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A Quality Function Deployment model: Application design for sauce bottle washer

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ABSTRACT
Small and Medium Enterprises (SMEs) play a crucial role in employment generation and contribute substantially to national economic development, particularly in developing countries. This study examines an SME in Yogyakarta that produces, on average, 175 crates (4,200 bottles) of sauce and 5 crates (1,200 bottles) of sweet sauce daily. The bottle washing process is currently performed manually, requiring up to 3,737 minutes per day. This inefficiency increases labor dependency and delays production due to the unavailability of clean bottles. To address this issue, the study adopts the Quality Function Deployment (QFD) method to translate customer needs into technical specifications for product development. The House of Quality (HoQ) framework is utilized to identify twelve critical product attributes that inform the design of a sauce bottle washer. The resulting design comprises 17 components, including a main frame, dynamo, washing basin, bottle holder, bearing units, inner brush shafts, pulley shafts, brushes, pulleys (2.5-inch and 10-inch), gears, V-belts, chains, caps, wheels, switches, and stoppers. The implementation of this washing system successfully reduces the total bottle washing time by 720 minutes per day. This improvement enables the SME to meet its daily production targets more effectively and contributes to increased operational efficiency.

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1. INTRODUCTION

Small and Medium Enterprises (SMEs) play a pivotal role in developing countries by generating employment and stimulating economic growth through entrepreneurial activities [1], [2]. These enterprises, often owned by individuals or single business entities, operate independently without direct or indirect links to larger firms and are generally classified as micro-enterprises [3]. In 2024, Indonesia recorded more than 65 million SMEs. When effectively managed, these businesses possess the potential to substantially strengthen the national economy [4]. According to a 2023 report by the SMERU Research Institute, SMEs contributed 60.5% to Indonesia's Gross Domestic Product (GDP) and accounted for 59.3% of informal employment in 2022 [5].

Despite their considerable contribution, many Indonesian SMEs continue to struggle with inefficiencies stemming from manual production processes [6]. Efficiency is vital to business success, as it directly affects performance and profitability [7]. In manufacturing, efficiency involves maximizing the use of resources—including time, labor, materials, capital, and energy—while minimizing waste [8]. Inefficiency occurs when production fails to meet expectations, such as when processes yield acceptable outcomes but require excessive time [9]. Many researchers emphasize that investing in appropriate machinery is a key strategy to enhance production efficiency [10], [11] .

Machinery significantly supports the production process by reducing human workload, minimizing defects, improving product quality, and decreasing processing time [12]. Several studies have demonstrated the effectiveness of machinery in improving SME performance. Irawan and Nadliroh [13] reported that a semi-automatic banana washing machine with a 120 kg/hour capacity allowed workers to wash 2 kg of bananas per minute, conserving both time and labor. Another study found that a semi-automatic cup sealer reduced packaging time by 20%, increased production capacity from 20 to 50–100 boxes per day, and enhanced packaging quality, which in turn lowered labor costs [6]. Sumarni and Harjanto [14] showed that installing a slicing tool in a cracker SME reduced labor needs by 62.5%, saved 66.7% in production time, and cut production costs by 50%. Additionally, research at SME Kelorida found that using a moringa leaf flour machine increased production by up to 15 kg per day while maintaining consistent quality and food-grade standards [15]. These studies demonstrate that machinery can significantly optimize cycle time—a crucial parameter in assessing efficiency, cost structures, product quality, and customer satisfaction [16].

However, an SME located in Bantul, Yogyakarta, established in 2022, continues to rely on entirely manual production methods. This SME produces bottled sauces, plastic-packaged sauces, and bottled soy sauce, with a monthly output of 2,500 crates of bottled sauce and 100 crates of soy sauce. Despite these volumes, workers manually carry out each production step. Fourteen employees handle production, and six manage marketing. Workers soak dirty bottles for six hours, manually remove labels with aluminum tools—taking one minute per bottle—then clean the bottle interiors with a cloth-wrapped lever, which also takes one minute per bottle. They then leave bottles to dry for an additional six hours. On average, the SME produces 175 crates (4,200 bottles) of sauce and five crates (120 bottles) of soy sauce daily. A preliminary assessment revealed that it takes four workers a total of 3,737 minutes to wash 4,320 bottles.

