Comparative Analysis of Cost and Performance of Plastic Shredder Machines Using Heatmap-Based Scoring

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ARTICLE INFORMATION

ABSTRACT

The growing problem of plastic waste requires innovative and sustainable solutions in terms of processing and recycling. One of the key technologies in the recycling process is the shredder machine, which serves to shred plastic waste into smaller sizes before further processing. However, in practice, industry players, especially at the microscale, often face a dilemma in choosing the optimal shredder machine between performance and cost aspects. This research aims to fill the gap by conducting a comparative analysis of three shredder designs based on price and technical performance criteria. The method used in this research involves quantitative measurements of vary in several key aspects, namely: physical dimensions (body area), frame length, transmission system (gearbox and/or clutch), storage capacity, chopper type, motor specifications (power), speed controller, additional features such as presser, foldability, and total price. Furthermore, the data was analyzed using a simple machine learning approach based on heatmap scoring with the help of Python libraries such as Pandas, Seaborn, and Matplotlib. The analysis results show that the 3rd design provides the best performance. This research contributes to data-driven decision making in shredder machine selection, with an approach that combines technical and economic aspects in an integrated manner. The findings are expected to serve as a reference for the development of efficient and sustainable waste plastic processing technology in the microscale industry sector.

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1. INTRODUCTION

Plastic is one of the most widely used materials in everyday life, both in industry and the surrounding environment. Along with the increase in population, economic activity, and development of residential areas, the amount of waste generated by each resident, family, legal entity and trade activities also increases

(Kurniaty et al., 2016). This is due to the advantages of plastic's characteristics of lightness, strength, rust resistance and good sealing properties compared to other material characteristics. However, the high consumption of plastic leads to an increase in plastic waste that is difficult to decompose naturally (Sopyan & Suryadi, 2022). Waste plastics, particularly those made from PET and HDPE, require innovative treatment strategies to reduce environmental impact and increase recyclability, making effective treatment of these materials critical (Indirawati et al., 2023; Muhfidin et al., 2024).

This increasing amount of plastic waste is increasingly becoming a serious problem worldwide, triggering an urgent need for management solutions. One approach that is starting to gain attention in plastic waste management is the use of shredder machines. Plastic shredder machines function to cut plastic waste into smaller sizes so that it can be more easily processed further, either to be recycled into new products or used in alternative energy processes. With the characteristics of plastic that are difficult to decompose, the processing process makes the shredder machine vital to facilitate more efficient recycling and produce waste that is easier to reuse (Evode et al., 2021; M. Muslimin et al., 2023; Prawara et al., 2023).

There are various forms of innovation in the design and development of shredders, much of the existing research still focuses on their efficiency and material strength. (Himarosa et al., 2020; Selan et al., 2021; Soewono et al., 2021; Syaka et al., 2016), There are no scientific studies that systematically compare the performance effectiveness of these machines, especially in the context of the price-to-functional benefit ratio (Ferreira Neto et al., 2021). This creates a research gap in the field of technical and economic evaluation of small and medium-scale waste treatment machines (M. Muslimin et al., 2023; Usman et al., 2021; Wardani et al., 2023). Comparative information of this kind is needed by recycling businesses, especially at the household or small and medium industry (SME) scale, to be able to choose the most efficient and appropriate machine.

It is thus important to explore not only the technical and mechanical potential of the shredder, but also to formulate a cost-benefit analysis that can give the industry better insight into the selection of the optimal machine for waste plastic processing (Rohima et al., 2024; Wardhana et al., 2022). This research was conducted to fill this gap by comparing three shredder designs that vary in size, capacity, motor type, transmission, and additional features such as presser and foldability. The evaluation was conducted based on ten criteria, namely body area, frame length, transmission system, storage capacity, chopper type, motor specification, speed controller, presser presence, foldability, and total price.

In an effort to support the objectivity of the analysis, this research utilizes machine learning-based visualization algorithms using the heatmap method with Python libraries such as pandas, seaborn, and matplotlib.pyplot. Each design is scored based on user preference (the higher the score, the better) reflecting the compromise between price and performance. The visualization results in the form of heatmaps make it easy to identify which designs provide the most significant efficiency and advantages based on these criteria (Holland-Letz & Kopp-Schneider, 2020). By using this approach, the study not only provides data-based information to end-users in selecting the most appropriate shredder, but also expands the utilization of machine learning in the engineering decision-making process. The results of this study are expected to serve as a reference in the development and selection of more efficient and sustainable waste plastic processing technologies.

