Journal of Current Science and Technology, September-December 2023 Vol. 13 No. 3, pp. 695-707

ISSN 2630-0656 (Online)

Cite this article: Wongsangnoi, P., Pianthong, N., and Pannucharoenwong, N. (2023). Using quality function deployment for the rubber sheet machine design. *Journal of Current Science and Technology, 13*(3), 695-707.
https://doi.org/10.59796/jcst.V13N3.2023.1276

Journal of Current Science and Technology

Journal homepage: https://jcst.rsu.ac.th

Using Quality Function Deployment for The Rubber Sheet Machine Design

Phanuwat Wongsangnoi[1], Nalin Pianthong[1*], and Nattadon Pannucharoenwong[2]

[1]Department of Industrial Engineering Faculty of Engineering, Ubon Ratchathani University, Ubon Ratchathani 34190, Thailand
[2]Department of Mechanical Engineering Faculty of Engineering, Thammasat School of Engineering Thammasat University 12120, Thailand

*Corresponding author; Email: nalin.p@ubu.ac.th

Received 18 May, 2023; Revised 2 June, 2023; Accepted 27 June, 2023;
Published online 30 August, 2023

Abstract

The purpose of this research was to improve the process and production process of flat rubber sheets by using the Quality Function Deployment technique (QFD) since the traditional rubber sheet production process is human-intensive causing fatigue and delays. The customer needs were identified by groups of rubber farmers in Sakon Nakhon, Nakhon Phanom, Mukdahan, and Bueng Kan Provinces in Thailand. The house of quality (HoQ) of QFD was then applied to translate the customer needs into design targets. The Theory of Inventive Problem Solving (TRIZ) was applied to minimize conflicts between technical requirements. An experiment was designed to determine the optimum speed and distance between the rolls. The results showed that the optimal motor speed was 400 rpm and the optimal distance between the rollers in rubber sheet extrusion was 3.0 millimeters. The average measurements for width, length, and thickness were 448, 849, and 3.82 millimeters, respectively. These measurements align with raw rubber sheet standard 2, where the thickness of the sheet should not exceed 4 millimeters and the weight should not surpass 1,200 grams. The production process was streamlined from 19 steps down to 14. Additionally, the product movement distance was reduced from 16.90 meters to 10.25 meters, and the production time decreased from 263 minutes to 187 minutes for a batch of 60 sheets. The developed rubber sheet machine has reduced the production time by 76 minutes for 60 sheets, with *a*high customer satisfaction level (Mean 4.63, S.D. = 0.49).

Keywords: *Quality function deployment; TRIZ; Rubber sheet machine; DOE; Rubber; Machine Design*

1. Introduction

The agricultural industry has long been a cornerstone of global economic growth. Even today, it is the industry with the highest share of total domestic product in many countries, especially in developing countries. In addition, other industrial sectors are often involved in the agricultural industry, for example, the use of agricultural products as raw materials for processing which leads to the creation of new products. (Thangphisityothin et al., 2020). Rubber is an important economic crop in Thailand. Currently, Thailand boasts over 23 million rubber plantations spanning more than 60 provinces and produces 4.90 million tons of natural rubber per year, making it the world leader in rubber exports. In 2018, Thailand exported rubber worth over 4.60 billion US dollars.

Currently, numerous countries are grappling with social well-being issues stemming from an aging society, accompanied by a declining trend in the younger population. For Thailand, the elderly population has an increasing rate of 3% per year, while the young population has an increase of approximately 0.5 % per year. In 2022, Thailand officially became an aging society (Jarinthong et al., 2017). The importance of the elderly issue does not depend solely on the increasing number of people, but it depends on the quality of the elderly's life as well. This can be attributed to the challenges that arise with elderly farmers, as they experience physiological changes that lead to deterioration in physical and mental health, etc. (Chewasopit, 2019).

