Conceptual design for smart organic waste recycling system

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Abstract. Composting can reduce the disposition of food waste, but it is a complex and time-consuming process. In order to shorten the processing time of composting, designing a machine that can provide the optimum condition for the decomposition of food material is needed. This paper presents the development of conceptual design for a smart organic waste recycling system. Customer requirements is identified and translated as engineering characteristics. A total of 5 conceptual design is generated. From the Pugh selection chart and weighted decision matrix, the conceptual concept 1 is selected.

1. Introduction

In Malaysia, 23% of the food waste was contributed by the restaurants [1]. The main causes of food waste in restaurants include over-buying, over-portioning, and poor planning. There are five distinct types of food waste at the restaurant which are storage loss, preparation loss, kitchen leftovers, buffet table leftovers, and plate leftovers [2]. To reduce the food waste being disposed, composting can be used to recycle the food waste.

Composting is a process of decomposition of food material and recycling food material into fertilizer. Compost is the result of various decaying food material. There are two types of composting which are aerobic composting and anaerobic composting [3]. Composting is a complex and time-consuming process as it depends on the microbial activity in the food material. There are many factors that can affect the microbial activity in the food material such as the size, aeration, temperature, and moisture [4].

The composting of food material usually involves the microbes in decomposition process. Some of the pathogenic fungi in the compost can be harmful to human and plant. Pathogenic fungi such as Aspergillus fumigatus can cause serious infections to lungs and other human organs [4]. Generally, most of the pathogens are inactivated effectively at temperature above 50°C. The maximum exposure to high temperatures is thus necessary for the full elimination of pathogenic fungi from compost.

Conventional composting systems usually promote biodegradation of organic materials under neutral to alkaline conditions at temperatures between 40 to 60°C. These composting systems tend to
emit odors and the composting activity normally diminishes with a decrease in pH of the compost. To overcome these disadvantages, a process called acidulocomposting is introduced in composting system under acidic condition. In acidulocomposting, Alicyclobacillus sendaiensis is used as a starter microorganism for food waste composting. From the research paper [5], the degradation of substrate was completed within 24 hours at high temperature (50-70°C). Besides, the pH of the compost is maintained between 3.5 and 6.5 throughout the process. The process was sustained with very low emission of odor and does not require tedious procedures to maintain the process. In this project, we aim to shorten the processing time. In order to achieve this target, we will be focusing on designing a machine that can provide the optimum condition for the decomposition of food material.

2. Need identification

The target market for the organic waste recycling machine will be focused on the operator of eating establishment. 50 operators of eating establishment who currently operating a middle-scale business in Malaysia were selected to answer the questionnaires. Therefore, restaurant operators are suitable candidates to be the target customers. Any eating establishments have small-scale businesses such as hawker stall are not considered.

A questionnaire was designed to investigate the food waste generated and the food wastes management practice on adopting recycling program at restaurants. The questionnaire consists of three sections which are the demographic profile, general overview and problem, and opinion for the design product. The questionnaire consists of three sections: 1. background information of the respondents, 2. general overview such as the amount of food wastes generated, problem encountered, and awareness of the restaurant operators, and 3. respondents’ opinions on the design specification.

It is found that the majority of the respondents (42%) are aged between 30-39 years old. It is found that 42% of the respondents contribute around 20-29 kg of food waste at their restaurants. 26% of the respondents generate more than 30 kg of food waste per day. Also, it is found that majority of the respondents (58%) faced difficulty in managing the food waste generated. The customer requirement of 36 respondents’ feedback who are willing to buy a similar food waste management machine is summarized in Figure 1. The score of the customer requirement is determined. For example, the total score for “User-friendly” is 0(1) + 0(2) + 2(3) + 14(4) + 20(5) = 162. The total scores for each factor are recorded for each customer requirement are further evaluated as the importance weight factor in the house of quality (HOQ) to determine the importance ranking of the engineering characteristics.

![Figure 1. Customer requirements.](image-url)
3. Benchmarking

Table 1 shows the benchmarking conducted on 3 products with the specification shown. Based on Table 1, the operating characteristics of the benchmarking products served as the key performance metrics for the design product that will be measured and used for comparison.

