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Enhancing the Quality of Rice Milling by Systematic Innovation Techniques

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Abstract

Rice is a key food of humankind, the third largest food crop in the world, behind only corn and wheat. The process of removing the rice husk, the rice skin portion, and the rice germ to make white rice is called rice milling. This empirical study applied some tools (Cause-and-Effect Diagram, QFD, FAA and TRIZ) to improve the quality of rice milling. At first, this study used Yixing Rice Milling Company in Taiwan to illustrate the process of fully automated rice milling. There are eight steps in the rice milling process system: testing, drying, refrigeration, hulling, milled rice, rice washing, color sorting, and packaging. Second, using risk assessment theory, the eight steps of the process were evaluated to determine which steps were the most vulnerable to risks. Four key factors in poor milling quality were identified: the hue recognition subsystem, the cold storage structure, ventilation, and the air pressure nozzle subsystem. Finally, the four key factors were improved with systematic innovation methods (TRIZ). We then made recommendations for improving the quality of rice production operations to Yixing Rice Milling Company.

Keywords: automated rice miller, risk assessment theory, related factors, key factors, systematic innovation technique

1. Introduction

Rice is a key food, the third largest crop on earth, behind only sugarcane and maize, according to 2012 FAOSTAT data ("Rice," n.d.). There are more than 140,000 varieties of rice plants in the world. The simplest way to classify rice is according to their starch content. Rice starch consists of amylose and amylopectin. The lower the amylose content, the higher the viscosity of the boiled rice. Based on the differing proportions of amylose and amylopectin in rice, its varieties can be divided into three categories: indica rice or Raimi (Oryza sativa hsien), Japonica rice or Penglai rice (Oryza sativa keng) and glutinous rice (Oryza sativa var glutinosa) (Owen, 1996).

Rice without the rice husk is called brown rice. Because of its rough fiber that resists moisture, boiled brown rice is usually hard and without viscosity. Its taste is not popular. In order to satisfy the public taste, brown rice will generally be ground and peeled (removal of the bran layer) before sale. It is then known as embryo rice. Because rice germ is rich in nutrients, has a high fat content, and easily becomes moldy during storage, the rice germ is usually removed before the rice is sold. After the germ of the embryo rice is milled away, the rice becomes white rice. The grain texture of rice white is clear and crystalline, and its taste is preferred by the public.

The process of removing rice husk, the skin portion, germ, and making white rice is called rice milling.

This research first used the example of fully automated rice milling performed at Yixing Rice Milling Company in Taiwan. The rice milling process system has eight steps: inspection, drying, refrigeration, hulling, milled rice, rice washing, color sorting, and packaging. Second, using risk assessment theory, the eight steps of the process were evaluated to determine those steps that were most vulnerable to risk. After analyzing these steps, factors that cause poor milling quality were identified. Using these factors, the key factors were revealed. Finally, using a systematic innovation approach, the key factors in poor quality rice milling were addressed to help the rice miller improve rice production operations.

2. Evaluating the rice milling process and determining key factors

2.1 Evaluating the rice milling process

In this study, the factory manager, engineers, and workers of Yixing Rice Milling Company were first invited to describe and discuss the eight steps of the rice milling production process. Using two indexes which refer to the degree of severity and the probability of an event occurring, a risk assessment for rice milling production process at the company was performed. Three steps, drying, refrigeration, and color sorting appeared to have the greatest risk. After addressing potential problems, the quality of rice milling should increase.

2.2 Identifying vital factors from the three steps of great risk

This study used a Cause-and-Effect Diagram to analyze the three riskiest steps in the rice milling process and identified eight factors that cause poor quality rice milling: (A) refrigerated barrel structure; (B) air conditioner; (C) ventilation facilities; (D) hue recognition subsystem; (E) pressure nozzle subsystem; (F) Moisture testing; (G) Heat temperature; and (H) Rice transporting mechanism, as shown in Figure 1.

