alternative design for a sago-stacking bag assistive device, supporting Quality Function Deployment (QFD) to align customer requirements with engineering characteristics for the detailed design stage.

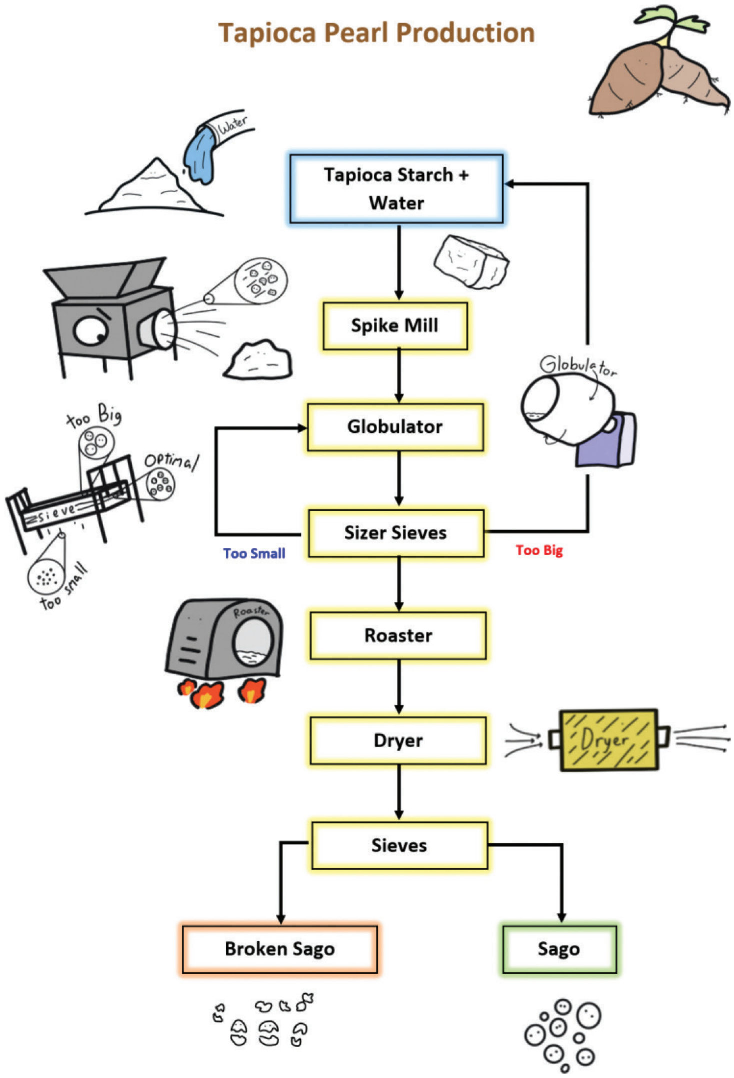


Fig. 7. The steps required for accomplishing task

VI. System Level Design

System level design involves defining the main components and subcomponents of a system. Main components are the major parts or modules of the system, while subcomponents are smaller units that contribute to the functionality of the main components. This process also includes specifying how these components interact with each other and with external systems, as well as defining the data flow and interfaces between components. Overall, system level design aims to create a structured framework that guides the detailed design and implementation of the system. Three main components are listed; handle, body, and base as shown in Fig. 8.

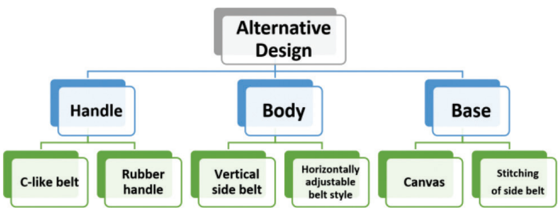


Fig. 8. Main components and sub-components

VII. Detailed Design

Based on the insights garnered from business owners consistently employing pallets and P-Sling for material handling, the design teams have compiled a comparative analysis between these two methods. This effort aims to support the concept of redesigning a supportive apparatus for the efficient handling, loading, and unloading of heavy objects, specifically within the realm of stacked-bag platforms.

Comparing the level of support between P-Sling and Pallet involves assessing several factors. P-Sling provides a flexible and adaptable support system, allowing for a degree of contouring to the load. It is particularly effective for irregularly shaped or fragile items, providing more customized support. On the other hand, Pallets offer a rigid and standardized support structure. They are suitable for uniform and sturdy loads, providing consistent support across the entire base.

In terms of versatility, P-Sling may excel in accommodating varying load sizes and shapes due to its adjustable nature. Pallets, while efficient for standardized loads, might face limitations with irregularly shaped or smaller items.

Portability is another aspect to consider. P-Sling, being more lightweight and flexible, may offer easier transportation and storage. Pallets, while sturdy, can be bulkier and may require more space.

The guidelines for developing an alternative design are illustrated in Fig. 9. These guidelines outline the characteristics and requirements necessary to support the design stage and facilitate comparison with existing design platforms. These include considerations of appearance, performance, functionality, and usability characteristics.

