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Innovation in Designing an Ergonomic Waste Shredding Machine for Waste Processing at TPS3R Kudus Regency

Ary Putra Prasetia[1*], Mohammad Aunun Yusron[2], and Dwi Nurul Izzhati[3]
[1,2,3] Industrial Engineering Study Program, Faculty of Engineering, Dian Nuswantoro University, Jl. Nakula 1 No.5-11, Semarang, Central Java, 50131, Indonesia
Email: arypp123@gmail.com[1], aununyusyus04@gmail.com[2], dwi.nurul.izzhati@dsn.dinus.ac.id[3]

Abstract

Waste is a serious environmental issue both in Indonesia and globally, with negative impacts on the environment and health. Effective waste management, from TPS3R to households, is crucial in reducing its impact. In Kudus Regency, TPS3R implements the 3R concept before sending residual waste to TPA Tanjungrejo. Despite generating 31,855.73 tons of waste annually, only a small portion can be managed due to inadequate processing technology. Developing a waste shredder machine can enhance processing efficiency. This machine can shred various types of waste into compost or valuable raw materials. The research aims to design an ergonomic waste shredder machine for TPS3R Kudus using Quality Function Deployment (QFD), integrating customer preferences into technical design. Among 13 primary attributes, multifunctionality in shredding receives high priority with an importance rating (IR) of 4.6, while waste washing facility has the lowest IR at 4. Benchmarking against competitor products shows superiority in customer satisfaction for the designed machine. Improvement priorities in the House of Quality (HoQ) include machine frame at 10% and security sensor at 6%. The waste shredder machine is designed using QFD method, focusing on 13 main attributes with design dimensions based on anthropometric data: height 106 cm, width 78 cm, length 170 cm, and overall height 135 cm, ensuring comfortable and efficient use for operators.

Keyword*; Waste management; TPS3R; Waste shredder machine; Quality Function Deployment*

1. Introduction

Waste is leftover material that is no longer needed after the end of a process. Every day, waste is continuously produced throughout the year (Kholili et al., 2021). Public perception of waste generally revolves around its unhygienic nature, unpleasantness, and lack of functionality due to its foul odor and negative impact on the surrounding environment. Waste is a significant environmental challenge, both in Indonesia and globally. Major ecological concerns arise from the use of non-environmentally friendly plastic and organic materials. The harmful impact of waste on the environment directly correlates with its negative effects on human health.

Waste can be divided into two types based on its nature: organic and inorganic. Organic waste decomposes easily and tends to rot quickly. Conversely, inorganic waste is difficult to decompose and does not rot easily (Kholili et al., 2021). Disposing of waste, whether organic or inorganic, directly to a 3R Waste Management Site (TPS3R) without proper management can cause environmental problems. Therefore, effective waste management is essential, starting from TPS3R to household-level management practices, to ensure optimal waste processing.

Organic waste management offers the potential to be utilized into economically valuable products, such as fertilizer raw materials (Zahri & AR., 2022). Plastic, as one type of inorganic waste, can also be recycled. Before plastic can be processed into new products, it needs to be converted into granules to facilitate further processing (Masruri et al., 2021). Recycled plastic waste products can be reused to make various plastic items (Prayogo, 2020). One method of processing plastic waste is by using a waste shredding machine.

TPS3R in Kudus is an integrated waste management site that uses the 3R system (reduce, reuse, recycle) before difficult-to-manage waste is sent to the Tanjungrejo Landfill. In Kudus Regency, there are 9 TPS3R managed by the PKPLH Office. In 2022, the waste generation rate in Kudus Regency reached 31,855.73 tons per year. Of the total waste generation, only about 19% of organic and inorganic waste can be managed. Most of the organic and inorganic waste that can be processed is still not utilized optimally. The main problem in waste management is the lack of equipment or technology, resulting in suboptimal waste processing. Human awareness and technological advancements can help improve waste processing efficiency in the future.

The lack of equipment or technology to handle waste results in suboptimal waste processing. Advances in science and technology in this modern era have driven the development of increasingly efficient machines

[1*] Ary Putra Prasetia
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(Prabowo, 2019). The issue of waste management has triggered various technological innovations aimed at reducing environmental pollution (Burlian et al., 2019). One technology that provides significant benefits in waste management is the organic and inorganic waste shredding machine. This machine can tear and crush various types of waste in a single process, such as leaves, grass, and plastic. Shredded organic waste can then be processed into compost, while shredded plastic waste can be recycled into valuable raw materials for the craft and recycling industries (Larisang & Yunandi, 2021).

The design of a waste shredding machine at TPS3R in Kudus is necessary because there is still a lot of organic and inorganic waste that has not been optimally processed. Effective waste processing can reduce the accumulation of waste at the Tanjungrejo Landfill in Kudus and create opportunities for small industries. The main objective of designing the waste shredding machine is to produce an ergonomic machine design that meets customer needs, obtained through the Quality Function Deployment (QFD) method. QFD is a systematic approach to translating customer preferences into technical designs, manufacturing processes, and production planning (Wijaya, 2018).

The process of designing a waste shredding machine involves ergonomic research and the implementation of QFD results. After the research phase is completed, the machine design can be realized, allowing the measurement of the amount of waste that can be processed by the machine. The goal of this research is to design an ergonomic waste shredding machine for TPS3R Kudus workers using the Quality Function Deployment (QFD) method.

2. Research Methods

The research methodology is the reference used in conducting research. It is designed so that the research can proceed smoothly and appropriately. This research was conducted using two methods: the Quality Function Deployment (QFD) method and the Ergonomic Anthropometry method as the basis for design measurements. To ensure the research runs smoothly and aligns with the study's objectives, a research flowchart must be created. Below is the research flowchart that was followed.