This excessive time requirement for bottle washing highlights a critical inefficiency in the production process. The SME often must extend workers' hours and delay production due to the unavailability of clean bottles. Commercially available bottle-washing machines fail to offer a suitable solution, as their designs often overlook employee comfort and consumer preferences [17]. Therefore, the SME needs a custom-designed machine that aligns with its operational requirements and workforce needs. Introducing machine innovation can help boost productivity, minimize production costs, improve product quality, and enhance production flexibility [18].

To address this challenge, this study proposes using the Quality Function Deployment (QFD) method to translate customer requirements into technical specifications [19], [20]. Initially developed by Yoji Akao, QFD supports product designers in delivering customer-focused design quality [17]. This study integrates anthropometric data into the design process to align machine dimensions with workers' postures, promoting ergonomic efficiency and reducing bottle-washing time [11], [21]. QFD allows organizations to effectively prioritize technical features while incorporating cross-functional planning [22]. Incorporating anthropometric data ensures the design addresses ergonomic aspects that are essential for comfort, safety, and performance [23]. Ignoring ergonomics can lead to discomfort, increased costs, accidents, work-related illnesses, and decreased efficiency [24]. Ergonomics aims to optimize the interaction between workers and machines, improving overall system performance [25].

By combining QFD with an anthropometric approach, designers can enhance employee satisfaction, align organizational and worker goals, and improve productivity and profitability [26]–[28] . Several prior studies have demonstrated the success of this integration. Drawing from these findings, this study aims to develop a reusable sauce bottle washer tailored to SME needs. By applying the QFD method and anthropometric data, the proposed design seeks to streamline the bottle-washing process, reduce processing time, and improve overall production efficiency.

2. MATERIALS AND METHODS

This research employed both observational methods and questionnaire-based surveys to collect data relevant to the design of a bottle-washing tool tailored to SME operations. The primary aim of the questionnaire distribution was to capture the needs and preferences of end users. Two types of questionnaires were utilized: open-ended questionnaires, which were administered to workers directly involved in the bottle-washing process, and closed-ended questionnaires, which were distributed to SME owners and general users.

A total of four respondents completed the open-ended questionnaires, providing qualitative insights into operational challenges and user expectations. Meanwhile, 14 respondents participated in the closed-ended survey, offering structured feedback that could be quantified and translated into technical attributes to inform the product design process

2.1. Respondent demographics

The demographic profile of the 14 respondents—who are active workers at a sauce-producing SME located in Bantul, Yogyakarta—is presented in Table 1. Respondents were selected based on their direct involvement in the bottle-washing activities or their potential to substitute for bottle-washing operators. Key demographic variables include age, work experience, and gender, which are considered essential for aligning the design with user characteristics and ergonomic principles. Table 1 presents the distribution of demographic characteristics among the selected participants.

Table 1 Demographic data of respondents

No	Name	Age (Years)	Experience (Years)	Gender
1	Respondent 1	60	6	Male
2	Respondent 2	30	4	Male
3	Respondent 3	39	4	Male
4	Respondent 4	41	4	Male
5	Respondent 5	42	4	Female
6	Respondent 6	22	3	Male
7	Respondent 7	34	4	Female
8	Respondent 8	36	4	Male
9	Respondent 9	35	4	Male
10	Respondent 10	27	3	Male
11	Respondent 11	37	4	Male
12	Respondent 12	45	5	Male
13	Respondent 13	52	5	Male
14	Respondent 14	39	4	Male

2.2. Research mindmap

The object of this research is a Small and Medium Enterprise (SME) located in Bantul, Yogyakarta, which produces approximately 175 crates of sauce bottles (4,200 bottles) and 5 crates of soy sauce bottles (120 bottles) per day. Figure 1 illustrates the sequence of research steps in the form of a mindmap.

The research began by identifying and clarifying the project objectives, followed by gathering the voice of the customer through the distribution of questionnaires to key stakeholders, including workers and SME owners. This stage aimed to capture consumer expectations and operational needs from a user-centered perspective. Figure 1 explains the step in sequence.

Next, researchers translated the identified customer needs into technical requirements through a structured process using the House of Quality (HoQ) framework. The steps involved in developing the HoQ matrix included constructing the planning matrix, defining the voice of the developer, determining technical specifications, evaluating interrelationships among design elements, and calculating the absolute importance values for each attribute.

Subsequently, the study proceeded to the collection and analysis of anthropometric data from selected workers. The team measured relevant anthropometric dimensions and calculated appropriate percentile values to ensure the final design adheres to ergonomic standards. This step was crucial in developing a machine design that accommodates operator comfort, safety, and efficiency.

The final stage involved integrating all the data and design inputs into the development of a product prototype—a sauce bottle washer tailored to SME needs and aligned with ergonomic principles.