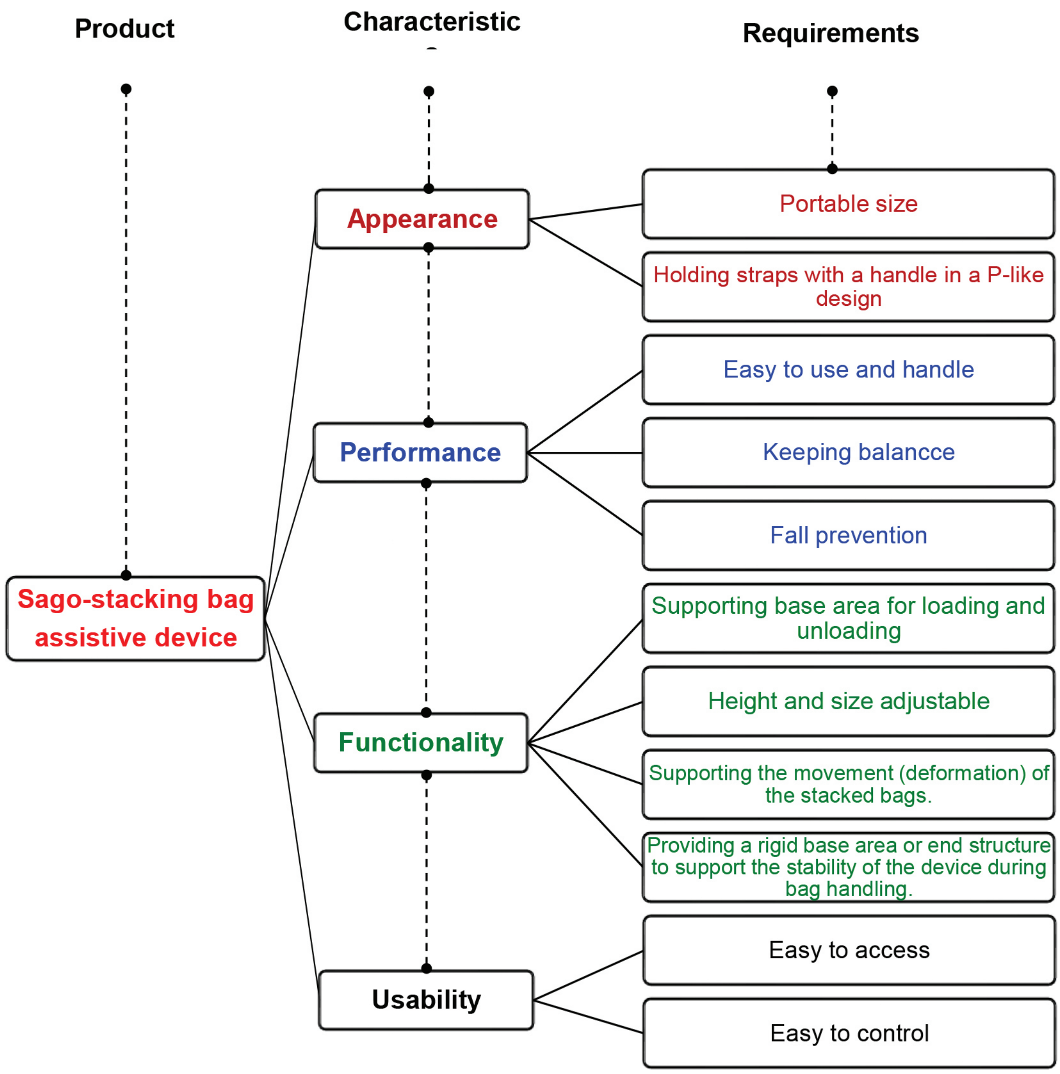


Fig. 9. Guidelines for creating an alternative design

The choice between P-Sling and Pallet depends on the specific requirements of the load, considering factors such as shape, size, and fragility. It is essential to weigh the benefits of flexibility and customization against the stability and standardization offered by each method to determine the most suitable level of support for the given application.

VIII. Applying Key Factors to Create a New Design

According to Fig. 9, which outlines specific requirements for developing the sago stacking bag assistive device, these requirements will serve as guidelines for selecting the appropriate design. Key factors addressed include the height of holding or carrying by the forklift, size of the bag, type of handling mechanism, and type of material. These factors are crucial for supporting the conceptual design of the assistive device, considering six main stages (Fig. 10). Subsequent subsections will explore the details of each consideration.

Step 1: Issue Identification and Target Group Definition

In the initial phase, the design team outlines key concerns related to stacking sago bags, formulating a set of questionnaires. Simultaneously, the target group is specified, consisting of manufacturers or business owners involved in sago production and packaging. The identified problem revolves around disorganized bag stacking on the floor, leading to challenges in management and loading onto containers, resulting in inefficiencies.

Step 2: Customer Needs Identification

The second step involves extracting needs from the target customers. The design team aims to create a preliminary design for an assistive carrying device or method that streamlines the transportation of stacked sago bags, considering cost as a primary factor. The utilization of the "House of Quality (HoQ)" is planned to unveil conceptual design needs, with a thorough analysis of competitors.