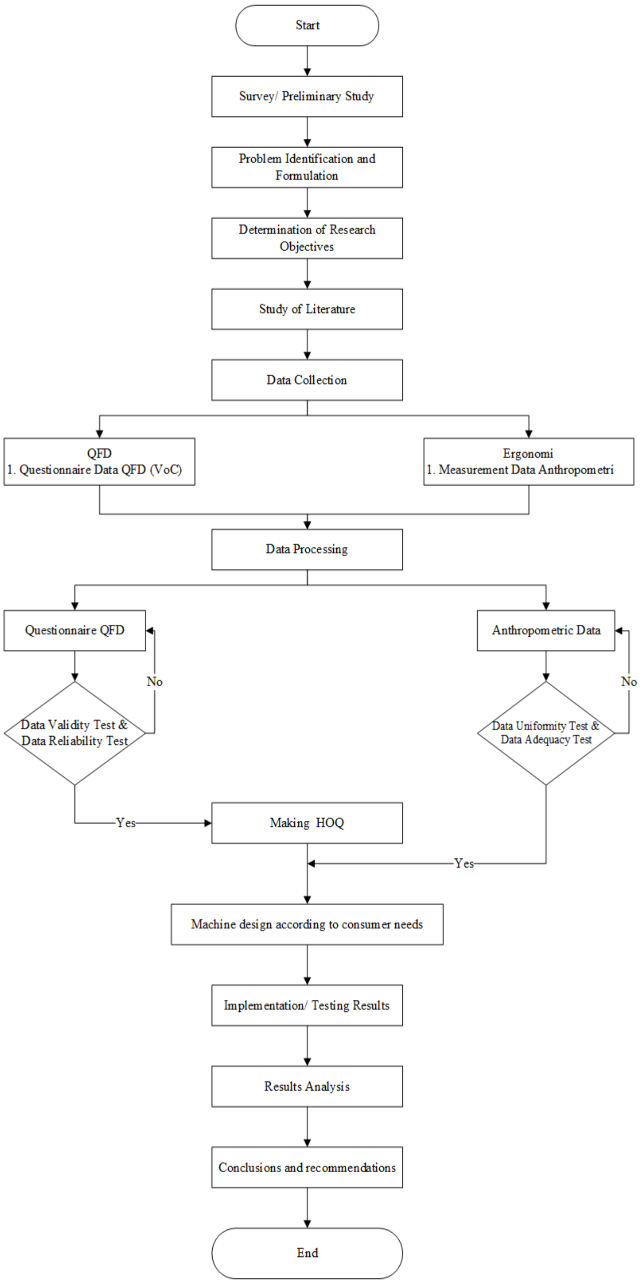


Figure 1: Research Flowchart

The Quality Function Deployment (QFD) method stage in this research involves data collection through questionnaires distributed to TPS3R workers in Kudus Regency. Workers are asked to carefully fill out the questionnaires to understand and communicate their needs, resulting in the "voice of the customer." The collected data is used as a reference in designing the waste shredding machine. Next, the House of Quality (HoQ) matrix is compiled to create a list of customer needs, develop relationships between the "what" and "how" matrices, determine relationships between the "how" matrices, and set targets. Meanwhile, the Ergonomic Anthropometry method stage involves measuring the body dimensions of TPS3R workers in Kudus Regency. The resulting anthropometric data is used as a reference to determine the dimensions in designing the waste shredding machine in this research.

3. Results and Discussion

3.1 Respondent Characteristics

This research involved 35 respondents who participated in the study. All respondents are workers from TPS3R under the auspices of the PKPLH Office of Kudus Regency, serving as waste sorting and processing officers. Below is the summary table of respondent data in the research

Table 1: Summary of Respondent Characteristics

No	Respondent Place	Gender	Number of Respondents
1	TPS3R Rendeng	Man	21
2	TPS3R Getas Pejaten	Man	14

3.2 Identification of Consumer Needs

The stage of identifying customer needs is the initial step in the data collection process of Quality Function Deployment (QFD), resulting in the Voice of Customer (VoC). This process focuses on adjusting the needs of TPS3R workers as users of the waste shredding machine and formulating the machine's design specifications. After obtaining the Voice of Customer (VoC), the attributes of customer needs can be formulated. The customer needs attributes, obtained through the VoC, are used as a reference in the House of Quality (HoQ) and to benchmark the design product against other competing products. Below is the identification of customer needs.

Table 2: Identifying Consumer Needs

No	Voice of Customer	*Attribute/ Customer Need*
1	The waste shredder machine is designed according to the body size of the officer so that it is comfortable when used	Size according to the officer
2	The machine frame will be designed so that it is not easily damaged	Frame is not easily damaged
3	The machine that is designed can be easily maintained	Easy/long-term machine maintenance
4	The machine is designed by combining 2 (two) types of shredder machines so that it can shred waste in 1 (one) machine	Multifunction
5	The machine is designed with a place to wash waste	Has a place to wash garbage
6	The machine is designed with wheels so that it is easy to move and the components can be disassembled	Easy to move/flexible/disassemble
7	The shredder machine is designed to be easy to operate and not dangerous	Easy to use
8	The shredder machine has different input and output holes for different types of waste	Has 2 separate input output holes
9	The waste shredder machine is designed to be equipped with safety that can make it safe and minimize work accidents for operators	Safety sensor
10	The waste shredder machine has a sensor that functions as a safety for the machine	Machine safety
11	The waste shredder machine is designed to implement occupational health and safety (K3) for operators	Minimal risk of accidents
12	The waste shredder machine is driven by an electric motor	Electric powered
13	The waste shredder machine is designed with a sturdy frame to withstand heavy shredding conditions	Sturdy frame

3.3 Validity Test and Reliability Test

According to Ghozali (2002), validity assessment is used to ensure the accuracy of a questionnaire. When questionnaire items effectively reveal the targeted dimensions, the items are considered valid. The validity test was conducted with the help of IBM SPSS Statistics 25 software, which facilitated the validation process in the research. Below are the results of the Quality Function Deployment (QFD) questionnaire validity test.

Table 3: Validity Test Results

No	Attribute	Pearson Corelation	Significant Value	N	Results
1	Attribute 1	0,551	0,001	35	Valid
2	Attribute 2	0,611	0,000	35	Valid
3	Attribute 3	0,787	0,000	35	Valid
4	Attribute 4	0,544	0,001	35	Valid
5	Attribute 5	0,719	0,000	35	Valid
6	Attribute 6	0,58	0,000	35	Valid
7	Attribute 7	0,712	0,000	35	Valid
8	Attribute 8	0,793	0,000	35	Valid
9	Attribute 9	0,747	0,000	35	Valid
10	Attribute 10	0,589	0,000	35	Valid
11	Attribute 11	0,745	0,000	35	Valid
12	Attribute 12	0,697	0,000	35	Valid
13	Attribute 13	0,605	0,000	35	Valid

In the validity test results, it was found that all attribute questions in the questionnaire were declared valid. This is because the 35 respondents' answers produced significant values below 0.05.