The agricultural sector plays an important role in driving Thailand's economy. In 2015, the agricultural sector accounted for 13 million workers, or 34% of the total workforce. When examining the ages of workers in the agricultural sector, there was a noticeable decrease in the 15-24 and 25-39 age groups. Conversely, the number of workers in the 40-59 and 60+ age groups showed a continuous increase (Wirojsattabut et al., 2019).

The production of traditional flat rubber sheets involves numerous steps, with a particular emphasis on the process of rolling them flat. This intensive process often leads to worker fatigue. Moreover, the distinction between smooth rolling and pattern rolling necessitates the use of specific machines, leading to 'MUDA' — inefficiencies like waiting time, unnecessary adjustments, reworks, excess inventory, overproduction, frequent movement of people or machines, and suboptimal production methods, such as relocating rubber to different rolling machines. These inefficiencies delay the rubber sheet flattening process, especially since pressing the rubber sheet is inherently time-consuming. Furthermore, each time the sheet is rolled, there's a noticeable variation in its width, length, and thickness due to uneven pressure applied during the process. Currently, production is conducted manually. Additionally, the average age of agricultural workers is on the rise, which can affect labor productivity. Consequently, this research aims to employ the quality function deployment technique to design and develop a rubber sheet machine. Another objective is to compare the rubber sheet production process before and after the improvements, enhance the production rate, and address the challenges posed by an aging workforce as the agricultural sector progresses towards an aging society. This transition is illustrated in Figures 1 and 2.

1.1 Literature Review

Quality Function Deployment technique (QFD) was originally applied to the development of products and services in Japan (Zhong et a., 2014). QFD approaches have been widely used as their implementation could be particularly effective in addressing specific project needs (Kamara et al., 1999). In addition, the QFD approach could effectively lead designers to understand stakeholders' requirements while enhancing communication between the users and the designers (Delgado-Hernandez et al., 2007).