Step 3: Market Research on Related Products

In the third step, the team delves into researching related products like P-Sling and pallets. Feedback, comments, and cost considerations are documented and analyzed as part of a marketing survey. This phase may involve online searches through internet engines for comprehensive insights.

Steps 4 and 5: Component Listing and Design Refinement

The fourth and fifth steps entail listing the main and sub-components of the drafted design, all while keeping the target users' requirements in mind. Leveraging insights from the HoQ, the specifics of product characteristics, including appearance, performance, functionality, and usability of the developed sago-carrying device, are meticulously mapped out (refer to Fig. 9).

Step 6: Material Selection Guidelines

In the final step, material suggestions for crafting the assistive carrying device are provided as guidelines. This aims to steer customers toward selecting materials that ensure strength, durability, ease of use, and minimal human labor. The overarching goal is to facilitate informed decision-making in the material selection process.

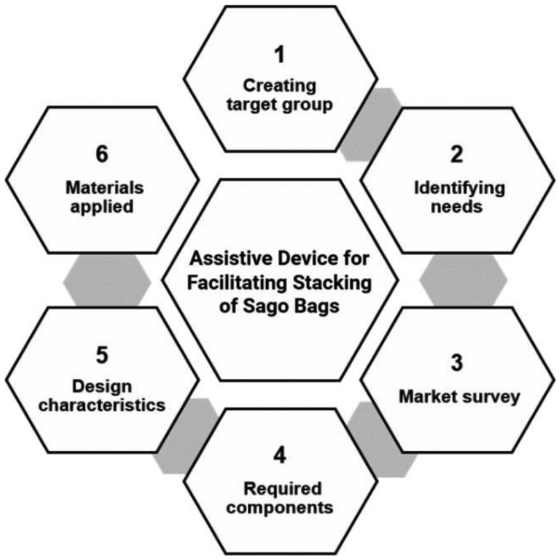


Fig. 10. Six stages required for accomplishing the proposed research

A. *Customer Requirements Versus Engineering Requirements*

The Quality Function Deployment (QFD) serves as a crucial tool in this study, aiding researchers in identifying essential engineering factors for the alternative design of a stacking-bag assistive device The engineering specifications, categorized by the researchers' perspectives, may display some subjective design aspects in product characteristics [31]-[40].

The House of Quality (HoQ) method is employed to establish the relationship between customer requirements and engineering specifications. To construct the HoQ, the team initiates by asking, "What do customers want?" The translated answers are then listed in the first row (engineering attributes) and the first column (customer requirements) of the house.

Illustrated in Fig. 11 is about "House of Quality for the desired product" to indicate that the House of Quality is a tool used to analyze and define the desired product's quality characteristics based on customer requirements.

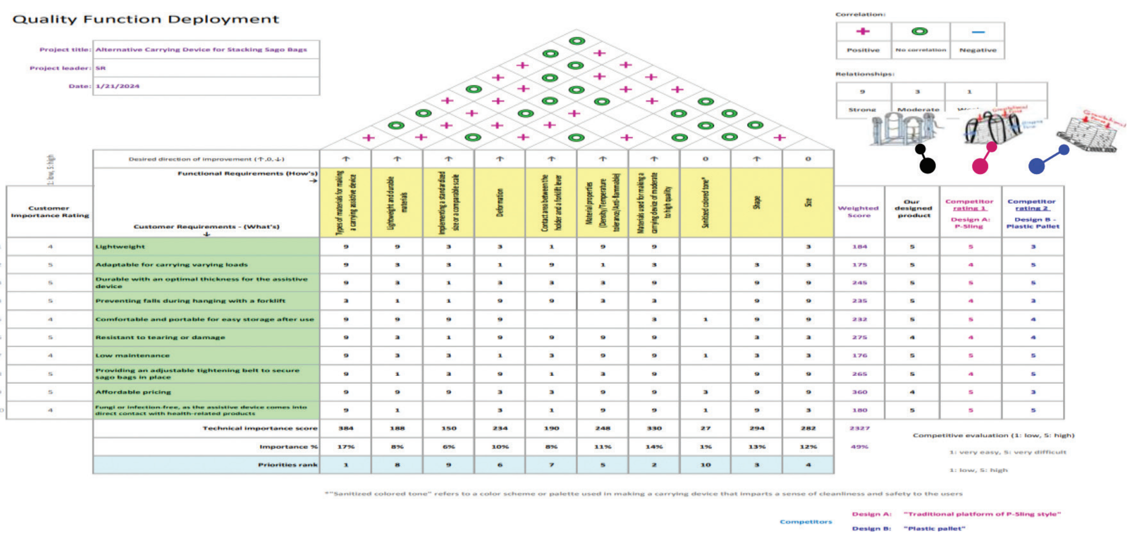


Fig. 11. House of quality with relationship matrix between customer requirement and design characteristics

Table III provides a list of product characteristics along with their definitions, while Table IV outlines the corresponding engineering attributes or requirements. The interviews conducted with the target customers have been extracted and analyzed based on the design team's perceptions and experiences in product design and development (PDD). This analysis informed the creation of a graphical 2D sketch for a proposed assistive device (Fig. 12) designed to support stacked sago bags with various loads.

