QUALITY FUNCTION DEPLOYMENT (QFD) FOR DESIGNING ROCK SUGAR CHOPPING MACHINE

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การออกแบบเครื่องสับน้ำตาลก้อนกรวดโดยการแปลงหน้าที่ผลิตภัณฑ์เชิงคุณภาพให้เป็นแนวทางปฏิบัติ

น.ส.เจนจิรา ปัณณวัฒน์กุลธร

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เจนจิรา ปัณณวัฒน์กุลธร : การออกแบบเครื่องสับน้ำตาลก้อนกรวดโดยการแปลงหน้าที่ผลิตภัณฑ์เชิงคุณภาพให้เป็นแนวทางปฏิบัติ. (QUALITY FUNCTION DEPLOYMENT (QFD) FOR DESIGNING ROCK SUGAR CHOPPING MACHINE) อ.ที่ปรึกษาหลัก : ปารเมศ ชุติมา, อ.ที่ปรึกษาร่วม : ชูเวช ชาญสง่าเวช

งานวิจัยนี้มีวัตถุประสงค์ในการศึกษาและประยุกต์ใช้การแปลงหน้าที่ผลิตภัณฑ์เชิงคุณภาพให้เป็นแนวทางปฏิบัติเพื่อออกแบบเครื่องสับน้ำตาลก้อนกรวดให้โรงงานน้ำตาลตัวอย่างที่เลือกมาโดยเน้นไปที่การเพิ่มปริมาณของน้ำตาลก้อนกรวดในกระบวนการสับน้ำตาล กรณีศึกษานี้ได้รวบรวมข้อมูลมาจากการสังเกตและสืบสวนที่หน้างานและการสัมภาษณ์เจ้าของโรงงานน้ำตาลโดยตรง โดยข้อมูลได้ชี้ให้เห็นว่าทางโรงงานดังกล่าวมีปัญหาในด้านของจำนวนปริมาณการผลิตน้ำตาลก้อนกรวดที่ไม่เพียงพอและข้อมูลยังชี้ให้เห็นว่ากระบวนการการสับน้ำตาลคือคอขวดของกระบวนการผลิตทั้งหมด ซึ่งงานวิจัยนี้สามารถช่วยให้โรงงานเพิ่มผลผลิตรวมไปถึงเพิ่มกำไรได้อีกด้วย นอกจากนี้ผลของงานวิจัยยังสามารถช่วยลดจำนวนคนงานโดยที่คุณภาพของผลิตภัณฑ์ไม่มีการเปลี่ยนแปลงและเพิ่มผลกำไรให้กับโรงงานได้ในระยะยาว

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Janejira Pannavatkulthon : QUALITY FUNCTION DEPLOYMENT (QFD) FOR DESIGNING ROCK SUGAR CHOPPING MACHINE. Advisor: PARAMES CHUTIMA Co-advisor: Chuvej Chansa-ngavej

The objective of this research is to study and apply the principles of quality function deployment to design rock sugar chopping machine for selected sugar factory in order to increase productivity of current chopping process. The design of machine is analyzed using House of Quality which is a part of quality function deployment methodology. The data collection was conducted by on-site investigation and face-to-face interview with the owner of sugar factory. It is found that the main problem of this factory is inadequate of in-house production capacity and the bottleneck of manufacturing processes is chopping process. The result of this research supports the factory to increase overall productivity as well as revenue. The result also ensure that factory could reduce manpower cost, maintain quality of rock sugar, and generate greater revenue for the factory in long term.

Field of Study:	Engineering Management	Student's Signature ....
Academic Year:	2019	Advisor's Signature ....
		Co-advisor's Signature ....

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Finally, I would like to address my gratitude to my family who have been a great supportive system and encouragement throughout all these years of studying until the completion of this thesis. I could not have done without all of the above mentioned individuals. Thank you all very much.

Janejira Pannavatkulthon

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Chapter 1 Introduction

1.1 Industry Overview

As the world's second biggest sugar exporter, Thailand, is expected to increase sugarcane production to 130 million metric tons by 2019 or 2% increase from 2018. Production volume has been increasing year by year. Sugarcane is one of the raw materials used in sugar production. Sugar is the product that has need the entire year since majority of its application is for consuming either in type of food or beverage.

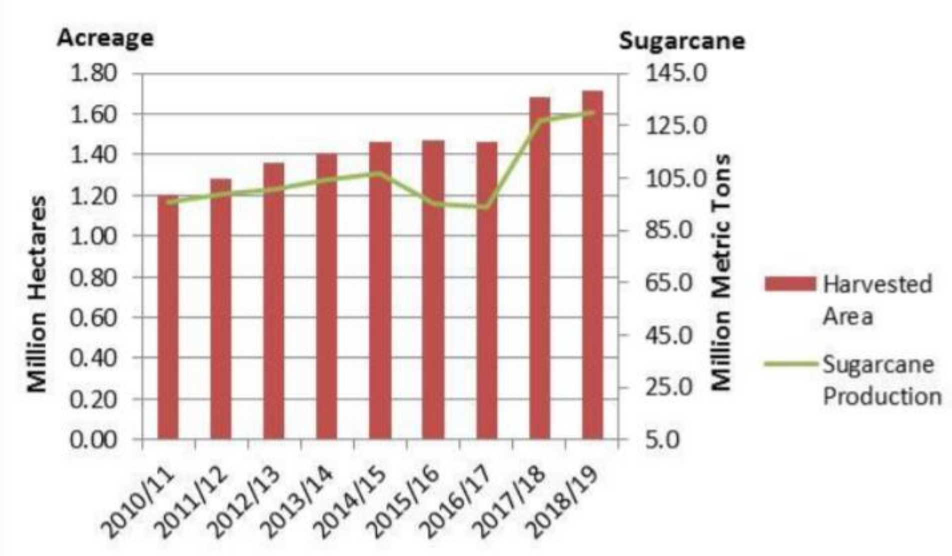


Figure 1: Sugarcane production volume in Thailand

One of the popular types of sugar for food and beverage producer is rock sugar; the reason is because rock sugar is more delicious than normal sugar according to those producers who use rock sugar for their food and beverage products.

Figure 2: Rock Sugar (Ta-Petch, 2017)

It is made from the combination of refined sugar and cane syrup. Refined sugar will be boiled into liquid state then mixing with cane syrup until it meets curtain level of sweetness. After boiling, liquid sugar will be kept in buckets for crystallization. Then crystalized sugar will be chopped into small sizes and send to pack for delivery to customers. Since the demand for sugar is high throughout the year, most of manufacturers are currently facing inadequate production problem. And there are quite number of local manufacturers across the country that rely on workers rather than invest in machines to handle repetitive processes.

1.2 Background

The selected sugar factory for this thesis is Ta-Petch Group Company located in Nonthaburi province, Thailand. The company sells rock sugar factory under 4 brands as shown in below figure.

Figure 3: Brands under Ta-Petch Group Company (Ta-Petch, 2017)

Ta-Petch Group's customers are covering both domestic and overseas. Majority of customer is in Thailand with nearly 200 of customers combined in North, Northeast, Central, and South regions. And there are 2 oversea customers in Malaysia and Singapore. Domestic sell volume is accounted for 86 percent, and the rest is overseas.

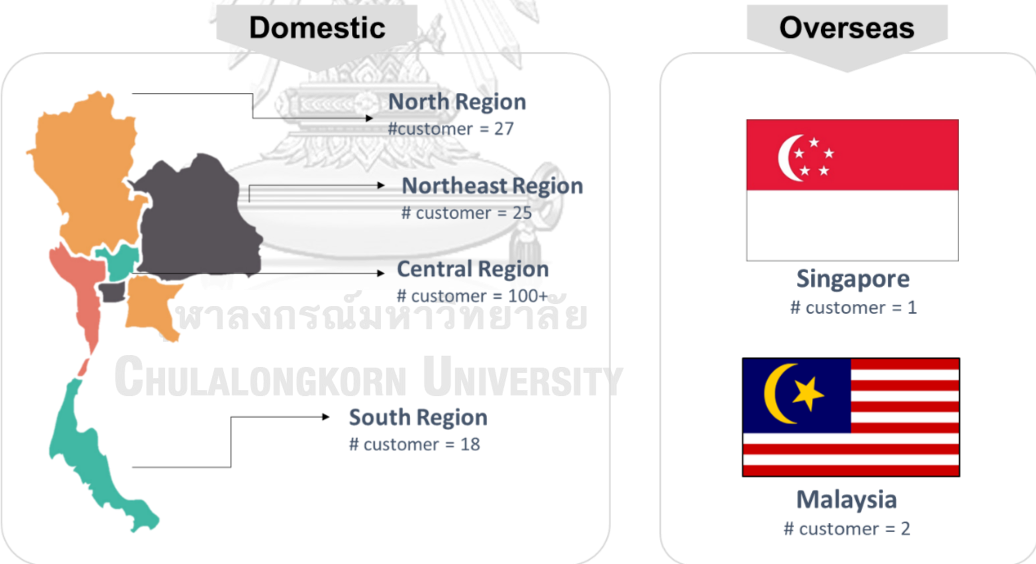


Figure 4: Ta-Petch's customers

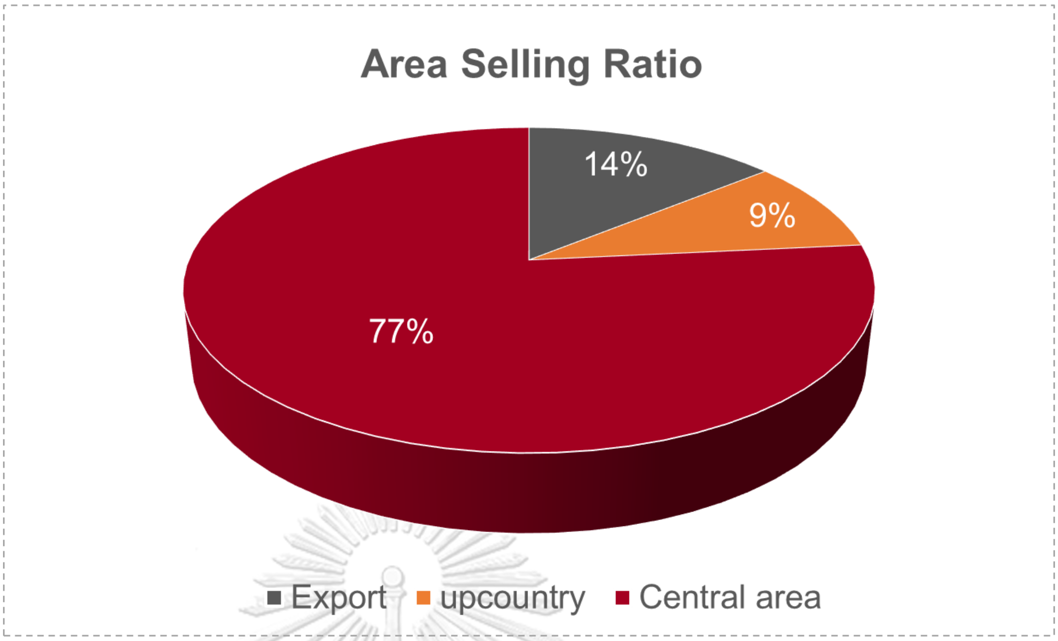


Figure 5: Area selling ratio

According to data collection from selected sugar factory, current production capacity is around 117 tons a month while the demand from customers is around 137 tons a month. The owner of selected sugar factory is solving this problem by purchasing rock sugar from another factory every month to re-pack as its own brands and sell to their customers.

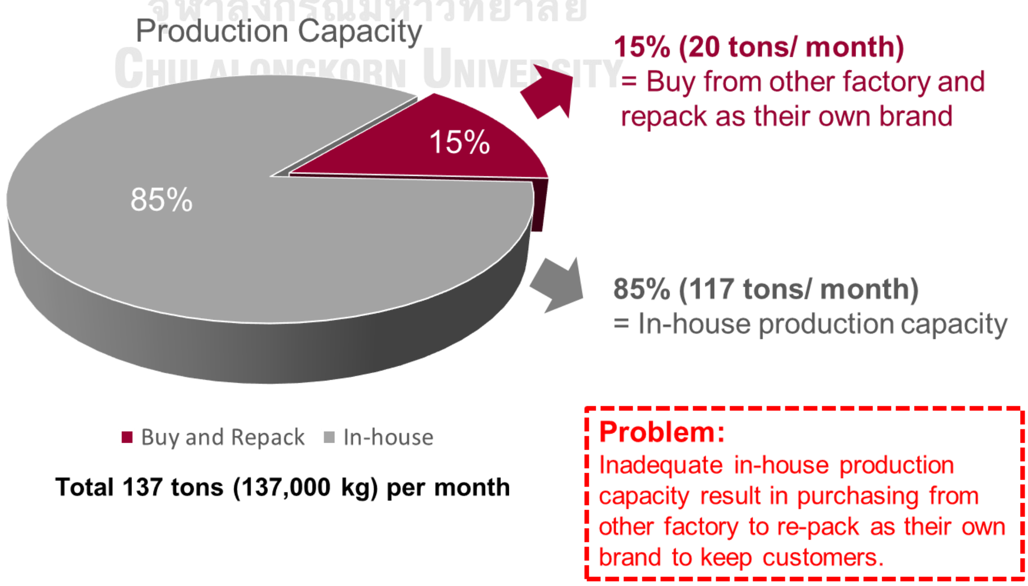


Figure 6: Production capacity of rock sugar

Prior investigated data has shown that manufacturing processes are mainly carry out manually by workers. There are only few processes that using machines helping those workers to perform the jobs.

1.3 Problem Statement

The main problem is outside purchasing to re-pack and sell to customers as its own brand and the cause of this problem is because inadequate in-house production capacity. After prior investigation in manufacturing process, the author found out that most of processes are carried out manually by workers even for repetitive process while there are only few machines in the factory.

Overview of rock sugar manufacturing processes is shown in below figure.

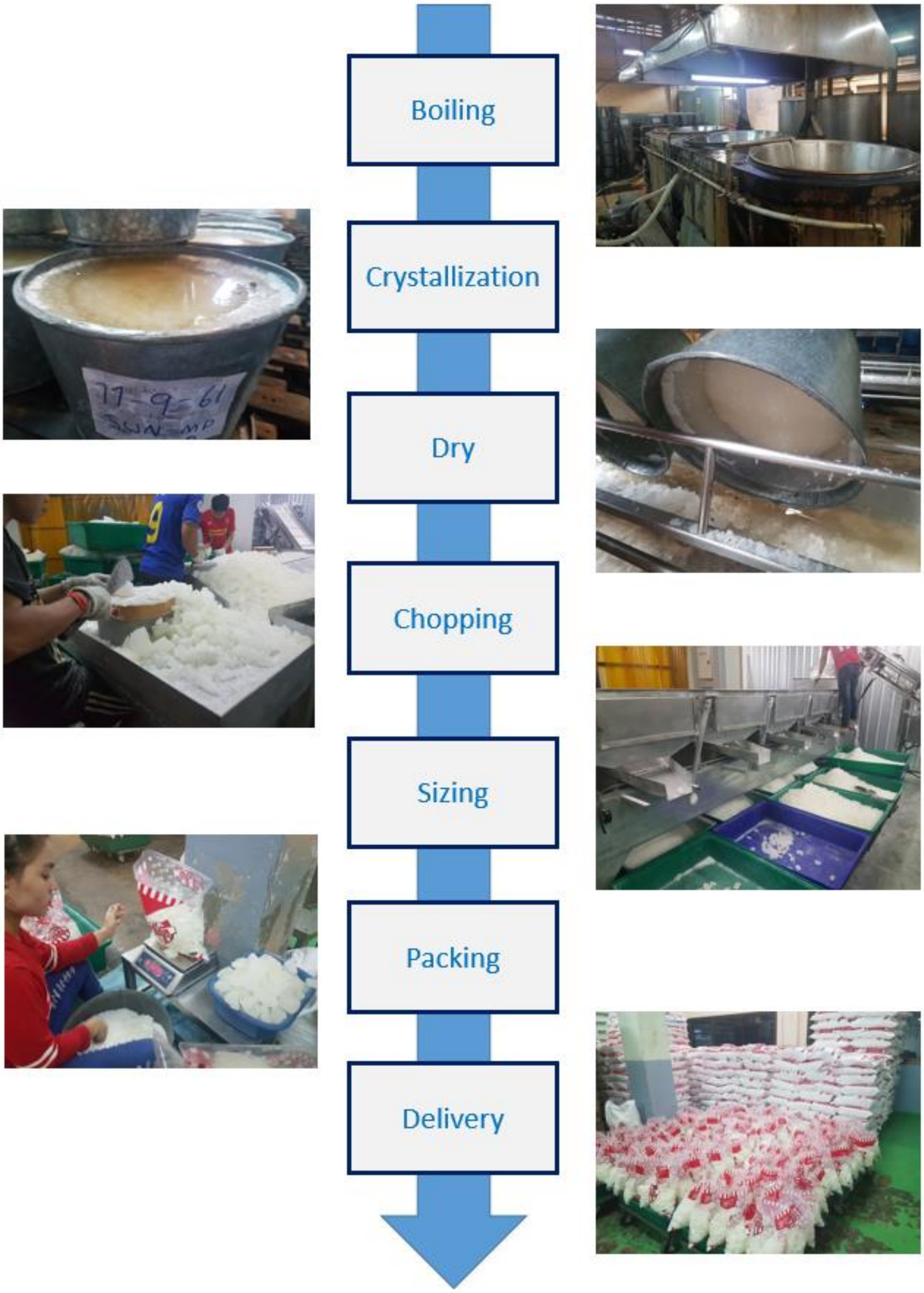


Figure 7: Overview of rock sugar manufacturing process

Detail of each manufacturing process are as following:

1.3.1 Mixing Process

The very first process is to mix all ingredients which are white sugar, refined sugar, and water together in tanks.

Figure 8: Mixing process

1.3.2 Boiling Process

All mixed ingredients will then be transferred from mixing tanks to boilers while worker keep filling more water into the boilers for two and a half hours until the sweetness meets desired level.

Figure 9: Boiling process

1.3.3 Crystallization Process

Boiled liquid sugar is filled into aluminium buckets and leave for crystallization at room temperature for 20 to 25 days.

Figure 10: Crystallization Process

1.3.4 Drying Process

In this process, surface of crystallised sugar will be ripped off to reveal the layer of uncrystallised sugar underneath in form of liquid. Then liquid sugar will be separated to produce other form of sugar. While the rest crystalized sugar in buckets are put upside down to dry for a night.