Figure 1 Traditional process of flat rubber sheets

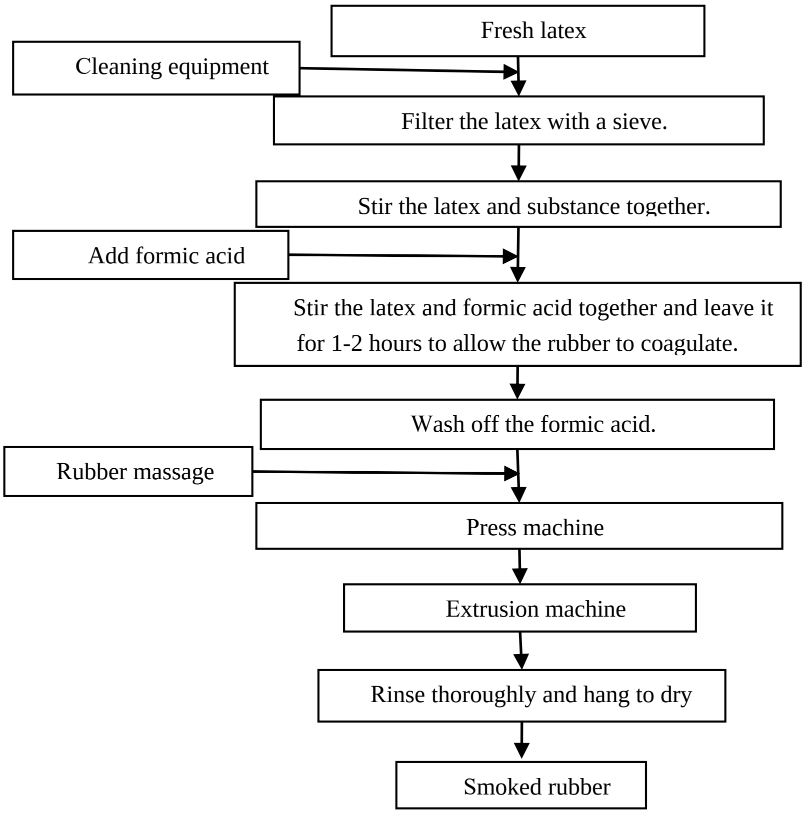

Figure 2 Traditional process of flat rubber sheets

Previous applications involve early design stage development (Kamara et al., 1999; Eldin & Hikle, 2003), bridge design (Malekly et al., 2010; Bolar et al., 2014), maintenance (Bolar et al., 2014), energy efficiency measures in the office (Shao et al., 2014), residential buildings (Singhaputtangkul et al., 2014), and sustainable performance assessments (Vinodh & Rathod, 2011; Bolar et al., 2014; Eleftheriadis et al., 2016). If QFD is implemented early in the design development process, it can be particularly useful with the following: 1) prioritization of project requirements; 2) articulation of design criteria; 3) efficient resource management (quality, construction delays, materials waste, etc.) (Eldin & Hikle, 2003; Bolar et al., 2014); and 4) information transfer between disciplines (Singhaputtangkul et al., 2014). Furthermore, it was reported that early interactions among decision-makers in QFD could increase the feasibility and adoption of design solutions (Shao et al., 2014).

QFD technique requires a series of steps to incorporate the desires of every customer into each matrix of the QFD analysis (Militaru et al., 2014). At each stage of the QFD process, the Voice of Customer (VoC) is integrated with the company's policies for product quality and service improvement (Sivaloganathan, 2015). QFD transferred customer needs into parameters and also conveys customer requirements at the operational level (Chih, 2022). It altered the traditional quality systems into a new system that minimized negative quality issues like poor services (Mazur, 2014) and assisted in the planning and designing department of the company by providing an organized way of considering customer expectations of the products and services (Mazur, 2014). Mitsubishi's Kobe yard was the first industry-implemented QFD technique (Basri, 2015). By using QFD, researchers found a lot of advantages in manufacturing enhancement and service level improvement (Jacques & Rossion, 2014). For this approach, in the organization known as concurrent engineering where the critical step was collecting data prioritization and structuring end-user desires through their voices (Gaskin et al., 1991; Greg et al., 1994). The manufacturing and services industries recognized the need for improvements in their systems with regard to customer satisfaction, from both a technical and economic perspective; hence, manufacturing companies and service industries across America and Japan adopted this technique (Rahimi-Ghahroodi et al., 2019). Sweden adopted this technique and used it in every manufacturing and service sector (Gustafsson, & Johnson, 2014; Yusuf, 2014; Zhao et al., 1995). The component characteristics in QFD shifted to the process matrix and were compared with each process involved (Basri, 2015; Rahimi-Ghahroodi et al., 2019). Various steps involved the construction of a process matrix, which had each process involved on the horizontal axis and each component's characteristics on the vertical axis (Jaiswal, 2012). In Thailand, research related to the improvement of efficiency in manufacturing processes in industrial plants and community enterprise groups, as well as the application of the quality function deployment technique, has been consistently published (Wongsangnoi & Pianthong, 2023) and found that the application of quality function deployment technique was suitable to make the production process more efficient and to help reduce work steps and production time.

2. Objectives

The purpose of this research is to design and develop a rubber sheet machine by applying a quality function deployment technique.

3. Materials and methods

Based on the literature review in the context of QFD on product quality improvement, the systematic framework comprises the following steps: First, explore the current problem of flat sheet rubber production. The purpose of this step is to study from the beginning of the design process, analyze, and determine customer needs with the production process of rubber sheets. Then, survey the needs of rubber sheet buyers. The objective of this part is to determine the characteristics of the flat rubber sheets using a questionnaire. To ensure reliable results, it is important to determine an appropriate sample size for surveying the demands of rubber sheet buyers. This involves applying statistical principles for analysis, the application of quality function deployment techniques, and improvements. The design process of a rubber sheet machine using the Four-Phase Model, which consists of 4 phases as follows: 1) product planning; 2) product design; 3) process planning; and 4) process control planning as shown in Figure 3.