2. LITERATURE REVIEW
Plastic is a synthetic polymer material that is often used in a variety of products thanks to its lightweight, durable and flexible characteristics. Plastic waste is difficult to decompose and can remain in nature for hundreds of years (Nayanathara Thathsarani Pilapitiya & Ratnayake, 2024). Therefore, it is important to manage and recycle plastic to reduce its negative impact. The use of shredders in the plastic waste recycling process has become a key strategy in supporting circular economy and solid waste reduction (Harjuma et

al., 2024). Previous studies have highlighted the importance of shredding efficiency and machine operational performance in processing plastic types such as PET and HDPE (Damilola Victoria Awe et al., 2024). PET is a common plastic used for beverage bottles and food packaging. It has high strength and moisture resistance (Joseph et al., 2024). HDPE is a plastic that is commonly used in plastic bottles, this plastic has strength and resistance to many chemicals. In addition, HDPE plastic is the type of plastic that produces the most fuel oil (Joseph et al., 2024). The shredder-type plastic shredding machine comes as a mechanical answer, but its implementation still faces a variety of challenges (Anwar et al., 2024).

Most of the previous studies focused on the engineering aspects of machine design or shredding characteristics, without touching the aspects of comparative evaluation between several shredder variants quantitatively. for example, analyzing the impact of knife geometry on the size distribution of PET shreds(Wong et al., 2022), but not considering the relationship with procurement costs or return on investment. In fact, in practice, waste plastic processing industry players strongly consider the cost-to-benefit ratio in choosing a shredder(Kassab et al., 2023). To get good shredding results, several parameters are required. Material selection must be carefully calculated to be durable and efficient. For example, the ideal angle of the blade used is approximately 35°, to produce a blade sharpness that suits the needs of field use (Anggraeni & Latief, 2018).

In this study, a simple machine learning approach based on heatmap visualization was used to assess and compare the performance of three different shredder designs. This technique allows the mapping of key parameters such as shred volume, process speed, energy efficiency, and estimated profit, which are then analyzed alongside cost aspects. Similar approaches are beginning to be used in performance analysis of industrial machinery in general (Vishesh & B, 2007). However, its application in the context of plastic recycling is still very limited. The use of heatmap scoring provides advantages in terms of interpretability of results and ease of comparing multiple designs objectively.

3. RESEARCH METHOD
A. Material
This study used three different shredder designs as comparative test objects. The three designs have configurations and specifications that vary in several key aspects, namely: physical dimensions (body area), frame length, transmission system (gearbox and/or clutch), storage capacity, chopper type, motor specifications (power), speed controller, additional features such as presser, foldability, and total price. Detailed specifications of the three designs are presented in Figure 1 and Table 1. The designs were virtual prototypes developed using CAD software, and the data were processed for comparative analysis based on performance parameters.

(A) (B) (C)
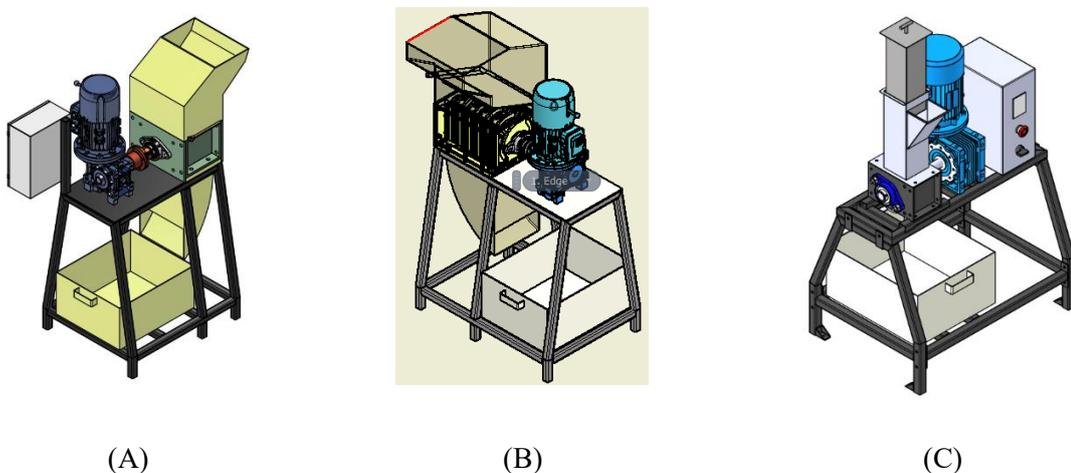
Figure 1. Comparison of three shredder machine design A (A); design B (B); design C (C)