Meanwhile, according to Ghozali (2002), the reliability test is used to evaluate a questionnaire that functions as a guide for variables or constructs. In this test, a questionnaire is considered reliable if the respondents' answers are consistent or stable over time. In the conducted research, the reliability test was carried out using IBM SPSS Statistics 25 software. Below are the results of the reliability test conducted.

Table 4: Reliability Test Results

Cronbach's Alpa	N of Items
0.896	13

According to Ghozali (2002), a construct or variable is considered reliable if it provides a Cronbach's Alpha value > 0.07. From the results of the reliability test conducted, the consumer needs attribute questionnaire can be declared reliable because the Cronbach's Alpha value is greater than 0.07, which is 0.896.

3.4 Assessment of Consumer Needs Attributes

The assessment of consumer needs attributes is calculated from the importance rating value of each customer need attribute obtained by distributing the second-stage or closed Quality Function Deployment (QFD) questionnaire. The assessment of each customer need attribute in the second-stage questionnaire uses a Likert scale rating with the following descriptions:

a. 1: Very Unimportant (STP)
b. 2: Unimportant (TP)
c. 3: Somewhat Unimportant (KP)

d. 4: Important (P)
e. 5: Very Important (SP)

Table 5: Recapitulation of Attribute Assessment Results

No	Attribute	Rating 1	Rating 2	Rating 3	Rating 4	Rating 5	Number of Respondents	Total	*Importance Rating*
1	Size according to the officer	0	0	0	15	20	35	160	4.6
2	Frame is not easily damaged	0	0	0	20	15	35	155	4.4
3	Easy/long-term machine maintenance	0	0	1	15	19	35	158	4.5
4	Multifunction	0	0	0	14	21	35	161	4.6
5	Has a place to wash garbage	0	0	8	19	8	35	140	4
6	Easy to move/flexible/dis assemble	0	0	0	24	11	35	151	4.3
7	Easy to use	0	0	0	14	21	35	161	4.6
8	Has 2 separate input output holes	0	0	0	15	20	35	160	4.6
9	Safety sensor	0	0	0	19	16	35	156	4.5
10	Machine safety	0	0	0	15	20	35	160	4.6
11	Minimal risk of accidents	0	0	0	21	14	35	154	4.4
12	Electric powered	0	0	3	19	13	35	150	4.3
13	Sturdy frame	0	0	0	13	22	35	162	4.6

Based on Table 5, the recapitulation results of each attribute's assessment show that the attribute with the highest importance rating is the multifunctionality in shredding. Meanwhile, the attribute with the lowest importance rating is the presence of a waste washing facility. This indicates that the multifunctionality in shredding can be an important aspect in the design being carried out.

3.5 Technical Response Identification Results

The results of the identification of technical requirements are the process of determining the respondents' technical needs based on the generated attributes. Technical requirements are used to translate user needs into general technical language. After the technical requirements are identified, the next step is to determine the target specifications, which involves setting targets for each technical requirement to meet the technical specifications for each attribute of the waste shredding machine. Below are the results of the identification of technical requirements.

Table 6: Technical Response Identification Results

No	Attribute/ *Customer Need*	*Technical Requirement*	Target
1	Size according to the officer	Machine design according to the size of the officer's body	The size of the machine is in accordance with the body of the
2	Frame is not easily damaged	The machine frame is not easy to rust	The machine frame is painted anti-rust
3	Easy/long-term machine maintenance		
4	Multifunction	The machine has more than 1 function	The machine can shred organic and inorganic waste and wash waste
5	Has a place to wash garbage		
6	Easy to move/flexible/disassemble	The machine can be adjusted in position	The machine is equipped with wheels and each component is connected with bolts
7	Easy to use	The machine is easy for	The machine is in accordance with the
8	Has 2 separate input output holes	The machine has 2 input and output holes	The machine can be directly organic and inorganic
9	Safety sensor	There is an operator safety	The machine is equipped with a
10	Machine safety	There is a machine safety	The machine is equipped with an
11	Minimal risk of accidents	Implementation of K3 operating the machine	Provision of operational and hazard signs on the machine
12	Electric powered	The machine uses an electric	Using a 2HP 1 Phase electric motor
13	Sturdy frame	The frame uses materials	The frame material uses standard 40,

3.6 Calculation of Customer Competitive Evaluation (CCE)

Customer competitive evaluation (CCE) is a stage to determine customer satisfaction with the designed or developed product compared to similar competing products. In addition to determining customer satisfaction with the designed product, CCE can also be used to evaluate the shortcomings of the designed product. The CCE is determined by benchmarking the designed product, which is the waste shredding machine, against competitor product 1, an inorganic plastic waste shredding machine, and competitor product 2, an organic waste shredding machine. The CCE assessment is conducted by distributing customer satisfaction questionnaires to respondents using a Likert scale. Below is the table of recapitulation of the customer competitive evaluation (CCE) calculation.

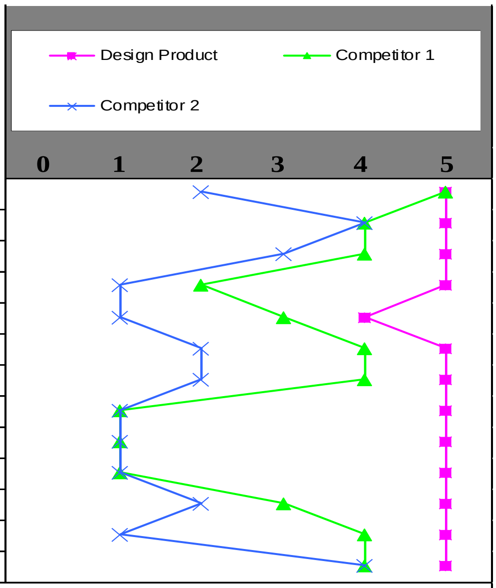
Table 7: Customer Competitive Evaluation Recapitulation Results

