Application of design for six sigma methodology on portable water filter that uses membrane filtration system: A preliminary study

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Abstract. Portable water filter has grown significantly in recent years. The use of water bottles as a water drink stuff using hand pump water filtration unit has been suggested to replace water bottled during outdoor recreational activities and for emergency supplies. However, quality of water still the issue related to contaminated water due to the residual waste plants, bacteria, and so on. Based on these issues, the study was carried out to design a portable water filter that uses membrane filtration system by applying Design for Six Sigma. Design for Six Sigma methodology consists of five stages which is Define, Measure, Analyze, Design and Verify. There were several tools have been used in each stage in order to come out with a specific objective. In the Define stage, questionnaire approach was used to identify the needs of portable water filter in the future from potential users. Next, Quality Function Deployment (QFD) tool was used in the Measure stage to measure the users’ needs into engineering characteristics. Based on the information in the Measure stage, morphological chart and weighted decision matrix tools were used in the Analyze stage. This stage performed several activities including concept generation and selection. Once the selection of the final concept completed, detail drawing was made in the Design stage. Then, prototype was developed in the Verify stage to conduct proof-of-concept testing. The results that obtained from each stage have been reported in this paper. From this study, it can be concluded that the application of Design for Six Sigma in designing a future portable water filter that uses membrane filtration system is a good start in looking for a new alternative concept with a completed supporting document.

1. Introduction

The use of the membrane as a water filter to treat water for aesthetic purposes by removing chlorine, bad taste, odor, and heavy metals such as lead and mercury [1]. Portable water filter can be used by recreational enthusiasts, military personnel, survivalists, and others who need to get drinking water from sources that are untreated (rivers, lakes, etc.) [2]. However, the use of the membrane as a water filter system is still at the beginning because it requires the design of appropriate filtration system to filter. Therefore, a comprehensive study is needed to design portable water filters using membrane systems.

This study aims to design a portable water filter that uses membrane filtration system using Design for Six Sigma methodology (DFSS). DFSS is a method that can be used to systematically designing a
new product, service, or process. This method focuses on designing products, services or processes correctly the first time so as to reduce the time needed to be spent on improving the product, service, or process. Six Sigma can only take an organization so far, and organizations need to focus on product design and good product, less so where the need for them should they fix for avoidance of mistakes [3]. Quality and profitability of Deming cycle, increasing design quality can lead to higher value customers, which can contribute to increased market share, margins, earnings, and profitability [4, 5]. Most organizations can achieve a 4.5 sigma level through the implementation of Six Sigma projects to improve processes and enhance their products and services through the redesign of products or services [6]. DFSS is a powerful and complex mechanisms that can help to maximize market success of a new product or technology [7]. Nevertheless it must midweek that this concept analysis approach to product design. Design methods Six Sigma uses statistics to analyze different critical parameters specified.

2. Methodology

In this study, the research is about to design a portable water filter that uses membrane filtration system using Design for Six Sigma methodology (DFSS). DFSS that based on DMADV is used. DMADV is one of the most popular design and is defined as Define, Measure, Analyze, Design and Verify [8, 9]. Detail about DMADV as follows:

2.1. Define

Define is the first step in DFSS methods in which this step is to define the project goals and customer needs (internal and external). Thus the user's voice is a priority in proposing and tells the problems that has been faced by customer when using the existing product in the market. This information will be recorded for review.

2.2. Measure

The second step in DFSS is measure which this step is to measure and determine customer needs and specifications. The specification defines the product or service in a way that can be measured, which allows data to be collected and compared with the requirements set.

2.3. Analyze

At this stage, the proposed process or product is analyzed and reviewed to determine whether there is a better way to achieve the desired results. Areas that require adjustments or improvements, both in products and manufacturing processes, are identified. Prototype at this stage and analyzed. The purpose of this step is to come up with alternatives, analyze alternatives, and incorporating alternatives to improve the process or product.

