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Original Article

Integration of quality function deployment and value engineering: A case study of designing a Texon cutting tool

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Abstract

This research aimed to evaluate the design of a Texon cutting tool which was done using the concept of integration of quality function deployment (QFD) and value engineering (VE). QFD was used to obtain the variable attributes desired by the operator, priority technical characteristics, and critical parts of the product while VE was used to provide an alternative improvement of materials used to reduce the manufacturing costs. The final stage of the design process was to increase the value of the products for consumers and reduce the costs to be incurred by the manufacturer. To reduce the cost, the design process modified the components by buying materials that have a lower price but have the same quality.

Keywords: product design, quality function deployment, value engineering, brainstorming, Texon cutting tool

1. Introduction

In the actual market situation, manufacturing companies must develop products that can be accepted by the customers, and at the same time the product must be able to give satisfaction to the customer. Product design must be optimized by considering the costs, design requirements, and the value of the product taking into account the customer needs (Prasad, Subbaiah, & Rao, 2011). The success of a product is determined by how a company determines the needs of the customers. The task of the company is to create a strategy to determine the desires of consumers and measure their satisfaction levels based on quality criteria. The company's strategy is strongly related to the design and production processes with the most optimum level of the product quality based on what the customers need (Vavdhara, A.Yadav, L. Yadav, & Ghosh, 2011).

There are several factors that can impact the competitiveness of a company: quality, the speed of delivery, cost, innovation, and product limitations (Olhager & West, 2002). Customer satisfaction and optimizing the total value of the product design is the most important goal for product development time. After defining the design of the product, the production cost can be used to create a new alternative of product design, The company should carefully define the most optimum choices of the alternatives of a product design which is combined with the existing value based on the company's budget (Cariaga, Diraby, & Osmanm, 2007).

A small and medium enterprise in the footwear industry in Medan, Indonesia was selected for this present study. The process of making shoes in this company uses conventional technology and tools that are manual and simple. During the last 5 years, researchers (Ginting, 2016) have studied the development of a Texon cutting tool in the footwear industry. Based on feedback gained from the research, the development of a more in-depth, specific, and structured design of the Texon cutting tool was based on the needs of the operators. Based on the research, the researchers proposed a redesign of the Texon cutting tool using an integration model of the quality function deployment (QFD) method with value engineering (VE) and brainstorming.

The QFD method that was applied to design the Texon cutting tool in this study focused on the matrix called the house of quality (HOQ) which consists of Phase 1 and Phase 2. Meanwhile, the VE method was performed to substitute materials with regard to the quality of the product to reduce the production cost.

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QFD can help a company determine customer needs during the product development cycle. Through QFD, a company can translate customer needs based on current needs at every stage of the product development cycle (Vavdhara *et al.,* 2011). Through VE, the company can analyze the function of the product to produce functional requirements at a total lower cost without compromising the quality of the products (Prasad *et al.,* 2011). In addition, VE focuses on cost management in the production process. This technique provides results whereby the company can minimize production costs by evaluating the details of the product requirements in terms of components which reduces production costs and better meets market expectations.

2. Literature Review

2.1 Quality function deployment

QFD methodology is designed to drive the development of products from conception to production. HOQ is a graphical tool closely related to QFD that is used to display the results of the analysis at the design stage and provides a correlation between the customer needs and technical specifications of the products. It also provides customer perceptions of the product in connection with competing products and opportunities to design (Jaiswal, 2012). QFD was developed by Yoji Akao in Japan in 1966 (Martin & Matheson, 2012). Yoji Akao described QFD as a "method to transform user demands into design quality, to deploy the functions forming quality, and to deploy methods for achieving the design quality into subsystems and components, and ultimately to specific elements of the manufacturing process." (Poel, 2009).

QFD has been recognized as an effective method for integrated product and process development. QFD is a structured approach to integrating the voice of the customers into the product design and development (Jariri & Zegordi, 2008). QFD is a suitable method to implement as a multi-phase process, and QFD offers the greatest potential to achieve significant benefits (Dikmen, Birgonul, & Kiziltas, 2005). The introduction of QFD to America and Europe began in 1983. Today, QFD continues to inspire around the world in academia and industry. It is applied in many industries such as automotive, electronics, construction, and the service sector (Dimsey & Mazur, 2002). The purpose of QFD is to improve the customer satisfaction, organizational integration of customer needs, improve profitability, and develop new products. QFD is a useful approach to maximize customer satisfaction (Annappa & Panditrao, 2012).

