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*by* Nilda Putri

# The improvement of thresher design by using the integration of TRIZ and QFD approach

Nilda Tri Putri*

Department of Industrial Engineering,
Faculty of Engineering,
Andalas University,
Padang, Indonesia
Email: nilda@ft.unand.ac.id
*Corresponding author

Agus Sutanto

Department of Mechanical Engineering,
Faculty of Engineering,
Andalas University,
Padang, Indonesia
Email: sutanto@ft.unand.ac.id

Nafroh Bifadhlih

Department of Industrial Engineering,
Faculty of Engineering,
Andalas University,
Padang, Indonesia
Email: nafrohbifadhih@gmail.com

**Abstract:** The research described in this paper aimed to propose an integrative method by using quality function deployment (QFD) and TRIZ approach to improve thresher design manufactured by SMEs in West Sumatra, Indonesia. The process consisted of the following stages: 1) identification of the customer needs followed by the determination of their requirements rating; 2) the preparation of QFD phase 1; 3) the creation of QFD phase 2 for technical characteristics which do not contradict with the design characteristics or the selection of alternative solutions using TRIZ for both contradictory characteristics; 4) the thresher design improvement according to the design characteristics in the final stage. The distinctions between the re-design threshers with the reference design were wheels to facilitate mobilisation; screw type threshing teeth design on the threshing cylinder to meet the user need; and the ergonomic feeding table dimension to improve the user convenience.

**Keywords:** thresher; quality function development; QFD; TRIZ approach; consumer requirements; design characteristics.

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**Biographical notes:** Nilda Tri Putri is a Senior Lecturer in the Department of Industrial Engineering, Faculty of Engineering, Andalas University, Padang, Indonesia. She received her Doctor of Philosophy from the Department of Manufacturing and Industrial Engineering, University Technology Malaysia in 2011. Her research interests include quality engineering, quality control, and total quality management.

Agus Sutanto is currently working as a Senior Lecturer in the Department of Mechanical Engineering at the Andalas University, Padang, Indonesia. He obtained his Doctor's degree (Dr.-Ing) in Institute for Factory Automation and Production Systems, University of Erlangen-Nuremberg Germany in 2005. He also obtained a Master's degree (MT) in Mechanical and Production Engineering at Bandung Institute of Technology in 1996. He has more than 15 years of teaching/research interests in the area of manufacturing processes and systems. His research interests presently are web-based planning tools, product-service systems and cloud manufacturing.

Nafroh Bifadhlih is currently working as a Production Planning and Evaluation Supervisor at the WIKA Energy Industry, Wijaya Karya Company. He obtained his Bachelor's degree in Department of Industrial Engineering, Faculty of Engineering, Andalas University, Padang in 2015.

## 1 Introduction

In today's competitive world, it has become essential that small medium enterprises (SMEs) achieve both customer satisfaction and innovative product to remain in the market. In order to reach these objectives, it is necessary that SMEs which produce agricultural machinery know its customers well, identify their requirement and needs as well as manufacture product that can satisfy their customer. Agricultural machinery, (also known as Alsintan) has contributed to improving the yield and quality of agriculture in Indonesia.

Nowadays, the use of Alsintan covers the entire agricultural sectors, especially in the sectors of food crops such as rice. One of the Alsintan that plays a role in the process is the rice harvest thresher. The major and related problems being faced by SMEs agricultural machinery in West Sumatra, Indonesia, was their product did not conform to farmer's requirements. In addition, the product also does not meet the standards that are recognised nationally and internationally.

The success of any new product development (NPD) depends on the identification of customer requirements and their conversion into engineering design requirements (Mehrjerdi, 2010; Sutanto et al., 2015). To do so, the authors reviewed the fundamental concept of some techniques applied by previous researchers in product development. Several researchers have made efforts to integrate (QFD) with other design methods and tools.

Hashim and Dawal (2012) suggested the integration of Kano model with QFD to improve the school workshop's workstation design for adolescent. The analytic hierarchy process (AHP) structure is further included within the QFD framework by Qattawi et al. (2013) who presented a joint QFD-AHP methodology for design decisions of automotive production line, specifically for automotive body-in-white panels. Others have proposed integration with TRIZ and human centred design (Pelt and Hey, 2011) or logical framework approach (LFA) (Buttigieg et al., 2016). Khorshidi et al. (2016) combined SERVQUAL, QFD, and SPC on internal services of train with regard to service quality evaluation and process control. Vinodh et al. (2014) proposed a model which integrates environmentally conscious quality function deployment (ECQFD), TRIZ, and AHP for innovative and sustainable product development of automotive components. They used ECQFD and correlated with TRIZ to determine innovative design alternatives and then, AHP used to obtain the best design in terms of innovation and sustainability.

It is believed that there is a clear need for a framework that could be used to determine the customer requirement lists for product development process. In this research, the integration approach amongst Kano model, QFD, and TRIZ method for thresher design improvement was explored. The objective of this study was to demonstrate how Kano model, QFD, and TRIZ were able to improve the design of thresher through ergonomic design which focused on the relationship of objects and environments with human factors.