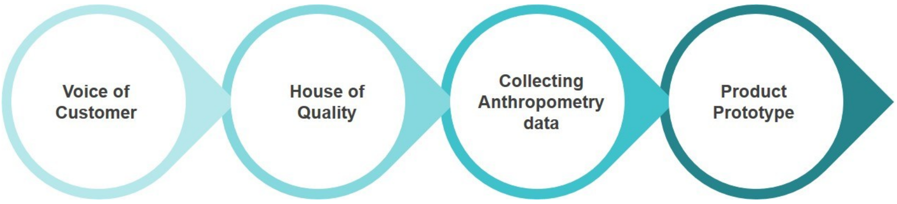


Figure 1. Mindmap

2.2.1. Quality function development (QFD)

Quality Function Deployment (QFD) consists of three interrelated stages: collecting the Voice of the Customer (VOC), constructing the House of Quality (HoQ), and analyzing and implementing the findings [27]. Each stage is elaborated below.

a. Voice of the Customer (VOC)
   The VOC stage addresses the customer requirements section within the HoQ matrix. In this phase, researchers collect statements or expressions—both positive and negative—from customers or potential users to identify their expectations regarding the planned product or service. The standard procedure to extract customer needs includes the following steps [26]:
   1) Conduct visits and interviews with customers to gather all VOC inputs.
   2) Categorize the VOC into major segments such as: product needs and benefits, substitute quality characteristics, and reliability requirements.
   3) Organize the needs in an Affinity Diagram
   4) Incorporate the structured needs into the customer requirements section of the HoQ
b. House of Quality (HoQ)
   The HoQ serves as a structured planning tool to guide the QFD design process [29]. It helps identify and translate customer needs into engineering characteristics. The preparation of the HoQ involves several critical attributes [30]:
   1) Attribute A (customer needs and benefits)
      This attribute compiles customer expectations and the benefits they seek in the product, derived directly from the VOC analysis.
   2) Attribute B (planning matrix)
      This matrix includes relevant planning data such as the importance rating, improvement ratio, sales point, target values, raw weights, and normalized raw weights for each customer requirement.
   3) Attribute C (technical response)
      In this step, technical personnel interpret customer expectations and provide feasible technical response
   4) Attribute D (relationship matrix)
      The QFD team maps out the correlation between customer requirements and technical responses, indicating how effectively each response satisfies user needs
   5) Attribute E (technical correlation)
      This matrix analyzes interdependencies among technical responses to determine whether they support or conflict with each other.
   6) Attribute F (technical target)
      This matrix sets measurable technical goals for each attribute to ensure alignment with customer needs and internal capabilities.

7) Absolute importance (AI)
   AI quantifies the priority level of each technical response by integrating customer importance and relationship strength.

c. Importance and relative weight
   The importance weight reflects the significance of each customer requirement and is calculated by multiplying the customer importance percentage by its relationship score. Meanwhile, the relative weight indicates the impact of each technical response on fulfilling customer expectations.

2.2.2. Anthropometry

Anthropometry, derived from the Greek terms *"antro"* (human) and *"metry"* (measurement), refers to the scientific study of the dimensions and physical characteristics of the human body [28]. Anthropometry in other term is a study related to measuring the dimensions of the human body [31]. Anthropometry deals with body measurement particularly related to body size, shape, strength and working capacity. This discipline plays a critical role in ergonomic product design by accommodating variations in human size, strength, and capacity [32]. In this study, anthropometric data was collected to ensure that the machine design aligns with ergonomic principles, particularly for operators in the sauce production SME. The measured anthropometric dimensions included:

1. Arm Span Distance – measured from the shoulder to the tip of the fingers with the arm fully extended forward.
2. Palm Width – measured with both arms stretched outward to the left and right.
3. Elbow Height – measured in an upright standing posture from the floor to the elbow.

These data points were used to determine design parameters that support comfort, safety, and operational efficiency for end users.

3. RESULTS

The analysis of consumer needs was conducted to classify product attributes based on user expectations, as gathered through the open-ended questionnaire. The initial interpretation was performed by the designer, followed by validation from SME workers or users to ensure the accuracy and relevance of the identified needs. Customer feedback, obtained through structured open-ended responses, was analyzed and categorized into actionable product attributes. The designer grouped similar statements and extracted key needs that reflect the practical requirements of users in the washing process. Each interpreted need was then confirmed with SME workers to enhance the validity of the data. Table 2 presents the summary of interpreted customer needs.