Figure 11: Drying process

1.3.5 Knocking Process

After drying, workers will knock crystallised sugar out of buckets, which is now big size rock sugar.

Figure 12: Knocking process

1.3.6 Chopping Process

Then those big size of rock sugar will be chopped into smaller pieces manually by workers in this process.

Figure 13: Chopping process

1.3.7 Sizing Process

Then chopped rock sugar will be separated into each size by sizing machine.

Figure 14: Sizing Process

1.3.8 Packing Process

Finally, workers will have to measure the quantity of rock sugar then fill in different types of package according to size of rock sugar.

Figure 15: Packing process

As per prior investigation, it has been found that bottleneck in manufacturing processes is chopping process, it is the most time consuming process as workers require to chop rock sugar into smaller size manually.

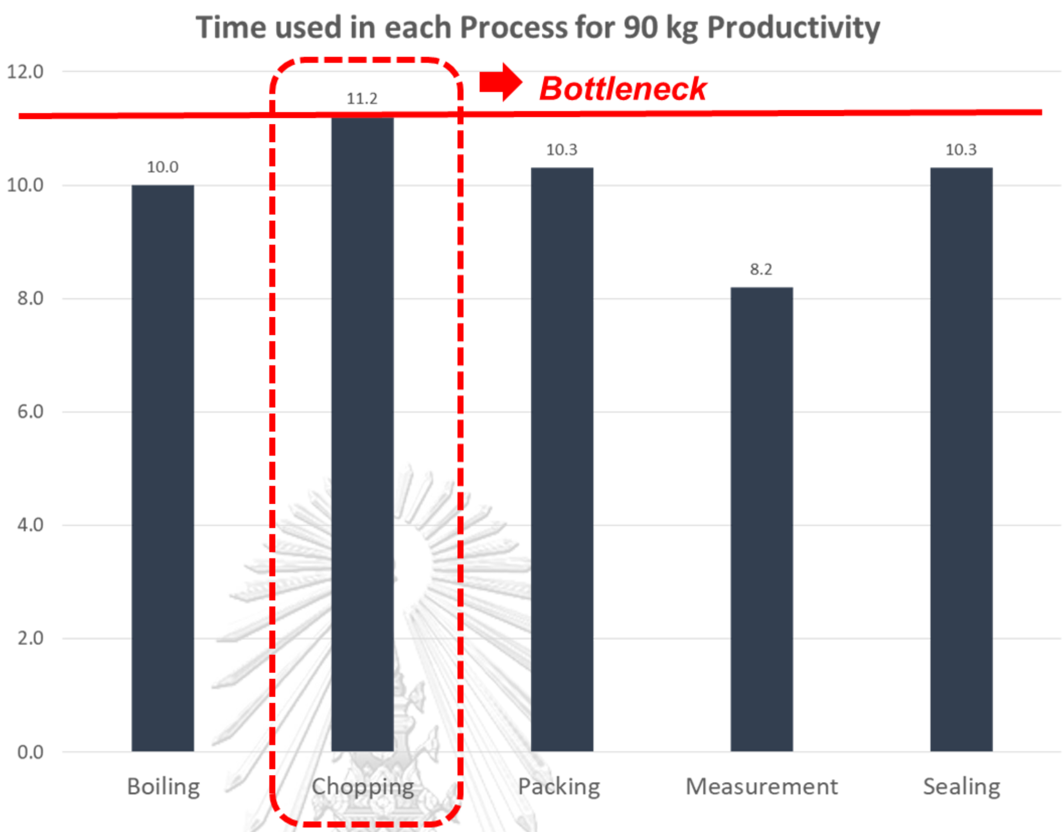


Figure 16: Process breakdown

In order to produce 90 kilograms of productivity, chopping process consumes the most time which is 11.2 minutes.

In conclusion, there have not been enough considerations on using machines in repetitive work processes instead of workers to improve productivity of rock sugar chopping process in this factory.

1.4 Research Objectives

The objective of this research is to increase productivity of chopping process in order to reduce quantity of outside purchasing by using Quality Function Deployment (QFD) methodology to design new rock sugar chopping machine.

To reach this objective successfully, these following tasks are aims to carry out: (1) Understanding and study current operations and approaches of manual chopping process (2) studying and investigating current problems and analyse to find appropriate approaches and solutions (3) Execute and measure overall productivity after implementation.

1.5 Research Questions

(1) Does implementation of new chopping machine according to QFD methodology improve rock sugar productivity in chopping process?

(2) Does improving of productivity by chopping machine affect the quality or size of rock sugar?

(3) Is the improvement of rock sugar productivity by new chopping machine implementation helps to reduce quantity of outside purchasing for re-packing, and worth the cost in terms of profit increment?

1.6 Hypothesis Development

According to the above three questions, it can be hypothetically developed based on existing knowledge and evidences as following:

(1) New chopping machine which shall be built according to QFD methodology can improve productivity in chopping process.

(2) Improving of productivity by chopping machine could maintain the original quality or size of rock sugar.

(3) The improvement of rock sugar productivity by new chopping machine implementation can help to reduce quantity of outside purchasing for re-packing, and increase profit to the factory in long term.

1.7 Scope of Research

This research will focus on improving the bottleneck in manufacturing processes which is chopping process in this case to increase productivity by implementing new machine for this particular process using QFD methodology to help in designing. However, the prototype machine will be built in this case in regard to financial purpose, and for the owner of selected rock sugar factory to see potential of chopping machine then decide whether or not they want to build the full scale machine in the future.

1.8 Expected Outcome

Implementation of rock sugar chopping machine which has been designed using QFD methodology which is expected to benefit the factory in following areas:

(1) Improve rock sugar productivity in chopping process.

(2) Maintain current quality or size of the product.

(3) Increase profit to the factory in the long term.

Chapter 2 Literature Review

In each country, we are able to see the differences clearly between global and local manufacturers. One of the factors is manufacturing processes where those big players are operating systematically and autonomously using machines and robots to perform repetitive process while local manufactures are still relying on workers heavily to avoid investing in machines for financial purpose. Manufacturers would always seek for additional options to increase the productivity in order to maximize benefits. To do so, development of manufacturing processes and products are mandatory. QFD is widely known as a methodology to integrate the voice of customer into product or service. The concept, principles and approaches of QFD which shall be adopt further to help in concept design of rock sugar chopping machine.

In additional, this concept of hammer mills shall also be adopt in this thesis to support in machine design process in terms of major components of the machine. Further detail regarding QFD and hammer mill will be discussed in this chapter.

2.1 Quality Function Deployment (QFD) Principles

QFD was originally developed by Yoji Akao (Akao & Mazur, 2003) in Japan in the late 1960s and had entered to United States in the early 1980s then became popular since it brought outstanding result in the automotive and electronics manufacturers. Currently QFD is being used in several of industries which are not limited to manufacturer but also including service organisations.

According to Akao, he says, “QFD is a method to transform qualitative user demands into quantitative parameters to deploy functions forming quality and to deploy methods for achieving the design quality into subsystems and component parts and ultimately to specific elements of the manufacturing process." QFD is a method to transform voice of customer into engineering characteristics to be developed for product or services in order to achieve customer expectation as it helps organisation to deeply understand the real needs of customer either spoken or unspoken needs.

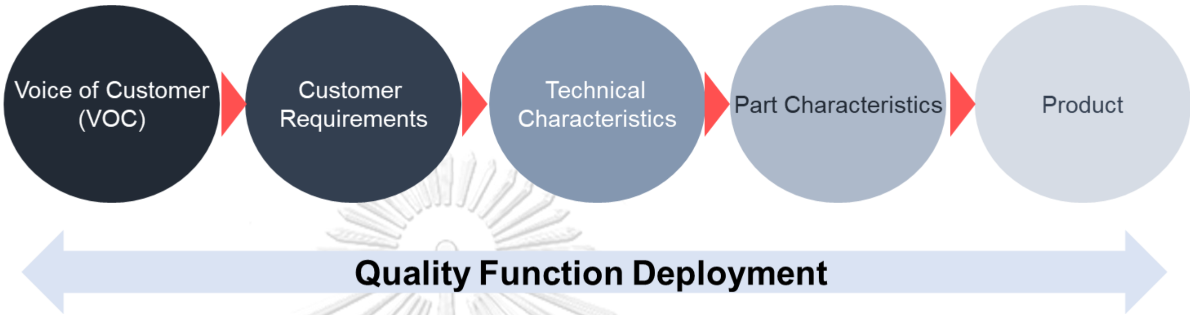


Figure 17: Concept of how QFD transform VOC to Product or Service

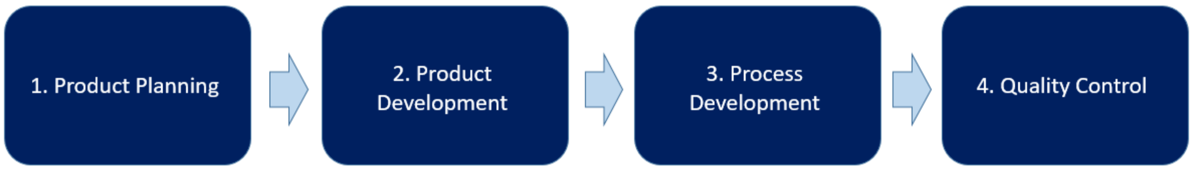


Figure 18: QFD 4-phase approach

2.1.1 Product Planning

Product Planning or product definition is to collect voice of customer to transform to engineering characteristics or technical requirements to be refined to product development or technical targets further in next step (Moubachir & Bouami, 2015). According to Hunt and Xavier (Hunt & Xavier, 2003) QFD have set of tools for extracting voice of customer to engineering characteristics. House of quality is the basic design tool of quality function deployment. It helps to prioritise customer expectation through identification and classification of customer requirements through graphic and integrated thinking, which will be refined to engineering characteristic and further for product and process development to respond to customer needs based on the research from Han, et al., (2001). Moreover, house of quality also allows, the organisation to compare its design or product with competitor by competitive opportunities analysis, and captures and combines the engineering thought process.

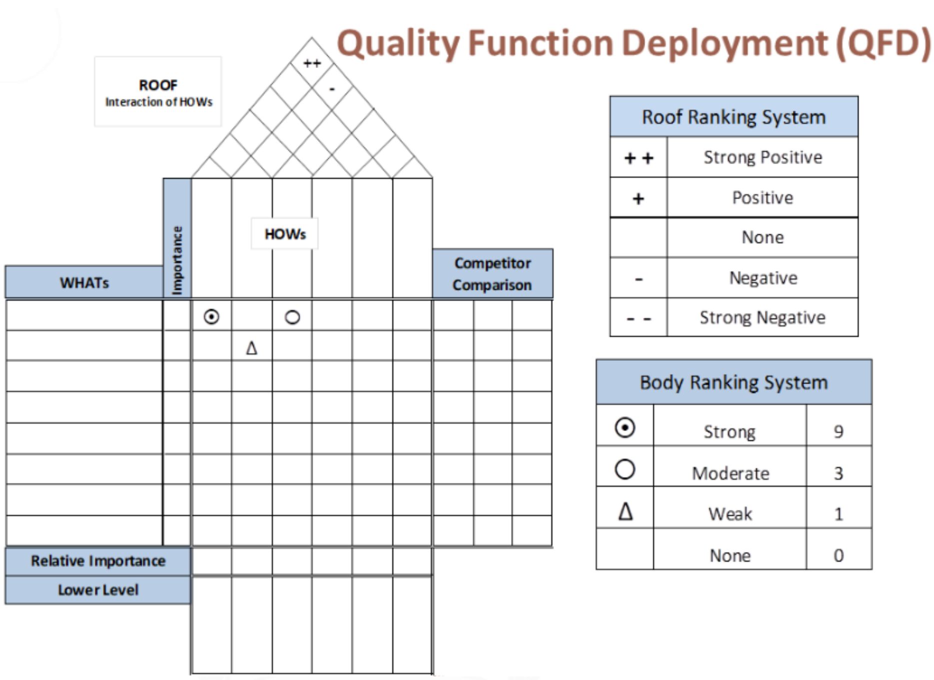


Figure 19: House of quality template

The matrices in house of quality are being used to transform higher level of "WHATs" or requirements into lower level of "HOWs" or product requirements or critical characteristics which are responded to needs (Garvin, 1988).

Description of each matric in House of Quality is listed below (Bolar, et al., 2017):

- "WHATs" is the first task to be completed in house of quality. This part is where the voice of customer or customer requirement is addressed.
- "HOWs" or the ceiling of the house is where the idea of design features and technical specifications that conform to voice of customer are contained.

- Main room of the house is the place where qualities of "HOWs" are ranked based on the correlation and its capabilities to fulfil voice of customer or "WHATs" section.
- Roof of the house is where the interrelationships between each design requirements are addressed to see the level of rating from strong negative to strong positive which will be indicated in symbol.
- Competitor comparison in right side of the house is where competitor's product regarding "WHATs" is listed by ranking according to the level of customer satisfaction.
- Relative importance is where the calculation results are addressed. It represents the impact of "HOWs" which is assist to prioritise resource allocation.
- Lower level or bottom of the house is where specific target values for critical characteristics which are related to "HOWs" are listed.

Completion of house of quality matric assists in visualisation of characteristics and its correlations between each other based on user demand or customer voice (Burge, 2007).

2.1.2 Product development

In this process, critical parts and assemblies will be defined, and transform to critical characteristics or specifications which will be refined to process development in the next stage by flowing down critical product characteristics (Shrivastava, 2015). Product design at any levels such as system, subsystems, or component parts could apply the same method from house of quality as a tool for identification and classification of customer requirements (Padagannavar, 2016).

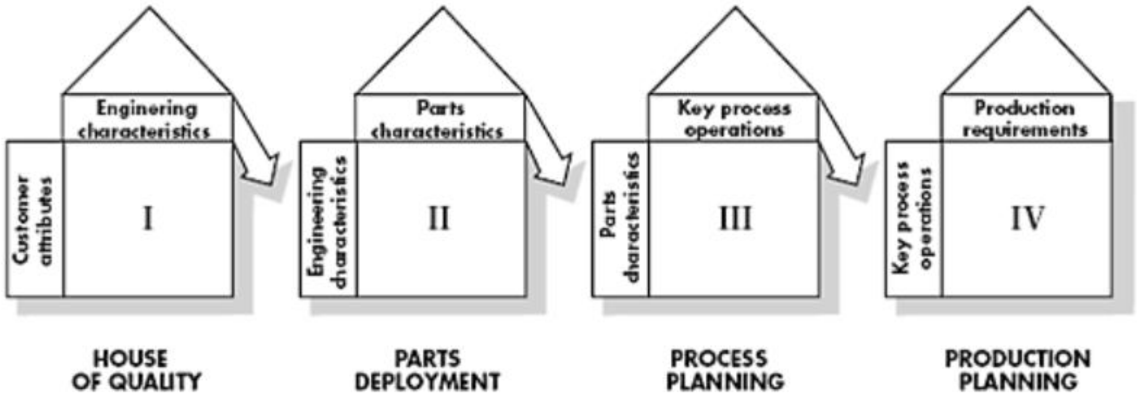


Figure 20: Cascade flow of house of quality

2.1.3 Process Development

Define critical process and process flow, design and develop manufacturing process according to product specifications, identify critical process characteristics, develop production equipment requirements, establish critical process parameters.

2.1.4 Process Quality Control

Process quality control are the step to diagnose critical part and process characteristics, establish process control parameters including test methods parameters to ensure overall process after implementation (Jaiswal, 2012).

According to academic researches on QFD (Jaiswal, 2012), there are numerous of benefits that QFD could bring to organisations such as following:

- Deep understanding on customer requirements from customer perspective as the house of quality focus on voice of customer.
- Competitor comparison analysis helps to organisations to acknowledge its standing point and seek for more value added features to stay ahead of its competitors.

- Visualisation of systematic thinking and engineering thought in each process helps deciding in adding each feature to add more value to product including determining the level of performance to deliver.
- Decrease cost and major reduction in development time.
- Historical data collection of any adjustment through development period is well structured and could be transferred to other related parties for further development.
- Leading to truly customer focused product which could deliver high level of customer satisfaction.

To sum up, QFD is one of the useful methodologies to improve product for manufacturer through house of quality application as discussed above. Though, QFD will be the main methodology using to improve the rock sugar chopping process in order to enhance overall productivity of the factory.

2.2 Hammer Mill Principles

Hammer mill has been mostly used to increase the productivity of agricultural material for a very long time. The principle of it, is to crush, cut, chop, or smash material into smaller pieces using hammer inside of the machine (Pharmapproach, 2019). Meaning that purpose of hammer mills is aligned with the result of chopping process. Hence, the concept and principles of hammer mills has been selected to support in terms of machine design in this thesis. To be specific, major components of hammer mills will be utilized as components in the prototype of rock sugar chopping machine to demonstrate mechanism of it.