In the HoQ diagram, the relationships between customer requirements (Whats) and engineering specifications (Hows) are represented on a four-scale level:

- 9 for a strong relationship
- 3 for a moderate relationship
- 1 for a weak relationship
- None for no relationship

For "customer requirements", questionnaire results guide the design team in understanding the direction and trend for the new product. In this study, the walking assistive device is expected to be light, portable, feature-rich, aesthetically pleasing, of high quality, and priced acceptably.

For "engineering attributes", the top five specifications—size, weight, comfort, price, and durability—are selected after team brainstorming. These specifications reflect the manufacturer's viewpoint regarding product design and characteristics.

In the HoQ, interrelationships between engineering attributes are divided into five levels with symbols: strong positive correlation (+), no correlation (O), and negative correlation (—).

Simply saying that, the correlation between "size" and "weight" is analyzed to be a "strong positive correlation", as larger carry-assistive device sizes are expected to result in higher weights. This correlation is symbolized in the correlating matrix.

Conversely, there is a "strong negative correlation" between "ease-to-carry" and "weight," signifying that an increase in weight may lead to decreased ease of carrying (—).

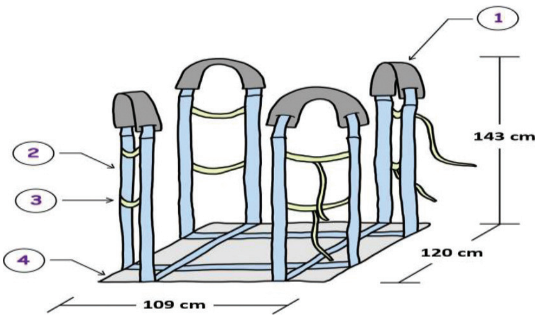


Fig. 12. Illustration for the alternative design

TABLE II
MAIN COMPONENTS OF THE ALTERNATIVE DESIGN

No.	Components	Descriptions
①	Handle	Rubber handle
②	Side belt	*Material:* Polyster *Thickness:* 1.5 mm
③	Horizontally adjustable belt style	Designed for 50% and 100% capacity
④	Base	*Material:* Polypropylene (PP) *Thickness:* 1 mm *Size:* 109 x 120 cm

TABLE III
PRODUCT CHARACTERISTICS AND THEIR DEFINITIONS

Engineering Requirements	Definitions
Types of materials for making a carrying assistive device	Materials must offer durability, toughness, and resistance to temperature, moisture, and chemicals while supporting diverse loads. The options include HDPE, PP, ABS, and Polyester.
Lightweight and durable materials	Polymers materials are the choice. Not super hard and solid as metals.
Implementing a standardized size or a comparable scale	The assistive device is designed with a standardized size around the contact area necessary for connection and application with the forklift lever. Using commercially available materials and a simple design facilitates easy maintenance for users, allowing them to find and replace parts with commercial spare parts readily.
Deformation	Polymer materials are the preferred choice, offering a balance between hardness and solidity that differs from the super-hard and solid nature of metals. Additionally, the elastic properties of these polymers allow for the deformation of the entire shape freely during the handling of heavy loads. This flexibility is crucial, especially in a stacking-like building style, where there are no supportive belts, as seen in pallets, to be compromise shock absorption.
Contact area between the holder and a forklift lever	The supportive-shoulder straps with rubber is applied around the contacting area between handle belt and a forklift lever.
Material properties (Density/ Temperature tolerance/ Anti-flammable)	Rubberized supportive shoulder straps are utilized around the contact area between the handle belt and a forklift lever.
Materials used for making a carrying device of moderate to high quality	The materials are of industrial-grade quality, robust enough to withstand various forces encountered during transportation and storage.
Sanitized colored tone	Clean and clear color tones, following a hygienic style, are carefully considered to enhance the presentation of health-related products.
Shape	Compact and easily accessible design, ensuring neatness both in storage and when suspended from a forklift lever.
Size	The assistive device can be conveniently folded into a compact size of 109cm x 30cm x 10cm. Its design allows for easy stacking without the risk of failure or disorderliness during loading, unloading, or retrieval for use.