Table 1. Benchmarking of competitive products.

| Products         | Product 1                      | Product 2                      | Product 3                      |
|------------------|--------------------------------|--------------------------------|--------------------------------|
| Aditya OK-30 [6] | Eco-Smart ESF-30 [7]           | Maeko RW30 [8]                 |
| Weight (kg)      | 250 kg                         | 390 kg                         | 260 kg                         |
| Size (mm × mm × mm) | 1000 × 640 × 1150               | 1100 × 850 × 1350              | 900 × 680 × 1300               |
| Processing method | Aerobic composting              | Fermentation decomposition     | Aerobic biotech composting     |
| Duration (day)   | 1                              | 7 (continuous input)           | 1                              |
| Capacity (kg)    | 30                             | 30                             | 30                             |
| Shredding mechanism | Build-in grinder                | -                              | Build-in grinder                |
| Storage compartment | -                              | -                              | -                              |
| Safety aspect    | Emergency stop switch          | -                              | Safety sensor                  |

4. House of quality (HOQ)

House of quality (HOQ) is used to translate customer requirements into generally quantifiable design variables, called engineering characteristics. Table 2 shows the HOQ for the smart organic waste recycling machine. The left side of the HOQ lists is the customer requirement and the importance weight factor derived from the market surveys. The center of HOQ is the Relationship Matrix that shows relationship of the customer requirements and engineering characteristics. An exponential range of numbers (9, 3, and 1) are used to indicate the strength of the causal association between the engineering characteristic of its column and the customer requirement of its row. Each engineering characteristic is considered whether it will contribute to fulfilling the customer requirement in the cell’s row significantly (9), moderately (3), slightly (1) or no impact (left blank).

The calculation is based on the result of customer requirement in market survey in Figure 1. For example, the total score for “User-friendly” is 162 divided by the number of respondents’ feedback who are willing to buy the design product (36). Then, rounding off the value into whole number.

5. Morphological chart

Table 3 shows the morphological chart for the organic waste recycling system design. The chart is generated by listing the product functions on the left side while listing possible solutions or mechanisms on the other side, each viable combination of the solution is selected to be further evaluated.
| Table 2. House of quality |
|---------------------------|
| Improvement direction     | ↑ | ↓ | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ |
| Unit                      | Importance | weight factor | Ease in usage | Processing duration | Capacity | Processing method | Hygiene | Safety | Maintainability | Performance | Cost |
| Customer requirements     |   |   |   |   |   |   |   |   |   |   |   |
| User-friendly             |   |   |   |   |   |   |   |   |   |   |   |
| Ability to process the food waste faster | 4 | 9 | 9 | 9 | 9 | 9 | 9 |
| Ability to process more food waste | 4 | 3 | 9 | 9 | 9 | 9 | 9 |
| Ability to shred the food waste into smaller pieces | 4 | 9 | 9 | 9 | 9 | 9 | 9 |
| Does not emit unpleasant smell | 4 | 3 | 9 | 9 | 9 | 9 | 9 |
| Does not attract flies | 4 | 3 | 9 | 9 | 9 | 9 | 9 |
| Consist of removeable compost storage compartment | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Safe for operation | 5 | 1 | 9 | 9 | 9 | 9 | 9 |
| Raw score (675) | 102 | 72 | 41 | 152 | 72 | 114 | 5 | 108 | 9 | 9 |
| Relative weight % | 15.1 | 10.7 | 6.1 | 22.5 | 10.7 | 16.9 | 0.7 | 16.0 | 1.3 | 1.3 |
| Rank order | 4 | 5 | 7 | 1 | 5 | 2 | 9 | 3 | 8 | 8 |

| Table 3. Morphological chart |
|------------------------------|
| Function                     | Solution |
|------------------------------|----------|
| 1                            | 2        | 3        | 4        |
| Input mechanism              |          |          |          |
| Flap door                    |          |          |          |
| Funnel                       |          |          |          |
| Hatch                        |          |          |          |
| Automated lid                |          |          |          |
| Shredding mechanism          |          |          |          |
| Cutting blade                |          |          |          |
| Single shaft shredder        |          |          |          |
| Dual shaft shredder          |          |          |          |
| Heating mechanism            |          |          |          |
| Band heater                  |          |          |          |
| Coil heater                  |          |          |          |
| Air heater                   |          |          |          |
| Strip heater                 |          |          |          |
| Agitator                     |          |          |          |
| Drum rotation                |          |          |          |
| Rotating screw-sharp rod     |          |          |          |
| Double ribbon                |          |          |          |
| Rotating blade               |          |          |          |
| Body material                |          |          |          |
| Acrylic                      |          |          |          |
| Stainless steel              |          |          |          |
| Aluminum                     |          |          |          |
6. Conceptual design

5 conceptual designs are generated by synthesizing possible combinations of alternatives for each subproblem solution identified in Table 3 and shown in Figure 2. Concepts generated from the chart are checked for feasibility and may not represent viable overall design alternative. The advantage of creating a morphological chart is that it allows a systematic exploration of many possible design solutions.