The QFD method is known by several names and the most common is the voice of the customer and HOQ (Cariaga *et al.*, 2007). A QFD chart is a tool used by engineers during the design and development phase of new products to better meet customer needs. The information in the QFD chart is arranged, and therefore highlights the relationship between customer demands and the quality characteristics of the product. The QFD chart is a great asset to the product development process because it helps engineers identify key features to be considered during the product design (Dikmen *et al.,* 2005). Since the voices of the customers are needed, HOQ converts any customer requirement into one or more technical requirements in the first phase of QFD. The main objective of the HOQ is to identify customer needs and weights for the product (Whats) and then to convert these requirements into technical requirements (Hows).

HOQ has major benefits that combine customer needs and technical requirements for the designers. The manufacturers can then help the company provide better products, enhance their competitiveness in the market, and increase customer satisfaction (Chin, Lam, Chan, Poon, & Yang, 2005). Each matrix represents every stage of the process and each matrix represents a phase (Bouchereau & Rowlands, 2012).

Four phases of QFD are developed with the intent of creating innovative products that satisfy customer needs, meeting target specifications, achieving cost targets, achieving a product development schedule, and realizing high production yields (Yeh, Jay, Huang, & Yu, 2011). The four-phase approach is done using a series of matrixes that guide the activities of product teams by providing standard documentation for product and process development. Each phase has a matrix that consists of a vertical column "Whats" and the horizontal lines "Hows". "Whats" is customer requirements and "Hows" is the way to achieve them. At each stage, the "Hows" are taken to the next stage as the "Whats". QFD uses some of the principles of concurrent engineering, which is a cross-functional team involved in all stages of product development. Each of the four phases in the process of QFD uses a matrix to translate customer needs from the initial planning stages through production controls. Each phase, or matrix, is a more specific aspect of product requirements. The relationships between the elements are evaluated at each stage. Only the most important aspects of each phase are deployed into the next matrix (Bethany, 2003).

2.2 Value engineering (VE)

VE was developed by Larry Miles during World War II to minimize manufacturing costs. Olhager and West (2002), explained that from the functions of a product the designer can develop alternative solutions that show the same functions but with a lower cost. VE aims to optimize functionality and cost (Dimsey & Mazur, 2002). VE is a technique that identifies the functions of products and services, monitors the value of each function, and provides the needs for the function of a product at a low cost. There are several types of value, namely, the value of usability, cost, price, and exchange value.

VE is a method to reduce production costs by calculating the value of components, equipment, and procedures. There are several stages in VE, namely orientation phase, information phase, functional phase, creative phase, evaluation phase, development phase, presentation phase, and implementation phase. Table 1 shows some QFD integration models with VE which were conducted in several previous studies in designing products. Meanwhile, the relationship between QFD and VE can be described in Table 2.

2.3 Concept of the integration of QFD–VE–brainstorming

Besides having advantages, QFD also has its limitations. Research and studies were conducted on various issues of QFD. For example, Daws, Ahmed, and Moosa

Table 1. Examples of integrating quality function deployment and value engineering in product design.

No	Year	Reference	Product design
1	2002	Jim Demsey, Glenn Mazur	Braking systems
2	2005	Kwai-Shang Chin	Automotive equipment
3	2009	N. Kongprasert, D. Brissaud, C. Bouchard, Ameziane Aoussat, Suthep Butdee	Bags, Clothing
4	2011	K. G. Durga Prasad	Refrigerator
5	2011	K. Yegenegi, M.Arasti, M.Mousakhani	Health center
6	2012	J.H. Farsi, Noraddin Hakiminezhad	Oil pump, air conditioner controller, tractor control system
7	2013	C.M. Annappa, Kallurkar Shrikant Panditrao	Computer desk/desktop
8	2013	Chougule Mahadeo Annappa	Computer desk
9	2014	Leonardo Frizziero	Coffee drink machinery
10	2014	Zahra Karimi, Alireza Jafari	Acicular concrete sleeper
11	2016	Suryanarayana Chowdary Gunnam, Emmanuel S. Eneyo	Smartphone

Table 2. Relationship between quality function deployment (QFD) and value engineering.

