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RESEARCH ARTICLE

Design for an Intelligent Waste Classifying System: A Case Study of Plastic Bottles

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ABSTRACT The use of plastic bottles has become a significant environmental concern, and recycling them has become a priority. Small and medium-sized recycling companies must collect and categorize large volumes of plastic bottles and sell them to larger recycling firms, a process that is time-consuming, costly, and labor-intensive. This manual sorting process can pose health risks, particularly during the COVID-19 pandemic, and can affect worker productivity. To address these issues, this study proposes the development of an automated conveyor belt system that can rapidly and accurately separate plastic bottles by type. The system utilizes an opaque and transparent plastic bottle separation platform, which saves time, cost, and manpower. This system design provides recycling SMEs with a competitive advantage by serving as a practical application model and a prototype with an easy-to-use concept. Key tools employed in this research include product design development (PDD), Kansei engineering, manufacturing process design, controlling system, and fault tree analysis (FTA). The light sensors are critical components in the separation process, detecting the opacity or transparency of the bottles' surfaces. The proposed prototype's reliability will be assessed by FTA, which considers all potential failures. This study contributes to the body of knowledge surrounding the integration of conveyor systems and provides valuable information for businesses seeking to optimize their sorting processes. The guidelines developed in this study can serve as a starting point for further research on the integration of conveyors in waste sorting plants.

INDEX TERMS Product design and development, Kansei engineering, conveyor belt, microcontroller, light sensor, fault tree analysis.

I. INTRODUCTION

The mismanagement of a large amount of waste poses a significant risk to the environment, public health, and the ecosystem [1]. Despite these challenges, it is crucial to prioritize environmental protection, public health, hygiene, material recovery, waste reduction, emissions reduction, and disease prevention [2]. Effective recycling depends on efficient separation, and the market offers a wide range of separation technologies that have been developed and applied [3], [4], [5]. Advanced waste separation systems lead to higher-quality material recovery, resulting in increased revenue. Several companies have introduced medium-to-high scale chain belt conveyors with robust output for various applications (Figure 1) [6], [7], [8], [9]. Chain belt conveyors are a popular choice in the recycling industry due to their sturdy and durable construction. Their stability is complemented by great flexibility, as they can be easily adapted or extended to meet specific needs. These conveyors can be equipped with rubber, and are built with heavy-duty modular frames, high vertical side pieces, and quality bearings and gearboxes. Variable speed controls can also be added to all chain belt conveyors [10], [11], [12]. Plastic recycling plants use various techniques, such as remolding, to reduce the environmental impact of plastic bottles. Before melting the bottles down, they must first be separated based on their material properties. Small recycling companies are often relied upon to collect used bottles from customers [13], [14], [15].

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FIGURE 1. Belt conveyor for waste management [8].

However, these conveyors are typically medium-to-large in size, and require sufficient space for equipment and materials. Due to budgetary constraints, many small and medium-sized enterprises (SMEs) choose to rely on manual sorting processes to separate various types of plastic bottles. However, this approach poses significant health risks to employees, as bacteria can thrive on unwashed water bottles that are left unattended for a week [16], [17]. Given the potential for infections and illnesses associated with manual sorting processes, it is crucial for SMEs to consider alternative methods of sorting plastic bottles. Automated conveyor systems, for example, can perform sorting tasks quickly and efficiently, without exposing employees to health risks. While such systems may require an initial investment, they can provide long-term benefits in terms of increased productivity, reduced labor costs, and improved workplace safety. It is essential for SMEs to prioritize the health and safety of their employees when considering methods for sorting plastic bottles. Investing in automated sorting systems can not only reduce health risks but also improve overall efficiency and profitability in the long run.

To address these concerns and simplify the process, this study proposes an alternative sorting conveyor system that is compact in size and capable of categorizing bottles into two groups: *transparent* and *opaque*. Belt conveyors are widely used in industries due to their strong conveying capacity [8], [9], [10], making them an ideal solution for this purpose. The sorting conveyor system's specifications are determined by the type of waste, structural conditions, and existing production machines. The system's overall concept focuses on reliability and practicality, ensuring that the conveyor runs smoothly and the sorting process remains efficient with trouble-free operation in everyday use. These adaptations are essential when setting up disposal systems to improve the efficiency and safety of the sorting process.

II. RELATED WORKS

A. CONVEYING AND SORTING TECHNOLOGY IN INDUSTRY AND PRODUCTION

Conveying and sorting technology is highly adaptable and can process a wide variety of materials. However, different systems are optimized for specific types of waste, which highlights the importance of selecting the appropriate conveyor system for the task at hand. For instance, pneumatic conveying systems are ideal for managing small waste generated during production, such as paper scraps, cardboard, and plastic waste from a shredding system [18], [19].

Conveyor belts are versatile and can handle irregularly shaped materials, such as metal scrap, PET, and other waste. Chain conveyors are better suited for transporting larger unit loads, such as containers, pallets, or goods carriers. Conversely, tilt conveyors can handle all materials that are collected in containers or boxes, including small items like plastic and Styrofoam, as well as bulkier waste like car tires and wood. Industrial sectors and researchers anticipate that conveying and sorting technology will offer automation, safe and efficient removal of materials, energy conservation, and cleanliness. These requirements can be achieved through various solutions [19], [20], [21], [22], [23].

Pneumatic systems [24], [25], [26], [27], for instance, offer a direct link between the production site and waste disposal and can be combined with other systems like extraction systems, presses, and containers to create an automatic transport and disposal system. Waste generated during production can be transported directly to the desired destination via the conveyor system, avoiding pollution at the production site or in the factory. The conveyor system can also transport waste directly from the factory floor to a container, freeing up valuable space within the production facility for other tasks.

To automate the disposal of recycled material and residual waste, a sorting plant is necessary. Modern sorting technology can cleanly and efficiently separate different types of residual materials, contributing to an environmentally friendly recycling process [22], [28], [29], [30], [31], [32], [33]. Sorting plants typically consist of a multi-stage sorting line that removes foreign materials and sorts paper waste. Conveyor technology is integral to the sorting process, transporting the respective materials to their desired points automatically. Clean sorting is essential for a high degree of recycling and a circular economy, particularly for important raw materials like paper and cardboard. To support environmentally friendly recycling, our sorting plants rely on a multi-stage sorting line that effectively removes foreign materials and sorts paper waste. The plant's advanced technology, including conveyor belts, automatically transports each material to its intended destination, allowing for a fully automated process - development of automatic sorting conveyor belt using PLC [28]. Conveyor technology is a vital component of the sorting system, enabling efficient and seamless operation.

For the optimization process of conveyor belts for separating waste, two methods related to the optimization process of conveyor belts for separating waste were found to be interesting and useful for further study [34], [35]. Both studies aim to optimize the conveyor belt system used in waste separation to improve efficiency and accuracy, and the proposed methods have shown promising results in achieving this goal. Yasin et al. proposed an optimization method for a conveyor belt system used in municipal solid waste separation. The study aims to optimize the conveyor belt system's operational parameters, including the conveyor speed and the angle of inclination, to improve the separation efficiency of the waste. The authors used a simulation model to evaluate the performance of the optimized conveyor belt system and found that it could effectively separate municipal solid waste into different categories with higher accuracy and efficiency compared to traditional conveyor systems. Huang et al. proposed an automatic sorting system based on programmable logic controllers (PLC) for waste separation. The authors developed an optimization method for the conveyor belt system used in the sorting process to improve the system's efficiency and accuracy. The study proposed a sorting algorithm based on the weight, size, and color of the waste and optimized the conveyor belt speed and belt width. The simulation results showed that the proposed system could effectively separate different types of waste with higher accuracy and efficiency compared to traditional conveyor belt systems.

Sorting systems utilize various methods such as screens, air classifiers or separators, and NIR spectroscopy [32], [33]. In the latter, infrared sensors detect the type of material on the conveyor belt and sort it out accordingly, even checking each individual piece. Automated sorting technology offers several advantages, such as reducing the need for manual labor and promoting order, making it an integral feature in waste management. In addition to waste management, conveyor technology has become a crucial aspect of recycling plants. Its use in combination with tipping devices and press containers allows for convenient filling, while conveyor belts can transport residual waste from reception to sorting and disposal, optimizing everyday operations.

However, due to their automated sorting capabilities, machines like these require minimal human workers. Apart from loading the garbage into the machine, there may be only a few other areas in the sorting process that require human workers. The machine handles most of the sorting process on its own. The sorting system proposed in this research is designed to assist small-scale waste separation plants. Although human workers are still needed for various tasks, their roles have changed. Instead of sorting plastic bottles one by one, they may rotate to perform waste management planning, marketing, maintenance, route planning transportation, or customer service, thereby avoiding direct contact with the waste.

B. PRODUCT DESIGN AND DEVELOPMENT (PDD)

Product design and development (PDD) is a systematic process that involves generating ideas or concepts, developing

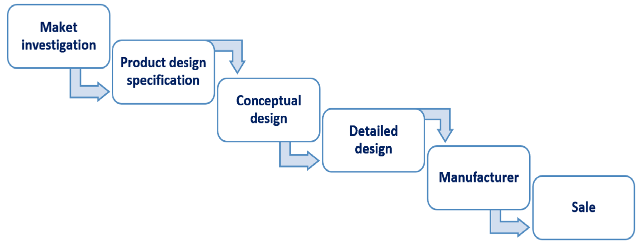


FIGURE 2. Total design model [34].

and evaluating concepts, manufacturing and testing or implementing a product or service. While industrial design is focused on the aesthetics of a product, such as its form, color, texture, structure, and feeling, product design encompasses a blend of marketing, product management, industrial design, and engineering characteristics [36]. According to Mazumdar, product development involves translating customer needs into product design and manufacturing processes, and managing dependencies throughout the product life cycle, including design, manufacturing, distribution, technical support, and disposal or recycling stages [37]. The total design model is illustrated in Figure 2, which starts with market investigation to check the basic requirements, followed by product design specifications (PDSs) that identify components and sub-components of a new design.

In the design process, after the conceptual design is completed, a 3D CAD model is generated based on important factors determined in the previous step. The detailed design phase involves specifying the precise details of each component, such as materials, manufacturing processes, and physical properties required. At this stage, a reasonable cost is assigned for manufacturing, detailing, and selling the model. This design process is applicable to a range of engineering and consumer products, including those in the composite field.

1) MARKET INVESTIGATION

The primary objective of market research is to gather crucial information about the product of interest from multiple sources, including questionnaires, social media, the internet, competitors, and advertisements. It involves conducting a market survey to determine customer preferences and evaluate the performance of competitor products.

2) PRODUCT DESIGN SPECIFICATION

The formal document called product design specification is developed by the product design team, which includes information gathered from market investigation. This document serves as a guide for the design process and can be adjusted accordingly. The product design specification is developed based on information obtained from various sources, including published literature and competitor's products. It covers various aspects such as performance, safety, maintenance, environment, and materials.

3) CONCEPTUAL DESIGN

In the product development cycle, conceptual design plays a pivotal role as it transforms the requirements of the target customer into a tangible object. Quality cost, manufacturability, and product life cycle characteristics are factors that can influence the process of conceptual design. Additionally, conceptual design is primarily concerned with the generation of ideas and is often referred to as conceptualization, which is closely related to creativity.

4) DETAILED DESIGN AND PROTOTYPING

The detailed design phase is critical as it ensures that the new product meets all functional requirements, cost targets, and manufacturing constraints. The design team should work closely with the manufacturing team to ensure that the design is optimized for efficient production. Prototyping and testing may be necessary during this phase to ensure that the design works as intended and meets all requirements. The use of virtual simulation can help to reduce the time and cost of physical prototyping, as it allows for testing and refining the design before a physical prototype is created. Overall, the detailed design phase is essential in ensuring that the final product meets all requirements and is ready for manufacture and launch into the market.

5) MANUFACTURE

In addition to material properties and manufacturing processes, other factors to consider in this stage include production volume, lead time, and environmental impact. The selected manufacturing process should be able to handle the desired production volume efficiently and within the desired lead time. Additionally, the environmental impact of the chosen manufacturing process should be considered, including the amount of waste generated and energy consumption. In recent years, sustainable manufacturing processes have become more popular, as they prioritize minimizing waste and reducing energy consumption, leading to a reduced carbon footprint. The material and manufacturing process selection stage is critical in determining the quality and cost-effectiveness of the final product.

C. KANSEI ENGINEERING

Kansei Engineering (KE) originated in Japan during the 1970s as a tool to link customers' emotional responses to the product design process by converting feelings into measurable and physical design specifications [38], [39], [40], [41], [42], [43]. The word ''Kansei'' refers to the instinctual mental activity of a person who perceives an impression from an external stimulus. When customers plan to purchase a product, they already have a preconceived positive or negative image in their minds. KE starts by observing customer behavior, capturing their emotions and affections through psychological scaling, and analyzing the emotions using various statistical methods to create product or system design specifications, aiming to maximize customer satisfaction with their purchases. As customers become more informed, demanding, and sophisticated, Kansei may be the deciding factor. Six types of Kansei Engineering are explained as follows.