3.1 Data collection

In this research, there were field interviews for small and medium enterprises in the target group of Sakon Nakhon, Nakhon Phanom, Mukdahan, and Bueng Kan Province, which has 85,058 members. Customers' voices were collected from 384 rubber farmers. This is to identify the customer requirement and then the prescreening including grouping, eliminating, and combining is performed on such criteria as similarity, relevancy, dependency, and redundancy. As a result, the initial customer needs are identified and converted into customer requirements, as detailed in Table 1. To ensure the accuracy and reliability of these requirements, a questionnaire was developed. This questionnaire encompasses a comprehensive set of pre-screened customer requirements.

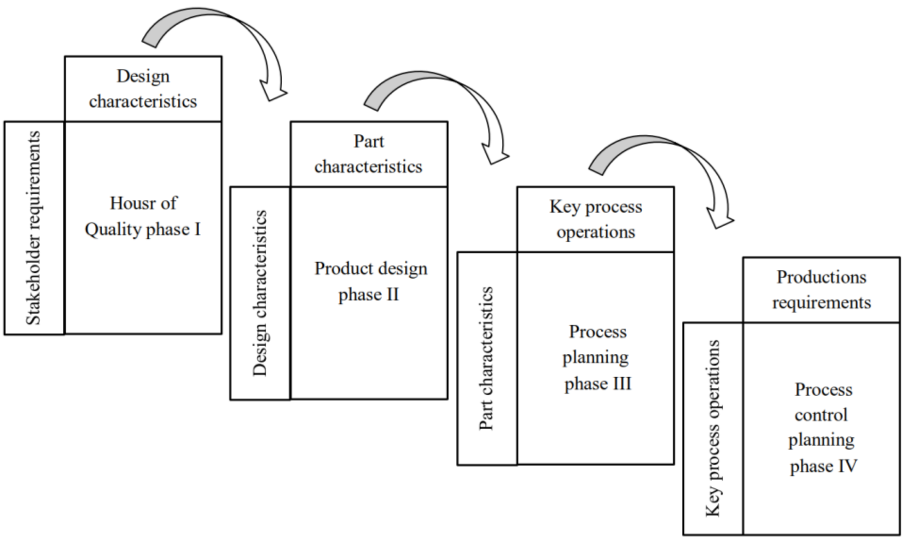

Figure 3 The Four-Phase Model.

Table 1 Initial customer needs of the rubber sheet machine

No	what customers want	customer requirements
1	Short production time	Continuous rolling process
2	Evenly sized rubber sheets	Low size variation
3	Able to adjust roller mill distance	Adjustable roller distance
4	Able to adjust knurling roller distance	Adjustable knurling roller distance
5	Adjustable speed	Adjustable speed
6	No danger in use	Safe
7	Can be used with electrical system	Can be used with household electrical systems
8	Can be easily controlled in operation	Easy to control
9	Inexpensive	Reasonable price
10	Not too heavy	Suitable weight
11	Able to disassemble and assemble equipment to work conveniently	Easy to disassemble and assemble
12	The machine is suitable and can be easily moved	Easy to move
13	It can be used for a long time.	Acceptable running hours
14	Easy and convenient to repair and maintenance of materials and equipment	Easy maintenance
15	The size of the machine is suitable for use	Suitable machine size
16	With low vibration	Acceptable vibration level
17	Structure is reasonable	Strong
18	The manual is easy to read and understand before operation	User manual

Table 2 Technical specifications of rubber sheet machine

customer requirements	technical specification
1. Continuous rolling process	1. Sloping machine structure.
2. Acceptable vibration level	2. There is a device to hold and lock the wheels while working.
3. Adjustable speed	3. There is a suitable rotation speed.
4. Low size variation	4. Distance between rollers
5. Acceptable running hours	5. Running hours of rolling
6. Adjustable knurling roller distance	6. Distance between knurling rollers
7. Adjustable roller distance	7. Distance between rollers
8. Easy to control	8. There is an on-off switch to control.
9. Can be used with household electrical systems	9. Use electricity 220 V.
10. Safe	10. Belt cover
11. User manual	11. Explain the working process clearly.
12. Easy to maintain	12. Easy to remove and replace parts.
13. Easy to disassemble and assemble	13. The machine is not complicated.
14. Strong	14. Steel machine structure
15. Suitable weight	15. Machine weight
16. The size of the machine is suitable for use.	16. The machine has a suitable height.
17. The machine is suitable, can be moved easily.	17. There is a moving device.
18. Reasonable price	18. Machine price