TABLE IV
ENGINEERING REQUIREMENTS AND THEIR DEFINITIONS

Product Characteristics	Definitions
Lightweight	The proposed product features a lightweight and durable synthetic material capable of supporting the stacking of sago bags weighing between 1,200 and 1,350 kg.
Adaptable for carrying varying loads	The suggested product features an adjustable horizontal belt designed to support the carrying of stacked sago bags, accommodating a range from 20 bags (each weighing 30 kg) to 80 bags (each weighing 15 kg).
Durable with an optimal thickness for the assistive device	The thickness of the supportive device can provide to handle the stacking sago bags to the maximum weighting as 1350 kg.
Preventing falls during hanging with a forklift	The length of the handle on the designed device is determined by the distance between the topmost area of the stacked sago bags and the forklift lever, which is approximately 45-50 cm. This length is carefully chosen to prevent any swinging moment that could potentially tip the forklift during transportation.
Comfortable and portable for easy storage after use	The compact size of the assistive device allows for easy folding and storage, ensuring a neat and organized feel when unpacked for use.
Resistant to tearing or damage	The materials used for making assistive device provide less sensitive to the environment temperature in the cargo or working space. The proper thickness and medium-to-high standards of synthetic or composite materials are provided.
Low maintenance	The materials utilized in the device are resistant to humidity and can be easily cleaned with fresh water. The design is rooted in universal and minimalistic concepts, prioritizing ease of access and user-friendliness.
Providing an adjustable tightening belt to secure sago bags in place	All stacked bags are securely located and positioned in place during transportation.
Affordable pricing	Based on the appropriate thickness and the medium-to-high standards of synthetic materials, the expected price range is between 200 to 400 THB (5.8 to 11.6 USD).
Fungi or infection-free, as the assistive device comes into direct contact with health-related products	The material used in the device is inorganic, thus it does not promote the growth of fungal or microbial organism. This will mean a lower chance of product spoilage stemming from direct contact with the device.

IX. Material Property Consideration

In order to determine the suitable material conditions for creating a prototype, it is essential to study the thermal expansion characteristics of the materials in the preliminary stage. Given that the sago factory involves temperatures ranging from 130-200 °C, and the storage or loading/unloading areas are in close proximity to hot chambers or roasters, understanding the expansion or shrinkage of the carrying device becomes crucial.

For the initial material selection phase, 'Pallet' with various material types, offering rigid and straight planar contacting areas that come into contact with the sago bags, is chosen as the case study for calculating 'Thermal Expansion'.

Case Study I: Pallet with Metal Materials

In the sago factory studied in this proposed research, the metal materials commonly used for making pallets include [41]:

Aluminum: Aluminum pallets are lightweight and resistant to corrosion. They are often used in situations where weight is a critical factor or in industries where corrosion resistance is essential.

Stainless Steel: Stainless steel pallets offer corrosion resistance and durability. They are suitable for applications where cleanliness and hygiene are important, such as in the food or pharmaceutical industries.

Steel: Steel pallets are known for their strength and durability. They are suitable for heavy loads and can withstand harsh environments.

Table V presents the thermal expansion coefficients for three types of materials: aluminum, stainless steel, and steel [41].

TABLE V
THERMAL EXPANSION – METALS

Material	Expansion Coefficient
Aluminum	22.5×10^{-6}/ °C
Stainless Steel	17.3×10^{-6}/ °C
Steel	11.65×10^{-6}/ °C

The design team perceives that the most suitable material for supporting stacked sago bags is 'steel' due to its lower thermal expansion coefficient, approximately 11.65×10^{-6}/ °C, compared to other materials. Given an original length of 1 meter, a linear thermal expansion coefficient for steel of approximately 11.65×10^{-6}/ o C, an inside temperature of 32 °C, and an outside temperature of 42 °C, the thermal expansion can be calculated using the formula.

$$\boldsymbol{l} = \boldsymbol{l_0}[\mathbf{1} + \boldsymbol{\gamma}\Delta\boldsymbol{T}] \quad \text{Eq.1}$$

ΔT = $T - T_0$
γ = The linear thermal expansion coefficient
l = Length of the material after facing heat
l_0 = Original length of the material

Therefore,

l = $(1)[1+(11.65 \times 10^{-6}$ /C°)(10 C°)]
= 1.0001165 m.

The material experiences an expansion of approximately 0.0001165 meters from its original length. This expansion can provide insights into the durability of materials like metal, which may be compromised when subjected to sudden and significant temperature changes between the interior and exterior of a factory or storage space due to weather, seasons, and climate variations. Such fluctuations can directly impact the material's durability and stability during transportation. Although metal is inherently tough, it is susceptible to issues such as rusting and deformation with distorted shapes. These factors increase the risk of sago bags, arranged in a stacking style, falling down due to uneven surfaces.

Case Study II: P-Sling with Polymer Material

If the device used for supporting stacked sago bags, formed in a 'P-Sling style', is made of polymer, it is essential to consider the thermal expansion coefficient and tensile strength values. The required information for popular polymers such as polyester and polypropylene can be found in Table VI [41] for thermal expansion coefficients and Table VII for tensile strength values [42], [43].

TABLE VI
THERMAL EXPANSION – POLYMERS

Material	Expansion Coefficient
Polyester	124×10^{-6}/ °C
Polypropylene	81×10^{-6}/ °C

TABLE VII
TENSILE STRENGTH – POLYMERS

Material	Expansion Coefficient
Polyester	50 - 150 MPa
Polypropylene	25 - 40 MPa

From Tables VI and VII, the obtained data suggest insights into the flexibility of polymers. 'Polyester' appears to be stronger and more flexible, capable of withstanding pulling (stretching) under high temperatures or temperature fluctuations, which is crucial in environments like a sago factory with pervasive heat. Thus, the belt areas should be considered as 'Polyester-style', since the belt needs to be carried with a forklift lever while containing 1,200 to 1,350 kg of the sago bags.