## 2 Review of the methods

Kano model implemented in this study to classify the customer needs. Kano model was developed by Noriaki Kano from Tokyo Riko University in 1984 (Kano et al., 1984; Walden, 1993). The main focus of Kano model was to determine customer requirements and exceeded their expectation. There are five categories of requirements which affect customer satisfaction in different ways (Walden, 1993; Sauerwein et al., 1996):

a Attractive (A) – exceed user expectation, however if they are not present, user will not be dissatisfied.

b One dimensional (O) – user will be satisfied if the qualities are fulfilled and dissatisfied if they are not fulfilled.

c Must be (M) – if these requirements are not fulfilled, the customer will be extremely dissatisfied. Meanwhile, as the customer takes these requirements for granted, their fulfilment will not increase his satisfaction.

d Indifferent (I) – these are the requirements that the customers simply do not care if they are present or absent, their satisfaction remains neutral under either circumstance.

e Reserve (R) – the opposite of the one-dimensional category. These are requirements that cause dissatisfaction when present and satisfaction when absent. These are very rare but do happen occasionally.

f Questionable (Q).

According to a recent definition by the American supplier institute, quality function deployment (QFD) is a system for translating customer requirements into appropriate company requirements at every stage, from research through production design and development, to manufacture, distribution, installation and marketing, and sales and services. QFD is a tool documented in a series of matrices to help companies focus on what customers perceive and certify that these desired abilities exist in the final product or service. Normally, it is used before starting on the activities of development, engineering, and production of new products or services. QFD is a set of methods to take all of the information gathered from a firm's customers and potential customers and organise it to facilitate the product development process. QFD is a communication and translation tool. It allows a cross-functional team to share information effectively (Chan and Wu, 2002; Vinayak and Kodali, 2013; Fredendall and Hill, 2012; Iqbal et al., 2015). QFD has been widely used by previous researchers to translate the voice of customers in engineering design quality that fulfils customer satisfaction. Hilmi (2010) used QFD to determine the engineering characteristics of automobile engines that firms have to focus on, in order to design automobile engines for remanufacture. González et al. (2003) design school furniture in developing countries using QFD. Kathiravan et al. (2008) applied total QFD in an Indian rubber processing company. QFD is not only used to design the product in the form of goods, but also widely applied in the field of services such as Ayer and Odegaard (2012) that provided an example of QFD application for retail environment. Gremyr and Raharjo (2013) showed that QFD can be applied in healthcare. They use QFD for improving medication process in the hospital. Haron et al. (2014) developed QFD model to enhance the adoption of industrialised building system in housing projects.

QFD can also combined with other methods in its application. Suguraman et al. (2014) integrated QFD and AHP with total productive maintenance in an automotive accesories manufacturing company to improve equipment effectiveness. They called analytic maintenance quality function deployment (AMQFD) technique. Buttigieg et al. (2016) combined QFD and LFA to improve quality of care in accident and emergency (A&E) unit of a Maltese Hospital. Yeh et al. (2013) proposed a four-phase quality function deployment (QFD) involving TRIZ thinking strategy to enhance breakthrough capabilities for preventative and proactive design in product R&D process.

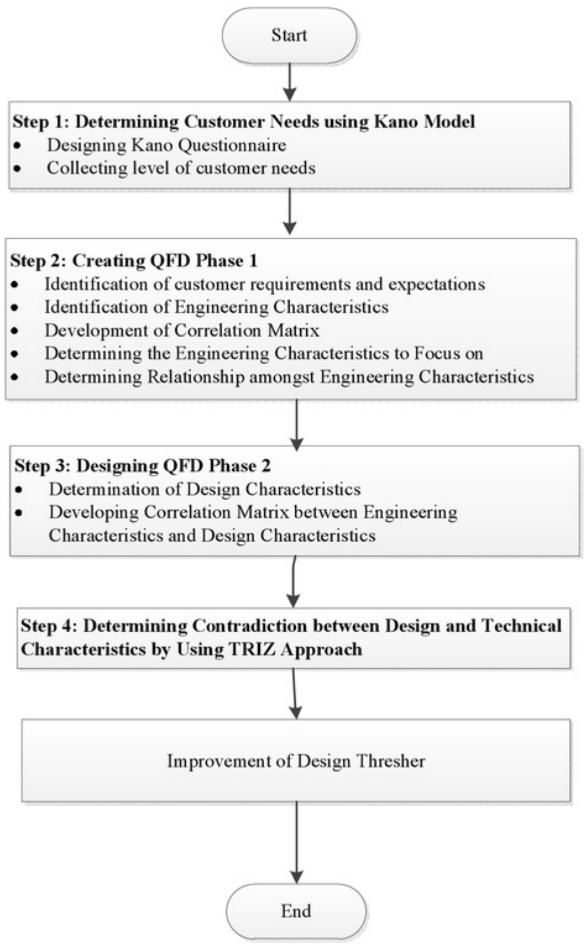
TRIZ is the Russian acronym for Theoria Resheneyva Izobretatelskehuh Zadach that in English means theory of inventive problem solving (TIPS) is developed by a Russian engineer and scientist Genrikh Altshuller. It is aimed at assisting engineers in finding innovative solutions to technical problems in product development processes (Yamashina et al., 2002; Maia et al., 2015; Zhongsheng et al., 2007). It was created in 1946 and TRIZ can be presented as a methodology for problem-solving, ideas-generating and forecasting in innovation, based on logic and data (Renev and Chechurin, 2016). Spreafico and Russo (2016) conducted a critical survey on more than 200 case studies from TRIZ journal and ETRIA TRIZ future conference. They concluded that TRIZ is one of the most powerful and accepted methods to make systematic innovation. TRIZ includes analytical tools that are necessary for problem solving and knowledge-based tools necessary for system transformation and their theoretical foundations. Using all the information about the problems of the products, the analytical tools of TRIZ can be used for transforming, modelling and analysing problems. The main goal of TRIZ method is to find the ideal solution or perfection.