Hammer mills major components are (Ezurike, et al., 2019):

- Hopper/ delivery device

- Chamber
- Hammers
- Shaft
- Sieve
- Pulley
- Belt
- Motor
- Take Away

Example of main components of hammer mill (1)

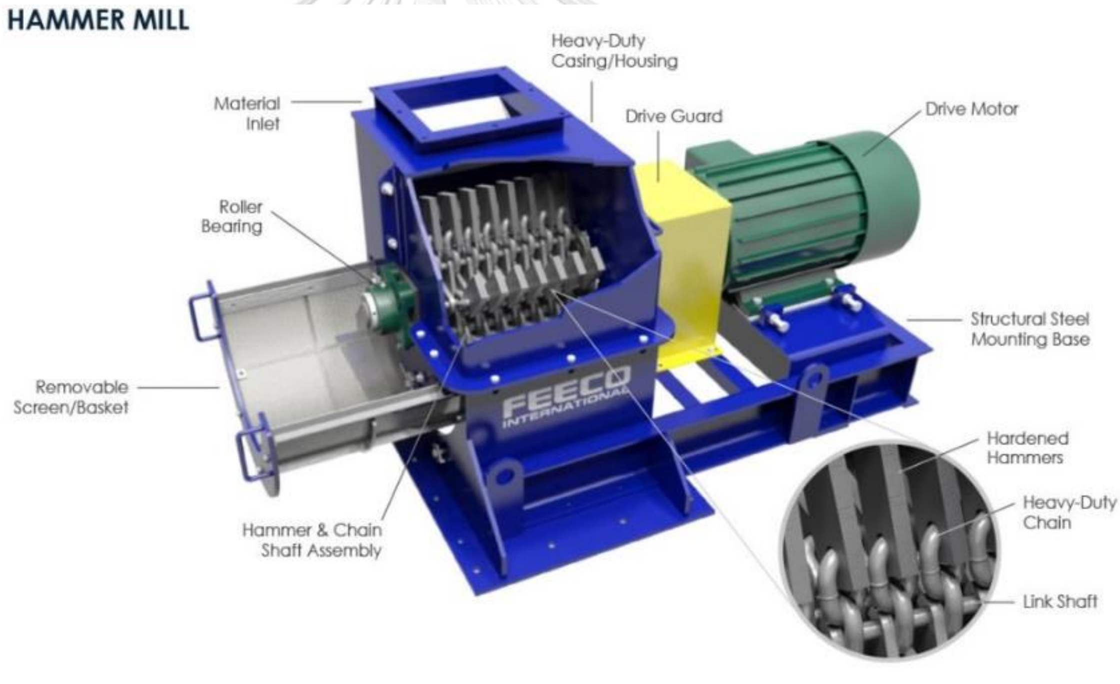


Figure 21: Main components of hammer mill (International, 2019)

Example of main components of hammer mill (2)

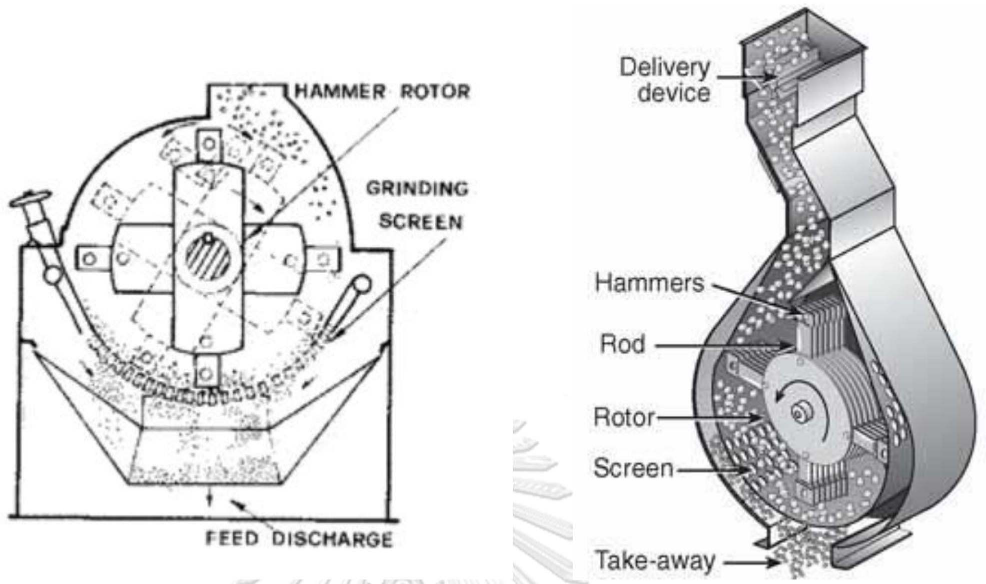


Figure 22: (2) Main components of hammer mill (Feedmachinery.com, 2019)

Example of main components of hammer mill (3)

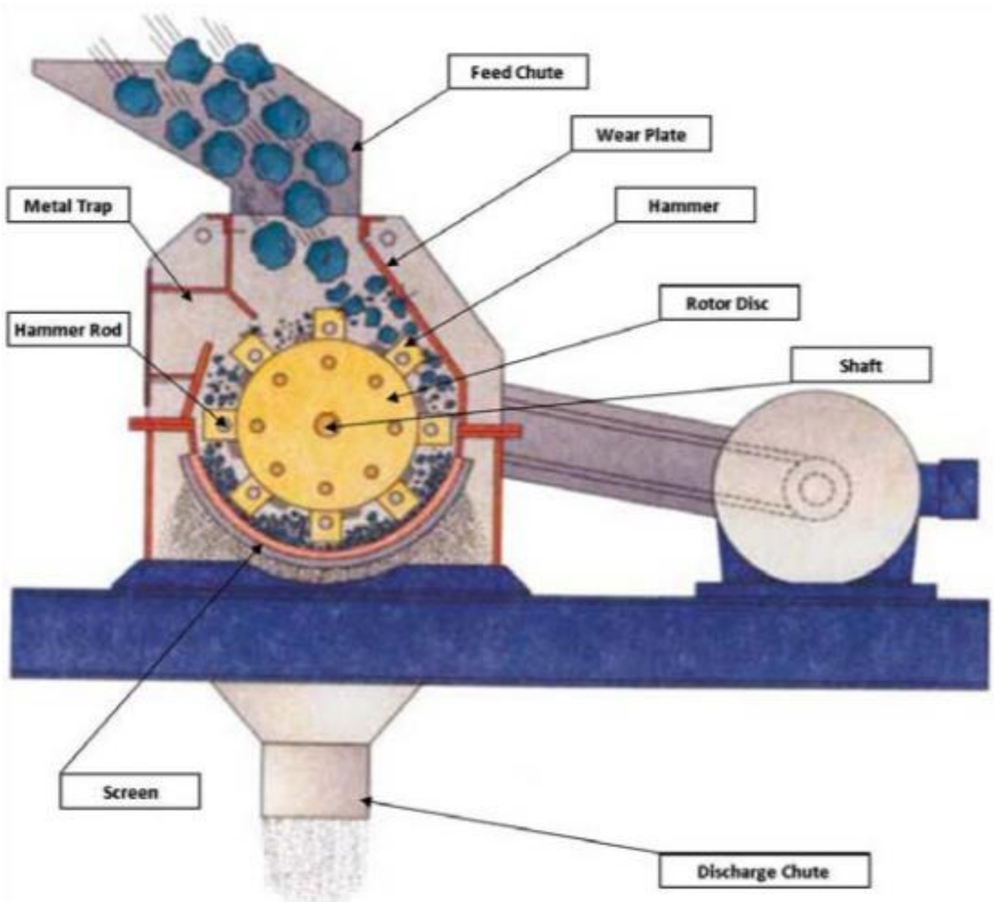


Figure 23: (3) Main components of hammer mill (Hammermill, 2014)

Hopper or delivery device is where material is being input then it will go into chamber where the hammers are located to crush material into smaller pieces then crushed material will fall into sieve to be screened into desired size before falling to take away part. Power to run hammer mill is usually generated by motor, transmitted through pulley and belt to the main shaft and hammer. However, the size of motor depends on desired force to crush material and level of duty of hammer mill (Yancey, et al., 2013).

According to design theory for hammer mill (Nasir, 2005), there are several parameters to take into consideration; shaft speed, length of the belt, angle of wrap and driven pulleys, belt contact angle, tension in slack side of the belt, tension in tight side of the belt, torque transmitted to shaft, power transmitted to shaft, weight of hammer, centrifugal force, and diameter of shaft. These parameters will be calculated once the prototype of rock sugar chopping machine is completed for the reference of future works in case the owner of sugar factory would like to build the full scale of machine in the future.

Parameters	Symbol	Measure Unit
Shaft speed	N	r.p.m
Length of belt	L	mm
Angle of wrap for drive pulley	α	degree
Angle of wrap for driven pulley	α_2	degree
Belt contact angle	β	degree
Tension in the slack side of belt	T_2	N
Tension in the tight side of belt	T_1	N
Torque transmitted to shaft	T	Nm
Power transmitted to shaft	P	W
Centrifugal force	F_c	KN
Diameter of main shaft	d	mm
Weight of hammer	W_h	kg/m^2

Table 1: Parameter of hammer mill

Determination of Shaft Speed:

Shaft speed can be calculated by the following formula (Parmley, 1985):

$$\frac{D_1}{D_2} = \frac{N_2}{N_1}$$

Where:

D_1 = Diameter of drive pulley (mm)

D_2 = Diameter of driven pulley (mm)

N_1 = Revolution of the smaller pulley (r.p.m)

N_2 = Revolution of the larger pulley (r.p.m)

Determination of Length of the Belt:

Length of the belt can be calculated by the following formula (Hannah & C, 1984):

$$L = 2C + 1.57(D_2 + D_1) + \frac{(D_1 + D_2)}{4C}$$

Where:

L = Length of the belt

C = Center distance between smaller pulley and larger pulley (mm)

Determination of Angle of Wrap for Smaller and Larger Pulleys:

Angle of wrap for smaller and larger pulleys can be calculated by the following formula (Hall, et al., 1980):

$$\alpha_1 = 180 + 2\sin^{-1}(\frac{R - r}{C})$$

$$\alpha_2 = 180 - 2\sin^{-1}(\frac{R - r}{C})$$

Where:

α_1 = Angle of wrap for smaller pulley (degree)

α_2 = Angle of wrap for larger pulley (degree)

R = Radius of larger pulley (mm)

R = Radius of smaller pulley (mm)

Determination of Belt Contact Angle:

Belt contact angle of open belt can be calculated by the following formula (Hall, et al., 1980):

$$\sin\beta = \frac{(R - r)}{C}$$

Where:

β = Belt contract angle (degree)

Determination of Belt Tension:

Belt tension can be calculated by the following formula (Hall, et al., 1980):

$$\frac{T_1 - T_C}{T_2 - T_C} = e^{\mu\theta}$$

And,

$$T_C = \frac{T_1}{3}$$

And,

$$T_C = MV^2$$

And,

$$M = width \times thickness \times belt\ density$$

And,

$$V = \frac{\pi D_1 N_1}{60}$$

According to (Khumi & Gupta, 2010), coefficient of friction between belt and pulley is 0.3, density of rubber belt is given as 1,140 (kg/m^3).

Where:

T_1 = Tension in the tight side of the belt (N)

T_2 = Tension in the slack side of the belt (N)

T_C = Centrifugal tension (N)

μ = Coefficient of friction

θ = angle of wrap of smaller pulley for open belt (degree)

M = Mass of belt per unit length (kg/m)

V = Velocity of the belt (m/s^2)

Determination of Power and Torque Transmitted to the Shaft:

Power transmitted to the shaft can be calculated by the following formula (Spolt, 1988):

$$P = (T_1 + T_2)V$$

Torque transmitted to the shaft can be calculated by the following formula (Spolt, 1988):

$$T = (T_1 - T_2)R$$

Where:

P = Power transmitted to the shaft (watt)

T = Torque transmitted to the shaft (Nm)

R = Radius of larger pulley

Determination of Hammer Weight:

Hammer weight can be calculated by following formula (Patton, 1980):

$$W_h = m \times g$$

Where:

W_h = Hammer weight (N)

m = Mass of hammer (kg)

g = acceleration due to gravity ($9.81\ m/s^2$)

Determination of Centrifugal Force:

Centrifugal force by hammer can be calculated by the following formula (Hannah & C, 1984):

$$F_C = \frac{mV^2}{r}$$

F_c = Centrifugal force

r = Radius of the shaft (m)

Testing Procedures

After building the prototype of hammer mill machine, testing has to be carried out to evaluate the overall performance of it. Thus, key indicators like capacity, efficiency, and losses must be measured and calculated. For chopping capacity, the mass of chopped rock sugar in specific period of time will be recorded, there will be 5 rounds of running machine to see the average value. For efficiency and losses, amount of input rock sugar, output rock sugar, and sugar powder will be recorded and there will be 5 rounds of trial to see the average value as well (Radwan, et al., 2018).

Determination of Chopping Capacity:

Chopping capacity can be calculated by following formula:

$$Chopping\ Capacity = \frac{Average\ mass\ of\ chopped\ rock\ sugar}{Average\ time\ taken}$$

Determination of Chopping Efficiency:

Chopping efficiency can be calculated by following formula:

$$Chopping\ Efficiency = \frac{Mass\ of\ output\ product}{Mass\ of\ input\ product} \times 100$$

Determination of Losses:

Losses can be calculated by following formula:

$$Losses = \frac{M_b - M_a}{M_b}$$

Where:

M_b = Mass before chopping

M_a = Mass after chopping

2.3 Research Contribution

In academic achievement perspective, this research is contributed as evidence in supporting the concept of QFD to design new machine in manufacturing process by transformation of VOC into engineering characteristics towards product. The research could be useful for a further of research on new machine design to improve productivity in the same or different industries.

In business achievement perspective, this research is contributing to maximize the profit of factory by focusing in long term rather than short term profit. Improving productivity by eliminating manual manufacturing process would have enhance the overall efficiency and increase revenue for the factory in the long term.

Chapter 3 Research Methodology

3.1 Investigation of Current Manual Rock Sugar Chopping Process

To understand thoroughly on the current manufacturing process including existing problems or pain points. The tasks to be done are as following (1) drawing current rock sugar chopping process in detail, (2) Current methodologies or approaches analysis of chopping process, and address problems.

3.2 Applying QFD to design new rock sugar chopping machine

To identify all design specification by applying QFD methodology and hammer mills concept, tasks to be done are as follows (1) collecting all of customer voice by engaging with customers and discuss customer's expectations in detail, (2) create house of quality for chopping machine to refine all of ideas and requirements.

3.3 Machine Prototype Creation

To create machine prototype according to QFD result, tasks to be done are as follows (1) Contacting to outsource company to discuss more in design and specification, (2) Building machine prototype.

3.4 Testing

To test prototype machine, measure, and record to evaluate its performance, tasks to be done are as follows (1) creating all parameters to evaluate during testing, (2) record all testing results to compare and analyse between pre-implementation and post-implementation results.

3.5 Writing a Complete Dissertation

This is a critical step to finish the dissertation. Dissertation requires to be written according to regulations and structure of the University of Warwick for quality of work. Tasks to be done are (1) outlining the complete dissertation, (2) drafting the complete dissertation, and (3) finishing the complete dissertation.

3.6 Planned Tasks

STEP	ACTIVITY	Jun-19				Jul-19				Aug-19				Sep-19				Oct-19				Nov-19				Dec-19			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	Investigation of Current Manual Rock Sugar Chopping Process																												
	1.1 Drawing current rock sugar chopping process in detail	■	■																										
	1.2 Current methodologies and approaches analysis, and address problems		■	■																									
2	Applying QFD to Design New Rock Sugar Chopping Machine																												
	2.1 Collecting all of customer voice and discuss customer's expectation in detail				■	■																							
	2.2 Creating house of quality for chopping machine to refine all of ideas & requirements						■	■	■	■																			
3	Machine Prototype Creation																												
	3.1 Contacting to outsource company to discuss more in deisgn and specification										■	■	■	■															
	3.2 Bulding machine prototype													■	■	■	■	■											
4	Trial																												
	4.1 Creating all parameters to evaluate during testing																	■											
	4.2 Record all testing results																		■	■									
	4.3 Analyse between pre-implementation and post-implementation results.																			■	■	■							
5	Writing a Complete Dissertation																												
	5.1 Outlining the complete dissertation						■	■	■																				
	5.2 Drafting the complete dissertation											■	■	■	■	■	■	■	■	■	■	■	■	■					
	5.3 Finishing the complete dissertation																								■	■			

Chapter 4 Results

This chapter consists of four main sections the first one is to illustrate how the author design new rock sugar chopping machine using Quality Function Deployment methodology. From QFD phase 1, finding design or technical requirements from customer requirements. And also QFD phase 2, finding part characteristics from design requirements. The second section is to illustrate the rock sugar chopping machine based on QFD phase 1 and 2. The third section is to view pre-implementation results in each parameter. And the last section is to demonstrate post-implementation results in each parameter as well.

4.1 House of Quality for Rock Sugar Chopping Machine

Technical Requirements is the main target of building the first phase House of Quality according to QFD methodology, voice of customers has to be determined first in order to understand what customer needs and translate into design requirements or technical requirements respectively.

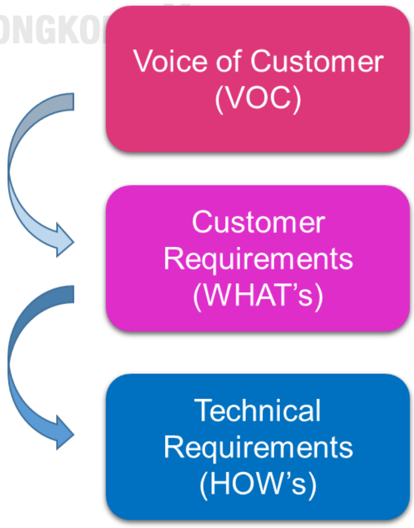


Figure 24: Translation of VOC to technical requirements

4.1.1 Voice of Customer (VOC)

Voice of customer (VOC) must be collected in order to translate to customer requirements. In this situation, customer is owner of selected rock sugar factory because new rock sugar chopping machine will be used at this factory to increase its productivity. There are several methods to collect voice of customer such as phone interview, face-to-face interview, focus group, etc. However, the author has chosen face-to-face interview to obtain customer requirements since the owner of rock sugar factory is customer in this case. Hence I has requested to set up a session with factory's owner, to understand all requirements that they want from new the rock sugar chopping machine. And collected voice of customer show in below table:

Figure 25: Voice of customer

Above table shows that there are total eight items that customer wants from new rock sugar chopping machine;

Item 1 Proper size – not too big: due to limitation of space in chopping area, the owner requests to have small size of machine.

Item 2 Affordable price: the owner has requested to build this machine as a mock up so they could evaluate overall performance of it and decide if they should invest in building the full scale machine in the future, thus production cost has to be limited to maximum of 20,000 THB.

Item 3 Long life: machine should be able to operate throughout a day which is maximum of 9 hours a day in case of full day operation. And it should be able to operate at least a year for continually of using and worth the investment.

Item 4 Not so loud noise: as there is a machine which is being used to separate size of rock sugar and it has very loud noise during operating. Thus, owner requests to have a machine with the level of noise that will not cause annoyance.

Item 5 Easy to use: workers at the factory will be the ones to operate machine and they have limited knowledge and IQ, thus machine should be easy to operate to avoid complications.

Item 6 Low Operating Cost: the cost occurs from machine operation should have not exceed labour cost for workers otherwise it might not worth using machine instead of workers.

Item 7 Chop into multi sizes: the owner is selling rock sugar in different sizes thus machine should be able to produce rock sugar in different sizes as well.

Item 8 Faster than manual: this is the ultimate purpose of building a new machine as the problem is to fix bottleneck from manual chopping process. Thus, the machine must be able to produce more productivity comparing with the current chopping process by workers manually.

4.1.2 Customer Requirements

These voice of customers are not customer requirements (WHAT's) yet. Customer requirements is item that QFD's creator has translate from VOC into quantifiable items.