X. Discussion of The Proposed Design

This study explores an alternative approach to create a user-friendly platform for loading and unloading bags containing a natural product, with sago as the focal point in this case. Changing from powdered starch to a fine-spherical shape, sago is carefully packed into canvas bags with varying loads, including 15-kg, 25-kg, and 30-kg sizes. The non-uniform pattern created by the distribution of sago particles within the bag poses challenges in maintaining a stable structure during transport, leading to deformation based on the carrier's movements. The chosen materials for the assistive device must possess qualities such as durability, toughness, and resistance to temperature, moisture, and chemicals, making options like HDPE, PP, ABS, and Polyester suitable. These polymer materials offer a balance between hardness and solidity, differentiating from the super-hard and solid nature of metals. The standardized size of the device facilitates easy connection and application with the forklift lever, and its simple design, utilizing commercially available materials, ensures easy maintenance and part replacement with readily available spare parts. The elastic properties of polymer materials allow for the deformation of the entire shape during the handling of heavy loads, crucial in a stacking-like building style where shock absorption is vital. Rubberized supportive shoulder straps are applied around the contact area between the handle belt and a forklift lever. The industrial-grade quality materials ensure robustness to withstand various forces during transportation and storage. Consideration of clean and clear color tones enhances the presentation of health-related products. The compact and easily accessible design ensures neatness in both storage and when suspended from a forklift lever. The device can be conveniently folded into a compact size of 109cm x 30cm x 10cm, allowing for easy stacking without the risk of failure or disorderliness during loading, unloading, or retrieval for use. For the proposed design, the handle features a rubber handle for comfortable grip. The side belt is made of polyester with a thickness of 1.5 mm. The horizontally adjustable belt style is designed to accommodate 50% and 100% capacity. The base is constructed from polypropylene (PP) with a thickness of 1 mm and has dimensions of 109 x 120 cm.

XI. Conclusion

The user experience is essential in the development of the assistive device. The handle's rubber grip ensures comfort during operation, while the side belt, made of 1.5 mm thick polyester, accommodates 50% and 100% capacity with its horizontally adjustable design. The base, constructed from 1 mm thick polypropylene (PP), measures 109 x 120 cm, offering durability and stability. The device can be conveniently folded into a compact size of 109cm x 30cm x 10cm for easy stacking and storage. Rubberized shoulder straps enhance grip and durability. The device's standardized size allows for easy connection and application with the forklift lever, with a simple design for easy maintenance and part replacement. Polymer materials' elastic properties enable deformation during heavy load handling, crucial for shock absorption in a stacking-like building style. The assistive device is designed to provide a robust and efficient solution for handling sago bags, addressing challenges in stability and transport associated with their non-uniform distribution.

IX. Limitation and Recommendation

The study's scope and limitations focus on sizes, weights, and particle sizes, delineated by examining tapioca pearls within the size range of 1 to 2.5 mm. These pearls are exclusively produced from tapioca starch and undergo processes limited to granulation, roasting, and drying. The weight is standardized as 1000 particles equaling 0.929 g, offering insights into the density and volume of each particle. The study considers the capacities for filling sago bags, which range from 15 kg to 30 kg.

The existing body of literature extensively explores the transformative utilization of factory waste to create innovative products, as evidenced by numerous articles available on the internet. However, upon thorough investigation, it is evident that none of these studies have specifically investigated the potential of repurposing defective tapioca pearls. This research gap highlights the unique and unexplored opportunity to contribute to the field by examining the viability and novel applications of defective tapioca pearls in the creation of innovative products, setting this research apart from the existing body of knowledge in the domain. In tapioca pearl factories, defective pearls in terms of size and color are routinely discarded, typically sold as animal feed, a practice that does not generate significant financial returns for the industry. The further study should explore innovative applications for these rejected small tapioca pearls, intending to increase their market value compared to their non-defective counterparts. By identifying new uses for these pearls, the goal is to enhance their value and contribute to increased revenues for tapioca pearl manufacturers.

The research goals should include investigating potential applications for defective tapioca pearls as a novel product. To efficiently transform rejected products into valuable by-products, there is a departure from the prevailing practice of selling them as animal feed, with careful consideration of food-grade material standards. This shift towards developing a new product from the defective tapioca pearls not only ensures increased value but also expands the product offerings of tapioca pearl factories.

Moreover, unwanted-sized sago particles can serve as an alternative material to support the item inside the container or box during transportation, similar to bubble wrap or synthetic supportive plates. Using rubber as a supportive material for the handle ensures the longevity of the main polyester handle by absorbing friction during the transportation process. This, in turn, reduces the frequency of product replacement, making it more cost-effective.