TRIZ methodology depends on four basic paradigms; contradictions; perfection; functionality; and using resources (Ekmekci and Koksal, 2015). Pelt and Hey (2011) revealed that TRIZ practitioners place physical and technical contradictions and potential at the forefront. TRIZ is highly structured approach which is useful in providing structure to clarify relationships and end goals. TRIZ also can be applied in service. Jiang et al. (2012) have been developed a conceptual framework of service system design (SSD). They integrated the two main cognitive gaps into a conceptual developed framework of SSD, the expectation may cause the main cognition gaps to be closer with the real gaps, which will provide an improved guide for further TRIZ service researchers. Muruganantham et al. (2014) applied the concept TRIZ with lean. They have taken case studies in a machine shop. They used lean to reduce waste and find the improvement solutions to increase productivity and TRIZ has been applied to solve the contradictions in identification of the waste problems and better results were obtained.

## 3 Methodology

The research procedures applied in this study is shown in Figure 1.

**Figure 1** Research procedure



### *3.1 Step 1: determining customer needs*

Identification of customer needs was conducted in order to determine the characteristics of the customer's needs or desires regarding to thresher. This identification was undertaken through direct interviews with those who knew and related directly to the thresher such as person in charge in department of agriculture (as controller), thresher producer, and group of farmers as users. In this phase, the Kano approach will be used in determining the customers' requirements and expectations.

This interview was intended as a reference to design the Kano questionnaire. There were nine characteristics of the customer's needs based on the interview. They are as follows: a large threshing capacity; reducing the level of loss of grain; shortening the time of threshing; minimising the amount of dirt panicle; easy to carry/transferred (moveable); affordable prices; product lifespan (durability); comfortable and ergonomic; availability of product usage information.

Nine characteristics of the consumer needs were obtained from interviews and then grouped into five dimensions of quality, i.e., economic aspects, ergonomics, durability, performance, and feature. Based on the five dimensions, the questions on the Kano questionnaire designed, so that it could represent the assessment of each dimension based on preliminary interviews. There were three questionnaires filled out by farmers in this study, i.e., Kano questionnaire; questionnaire level of importance; and satisfaction level.

**Table 1** Quality dimension and its attributes

| *Aspects* | | *Attribute* |
|---|---|---|
| Economic | 1 | Affordable price |
| | 2 | Price according to the quality |
| | 3 | Price according to benefit or function |
| Ergonomic | 4 | Comfortable to use |
| | 5 | Pass to the user's body dimension |
| | 6 | Easy to operate |
| | 7 | Minimise potential injuries (safety operation) |
| Durability | 8 | Highly durable |
| | 9 | Rigid structure |
| Performance | 10 | Short threshing time |
| | 11 | High capacity |
| | 12 | Low grain loss rate |
| | 13 | Slight impurities rate, e.g., stalks |
| | 14 | Efficient working power |
| Others features | 15 | Portable design |
| | 16 | Easy to store |
| | 17 | User manual is available |

Kano questionnaire was designed using two perspectives, namely functional (what was perceived customer if a variable was good) and dysfunctional (what the customer feel if a variable was not good). Functional table was a feeling of customers (farmers) if the variables (questions) on the product thresher functioned; and dysfunctional table was a feeling of customers (farmers) if the variables (questions) on thresher product did not work. Likert scale was used in this Kano questionnaire (scale 1–5). Scale 1 indicated dislike; scale 2 indicated tolerances; scale 3 indicated neutral; scale 4 indicated expectations; and scale 5 indicated like.

Besides, this questionnaire also contained the level of interest and the level of customer satisfaction for each variable. The level of interest represented the expectation of user relating to current thresher, as well as the level of satisfaction represents respondents' judgment about the current thresher. Both questionnaires used Likert scale (scale 1–5). Respondents involved filling and responding to the questionnaire that has been designed were 97 farmers in the cities of Padang and Pariaman district. Cronbach alpha values for all of questionnaires were 1.06 (> 0.65) which means the questionnaires were reliable to be used in this study. Table 1 shows each quality dimension and its attributes.