Items	Voice of Customer	Customer Requirements (What's)
1	Proper machine's size	Access ergonomics
2	Affordable price	Cheap machine's cost
3	Long life	Durable
4	Not so loud noise	Low noise level
5	Easy to use	Easy to use
6	Cheap operating cost	Cheap running cost
7	Chop into multi sizes	Good chopping performance
8	Faster than manual	Good chopping performance

Table 2: Translation of VOC to customer requirements

To put customer requirements in QFD, voice of customer has to be translated into customer requirements which will be translated further into technical requirements.

In this case Proper size is represented by Access Ergonomics, affordable price to cheap machine's cost, long life to durable, not so loud noise to low noise level, easy to use has no changes as it could be customer requirement within itself already, cheap operating cost to cheap running cost, chop into multi sizes to good chopping performance, and faster than manual to good chopping performance.

4.1.3 Importance of Customer Requirements

After obtaining customer requirements, next step according to QFD is to determine the level of importance of each attribute of customer requirement.

Items	Customer Requirements (What's)	Importance Weight	Importance %
1	Access ergonomics	8	15%
2	Cheap machine's cost	9	16%
3	Durable	7	13%
4	Low noise level	6	11%
5	Easy to use	7	13%
6	Cheap running cost	8	15%
7	Good chopping performance	10	18%

Table 3: Importance of customer requirements

In this case, good chopping performance has the most importance percentage with 18% as the ultimate goal from this research is to increase productivity for chopping process. The second most importance's customer requirement is machine cost because the owner of rock sugar factory has requested to limit production cost to THB 20,000. The third most importance's customer requirements are access ergonomics and cheap running cost with equally of 15%. The forth importance of customer requirements are durable and easy to use with 13%. And the least important of customer requirement is noise level with 11%.

4.1.4 Technical Requirements

Next step is to determine technical requirements from customer requirements to put in QFD. And the key is to translation into the attributes that measurable as target of each technical requirement will be set later.

Measurable

Voice of Customer	Customer Requirements (What's)	Technical Requirements (How's)
Proper machine's size	Access ergonomics	Support and Chamber
Affordable price	Cheap machine's cost	Production cost
Long life	Durable	Expected life
Not so loud noise	Low noise level	Noise level
Easy to use	Easy to use	Using step
Cheap operating cost	Cheap running cost	Operating cost, distribution power, receive power
Chop into multi sizes	Good chopping performance	Sizes and output
Faster than manual	Good chopping performance	Cutting speed

Table 4: Translation of VOC into techinical requirements

Access ergonomics is represented by support or chamber in technical requirement column since it is focused on the dimension of the machine and support or chamber is the place to store or operate the product and it affects directly to dimension of machine.

Cheap machine's cost is represented by production cost which is the total cost of building machine such as parts, labour cost, etc.

Durable is represented by expected life where expected life means the forecast of total operating hours of machine before it breaks.

Low noise level is represented by noise level which is measurable item.

Easy to use is represented by using step and the lesser steps mean the easier of machine to use.

Cheap running cost is represented by operating cost, distribute power, and receive power because these attributes are going to affect running cost.

Good chopping performance is represented by multi-size, output, and cutting speed according to goals of building new rock sugar chopping machine.

Technical Requirements (How's)	Measurement Units
Cutting speed	Round per minute
Sizes	Diameter of each size
Noise level	Decibels
Output	Amount of chopped rock sugar (kg)
Distribution power	Watt
Receive power	Watt
Support	Height, Width, Depth (mm)
Chamber	Height, Width, Depth (mm)
Using step	Number of using step
Production cost	Amount of money in THB
Operating cost	Amount of money in THB
Expected life	Operating hours

Table 5: Technical requirements and measurement units

As mentioned above that, technical requirements is measurable attribute thus each measurement unit has to be determined.

Measurement unit of cutting speed is round per minute, multi-size's measurement unit is diameter of the biggest size of chopped rock sugar, noise level's measurement unit is decibels, output's measurement unit is amount of chopped rock sugar in kg, measurement units of distribute power and receive power are watt, measurement unit of support and chamber are dimension, production cost and operating cost's measurement units are total money in THB, and expected life's measurement unit is operating hours.

Customer Requirements and Technical Requirements Relationship

After obtaining customer requirements and technical requirements, next step is to evaluate relations of each other. Strong relationship is represented by symbol ʘ, medium relationship is represented by symbol O, weak relationship is represented by symbol Δ, and no relationship is blank as shown in below Table7:

Customer Requirements (What's) \ Technical Requirements (How's)		Importance Weight	Importance %	Chopping				Power System		Case		User	Cost		
				Cutting speed	Multi-size	Noise Level	Output	Distribution power	Receive power	Support	Chamber	Using steps	Production cost	Operating cost	Expected life
Ease of Use	Chopping performance	10	18%	Θ	Θ	O	Θ	O	Δ		O		Θ	O	
	Easy to use	7	13%									Θ	Δ		
	Access ergonomics	8	15%					Δ		Θ	O		Θ		
	Control noise	6	11%	Δ		Θ					Δ		Δ		
Cost	Machine cost	9	16%	O	Δ	Δ	O	Δ	Δ	O	O	Δ	Θ	Δ	O
	Running cost	8	15%	Δ			O	Θ	Δ				O	Θ	
	Durable	7	13%							O			Θ		Θ

Level of Relationship: Θ = 9 (Strong), O = 3 (Medium), Δ = 1 (Weak), Blank = 0 (No relationships)

Table 6: Customer requirements and technical requirements relationships in QFD

4.1.5 Technical Importance

After filling out relationship between customer requirements and technical requirements, next step is to calculate the value of technical importance according to relationships.

Technical Importance part in QFD consists of Technical Importance Rate and Technical Relative Importance Rate. Technical Importance Rate can be calculated by the sum of each customer requirement % of total weight multiply by the level of relationship between that customer requirement and technical requirement in the same column.

Technical Importance Rate

	Technical Requirements (How's) / Customer Requirements (What's)	Importance Weight	Importance %	Chopping				Power System		Case		User	Cost		
				Cutting speed	Multi-size	Noise Level	Output	Distribution power	Receive power	Support	Chamber	Using steps	Production cost	Operating cost	Expected life
Ease of Use	Chopping performance	10	18%	Θ	Θ	O	Θ	O	Δ		O		Θ	O	
	Easy to use	7	13%									Θ	Δ		
	Access ergonomics	8	15%					Δ		Θ	O		Θ		
	Control noise	6	11%	Δ		Θ					Δ		Δ		
Cost	Machine cost	9	16%	O	Δ	Δ	O	Δ	Δ	O	O	Δ	Θ	Δ	O
	Running cost	8	15%	Δ			O	Θ	Δ				O	Θ	
	Durable	7	13%							O			Θ		Θ
Technical Importance Rate		∑ 2,614		235	178	169	255	220	49	222	157	133	626	205	165

Level of Relationship: Θ = 9 (Strong), O = 3 (Medium), Δ = 1 (Weak), Blank = 0 (No relationships)

Table 7: Technical importance rate

- Technical Importance Rate of "Cutting Speed" calculation:

= (18 x 9) + (11 x 1) + (16 x 3) + (15 x 1)

= 235

- Technical Importance Rate of "Multi-size" calculation:

= (18 x 9) + (16 x 1)

= 178

- Technical Importance Rate of "Noise level" calculation:

= (18 x 3) + (11 x 9) + (16 x 1)

= 169

- Technical Importance Rate of "Output" calculation:

= (18 x 9) + (16 x 3) + (15 x 3)

= 255

- Technical Importance Rate of "Distribution power" calculation:

= (18 x 3) + (15 x 1) + (16 x 1) + (15 x 9)

= 220

- Technical Importance Rate of "Receive power" calculation:

= (18 x 1) + (16 x 1) + (15 x 1)

= 49

- Technical Importance Rate of "Support" calculation:

= (15 x 9) + (16 x 3) + (13 x 3)

= 222

- Technical Importance Rate of "Chamber" calculation:

= (18 x 3) + (15 x 3) + (11 x 1) + (16 x 3)

= 157

- Technical Importance Rate of "Using steps" calculation:

= (13 x 9) + (16 x 1)

= 133

- Technical Importance Rate of "Production Cost" calculation:

= (18 x 9) + (13 x 1) + (15 x 9) + (11 x 1) + (16 x 9) + (15 x 3) + (13 x 9)

= 626

- Technical Importance Rate of "Operating Cost" calculation:

= (18 x 3) + (16 x 1) + (15 x 9)

= 205

- Technical Importance Rate of “Expected Life” calculation:

= (16 x 3) + (13 x 9) = 165

<u>Technical Relative Importance Rate</u>

Once Technical Importance Rate has been determined, then the number of Technical Relative Importance Rate can be shown in below table:

Technical Requirements (How's) / Customer Requirements (What's)		Importance Weight	Importance %	Chopping				Power System		Case		User	Cost		
				Cutting speed	Multi-size	Noise Level	Output	Distribution power	Receive power	Support	Chamber	Using steps	Production cost	Operating cost	Expected life
Ease of Use	Chopping performance	10	18%	Θ	Θ	O	Θ	O	Δ		O		Θ	O	
	Easy to use	7	13%									Θ	Δ		
	Access ergonomics	8	15%					Δ		Θ	O		Θ		
	Control noise	6	11%	Δ		Θ					Δ		Δ		
Cost	Machine cost	9	16%	O	Δ	Δ	O	Δ	Δ	O	O	Δ	Θ	Δ	O
	Running cost	8	15%	Δ			O	Θ	Δ				O	Θ	
	Durable	7	13%							O			Θ		Θ
Technical Importance Rate		∑ 2,614		235	178	169	255	220	49	222	157	133	626	205	165
Technical Relative Importance Rate %				9%	7%	6%	10%	8%	2%	8%	6%	5%	24%	8%	6%

Level of Relationship: Θ = 9 (Strong), O = 3 (Medium), Δ = 1 (Weak), Blank = 0 (No relationships)

Table 8: Technical relative importance rate

Above table could be interpreted as following:

Production cost related with the most customer requirements and it has the highest technical relative importance rate at 24%. Meaning that production cost should be considered as the first priority of rock sugar chopping machine design. The second priority is output which has 10% of technical relative importance rate and it has relationships with chopping performance, machine cost, and running cost. The third one is cutting speed with slightly less technical relative importance rate at 9%. Next priorities are distribution power and operating cost at 8%. Fifth priority is multi-sizes of rock sugar at 7%. Sixth priorities are noise level, chamber, and expected life with equally technical relative importance rate of 6%. And the last one is receive power at only 2%.

4.1.6 Technical Targets and Degree of Difficulty of Phase 1 QFD

Next step is to set the technical targets of technical requirements and these targets need to be aligned with voice of customer as well.

Technical targets of technical requirements are set as below Table 9:

Customer Requirements (What's) \ Technical Requirements (How's)		Importance Weight	Importance %	Chopping				Power System		Case		User	Cost		
				Cutting speed	Multi-size	Noise Level	Output	Distribution power	Receive power	Support	Chamber	Using steps	Production cost	Operating cost	Expected life
Ease of Use	Chopping performance	10	18%	Θ	Θ	O	Θ	O	Δ		O		Θ	O	
	Easy to use	7	13%									Θ	Δ		
	Access ergonomics	8	15%					Δ		Θ	O		Θ		
	Control noise	6	11%	Δ		Θ					Δ		Δ		
Cost	Machine cost	9	16%	O	Δ	Δ	O	Δ	Δ	O	O	Δ	Θ	Δ	O
	Running cost	8	15%	Δ			O	Θ	Δ				O	Θ	
	Durable	7	13%							O			Θ		Θ
Technical Importance Rate		∑ 2,614		235	178	169	255	220	49	222	157	133	626	205	165
Technical Relative Importance Rate %				9%	7%	6%	10%	8%	2%	8%	6%	5%	24%	8%	6%
Ranking				3	5	6	2	4	8	4	6	7	1	4	6
Technical Target				≥ 8 kg of chopped rock sugar per min	≥ 3 sizes	<140 Decibels	≥ 8 kg of chopped rock sugar per min	3 phase AC Motor drive 220/380 volts	3 phase electricity	885mm x 480mm x1167mm (Width x Length x Height)	300 x 395mm x 394mm (Width x Length x Height)	≤ 5 steps	≤ 20,000 THB	≤ 2,100 THB per day	≥ 1 year operating hours
Degree of Technical Difficulty (0 = Easy to accomplish, 5 = Extremely difficult)				3	4	4	3	1	0	2	3	2	3	3	4

Table 9: Technical targets and degree of technical difficulty

It is important to note that dimension of the case has been set according to the second hand structural steel case that author bought due to financial purpose. As machine's product cost is the first priority of the owner thus decision has been made together with the owner to buy second hand of structural steel case that empty inside for this prototype machine.

Cutting speed and output targets are set to align with the current productivity from manual chopping which is 8 kilograms per minute, therefore target is more than 8 kilograms per minute.

Rock sugar sizes target is set to be more than 3 sizes as the three biggest sizes that factory is selling makes the more money than smaller sizes.

Noise level is set with less than 140 decibels according to information from World Health Organization (WHO, 2019) that level of noise higher than 140 decibels could harm human.

Distribution power and receive power targets are set according to electric system in the factory which is 3-phase AC.

Support and chamber dimensions targets are set based on purchased second hand structural steel as per mentioned above.

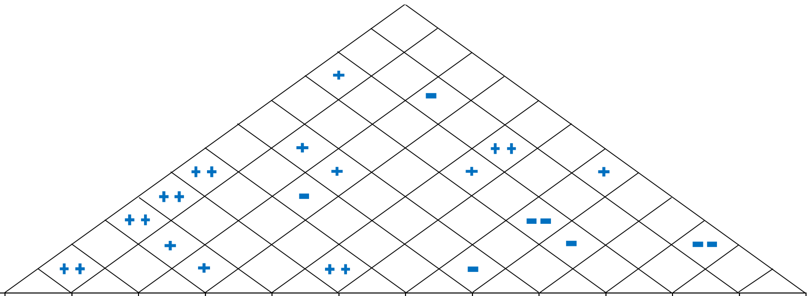
Using steps target is set at equal or less than 5 steps due to IQ limitation of workers in order to make it easy for them to operate.

Production cost target is set at 20,000 THB according to the budget from owner.

Operating hours target is set at least 1 year to be worth with the investment.

4.1.7 Phase 1 QFD

Then the complete of phase 1 QFD is shown in below table 9. The reason that it is called phase 1 QFD is because there will be 2 phases of QFD. The first phase is to translate voice of customer into technical targets and the second phase is to translate technical targets into part characteristics. And rock sugar chopping machine will be build based on both phases of QFD.



	Customer Requirements (What's) \ Technical Requirements (How's)	Importance Weight	Importance %	Chopping: Cutting speed	Chopping: Multi-size	Chopping: Noise Level	Chopping: Output	Power System: Distribution power	Power System: Receive power	Case: Support	Case: Chamber	User: Using steps	Cost: Production cost	Cost: Operating cost	Cost: Expected life
	Direction of Improvement (↑,↓)			↑		↑	↑	↓		↑		↓	↓	↓	↑
Ease of Use	Chopping performance	10	18%	Θ	Θ	O	Θ	O	Δ		O		Θ	O	
	Easy to use	7	13%									Θ	Δ		
	Access ergonomics	8	15%					Δ		Θ	O		Θ		
	Control noise	6	11%	Δ		Θ					Δ		Δ		
Cost	Machine cost	9	16%	O	Δ	Δ	O	Δ	Δ	O	O	Δ	Θ	Δ	O
	Running cost	8	15%	Δ			O	Θ	Δ				O	Θ	
	Durable	7	13%							O			Θ		Θ
	Technical Importance Rate	∑ 2,614		235	178	169	255	220	49	222	157	133	626	205	165
	Technical Relative Importance Rate %			9%	7%	6%	10%	8%	2%	8%	6%	5%	24%	8%	6%
	Ranking			3	5	6	2	4	8	4	6	7	1	4	6
	Technical Target			≥ 8 kg of chopped rock sugar per min	≥ 3 sizes	<140 Decibels	≥ 8 kg of chopped rock sugar per min	3 phase AC Motor drive 220/380 volts	3 phase electricity	885mm x 480mm x1167mm (Width x Length x Height)	300 x 395mm x 394mm (Width x Length x Height)	≤ 5 steps	≤ 20,000 THB	≤ 2,100 THB per day	≥ 1 year operating hours
	Degree of Technical Difficulty (0 = Easy to accomplish, 5 = Extremely difficult)			3	4	4	3	1	0	2	3	2	3	3	4

Table 10: Phase 1 QFD

4.1.8 From Technical Requirements to Part Characteristics

As technical requirements and technical targets have been determined in phase 1 QFD from voice of customer, next step is to create phase 2 QFD in order to determine part characteristics and part targets as well. Then the new rock sugar chopping machine shall be designed and built according to QFD phase 1 & 2.

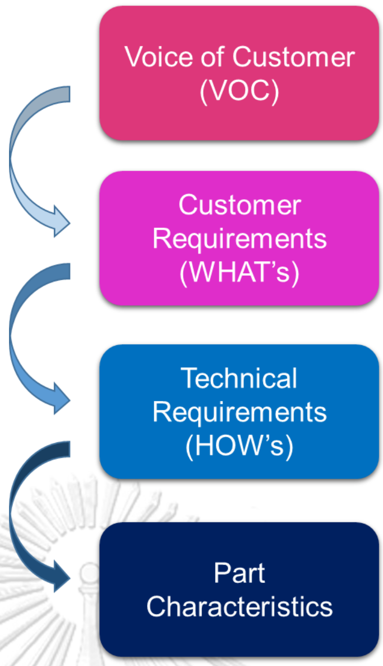
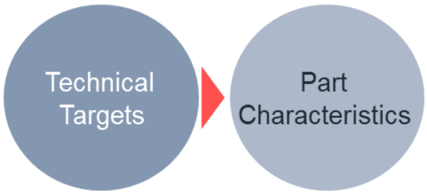


Figure 26: Translation from VOC to part characteristics

Part characteristics are created based on technical requirements and technical targets from phase 1 QFD though part characteristics have to be determined in order to achieve technical targets. In this phase 2 QFD, the author has chosen the design concept of hammer mill to utilise with part characteristics as the working principles of it is to crush or shred material into pieces or smaller sizes though it has similar output as chopping. And Hammer mill mainly consists of motor drive, plug, belt, pulley, hammer, main shaft, hammer shaft, sieve, chamber, hopper, and structural steel.