No	Attribute	IR Design Product	IR Competitor 1	IR Competitor 2
1	Size according to the officer	4.8	4.6	2.3
2	Frame is not easily damaged	4.5	3.9	4.3
3	Easy/long-term machine maintenance	4.6	3.9	2.9
4	Multifunction	5	2	1.1
5	Has a place to wash garbage	4.4	2.8	1.1
6	Easy to move/flexible/disassem ble	4.6	3.5	2.2
7	Easy to use	5	4.4	2.3
8	Has 2 separate input output holes	5	1.4	1
9	Safety sensor	4.7	1	1
10	Machine safety	4.7	1	1
11	Minimal risk of accidents	4.9	3	2
12	Electric powered	4.7	4.2	1.3
13	Sturdy frame	4.6	4.1	4.3

3.7 Benchmarking Chart

The obtained recap is the result of a data comparison recap of the importance rating (IR) from the designed product, competitor 1's product, and competitor 2's product, which can also be used to create a benchmarking graph as a reference for comparing the designed product with competitors' products. Below is a benchmarking graph compiled from the customer competitive evaluation (CCE) calculations.

No	Attribute	Design Product	Competitor 1	Competitor 2
1	Size according to the officer	5	5	2
2	Frame is not easily damaged	5	4	4
3	Easy / long-term machine maintenance	5	4	3
4	Multifunction	5	2	1
5	Has a place to wash garbage	4	3	1
6	Easy to move / flexible / dismantle	5	4	2
7	Easy to use	5	4	2
8	Has 2 separate input output holes	5	1	1
9	Safety sensor	5	1	1
10	Machine safety	5	1	1
11	Minimal risk of accidents	5	3	2
12	Electric powered	5	4	1
13	Sturdy frame	5	4	4



Design Product "Waste Shredding Machine"

Competitor 1 "Plastic Waste Shredding Machine"

Competitor 2 "Organic Waste Shredding Machine"

Figure 2: Benchmarking Chart

In the benchmarking section with consumer satisfaction comparisons, benchmarking is carried out by comparing the designed product, which is a waste shredding machine, with competitor 1's product, which is an inorganic waste shredding machine, and competitor 2's product, which is an organic waste shredding machine. The process of obtaining results or values of customer satisfaction is done by distributing customer satisfaction questionnaires. In Figure 4.15, it can be seen that the customer satisfaction graph, which serves as a benchmarking measure, shows that the designed product, the waste shredding machine, has high attribute values in each benchmarking category compared to competitor 1's and competitor 2's products. This indicates that the designed product, the waste shredding machine, is considered satisfactory by the consumers or users.

3.8 Calculation of Goal, Sales Point, Improvement Ratio, Raw Weight, and Normalized Raw Weight

The goal is the target set for the level of customer satisfaction with each attribute of the developed or designed product. The goal value is obtained from the average value of the importance rating (IR) from customer needs, the IR value of the designed product, the IR value of competitor product 1, and the IR value of competitor product 2. Meanwhile, the sales point is a value used to determine the ability to sell product attributes based on the perception of the designer or developer. The purpose of the sales point is to identify attributes that require improvement to enhance competitiveness in meeting consumer needs. A high sales point value indicates that the attribute significantly impacts customers. According to Cohen (1995), the sales point value is categorized into 3 levels as follows.

Table 8: Sales Point Value Category

No	Sales Point Category	Meaning
1	1	Low Selling Power
2	1.2	Medium Selling Power
3	1.5	High Selling Power

The improvement ratio is a ratio that can show the achievement of the set goal value. The improvement ratio is calculated by comparing the goal with the importance rating value of customer satisfaction for the designed product. In this case, the improvement ratio value is used to determine the performance position of the designed or developed product. Meanwhile, the raw weight is the calculated weight value for each attribute. The raw weight value is used as a basis for evaluating or improving each customer need attribute. Next, the normalized raw weight is the value of the column containing the raw weight values using a scale from 0 (zero) to 1 (one) or expressed as a percentage. According to Cohen (1995), the calculation value and classification categories of improvement ratio, raw weight, and normalized raw weight are obtained with the following formula.

Table 9 : Improvement Ratio Value Classification

Improvement Ratio Value	Classification
<1	No changes
1 – 1.5	Medium repair
>1.5	Complete overhaul

$$Improvement\ Ratio = \frac{Goal}{Importance\ Rating\ Produk\ Rancangan} \quad (1)$$

$$Raw\ Weight = Importance\ Rating\ Customer\ Need\ x\ Improvement\ Ratio\ x\ Sales\ Point \quad (2)$$

$$Normalized\ Raw\ Weight = \frac{Raw\ Weight}{Total\ Raw\ Weight} \quad (3)$$

The following are the results for the values of Goal, Sales Point, Improvement Ratio, Raw Weight, and Normalized Raw Weight.

Table 10: Results of Goal, Sales Point, Improvement Ratio, Raw Weight and Normalized Raw Weight values

No	Attribute	IR Design Product	IR Competitor 1	IR Competitor 2	Goal	Sales Point	Improvement Ratio	Raw Weight	Normalized Raw Weight
1	Size according to the officer	4.8	4.6	2.3	4.1	1.5	0.84	5.8	9%
2	Frame is not easily damaged	4.5	3.9	4.3	4.3	1.5	0.95	6.3	10%
3	Easy/long-term machine maintenance	4.6	3.9	2.9	4.0	1.5	0.87	5.9	9%
4	Multifunction	5.0	2.0	1.1	3.2	1.5	0.63	4.4	7%
5	Has a place to wash garbage	4.4	2.8	1.1	3.1	1.5	0.70	4.2	6%
6	Easy to move/flexible/disassemble	4.6	3.5	2.2	3.7	1.5	0.80	5.2	8%
7	Easy to use	5.0	4.4	2.3	4.1	1.5	0.82	5.6	9%
8	Has 2 separate input output holes	5.0	1.4	1.0	3.0	1.5	0.60	4.1	6%
9	Safety sensor	4.7	1.0	1.0	2.8	1.5	0.60	4.0	6%
10	Machine safety	4.7	1.0	1.0	2.8	1.5	0.60	4.1	6%
11	Minimal risk of accidents	4.9	3.0	2.0	3.6	1.5	0.73	4.8	7%
12	Electric powered	4.7	4.2	1.3	3.6	1.5	0.77	4.9	7%
13	Sturdy frame	4.6	4.1	4.3	4.4	1.5	0.96	6.7	10%

3.9 Relationship of Customer Need Attributes with Technical Requirements

The relationship between customer need attributes and technical requirements is a chart that shows the relationship or correlation between consumer needs and technical requirements. The correlation is based on the results of user desires by including symbols that have specific weights.