Kano model aimed to classify the attributes or customer needs. The classification was based on Kano evaluation table which can be seen in Table 2. The next step was to calculate the value of each Kano in each attribute of all respondents. Furthermore, Kano categories for each attribute were determined by using Blauth's formula with the following conditions:

- If the number of values (one dimensional + attractive + must be) > number of values (indifferent + reverse + questionable), then the maximum grade obtained from (one-dimensional, attractive, must be).
- If the number of values (one dimensional + attractive + must be) < number of values (indifferent + reverse + questionable), then the maximum grade obtained from (indifferent, reverse, questionable).
- If the number of values (one dimensional + attractive + must be) = the number of values (indifferent + reverse + questionable), then the maximum grade obtained among all Kano categories (one dimensional, attractive, must be, indifferent, reverse, questionable).

Based on the Blauth's formula, it was easier to identify whether qualities offered would likely fulfil user (farmer) satisfaction or prevent the user from dissatisfaction.

**Table 2** Kano evaluation

| *Customer requirements* | | | *Dysfunctional* | | | | |
|---|---|---|---|---|---|---|---|
| | | | *1 Like* | *2 Must be* | *3 Neutral* | *4 Live with* | *5 Dislike* |
| Functional | 1 | Like | Q | A | A | A | Q |
| | 2 | Must be | R | I | I | I | M |
| | 3 | Neutral | R | I | I | I | M |
| | 4 | Live with | R | I | I | I | M |
| | 4 | Dislike | R | R | R | R | Q |

**Table 3** Kano categories for each attributes using Blauth's Formula

| *Attributes* | *Kano categories* | | | | | | *Grade* |
|---|---|---|---|---|---|---|---|
| | *O* | *A* | *M* | *I* | *R* | *Q* | |
| Affordable price | 77 | 10 | 9 | 1 | 0 | 0 | O |
| Price according to the quality | 34 | 14 | 37 | 12 | 0 | 0 | M |
| Price according to benefit or function | 25 | 31 | 26 | 15 | 0 | 0 | A |
| Comfortable to use | 23 | 29 | 27 | 18 | 0 | 0 | A |
| Pass to the user's body dimension | 10 | 23 | 22 | 42 | 0 | 0 | A |
| Easy to operate | 19 | 18 | 16 | 44 | 0 | 0 | O |
| Minimise potential injuries | 8 | 12 | 26 | 51 | 0 | 0 | I |
| Highly durable | 14 | 11 | 45 | 27 | 0 | 0 | M |
| Rigid structure | 13 | 19 | 27 | 38 | 0 | 0 | M |
| Short threshing time | 32 | 19 | 36 | 10 | 0 | 0 | M |
| High capacity | 20 | 16 | 36 | 25 | 0 | 0 | M |
| Low grain loss rate | 28 | 33 | 18 | 18 | 0 | 0 | A |
| Slight impurities rate | 25 | 26 | 25 | 21 | 0 | 0 | A |
| Efficient working power | 4 | 25 | 9 | 59 | 0 | 0 | I |
| Portable design | 16 | 26 | 15 | 40 | 0 | 0 | A |
| Easy to store | 15 | 15 | 35 | 32 | 0 | 0 | M |
| User manual is available | 7 | 6 | 28 | 56 | 0 | 0 | I |

From Table 3, it is clear that farmer expected the price thresher according to its quality, durable thresher, thresher with strong material; work remove the grain using a thresher could accelerate working time, thresher had a lot of capacity, and easily stored and decided all of these categories as must-be category. However, thresher was sold at affordable prices and thresher easy to operate were classified as one-dimensional category and user would be disappointed if it was not present based on Kano value. Thresher did not cause injury when it was used; a user spent a little energy during the thresher used; and had information on how to use it were defined in indifferent categories. Customer needs defined as attractive category were the price thresher according to its function, thresher which was easily operated, dimension of thresher adjusted to the user's anthropometry, minimum grain loss rate, leaving fewer impurities such as pieces of stems and leaves, as well as easily moved.

## 3.2 *Step 2: creating quality function deployment (QFD) phase 1*

QFD phase 1 was aimed at converting customer needs directly on the characteristics or technical specifications of a product. The results of QFD phase 1 was used as a reference in determining design criteria on QFD phase 2 in this study.

### 3.2.1 *Identification of customer requirements and expectations*

The customer requirements used in this study were mostly focused on the customer needs that could improve the customer satisfaction. The customer needs were classified as one dimensional, attractive, and must be categories. Customer needs classified as indifferent category was not used. The existence of this category in the product would not improve customer satisfaction. Customer requirements used in this study can be seen in Table 4.

**Table 4** Customer requirements

| *Customer requirements* | | *Customer importance level* | *Grade* |
|---|---|---|---|
| 1 | Affordable price | 4,887 | O |
| 2 | Price according to the quality | 4,454 | M |
| 3 | Pass to the user's body dimension | 4,309 | A |
| 4 | Low grain loss rate | 4,299 | A |
| 5 | Portable design | 4,268 | A |
| 6 | High capacity | 4,206 | M |
| 7 | Price according to benefit or function | 4,196 | A |
| 8 | Comfortable to use | 4,165 | A |
| 9 | Short threshing time | 4,144 | M |
| 10 | Easy to store | 4,093 | M |
| 11 | Slight impurities rate e.g. stalk | 4,082 | A |
| 12 | Highly durable | 4,072 | M |
| 13 | Easy to operate | 4,041 | O |
| 14 | Rigid structure | 4,010 | M |

### *3.2.2 Identification of engineering characteristics*

The engineering characteristics in this study were obtained from the results of interviews conducted with thresher manufacturer. The engineering characteristics could be viewed from two aspects, namely in terms of design and raw materials as shown in Table 5.