1) TYPE I: CATEGORY CLASSIFICATION

The Category Classification method involves breaking down the Kansei category of a planned target into a tree diagram, which is then used to determine the physical design details. These sub-concepts serve as parameters for product design, and in some cases, questionnaires are used to assist manufacturers in finalizing the design.

2) TYPE II: KANSEI ENGINEERING SYSTEM

The Kansei Engineering Type II is a computer-assisted system that is related to Kansei Engineering. The Kansei Engineering System (KES) is a computerized system that uses an Expert System to facilitate the transfer of customer emotions and perceptions into physical product design. The KE system is comprised of four databases and an inference engine, as illustrated in Figure 3.

3) TYPE III: KANSEI ENGINEERING MODELLING

Kansei Engineering Type III involves using a mathematical model in a computerized system, in addition to a rule base. The mathematical model functions as a form of logic and is applied to define fuzzy sets that express the degree of desirability of a product for customers.

4) TYPE IV: HYBRID KANSEI ENGINEERING

Hybrid Kansei Engineering is a blend of Forward and Backward Kansei Engineering techniques. Kansei Engineering Type II is a computerized Kansei Engineering System that enables customers to determine the product that best suits their product feeling. In Type II, the flow of Kansei translation is from the customer's Kansei to the design details. Designers can also use this approach to determine the design of a Kansei product from the perspective of a ''market-in strategy''. The designer first settles on the design image of the new product and then identifies the design specifications of the product with the support of the KES. This direction is known as ''Forward Kansei Engineering''. However, designers sometimes want to assess the degree of fit between their image and design and Kansei. Backward Kansei Engineering provides computerized suggestions to designers on how to improve their design beyond what Type II can do. Figure 4 illustrates both Kansei translation directions in Kansei Engineering.

The Hybrid Kansei Engineering System allows designers to obtain design specifications from Kansei words through Forward Kansei Engineering. With the system's output, designers can fuel their creativity and design a new product based on their own ideas and the system's suggestions, which translate customer requirements. Next, the designer inputs their sketch into the system, and Backward Kansei Engineering recognizes the sketch through an image recognition system [44].

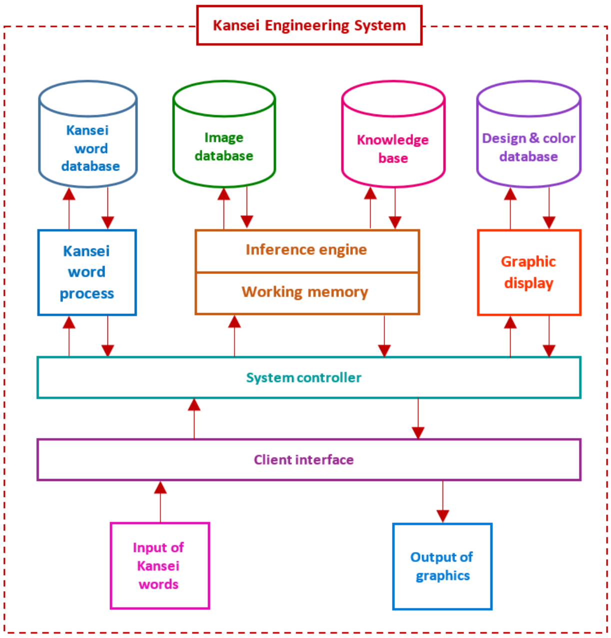


FIGURE 3. Kansei engineering system [45].

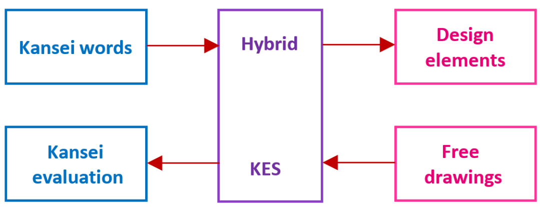


FIGURE 4. Kansei translation directions in Kansei engineering [45].

5) TYPE V: VIRTUAL KANSEI ENGINEERING

Virtual Kansei Engineering is a technique that combines Kansei Engineering and virtual reality technology. The system creates a virtual environment with a new product, which is determined by Kansei Engineering, and invites customers to test and provide feedback on the product within the virtual space. This feedback is then shared on social media platforms. The use of virtual reality technology in Kansei Engineering provides a cost-effective and efficient way to gather customer feedback and enhance the product design process.

6) TYPE VI: COLLABORATIVE KANSEI ENGINEERING DESIGNING

Collaborative Kansei Engineering Designing or Internet Kansei Designing System is a Kansei Engineering System supported by the internet. With the increasing reliance on the internet, this system facilitates the collaboration and exchange of ideas between the customer and designer, resulting in faster product development. In this system, customers can input their own Kansei words, and designers can use them to analyze and generate product designs based on the customer's input. This approach empowers customers to design products that truly reflect their feelings and preferences.

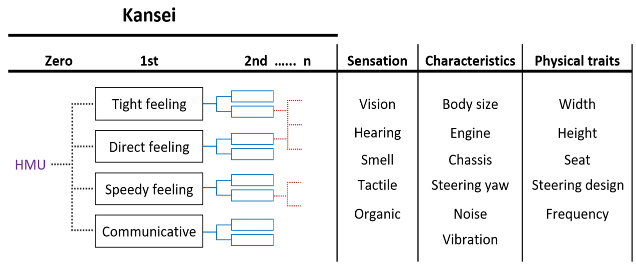


FIGURE 5. Translation of Kansei [44], [45]. Kansei Engineering Type I as used in the Mazda case Nagamachi.

D. KANSEI ENGINEERING–CASE STUDY

The application of KE has been introduced to various types of industries, one of the classic case studies of KE is shown in a new sports car named "Miata" (Eunos Roadster in Japan) of "Mazda". This car was developed and derived from Kansei Engineering [45]. The translation of Kansei (tree diagram) into car physical traits in the case of "Miata" is shown in Figure 5.

The key consideration in the car development case was the "Human-Machine Unity (HMU) concept", which was identified as the main heading at the first level of the tree structure. HMU was represented by four sub-concepts: *tight feeling*, *direct feeling*, *speedy feeling*, and *communication between the vehicle and the driver*. To achieve the tight feeling, the design team conducted a small Kansei Engineering experiment where participants voted for a body length around 4 meters and only two seats. The gear shift lever was identified as the essential tool for the direct feeling, and a gear shift lever of 9 cm in length was selected as the best fit for the intended Kansei. To achieve the speedy feeling, the power train team worked to shorten the time gap between pressing the accelerator and feeling the car accelerating. Other parts evaluated were the design of the engine, exterior and interior details, and the exhaust pipe. Overall, Kansei Engineering Type II using statistical data in combination with experiments was applied to identify and translate the customer's Kansei into concrete design parameters and characteristics for the car.

III. KEY CONSIDERATION OF THE PROPOSED RESEARCH

The focus of this study is on developing a conveyor belt that can efficiently separate plastic bottles of both opaque and transparent surface types. The design team aims to achieve this by applying an easy-to-access concept that will also support maintenance activities. The success of the prototype will be measured through reliability values to ensure that it meets the requirements of the company and the workers who will be handling the bottles for 8-hour tasks. The design must not only meet customer requirements but also consider cost, mixed-use development, and versatile application. To achieve this, the concepts of universal and accessible designs will be applied. The subsequent sections will elaborate on the addressed issues, which directly affect the design pattern, function, and size of the separating system. The ultimate goal is to develop a conveyor belt that not only efficiently separates plastic bottles but also reduces injuries and diseases that may arise from prolonged handling of the bottles.

A. MECHANISM
The product's mechanism should be capable of handling a large volume of plastic bottles efficiently. The system must operate seamlessly and ensure rapid separation of the bottles. Cost-effectiveness is also a key consideration, ensuring that the product is affordable for small and medium-sized enterprises (SMEs) to use in their operations.

B. PHYSICAL CHARACTERISTICS OF THE BOTTLES
The proposed design focuses on two key issues: the transparency and size of the plastic bottles. To effectively sort and separate the bottles, the design will utilize a light sensor to differentiate between opaque and transparent plastic bottles, with the opaque bottles being sorted into a separate location. The size of the bottle will also be taken into consideration, with standard sizes such as 350-ml, 600-ml, 1-liter, and 1.5-liter bottles being accounted for in the design process.

C. MATERIAL OF THE CONVEYOR
It is important that the material used in the conveyor system has sufficient strength to handle the weight of a large volume of bottles and the movement of the mechanism. Selecting the appropriate type of belt conveyor is crucial to ensure safe and productive operation, with easy maintenance and minimal impact on the environment [46], [47], [48], [49], [50], [51], [52], [53]. To ensure that the product is cost-effective and of good quality, it is recommended to estimate the cost of using various materials in the design before starting the manufacturing process.

D. SIZE OF THE CONVEYOR
Conveyor length and width (size) are determined based on product size and weight, and the load capacity of the system must be sufficient to handle the weight of the products without malfunction. Space is important as the system needs to fit comfortably in the designated area and be easily adjustable. The height and size of the conveyor belt should be suitable for worker ergonomics and not exceed the standard height of Asian individuals [54]. The sensor's placement should be strategically positioned to ensure accurate detection of the bottles regardless of their orientation.

E. SCOPES AND LIMITATIONS
During the initial design phase of the study aimed at creating an efficient conveyor and automation system for sorting plastic bottles, the researchers established certain limitations and boundaries. These limitations included the size of the machine and bottles, physical properties of the bottles, conveyor system, controlling platform, sensor capabilities, motor, and conveyor. The primary objective of the study was to develop a system that could help plastic recycling companies and waste separation plants to quickly sort different types of plastic bottles using this technology. The system was designed to include all necessary features and remain cost-effective. The scope and limitations of the key considerations are explained in the following topics.

1) CONTROLLER-PROGRAMMABLE LOGIC CONTROLLER (PLC)
Since the primary aim of this study was to explore the feasibility of integrating different types of conveyors to perform a sorting activity. The researchers chose a PLC-controlling platform as the reference system, which is commonly used by waste sorting plants as their existing conveyor system. To achieve the goal, an additional conveyor system controlled by Arduino was integrated with the existing system. The study sought to identify the factors necessary to successfully complete the task and create guidelines for further research. By investigating the integration of different conveyor types, the study aimed to provide insights into the design and implementation of conveyor systems in waste sorting plants. The application of PLC (Programmable Logic Controller) has become increasingly popular in automation, providing various common support functions, from small to large areas, for detecting, reporting, and recording data. Compared to the Arduino, which requires each function to be written from scratch [55], [56], the PLC offers a more comprehensive solution. However, the bare hardware cost for the controller and I/O is considered, the Arduino is a more cost-effective option than the PLC.

2) CONTROLLER-ARDUINO
The controller in the developed machine will work with devices such as sensors and motors to complete the function of the conveyor system. This study utilized the versatile Arduino platform, which offers a wide range of processors, sizes, and connectivity features. The Arduino software serves as an Integrated Development Environment (IDE) for all boards. The board is equipped with sets of digital and analog input/output (I/O) pins that can interface with various expansion boards, breadboards, and other circuits. The boards also feature serial communication interfaces, including Universal Serial Bus (USB) on some models, for loading programs from personal computers. The microcontrollers are programmed using a dialect of features from the programming languages C and C++ [57], [58], [59], [60]. The Arduino Mega 2560, based on the ATmega2560 microcontroller, is used in this study. It has 54 digital I/O pins (15 of which can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller, and it can

be connected to a computer with a USB cable or powered with an AC-to-DC adapter or battery to get started.

3) ARDUINO FOR THE STUDY

The Arduino board is cost-effective and suitable for a variety of microprocessors and controllers. The Arduino hardware is user-friendly and available at varying prices depending on the model. The Arduino platform is widely used and popular in education, electronics automatic control, and robotics. It can be quickly and easily learned, and users can apply it to various experiments and applications to demonstrate concepts learned in class. The Arduino also provides interesting teaching tools and an easy-to-learn platform for code writing and control concepts. The Arduino is suitable for small businesses where equipment cost is the main concern.

4) SENSOR

The sensor used in this system will detect the type of bottle by utilizing the light intensity properties. Proper adjustment of the distance between the bottle and the sensor is crucial, as the sensor will check the light intensity after exposing it directly to the body of the bottle [61], [62], [63]. In cases where the sensor cannot detect the light intensity, the rejector will not be able to separate opaque plastic bottles from transparent plastic bottles.