Table 11: Meaning of the Relationship Symbol between Customer Need Attributes and Technical Requirements

No	Symbol	Weight	Meaning
1	Θ	9	Strong Relationship
2	O	3	Medium Relationship
3	▲	1	Week Relationship

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Machine design according to the size of the officer's body	The machine frame is not easy to rust	The machine has more than 1 function	The machine can be adjusted to its position	The machine is easy for officers to operate	The machine has 2 input and output holes	There is an operator safety sensor	There is a machine safety sensor	Implementation of OSH to operate the machine	The machine uses an electric drive	The frame uses materials according to standards
1	9	7.9	4.6	Size according to the officer	Θ	▲	O	Θ	Θ	O	▲	▲	▲	▲	▲
2	9	7.6	4.4	Frame is not easily damaged	▲	Θ	▲	▲	O	Θ	▲	O	O	▲	Θ
3	9	7.8	4.5	Easy / long-term machine maintenance	▲	Θ	O	Θ	▲	O	▲	O	O	O	Θ
4	9	7.9	4.6	Multifunction	O	▲	Θ	Θ	Θ	Θ	O	O	O	▲	▲
5	9	6.9	4.0	Has a place to wash garbage	O	▲	Θ	▲	O	▲	▲	▲	▲	▲	▲
6	9	7.4	4.3	Easy to move / flexible / dismantle	Θ	▲	▲	Θ	O	▲	▲	▲	▲	O	▲
7	9	7.9	4.6	Easy to use	Θ	▲	Θ	Θ	Θ	Θ	O	O	Θ	O	▲
8	9	7.9	4.6	Has 2 separate input output holes	O	▲	Θ	▲	Θ	Θ	▲	▲	▲	▲	▲
9	9	7.8	4.5	Safety sensor	▲	▲	O	▲	O	▲	Θ	Θ	Θ	Θ	▲
10	9	7.9	4.6	Machine safety	▲	▲	O	▲	O	▲	Θ	Θ	Θ	Θ	Θ
11	9	7.6	4.4	Minimal risk of accidents	O	▲	O	▲	Θ	▲	Θ	O	Θ	▲	▲
12	9	7.4	4.3	Electric powered	▲	▲	Θ	▲	O	▲	Θ	Θ	▲	Θ	▲
13	9	7.9	4.6	Sturdy frame	▲	Θ	▲	▲	O	Θ	▲	▲	▲	▲	Θ

Figure 3: Relationship Between Customer Need Attributes and Technical Requirements

3.10 Column Weight Assessment

Column weight assessment is the evaluation of the columns in the house of quality (HoQ) chart. At this assessment stage, it is based on filling in the relationships between the attributes in the customer need and the technical requirement. According to Cohen (1995), column weight assessment can be calculated using the following formula.

$$\text{Column Weight} = \sum \begin{matrix} (Importance\ Rating\ x \\ \text{Nilai korelasi Kebutuhan Teknis}) \end{matrix} \quad (4)$$

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Machine design according to the size of the officer's body	The machine frame is not easy to rust	The machine has more than 1 function	The machine can be adjusted to its position	The machine is easy for officers to operate	The machine has 2 input and output holes	There is an operator safety sensor	There is a machine safety sensor	Implementation of OSH to operate the machine	The machine uses an electric drive	The frame uses materials according to standards
1	9	7.9	4.6	Size according to the officer	9	1	3	9	9	3	1	1	1	1	1
2	9	7.6	4.4	Frame is not easily damaged	1	9	1	1	3	9	1	3	3	1	9
3	9	7.8	4.5	Easy / long-term machine maintenance	1	9	3	9	1	3	1	3	3	3	9
4	9	7.9	4.6	Multifunction	3	1	9	9	9	9	3	3	3	1	1
5	9	6.9	4.0	Has a place to wash garbage	3	1	9	1	3	1	1	1	1	1	1
6	9	7.4	4.3	Easy to move / flexible / dismantle	9	1	1	9	3	1	1	1	1	3	1
7	9	7.9	4.6	Easy to use	9	1	9	9	9	9	3	3	9	3	1
8	9	7.9	4.6	Has 2 separate input output holes	3	1	9	1	9	9	1	1	1	1	1
9	9	7.8	4.5	Safety sensor	1	1	3	1	3	1	9	9	9	9	1
10	9	7.9	4.6	Machine safety	1	1	3	1	3	1	9	9	9	9	9
11	9	7.6	4.4	Minimal risk of accidents	3	1	3	1	9	1	9	3	9	1	1
12	9	7.4	4.3	Electric powered	1	1	9	1	3	1	9	9	1	9	1
13	9	7.9	4.6	Sturdy frame	1	9	1	1	3	9	1	1	1	1	9
				Max Relationship Value in Column	9	9	9	9	9	9	9	9	9	9	9
				Weight / Importance	346.9	286.2	482.8	411.7	520.3	445.9	377.2	362.4	396.2	331.0	349.7
				Relative Weight	8.0	6.6	11.2	9.6	12.1	10.3	8.8	8.4	9.2	7.7	8.1

Figure 4: Column Weight Assessment

3.11 Relationship of Technical Requirement Correlation Matrix

The correlation matrix relationship of technical requirements is a part of the house of quality (HoQ) chart that shows the relationships or correlations between technical requirements. In this section, the relationships between technical requirements are identified. The correlations are represented using 4 symbols with different meanings. Below is the table of symbols for the relationships between technical requirements.