3	≥ 8 kg of chopped rock sugar per min	3	9%	235		▷	○	▷			⊙	Cutting speed	Chopping
4	≥ 3 sizes	5	7%	178			▷				⊙	Multi-size	
4	<140 Decibels	6	6%	169			▷	⊙			○	Noise Level	
3	≥ 8 kg of chopped rock sugar per min	2	10%	255		○	○				⊙	Output	
1	3 phase AC Motor drive 220/380 volts	4	8%	220		⊙	▷		▷		○	Distribution power	Power System
0	3 phase electricity	8	2%	49		▷	▷				▷	Receive power	
2	885mm x 480mm x1167mm (Width x Length x Height)	4	8%	222	○		○		⊙			Support	Case
3	300 x 395mm x 394mm (Width x Length x Height)	6	6%	157			○	▷	○		○	Chamber	
2	≤ 5 steps	7	5%	133			▷			⊙		Using steps	User
3	≤ 20,000 THB	1	24%	626	⊙	○	⊙	▷	⊙	▷	⊙	Production cost	Cost
3	≤ 2,100 THB per day	4	8%	205		⊙	▷				○	Operating cost	
4	≥ 1 year operating hours	6	6%	165	⊙		○					Expected life	

Part Characteristics

Motor Drive	Power
Plug	
Belt	
Pulley	
Hammer	Hammer
Main Shaft	
Sieve	Sizing
Casing/Chamber	Case
Hopper	
Structural	

Table 11: Determination of part characteristics from technical requirements

Motor drive and plug are parts to distribute and receive power into machine. Belt, pulley, hammer, main shaft, and hammer shaft are parts to receive force and chop rock sugar into smaller pieces. Then sieve will be the part where chopped rock sugar is screened before taking out. Hopper and chamber are parts that rock sugar will be input and contained respectively. And structural steel is part to hold overall machine together as well as bearing the total weight. However, efficiency of each part will be determined later in Part Targets section. Thus technical requirements and part characteristics can be shown in phase 2 QFD as below table.

Technical Requirements \ Part Characteristics		Importance Weight	Importance %	Power				Hammer		Sizing	Case		
				Motor Drive	Plug	Belt	Pulley	Hammer	Main Shaft	Sieve	Casing/ Chamber	Intake/ Hopper	Structural Steel
Chopp-ing	Cutting Speed	235	9%										
	Muti-size	178	7%										
	Noise level	169	6%										
	Output	255	10%										
Power System	Distribute Power	220	8%										
	Receive Power	49	2%										
Case	Support	222	8%										
	Chamber	157	6%										
User	Using Steps	133	5%										
Cost	Production Cost	626	24%										
	Operating Cost	205	8%										
	Expected Life	165	6%										

Table 12: Part characteristics column in phase 2 QFD

Next step is alike as phase 1 QFD which is to determine level of relationship between technical requirements and part characteristics follows by part importance rate and part relative importance rate.

Technical Requirements \ Part Characteristics		Importance Weight	Importance %	Power				Hammer		Sizing	Case		
				Motor Drive	Plug	Belt	Pulley	Hammer	Main Shaft	Sieve	Casing/ Chamber	Intake/ Hopper	Structural Steel
Chopp-ing	Cutting Speed	235	9%	Θ		Δ	Θ	O	Θ				
	Muti-size	178	7%					Θ		Θ	O		
	Noise level	169	6%	O			Δ	O			O	Δ	
	Output	255	10%					Θ	O	Θ	O	O	
Power System	Distribute Power	220	8%	Θ	O		Θ		Θ				
	Receive Power	49	2%	Δ	Δ		Δ		Δ				
Case	Support	222	8%	Δ			Δ	O	Δ		Θ	O	Θ
	Chamber	157	6%					Θ		O	Θ	O	O
User	Using Steps	133	5%									O	
Cost	Production Cost	626	24%	O	O	Δ	O	Θ	O	Δ	O		Θ
	Operating Cost	205	8%	Θ									
	Expected Life	165	6%	O		Δ		O	O	Δ	O	O	O

Level of Relationship: Θ = 9 (Strong), O = 3 (Medium), Δ = 1 (Weak), Blank = 0 (No relationships)

Table 13: Technical requirements and part characteristics relationship in phase 2 QFD

<u>Part Importance Rate</u>

Calculation of part importance rate is exactly the same as technical importance rate's calculation.

- Part Importance Rate of "Motor Drive" calculation:

  = (9 x 9) + (6 x 3) + (8 x 9) + (2 x 1) + (8 x 1) + (24 x 3) + (8 x 9) + (6 x 3)

  = 343

- Part Importance Rate of "Plug" calculation:

  = (8 x 3) + (2 x 1) + (24 x 3)

  = 98

- Part Importance Rate of "Belt" calculation:

  = (9 x 1) + (24 x 1) + (6 x 1)

  = 39

- Part Importance Rate of "Pulley" calculation:

  = (9 x 9) + (6 x 1) + (8 x 9) + (2 x 1) + (8 x 1) + (24 x 3)

  = 241

- Part Importance Rate of "Hammer" calculation:

  = (9 x 3) + (7 x 9) + (6 x 3) + (10 x 9) + (8 x 3) + (6 x 9) + (24 x 9) + (6 x 9)

  = 510

- Part Importance Rate of "Main Shaft" calculation:

  = (9 x 9) + (10 x 3) + (8 x 9) + (2 x 1) + (8 x 1) + (24 x 3) + (6 x 3)

  = 283

- Part Importance Rate of "Hammer Shaft" calculation:

  = (9 x 3) + (7 x 3) + (6 x 1) + (10 x 3) + (8 x 1) + (6 x 9) + (24 x 3) +

(6 x 3)

= 236

- Part Importance Rate of “Sieve” calculation:

= (7 x 9) + (10 x 9) + (6 x 3) + (24 x 1) + (6 x 1)

= 201

- Part Importance Rate of “Chamber” calculation:

= (7 x 3) + (6 x 3) + (10 x 3) + (8 x 9) + (6 x 9) + (24 x 3) + (6 x 3)

= 285

- Part Importance Rate of “Hopper” calculation:

= (6 x 1) + (10 x 3) + (8 x 3) + (6 x 3) + (5 x 3) + (6 x 3)

= 111

- Part Importance Rate of “Structural Steel” calculation:

= (8 x 9) + (6 x 3) + (24 x 9) + (6 x 3)

= 324

Part Relative Importance Rate

Also same as phase 1 QFD, part relative importance can be calculated from part importance rate as show in below table.

	Technical Requirements \ Part Characteristics	Importance Weight	Importance %	Power				Hammer		Sizing	Case		
				Motor Drive	Plug	Belt	Pulley	Hammer	Main Shaft	Sieve	Casing/ Chamber	Intake/ Hopper	Structural Steel
Chopp-ing	Cutting Speed	235	9%	Θ		Δ	Θ	O	Θ				
	Muti-size	178	7%					Θ		Θ	O		
	Noise level	169	6%	O			Δ	O			O	Δ	
	Output	255	10%					Θ	O	Θ	O	O	
Power System	Distribute Power	220	8%	Θ	O		Θ		Θ				
	Receive Power	49	2%	Δ	Δ		Δ		Δ				
Case	Support	222	8%	Δ			Δ	O	Δ		Θ	O	Θ
	Chamber	157	6%					Θ		O	Θ	O	O
User	Using Steps	133	5%									O	
Cost	Production Cost	626	24%	O	O	Δ	O	Θ	O	Δ	O		Θ
	Operating Cost	205	8%	Θ									
	Expected Life	165	6%	O		Δ		O	O	Δ	O	O	O
	Part Importance Rate		∑ 2,435	343	98	39	241	510	283	201	285	111	324
	Part Relative Importance Rate %			14%	4%	2%	10%	21%	12%	8%	12%	5%	13%
	Ranking			2	7	8	5	1	4	6	4	7	3

Level of Relationship: Θ = 9 (Strong), O = 3 (Medium), Δ = 1 (Weak), Blank = 0 (No relationships)

Table 14: Part relative importance in phase 2 QFD

4.1.9 Phase 2 QFD

Similar to phase 1 QFD, part characteristics targets are set to be aligned with technical requirements and voice of customer.

Technical Requirements \ Part Characteristics		Importance Weight	Importance %	Power				Hammer		Sizing	Case		
				Motor Drive	Plug	Belt	Pulley	Hammer	Main Shaft	Sieve	Casing/ Chamber	Intake/ Hopper	Structural Steel
Chopp-ing	Cutting Speed	235	9%	⊙		Δ	⊙	O	⊙				
	Muti-size	178	7%					⊙		⊙	O		
	Noise level	169	6%	O			Δ	O			O	Δ	
	Output	255	10%					⊙	O	⊙	O	O	
Power System	Distribute Power	220	8%	⊙	O		⊙		⊙				
	Receive Power	49	2%	Δ	Δ		Δ		Δ				
Case	Support	222	8%	Δ			Δ	O	Δ		⊙	O	⊙
	Chamber	157	6%					⊙		O	⊙	O	O
User	Using Steps	133	5%									O	
Cost	Production Cost	626	24%	O	O	Δ	O	⊙	O	Δ	O		⊙
	Operating Cost	205	8%	⊙									
	Expected Life	165	6%	O		Δ		O	O	Δ	O	O	O
	Part Importance Rate		∑ 2,435	343	98	39	241	510	283	201	285	111	324
	Part Relative Importance Rate %			14%	4%	2%	10%	21%	12%	8%	12%	5%	13%
	Ranking			2	7	8	5	1	4	6	4	7	3
	Part Characteristic Target			3 phase electric motor, 1.5 Kw, 1400 r.p.m	Thailand domestic 15 amp plug for 3-phase electricity	V-Belt, B41	Diameter for smaller pulley: 76mm Diameter for larger pulley: 128mm	3 blades per round, 4 rounds	Steel rod < 800 mm Length, 25mm diameter	≥4 x 4 and ≤7 x 7	300 x 395mm x 394mm (Width x Length x Height)	395mm x 140mm (Length x Width)	885mm x 480mm x1167mm (Width x Length x Height)

Table 15: Phase 2 QFD

Part characteristic targets are set based on reasons as shown in below figure.

Target	Reason	Part	Group
3 phase electric motor, 1.5 Kw, 1400 r.p.m	Motor for normal duty	Motor Drive	Power
Thailand domestic 15 amp plug for 3-phase electricity	Plug to use with 3-phase electricity	Plug	Power
V-Belt, B41	Belt for power transmission	Belt	Power
Diameter for smaller pulley: 76mm Diameter for larger pulley: 128mm	Set to align with structural steel case	Pulley	Power
3 blades per round, 4 rounds	For minimum balance when rotating	Hammer	Hammer
Steel rod < 800 mm Length, 25mm diameter	To fit with the case	Main Shaft	Hammer
≥4 x4 and ≤7 x7	Set from diameter of rock sugar	Sieve	Sizing
300 x 395mm x 394mm (Width x Length x Height)	Dimension from actual part	Casing/ Chamber	Case
395mm x 140mm (Length x Width)	Dimension from actual part	Intake/ Hopper	Case
885mm x 480mm x1167mm (Width x Length x Height)	Dimension from actual part	Structural Steel	Case

Figure 27: Part characteristic targets

As the part characteristics targets are set, then rock sugar chopping machine will be built based on information from Phase 1 and 2 QFD.

4.2 Rock Sugar Chopping Machine

4.2.1 Rock Sugar Chopping Machine Design

Major components of rock sugar chopping machines from QFD:

- Motor (1,500 watt, 1,400 r.p.m)
- Diameter of drive pulley (76 mm)
- Diameter of driven pulley (128 mm)
- Belt (B41 V-Belt, thickness = 10.3 mm, width = 16.7 mm)

- Diameter of main shaft (25 mm)
- Mass of hammer (6.5 kg)

Front and side views of hammer design

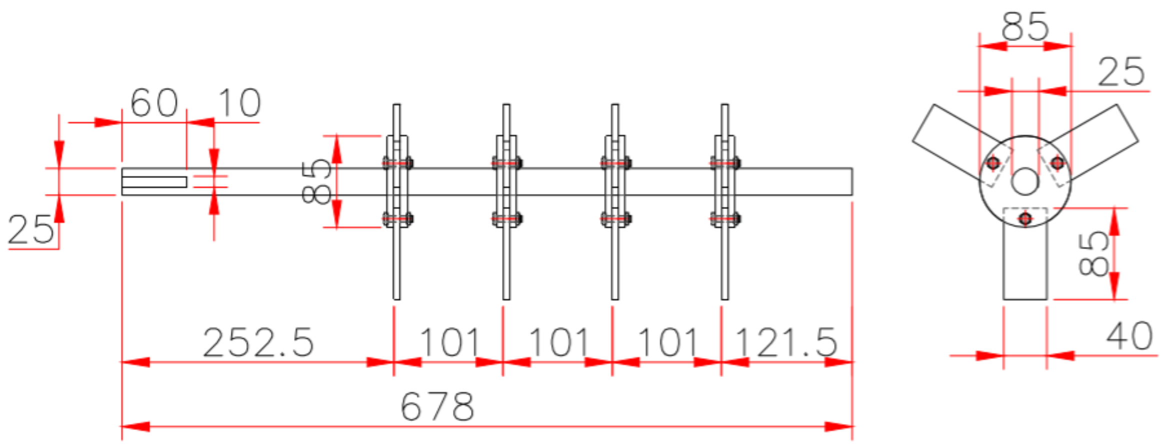


Figure 28: Hammer design (front & side views)

Front and side views of assembly of hammer and bearing design

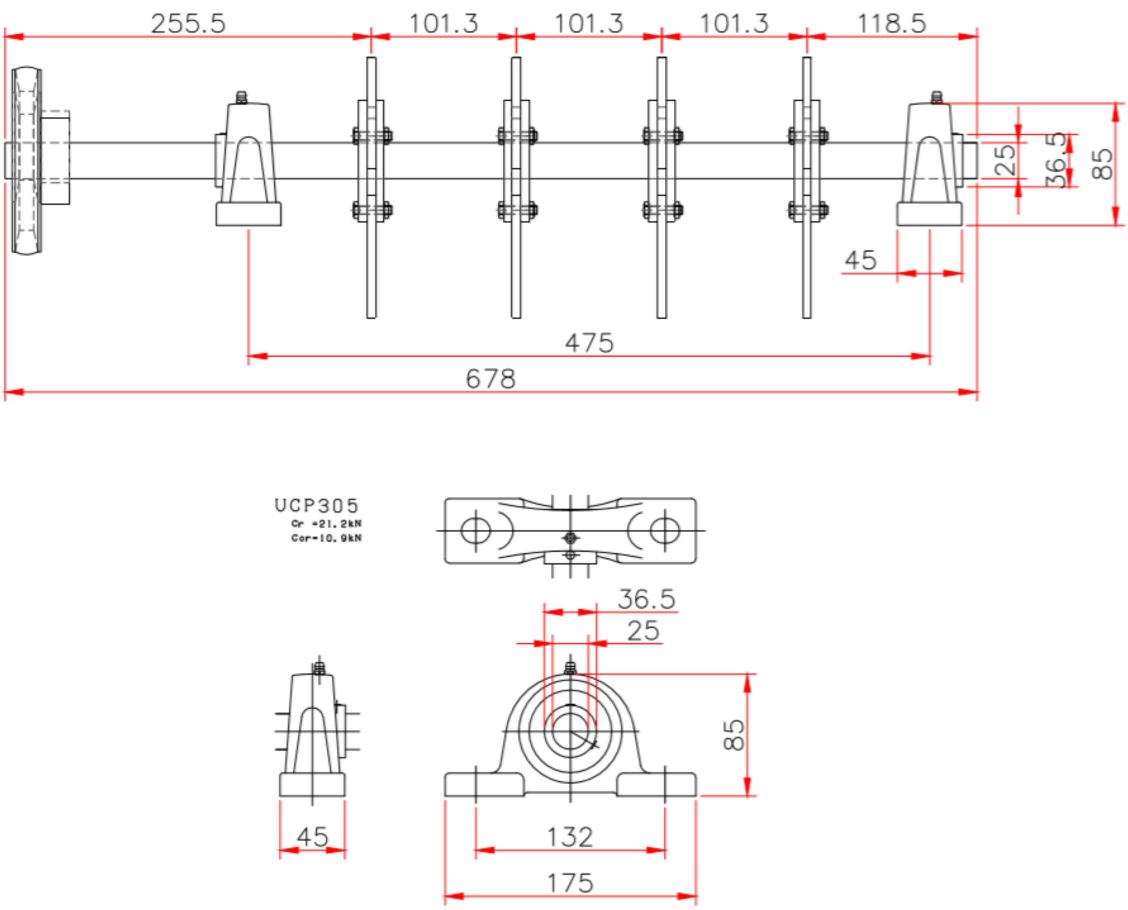


Figure 29: Assembly of hammer and bearing design (front and side views)

Side View of Hammer, Chamber, and Motor Design

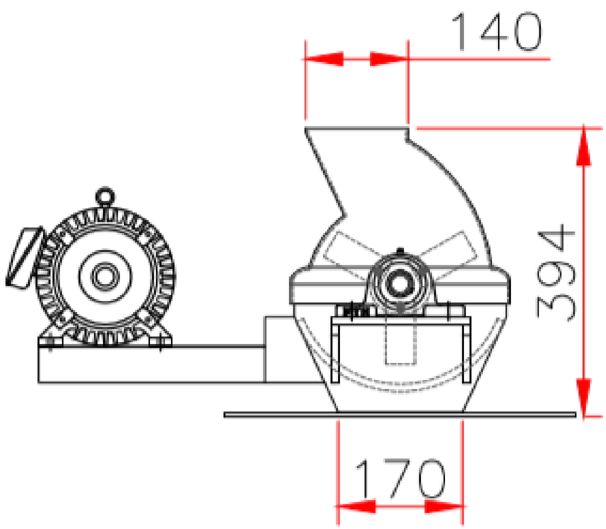


Figure 30: Hammer, chamber and motor design (side view)