Table 2. Attributes of closed questionnaire statements

No	Code	Attribute
1	X1	The tool can clean bottles quickly
2	X2	The materials used are sturdy and strong
3	X3	Easy to maintain and deal with damage
4	X4	Safe tool when used
5	X5	The tool can clean optimally
6	X6	Economical tool operating costs
7	X7	The tool is easy to operate
8	X8	The tool can clean all types of dirt
9	X9	Water resistant tool
10	X10	The tool requires minimal space
11	X11	The design of the tool suits the worker's body posture
12	X12	Tool is easy to move

3.1. House of Quality

The Voice of Customer was collected through the distribution of closed-ended questionnaires to respondents, consisting of workers directly involved in the operational processes at the research site. These questionnaires gathered information regarding the respondents' expectations, perceptions, and priorities related to the attributes of the existing product.

a. Calculating *planning matrix*

Using the responses from the closed-ended questionnaires, a planning matrix was developed as the foundation for constructing the House of Quality (HoQ). The matrix incorporates several key attributes, including Importance to Customer (IC), Expected Satisfaction Performance (ESP), Current Satisfaction Performance (CSP), Improvement Ratio (IR), Sales Point (SP), Raw Weight, and Normalized Raw Weight (NRW). Each metric plays a critical role in quantifying and prioritizing customer needs. The results of the planning matrix calculation explained in Table 3.

Table 3. Summary of Planning Matrix

No	Attribute	IC	ESP	CSP	IR	SP	Weight	NRW	Priority
1	The tool can clean bottles quickly	3.9	3.9	3.8	1,038	1.5	4,003	0.0885	1
2	The materials used are sturdy and strong	3.7	3.8	3.7	1,019	1.5	3,786	0.0837	5
3	Easy to maintain and deal with damage	3.7	3.9	3.7	1,058	1.5	3,929	0.0869	2
4	Safe tool when used	3.6	3.8	3.6	1,039	1.5	3,786	0.0837	6
5	The tool can clean optimally	3.7	3.8	3.6	1,039	1.5	3,860	0.0853	3
6	Economical tool operating costs	3.7	3.7	3.6	1,020	1.5	3,787	0.0837	7
7	The tool is easy to operate	3.7	3.8	3.6	1,039	1.5	3,860	0.0853	4
8	The tool can clean all types of dirt	3.6	3.7	3.6	1,020	1.5	3,714	0.0821	9
9	Water resistant tool	3.6	3.6	3.6	1,000	1.5	3,571	0.0790	11
10	The tool requires minimal space	3.6	3.6	3.6	1,000	1.5	3,571	0.0790	12
11	The design of the tool suits the worker's body posture	3.6	3.6	3.6	1,020	1.5	3,716	0.0822	8
12	Tool is easy to move	3.6	3.6	3.6	1,020	1.5	3,643	0.0805	10

b. Calculating *technical response*

The technical response refers to the specific actions and design solutions proposed by product developers to address the identified customer needs and expectations. These responses are derived from the Voice of Customer (VoC) and are translated into technical characteristics that can be integrated into the product design. Table 4 presents the summary of interpreted customer needs.

Table 4. Technical Response (Hows)

No	*Technical Response (How to)*
1	Bottle washing tool with 4 brushes
2	The tool is made from 3x3 *hollow iron*
3	The tool can be disassembled easily
4	The tool can maintain operator work safety
5	The bristles can reach all parts of the bottle
6	Low power drive engine
7	There is a brush drive lever and an *on-off switch*
8	Use quality bristle brushes
9	Waterproof *galvanized* tool
10	Tools with a small driving engine
11	The design of the tool is measured by anthropometric data
12	There are wheels on each leg of the machine

c. Determine technical response priorities

Determining the priority order of technical responses is essential to identify which design features should be implemented first to most effectively meet customer needs and expectations. This prioritization helps ensure that the product development process focuses on technical attributes that offer the greatest impact on user satisfaction and product performance. Table 5 presents the results of the calculation of absolute importance values for each technical response. These values indicate the relative priority of each response based on its contribution to fulfilling the identified customer requirements.