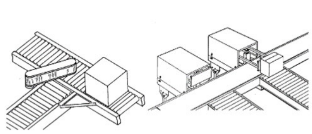
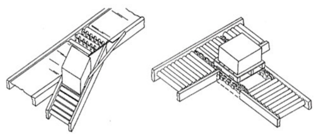
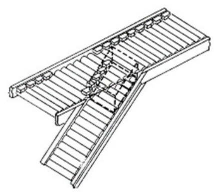
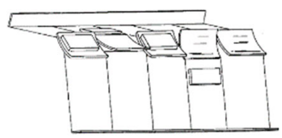
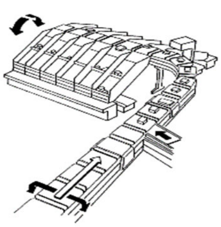
5) MOTOR

The motor's speed, position, and acceleration are interrelated, as the speed is the derivative of position, and acceleration is the derivative of speed. Even if only one of them is known, it is possible to determine all three factors [63]. In a movement system that separates the correct type of bottle, the motor's speed is the main parameter. To minimize errors during task performance, the controller's program input should be correctly and concisely formatted. In this study, a DC motor is used due to its simpler installation and maintenance, high startup power and torque, fast response times to starting, stopping, and acceleration, and availability in several standard voltages. DC motors generally have higher efficiency and make better use of their input energy. Using a microcontroller like Arduino to control the DC motor of the conveyor belt system is a cost-effective solution compared to other methods. However, AC motors are generally more powerful than DC motors because they can generate higher torque by using a more powerful current. Both AC and DC motors are available in various sizes and strengths that can meet any industry's power requirements.

6) CONVEYOR

Conveyors are mechanical devices used for the easy movement of objects, items, or packages. They typically consist of frames that support rollers, wheels, and belts, which can be powered by motors or operated manually [64], [65]. High-friction belts can be applied to prevent product slippage. Belt conveyors are commonly used as material handling systems that use continuous belts to convey objects. Efficient and effective material handling requires the appropriate selection of belt type and shape for belt conveyors. Location and positioning of the conveyor within the production

TABLE 1. Types of sortation conveyor [63].

Type of Conveyor	Properties
	**Diverter:** Presented here are stationary or movable arms that can be used to deflect, push, or pull a product to a desired destination. This method is both simple and cost-effective.
	**Pop-Up Device:** This type of conveyor system features one or more rows of powered rollers or wheels/chains that rise above the surface of the conveyor to lift the product and guide it off at an angle. The wheels are lowered when the products do not need to be diverted.
	**Sliding Shoe Sorter:** The sliding shoe sorter is a sorting system that employs diverter slats which slide across a horizontal surface to engage the product and guide it off the conveyor. This method allows for gentle and gradual handling of products.
	**Tilting Device:** Tilt slat sorters carry products on flat-surface slat conveyor and can handle wider variety of products compared to tilt tray.
	**Cross-Belt Transfer Device:** Each carriage in this system is equipped with a small belt conveyor, known as a cell, which is mounted perpendicular to the direction of travel along the loop. As the carriage moves, the cell automatically separates a single line of products into multiple in-line discharge lines and delivers the product to the desired destination.

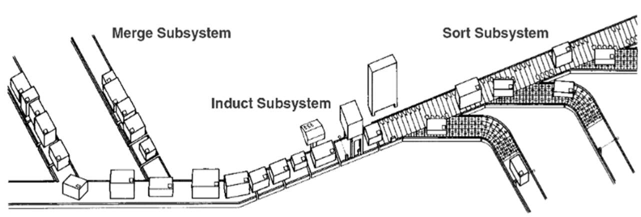


FIGURE 6. Conveyor sortation systems [66].

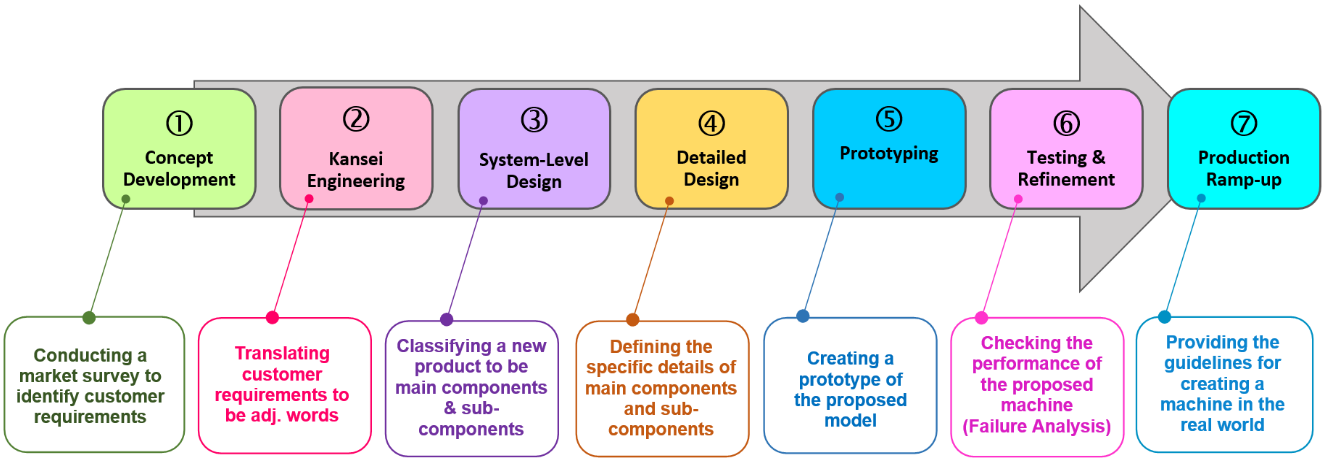


FIGURE 7. Seven steps are required to accomplish the task.

facility must also be considered during the design process. AC or DC motors can be used to power belt conveyors, directly or through reduction gears, chains, or sprockets, and control systems can range from simple on/off switches to advanced variable frequency drives that regulate motor speed and acceleration.

Table 1 and Figure 6 show the types of sortation conveyors used for merging, identifying, inducting, and separating products that are conveyed to specific destinations.

7) CONVEYOR SELECTION

The belt conveyor's crucial specifications [67], [68], [69] pertain to the type and shape of the belt, conveyor size (length and width), load capacity, location, and electrical supply. These requirements must be carefully considered and met to design an alternative belt direction. The selection of a conveyor depends on various factors, such as product type, speed, elevation change, and industry focus. Belt conveyors come in various sizes, ranging from foot-long units used for packaging lines to mile-long systems for mining operations. Typically, AC and DC motors power them, either directly or through reduction gears, chains, or sprockets. Certain conveyors are designed to locate products precisely between manufacturing operations. The controller system for the conveyor can be a simple on/off switch or a variable frequency drive that regulates the motor's speed and acceleration. Several additional control options are available, and long belt conveyors transport has been introduced [70].

Conveyor systems are typically used in large-scale industrial operations, and they can be costly to install and maintain. The cost of equipment and materials required for constructing conveyors can vary widely depending on the type of conveyor, the length and complexity of the system, and other factors such as the materials used in the construction. Maintenance costs for conveyor systems can also be significant, as regular cleaning, lubrication, and replacement of parts are necessary to keep the system running smoothly and prevent breakdowns. However, the benefits of using a conveyor system, such as increased efficiency, reduced labor costs, and improved safety, often outweigh the initial and ongoing expenses. It is important for businesses considering the installation of a conveyor system to carefully evaluate their needs and budget to determine whether the benefits justify the costs. It may also be helpful to consult with experts in the field to ensure that the system is designed and installed properly and that maintenance costs are minimized over the long term.

8) SORTATION CONVEYORS

Sortation conveyors are designed to separate and divert products to different lanes based on size, weight, and other criteria, and are commonly used in shipping, palletizing, and packing stations. The specific design of a sortation system will depend on the needs of the production facility, including the type of products being transported and the desired level of sorting accuracy. To sort and divert products based on size, weight, and other criteria, sortation conveyors are an excellent solution. They are frequently used in shipping and palletizing operations, as well as packing stations [71], [72]. They have been used as the initial platforms for model analysis in subsequent processes. Typically, two types of surfaces are used to make bottles: transparent and opaque.

IV. RESEARCH METHODS

To implement the proposed approach, seven main steps are necessary, which integrate three methods: Product Design and Development (PDD), Kansei Engineering (KE), and Maintenance Engineering (Failure Analysis). These steps are illustrated in Figure 7, and each of them is accompanied by a brief description.

A market survey was conducted to develop a conveyor for separating types of plastic bottles in order to meet customer requirements. Data was collected using a questionnaire, which was distributed through online, offline, and interview

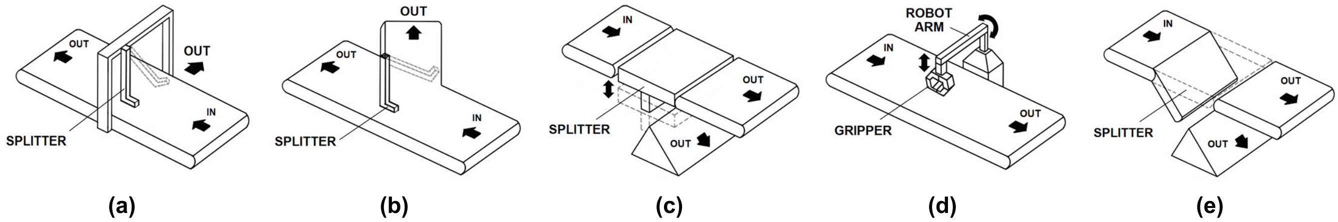
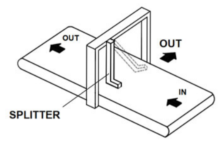
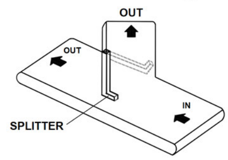
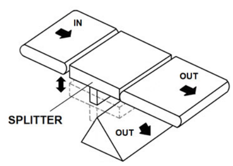
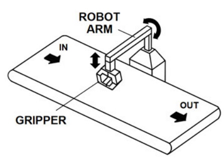
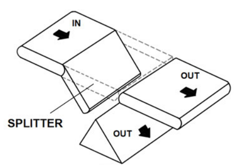


FIGURE 8. **Conceptual model of 5 types of conveyor (a) One-Way splitter (b) Two-Way splitter (c) Falling bridge splitter (d) Robot arm (e) Gravity conveyor.**

TABLE 2. **Descriptions of conceptual models.**

Name	Speed	Separating Method	Design
One-Way splitter	High	The rejector has the ability to swipe either left or right.	
Two-Way splitter	High	The rejector has the ability to swipe either left or right.	
Falling bridge splitter	Low	The rejector has the ability to move in the up and down direction.	
Robot arm	Low	Using the robot arm to pick up the bottle.	
Gravity conveyor	High	The bottle is released downwards using the force of gravity.	

methods. The questionnaire was designed to determine parameters such as the desired material, size, and price of the system that would satisfy customer requirements. A total of 46 participants completed the questionnaire. The results showed that 100% of the participants considered the bottle separation machine to be important for improving their business.

A. STEP 1: CONCEPT DEVELOPMENT

The researchers undertook a comprehensive analysis of the challenges faced by recycling SMEs in separating clear and turbid plastic bottles, with the aim of generating ideas for the proposed separating conveyor system. Currently, these companies spend significant time and resources on this task. To address this issue, the researchers proposed the development of an innovative separating conveyor system that could be marketed to recycling SMEs. To this end, a market survey was conducted to identify customer requirements, and existing products on the market were reviewed. After conducting the necessary research, the researchers were able to create five conceptual designs for the proposed separating conveyor system. These designs include the One-Way splitter, Two-Way splitter, Falling bridge splitter, Robot arm, and Gravity conveyor. Figure 8 illustrates the designs visually, and details on each design are provided in Table 2.

B. STEP 2: KANSEI ENGINEERING

In this stage, the Kansei Engineering method is utilized to meet the customer's needs. Before beginning the KE process, the approach's scope is defined, and adjective words are identified. The KE method is sensitive to the fact that people from different cultures and ages think differently, and the designs created by western or European platforms may not be suitable for Asian characteristics. The KE results will provide a conceptual design that meets customer requirements. After analyzing the questionnaire, the 3F's (Form, Fit, and Function) were used to generate the conceptual design. The conveyor belt kit must be capable of automatically separating transparent and opaque plastic bottles and accommodating bottles of any size. It should also be suitable for placement in a recycling plant. The KE process is employed to create the conceptual design that meets customer requirements by first generating a set of questionnaires and then distributing them to the target customers. The obtained results are valuable for factor analysis in the subsequent process, where the draft design of a new product can be created systematically. The processes required to accomplish the KE task can be expressed as:

1) PLAN AND DESIGN QUESTIONNAIRE

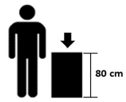
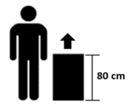
This research targeted small recycling companies and aimed to improve their bottle recycling process. The study utilized a questionnaire completed by 46 participants who were directly involved in the process of recycling bottles. The questionnaire was divided into three main parts: input, processing, and output. The study focused on developing a conveyor to assist the bottle-separation unit and considered three main phases: input, processing, and output. To design the conveyor, the product characteristics of each phase were described using adjective words obtained from the questionnaire responses. These adjective words were used to draft the conveyor design in the subsequent process.