**Table 5** Engineering characteristics

| *No.* | *Engineering characteristics* |
|---|---|
| 1 | Ergonomic design of the thresher |
| 2 | Dimensions of product |
| 3 | Design of the thresher wheel |
| 4 | Selection of materials types |
| 5 | Using lightweight material |
| 6 | Using strong material |
| 7 | Additional features |
| 8 | Type of machine |

### *3.2.3 Developing the relationships between customer's requirements and expectation with engineering characteristics (development of correlation matrix)*

The relationship between customer requirements and engineering characteristics point to the link between the customer's demands and engineering characteristics required in designing product (Cohen, 1995). Engineering characteristics and the relationships between these engineering characteristics and expectations of the farmers were established by the interviews with the thresher manufacturer. Table 6 shows the symbols and values used to represent the relationship in correlation matrix. For example: in designing thresher, farmer wanted thresher with big capacity. It had strong relationship with the type of thresher used. Due to a big capacity was associated with the type of machine used. The better the machine used, the greater the capacity of thresher, vice versa.

**Table 6** Symbols and relationship values

| *Symbol* | *Relationship* | *Value* |
|---|---|---|
| Blank | No | 0 |
| Δ | Low | 1 |
| ○ | Medium | 3 |
| ❶ | Strong | 9 |

*Source:* Cohen (1995)

### 3.2.4 Determining the engineering characteristics to focus on

This stage was used to determine the priority of engineering characteristics as design characteristics in QFD phase 2. The calculation of priority value of engineering characteristics was obtained by multiplying the rate of customer requirements with relationships value in the correlation matrix between customer requirements and engineering characteristics using the following equation (Cohen, 1995):

$$NP_j = \left(TK_j \times NH_{ij}\right)$$

where:

$Np_j$ Priority value of engineering characteristics.

$TK_i$ Customer importance level.

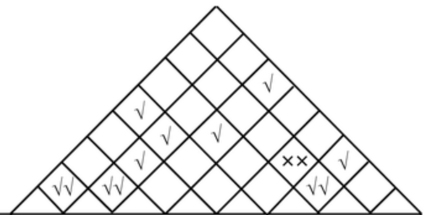
$NH_{ij}$ Relationship values between Engineering characteristics and Customer's requirements.

Table 7 shows the priority values of engineering characteristics which obtained from relationships between customer requirements and engineering characteristics.

**Table 7** Priority values of engineering characteristics

| *Engineering characteristics* | *Priority value* | *Priority* |
|---|---|---|
| Type of machine | 141,84 | 19,3% |
| Design of thresher wheel | 130,02 | 17,7% |
| Selection of materials type | 92,59 | 16,1% |
| Dimensions of product | 101,35 | 13,8% |
| Using strong material | 92,59 | 12,6% |
| Ergonomic product design | 80,31 | 10,9% |
| Additional features | 54,86 | 7,5% |
| Using lightweight material | 16,90 | 2,3% |

**Figure 2** Result of QFD phase 1 for thresher redesign



| | | Technical Characteristics | Design | | | | | Material | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ergonomic product design | dimensions of product | design of thresher wheel | type of machine | additional features | Selection of materials type | Using lightweight material | Using strong material |
| | | TKK | | | | | | | | |
| Consumen Needs | affordable price | 4,89 | | | | | | ⓿ | | |
| | price according to the quality | 4,45 | | | Δ | Δ | | ○ | | ⓿ |
| | pass to the human body dimention | 4,31 | ⓿ | ⓿ | | | | | | |
| | low grain loss rate | 4,30 | | | ⓿ | ○ | | | | |
| | portable design | 4,27 | | ○ | | | ⓿ | | ○ | |
| | high capacity | 4,21 | | | ○ | ⓿ | | | | |
| | price according to its benefit | 4,20 | | | ○ | ○ | | ○ | | Δ |
| | comfortable to use | 4,16 | ⓿ | ⓿ | | | Δ | | | |
| | short threshing time | 4,14 | | | ⓿ | ⓿ | | | | |
| | easy to store | 4,09 | | ○ | | | ○ | | Δ | |
| | low impurities rate e.g. stalks | 4,08 | | | ○ | ⓿ | | | | |
| | highly durable | 4,07 | | | | | | ○ | | ○ |
| | easy to operate | 4,04 | Δ | | ○ | | | | | |
| | rigid structure | 4,01 | | | | | | ⓿ | | ⓿ |
| Absolute priority values | | | 80,3 | 101 | 130 | 142 | 54,9 | 118 | 16,9 | 92,6 |
| Priority in percentage | | | 11% | 14% | 18% | 19% | 7% | 16% | 2% | 13% |