Table 5. Absolute values of technical parameters

No	*Technical Response (How to)*	AI Value	Mark (%)
1	Bottle washing tool with 4 brushes	51,318	7,423
2	The tool is made from 3x3 *hollow iron*	89,786	12,987
3	The tool can be disassembled easily	35,357	5,114
4	The tool can maintain operator work safety	34,071	4,928
5	The bristles can reach all parts of the bottle	104,192	15,071
6	Low power drive engine	34,084	4,930
7	There is a brush drive lever and an *on-off switch*	34,739	5,025
8	Use quality bristle brushes	136,335	19,721
9	Waterproof *stainless steel* tool	43,500	6,292
10	Tools with a small driving engine	32,143	4,649
11	The design of the tool is measured by anthropometric data	55,513	8,030
12	There are wheels on each leg of the machine	40,286	5,827

d. Anthropometrics-Based Design for Sauce Bottle Washer

The design of the sauce bottle washer utilized anthropometric data collected from the Indonesian population in 2018, sourced from the official website anthropometriindonesia.org. This data was specifically selected to ensure that the machine accommodates the physical characteristics of local users, who belong to the Asian ethnic group. The use of anthropometric measurements enables the equipment to be ergonomically optimized, thereby improving operator comfort, safety, and efficiency. The machine design incorporated the following anthropometric parameters:

- Forward Reach (Arm Span): The distance from the shoulder to the tip of the fingers when the arm is extended forward. This dimension uses the 95th percentile, with a measured length of 91 cm, to accommodate a broad range of users.
- Lateral Arm Reach (Palm Width): The horizontal distance when both arms are stretched outward to the left and right. This measurement uses the 5th percentile, with a value of 86 cm, ensuring inclusivity for smaller-sized users.
- Elbow Height (Standing Position): The vertical height from the ground to the elbow when the user is standing upright. This parameter uses the 5th percentile, measured at 87 cm, to support ergonomic alignment during operation in the washing section.

The following is a HoQ chart which can be seen in Figure 2. The HoQ serves as a structured planning tool to guide the QFD design process and helps identify and translate customer needs into engineering characteristics.

e. Tool/prototype design

This stage involves transforming the conceptual design into a tangible, three-dimensional prototype presented in Figure 3. The design process materializes the planned specifications into a physical model that can be tested and evaluated. The resulting prototype consists of 17 primary components that form the complete structure of the sauce bottle washer.

Information

● = Very Strong Relationship

◎ = Moderate Relationship

○ = Weak Link

Empty = No Relationship

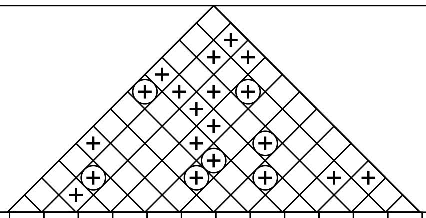
⊕ = Very strong positive

\+ = Positive is quite strong

Empty = No connection

− = Negative is quite strong

⊖ = Very strong negative



No	Atribut Pernyataan *(Whats)*	*Importance Customer*	1 Bottle washing tool with 4 brushes	2 The tool is made from 3x3 *hollow iron*	3 The tool can be disassembled easily	4 The tool can maintain operator work safety	5 The bristles can reach all parts of the bottle	6 Low power drive engine	7 There is a brush drive lever and an *on-off switch*	8 Use quality bristle brushes	9 Waterproof *galvanized* tool	10 Tools with a small driving engine	11 The design of the tool is measured by anthropometric data	12 There are wheels on each leg of the machine	*Improvment Ratio*	*Sales Point*	*Ratio Weight*	*Normalized Raw Weight*	Order of priority
1	The tool can clean bottles quickly		●				●			●					1,038	1,5	4,003	0,0885	1
2	The materials used are sturdy and strong			●							◎				1,019	1,5	3,786	0,0837	5
3	Easy to maintain and deal with damage				●									○	1,058	1,5	3,929	0,0869	2
4	Safe tool when used			●		●							◎		1,039	1,5	3,786	0,0837	6
5	The tool can clean optimally		◎				●			●					1,039	1,5	3,860	0,0853	3
6	Economical tool operating costs							●							1,020	1,5	3,787	0,0837	7
7	The tool is easy to operate								●						1,039	1,5	3,860	0,0853	4
8	The tool can clean all types of dirt		○				●			●					1,020	1,5	3,714	0,0821	9
9	Water resistant tool			◎						●	●				1,000	1,5	3,571	0,0790	11
10	The dimensions of the tool do not take up much space											●	◎	○	1,000	1,5	3,571	0,0790	12
11	The design of the tool suits the worker's body posture												●		1,020	1,5	3,716	0,0822	8
12	Tool is easy to move			◎										●	1,020	1,5	3,643	0,0805	10
Amount			51,318	89,786	35,237	34,071	104,192	34,084	34,739	136,335	43,500	32,143	55,513	40,286					
Presesntation			7,423	12,987	5,114	4,928	15,071	4,930	5,025	19,721	6,292	4,649	8,030	5,827					