2) IDENTIFY THE ADJECTIVE WORDS

To identify suitable adjectives that align with customer requirements, a brainstorming session and customer interviews were conducted. The list of potential adjectives was then categorized into the three main phases previously mentioned, and can be found in Tables 3 to 5. To facilitate the systematic transfer of details, the researchers attempted to translate these keywords into a technical-design platform. This process allowed for a comprehensive understanding of the desired product characteristics for each phase of the recycling process and informed the subsequent design of the conveyor system. Furthermore, the technical-design platform ensured that the details obtained from the questionnaire and interviews were accurately incorporated into the conveyor's design.

The design stage of the project requires careful consideration of various factors, such as the height of the conveyor for input parts. If the conveyor's height is below 80 cm, it may create challenges for loading or unloading the parts, causing ergonomic issues for workers who have to bend or crouch down to work with the conveyor. To address this issue, the conveyor's height could be adjusted to a suitable level. If the conveyor cannot be adjusted, a platform or step stool could be provided to elevate workers to the appropriate height. Alternatively, the parts could be delivered to the conveyor at a height that is more convenient for workers to load or unload. It is crucial to ensure that the conveyor's height is appropriate for the specific application and the workers who will be using it. Doing so can help improve efficiency and safety in the workplace.

TABLE 3. **Product characteristics and customer's requirements of "The Input Phase".**

Product Characteristic	Description
	**Below waist input** Height of conveyor for input part is lower than 80 cm.
	**Above waist input** Height of conveyor for input part is higher than 80 cm.
	**Heavy weight** The conveyor can support a substantial amount of weight.
	**Light weight** The conveyor can be used for handling light plastic bottles.
	**Narrow** It is necessary to place the plastic bottles in a vertical position only.
	**Wide** The plastic bottles can be placed in any orientation.

3) ADJECTIVE WORDS WITH 7-POINTS SEMANTIC DIFFERENTIAL SCALE

The researchers utilized a questionnaire that combined the 7-point semantic differential scale with adjective words to directly measure customer requirements based on their opinions. An example of the 7-point semantic differential scale for system adjectives is depicted in Figure 9.

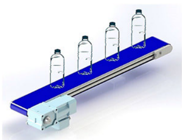
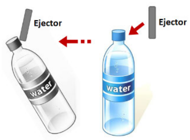
4) ANALYZE ADJECTIVE WORDS WITH 7-POINTS SEMANTIC DIFFERENTIAL SCALE

The responses of the 46 participants were analyzed using the SPSS program. The analysis revealed three main factors that needed to be taken into consideration.

a: KAISER-MEYER-OLKIN MEASURE OF SAMPLING ADEQUACY

To ensure the validity of the data for Factor Analysis, the Kaiser-Meyer-Olkin Measure of Sampling Adequacy was

TABLE 4. Product Characteristics and Customer's Requirements of "The Processing Phase".

Product Characteristic	Description
	**More Function** The separating system needs more functions to separate various types of plastic bottles.
	**Less Function** The separating system can separate only plastic bottles.
	**Vertical** Plastic bottles are separated in vertical direction. (Pushed out by ejector)
	**Horizontal** Plastic bottles are separated in horizontal direction. (Split to either left or right)
	**Modern access** [73] Touch screen system is used for accessing to the user interface.
	**Classic access** [74] Buttons are used for accessing to the user interface.
	**Heavy** [75] The weight of the main frame should be heavy for the stability, rigidity and durability purposes.
	**Light** [76] The weight of the main frame should be light enough to carry without extra equipment required.

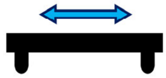
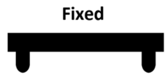
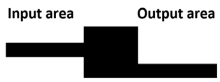
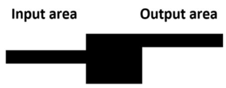
employed. A value of 0.5 or greater indicates that the data is reliable and suitable for Factor Analysis. The results of this test are shown in Figure 10.

b: BARLETT's TEST OF SPHERICITY

Barlett's Test of Sphericity is a statistical test used to determine whether a correlation matrix is significantly different from an identity matrix, indicating that the variables included in the analysis are interrelated and can be used in factor analysis. Barlett's Test of Sphericity result is applied to deal with the hypothesis test. For this test the hypothesis is shown as:

$$H_0 : \text{Correlation Matrix} = 1$$
$$H1 : \text{Correlation Matrix} \neq 1$$

TABLE 5. Product Characteristics and Customer's Requirements of "The Output Phase".

Product Characteristic	Description
	**Adjustable Length** The length of conveyor can be adjusted.
	**Fixed Length** The length of conveyor cannot be adjusted.
	**Lowered output area** The height of output area of the product should be lower than the input area.
	**Elevated output area** The height of output area of the product should be higher than the input area.

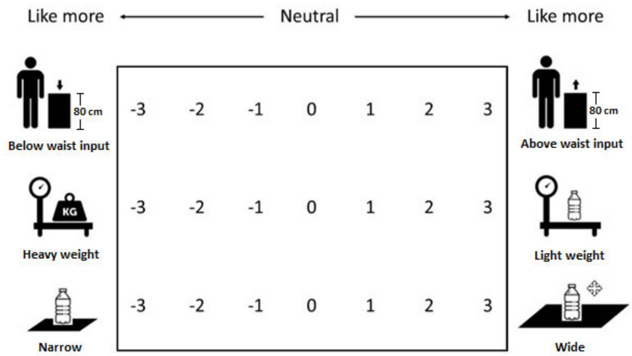


FIGURE 9. The example of 7-points semantic differential scale of system adjective.

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.550
Bartlett's Test of Sphericity	Approx. Chi-Square	154.450
	df.	36
	Sig.	.000

FIGURE 10. Kaiser-Meyer-Olkin Measure of Sampling Adequacy and significant results.

From Barlett's Test of Sphericity result, the significance value is less than 0.05, so H_0 is rejected. This can be concluded that the Correlation Matrix $\neq 1$.

c: ROTATED COMPONENT MATRIX

In this study, the rotated component matrix was used to determine which factor should be grouped together. This

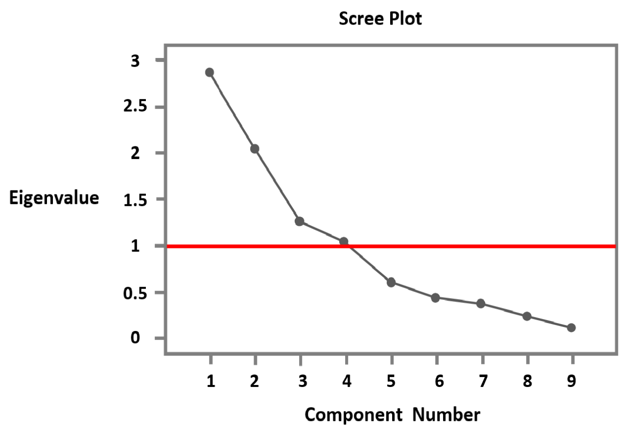


FIGURE 11. Scree plot.

was determined based on the factor loading of each factor, where the factor with the highest loading was placed in its respective group. The scree plot was used to display the Eigenvalue on the y-axis and the component number on the x-axis (Figure 11). It is important to note that when the Eigenvalue is greater than 1, the corresponding component number is considered and recorded.

A scree plot is a graphical representation of eigenvalues (y-axis) against the number of factors (x-axis). It displays a downward curve, and the point where the curve's slope flattens indicates the optimal number of factors to be generated by the analysis. However, both criteria used to determine the number of factors can sometimes result in an unreasonably high number of factors. In this study, the scree plot suggested three or five factors due to the two points where the slope levels off. The aim of factor analysis is to reduce many variables that describe a complex concept into a few interpretable latent factors that explain the maximum amount of variability in the data. In this study, the design of the innovative separating conveyor for different types of plastic bottles was separated into four groups, as shown in Figure 12.

Group 1: Function

- The output part height should be lower than the input part height.
- The height of the input part must be lower than the human waist, which is typically around 80 cm.
- The length of the conveyor must not be adjustable.
- The function of the system is limited to only separating plastic bottle types.

Group 2: Physical Characteristic

- The machine should be lightweight.
- The conveyor's width should be broad.

Group 3: Usability

- The button should be used to control the machine.
- Additionally, the machine should possess a high capacity to handle weight.

Group 4: Separation Method

- The separation method should be horizontal.

5) CUSTOMER SURVEY

To understand the needs and preferences of target customers, a questionnaire was designed that included five different conveyor designs. The respondents were initially uncomfortable with answering technical questions, so the design team provided them with pictures and descriptions of the designs to aid their understanding. The customers expressed concerns about integrating new technology with their traditional way of working and requested an easy-to-use platform that could operate the entire system with the press of a single button, similar to a washing machine. This requirement was identified as a key design consideration and was incorporated into the system-level design stage by breaking it down into main and sub-components.

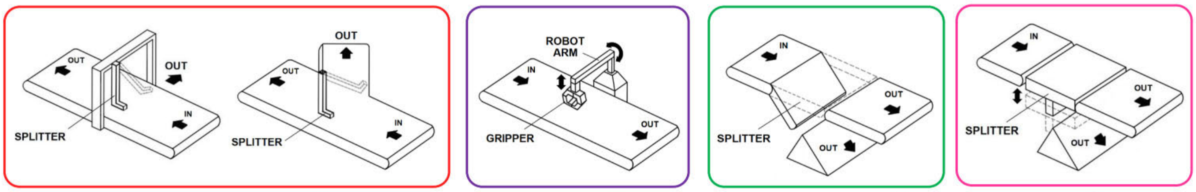
To minimize costs and make the new system more user-friendly, the researchers integrated the new platform with the existing PLC controlling platform that was already in use at the plant. Based on the survey results presented in Table 6, the one-way splitter and two-way splitter designs were the top two choices among respondents. To create the proposed separation system, these two designs were combined using Kansei Engineering to determine specific details.

6) GENERATE CONCEPTUAL DESIGN (3F'S)

The 3F's method, including form, fit, and function, was used to develop the conceptual design based on the results of the customer survey. The proposed design of the conveyor belt system was developed by applying the concepts of the waste conveyor and baggage scanner, as shown in Figure 13.

a: FORM

This refers to the physical appearance of the system. This includes considerations such as the overall shape and size of the system, the color and finish of the materials used, and how the system fits into the environment where it will be installed. When applying the "Form" concept in real-world design, the goal is to create systems that not only function efficiently but also have an attractive appearance that blends well with their surroundings. This is especially important in public spaces like waste management facilities, where the appearance of the equipment can impact people's perception of the facility and its activities. To achieve this, the design team has prioritized choosing a color scheme that aligns with the facility's branding or environment. By carefully selecting colors that complement the surroundings, the equipment can blend seamlessly into its environment, creating a cohesive and harmonious aesthetic. Furthermore, the team has incorporated design elements that enhance the system's visual appeal and user-friendliness, such as illuminated panels or user interfaces for operators. These elements not only add to the system's aesthetic appeal but also improve its functionality and ease of use. By focusing on the "Form" concept, designers can create systems that are both functional and aesthetically pleasing, making a positive impact on the user's experience and perception of the facility.