Front View of Hammer, Chamber, and Motor Design

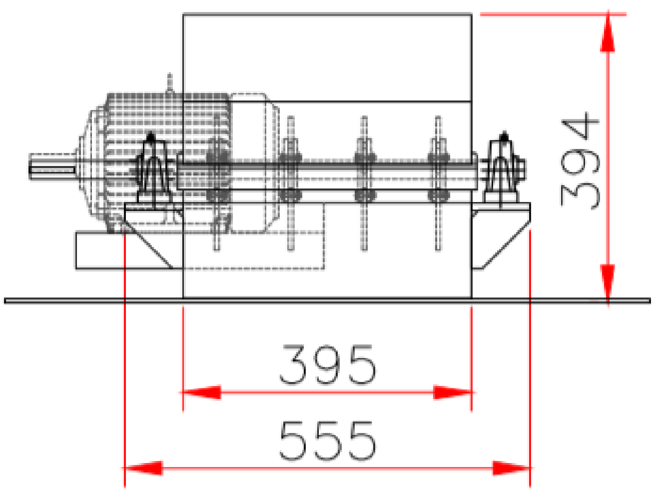


Figure 31: Hammer, chamber, and motor design (front view)

Back View of Hammer, Chamber, and Motor Design

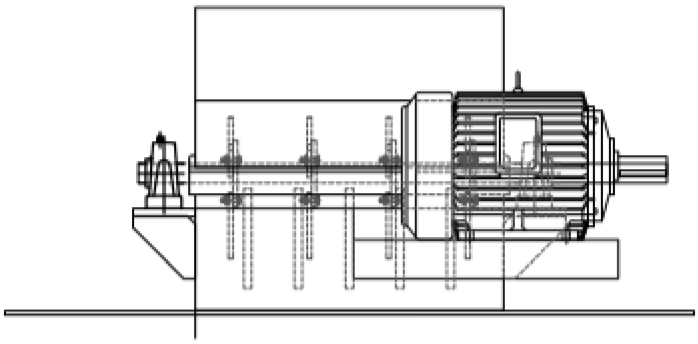


Figure 32: Hammer, chamber, and motor design (back view)

Side View of structural steel design

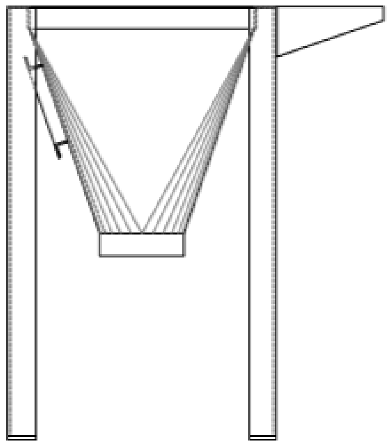


Figure 33: Structural design (side view)

Front View of structural steel design

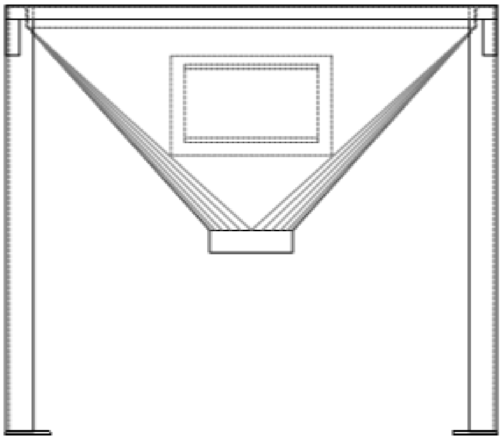


Figure 34: Structural steel design (front view)

Top view of structural steel design

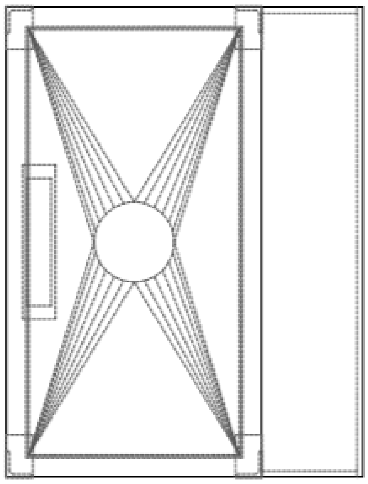


Figure 35: Structural steel design (top view)

Side View of Rock Sugar Chopping Machine Design

Structural steel in the bottom to bear total weight of machine with electric motor located parallel with main shaft to for force transmission.

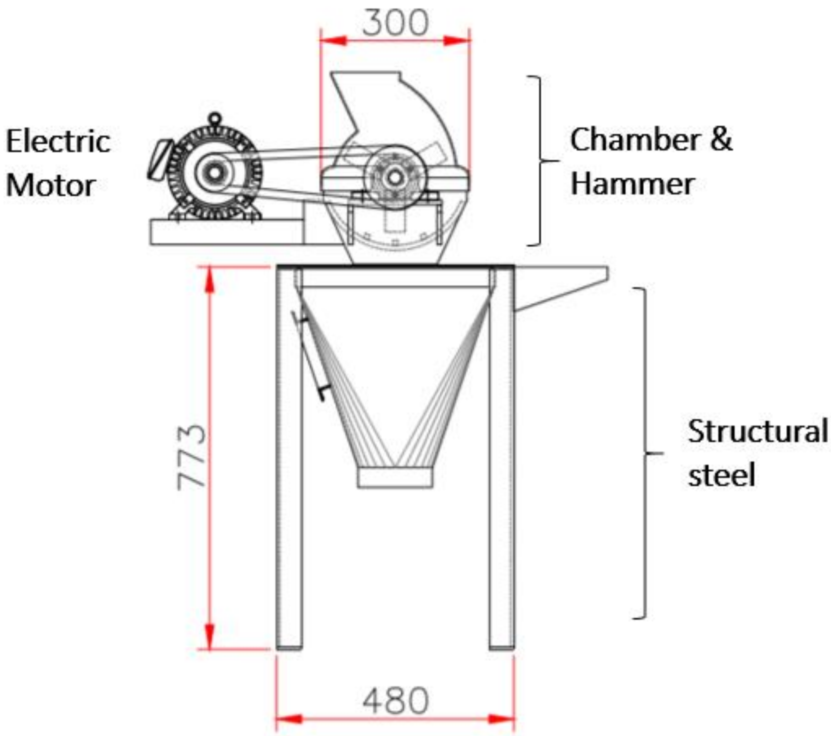


Figure 36: Rock sugar chopping machine design (side view)

Front View of Rock Sugar Chopping Machine Design

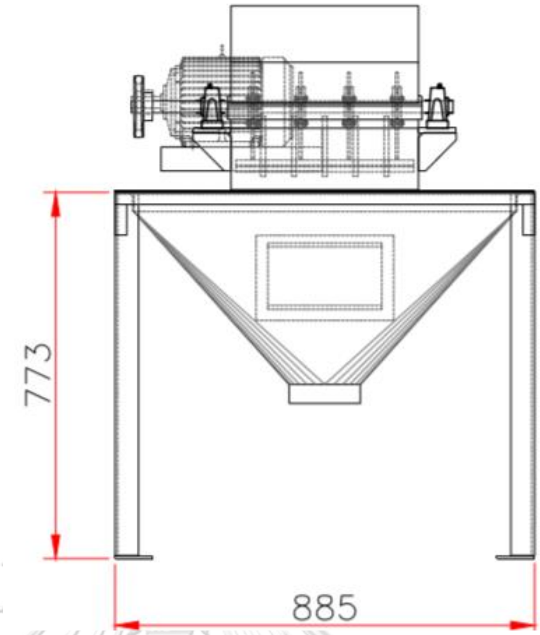


Figure 37: Rock sugar chopping machine design (back view)

Back View of Rock Sugar Chopping Machine Design

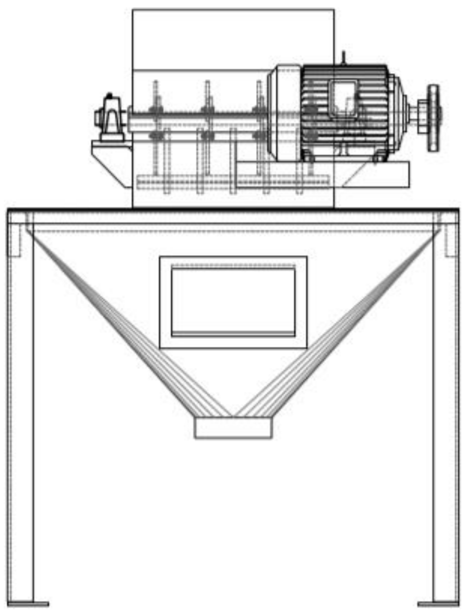


Figure 38: Rock sugar chopping machine design (front view)

Top View of Rock Sugar Chopping Machine Design

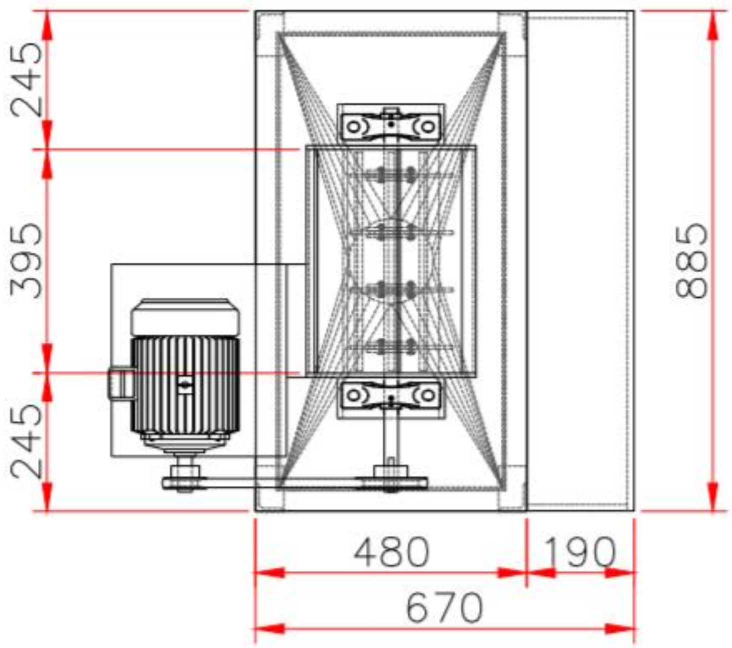


Figure 39: Rock sugar chopping machine design (top view)

Calculations for each parameter:

Shaft Speed:

$$\frac{D_1}{D_2} = \frac{N_2}{N_1}$$

$$\frac{76}{128} = \frac{N_2}{1400}$$

N_2 = 831 r.p.m

Length of the Belt:

$$L = 2C + 1.57(D_2 + D_1) + \frac{(D_1 + D_2)}{4C}$$

$$L = 2(365) + 1.57(128 + 76) + \frac{(76 + 128)}{4(365)}$$

$$L = 1050\ mm$$

Angle of Wrap for Smaller and Larger Pulleys:

$$\alpha_1 = 180 + 2\sin^{-1}(\frac{R-r}{C})$$

$$\alpha_1 = 180 + 2\sin^{-1}(\frac{64-38}{365})$$

$$\alpha_1 = 188.14°$$

And,

$$\alpha_2 = 180 - 2\sin^{-1}(\frac{R-r}{C})$$

$$\alpha_2 = 180 - 2\sin^{-1}(\frac{64-38}{365})$$

$$\alpha_2 = 171.85°$$

Belt Contact Angle:

$$\sin\beta = \frac{(R-r)}{C}$$

$$\sin\beta = \frac{(64-38)}{365}$$

$$\beta = 4.07\,°$$

Belt Tension:

$$M = width \times thickness \times belt\ density$$

$$M = 0.0167m \times 0.0103m \times 1140kg/m^3$$

$$M = 0.1961\ kg/m$$

And,

$$V = \frac{\pi D_1 N_1}{60}$$

$$V = \frac{3.142 \times 0.128m \times 1400r.p.m}{60}$$

$$V = 9.38\ m/s^2$$

And,

$$T_C = MV^2$$

$$T_C = 0.1961kg/m \times 9.38^2 m/s^2$$

$$T_C = 17.25\ N$$

And,

$$T_C = \frac{T_1}{3}$$

$$17.25N = \frac{T_1}{3}$$

$$T_1 = 51.75\ N$$

And,

$$\frac{T_1 - T_C}{T_2 - T_C} = e^{\mu\theta}$$

$$\frac{51.75 - 17.25}{T_2 - 17.25} = e^{0.3\times 3}$$

$$T_2 = 31.44\ N$$

Power and Torque Transmitted to the Shaft:

$$P = (T_1 + T_2)V$$

$$P = (51.75 - 31.44)9.38m/s^2$$

$$P = 780.32\ W$$

And,

$$T = (T_1 - T_2)R$$

$$T = (51.75 - 31.44)0.128$$

$$T = 2.60\ Nm$$

Hammer Weight:

$$W_h = m \times g$$

$$W_h = 6.5\ kg \times 9.81m/s^2$$

$$W_h = 63.77\ kg/m^2$$

Centrifugal Force:

$$F_C = \frac{mV^2}{r}$$

$$F_C = \frac{6.5kg \times 9.38^2 m/s}{0.0115m}$$

$$F_C = 49.73\ kN$$

Rock sugar chopping machine calculated parameters:

Parameters	**Symbol**	**Value**	**Measure Unit**
Shaft speed	N	831	r.p.m
Length of belt	L	1050	mm
Angle of wrap for drive pulley	α_1	188.14	degree
Angle of wrap for driven pulley	α_2	171.85	degree
Belt contact angle	β	4.07	degree
Tension in the slack side of belt	T_2	31.44	N
Tension in the tight side of belt	T_1	51.75	N
Torque transmitted to shaft	T	20.47	Nm
Power transmitted to shaft	P	780.32	W
Centrifugal force	F_c	49.73	KN
Diameter of main shaft	d	23	mm
Weight of hammer	W_h	63.77	kg/m^2

Table 16: Calculated parameters

Please be noted that above parameters from prototype machine has been calculated for future work purposes. In case, the owner of selected sugar factory would like to build full scale of chopping machine.

4.2.2 Rock Sugar Chopping Machine

According to design of rock sugar chopping machine above, the finished machine is built as below figures

Figure 40 : Sieve in rock sugar chopping machine

Figure 41: Assembly of hammer and shaft

Figure 42: Hammer assembled with bearing

Figure 43: Hopper of rock sugar chopping machine

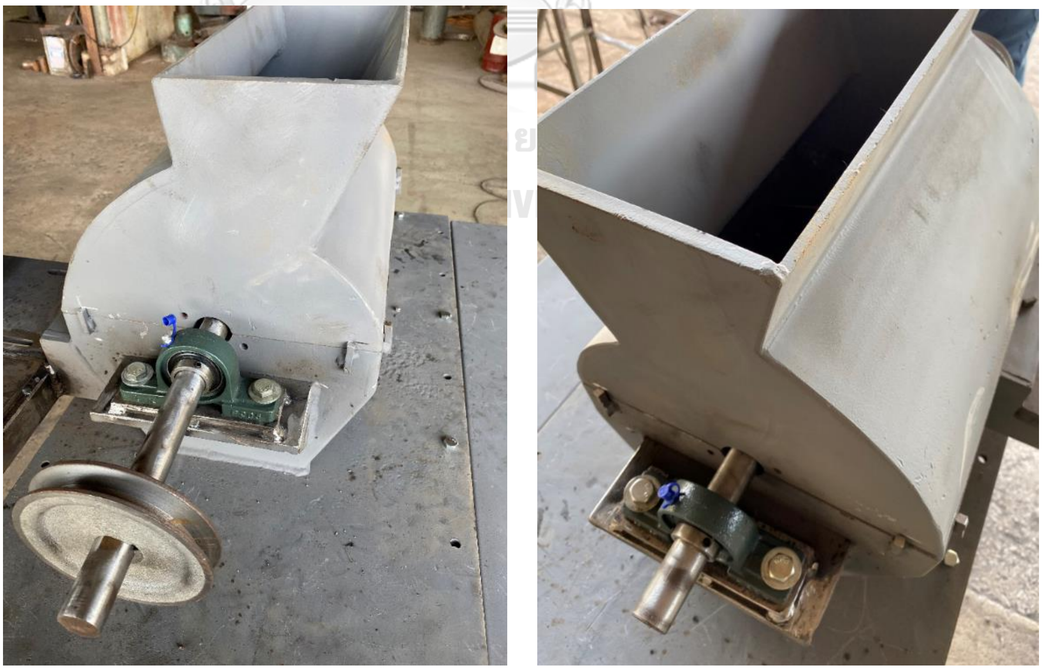


Figure 44: Chamber assembled with hopper, bearing, and pulley

Figure 45: Top view of hopper

Figure 46: Chopping machine and electric motor

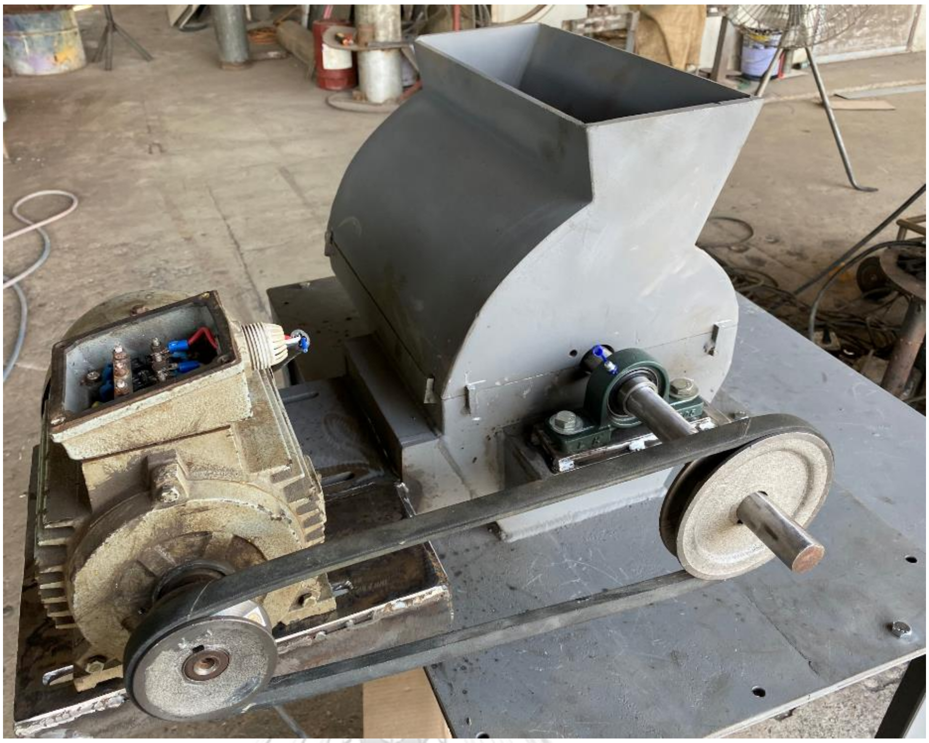


Figure 47: Chopping machine with belt

Figure 48: Chopping machine with belt (2)

Figure 49: Completed prototype of rock sugar chopping machine

4.3 Pre-Implementation Results

According to collected data and investigation, the selected sugar factory is selling 137 tons of rock sugar per month or 5,300 kg per day in average where 85% of production is from in-house and another 15% of production is from other factory in which they repack as their own brand and sell it to customers because of inadequate in-house production capacity.