### *3.2.5 Determining relationships amongst engineering characteristics*

Identification of relationships amongst engineering characteristics was determined by the correlation between one technical characteristic with other characteristics. Symbols and level of correlation among the technical characteristics can be seen in Table 8. The degree of the relationships between customer and technical requirements (strong, moderate, and weak) in the middle of the matrix was also assigned. This stage was considerably important since the determination which customer requirements would be implemented into the process as technical requirements due to their importance for the customers. If the value expressed strong relationships, it means that the technical characteristics presented a great influence since one of the technical characteristics was not implemented. For example: the relationship between ergonomic product design and dimensions of product showed a strong relationship. It means that the dimensions of product would greatly affect the ergonomic product design, vice versa.

**Table 8** Symbols and level of correlation

| *Symbol* | *Description* |
|---|---|
| √√ | Strong positive relationship level |
| √ | Low positive relationship level |
| 0 | No relationship level |
| ×× | Strong negative relationship level |
| × | Low negative relationship level |

*Source:* Cohen (1995)

The relationship between the customer requirement and technical characteristics (house of quality for thresher design) can be seen in Figure 2. Results obtained from Kano model were integrated into the house of quality (HoQ). HoQ the completing stage was the important and critical phase to determine certain characteristics as priority to be implemented into a thresher.

### *3.3 Step 3: creating quality function deployment (QFD) phase 2*

QFD approach is widely used to determine design characteristics of a new or improved product design (Hashim and Dawal, 2012). QFD phase 2 is an attempt to translate the technical characteristics into the design characteristics of the designed products. Design characteristics will be used as reference in designing the thresher that could meet customer needs. The technical characteristics that were translated into the design characteristics in the QFD phase 2 was the design characteristics that did not contradict (a negative relationship) on correlation matrix amongst the technical characteristics. Based on QFD phase 1, it was obtained six technical characteristics that were not mutually contradictory and can be seen in Table 9.

**Table 9** Technical characteristics of QFD phase 2

| *No.* | *Technical characteristics* | *Absolute priority values* | *Priority in percentage* |
|---|---|---|---|
| 1 | Type of machine | 141,84 | 19,3% |
| 2 | Wheel design | 130,02 | 17,7% |
| 3 | Materials selection | 92,59 | 16,1% |
| 4 | Dimensions of product | 101,35 | 13,8% |
| 5 | Using a good quality material | 92,59 | 12,6% |
| 6 | Ergonomic product design | 80,31 | 10,9% |

Furthermore, the HoQ for QFD phase 2 was arranged. The arrangement of HoQ for QFD phase 2 consisted of two phases.

### *3.3.1 Determination of characteristics design*

Technical and design characteristics in this study were also obtained through interviews with thresher manufacturer. Thresher manufacturer revealed that to convert the technical characteristics into design characteristics was based on product reference. Some of design variables from product reference were considered good; however there were some variables that required improvement. The results of the interview relating to the technical characteristics which were converted into design characteristics were as follows:

a Type of machine used

The machine used in the product reference was considered good because it had great power and was equipped with a blower. A great power on the machine served to enlarge capacity and accelerate threshing time. Meanwhile, blower served to clean the threshing results from remaining pieces of leaf stems. The machine used was the engine of diesel-powered nine HP equipped with a blower.

b Wheel design

Thresher wheel design on the reference product was good enough, but there were some improvements in the design, especially the improvement on dimensional distance between the teeth thresher (spur). Installation of spur at a certain distance greatly affected the performance of thresher. If the distance between spur enlarged, the thresher would have speedy time of threshing and also reduced the amount of residual threshing. However, this could lead to great losses. Conversely, if the distance between spur reduced, then the amount of shrinkage would be smaller, yet the threshing time became longer and increased the amount of residual threshing. In addition, the design of spur used was screw type (resembling bolt) which aimed to facilitate the dismantling and installation, so that the distance between the teeth thresher can be adjusted according to customer's requirements.

c Material selection

The material used in producing the thresher was mostly L-shape structural steel aluminium plate, and other common structural steel shapes. Considerations in the selection of the types of material were light and low price compared to other materials. Therefore, the use of this material could reduce the cost of production that affected to the price of the product. L-shape structural steel was used to produce the thresher frame and thresher wheel, while other common structural steel shapes and aluminium plate were used to manufacture the body structure of the thresher.

d Ergonomics design and product dimension

The ergonomic thresher design could be obtained by passing the anthropometric data of farmers to product dimension. The adjustment of thresher's dimension by using anthropometric data was performed on the height of feed table, which aimed to increase the comfortableness. However, other thresher dimensions used the dimension of the reference product. Table 10 shows the design characteristics of thresher based on customer preferences.

**Table 10** Design characteristics

| *No.* | *Design characteristics* |
|---|---|
| 1 | Driven unit has a big power |
| 2 | Driven unit is equipped with a blower |
| 3 | Reduce spacing between threshing teeth |
| 4 | Increase number of threshing teeth |
| 5 | Type threshing teeth |
| 6 | Frame using L-shape structural steel |
| 7 | Body structure using Al-plate and structural steel |
| 8 | Using anthropometric data |

### *3.3.2 Correlation matrix between engineering characteristics and design characteristics*

The correlation matrix shows the interrelation between technical characteristics and design characteristics of the designed product. This correlation matrix can be seen in Figure 3.