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References

[1] T. Krishnakumar, S. M. Sankarakutty, and N. Giri. (2024, Jan. 10). *Tapioca: Processing and Storage*. [Online]. Available: https://www.researchgate.net/publication/356747833_Tapioca_Processing_and_Storage

[2] S. Shipping and R. L. L. C. (2024, Jan. 10). *How to Optimize Your Cargo with Efficient Packing and Lashing*. [Online]. Available: https://www.linkedin.com/pulse/how-optimize-your-cargo-efficient-packing/

[3] I. Exports. (2024, Jan. 15). *Revolutionise Material Handling and Storage with Q Bags (Baffle FIBC Bags)*. [Online]. Available: https://shorturl.at/ovR78

[4] Gilbert International. (2024, Jan. 15). *Super Sacks on pallets: Efficient Storage and Transport Solutions*. [Online]. Available: https://blog.gilbertintl.com/super-sacks-on-pallets

[5] Z. Ujvari. (2024, Jan. 15). *Bulk Packaging: A Sustainable Solution for Various Industries*. [Online]. Available: https://www.fps.com/blog/bulk-packaging-bags/

[6] S. Abd-Aziz, "Sago Starch and Its Utilization," *J. Biosci. Bioeng*, vol. 94, no. 6, pp. 526-529, Dec. 2002.

[7] B. Santoso, *Recovery of Starch from Sago Pith Waste and Waste Water Treatmen.* Sago Palm, SG: Springer, 2018, pp. 261-269.

[8] K. L. Thyberg and D. J. Tonjes, "Drivers of Food Waste and Their Implications for Sustainable Policy Development," *Resour. Conserv. Recycl*, vol. 106, pp. 110-123, Jan. 2016.

[9] BIO-IS Staffs. (2013). *Food Wastage Footprint (Project) - Food Wastage Footprint: Impacts on Natural Resources: Summary Report.* [Online]. Available: https://www.fao.org/3/i3347e/i3347e.pdf

[10] Z. Dou, J. D. Toth, and M. L. Westendorf, "Food Waste for Livestock Feeding: Feasibility, Safety, and Sustainability Implications," *Glob. Food Secur*, vol. 17, pp. 154-161, Jun. 2018.

[11] M. Bilal and H. M. N. Iqbal, "Sustainable Bioconversion of Food Waste into High-value Products by Immobilized Enzymes to Meet Bio-economy Challenges and Opportunities – A Review," *Food Res. Int*, vo1. 23, pp. 226-240, Sep. 2019.

[12] O. A. Paulina, "Fortification of Carbohydrate-rich Foods (Spaghetti and Tapioca Pearls) with Soybean Flour, a Timely and Evergreen Necessity," *J. Food Secur*, vol. 5, no. 2, pp. 43-50, 2017.

[13] B. Kaur, R. Y. Quek, G. C. Ng et al., "Comparison of Boba Pearls Made from Tapioca Starch and Other Unconventional Flours and Starches: Their Glycaemic Response (GR)," *Malays. J. Nutr*, vol. 28, no. 3, Dec. 2022.

[14] N. N. Zhang, S. Yang, Y. Y. Kuang et al., "Effects of Different Modified Starches and Gums on the Physicochemical, Functional, and Microstructural Properties of Tapioca Pearls," *International Journal of Biological Macromolecules*, vol. 206, pp. 222-231, May. 2022.

[15] F. S. Jong, *An Overview of Sago Industry Development, 1980s-2015.* SG. Springer, 2018, pp. 75-89.

[16] R. Sivakumar, A. Elayaperumal, and R. Saravanan "Drying and Energy Aspects of Tapioca Sago Processing-An Experimental Field Study," *J. Mech. Sci. Technol*, vol. 31, no. 6, pp. 3035-3042, Jun. 2017.

[17] S. Anwar, *The Optimization Models for Shipping Allocation and Transportation within a Sago-Starch Supply Chain*. Daerah Istimewa Yogyakarta, ID: Departemen Teknik Mesin dan Industri Fakultas Teknik Universitas Gadjah Mada, 2018, 188-196.

[18] M. Ayu Trisia, M. Tachikawa, and H. Ehara, "The role of the Sago Supply Chain for Rural Development in Indonesia: A review and Perspective," *Rev. Agric. Sci*, vol. 9, pp. 143-156, 2021.

[19] Y. Fu, L. Dai, and B. B. Yang, "Microwave Finish Drying of (Tapioca) Starch Pearls," *Int. J. Food Sci. Technol.*, Vol. 40, no. 2, pp. 119-132, Feb. 2005.

[20] N. A. Edama, A. Sulaiman, and S. N. Abd. Rahim, "Enzymatic Saccharification of Tapioca Processing Wastes into Biosugars through Immobilization Technology (Mini Review)," *Biofuel Res. J.*, vol. 1, no. 1, pp. 2-6, Mar. 2014.

[21] L. Wangmo, A. Suratsawadee, T. Ratvijitvech et al. "A Novel Sensor Based on Bead-counting of Purple Sweet Potato Tapioca Pearl for Freshness Monitoring of Shrimp," *Food Chem*, vol. 368, p. 130863, Jan. 2022.

[22] K. Fan, S. H. Liu, Y. P. Cheng et al., "Effect of Infilled Materials and Arrangements on Shear Characteristics of Stacked Soilbags," *Geosynth. Int*., vol. 27, no. 6, pp. 662-670, Dec. 2020.