Kansei words		Component			
Positive	Negative	1	2	3	4
Lowered output	Elevated output	-0.877	0.208		0.316
Below waist	Above waist	0.832		0.205	
Adjustable	Fixed	0.6	0.484	0.312	0.283
More Function	Less Function	0.462	-0.447	0.26	0.435
Heavy MC	Light MC		0.881		
Narrow	Wide	-0.333	-0.761		0.268
Modern access	Classic access			0.94	
Carry heavy weight	Carry only plastic	-0.402	0.39	-0.595	0.35
Vertical	Horizontal				0.868

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.[a]

Function
Physical Characteristic
Usability
Separating Method

FIGURE 12. Rotated component matrix.

b: FIT

In designing a new conveyor belt for a waste separating plant, the "Fit" concept is of utmost importance. The conveyor belt kit must be designed to seamlessly fit into the plant's working area. It is essential that the conveyor belt can be easily adjusted for height and length to accommodate a range of plant sizes. Figure 14 depicts a real working space where the separating conveyor system is installed, emphasizing the importance of proper fitting. By prioritizing the "Fit" concept, the design team can ensure that the conveyor belt fits perfectly into the plant's working area, enabling efficient waste separation and maximizing the plant's overall performance. A well-fitted conveyor belt system reduces the risk of jams or malfunctions, enhancing the system's overall reliability and reducing downtime. In conclusion, the "Fit" concept plays a crucial role in designing a conveyor belt system for a waste separating plant. By ensuring proper fitting and adjustability, the design team can optimize the system's performance and reliability, ultimately leading to a more efficient and effective waste separation process.

c: FUNCTION

The machine's effectiveness relies on its ability to accurately and efficiently separate different types of plastic bottles based on their varying light intensities. This is based on the principle that as light passes through a material, such as a plastic bottle, its intensity decreases. To test and experiment with light intensity, a controlled environment box was designed. Three light sensors (LDR) were connected to a microcontroller to collect light intensity data in three different situations: clear plastic bottles, turbid plastic bottles, and opaque plastic bottles (as shown in Figure 15). Two types of control modules were utilized: a programmable logic controller (PLC) for the "opaque lane" and a microcontroller for the "transparent lane." The advantages of these two control modules were

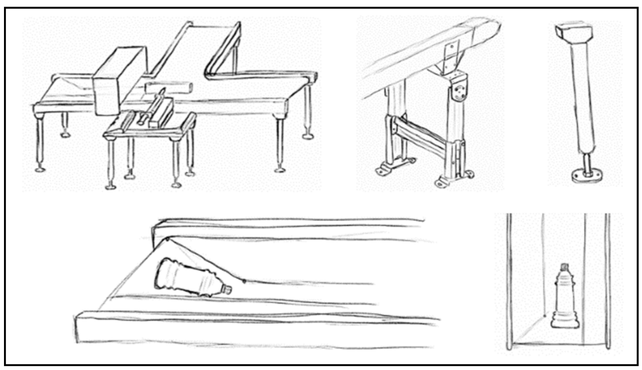


FIGURE 13. The drafted design of the proposed system.

TABLE 6. The result from questionnaire.

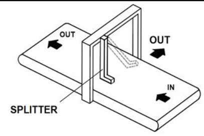
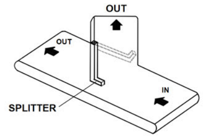
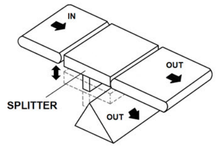
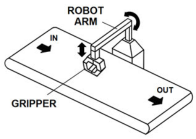
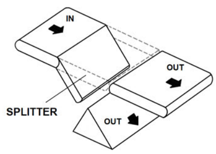
Name	Design	Percentage (%)
One-Way splitter		53
Two-Way splitter		37
Falling bridge splitter		7
Gravity conveyor		3
Robot arm		0

FIGURE 14. Examples of the areas for setting-up conveyor: multi-bended style (left), and straight pattern (right) [77], [78].

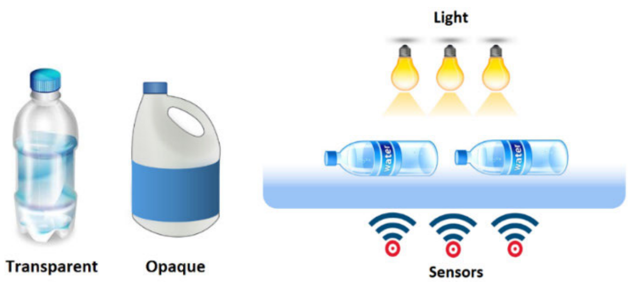


FIGURE 15. Function" of the developed system with 3 types of bottles.

documented and analyzed to provide guidance for waste separating plant manufacturers to identify and address issues without resorting to trial-and-error processes. The prototype created can assist in reducing potential failures during the separating process in a real situation. Figure 16 displays an example of a commercial conveyor belt kit with counter sensors controlled by a PLC.

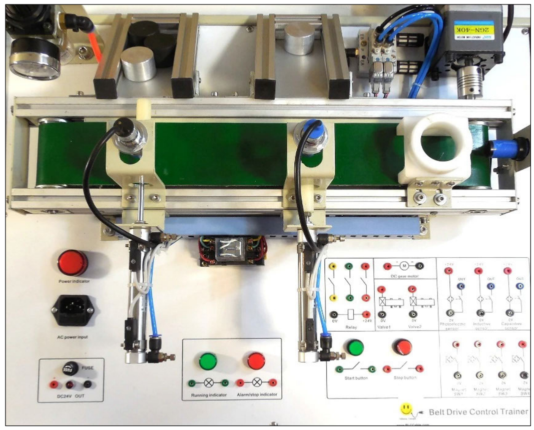


FIGURE 16. Conveyor belt connected to PLC [79].

C. STEP 3: SYSTEM-LEVEL DESIGN

The conveyor belt kit comprises three main modules or components: the delivering module, controlling module, and detecting module. These modules and their respective components are illustrated in Figure 17.

The proposed design aims to develop a waste separating conveyor for plastic bottles. As such, preliminary studies were conducted to explore ways to separate different types of bottles. The main modules of the conveyor will be discussed, including the use of light sensors to identify transparent and opaque bottles. The input task involves placing empty bottles onto the conveyor platform in a single-line sequence. However, this platform cannot support a large volume of bottles being thrown onto the collection area simultaneously. To address this issue, "*an extra shaking bed*" may be required at the initial stage of "*the delivering module*" to organize a large quantity of bottles into a specific order, ensuring they are arranged in sequence before being sorted by the light sensors.

The proposed conveyor belt kit consists of three main modules:

- The *delivering module* is responsible for the delivery of plastic bottles (see Table 7).
- The *detecting module* is responsible for detecting and separating the types of plastic bottles (see Table 8).
- The *controlling module* is responsible for controlling the conveyor belt kit's system components, such as motors, rejectors, and sensors (see Table 9).

Efficient and accurate separation of plastic bottles according to their type is achieved through the seamless integration of the three modules. The modules work together to ensure the optimal performance of the separation process, resulting in high-quality plastic that can be recycled efficiently.

The *delivering module* is responsible for organizing and delivering the bottles onto the conveyor platform, while the controlling module is responsible for separating the bottles based on their type using light sensors and controlling the

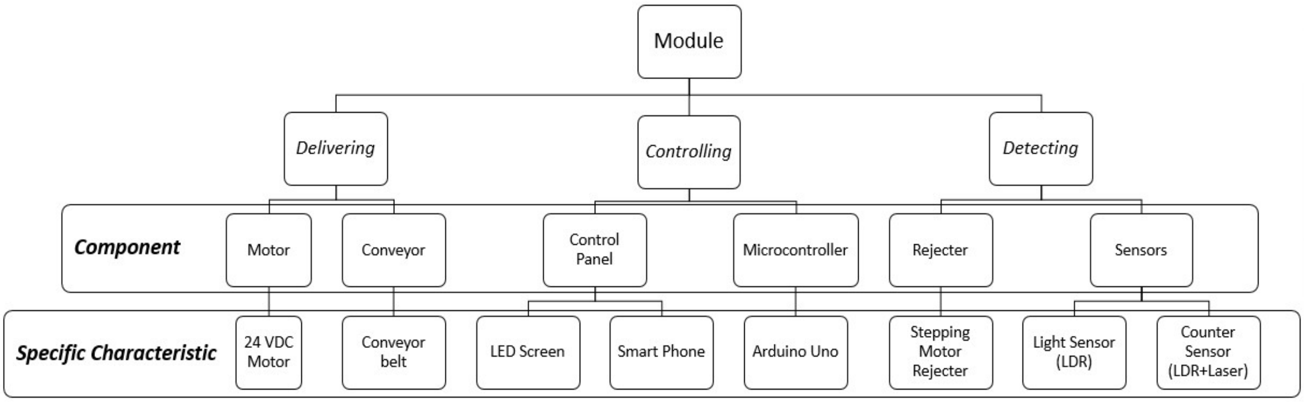


FIGURE 17. The module and its components.

TABLE 7. Delivering module, its component and definitions.

Component	Description
	*Motor* [80] is used to drive the belt conveyor. The 24 VDC is selected because it has more power than 12 VDC. The more power motor, the more weight can be drive. **(1,700 THB or 49.90 USD)**
	*Conveyor belt* [81] is a modern part of transportation of handling equipment. It helps transport materials from one place to the next, drastically cutting out manual labor and saving time. **(8,000 THB or 232 USD)**

speed of the conveyor belt. The detecting module is responsible for detecting and counting the separated bottles.

The *detecting module* was designed to detect the separated bottles and count them. The light sensors in the detecting module are responsible for measuring the light intensity passing through the plastic bottle. The microcontroller processes the data from the light sensors and determines the type of plastic bottle. The signals from the microcontroller are sent to the PLC in the controlling module to adjust the operation of the separating platform. Counter sensors were used to count the number of bottles passing through each lane. The counting information was sent to the controlling module for further analysis and processing.

The *controlling module* was designed to control the speed of the conveyor belt based on the output signals from the light sensors. The programmable logic controller (PLC) was used to control the opaque lane, which is the lane where opaque bottles are separated. The PLC receives input signals from the light sensors and determines the type of bottle passing through the lane. The microcontroller was used to control the transparent lane, which is the lane where transparent bottles are separated. The microcontroller receives input signals from the light sensors and controls the speed of the conveyor belt based on the type of bottle passing through the lane.

TABLE 8. Controlling module, its component and definitions.

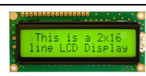
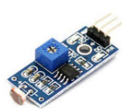
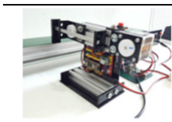
Component	Description
	The primary controller responsible for controlling the conveyor belt kit system is the *microcontroller* [60]. The Arduino microcontroller was chosen as the preferred controller due to its widespread popularity among beginners and its user-friendly nature, making it easy to understand and work with. **(1,875 THB or 54.40 USD)**
 	*Control panel* is a graphical user interface (GUI) that allows users to view and modify system settings and configurations. It is typically used to manage and control a software application, operating system, or hardware device. Users can interact with the control panel through menus, icons, buttons, and other user interface elements to make changes to the system. **(299 THB or 8.67 USD)**

TABLE 9. Detecting module, its component and definitions.

Component	Description
	*Light Dependent Resistor (LDR)* [82] is utilized to detect the level of light passing through the plastic bottle. This allows differentiation between clear and opaque plastic bottles based on the difference in light intensity passing through each type. **(310 THB or 9 USD)**
	*Proximity sensor* [83] acts as a presence detector and can be used in a variety of applications, including in manufacturing lines to count products or in security systems to detect the presence of intruders. **(350 THB or 10 USD)**
	*Rejector* [84] is utilized to segregate clear and turbid plastic by pushing the turbid plastic off the conveyor, while the clear plastic continues along the production line. **(2,250 THB or 65.25 USD)**

The cost of all the necessary components for all modules amounts to roughly 14,784 THB or 428.74 USD.

D. STEP 4: DETAILED DESIGN

Motor plays a crucial role in the operation of the conveyor system, providing the necessary power to move the belt and transport products along the production line. A motor is an electrical device that converts electrical energy into mechanical energy. In this case, a motor is being used to drive the belt conveyor. A 24 VDC (Volts Direct Current) motor has been selected over a 12 VDC motor, as it is capable of providing more power to drive the conveyor. By selecting a more powerful motor, the system is able to drive heavier loads on the conveyor. This is because a higher power motor is able to provide more torque, or rotational force, to the conveyor belt, allowing it to move heavier objects along the production line. The selection of a motor with a specific voltage rating is dependent on the power requirements of the system and the load that needs to be moved. In this case, a 24 VDC motor was chosen as it was deemed to have sufficient power to drive the conveyor with heavier loads.

Conveyor belt is a modern piece of transportation and handling equipment that is widely used in various industries. It consists of a continuous loop of material, typically made of rubber or plastic, that moves along a series of rollers or pulleys. The conveyor belt is being used to transport materials from one place to another, helping to automate the process and save time. The use of conveyor belts in manufacturing and distribution facilities has become increasingly common as it allows for the efficient movement of materials and products without the need for manual labor. This can result in increased productivity and lower costs for businesses. Conveyor belts come in a variety of shapes and sizes and can be customized to suit the specific needs of the industry. They are used to transport a wide range of materials including food products, construction materials, and industrial parts. Conveyor belts are a vital part of modern transportation and handling equipment, providing a safe and efficient means of transporting materials and products across various industries.