**Figure 3** Correlation matrix of thresher design

| | | design characteristics | drive unit has big power | drive unit is equipped with a blower | reduce spacing between the threshing teeth | increase number of threshing teeth | screw type threshing teeth | frame using L-shape structural steel | bodystructure using Alu-plate and other structural steel shapes | using anthropometric data | using standardized dimensions |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CIL | | | | | | | | | |
| Technical Characteristics | type of machine | 19,3 | ● | ● | | | | | | | |
| | whell design | 17,7 | | | ● | ● | ● | | | | |
| | materials selection | 16,1 | | | | | ○ | ● | ● | | |
| | dimensions of product | 13,8 | | | | | | | | ● | ● |
| | using high quality material | 12,6 | | | | | Δ | ○ | ○ | | |
| | ergonomic product design | 10,9 | | | | | Δ | | | ● | ● |
| Absolute Priority Values | | | 173 | 173 | 159 | 159 | 231 | 182 | 182 | 222 | 222 |
| Percentage Priority | | | 10% | 10% | 9% | 9% | 14% | 11% | 11% | 13% | 13% |

### 3.4 *Determining contradiction between design characteristics and technical characteristics by using TRIZ approach*

Design characteristics which had contradiction with the technical characteristics in HoQ matrix could not be solved by using QFD phase 2. However, the TRIZ method could be used to resolve the alternative solution. TRIZ methodology categorised the technical characteristics which posed negative relationships with other technical characteristic as specific problem. By using 39 engineering parameters of TRIZ method, the specific problems must be converted into general problems. Furthermore, the general problems identified in the previous stage ware then grouped together to form the TRIZ Contradiction Matrix. The general problems then were classified into improving parameters and worsening parameters. Improving parameters impacted positively for the customer while worsening parameters deteriorated the result. The last stage of TRIZ method was the determination of alternative solutions by using 40 inventive principles of TRIZ.

The technical contradiction in the previous HoQ was additional features and light. An additional feature for redesigning the thresher was the usage of wheels to facilitate the ease of handling and mobility of the thresher. And at the same time the use of light material was intended to make product lighter for it to be easily moved and positioned. Both of these characteristics contradicted each other because the additional features will increase the weight of the product. Table 11 shows this contradiction matrix.

**Table 11** Contradiction matrix

| | *Improving parameter* | *Worsening parameter* |
|---|---|---|
| Specific problems | Additional features | Using light weight material |
| | Ease of handling and movable | Addition of weight |
| General problems | Ease of operation (33) | Weight of moving object (1) |

Table 11 shows additional features which are generalised into the ease of operation (33). This generalisation corresponded with the problem on how to ease handling and moving the product. On the other hand, the technical characteristic for using light material is generalised into *weight of moving object* (1). After finding out the contradictions between the technical characteristics and then generalised them, the next step is to propose a solution. This was selected from the 40 inventive principles. The contradictions matrix for the solution for this contradiction can be seen in Table 12.

**Table 12** Contradiction matrix: ease of operation vs. weight of moving object (see online version for colours)

| *Worsening feature* / *Improving feature* | | *Weight of moving object* | *Weight of stationary object* | *Length of moving object* |
|---|---|---|---|---|
| | | *1* | *2* | *3* |
| Ease of manufacture | 32 | 28, 29 | 1, 27 | 1, 29 |
| | | 15, 16 | 36, 13 | 13, 17 |
| Ease of operation | 33 | 25, 2 | 6, 13 | 1, 17 |
| | | 13, 15 | 1, 25 | 13, 12 |
| Ease of repair | 34 | 2, 27 | 2, 27 | 1, 28 |
| | | 35, 11 | 35, 11 | 13, 12 |

The alternative solution that could be used to resolve the contradiction problem was using principles 25, 2, 13, and 15 (Table 12). Explanations of each alternative solution were:

- Principle 25: self-service, self-organisation.
- Principle 2: extraction, separation, removal, segregation.
- Principle 13: the other way around, inversion.
- Principle 15: dynamicity, optimisation.

Based on the four principles, then a suitable solution for this issue was TRIZ principle 15 dynamics. This principle suggested the optimal wheel design by making the lighter wheels (using a light material) such as wheels used on mountain bike.

## *3.5 Improvement of thresher design*

The product design conducted on this study was based on the reference product. Design modification was undertaken based on design characteristics which suited the customers need. Figure 4 is the comparison of the reference product with the new designed product.