Method	What	How
QFD	Identification the customer need	Organizing the customer need
	Determining the customer need with technical characteristic	Determining the level of customer interest
	Designing a target as the level of customer satisfaction rating	Determining the technical characteristic
		Determining the relationship among the technical characteristic
		Determining the rating target
Value engineering	Product positioning into competition	Identify the support and basic functions of the product component
	Reducing the cost, which is balanced with quality	Counting the cost of the component
		Determining the functional cost

(2009), stated that to implement QFD, it is necessary to have a human expert to develop the right attributes, matrixes, and the links between advanced matrixes. For the development of new products, it is not too difficult when everyone is working together and sharing information. However, in the case of modification of existing products to meet changing customer needs, conventional QFD will be modified and the addition of new attributes or matrixes will occur due to the shortage of people who developed the early QFD matrix. Therefore, it is necessary to keep a track record of changes and map the knowledge of the expertise in the development of QFD whenever possible (Dikmen *et al.,* 2005). There are two limitations of QFD.

1) Global limitations

One of the most important challenges in the QFD is quality. Product quality is very important in QFD to improve customer satisfaction. Product quality is quite limited to the company's financial budget, schedule, and technologies used in producing a quality product.

2) Application limitations

Problems in the QFD in the production process are time, resources, and effort. The HOQ matrix in QFD is highly dependent on the process which sometimes causes misunderstandings and miscalculations in determining the target assessment (Jaiswal *et al.*, 2012).

Ginting and Ali (2016), argued that these problems or drawbacks prompted the need for other approaches to be added when applying the QFD method and suggested that combining QFD with other techniques helps to address these drawbacks and can form a basis for future research. Due to the complexity of the deployment, various quantitative methods have been proposed to improve the reliability and purpose of QFD (Chan & Wu, 1998). QFD performance can be improved by combining other product design tools. The concept of integration applied in this study can be seen in Figure 1.

2.4 Research methodology

This research is descriptive in the form of survey research which aimed to obtain proposals for improvements in the product design of a Texon cutting tool that was desired by the operators. This research was conducted at a small and medium enterprise in the footwear industry in Medan, Indonesia. Samples taken in this research were workers or operators (n=8) who used a Texon cutting tool. The sampling technique was the total sampling technique. The research methodology used in this study consisted of several stages (Figure 2). In this study, the researchers focused on QFD Phase 1 and Phase 2. The purpose of applying Phase 1 in this study was to determine the operator complaints, identify variables of the consumer wants and needs of the cutting tool, identify variables that were considered as important technical characteristics, and the relationships among them. Phase 2 is a phase of product design by identifying the critical parts the product and the relationships with the technical response. The instrument used in this study was a questionnaire to identify the complaints of the operators, a digital camera, and open and closed questionnaires to identify the operators needs. A brainstorming questionnaire was used to identify the technical parameters and critical parts. The model of the product design used A software.

3. Results

Step 1: Identify the needs and desires of the user (operator). At this stage, the questionnaire was distributed

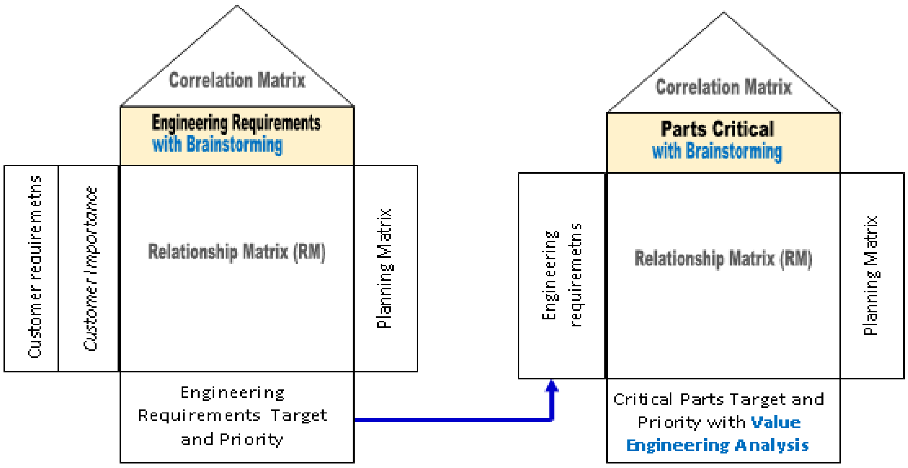

Figure 1. Proposed integration of quality function deployment–value engineering–brainstorming.