Table 3 Functions of the components of the rubber sheet machine

No	component	Duty
1	Machine structure and base	Supports the entire weight of the rubber press and holds the parts together.
2	Power source	Convert electrical energy into mechanical energy
3	Powertrain system	Transfer power from the power plant to the rubber extrusion set.
4	Rubber pressing set	Pressing rubber sheet to 1- 2 cm. thickness
5	Rubber flat ironing set	Flatten the rubber to get a thickness of 3-4 mm, width 380 - 460 mm, length 800 - 900 mm.
6	Rubber print set	Printed rubber pattern, giving a thinness of 3-4 mm, width of 380 - 460 mm, length of 800 - 900 mm, and clear pattern.
7	Thickness adjuster set - thin, rubber	Adjust the distance of the ironing unit and print the rubber pattern to the desired size.
8	Water drip system	Provide smoothness and ease of ironing and printing rubber patterns to meet the needs. Reduce the problem of rubber sticking to the machine

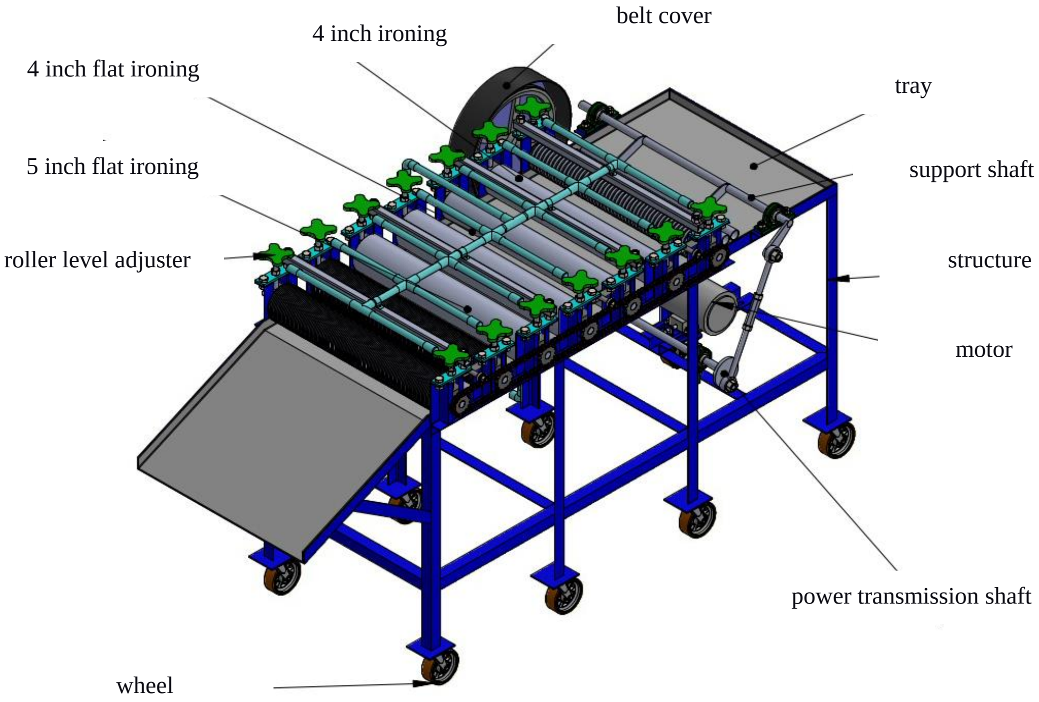

Figure 4 Developed rubber sheet machine

A 5-point linear numeric rating scale gauges the importance of each customer requirement. The mean score of the customer requirements is utilized as the important score in phase 1. To align with customer requirements, the subsequent step focuses on specifying the technical requirements for the flat sheet rubber press machine, as detailed in Table 2. Brainstorming with experts and relevant stakeholders helps achieve this. These technical requirements serve as a guideline for enhancing the flat sheet rubber pressing machine to meet the needs of the sample farmers.