Figure 2. Conceptual designs.
(a) Concept 1, (b) Concept 2, (c) Concept 3, (d) Concept 4, (e) Concept 5
7. Design selection

5 conceptual designs are generated for the smart organic waste recycling system. The Pugh concept selection process is applied to the set of five concepts to reduce the group to the best alternatives. The selection criteria for the selection process are determined from the development and interpretation from the HOQ in Table 2. The datum of the Pugh chart in Table 4, is Aditya OK-30 model in Table 1. Table 5 shows the weighted decision matrix. Both Tables 4 and 5 show that Concept 1 is the best concept.

### Table 4. Pugh selection chart

| Selection Criteria          | Aditya OK-30 | Concept 1 | Concept 2 | Concept 3 | Concept 4 | Concept 5 |
|-----------------------------|--------------|-----------|-----------|-----------|-----------|-----------|
| Ease in usage               | + - - + +    | 8         | 5         | 4         | 5         | 7         |
| Processing duration         | + - - - +    | 4         | 3         | 2         | 3         | 4         |
| Capacity                    | S S S S S    | 1         | 1         | 1         | 1         | 1         |
| Processing method           | DATUM        | 8         | 5         | 4         | 5         | 7         |
| Hygiene                     | + - - - -    | 1         | 1         | 1         | 1         | 1         |
| Safety                      | + - - - +    | 0         | 3         | 4         | 3         | 1         |
| Maintainability             | + - + + +    | 1         | 1         | 1         | 1         | 1         |
| Performance                 | + - + + +    | 8         | 5         | 4         | 5         | 7         |
| Cost                        | + - - - -    | 8         | 5         | 4         | 5         | 7         |
| # of pluses (+)             | 8            | 5         | 4         | 5         | 7         |           |
| # of minuses (+)            | 0            | 3         | 4         | 3         | 1         |           |
| # of similarity (S)         | 1            | 1         | 1         | 1         | 1         |           |
| Total weighted score        | 8            | 2         | 0         | 2         | 6         |           |

### Table 5. Weighted decision matrix

| Decision criterion   | Weight factor | Concept 1 | Concept 2 | Concept 3 | Concept 4 | Concept 5 |
|----------------------|---------------|-----------|-----------|-----------|-----------|-----------|
| Ease in usage        | 0.11          | 8         | 0.88      | 5         | 0.55      | 5         | 0.55      | 6         | 0.66      | 8         | 0.88      |
| Processing duration  | 0.07          | 8         | 0.56      | 7         | 0.49      | 6         | 0.42      | 6         | 0.42      | 8         | 0.56      |
| Capacity             | 0.03          | 7         | 0.21      | 7         | 0.21      | 7         | 0.21      | 7         | 0.21      | 7         | 0.21      |
| Processing method    | 0.31          | 8         | 2.48      | 6         | 1.86      | 6         | 1.86      | 6         | 1.86      | 7         | 2.17      |
| Hygiene              | 0.07          | 6         | 0.42      | 6         | 0.42      | 5         | 0.35      | 5         | 0.35      | 5         | 0.35      |
| Safety               | 0.22          | 8         | 1.76      | 6         | 1.32      | 5         | 1.32      | 6         | 1.32      | 7         | 1.54      |
| Maintainability      | 0.02          | 8         | 0.16      | 6         | 0.12      | 7         | 0.12      | 6         | 0.12      | 6         | 0.12      |
| Performance          | 0.15          | 9         | 1.35      | 6         | 0.90      | 6         | 0.90      | 6         | 0.90      | 7         | 1.05      |
| Cost                 | 0.02          | 6         | 0.12      | 8         | 0.16      | 7         | 0.10      | 5         | 0.10      | 9         | 0.18      |
| Total weighted score | 7.94          | 6.03      | 5.67      | 5.94      | 7.06      |           |           |           |           |           |           |

8. Conclusion

The conceptual design for the smart organic waste recycling system were developed step-by-step through need identification, benchmarking, translating customer requirements, and selecting the best conceptual design. Market survey was conducted towards 50 respondents. Customer requirements were determined and translated as engineering characteristics: ease in usage, processing duration, capacity, processing method, hygiene, safety, maintainability, performance, and cost. Through the morphological chart, a total of 5 conceptual design is generated. From the Pugh selection chart and weighted decision matrix, concept 1 is the best design among the generated conceptual designs.
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