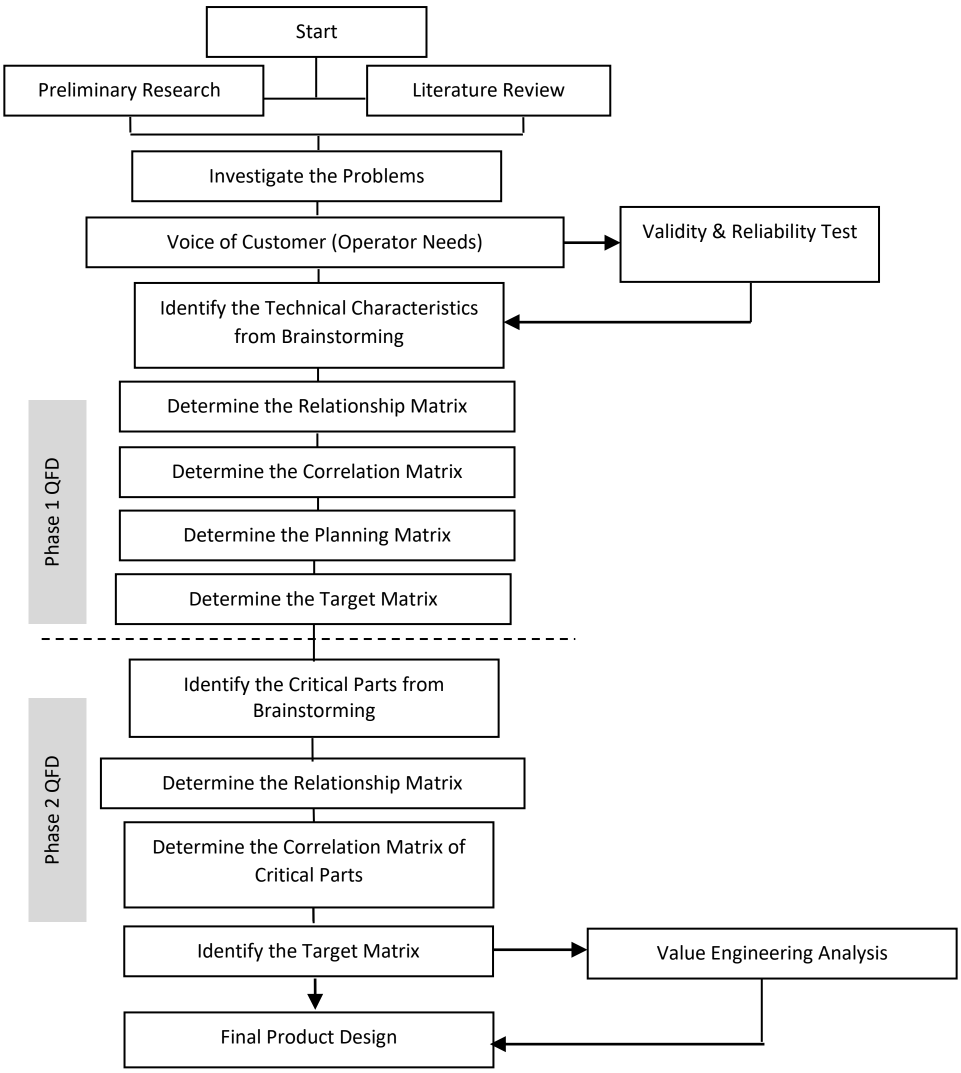

Figure 2. Research methodology.

directly to the operators. The open questionnaire was given to 8 respondents and the sampling technique used in this study was total sampling. The attributes were namely the coating material of the handle, blade material, rod material suppressants, color of the tools, the shape of leg braces, thickness of session frame, thickness of the anvil cutter, thickness of the blade, additional functions, and durability. The results of the questionnaires to determine the attributes of a Texon cutting tool that was needed and desired by the operators are given in Table 3.