Figure 4 shows the components of the rubber sheet machine press as follows: structure of the flat sheet rubber press machine, rubber tray before kneading set, belt cover, roller level adjuster, 5-inch flat roller, rolling roller 4-inch flat type, 4 - inch patterned ball, transmission shaft, rubber massage support shaft, 2 HP power motor and casters.

3.2 Quality Function Deployment (QFD)

It is a step-by-step implementation of the 4-phase QFD technique with the following steps:

Phase 1: Product Planning

At this stage, feedback was collected from 18 customers using focus group discussions, interviews, and questionnaires. The House of Quality matrix is employed to translate customer requirements into technical specifications.

Phase 2: Product Design

Identify 15 key technical specifications, or quality characteristics, that account for 80% of 18 technical requirements from phase 1.

Phase 3: Process Planning

It is the conversion of requirements or properties of components obtained from phase 2 into the requirements of the production process, which has the following steps: component requirements and target values from phase 2 product design as input into phase 3: process planning.

Phase 4: Production Planning

The process requirements derived from phase 3 serve as input for phase 4. They are then converted into standard work or operational processes to align with customer needs.

The details for defining the operational process to satisfy these process requirements are as follows:

Rubber sheet machine

A rubber sheet machine is designed to use the right materials and components in order to get a flat rubber sheet machine according to the needs of users and at a reasonable price. Therefore, there must be a study and selection of thematerials for assembling and constructing flat rubber sheet machine which can be divided into 8 parts of the flat rubber sheet press machineas , shown in Table 3

4. Results and Discussion

An experiment to study the effect of the combination of all possible levels of factors is needed. Therefore, a factorial design method was used by requiring a total of 5 replicates in each experimental condition. There were 4 Rotational speeds with 3 Rolling distances. The experiments are randomly performed. The average of 5 replicates are shown in Table 4.

Table 4 The average flat rubber sheet size produced by rubber sheet machine (before drying)

Rotational speed	Rolling distance	rubber sheet size			
		width (mm)	length (mm)	thickness (mm)	weight (gram)
300	3.0	548	942	4.14	1,740
	3.5	540	932	4.11	1,700
	4.0	522	930	4.13	1,680
350	3.0	524	916	4.08	16,80
	3.5	514	922	4.13	1,720
	4.0	520	926	4.10	1,680
400	3.0	520	918	4.07	1,660
	3.5	516	922	4.10	1,660
	4.0	512	932	4.11	1,660
450	3.0	520	918	4.07	1,740
	3.5	518	928	4.13	1,700
	4.0	512	920	4.07	1,720

From Table 4, it's evident that all the rubber sheets have been dried. The rubber sheet's quality was then assessed based on the rubber sheet quality standard 2 (Rubber Authority of Thailand, n.d.), which stipulates a width of 38-46 centimeters, a length of 80-90 centimeters, a thickness not exceeding 4 millimeters, and an average weight between 1.0 and 1.2 kg per sheet. These results can be viewed in Table 5. Accordingly, the rubber sheet machine, operating at a speed of 400 rpm and a rolling distance of 3.0 mm, produces rubber sheets of satisfactory quality.

Subsequently, a repeated experiment was conducted using 10 rubber sheets at the same speed and rolling distance. The dimensions and weight of the rubber sheets are detailed in Table 6. After drying, the dimensions and weight of the dried rubber sheets can be found in Table 7.

Table 5 Experimental results

No-load speed (r/min)	Rolling distance (mm)	the rubber sheets met the quality standards				
		1	2	3	4	5
300	3.0	✓	✕	✕	✓	✕
	3.5	✕	✓	✕	✓	✕
	4.0	✕	✓	✓	✕	✕
350	3.0	✓	✕	✓	✕	✓
	3.5	✓	✓	✕	✕	✓
	4.0	✕	✓	✕	✓	✕
400	3.0	✓	✓	✓	✓	✓
	3.5	✓	✓	✓	✕	✓
	4.0	✓	✕	✓	✓	✕
450	3.0	✕	✓	✕	✕	✕
	3.5	✓	✕	✓	✕	✓
	4.0	✓	✓	✕	✕	✓

Note: ✓ The rubber sheet meets the standards.
✕ The rubber sheet does not meet the standards.