[23] N. Almasarwah, E. Abdelall, G. Suer et al., "Pallet Loading Optimization Considering Storage Time and Relative Humidity," *J. Ind. Eng. Manag.*, vol. 16, no. 2, pp. 453-471, Jul. 2023.

[24] S. Gallagher and J. R. Heberger, "The effects of operator position, pallet orientation, and palletizing condition on low back loads in manual bag palletizing operations," *Int. J. Ind. Ergon*, vol. 47, pp. 84-92, May. 2015.

[25] CCOHS. (2024, Feb. 20). *Manual Materials Handling (MMH)*. [Online]. Available: https://www.ccohs.ca/oshanswers/ergonomics/mmh/compactbags.html

[26] Y. Akao, *Quality Function Deployment*, Productivity Press, MA: Cambridge, 1990. pp.1-392.

[27] A. Griffin and J. R. Hauser, "The voice of the customer," *Mark. Sci,* vol. 12, no. 1, pp. 1-27, Feb. 1993.

[28] S. B. Han, S. K. Chen, M. Ebrahimpour et al., "A Conceptual QFD Planning Model," *Int. J. Qual. Reliab. Manag*., vol. 18, no. 8, pp. 796-812, Nov. 2001.

[29] RIAPLAST. (2024, Feb. 21). *Big Bag User Manual*. [Online]. Available: https://riaplast.com/big-bag/Instructions-for-use/

[30] Bank of Thailand. (2024, Feb. 2). *Daily Foreign Exchange Rates*. [Online]. Available: https://www.bot.or.th/en/statistics/exchange-rate.html

[31] S. Rianmora and S. Werawatganon, "Applying Quality Function Deployment in Open Innovation Engineering," *J. Open Innov.: Technol. Mark. Complex*, vol. 7, no. 1, p. 26, Mar. 2021.

[32] O. C. Racela, "Customer Orientation, Innovation Competencies, and Firm Performance: A Proposed Conceptual Model," *Procedia Soc. Behav. Sci*, vol. 148, pp. 16-23, Aug. 2014.

[33] X. Lai, K. Tan, and M. Xie, "Optimizing Product Design Using Quantitative Quality Function Deployment: A Case Study," *Qual. Reliab. Eng*, vol. 23, no. 1, pp. 45-57, Jan. 2007.

[34] S. Gutierrez and C. Tulkoff, "Benchmarking and QFD: Accelerating the Successful Implementation of No Clean Soldering," in *Proc.* 16th IEEE/CPMT International Electronic Manufacturing Technology Symposium, 1994, pp. 389-397.

[35] Y. H. Wang, C. H. Lee, and A. J. C. Trappey, "Service Design Blueprint Approach Incorporating TRIZ and Service QFD for a Meal Ordering System: A Case Study," *Comput. Ind. Eng*., vol. 107, pp. 388-400, May 2017.

[36] E. E. Karsak, S. Sozer, and S. E. Alptekin, "Product Planning in Quality Function Deployment Using a Combined Analytic Network Process and Goal Programming Approach," *Comput. Ind. Eng.*, vol. 44, no. 1, pp. 171-190, Jan. 2003.

[37] M. S. Cherif, H. Chabchoub, and B. Aouni, "Integrating Customer's Preferences in the QFD Planning Process Using a Combined Benchmarking and Imprecise Goal Programming model," *Int. Trans. Oper. Res*, vol. 17, no. 1, pp. 85-102, Dec. 2009.

[38] R. G. Askin and D. W. Dawson, "Maximizing Customer Satisfaction by Optimal Specification of Engineering Characteristics," *IIE Trans*, vol. 32, no. 1, pp. 9-20, 2000.

[39] G. S. Wasserman, "On How to Prioritize Design Requirements During the QFD Planning Process," *IIE Trans*, vol. 25, no. 3, pp. 59-65, May. 1993.

[40] L. F. M. Kuijt-Evers, K. P. N. Morel, N. L. W. Eikelenberg et al., "Application of the QFD as a Design Approach to Ensure Comfort in Using Hand Tools: Can the Design Team Complete the House of Quality Appropriately?" *Appl. Ergon*, vol. 40, no. 3, pp. 519-526, May. 2009.

[41] The Engineering Toolbox. (2024, Feb. 20). *Thermal Expansion - Linear Expansion Coefficients*. [Online]. Available: https://www.engineeringtoolbox.com/linear-expansion-coefficients-d_95.html

[42] E. Richaud, B. Fayolle, and P. Davies, *Tensile Properties of Polypropylene Fibers.* Elsevier, NL: Amsterdam, 2018, pp. 515-543, 2018.

[43] G. Gunduz, D. Erol, and N. Akkas, "Mechanical Properties of Unsaturated Polyester-isocyanate Hybrid Polymer Network and its E-glass Fiber-reinforced Composite," *J. Compos. Mater*, vol. 39, no. 17, pp. 1577-1589, Sep. 2005.

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