Table 3. Summary of the questionnare.

No.	Question	Answer	Quantity	Modus
1	Coating material of handle	Foam Rubber	6 2	Foam
2	Blade material	Cast Iron Iron Stainless	1 4 3	Iron
3	Rod material suppressants	Iron pipe Solid Iron	5 3	Iron Pipe
4	Color of tools	Yellow Blue Green	2 4 2	Blue
5	Shape of leg braces	Elbow Round	6 2	Elbow
6	Thickness of session frame	8 mm 10 mm	5 3	8 mm
7	Thickness of anvil cutter	10 mm 15 mm 16 mm	2 2 4	16 mm
8	Thickness of blade	8 mm 10 mm	2 6	10 mm
9	Additional functions	Table for carton gluing Cutting of Top Pattern	5 3	Table for carton gluing
10	Durability	5 years	1	10 years

Stage 2: Define the customer importance. After the open questionnaires were analyzed, a closed questionnaire was drafted. Respondents gave an assessment of the attributes using the Likert scale method. The closed questionnaire was used to determine the weights and levels of importance of the customer needs as perceived by the respondents and the level of satisfaction based on the expectations of the respondents.

Stage 3: Identify the technical response. Attributes of the technical responses were collected through the open and closed questionnaires which were preceded by brainstorming to determining the attributes on the questionnaire.

Stage 4: Define the relationship matrix. To determine the relationship matrix, the attributes which were translated into technical responses were placed in a vertical column at the left side while the technical characteristics were laid out in the horizontal row at the top. Meanwhile, identification of the relationships between the product attributes with the technical responses was done using the highest scores to identify the technical characteristics that most affected customer satisfaction.

Stage 5: Define the correlation matrix. The next step was to identify the relevant interactions between each of the technical characteristics. In HOQ, the quantity is placed on the roof. Using the roof matrix facilitates the examination of the interrelationship among the technical responses.

The next stage is to determine the targets to be achieved for the measurement of parameters of the technical responses which generate a product that satisfies the customers.

1) Determine the level of difficulty. This was determined from the relationship of the engineering requirements. The calculation was performed by translating all the weights of the relationships and then dividing the weight of each engineering requirement by the total weight. Next, the level of difficulty on a scale of 1 to 9 was given based on the ranges of percentages obtained.

   a) 0–5% degree of difficulty = 1
   b) 6–11% degree of difficulty = 3
   c) 12–17% degree of difficulty = 5
   d) 18–23% degree of difficulty = 7
   e) >24% degree of difficulty = 9

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The level of difficulty of each technical characteristic is determined by Equation 1.

$$\frac{\textit{Weight of each engineering requirements}}{\textit{Total of weight engineering requirements}} \; x \; 100\% \qquad (1)$$

2) Determination the level of interest. This value is the level of importance. It is determined using Equation 2 to calculate the total weight for each relationship between the product attributes and technical responses.

$$\frac{\textit{Weight of each engineering requirements with Attributes}}{\textit{Total of weight engineering requirements with Attributes}} \; x \; 100\% \qquad (2)$$

3) Cost estimation. The estimated cost is a factor of the level of difficulty. The harder the technical response, the greater the cost allocation. The estimated cost is expressed in percent and is influenced by many considerations of the designer.

Stage 6: HOQ of Phase 1. The last stage of Phase 1 of QFD is shown in Figure 3. From the HOQ above, several things can be analyzed.

1) Level of difficulty. Almost all the technical responses were difficult except for the types of material, precision of cutting, and design attractiveness.

2) Level of importance. Very important criteria were indicated in the technical response on the types of material and material strength. The important criteria that were indicated were precision of cutting and design attractiveness. Meanwhile, the ease of grip and comfortable working position had a medium level.

3) Estimated cost. Estimates of the product design cost were quite expensive.

4) Customer perceptions. Attributes 3, 4, and 9 were at a very good level. Attributes 1, 2, 5, 7, and 8 were at a good level. The other attributes of 6 and 10 were at an adequate level.

Stage 7: **Determine the priority of the technical responses.** The technical characteristics from Phase 1 will be used as input for Phase 2.