Table 6 Raw rubber sheet produced with speed of 400 rpm and a rolling distance of 3.0 mm.

No	Thickness of raw rubber before rolling (mm)	before drying			
		width (mm)	length (mm)	thickness (mm)	weight (gram)
1	20	510	900	4.05	1,600
2	20	510	910	4.05	1,600
3	20	520	920	4.05	1,600
4	20	510	910	4.10	1,700
5	20	520	920	4.10	1,700
6	20	510	910	4.05	1,600
7	20	510	920	4.05	1,700
8	20	520	910	4.05	1,700
9	20	510	910	4.05	1,600
10	20	520	920	4.10	1,700
average	20	510	910	4.06	1,650

Table 7 Results of dried rubber sheet produced with the speed of 400 rpm and a rolling distance of 3.0 mm

No	after drying			
	width (mm)	**length (mm)**	**thickness (mm)**	**weight (gram)**
1	450	850	3.82	1,200
2	440	850	3.70	1,100
3	450	840	3.86	1,200
4	450	850	3.95	1,200
5	440	840	3.88	1,200
6	450	860	3.74	1,100
7	450	850	3.76	1,100
8	450	860	3.88	1,200
9	450	840	3.76	1,100
10	450	850	3.84	1,200
average	448	849	3.82	1,160

From Table 7, it's observed that the average thickness of the rubber is 20 mm. Once processed by the rubber sheet machine, the dimensions were an average width of 510 mm and a length of 910 mm. The average thickness reduced to 4.06 mm, and the average weight was 1,650 grams. Furthermore, the dried flat rubber sheet, as presented in Table 7, had dimensions of an average width of 448 mm and a length of 849 mm, with an average thickness of 3.82 mm and a weight of 1,160 grams. This meets the criteria for rubber sheet quality standard 2.

4.1 Satisfaction measurement

Customer satisfaction with the designed and developed rubber sheet machine was evaluated by 20 rubber farmers. Of these, 17 were males, representing 85%, and 3 were females, representing 15%. In terms of age distribution, 8 individuals were between 30-39 years old, accounting for 40%, while 12 were between 40-49 years old, representing 60%. Regarding education, 5 farmers had completed lower secondary school (25%), and 15 had upper secondary education, making up 75%. Detailed feedback from these respondents is presented in Table 8. The overall satisfaction score was an impressive 4.65 out of 5.

Table 7 Results of dried rubber sheet produced with the speed of 400 rpm and a rolling distance of 3.0 mm

No	after drying			
	width (mm)	**length (mm)**	**thickness (mm)**	**weight (gram)**
1	450	850	3.82	1,200
2	440	850	3.70	1,100
3	450	840	3.86	1,200
4	450	850	3.95	1,200
5	440	840	3.88	1,200
6	450	860	3.74	1,100
7	450	850	3.76	1,100
8	450	860	3.88	1,200
9	450	840	3.76	1,100
10	450	850	3.84	1,200
average	448	849	3.82	1,160

Table 8 Customer satisfaction of the rubber sheet machine

No	Topics	Mean	S.D.
1	Able to continuously roll rubber	4.65	0.49
2	Less vibration while working	4.70	0.50
3	Adjustable speed of rolling the rubber	4.70	0.47
4	Sheets can be produced to a standard size	4.65	0.49
5	Durable working machinery	4.65	0.49
6	Adjustable distance between print balls	4.70	0.47
7	Adjustable distance between rolling balls	4.70	0.47
8	Easy to control	4.65	0.49
9	Can be used with household electricity	4.65	0.49
10	It is safe to work	4.70	0.50
11	Manual is easy to understand	4.70	0.50
12	Easy to maintenance	4.40	0.50
13	Easy to disassemble and assemble	4.70	0.47
14	The machine structure is strong	4.70	0.47
15	The weight of the machine is appropriate	4.60	0.50
16	The size of the machine is suitable to use	4.65	0.49
17	Easy to move the machine	4.70	0.50
18	Acceptable price	4.70	0.50
	Average	**4.65**	**0.48**