Table 12: Meaning of Technical Requirement Correlation Symbols

No	Symbol	Meaning
1	++	Very Strong Correlation
2	+	Strong Correlation
3	−	Week Correlation
4	▼	Very Week Correlation

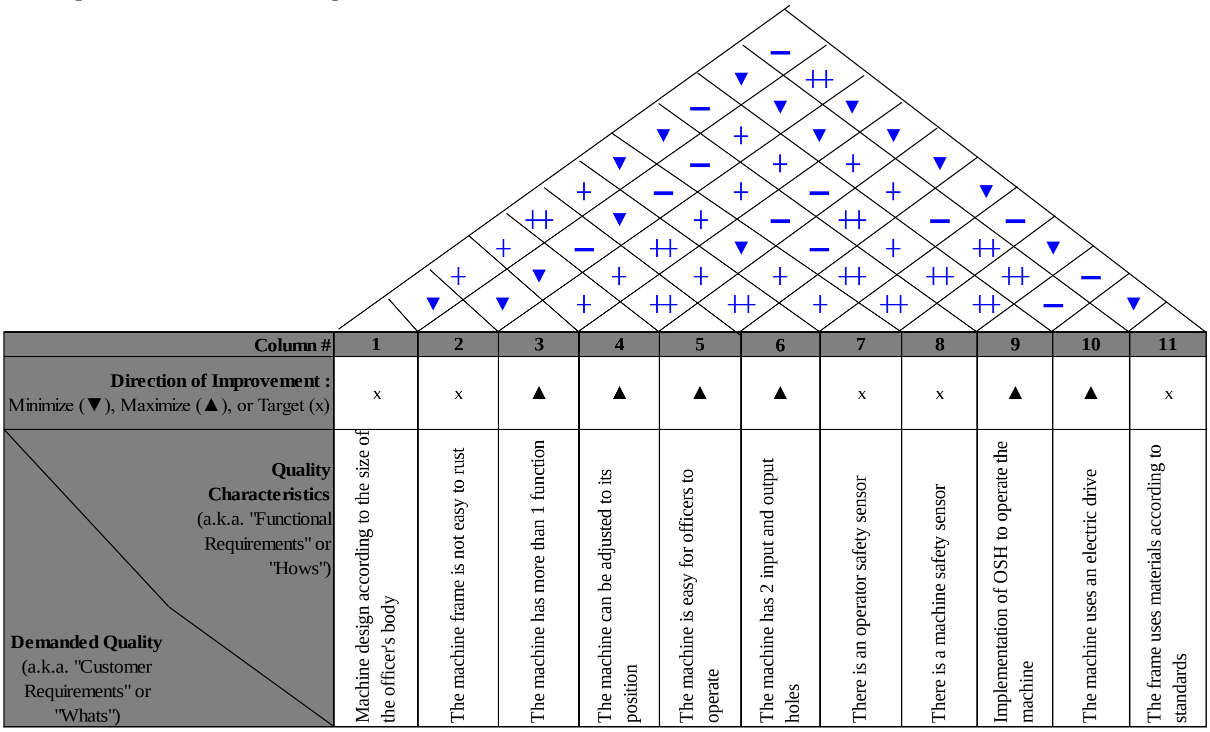
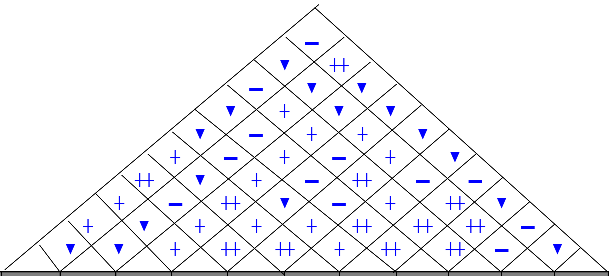


Figure 5: Technical Requirement Correlation

3.12 House of Quality (HoQ) Results

An important stage in the QFD methodology is the House of Quality (HoQ), which visually represents the relationship between user needs and design requirements (Pamungkas, 2020). HoQ includes compiling design specifications and user needs, integrating features and technical attributes desired by customers (Basuki et al., 2020). These customer needs are prioritized and translated into actionable steps for company production, highlighting the importance of the HoQ development stage in the QFD system (Rahmayanti et al., 2018). The final result of the House of Quality (HoQ) consists of 6 (six) charts in total. Below are the overall results of the House of Quality (HoQ) based on the data collection and processing that have been conducted.



Column #	1	2	3	4	5	6	7	8	9	10	11
Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	x	x	▲	▲	▲	▲	x	x	▲	▲	x