Stage 8: **Determine the critical parts.** The critical parts were the characteristic parts or priority components of the product obtained from the literature and interviews the experts, such as *contents of steel, thickness of the plate, and temperature of welding.*

Stage 9: **Determine the relationships among the critical parts.** The compilation of design matrix deployment was to compare the relationship among critical parts by analyzing whether the critical part is strong, moderate, or weak.

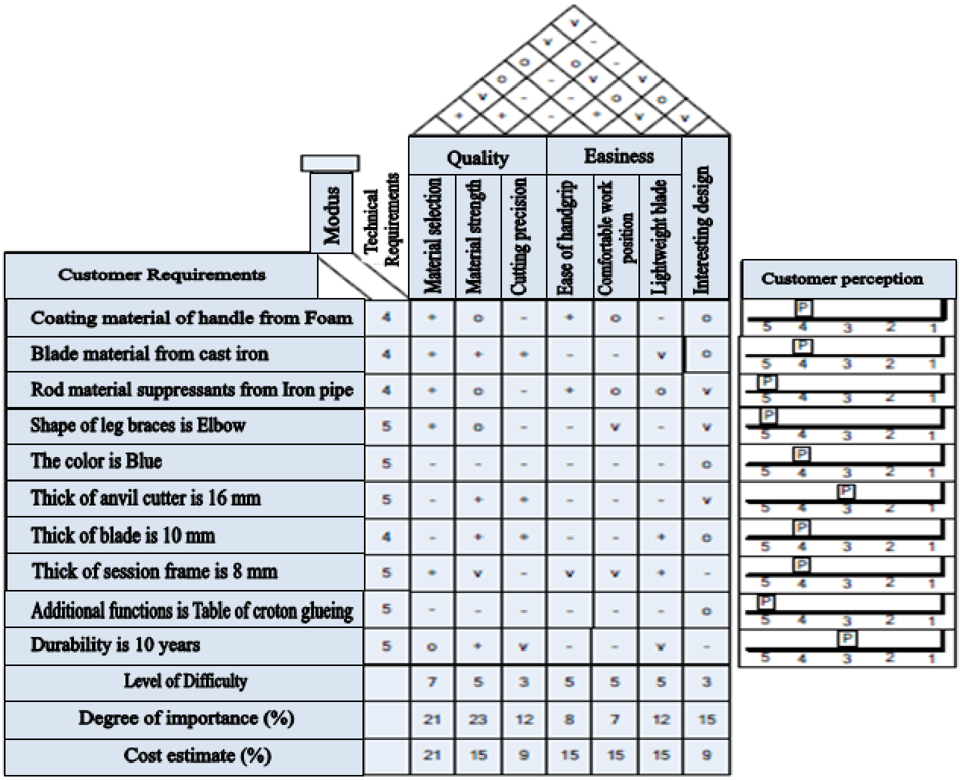
Stage 10: **Determine the relationships between the technical response and critical parts.** This stage was done by comparing the relationships between the technical responses and the critical parts.

Stage 11: **Determine the technical matrix.** Determining the technical matrix was based on performance measures of phase 2 which consisted of three aspects, namely the level of difficulty, the level of interest, and cost estimates.

1) Level of difficulty. The level of difficulty was determined from the relationships of the critical parts. The calculation is done by translating all weight values and then dividing by the weight of each critical part. The level of difficulty is given by the percentage range. The value for the level of difficulty can be calculated by calculating the total weight of the relationships among the critical parts.

2) Level of importance. The degree of the value of importance can be obtained by calculating the total weight for each of the relationships between technical response and critical parts and then using Equation 3.

$$\frac{\textit{Weight of each of engineering requirements with critical parts}}{\textit{Total of each of engineering requirements with critical parts}} x\ 100\% \tag{3}$$