Proximity sensors are commonly used in automation and manufacturing processes to detect the presence or absence of objects in their proximity. There are different types of proximity sensors, but one common type is the photoelectric sensor, which uses a light source and a receiver to detect the presence of an object. A photoelectric sensor is being used as a counter sensor. The sensor consists of a laser and a light dependent resistor (LDR) which receives the light from the laser. In its normal stage, the LDR receives the light from the laser, and the sensor output indicates that there is no object present. However, when an object passes by and blocks the light from the laser, the LDR receives less light, causing a change in its resistance, and the sensor output detects that there is an object present. This change in the sensor output can be used to trigger a counter or other automated process.

A light dependent resistor (LDR), also known as a photoresistor, is a type of sensor that changes its resistance based on the amount of light it receives. It is commonly used in a variety of applications where the detection of light levels is required. An LDR is being used to detect the level of light passing through a plastic bottle. This allows differentiation between clear and opaque plastic bottles based on the difference in light intensity passing through each type. Clear plastic bottles allow more light to pass through them, while opaque bottles block more light. By measuring the amount of light that passes through the bottle using the LDR, the system can differentiate between the two types of bottles. This type of sensor is commonly used in manufacturing and packaging processes, where it is necessary to sort objects based on their properties. The LDR can be used in conjunction with other sensors and automated systems to sort objects based on their transparency or other physical characteristics, helping to improve efficiency and accuracy in these processes.

A rejector is a mechanical device used in manufacturing and packaging processes to separate or remove defective or unwanted products from a conveyor or production line. A rejector is being used to push clear or turbid plastic from the conveyor to separate these two types of plastic. The rejecter is typically equipped with an actuator that generates a mechanical force to push the defective or unwanted products off the conveyor or production line. In this case, the rejecter is being used to separate clear and turbid plastic by pushing the turbid plastic off the conveyor while allowing the clear plastic to continue along the production line. The decision to reject or separate the turbid plastic is likely made by a sensor or detector, such as the light dependent resistor (LDR) mentioned earlier, that detects the level of light passing through the plastic bottle. If the plastic is determined to be turbid and therefore unsuitable for the intended use, the rejecter is activated to push it off the conveyor and out of the production line. The rejector is an important tool in manufacturing and packaging processes as it helps to ensure the quality and consistency of the final product by removing defective or unwanted items from the production line.

E. STEP 5: PROTOTYPING

1) FUNCTIONAL DESIGN

The functional design was developed based on the main requirements and preliminary study, which included the use of a conveyor belt connected to a programmable logic controller (PLC) and counter sensors to monitor the motor's operation, the components of the conveyor belt kit, PLC programming, and electronic connections. The proposed model is designed to separate different types of plastic bottles based on their varying levels of light intensity, as explained earlier. Figure 18 provides an overview of the functions of the proposed model, which includes the following:

Bottle detection: The system detects the presence of a bottle on the conveyor belt.

Light intensity measurement: The system measures the light intensity passing through the bottle.

Bottle separation: The system separates the bottles into different lanes based on their light intensity levels.

Rejector: The system identifies and rejects any non-targeted materials or bottles that do not meet the specified light intensity level.

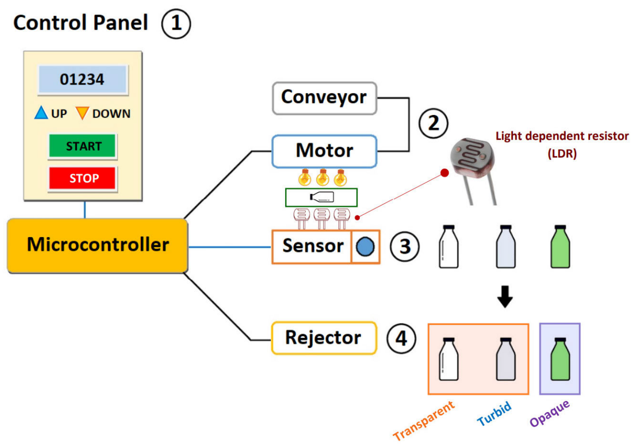


FIGURE 18. Functional design diagram.

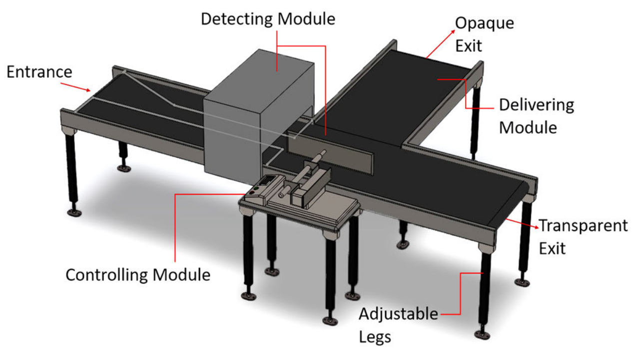


FIGURE 19. The drafted design of conveyor system.

Data collection: The system collects and stores data related to the bottle separation process for future analysis and optimization.

The functional design of the proposed model incorporates the knowledge gained from the main requirements and preliminary study, with the aim of developing an efficient and accurate bottle separation system.

The functional design consists of four steps: *first*, the user activates the conveyor belt kit's control panel; *second*, the microcontroller sends a signal to the motor, which moves the bottle to the sensors' area; *third*, the sensors detect the light intensity passing through the plastic bottle to determine its type and send the data to the microcontroller; *fourth*, the microcontroller sends a signal to the rejector to accept or reject the plastic bottle.

2) DRAFTED DESIGN

In addition to the three main modules, the design draft also includes adjustable legs that can be used to customize the height of the system to suit different users (as shown in Figures 19 and 20). The design team made accessibility a priority during the design process, ensuring that the system is easy to use and maintain. This includes features such as easy access to internal components for maintenance,

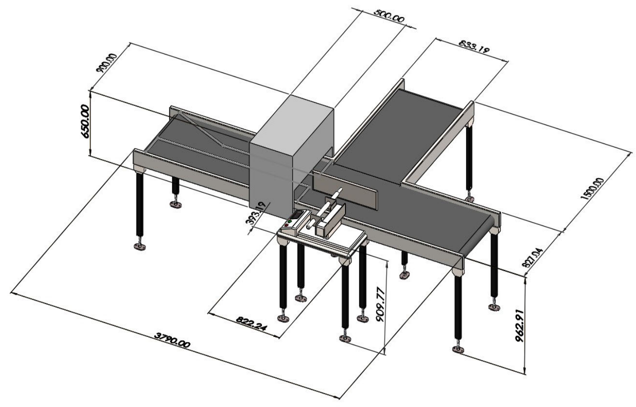


FIGURE 20. Dimensions of the drafted conveyor system.

FIGURE 21. The prototype of the separating system proposed in this research.

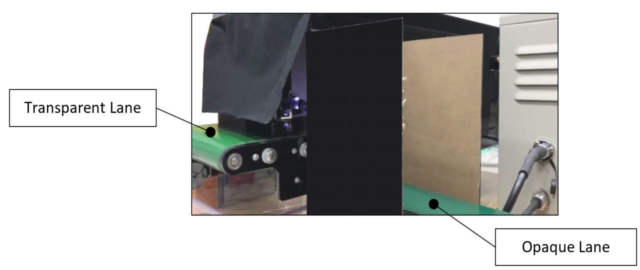


FIGURE 22. Two lanes of the separating system.

as well as clear labeling and instructions to make it simple for users to operate the system. The design draft prioritizes user-friendliness and ease of maintenance, which should help to improve the system's overall efficiency and effectiveness in separating waste.

3) FINAL PROTOTYPE

The physical prototype (Figure 21 to 23) developed in this research differs slightly from the drafted design, as its

FIGURE 23. The opaque lane controlled by PLC.

FIGURE 24. Separating different types of bottles: (a) Truly transparent, (b) Partly transparent, and (c) Opaque.

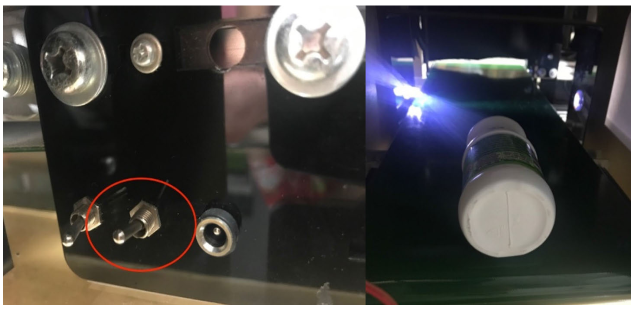


FIGURE 25. Loading the bottle to the conveyor and starting the separating process.

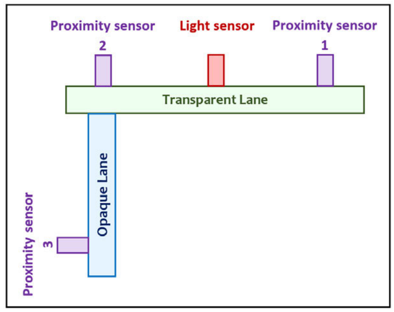


FIGURE 26. Position of proximity sensors and light sensor.

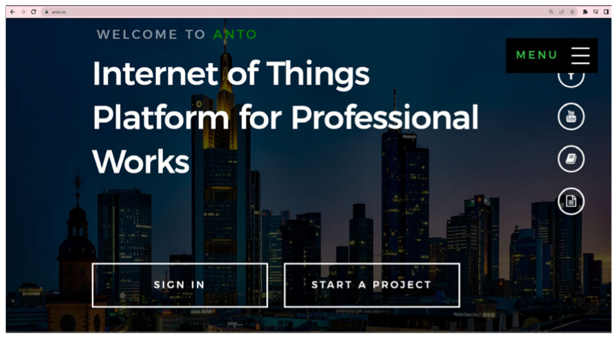


FIGURE 27. Online mode with open access (online) platform.

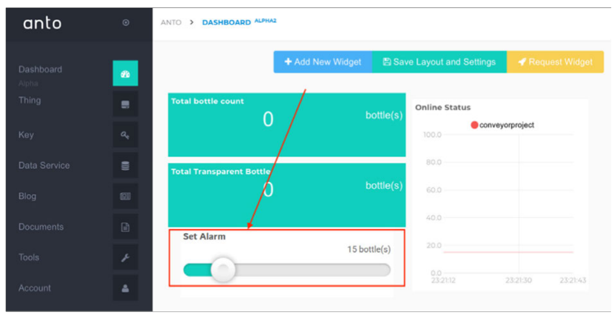


FIGURE 28. Adjust the alarm (based on the number of bottles) to activate the notification light.

purpose was to demonstrate the functionality of the separating system and not to create a full-scale version. As a result, some parts or components, such as the conveyor belts, lighting hall, and collecting tray, were modified to fit the smaller scale of the platform.

F. STEP 6: TESTING AND REFINEMENT

1) WORKING SYSTEM

The machine operates in two main processes: the separating process and the counting process. To initiate the system, a bottle is placed onto the conveyor belt, and the start switch is pressed, as demonstrated in Figure 24. During the counting process, three proximity sensors are used to detect bottles. Proximity sensors No. 1 and No. 2 are installed on the transparent lane, while proximity sensor No. 3 is installed on the opaque lane, as shown in Figure 25.

Figure 26 illustrates the layout plan for the working space. The transparent lane and the opaque lane are clearly demarcated, and the proximity sensors are strategically positioned to ensure accurate detection of the bottles. By using proximity sensors, the system can accurately count the number of bottles passing through, enabling efficient separation of plastic bottles according to their type.

For the *key consideration*: the working system is designed to be reliable, efficient, and easy to use.

Additionally, in order to count the bottles in the transparent lane, two modes were implemented: *online* and *offline* modes, which work simultaneously.

The *online mode* utilizes a free online tool called www.anto.io. This tool allows the user to command and assign specific parameters, such as the number of bottles to be counted or an alarm to trigger a notification light. To access this tool, the user must enter a username and password and select the dashboard to assign the desired task, as shown in Figure 27. The controlling platform is created (Figure 28).

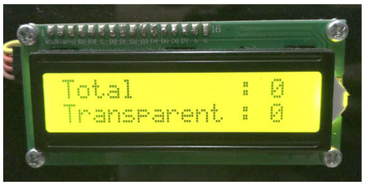


FIGURE 29. Screen of developed system.

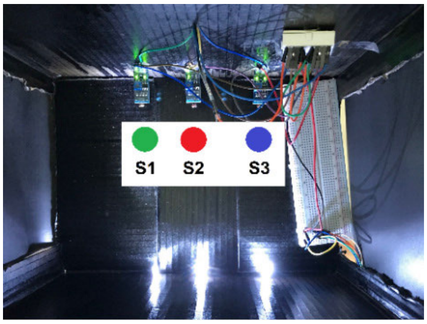


FIGURE 30. Three light intensity sensors for separating bottles.