2.4. Design

Based on what is learned in the analysis, it can design the new products and processes. To review the work that has been done, the analysis step is repeated to compare the new design with the features specified. Customers can test the product and the product can be used to test new designs to determine the extent to which they meet the expectations or needs of customers.

2.5. Verify

The fifth step involves confirming that the end result meets or exceeds customer requirements. This includes verifying the product was made as it should be done, and whether it meets the requirements of the specification. This is an ongoing process. Even after the product is released, customer feedback should be encouraged and incorporated into future designs. The desired result is to have products that perfectly meet the needs of the customer.
3. Application of DFSS on Portable Water Filter that uses Membrane Filtration System

In this section, a process of making a portable water filter using DFSS is conducted to illustrate the proposed approach. The DFSS that based on DMADV is presented as follows:

3.1. Define using Questionnaire approach

In continuation to know the needs of customers who use portable water filters, a survey has been conducted on 30 respondents. Survey forms were made to determine the effectiveness of portable water filters that available in the market and also to know the specifications and needs that the user want for a portable water filter in future. The results from this survey is shown in Figure 1.

![Figure 1. Portable water filter using membrane filtration system based on users’ needs.](image)

3.2. Measure using Quality Function Deployment (QFD)

Quality Function Deployment (QFD) is a systematic method in which the structure and development of information design problems. Structure House of Quality (HoQ) is started where the customer needs were define at first and then the weight of the interests of customers were determined. Next, engineering characteristics were identified. Once completed, correlation matrix between customer requirements and engineering characteristics were performed. Assessment was conducted to calculate the score given based on the correlation matrix. Table 1 shows the detail results of portable water filter using membrane filtration system using HoQ technique.

3.3. Analyze using Morphological chart and Weighted Decision Matrix

Morphological analysis is a method to represent and explore all the relationships in multidimensional problems. Morphological methods to help structure the problem to synthesize different components to meet the desired function. This process is made easier to find parts in one catalog. Morphological analysis assists in compiling the findings of research into the structure to enable the processing of information. Table 2 shows morphological chart of portable water filter for membrane and Figure 2 shows several initial sketches that have been generated based on the morphological analysis method.

The weighted decision matrix is a method in the evaluation of the concept. It is used to determine which of the components more suitable for the manufacture of the product. The selection is dependent on the suitability of components and demand based on market research conducted. The highest number of votes will become the weighting of the best and suitable. In this case, several criteria have
been assigned to select which one is the most suitable among the generated alternative solutions from the previous stage. The evaluation and selection using this tool was not presented in this paper due to limited of pages. Based on the results, the third concept of alternative solution has the highest score among the others and certainly was selected for the next stage.

Table 1. House of Quality for Portable Water Filter using membrane filtration system.

| No | Customer Requirements  | Weight (kg) | Number of segments | Height (cm) | Safety (yes/no) | Warranty (year) | Pore size (µm) | Water filter type | Price (RM) | Number of parts | Material types |
|----|------------------------|-------------|--------------------|-------------|-----------------|----------------|----------------|------------------|------------|----------------|---------------|
| 1  | Easy to use            | 0.2         | 3                  |             | 3               |                |                |                  |            |                |               |
| 2  | Durable                | 0.075       |                    |             |                 | 3              | 1              | 9                |            |                |               |
| 3  | Long lasting           | 0.025       | 9                  | 9           | 1               | 3              |                |                  | 9          |                |               |
| 4  | Cheap                  | 0.2         |                    |             |                 |                |                |                  |            | 9              |               |
| 5  | Lightweight            | 0.15        | 9                  |             |                |                |                |                  |            |                |               |
| 6  | Easy to clean          | 0.1         | 3                  | 3           | 3               | 3              |                |                  |            |                |               |
| 7  | Portable               | 0.1         | 3                  | 3           | 3               | 3              |                |                  |            |                |               |
| 8  | Safe                   | 0.05        | 9                  | 9           |                |                |                |                  |            |                |               |
| 9  | Easy assemble and disassemble | 0.1 | 9 | 1 | 1 | | | | | | |