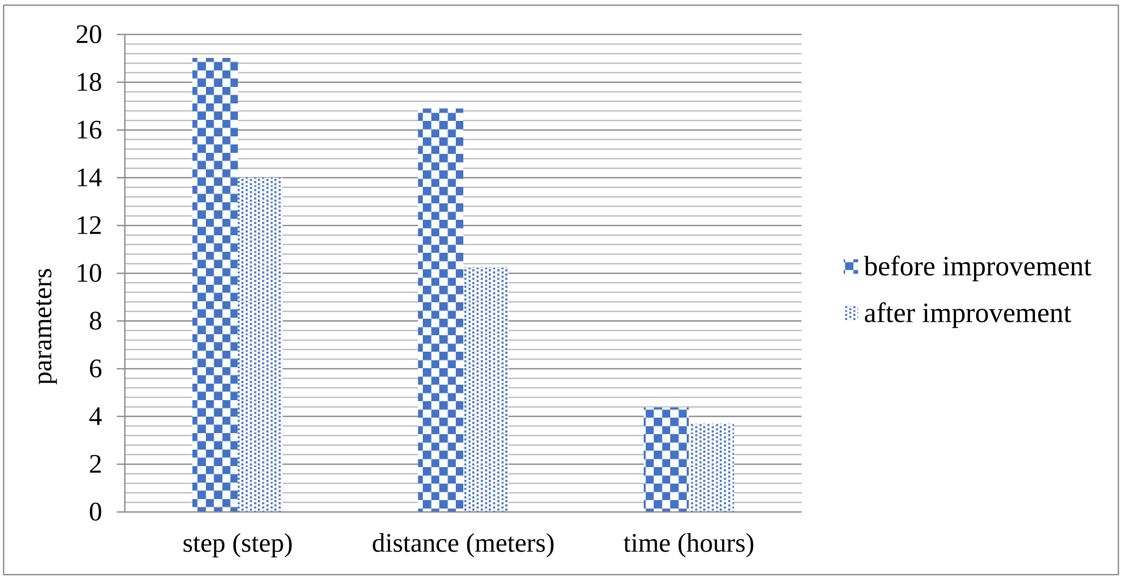

Figure 5 The comparison between before and after improvement of production process

From Figure 5, the production process has been reduced from 19 steps to 14 steps, the distance has been reduced from 16.90 meters to 10.25 meters, the production process time has been reduced from 4.38 hours to 3.7 hours.

5. Conclusion

In this research, the rubber sheet machine was developed using QFD. Customer feedback was collected from farmer groups in the Sakon Nakhon, Nakhon Phanom, Mukdahan, and Bueng Kan province. Then, the customer needs were analyzed and converted into a technical requirement of 4-phase model QFD: phase 1 product planning; phase 2 product design, phase 3 process planning, and phase 4 production planning. The information gathered was utilized for the development of a rubber sheet machine. The developed rubber sheet machine was then tested following the principles of experimental design to determine the optimal rotation speed and roller distance. There were four levels of rotational speed: 300, 350, 400, and 450 rpm. Also, there were three rollers distances which were 3.0, 3.5, and 4.0 mm. Each experiment was conducted five times to ensure the reliability of the results. The experimental results showed that rubber sheets produced at a speed of 400 rpm and a roller distance of 3.0 mm met the established quality standards.

6. Acknowledgements

The author would like to thank all of the anonymous referees for the comments and suggestions to improve this paper. In addition, the authors would like to thank the groups of rubber farmers in Sakon Nakhon, Nakhon Phanom, Mukdahan, and Bueng Kan Provinces for their corporation for this research.

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