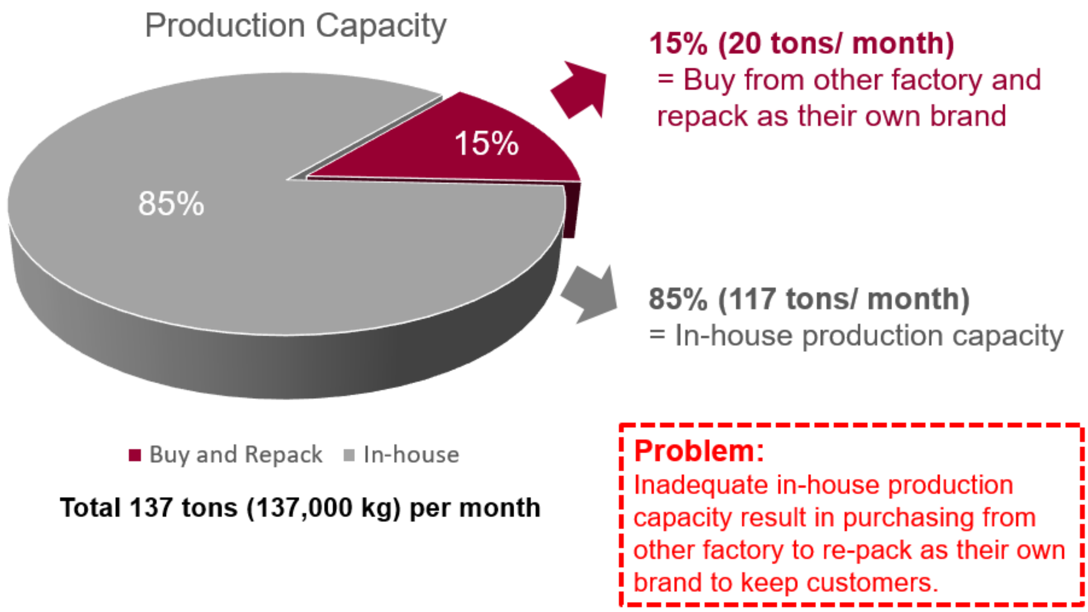


Figure 50: Overview production capacity of selected sugar factory

4.3.1 Productivity Level

Data has shown that among all production processes, which are boiling, chopping, packing, measurement, and sealing, chopping is the most time consuming process. Chopping process takes 11.2 minutes in order to reach 90 kilograms of productivity, while boiling, packing, measurement, and sealing processes take 10, 10.3, 8.2, and 10.3 minutes respectively. Moreover, chopping process takes manpower up to 6 people a day to chop rock sugar manually.

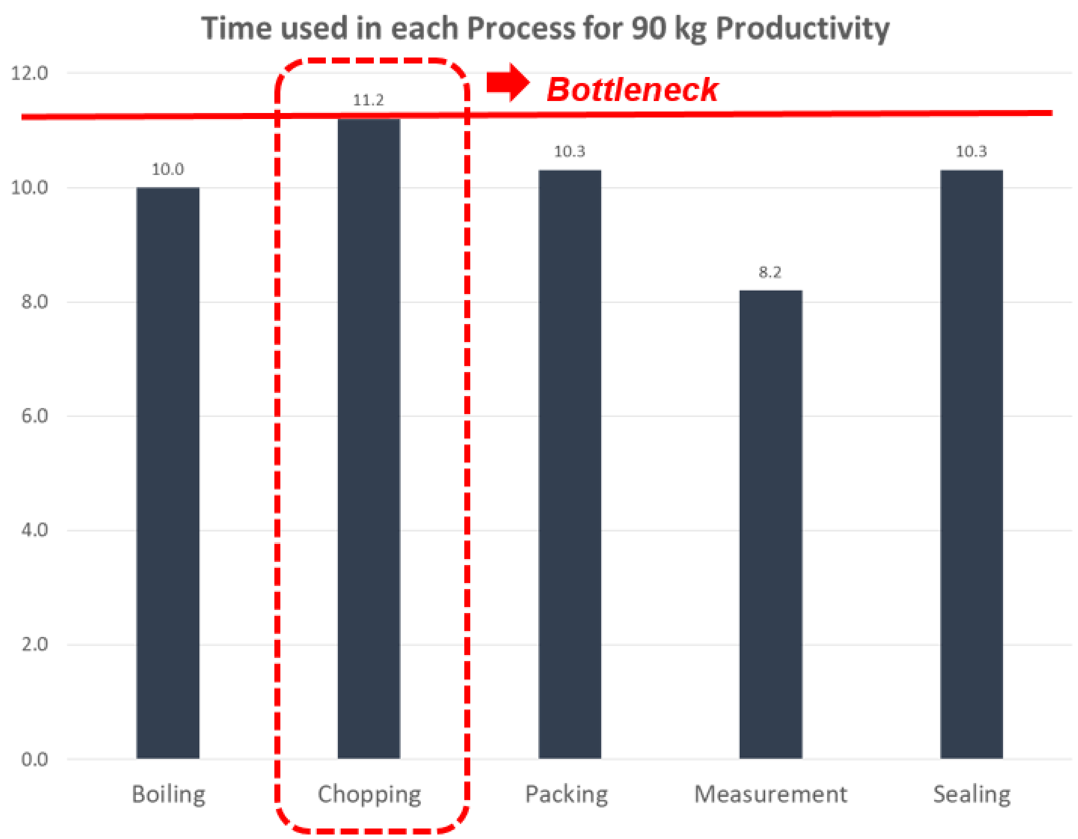


Figure 51: Process breakdown

4.3.2 Quality Level (Sizes)

In this case, quality level means size of rock sugar as the factory sells it in 5 different sizes. There are “size 5”, “size 4”, “size 3”, “size 2”, and “granulated sugar” where size 5 is the biggest size and granulated sugar is the smallest size. Rock sugar size will be separated after chopping process by workers where they will put chopped rock sugar into size separation machine.

Approximate diameters of each size are as following:

Type	Approximate Diameter
Size 5	> 6 cm to 9 cm
Size 4	> 4 cm to 6 cm
Size 3	> 2 cm to 4 cm
Size 2	> 1 cm to 2 cm
Granulated Sugar	≤ 1 cm

Table 17: Approximate rock sugar diameters of each size

Size 5 rock sugar has diameter more than around 6 to 9 centimetres, size 4 rock sugar has diameter more than 4 to 6 centimetres, size 3 rock sugar has diameter more than 2 to 4 centimetres, size 2 rock sugar has diameter more than 1 to 2 centimetres, granulated sugar has diameter from 1 centimetres and less, and all the rest in the form of powder called sugar powder which is the least wanted size of sugar because it has lowest price among others.

According to investigated data, the average amount of sugar powder in every 90 kilograms of rock sugar is 7.2 kilograms.

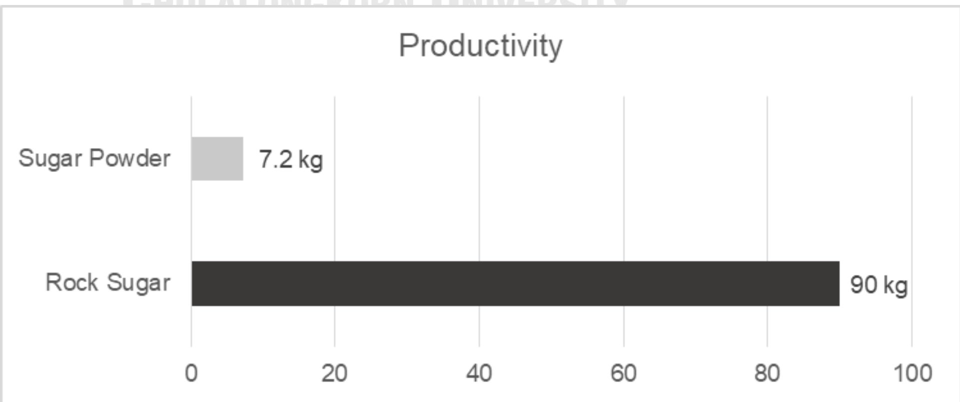


Figure 52: Amount of sugar powder from 90 kg of rock sugar

Figure 53: Different sizes of rock sugar

4.3.3 Revenue Level

Collected data has shown that the average selling price per unit is 290 THB (10 kilograms per unit), 11,700 units were produced from in-house production thus the revenue from in-house production is approximately 3,393,000 THB. Moreover, there is another 20 tons from re-packing which equals to 2,000 units. However, the cost from purchasing from other factory is 25,000 THB per ton so total cost is 50,000 THB. Revenue from repacking after cost reduction is around 530,000 THB and that make the total revenue per month of this sugar factory to around 3,923,000 per month.

Figure 54: Sugar factory revenue per month

4.4 Post-Implementation Results

After finish building rock sugar chopping machine, the tests had been conducted to evaluate the performance of it. Testing are aiming to evaluate level of capacity, efficiency, and losses of the machine. According to testing procedures mentioned in literature review chapter, rock sugar was fed into the hopper within specific time for 5 rounds. Then the result of input and output including time had been recorded to obtain the average values for performance calculations and further analysis.

In this case, 2 kilograms rock sugar had been input into the hopper of machine continuously for 1 minute per round. The reason behind 2 kilograms of rock sugar is because limitation of hopper size and chamber. However, similar to rock sugar chopping manually by human, these 2 kilograms of rock sugar were hammered into smaller after knocking out of the bucket in order to input through hopper.

Figure 55: Rock sugar in bucket

Figure 56: Rock sugar after knocking out of the bucket

Figure 57: Manually hammered rock sugar by human

Testing Procedures:

- Start counting time
- Input 2 kilograms of rock sugar into hopper
- Wait until all rock sugar was chopped
- Repeat inputting 2 kilograms of rock sugar into hopper until 1 minute is up
- Measure and record amount of output rock sugar and sugar power in each round

Chopped rock sugar from machine is shown in below picture:

Figure 58: Chopped rock sugar from rock sugar chopping machine

Recorded results of amount of input rock sugar are shown in below table:

Round	Mass of Input Rock Sugar	Time
1	17 kg	1 Min
2	19 kg	1 Min
3	19 kg	1 Min
4	18 kg	1 Min
5	18 kg	1 Min

Table 18: Results of input rock sugar in one minute

For the first round of testing, the total input amount of rock sugar in 1 minute is 17 kilograms. Then 19 kilograms, 19 kilograms, 18 kilograms, and 18 kilograms for second, third, fourth, and fifth round respectively.

According to results above, the average mass of input rock sugar in 1 minute can be calculated as following:

$$Average\ Amount\ of\ Input\ Rock\ Sugar = \frac{17\ kg + 19\ kg + 19\ kg + 18\ kg + 18\ kg}{5}$$

$$Average\ Amount\ of\ Input\ Rock\ Sugar = 18.2\ kg$$

Recorded results of mass of chopped rock sugar are shown in below table:

Mass of Chopped Rock Sugar	Sugar Powder	Time
15.9 kg	1.1 kg	1 Min
17.6 kg	1.4 kg	1 Min
17.4 kg	1.6 kg	1 Min
16.9 kg	1.1 kg	1 Min
16.8 kg	1.2 kg	1 Min

Table 19: Results of chopped rock sugar and powder in one minute

In the first round, measured chopped rock sugar and sugar power are 15.9 and 1.1 kilograms respectively. Second round results are 17.6 kilograms for chopped rock sugar and 1.4 kilograms for sugar powder. Third round results are also 17.4 kilograms for chopped rock sugar and 1.6 kilograms for sugar powder. Fourth round results are 16.9 kilograms for chopped rock sugar and 1.1 kilograms for sugar powder. And the fifth round results are 16.8 and 1.12 kilograms for chopped rock sugar and sugar powder respectively.

According to results above, the average mass of chopped rock sugar and sugar powder in 1 minute can be calculated as following:

$$Average\ mass\ of\ chopped\ rock\ sugar = \frac{15.9 + 17.6 + 17.4 + 16.9 + 16.8}{5}$$

$$Average\ mass\ of\ chopped\ rock\ sugar = 16.92\ kg$$

And,

$$Average\ mass\ of\ sugar\ powder = \frac{1.1 + 1.4 + 1.6 + 1.1 + 1.2}{5}$$

$$Average\ mass\ of\ sugar\ powder = 1.28\ kg$$

4.4.1 Productivity Level

In terms of productivity level, determination of chopping capacity, efficiency, and losses were carried out to evaluate overall performance of rock sugar chopping machine.

Rock Sugar Chopping Machine Capacity:

$$Chopping\ Capacity = \frac{Average\ mass\ of\ chopped\ rock\ sugar}{Average\ time\ taken}$$

$$Chopping\ Capacity = \frac{16.92\ kg}{1\ minute}$$

$$or\ Chopping\ Capacity = 1{,}015.2\ kg\ per\ 1\ hour$$

Rock Sugar Chopping Machine Efficiency:

$$Chopping\ Efficiency = \frac{Mass\ of\ output\ product}{Mass\ of\ input\ product} \times 100$$

$$Chopping\ Efficiency = \frac{16.92\ kg}{18.20\ kg} \times 100$$

$$Chopping\ Efficiency = 92.97\%$$

Rock Sugar Chopping Machine Losses:

$$Losses = \frac{M_b - M_a}{M_b} \times 100$$

$$Losses = \frac{18.20\ kg - 16.92\ kg}{18.20\ kg} \times 100$$

$$Losses = 7.03\%$$

From testing results, the average chopped rock sugar is 16.92 kg in 1 minute, meaning that it will take 5.32 minutes to get 90 kg productivity using the rule of three.

4.4.2 Quality Level (Sizes)

In terms of quality level, this thesis is focusing on the size of chopped rock sugar as the factory sells 6 different sizes of rock sugar. As the biggest selling size's diameter is around 6 to 9 cm thus the biggest size of chopped rock sugar is measured to ensure that it's in the range, and any other sizes smaller than that could sell to customers.

Figure 59: Chopped rock sugar from machine

The size of biggest chopped rock sugar from machine during testing is around 6.2 cm

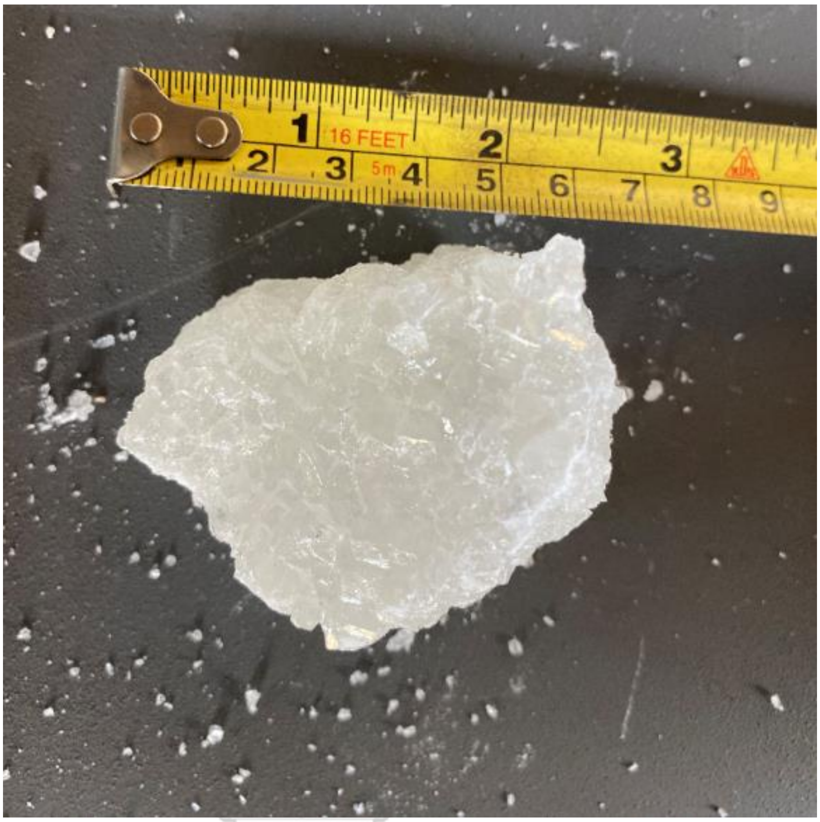


Figure 60: Biggest diameter of chopped rock sugar from machine

In terms of sugar powder, as per above calculations in productivity level, it takes 5.32 minutes to produce 90 kg productivity. Then there will be (1.28 kg x 5.32 minutes) 6.81 kg of sugar powder from the same amount of the time used in producing 90 kg of rock sugar.

4.4.3 Revenue Level

In terms of overall revenue, now that it takes only 5.32 minutes to produce 90 kg of rock sugar, meaning that chopping process is not the bottleneck process of manufacturing processes anymore. The current bottleneck process shall be sealing and packing processes which takes 10.3 minutes for 90 kg productivity. Thus, the potential revenue after implementation of rock sugar chopping machine will be calculated based on the condition that sealing and packing processes are the bottleneck.