**Figure 4** (a) Existing thresher (b) Redesign thresher (see online version for colours)

(a)

(b)

There were some distinctions between reference and re-designed thresher as follows:

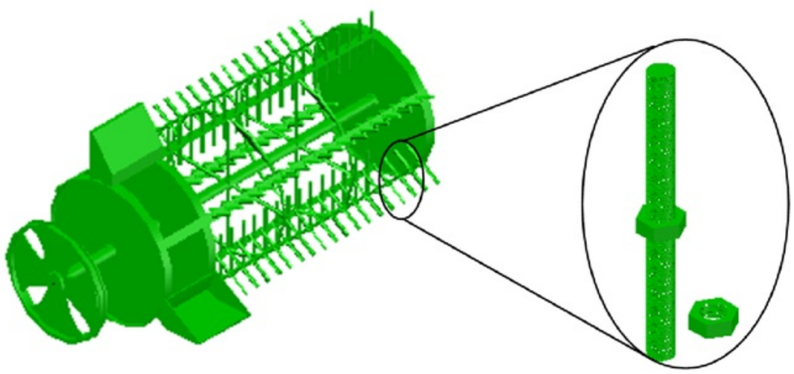
a The application of the anthropometry data on the reference thresher

The anthropometry data used on the re-designed product was standing elbow's height data and stretching distance data of the both elbows with the percentile of 50. Both these anthropometric data were utilised in designing the dimension of the feeding table. Data of the standing elbows' height was used for the height of the feeding table from the ground, while the stretching distance of the elbows was used for the length of the feeding table. The purpose of the data use on this feeding table was to set operator's position while working since the operator's working field when operating the machine located at this point so that the product could be more ergonomic. While the selection of the 50th percentile on the dimension of the feeding table was conducted due to the fact that it could accommodate the operator's body dimension generally; therefore, the design of the feeding table could be utilised comfortably to all ranges of the bodies' dimension, not only for those who had proportional bodies but also who had extra ordinary's dimension.

b Re-design of threshing cylinder

Re-design of threshing cylinder was performed on their threshing teeth. The spacing between the threshing teeth was reduced and the new threshing teeth were designed with screw type in order to simplify maintenance and adjust the spacing of the teeth. Figure 5 shows the improved design of the threshing cylinder and their threshing teeth.

**Figure 5** Redesign of threshing teeth on the cylinder (see online version for colours)



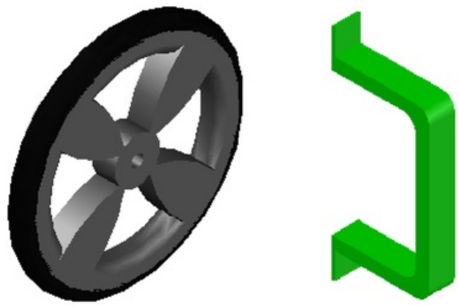
The default distance between threshing teeth on the re-designed thresher was 2.3 cm. However, the spacing between teeth can be extended at a distance of 4.7 cm by releasing one tooth among them. This ease of assembly and disassembly requirement is facilitated with a screw-type rod and two bolts, which joined at the part of the threshing cylinder (see Figure 4). By using this design, the users which require a low grain loss rate can be used the default threshing teeth at a distance of 2.3 cm.

However, if the users require a short threshing time, then the users can extend the distance between threshing teeth at a distance of 4.7 cm.

c Increasing the number of wheels

Increasing the number of wheels on the designed products aimed to ease the product's movements. The wheels which would be attached to this product were bicycle's wheels as they were fairly light. Besides, the product was also equipped with a handle to lift it; thus for a threshing undertaken in the middle of the rice field (difficult access), this product was light and portable. Figure 6 depicts the wheels and handle's shape used on the designed product.

**Figure 6** (a) Wheel (b) Handle (see online version for colours)



(a) (b)

Based on the QFD and TRIZ methods, there was a design's necessity in order for the final product could fulfil the needs of the customer. Table 13 shows the evaluation of design need application comparison on the reference products that were existing thresher and designed thresher.

**Table 13** Evaluation of design need application comparison

| *Design characteristic* | *Existing thresher* | *Re-design thresher* |
|---|---|---|
| Screw type threshing teeth | - | √ |
| Using anthropometric data | - | √ |
| Using standardised dimensions | √ | √ |
| Frame using L-shape structural steel | √ | √ |
| Body structure using Alu-plate and structural steels | √ | √ |
| Drive unit has big power | √ | √ |
| Drive unit is equipped with a blower | √ | √ |
| Reduce spacing between the threshing teeth | - | √ |
| Increase number of threshing teeth | - | √ |
| Equipped with transport wheel | - | √ |

From Table 13, it is clear that the new designed product was better in fulfilling the customers' needs compared to the reference design since it has met every design need based on the customers' needs while the reference product only complied to 5 out of 10 design needs.

## 4 Conclusions

The combination of QFD, TRIZ, and Kano approach created a conceptual design from thresher that suited the customer preference. Product design modification was conducted according to the design's need obtained. The significant difference between the new designed thresher and reference designed was the new thresher designed using wheels for easier mobilisation; threshing teeth design on the threshing cylinder designed by using screw-type threshing teeth with bolts in order to meet the user need and the feeding table dimension on the threshing machine designed utilising anthropometry data to lead the operator's working position at ease. Future research will try and fabricate this newly designed thresher and put it to use by farmers in Padang, Sumatera for further enhancement and improvements.

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