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats") / Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	Machine design according to the size of the officer's body	The machine frame is not easy to rust	The machine has more than 1 function	The machine can be adjusted to its position	The machine is easy for officers to operate	The machine has 2 input and output holes	There is an operator safety sensor	There is a machine safety sensor	Implementation of OSH to operate the machine	The machine uses an electric drive	The frame uses materials according to standards	Design Product	Competitor 1	Competitor 2	Goal	Sales Point	Improvement Ratio	Raw Weight	Normalized Raw Weight
1	9	7.9	4.6	Size according to the officer	Θ	▲	O	Θ	Θ	O	▲	▲	▲	▲	▲	5	5	2	4.1	1.5	0.8	5.8	9%
2	9	7.6	4.4	Frame is not easily damaged	▲	Θ	▲	▲	O	Θ	▲	O	O	▲	Θ	5	4	4	4.3	1.5	1	6.3	10%
3	9	7.8	4.5	Easy / long-term machine maintenance	▲	Θ	O	Θ	▲	O	▲	O	O	O	Θ	5	4	3	4	1.5	0.9	5.9	9%
4	9	7.9	4.6	Multifunction	O	▲	Θ	Θ	Θ	Θ	O	O	O	▲	▲	5	2	1	3.2	1.5	0.6	4.4	7%
5	9	6.9	4.0	Has a place to wash garbage	O	▲	Θ	▲	O	▲	▲	▲	▲	▲	▲	4	3	1	3.1	1.5	0.7	4.2	6%
6	9	7.4	4.3	Easy to move / flexible / dismantle	Θ	▲	▲	Θ	O	▲	▲	▲	▲	O	▲	5	4	2	3.7	1.5	0.8	5.2	8%
7	9	7.9	4.6	Easy to use	Θ	▲	Θ	Θ	Θ	Θ	O	O	Θ	O	▲	5	4	2	4.1	1.5	0.8	5.6	8%
8	9	7.9	4.6	Has 2 separate input output holes	O	▲	Θ	▲	Θ	Θ	▲	▲	▲	▲	▲	5	1	1	3	1.5	0.6	4.1	6%
9	9	7.8	4.5	Safety sensor	▲	▲	O	▲	O	▲	Θ	Θ	Θ	Θ	▲	5	1	1	2.8	1.5	0.6	4	6%
10	9	7.9	4.6	Machine safety	▲	▲	O	▲	O	▲	Θ	Θ	Θ	Θ	Θ	5	1	1	2.8	1.5	0.6	4.1	6%
11	9	7.6	4.4	Minimal risk of accidents	O	▲	O	▲	Θ	▲	Θ	O	Θ	▲	▲	5	3	2	3.6	1.5	0.7	4.8	7%
12	9	7.4	4.3	Electric powered	▲	▲	Θ	▲	O	▲	Θ	Θ	▲	Θ	▲	5	4	1	3.6	1.5	0.8	4.9	7%
13	9	7.9	4.6	Sturdy frame	▲	Θ	▲	▲	O	Θ	▲	▲	▲	▲	Θ	5	4	4	4.4	1.5	1	6.7	10%
				Target or Limit Value	The size of the machine is in accordance with the body of the officer with a machine height of 135 cm, a machine length of 170 cm, and a machine width of 78 cm	The machine frame is painted anti-rust	The machine can shred organic and inorganic waste and wash waste	The machine is equipped with wheels and each component is connected with bolts	The machine is in accordance with the size of the officer and uses on and off buttons	The machine can be directly organic and inorganic	The machine is equipped with a photoelectric proximi sensor	The machine is equipped with an inductive proximity sensor	Provision of operational and hazard signs on the machine	Using a 2HP 1 Phase electric motor drive	The frame material uses standard 40, 30 angle materials, 32 mm pipes and 2 mm plates								
				Max Relationship Value in Column	9	9	9	9	9	9	9	9	9	9	9								
				Weight / Importance	346.9	286.2	482.8	411.7	520.3	445.9	377.2	362.4	396.2	331.0	349.7								
				Relative Weight	8.0	6.6	11.2	9.6	12.1	10.3	8.8	8.4	9.2	7.7	8.1								

Competitive Analysis (0=Worst, 5=Best)

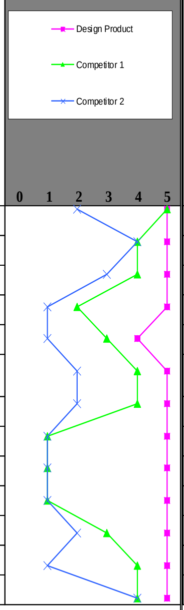


Figure 6: House of Quality Results

Figure 5 above shows that all attributes have a sales point value of 1.5 because the importance rating (IR) value is more than 3, indicating a high sales value or selling power. An improvement rating value below 1 categorizes all attributes as no change. Benchmarking was conducted by comparing the designed waste shredding machine with two competitors: the inorganic waste shredding machine and the organic waste shredding machine, through a customer satisfaction questionnaire. The results show that the designed waste shredding machine has high attribute values and high customer satisfaction. The priority consumer need that needs to be improved is the attribute "sturdy frame" with a normalized raw weight value of 0.1012 (10%), while the attribute "safety sensor" with a value of 0.0604 (6%) is an attribute that needs to be maintained

3.13 Anthropometric Ergonomic Measurement

Anthropometry is the science that focuses on determining the physical characteristics of humans. Humans vary in weight, shape, and size (such as height and width) (Wignjosoebroto, 2003). Anthropometry is an important tool in the development and redesign of products, considering the variations in body sizes across populations, genders, and ethnic groups. This adjustment to product design can be challenging for system or tool designers (Nurzikiresa, 2022). The anthropometric dimension measurements carried out in this study were obtained from direct measurements of body dimension samples of workers at the two largest TPS3Rs in Kudus Regency. Below are the results of ergonomic anthropometry measurements in the research.

Table 13: Results of Anthropometric Ergonomic Dimension Measurements

No	Anthropometric Data	Total	Average	Standard Deviation	Information
1	TSB (Standing Elbow Height)	3670	104,86	2,85	Determining the height of the machine frame
2	JT (Hand Reach)	2716	77,60	1,80	Determining the width of the machine
3	RT (Hand Stretch)	5917	169,06	4,28	Determining the length of the machine
4	TBB (Standing Shoulder Height)	4699	134,26	4,05	Determines the overall height of the machine

3.14 Data Uniformity Test

The data uniformity test is conducted by applying a control chart, which is a suitable tool for testing the uniformity of data obtained from observations (Putra & Jakaria, 2020). The data uniformity test is carried out to determine whether the data obtained is uniform or not. Uniform data is determined by data that does not exceed the upper control limit (UCL) and lower control limit (LCL).

Here are the equations to calculate UCL and LCL in the data uniformity test.

$$\text{UCL} = \bar{x} + k\sigma \quad (5)$$

$$\text{LCL} = \bar{x} - k\sigma \quad (6)$$

Information :

$\bar{x}$ = The average value of the data used

K = Level of confidence

σ = Standard deviation of the data used

Table 14: Data Uniformity Test Results

No	Anthropometric Data	UCL	LCL	Average	Data Uniformity
1	TSB (Standing Elbow Height)	110,33	99,39	104,86	Uniform
2	JT (Hand Reach)	81,20	74	77,60	Uniform
3	RT (Hand Stretch)	177,25	160,87	169,06	Uniform
4	TBB (Standing Shoulder Height)	142,36	126,15	134,26	Uniform

3.15 Data Adequacy Test

The data adequacy test aims to evaluate whether the collected data is sufficient or not. This process is carried out for each dimension used in the design of the waste shredding machine. According to Nurzikiresa (2022), the values for accuracy and confidence are as follows.

a. Level of Trust : K:95% =2
b. Degree of Accuracy : S:10%

$$N' = \left[\frac{k/_{S}\sqrt{N\sum X^2-(\sum X)^2}}{\sum X}\right]^2 \quad (7)$$