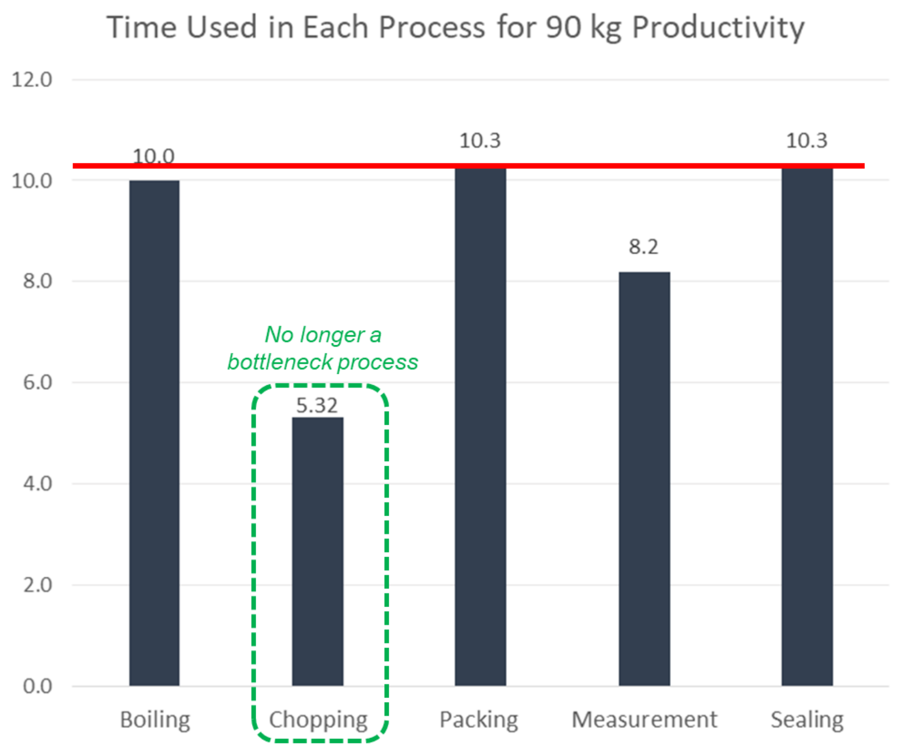


Figure 61: Time used in each process for 90 kg productivity

Then the bottleneck process is improved from 11.2 minutes (original time consumed for chopping process) to 10.3 or 8% faster. Since original productivity is 117 tons a month then potential productivity is (117 tons x 108%) increase to around 148 tons a month. With 148 tons of rock sugar a month, the factory will not have to purchase rock sugar from another factory anymore as it would cover overall demands from customers. Current selling price is 290 THB per 10 kg, then the overall potential revenue will be approximately 4.315 Million THB a month.

In terms of manpower, this chopping machine requires only two workers to operate machine, one to input rock sugar into the hopper and another one to take out chopped rock sugar below and put it in size separator machine. As it costs 300 THB for labour cost per person per day, then it will cost only 600 THB per day with this chopping machine.

In terms of operating cost, machine uses 1.5kW electric motor with 8 operating hours, operating cost could be calculated as following according to Metropolitan Electricity Authority of Thailand (MEA, 2018).:

$$\frac{Electric\ Power\ (watt)\ x\ Number\ of\ Machine\ Unit}{1{,}000} \text{x Operating Hours in 1 day}$$

$$\frac{1{,}500\ (watt)\ x\ 1\ Unit}{1{,}000} \text{x 8 Hours} = 12 \text{ units}$$

= 12 Units x 2.4226 THB = 29 THB/ day

Hence, this machine consumes 12 units a day or equal to 29 THB per day as electricity is 2.4226 THB per unit.

In terms of production cost, the total machine cost is 16,410 THB. Below table is machine cost breakdown.

Items	Parts	Cost (THB)
1	Structural Steel	3,000
2	Case	1,500
3	Hammer	2,500
4	Electric Motor	4,500
5	Belt	210
6	Sieve	1,200
7	Labour cost	3,500
	Total	**16,410**

Table 20: Machine cost breakdown

In additional, to ensure that this prototype of rock sugar chopping machine is aligned with voice of customer that has been addressed in the beginning, each item has been validated as shown in below figure.

Figure 62: VOC and results alignment

First is machine's size, this prototype dimension is only 300mm x 395mm x 394 (width x length x height) therefore the result is aligned with what customer wants.

Secondly the cost of this prototype is only 16,410 THB while budget is 20,000 THB therefore the result is also aligned.

Next item is level of noise which should not exceed 140 decibels. And the result is aligned with 98.2 decibels as shown in below figure.

Figure 63: Noise level of machine

The fourth item is how easy of machine to operate. And the result is aligned as it required only 2 steps for worker-to operate this machine; first step is inputting rock sugar into machine, and second step is to take out rock sugar after it has been chopped.

The fifth item is operating cost, the result is also aligned as mentioned in “Result” chapter, with the electricity cost of only 29 THB a day.

The sixth item is ability of machine to chop rock sugar into different sizes. The result is aligned with what customer wants as machine could chop rock sugar into 6 different sizes (including sugar powder).

The last item is speed, the result is aligned with what customer wants as the machine could chop faster than workers which could increase productivity significantly.

Chapter 5 Analysis

5.1 Productivity Level Analysis

As per above mentioned that the pre-implementation result of chopping process is the most time consuming process which takes 11.24 min for 90 kg productivity with 5 to 6 workers a day. And after implementation result has shown that the new rock sugar chopping machine could produce 90 kg of rock sugar within only 5.32 minutes with less manpower which is taking only 2 workers to operate the machine. Thus, the new rock sugar chopping machine has improved the productivity of sugar factory by 211% comparing with pre-implementation result.

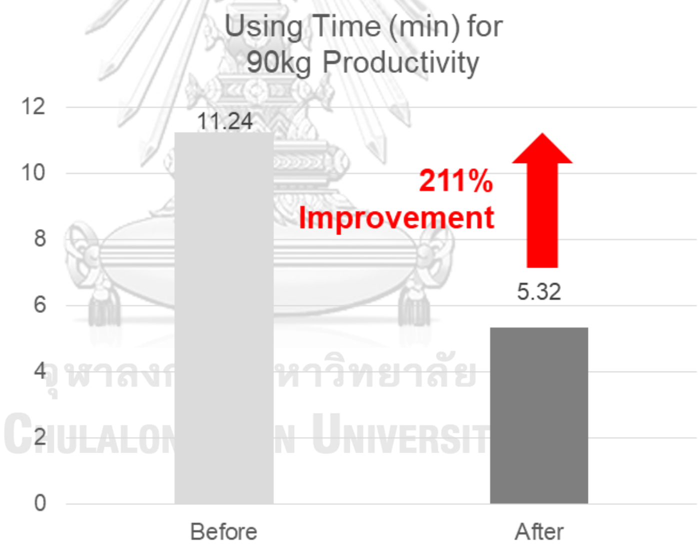


Figure 64: Productivity's post-implementation result

5.2 Quality Level Analysis

As sugar factory is selling rock sugar in 6 different sizes, post-implementation result has shown that the new rock sugar chopping machine could produce rock sugar in different sizes as well where diameter of the biggest size from chopped rock sugar is in the range of more than 6 to 9 cm conform to size 5 that factory sell to customers. Another importance thing to mention is amount of sugar powder occurred from rock sugar chopping machine since to the owner of sugar factory wants as low amount of sugar powder as possible due to its low selling price. From pre-implementation result, there were amount of 7.2 kg of sugar powder generated from every 90 kg productivity while there were 6.81 kg according to post-implementation result. Meaning that the new rock sugar chopping machine could reduce the amount of sugar powder by 5.7%.

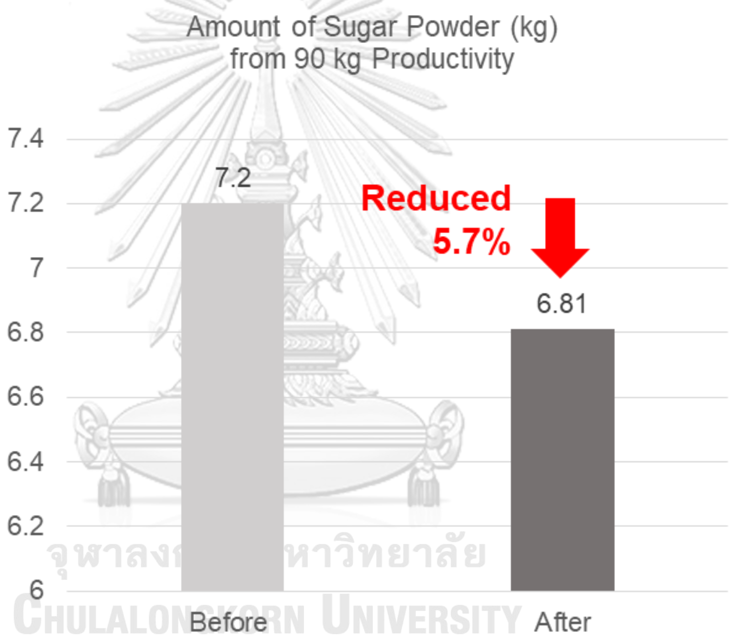


Figure 65: Amount of sugar powder from 90 kg productivity before & after implementation

5.3 Revenue Level Analysis

The original revenue as per mentioned in "results" chapter earlier is approximately 3.923 Million THB a month and the post implementation result is showing that potential revenue from rock sugar chopping machine is approximately 4.315 Million

THB. Thus, chopping machine could potentially increase revenue 392,000 THB a month for this rock sugar factory.

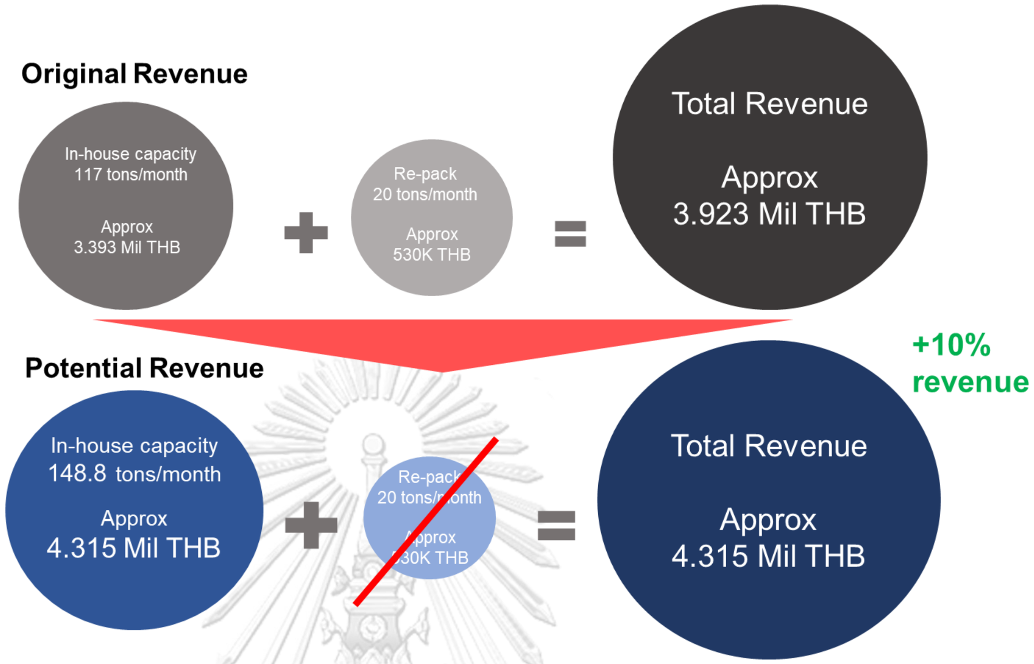


Figure 63: Revenue before and after implementation

In terms of manpower, post-implementation result has shown that new rock sugar chopping machine could reduce number of manpower for chopping process to only two workers from five to six workers before implementation.

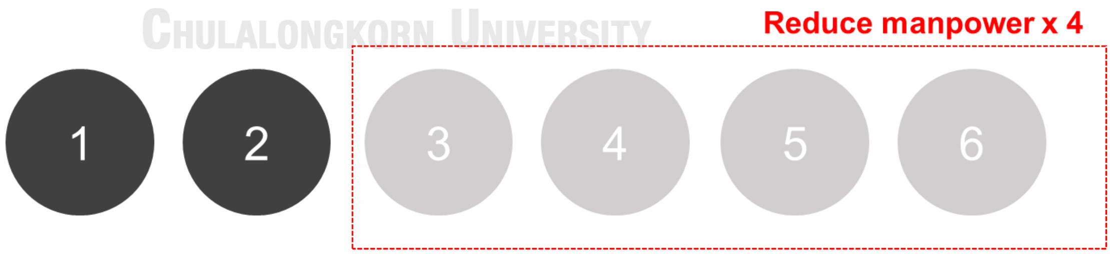


Figure 64: Number of manpower using in chopping process

Six workers is cost 1,800 THB a day as labour cost per day per person is 300 THB while two workers is cost only 600 THB a day. Hence manpower cost for this process is potentially reduced by 1,200 THB. Or the owner could use these manpower for other processes or assignments.

In terms of operating cost, new rock sugar chopping machine operating cost is only 29 THB a day which is way lower than labour cost.

Chapter 6 Discussion & Conclusion

6.1 Research Findings Discussions

Findings are separated into different measures for evaluation purposes. In this case, the first measure is time used to produce 90 kg of productivity. Second is the total amount of sugar powder from 90 kg productivity of rock sugar. Third measure is rock sugar size. Fourth measure is number of manpower using in chopping process. And the last measure is operating cost.

Measures	Changes & Findings	Percentage
Time used for 90 kg productivity	Significantly decrease	+211%
Revenue	Significantly increase	+10%
Sugar powder amount from 90 kg productivity	Slightly decrease	+5.7%
Rock sugar size	no different	n/a
Number of manpower	Significantly decrease	+250%
Operating cost	Significantly decrease	+286%

Table 19: Research Findings

Time used to produce 90 kg productivity is significantly improved by 211% from pre-implementation result. While sugar powder amount from 90 kg productivity is slightly improved with 5.7% less sugar powder than pre-implementation result. The overall revenue is significantly increased by 10% or equal to 392,000 THB a month. In terms of size, new rock sugar chopping machine could produce all desired sizes of rock sugar which consists of 6 different sizes, there is no changes in this particular measure. Number of manpower is significantly improved, this machine could reduce manpower by 250% comparing with pre-implementation result. And the operating cost is improved by 286% which means machine could reduce significant operating cost compares with pre-implementation result.

6.2 Research Conduction Judgement

This section is aiming to discuss on the overall result of process in doing this research.

6.2.1 What Went Well

Using quality function deployment principles help to guide this research from the very first to final step. Voice of customer is the most importance item in designing the new rock sugar chopping machine which ensure that finished machine is what customer wants or customer focused product. Following QFD principles have led each procedures in order properly and also having the ability to track back previous procedures that have relationships and effect with them. While the concept of hammer mill could outline working principles of new rock sugar chopping machine including major components. Thus, the end result of rock sugar chopping machine is satisfied.

6.2.2 What Went Bad

What went bad is a bit of delayed regarding the overall timeline of this research because some detail had not been point out and think through at the first place resulting in small changes along the way. Such as outsourcing third party to build the machine, decided timeline did not consider that outsource company could have other urgent works to interrupt the timeline or some components for machine were very hard to find in the market and it also affected the timeline or creating QFD had taken significant of time as each item in House of Quality has relationships with each other and it has to be aligned from phase 1 to phase 2 QFD including deciding technical targets of each phase.

6.3 Literature Review Criticization

Quality Function Deployment is the main principle that has been adopted in this research. And Hammer Mills concept is another principle that has been used in part design guidance. The principles of QFD has been used from the first step of this research, it allows to translate primary data such as voice of customer into product that aligned with customer requirements. Moreover, QFD methodology helps in visualise the overall mechanism of rock sugar chopping machine including traceability of every single item in the house of quality as each item correlate with one another.

In the early stage, QFD helps in translate voice of customer into customer requirements then led to technical requirements and technical targets respectively. Technical targets of every technical requirements have been pointed out in to achieve in order to build the machine according to voice of customer. In fact, QFD principles could have been used in even bigger scale such as new product development as House of Quality allows user to input information of competitors in the market in order to analyse both of competitors' and company's products to overview competitive advantage. However, the part of competitor's information did not mention in this research because the purpose of this rock sugar chopping machine is not for commercial purposes but to use within the factory only.

Then, hammer mills concept has been brought during designing stage to integrate major components of hammer mills with technical requirements in house of quality. And to understand how this prototype of chopping machine will be operated.

Therefore, Quality Function Deployment has enlighten and been a great asset throughout this research step by step.

6.4 Conclusion to the Research Questions, Hypotheses & Objectives

This section is aiming to conclude the results of this research in terms of research questions, hypotheses, and objectives.

6.4.1 Research Question & Hypotheses Alignment

The research questions are:

(1) Does implementation of new chopping machine according to QFD methodology improve rock sugar productivity?

(2) Does improving of productivity by chopping machine affect the quality or size of rock sugar?

(3) Is the improvement of rock sugar productivity by new chopping machine implementation helps to reduce quantity of outside purchasing for re-branding, reduce delay period in delivery, and worth the cost in terms of profit increment?

While the hypotheses are:

(1) New chopping machine which shall be built according to QFD methodology can improve overall rock sugar productivity to the factory.

(2) Improving of productivity by chopping machine could maintain the original quality or size of rock sugar.

(3) The improvement of rock sugar productivity by new chopping machine implementation can help to reduce quantity of outside purchasing for re-branding, reduce delay period in delivery, and increase profit to the factory in long term

According to the post-implementation results, the new rock sugar chopping machine has proved that it helps to improve productivity and the design of machine itself was developed from the results of QFD. Moreover, productivity from chopping machine has no changes in terms of rock sugar sizes. And as the machine could increase significant productivity of chopping process though it is fair to assume that implementation of rock sugar chopping machine could reduce quantity of outside purchasing for re-packing as well as delay period in delivery resulting in more profit to the sugar factory in long term. Hence, research questions and hypotheses are aligned.

6.4.2 Research Objective Alignment

The research objective is to increase productivity of rock sugar chopping process in order to reduce quantity of outside purchasing for re-packing and reduce delay period in delivery by using QFD methodology to design new chopping machine. It is fair to conclude that research objective is aligned with results referring to post-implementation results which are showing that new rock sugar chopping machine is able to improve in-house productivity using QFD to design machine.

6.4.3 More Intangible Benefits

In this case, there are several intangible benefits apart from items mentioned in post-implementation results section as following:

- More manpower for other manual processes: as the new rock sugar chopping machine could reduce at least three workers from the chopping process meaning that these three workers could be allocated to help with other manual processes in the factory and so they could help boosting productivity of that process as well.
- Opportunity to solve next bottleneck process: as productivity of chopping process has been improved significantly meaning that bottleneck process has been changed from chopping to other process in the factory. Though, this is an opportunity to improve other bottleneck process for further productivity improvement.
- More satisfaction from workers: chopping process is one of the most exhausting process comparing with other process due to it requires workers to chop rock sugar manually all day long. Thus, using machine instead of human could save their energy greatly.

6.5 Future Work

For future work, rock sugar machine could be re-design to make it more efficient - faster, bigger, etc. by using calculated parameters and created QFD as it could trace back to see relationships of each item. In addition, the next bottleneck process could be investigated to analyse the root causes and finding countermeasures in order to improve even more productivity for this sugar factory itself. In fact, QFD principles could be applied to design another machine to replace other manual processes.

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