Figure 2. House of quality matrix

f. Washing time testing

This stage aimed to evaluate the efficiency of the bottle-washing process by comparing the processing time between manual washing and the use of the newly developed bottle-washing tool. The experiment involved measuring the time required to wash one bottle manually and using the tool. Manual washing of a single bottle took approximately 1 minute, whereas the bottle-washing tool completed the task in only 0.33 minutes, indicating a significant reduction in processing time. Further testing was conducted to assess batch productivity using both methods. When washing four bottles manually, the process required 4 minutes, while the tool achieved the same task in only 0.33 minutes, demonstrating a substantial increase in productivity. For a full-day production volume of 4,320 bottles, the use of the bottle-washing tool significantly reduced the total processing time. Manual washing required 3,737 minutes, while the tool decreased the processing time to 2,839 minutes, clearly showing enhanced operational efficiency.

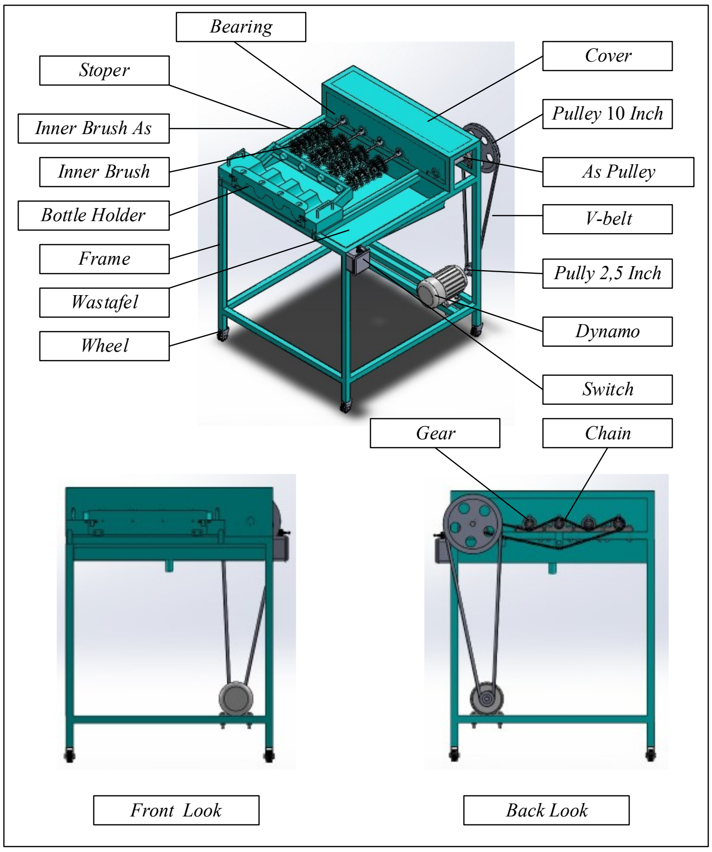


Figure 3. Prototype design of washing bottle machine

4. CONCLUSION

This study successfully designed a sauce bottle washer that meets the operational needs of a small-scale sauce production SME and effectively addresses the inefficiencies of the manual washing process. The developed equipment significantly enhances productivity, with the ability to clean 12 bottles per minute—compared to the manual method, which requires one minute per bottle. Implementation of the tool led to a notable reduction in production time. Testing showed that the manual washing process required approximately 3,737 minutes to clean 4,320 bottles in a day. After adopting the tool, the total washing time decreased to 2,839 minutes. This result demonstrates that the proposed solution can substantially improve process efficiency, reduce labor time, and support the operational sustainability of SMEs.

The development of the bottle-washing tool in this study presents several practical implications, particularly for small and medium-sized enterprises (SMEs) engaged in food and beverage production. The simplicity of the design and use of locally available materials make this tool easily replicable in other SMEs with similar operational contexts. By adopting this technology, other small-scale producers can expect comparable improvements in productivity and time efficiency. Broader adoption of such innovations in SME ecosystems could support local economic development by enhancing production capacity, reducing manual workload, and improving product quality and consistency. Furthermore, the approach used in this research—integrating Quality Function Deployment (QFD) with ergonomic principles—can serve as a reference model for future SME-focused equipment development initiatives.

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