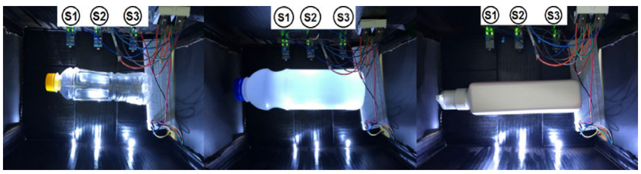


FIGURE 31. Three experiment settings for separating transparent (left), turbid (middle), and opaque (right) bottles.

On the other hand, in the offline mode, the counting number is continuously displayed on the screen (Figure 29) while the machine is running. Two versions of the conveyor belt for separating types of plastic bottles were developed due to the bottleneck of the Arduino UNO's capabilities. The second version, which uses the Arduino MEGA, is equipped with two delivering data boards (RS485) for more stable data delivery to the ESP32 board, which is used to send the data to the server for real-time online counting.

2) LIGHT INTENSITY TEST

To separate bottles based on their type, three light intensity sensors were employed to measure the amount of light passing through three different types of bottles: transparent, turbid, and opaque. These sensors were strategically placed such that sensor S1 was positioned at the leftmost part of the bottle, sensor S2 was situated in the middle, and sensor S3 was placed at the rightmost part. The positions of these sensors are depicted in Figure 30, while the experiment settings for the three types of bottles are illustrated in Figure 31.

The readings from the 3 sensors were reported as three distinct lines, and the different types of plastic bottles exhibited varying sensor readings. Therefore, based on the findings of the study, it was concluded that the sensors used were effective in differentiating between the various types

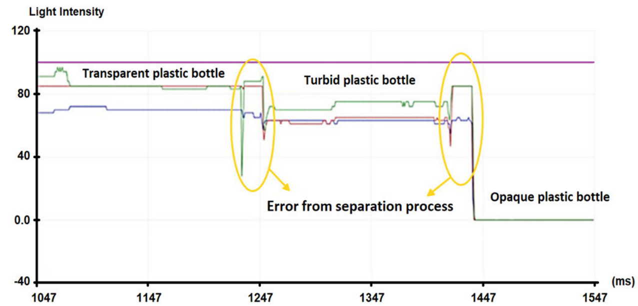


FIGURE 32. Graph of light intensity versus time (millisecond).

of plastic bottles with a high degree of accuracy. Figure 32 presents a graph that clearly illustrates the difference in light intensity readings between the three types of plastic bottles. The controlling platform displayed the graph, which was plotted based on the recorded data.

A turbid bottle is one through which light can pass from the top to the bottom, but not uniformly. The surface of the bottle is not completely transparent, which results in some areas being less transparent than others. In contrast, a *dirty bottle* may have areas where light can pass through uneventfully, but there may be other areas where the surface is partially or completely obscured by dirt, dust, or other materials.

An opaque bottle is one that does not allow any light to pass through its surface. Unlike turbid and dirty bottles, which allow some light to pass through, an opaque bottle completely blocks the transmission or reflection of light.

3) FAILURE RATE

To ensure that a developed system is operational and ready for use, a crucial aspect to consider is failure analysis. Failure is defined as the inability to meet an expectation or a lack of success. Failure analysis is performed for various reasons and factors, such as determining the failure rate, which can help calculate the system's reliability using an exponentially decaying probability function. Additionally, system availability can be affected by planned and unplanned downtimes, such as equipment failure, which results in a loss of availability.

These factors can all contribute to the overall issue of bottle sorting errors. To address these issues, it may be necessary to conduct a thorough analysis of the system to identify the root cause of the problem. This may involve examining the components and systems involved in the sorting process, including the rejector, LDR sensor, LED light bulb, motors, conveyor belts, power supplies, and controlling system. Once the root cause of the problem has been identified, appropriate measures can be taken to fix the issue and improve the overall efficiency and accuracy of the sorting process. This may involve repairing or replacing faulty components, adjusting settings or configurations in the controlling system, or redesigning certain aspects of the conveyor system to improve performance.

TABLE 10. Steps and equations required for calculating "Failure Analysis" [85], [86], [87], [88].

Steps for calculation	Equation	No.
Step 1: Calculate Mean time between failure (MTBF)	$BF = \frac{Total\ uptime}{no.of\ breakdown}$ or $MTBF = MTTF + MTTR$	(2)
Step 2: Calculate Mean time to repair (MTTR)	$MTTR = \frac{Total\ downtime}{no.of\ breakdown}$	(3)
Step 3: Calculate Mean time to failure (MTTF)	$MTTF = MTBF - MTTR$	(4)
Step 4: Calculate failure rate (λ)	$\lambda = \frac{1}{MTTF}$	(5)
Step 5: Calculate Probability of fail	$P_{of\ fail} = 1\text{-}R$	(6)
Step 6: Calculate Reliability (Probability of good): t is total mission hour for performing task (hr)	$R = e^{-\lambda t}$	(7)
Step 7: Apply "OR" gate calculation	" OR gate" $R_{system} = (1\text{-}P_{a\ failed})(1\text{-}P_{b\ failed})$	(8)
Step 8: Calculate for Availability	$Availability = \frac{MTBF}{MTBF + MTTF}$	(9)

Mean-time-to-repair (MTTR) is a useful maintenance metric that can measure the average time required to troubleshoot and repair failed equipment, indicating how quickly an organization can respond to breakdowns and fix them.

Another important factor that affects system availability is maintainability, which refers to the speed at which technicians can detect, locate, and restore asset functionality after downtime. When building a system, considering availability during all design and construction phases can help the design team plan for component failures and how to bring failed items back to normal. It is crucial to note that unrecoverable (hard) failures are critical compared to recoverable (soft) failures.

The reliability and failure rate of each component in a machine can be determined by considering various factors such as Mean Time to Repair (MTTR), Mean Time to Failure (MTTF), and Mean Time Between Failures (MTBF). Mathematical models and parameter considerations are typically used to analyze significant failure events and to show how the components are interconnected using "AND" or "OR" gates. Once the errors have been identified, efforts can be made to enhance the machine's performance to meet the desired standards.

4) FAULT TREE ANALYSIS (FTA)

In order to analyze the reliability and safety of engineering systems, Fault Tree Analysis (FTA) is utilized (as depicted in Figure 33). The diagram presents a fault tree with a specified fault event, which is used to determine the machine's reliability. The diagram clearly displays the reliability of the machine by depicting the end events. The fault tree diagram is generated through experimentation.

The Fault Tree Analysis (FTA) simplifies complex system failures into a single failure event. The reliability of the machine is determined by combining the failures of multiple components, connected through "AND/OR" gates. These gates help identify how the failure of a single or multiple components can cause the top event to fail, and have their own formula for calculating the machine's reliability.

The failure event that occurred during the experiment can be separated into four main factors; *inadequate separation opaque and transparent bottle*, *poor conveyor design*, *inaccurate data obtained from controlling system*, and *inadequate counting bottle*. From the fault tree diagram, the reliability and failure rate for each component of the machine can be determined by calculating from Mean time between failure (MTBF), Mean time to repair (MTTR) and Mean time to failure (MTTF) (Table 10 to 12). After the failure rate and reliability are calculated, the "AND/OR" gate is used to link every end event together to calculate the main failure event. The gate calculation is very important because the calculation between AND gate and OR gate is differing and each event also have differed gate too.

Causes that make the conveyer belt kit fail can be classified into 4 cases. The cases were come from;

Case 1 - Sub-system ①: The inadequate separation of opaque and transparent bottles can be attributed to rejector, LDR sensor, or LED.

Case 2 - Sub-system ②: A poor conveyor design may result from issues with the motor and conveyor belt in both Lane 1 (Set 1) and Lane 2 (Set 2).

TABLE 11. Failure rate and reliability.

Sub-system	Event	Equipment	MTTF (Hour)	MTTR (Hour)	MTBF (Hour)	Failure Rate (Failure/Hour)	Reliability
①	Inadequate separation opaque & transparent bottle	Rejector	286	14	300	0.0035	0.9522
		LDR Sensor	290	10	300	0.0034	0.9661
		LED	288	12	300	0.0035	0.9592
②	Poor conveyor design	Set 1: Motor + Conveyor Belt	279	21	300	0.0036	0.9275
		Set 2: Motor + Conveyor Belt	280	20	300	0.0036	0.9203
③	Inadequate counting bottle	Signal of Proximity Sensor1	277.5	22.5	300	0.0036	0.9221
		Signal of Proximity Sensor2	282	18	300	0.0035	0.9382
		Signal of Proximity Sensor3	268.5	31.5	300	0.0037	0.8893
		ESP32	270	30	300	0.0037	0.8948
④	Inaccurate data obtained from controlling system	Power Supply1	265	35	300	0.0038	0.8763
		Power Supply2	279	21	300	0.0036	0.9275
		Arduino	292	8	300	0.0034	0.9730
		PLC	290	10	300	0.0034	0.9661

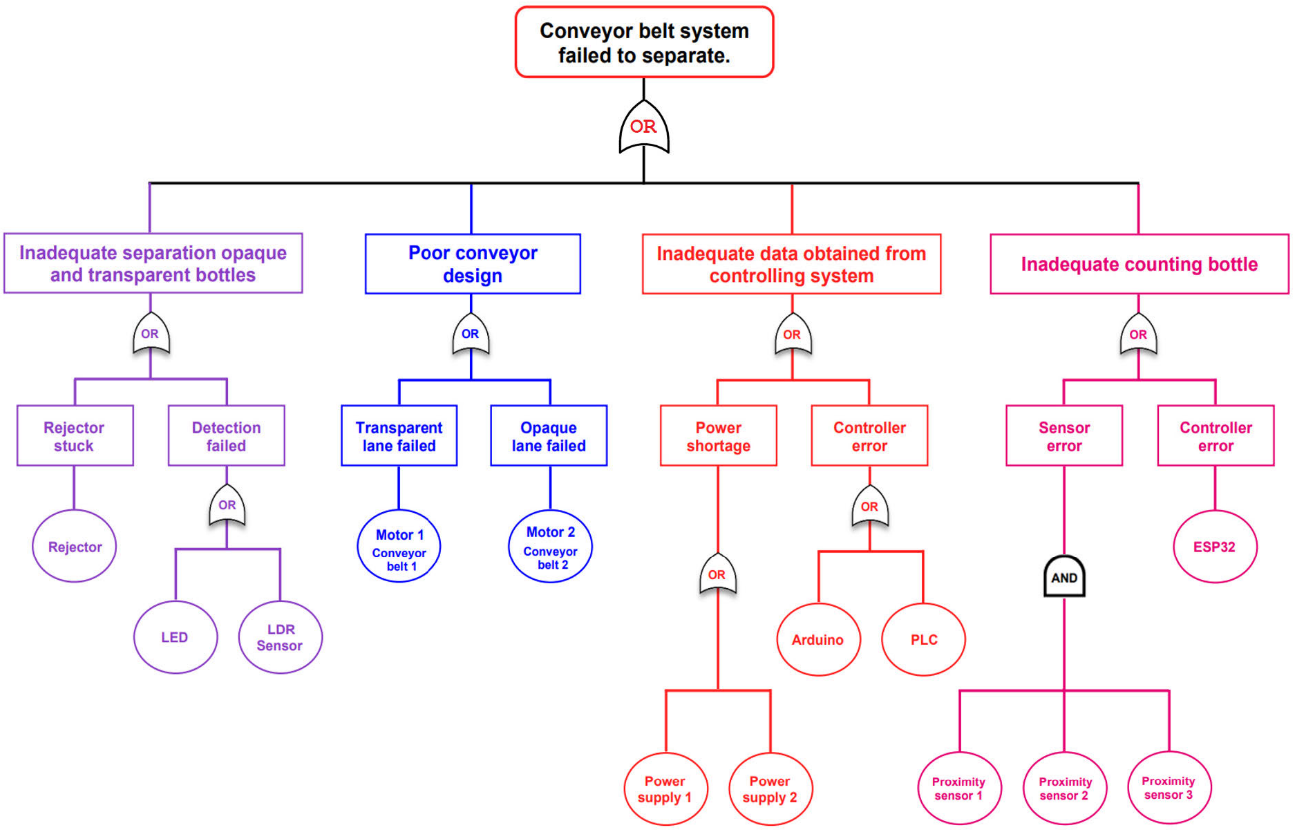


FIGURE 33. Fault Tree Analysis (FTA) diagram with specified fault event.

Case 3 - Sub-system ③: Inaccurate data obtained from the controlling system can be traced back to power supply 1, power supply 2, Arduino, or PLC.

Case 4 - Sub-system ④: Insufficient counting of bottles may be caused by problems with either all three proximity sensors failing or with the ESP32 board.