Table 15: Data Adequacy Test Results

No	Anthropometric Data	X bar ($\bar{X}$)	Standard Deviation	N	N'	Data Sufficiency
1	TSB (Standing Elbow Height)	104,86	2,85	35	1,15	Sufficient Data
2	JT (Hand Reach)	77,60	1,80	35	0,84	Sufficient Data
3	RT (Hand Stretch)	169,06	4,28	35	0,91	Sufficient Data
4	TBB (Standing Shoulder Height)	134,26	4,05	35	1,42	Sufficient Data

3.16 Percentile

Percentiles represent a specific percentage of a group that has dimensions higher, equal, or lower than that value. This approach allows the development of tools with the ability to be adjusted and customized with flexibility. Percentile values obtained from various anthropometric measurements are generally applied in ergonomic design. Calculating percentiles is a straightforward statistical process (Purnomo, 2013). The 95th percentile indicates that 95% or less of the population is sampled (Yudhistira, 2022). The 5th percentile indicates that 5% of the sample population is at or below that value.

Table 16: Percentile Selection Results

No	Anthropometric Data	P5	P50	P95	Percentile Selection
1	TSB (Standing Elbow Height)	99,7	103	106,3	P50
2	JT (Hand Reach)	67	72	78	P50
3	RT (Hand Stretch)	162,1	170	175	P50
4	TBB (Standing Shoulder Height)	128	135	141,3	P50

3.17 2-Dimensional Design of Waste Shredder Machine

A 2D drawing is a rough sketch of the product design that shows the length, width, and height. The process of making this sketch is very important because it specifically depicts the shape and size of the product from various viewpoints, thus minimizing errors or failures in product manufacturing. The 2D sketch is a crucial foundation for creating the 3D design of the product or its components. Below is the 2D drawing of the designed waste shredding machine.

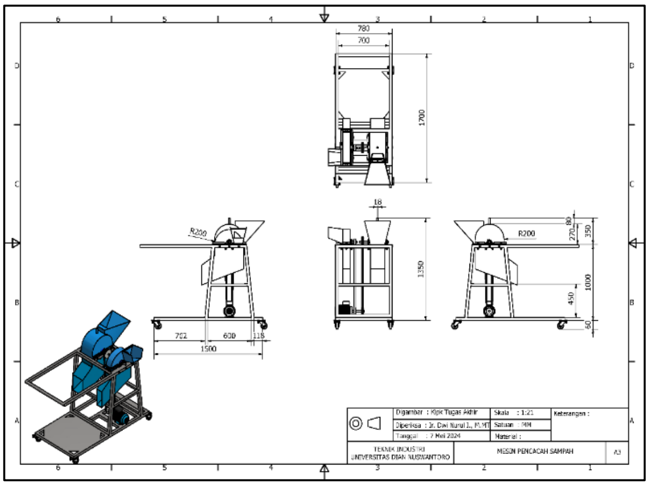


Figure 7: 2D Design of the Waste Shredding Machine

3.18 3-Dimensional Design of Waste Shredder Machine

A 3D drawing is a product design with dimensions that provide a volumetric view similar to real-world objects. The benefits of 3D modeling in product development include the ability to view the design from various perspectives and rotate it 360 degrees, allowing for detailed evaluation of the product, production costs, and design concepts. The 3D design is created using Autodesk Inventor software. Below is the 3D drawing of the designed waste shredding machine.

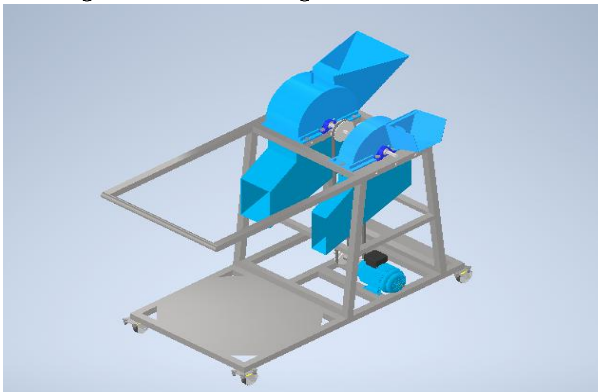


Figure 8: 3D Design of the Waste Shredding Machine

4. Conclusion

The waste shredding machine is designed using the Quality Function Deployment (QFD) method with 13 attributes, namely multifunctional shredding capability, easy to use, size according to the officer, has 2 separate input output holes, sturdy frame, machine safety, easy/long-term machine maintenance, safety sensor, frame is not easily damaged, minimal risk of accidents, easy to move/ flexible, electric powered, and has a place to wash garbage. The design uses reference data from the 50th percentile anthropometry with a frame height of 106 cm, machine width of 78 cm, machine length of 170 cm, and an overall machine height of 135 cm. In future research, further development of the waste shredding machine should consider several aspects not covered in this study to improve the machine. Additionally, future research is also expected to enhance the implementation of occupational health and safety (OHS) to minimize workplace accidents further.

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AUTHORS METADATA

I. **First Author*:**
1. First name : Ary
2. Middle Name : Putra
3. Last Name : Prasetia
4. E-mail : arypp123@gmail.com
5. Orcid ID : 0009-0009-4278-146X
6. Orcid URL : https://orcid.org/0009-0009-4278-146X
7. Affiliation : Universitas Dian Nuswantoro
8. Country : Indonesia
9. Bio Statement : Industrial Engineering Study Program, Faculty of Engineering
10. Phone Number :

II. **Second Author**
1. First name : Mohammad
2. Middle Name : Aunun
3. Last Name : Yusron
4. E-mail : aununyusyus04@gmail.com
5. Orcid ID :
6. Orcid URL :
7. Affiliation : Universitas Dian Nuswantoro
8. Country : Indonesia
9. Bio Statement : Industrial Engineering Study Program, Faculty of Engineering
10. Phone Number :

III. **Third Author:**
1. First name : Dwi
2. Middle Name : Nurul
3. Last Name : Izzhati
4. E-mail : dwi.nurul.izzhati@dsn.dinus.ac.id
5. Orcid ID :
6. Orcid URL :
7. Affiliation : Universitas Dian Nuswantoro
8. Country : Indonesia
9. Bio Statement : Industrial Engineering Study Program, Faculty of Engineering
10. Phone Number :