Table 1. Main specifications and features of three shredder machine designs

Aspect	Design A	Design B	Design C
Body Area	359 x 300 x 270 mm	359 x 300 x 270 mm	102 x 102 x 300 mm
Total Frame Length	6.5 m	6.3 m	6 m
Transmission	Gear box + Coupling	Gear box + Coupling	Only gear box
Storage	412 x 350 x 200,97	412 x 350 x 200,97	412 x 350 x 200,97
Chopper	Shredder	Crusher	Shredder
	214 x 300 x 200 mm	214 x 300 x 200 mm	129 x 202 x 135 mm
Motor	2 HP	1 HP	2 HP
Speed Controller	Inverter	Only gear box	Inventer
Presser	305 x 172 x 15 mm	-	90 x 90 x 300 mm
Foldable	No	No	Yes
Price Total	**7.662.500**	**4.712.500**	**7.300.000**

B. Methods

3.1 Assessment Method

The performance evaluation is based on ten criteria that represent a combination of technical and economic efficiency, namely:
- Body Area (the smaller the better)
- Total Frame Length (the shorter the better)
- Transmission (the simpler the better)
- Storage (the bigger the better)
- Chopper (the bigger the better)
- Motor (the smaller the power consumption the better)
- Speed Controller (the simpler the better)
- Presser (its existence provides added value)
- Foldable (allows better mobility and storage)
- Total Price (the lower the better)

Each machine design was scored on each criterion using an ordinal scoring system (1 = poor, 2 = fair, 3 = good), based on the user's ideal preferences and the functional value of the associated features. (D. Muslimin et al., 2023).

3.2 Data Analysis Method

To support visual analysis and data processing, a heatmap visualization algorithm implemented with Python libraries: pandas, seaborn, and matplotlib.pyplot was used. The analysis process was carried out through the following steps:
1. Dataframe Creation: The score data of each design was collected in the form of a dictionary and converted into a DataFrame using pandas.
2. Heatmap visualization: The DataFrame was visualized as a heatmap using seaborn.heatmap() with the YlGnBu color scheme, score annotations enabled, and boundary lines added to clarify differences between criteria.
3. Interpretation: The color and score values on the heatmap were used to compare the relative performance of the three engine designs, and to identify the most optimal design based on the overall criteria.

The Python-based heatmap method was chosen because of its ability to visually display multidimensional relationships, making it easier to make data-based decisions without the complexity of heavier machine learning algorithms. (Keith et al., 2021).

Table 2. Price of main components of shredder machine

Components	Design A (IDR)	Design B (IDR)	Design C (IDR)
Motor	1,800,000	900,000	1,800,000
Gearbox + Coupling	1,925,000	1,925,000	1,600,000
Speed Controller	1,600,000	0	1,600,000
Chopper	2,654,000	1,400,000	1,600,000
Presser	250,000	0	250,000
Folding Frame	0	0	0
Frame	487,500	472,500	450,000
Total (Estimation)	**8,716,500**	**4,697,500**	**7,300,000**

4. RESULT AND DISCUSSION

Before the process of using machine learning, it is necessary to plot the assessment criteria based on price and performance evaluation. Where the detailed price comparison can be seen in table 2. While the performance criteria in question can be seen in subchapter 3.1 Assessment Methods. Comparative Analysis on shredder machine design using machine learning has been successfully conducted. The heatmap visualization algorithm implemented is using Python libraries: pandas, seaborn, and matplotlib.pyplot. The algorithm code used is shown in Figure 2. With the score given using a scale of 1-3, where 3 = very good / excellent, 2 = medium, and 1 = poor.