Total: 1.00 2.55 2.1 0.3 0.68 0.23 1.5 0.9 1.8 0.58 1.3

Selected design: 64 15 20 Y 2 15 UF 463 8 PP
Competitor A: 22 6 15 Y 1 0.1 MF 142 2 PP
Competitor B: 40 6 25 Y 2 0.2 MF 131 2 PP
Competitor C: 57 5 18 Y 1 0.1 MF 170 3 PP
New product target: 30 4 15 Y 1 0.1 MF 70 2 PP
Table 2. Morphological chart for selection of suitable components.

| No. | Component           | Alternative 1 | Alternative 2 | Alternative 3 | Alternative 4 |
|-----|---------------------|---------------|---------------|---------------|---------------|
| 1.  | Shutter             |               |               |               |               |
| 2.  | Filter              | Microfiltration | Ultrafiltration | Nanofiltration | Reverse osmosis (RO) |
| 3.  | Bottle              |               |               |               |               |
| 4.  | Filter placement    |               |               |               |               |
| 5.  | Pump type           |               |               |               |               |

Figure 2. Initial sketches from the alternative combinations.

3.4. Design
SolidWorks software was used in this stage to assist in designing a 3D modeling of a portable water filter that based on the proposed concept in the previous stage. Figure 3 shows the 3D modeling of the third concept. This stage is important where the 3D modeling was tested in terms of the suitability of the available components and for proof-of-concept test in the next stage. The drawing includes the actual size of each part and component and the detail assembly as well.
3.5. Verify

In the last stage, verification on the selected design concept for portable water filter was made. This proof-of-concept test is critical since no design or concept has been made currently. For this task, the prototype has been developed. Figure 4 shows several components (mini pump, activated carbon filter, plastic bottle, membrane sheet unit, plastic cup and white garment) and was assembled into a complete prototype of the proposed design concept for the portable water filter that uses membrane as the filter.

After the complete prototype has been developed, several processes were conducted as preparation for proof-of-concept test. A bottle of dirty water from Sembrong river has been prepared. The water has been filled in the prototype for testing process. The water that has been filtered through this process was compared with the original water. Besides the color, turbidity testing also has been used using Genesys 10S UV-Vis Spectrophotometer machine as well. Figure 5 shows the comparison of turbidity readings between original water and filtered water, where the original water is 1.569A and the filtered water is 1.499A. The comparison was about 5% of the original water has been improved. From this result, it can be preliminary concluded that this concept can be further investigated in order to increase the percentage of improvement.

Figure 3. 3D modeling of the third concept for portable water filter.
4. Conclusion
In this paper, a portable water filter that uses membrane as a filter based on Design for Six Sigma approach has been successfully presented. The strength of this approach is the capability to guide a process of development systematically using DMADV: Define, Measure, Analyse, Design and Verify. Several tools were used to comply with these five stages for their specific objective. Define stage used questionnaire survey analysis to collect information from the user. For the Measure stage, QFD tool has been applied to convert the information from the users into engineering characteristics, so that those vague information from the users are capable to be understood in engineering terms. Morphological chart and weighted decision matrix have been used for concept generation and selection in the Analysis stage. For achieving the Design stage, 3D CAD modelling using SolidWorks software has been conducted as a pre-development for prototyping. In the last stage, verification of the proposed design concept has been made for proof-of-concept testing.

In summary, a new design of portable water filter using membrane filtration system has been developed and reported to overcome the stated problem. This study is a part of ongoing research which is about the use of membrane as a filtering system instead of the existing filter. Further works are needed to improve the selected design concept for better quality improvement of dirty water.
Figure 5. Turbidity reading of water before and after filtering process

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