Customer Requirements	Modus	Quality: Material selection	Quality: Material strength	Quality: Cutting precision	Easiness: Ease of handgrip	Easiness: Comfortable work position	Easiness: Lightweight blade	Interesting design	Customer perception
Coating material of handle from Foam	4	+	o	-	+	o	-	o	P at 4
Blade material from cast iron	4	+	+	+	-	-	v	o	P at 4
Rod material suppressants from Iron pipe	4	+	o	-	+	o	o	v	P at 5
Shape of leg braces is Elbow	5	+	o	-	-	v	-	v	P at 5
The color is Blue	5	-	-	-	-	-	-	o	P at 4
Thick of anvil cutter is 16 mm	5	-	+	+	-	-	-	v	P at 3
Thick of blade is 10 mm	4	-	+	+	-	-	+	o	P at 4
Thick of session frame is 8 mm	5	+	v	-	v	v	+	-	P at 4
Additional functions is Table of croton glueing	5	-	-	-	-	-	-	o	P at 5
Durability is 10 years	5	o	+	v	-	-	v	-	P at 3
Level of Difficulty		7	5	3	5	5	5	3	
Degree of importance (%)		21	23	12	8	7	12	15	
Cost estimate (%)		21	15	9	15	15	15	9	

Figure 3. Phase 1 of the house of quality of the Texon cutting tool.

3) Cost estimate. The factors for the level of difficulty were used as the basis of the cost estimate which was expressed in percent and influenced by many considerations of the designer.

The data of the previous steps are summarized using a matrix design deployment. The second phase of QFD can be seen in Figure 4.

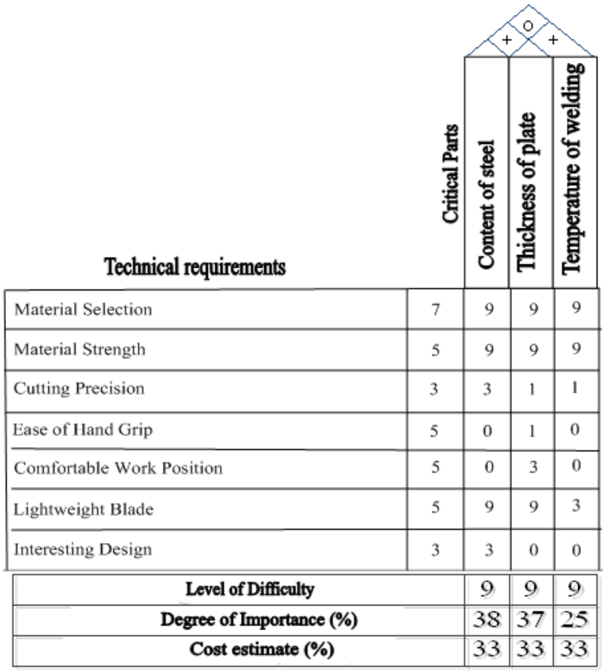


Figure 4. Phase 2 of the house of quality of the Texon cutting tool.

Stage 12. Analysis of product design cost with VE. The final stage of the design process was to increase the value of the product for the customer and reduce the cost to be incurred by the manufacturer. The solution was obtained from the alternatives that existed and then communicated to the customer through a product with all the advantages of its attributes by using VE in these 5 steps.

1) Make a list of the product components and identify the function of each component.

2) Determine the value of the identified functions. Based on the functions that have been identified, specified values were based on the perceptions of the consumers (Table 4).

3) Determine the cost of each component. Prepare a list of the prices as previously determined of the key raw materials, auxiliary materials, as well as auxiliary material for the manufacture of the products. The prices of these components were found at a hardware store (Table 5).

4) Finding the method to reduce cost without reducing the value. After the survey was completed, a cost reduction was obtained to increase the ratio of value to cost. To reduce these costs, a way was sought to reduce the costs but the quality remained the same by modifying the components by buying a blade of iron spring which had a cheaper price but had the same quality and buying round

Table 4. Values of each function.

No	Function	Value	Description
1	Design	Good	The design of Texon is quite unique in blue and the footrest is angled shaped, thus it is not easily shaken when used.
2	Material	Good	Materials used are steel, iron plate, iron pipe, iron axle which have good strength and quality.
3	Dimension	Adequate	The dimensions of this design are the thicknesses of the anvil (16 mm), blade (10 mm), and frame session (8 mm).
4	Quality	Good	The quality of the cutting tool when viewed from durability is of high quality material.
5	Function	Adequate	The cutting tool is expected to have other functions, such as a gluing desk.

Table 5. Prices of each component (existing vs. proposed).