Based on the results obtained from the heatmap, the value for design A = 20; design B = 21; design C = 26. So based on these values, the design C machine is the best design. Design A has advantages in most technical aspects, such as the size of the knife, speed controller and presser, but lacks in foldability and price. Design B stands out in terms of price, but has weaknesses in the speed controller, presser, and is not foldable, making it difficult to move. Design C has the highest score because it has a small hopper, the shortest frame, simple transmission, without sacrificing storage, and the only foldable design, but it needs to be considered, this design requires a large motor power.
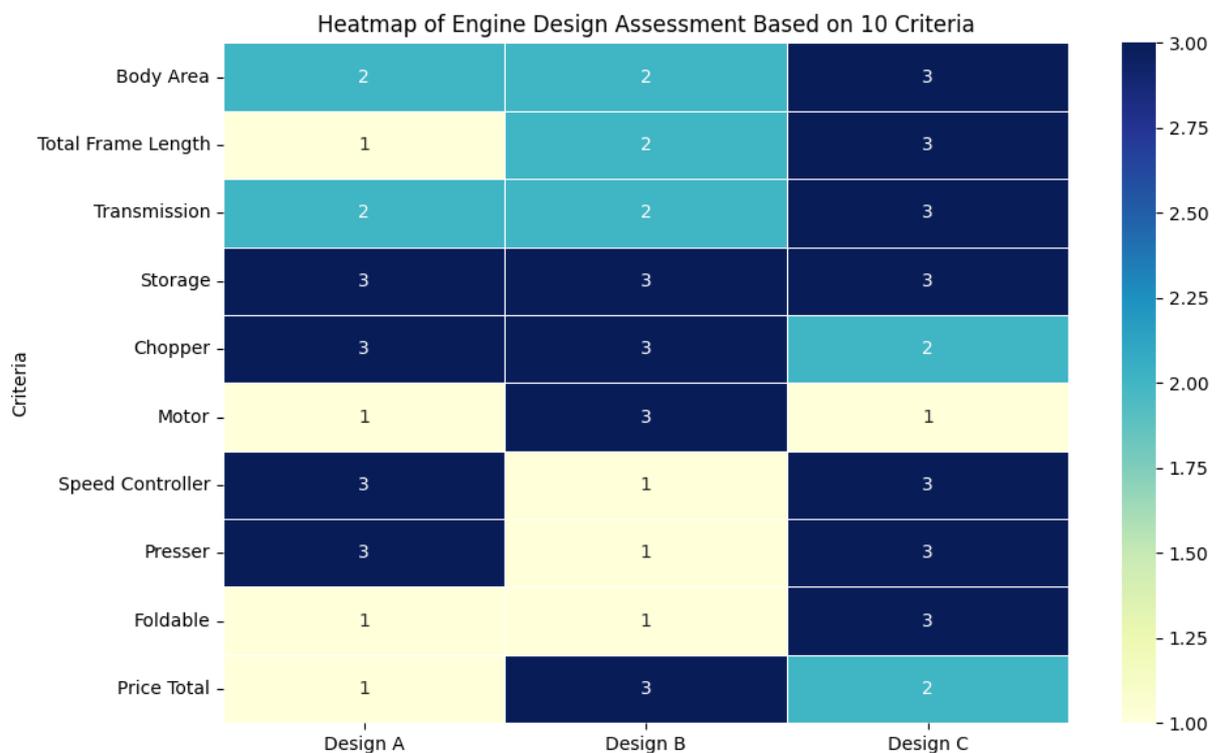
Figure 2. Heatmap design shredder machines

The heatmap visualization in Figure 2 provides an initial insight into the performance of the three shredder designs against ten technical and economic criteria. Design C excels on most technical criteria such as storage, chopper, motor, and physical dimensions (frame length and body area) while maintaining a competitive price score. This suggests that Design C visually consistently meets the high performance requirements, which is consistent with the finding that capacity and output consistency are strongly influenced by motor specification and rotor blade configuration as in previous studies. (Balasubramanian et al., 2020; Caguay et al., 2023). Designs A and B show lower performance in terms of cutting capacity and motor power, but excel in cost and ease of use. This finding is relevant to industry recommendations that small or medium-scale recyclers often require affordable and low-maintenance tools, despite their limited capacity (Wilson et al., 2006).

5. CONCLUSION

The results of the discussion of the design comparison of this shredder machine show that the design that has the highest value is design C. Design C consists of components that have body dimensions of 102 x 102 x 300 mm, the total length of the frame required is 6 m, the transmission is only a gearbox, with storage dimensions of 412 x 350 x 200.97 mm, Pinau Shredder with dimensions 129 x 202 x 135 mm, motor power 2 HP, speed regulator using inverter, has a presser to press plastic bottles with dimensions 90 x 90 x 300 mm, and can be folded so that it is easy to carry, and has a relatively cheap price of Rp. 7300,000. This test aims at planning which has the highest value so that it is feasible to produce. The score between the criteria does not yet reflect the user's priorities. This is an opportunity to develop a Preference Weight analysis method such as AHP to obtain more precise decisions. Henceforth, the results of the comparisons that have been carried out need to be tested for performance, where the performance test is a test that is directly after the machine manufacturing process.

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