5) FAILURE ANALYSIS

The "Failure Analysis" task involved a 300-hour mission, during which 600 tests were conducted. Each test took approximately 30 minutes to complete. The tests were conducted at a rate of 30 per week or 120 per month, and the entire mission was completed in five months. The exhaustive

TABLE 12. Failure rate and combined reliability of 4 main types of failure rate.

Sub-system	Event	Reliability of Sub-system
①	Inadequate separation opaque and transparent bottle	0.8824
②	Poor conveyor design	0.8536
③	Inadequate counting bottle	0.8943
④	Inaccurate data obtained from controlling system	0.7640

testing regimen allowed for a thorough analysis of the system's performance and helped identify potential failures or weaknesses. By conducting a comprehensive failure analysis, the design team was able to make the necessary improvements to ensure the system's reliability and robustness. The investment of time and resources into the failure analysis task paid off in the long run, as the resulting improvements helped create a more reliable and effective system.

Moreover, MTBF (in this study) means the total time spent for uptime (MTTF) and downtime (MTTR). It refers to the overall duration during which a system or equipment was operational (uptime) or not operational (downtime – process stops for maintenance purposes; repairing or inspecting). This includes all instances of planned or unplanned maintenance, repairs, and other activities that may affect the system's availability. The total time spent for uptime and downtime is an important metric for evaluating the performance and reliability of a system, as it reflects the system's overall efficiency and availability. Since the reliability and failure rate of the conveyor system were tested by running the system continuously for a fixed duration of 300 hours, during which the tester observed its performance. The fault tree diagram considered four factors, namely *inadequate separation of opaque and transparent bottles*, *poor conveyor design*, *inaccurate data obtained from the controlling system*, and *inadequate counting of bottles*. The failure rate of each equipment (end event of the diagram) was obtained, and the reliability of each component was calculated.

The researchers attempted to forecast the worst-case scenario of failed items that could potentially cause direct effects on the main system (sorting conveyor). As a result, all items are considered sensitive cases where an "OR gate" is applied for all sub-branches of the tree. If any of the items fail within a sub-system, the sub-system will fail. Similarly, if any of the sub-systems fail, the main system (sorting conveyor) will also fail. While the reliability analysis of each situation with the current configuration is over 75%, the system reliability produced only 51.46% when the sensitive reliability calculation was applied using the "OR gate".

Applying the parallel structure in reliability engineering (i.e., standby items or functions should be available), the system reliability can be increased as more than one set of function can support the system to perform tasks, as shown in standby mode with supportive similar equipment. The in-house prototyping system was constructed as a demonstration of the proposed approach to provide guidelines for target customers to easily understand how to improve their business by identifying the items' conditions that need improvement.

The design team dedicated significant effort towards developing a conveyor system with a user-friendly platform and high standards, while selecting reasonably priced components that cost less than 1,500 USD based on feedback from target customers.

G. STEP 7: PRODUCTION RAMP-UP

While conveyor systems are well-suited for industrial-scale plants, the costs associated with them can be significant. The initial investment required for equipment and materials needed to construct conveyors can be high, as can ongoing maintenance costs. These expenses can vary depending on factors such as the type and complexity of the system, as well as the materials used in its construction. Despite the costs, however, conveyor systems can offer significant benefits to businesses, including increased efficiency, reduced labor costs, and improved safety.

Careful evaluation of business needs and budget considerations can help determine whether the advantages of a conveyor system outweigh the expenses. It is also important to work with experts in the field to ensure that the system is designed and installed properly, which can help minimize maintenance costs over time. To launch this innovation to small and medium-sized enterprises (SMEs), two alternative ideas are presented and discussed.

Idea - Case 1: Purchasing the complete system, including a standard conveyor (2 lanes of 1-meter length and 160-mm width), would cost approximately 900 USD. Alternatively, SMEs can minimize costs by acquiring a second-hand conveyor with medium-to-high quality.

Idea - Case 2: SMEs who already have an existing conveyor can purchase only the key algorithm and control unit for approximately 200 USD. The purchased key algorithm and control platform, including the program and sensing devices, would be installed, mounted, and positioned appropriately on the existing conveyor system, similar to building a customized solution based on individual specifications.

Besides, Table 13 and 14 present the advantages of utilizing a microcontroller. The Arduino code is readily available on the internet as an open-source platform, allowing beginners

TABLE 13. The strong points of a microcontroller.

Characteristics \ Type of Controller	Microcontroller	PLC
1. Software	Open-source	Close-source
2. Size	Smaller	Bigger
3. Maintenance	Easier	Harder
4. Programming	Easier	Harder
5. Language	C++	Ladder logic
6. Price (USD)	29.25 – 58.50	>292.50
7. Application	Varied	Unvaried

**36.004 Baht/US Dollar - Foreign Exchange Rates as of 11 November 2022 [89].*

TABLE 14. The objective to sell the innovation.

Content \ Case	Case 1: Buy a whole system	Case 2: Buy the innovation
Two conveyors (Std. size)	Included	Not included
Sensors	Included	Included
Microcontroller	Included	Included
Price (USD)	900	200

or students to access and initiate electronic system control activities easily and quickly. By leveraging Arduino, individuals can construct impressive projects that enhance their future experiences. The primary benefits of incorporating Arduino in support of a developed system are as follows:

- Arduino's smaller size allows it to be installed in compact areas, making it an ideal alternative to PLC.
- Microcontroller maintenance is simplified due to the ''plugs-and-plays'' concept. In the event of damage, the microcontroller can be readily replaced.
- Arduino programming is less complex and requires less effort compared to ladder logic, which takes more time to reach the destination than the widely-used C++ language for Arduino. Errors and bugs can be easily rectified.
- Despite not being the base model (Arduino Mega), the microcontroller is significantly less expensive than PLC.
- Unlike PLC, microcontroller can control a wide range of moving mechanism applications, not just on-off systems.

''Buying a whole system'' refers to purchasing a complete set of components that work together to provide a particular functionality; purchasing a complete conveyor system that includes all the necessary sub-components, such as the controller, sensors, and movement-mechanism platform.

''Buying the innovation'' refers to acquiring the rights or ownership of a particular innovative product or technology. This involves purchasing the patent, copyright, or trademark associated with the innovation, or acquiring the entire business that owns the innovation.

In summary, the cost analysis indicates that the design team invested 14,784 THB (428.74 USD) [87] in developing the in-house conveyor system prototype. This prototype can offer insights into the future trend of object separation systems with an easy-to-access, smaller-scale platform. The proposed conveyor design has the potential to significantly reduce processing time, cost, and manpower required for sorting waste, from a day to just a few hours and with a 50% reduction in cost and the need for only 2-3 workers. However, the current capabilities of the sensor are limited to light intensity and can only sort bottles based on their transparency. To further improve the system's performance, enhancing the sensor's functionality with pattern recognition capabilities to detect colors and classify object shapes for waste separation could be beneficial.

V. SYSTEM DESIGN OPTIMIZATION

A. PROTOTYPING

The prototype features an acrylic sheet housing in black color to protect the electronics from external light. The conveyor belt has been designed to split into two parts and is linked to a separating conveyor. The system includes a rejector that immediately rejects the opaque bottle upon receiving a signal from the light sensor. The transparent lane sensor detects the color of the plastic bottle, and the sensors at the end of each conveyor count the number of bottles. The micro-controller receives commands through a smartphone or keypad and displays step-by-step instructions on an LCD screen. The motor speed is optimized to prevent missing steps and vibrating of the motor. The speed is carefully controlled to ensure it is neither too fast nor too slow, as either case can negatively impact the conveyor's performance.

B. MICROCONTROLLER-PLC INTEGRATION

The purpose of this study was twofold: to demonstrate the capabilities of the proposed conveyor design as a stand-alone system and as an assistive or additional platform that can be seamlessly integrated with the existing conveyor constructed on a PLC controlling platform. One of the main difficulties in designing a new platform is integrating it with an existing one. The developed sorting conveyor demonstrates how easy it is to access and apply to the real world, allowing target customers to use it alongside their old system without having to replace it. The two systems can work well together. The microcontroller was chosen for this research due to its open-source nature, lower cost compared to PLCs, and suitability for SMEs and start-up plants. Open-source applications are generally easier to command and adjust, require less effort, and can support various types of applications as an easy-to-access platform.

In contrast, PLCs are closed-source and require more time to create a ladder diagram with complex patterns of inputs and outputs. Users need to provide many numeric values and assigned parameters for some functions. When maintenance or remodification is needed, users must check each step of the ladder diagram to extract a command to activate the device(s). Different PLC brands require different codes and formats, which must be carefully understood; otherwise, the commands may not be sent to the machine functionally, and they cannot be easily modified. The conceptual model and design of the conveyor system were based on translated customer requirements obtained from Kansei Engineering (KE).

Therefore, the proposed conveyor system for separating different types of plastic bottles can support start-up companies or small-scale businesses where the fundamental requirements of customer expectations can be achieved in the proper direction. Additionally, the developed separating conveyor system can support recycling SMEs with a reasonable price while reducing the manpower required.

VI. CONCLUSION

The newly developed system is highly effective in sorting and separating different types of plastic bottles according to specific requirements. Its automatic operation significantly reduces time, cost, and manpower, just as anticipated. Consequently, it has become a valuable addition to SMEs, recycling companies, and sorting plants. When it comes to the controlling platform, two designs were considered in terms of cost. The first option involves a microcontroller, controller, sensors, and movement-mechanism platform subcomponents, it is priced at around 200 USD. The second option utilizes a PLC to manage the moving and separating mechanisms, which costs approximately 450 USD without the sensors. However, the current sensors used light intensity, which limited the system's ability to sort bottles based solely on transparency. To enhance the performance of this proposed model, additional features such as pattern recognition, which can detect the colors or shapes of objects, could be integrated. For motor application, AC motors can be a suitable choice for supporting a sorting conveyor system, especially when high torque is required. AC motors can generate higher torque by using a more powerful current, making them more powerful than DC motors. Additionally, AC motors are known for their reliability and can operate for extended periods without maintenance. However, they may require more complex installation and control systems than DC motors. Therefore, the choice of motor type ultimately depends on the specific requirements and constraints of the sorting conveyor system. Further study can be conducted to compare the performance and cost-effectiveness of AC and DC motors in a sorting conveyor system to determine which motor type is the best fit.

VII. CONTRIBUTION

The use of Arduino in the study is a noteworthy point. Arduino is a popular open-source platform that can be used for a variety of applications, including prototyping, and developing electronic devices. Its flexibility and ease of use make it an attractive option for researchers and students in various fields. Therefore, the choice to use Arduino in the study could offer several advantages. For example, it could provide a cost-effective and efficient means of prototyping electronic circuits and collecting data. Additionally, it could enable the study to be replicated by other researchers, as the Arduino platform is widely accessible and supported by a large community of developers. The decision to use Arduino in the study is a promising one, as it could open up new avenues for research and innovation in various fields.

VIII. RECOMMENDATION

A. IMPROVING THE SYSTEM

To improve the sorting conveyor system, several steps can be taken. First, the controller program input should be optimized to minimize errors during task performance. The program should be formatted correctly and concisely to ensure efficient communication between the controller and the motor. Second, sensors can be implemented to detect the position and speed of bottles on the conveyor belt. This information can be used to adjust the motor speed and position accurately, resulting in better sorting accuracy. Third, regular maintenance should be conducted on the conveyor belt and motor to prevent breakdowns and ensure optimal performance. The motor and belt should be checked for wear and tear and lubricated regularly. Fourth, upgrading to more advanced motor types, such as AC motors or servo motors, can improve the system's performance and accuracy. Advanced motor types can provide higher torque, better speed control, and more precise positioning. Finally, data analysis can be used to identify areas for improvement in the sorting conveyor system. Data collected from sensors can be analyzed to identify bottlenecks and other issues that can be addressed to optimize the system's performance. By implementing these steps, the sorting conveyor system's accuracy, reliability, and efficiency can be improved, resulting in better overall performance.

B. PERFORMING MAINTAINANCE TASKS

When a process stops for maintenance purposes, it means that the equipment or system is taken offline temporarily for repair, inspection, or other maintenance activities. These activities may be planned in advance (such as routine inspections or scheduled maintenance), or they may be unplanned due to equipment failure or other issues. During maintenance, the equipment or system is usually taken apart, inspected, cleaned, and repaired or replaced as necessary. Once the maintenance is complete, the equipment or system is tested to ensure that it is operating correctly before it is put back into service. Maintenance stops are necessary to ensure that equipment and systems are operating safely and efficiently, and to prevent breakdowns and other issues that can lead to downtime and decreased productivity. By conducting regular maintenance stops, companies can prevent equipment failures, extend the life of their equipment, and ensure that their processes are operating at peak efficiency.

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