No	Components	Quantity	Existing price (Rupiahs)	Existing cost (Rupiahs)	New price (Rupiahs)	New cost (Rupiahs)
1	Iron spring	25 kg	75,000/kg	1,875.000	40,000/kg	1,000.000
2	Iron plate 12 mm	0.28 m^2	2,263.000/1.2x2.4 m	226,300	2,263.000/1.2x2.4 m	226,300
3	Iron round pipe 1.5 inch, 1.6 mm	0.3 m	59,000/6 m	2,950	50,000/6 m	2,500
4	Iron plate 8 mm	0.28 m^2	1,511.000/1.2x2.4 m	151,000	1,511.000/1.2x2.4 m	151,000
5	Iron elbow pipe 40x30 mm	3 m	78,000/6 m	39,000	78,000/6 m	39,000
6	Iron elbow pipe 10x10 mm	2.7 m	43,000/6 m	19,350	43,000/6 m	19,350
7	Iron axle 4 inch	0.08 m	5,900.000/6 m	78,600	5,900.000/6 m	78,600
8	Iron axle 12.5 mm	0.1 m	411,000/6 m	6,850	411,000/6 m	6,850
9	Screw of axle 0 mm	0.88 m	330,000/6 m	48,400	330,000/6 m	48,400
10	Plywood	0.07 m^2	70,000/1.2x2.4 m	1,700	70,000/1.2x2.4 m	1,700
11	Paint	1 can	20,000/can	20,000	15,000/can	15,000
			Total	2,469.150		1,588.700

iron pipe with a thickness that was smaller but still had the same function as a pressure stem as well as paint component. The paint of another brand was used without changing the color and was more efficient. The cost reductions are given in Table 5.

5) Evaluation of alternatives and selecting the change. By reducing the cost through modifications, the solution obtained is then communicated through the product to the consumer with all the advantages.

After the evaluations were done using VE, the design of the work facilities of the Texon cutting tool is illustrated in the front, side, and top views in Figure 5.

4. Summary

Product design of a Texon cutting tool was designed in this study using the concept of integration methods of QFD with VE and brainstorming. The available alternatives had some weight criteria that were better but there are some attributes that lacked and were not balanced in performance, such as on the properties of the coating material handle, the blade material, and the material and thickness of the stem base oppressor. Improvements could be done in the quality of the materials used to better satisfy the customers through the use of product design such as changing the material of the blade and anvil and changing the material of the rod presses with smaller thickness as well as using a less expensive paint from another brand.

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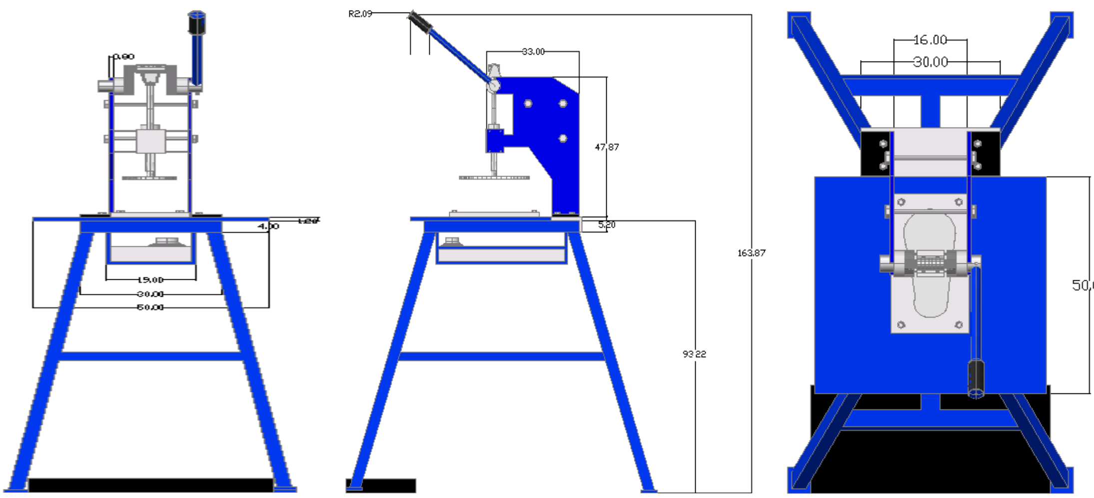

(A) (B) (C)

Figure 5. Design of the Texon cutting tool: (A) front, (B) side, and (C) top views.

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