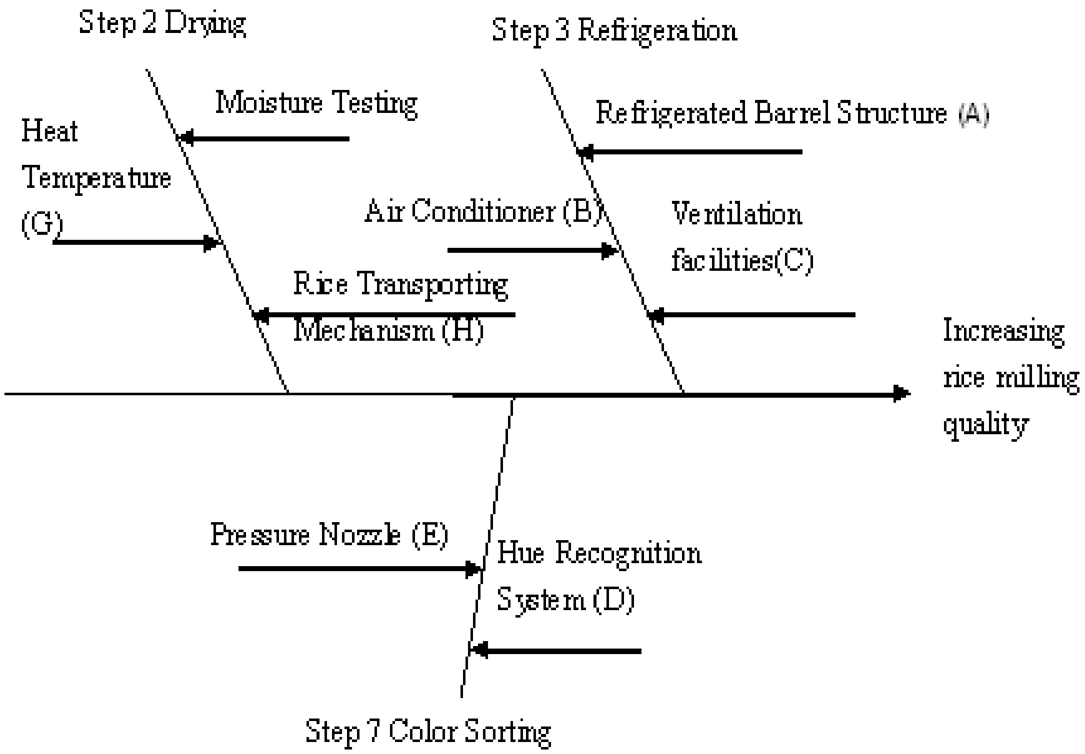

Fig. 1 Analysis of cause-and-effect diagram for enhancing rice milling quality.

2.3 Determining key factors

Using Quality Function Deployment techniques, we determined the key risk factors from among the eight risk factors. From the QFD (Quality Function Deployment) table (Table 1), we chose the four largest weight values (TWi): (1) hue recognition subsystem (D); (2) cold storage structure (A); (3) ventilation facilities (C); and (4) pressure nozzle subsystems (E). These became the four key factors for improving rice milling quality. The next step was to address the four key factors with a systematic innovation approach.

Table 1 Determining the key risk factors for enhancing the rice milling process.

Weight Definition w_i: Very Strong 4.0; Strong 3.0; General 2.0; Weak 1.0; Unrelated 0.0		Important factors/Vital factors								
		Risk indexes δ_i	A. refrigerated barrel structure	B. air conditioner	C. ventilation facilities	D. hue recognition subsystem	E. pressure nozzle subsystem	F. Moisture testing	G. Heat temperature	H. Rice transporting mechanism
Riskiest steps	Refrigeration	0.53	4	3	4	2	1	0	1	1
	Color sorting	0.50	2	1	1	4	4	0	1	1
	Drying	0.43	1	0	1	2	1	4	4	4
Weight value (TW_i)			3.55	2.09	3.05	3.92	2.96	1.72	2.75	2.75
Key factors			2		3	1	4			

3. Addressing risk factors via a systematic innovative approach

TRIZ is derived from the Russian Theoria Resheneyva Isobretatelskehuh Zadach, translated into English as An Innovative Theory for Solving Problems, which means a new and different theory of solving problems. As long as the procedures of the theory are followed using its practical tools, improvements can be made.

The QFD table analysis showed that quality of the milled rice can be increased by focusing on improving four key factors, (1) the hue recognition subsystem (D); (2) cold storage structure (A); (3) ventilation facilities (C); and (4) pressure nozzle with four subsystems (E). Two of the key factors, namely the hue recognition subsystem (D) and the pressure nozzle subsystem (E), are part of the color sorting step of the rice milling process, which is performed by a color sorting machine (Figure 2). The color sorter is composed of subsystems of component combinations, which makes it suited to functional attribute and causal chain analysis via the TRIZ. Two other key factors, the cold storage structure (A) and the ventilation facilities (C) are part of the refrigeration step in the rice milling process. They were more suited to analysis by the contradiction matrix of TRIZ.

Fig.2 Color Sorter.

3.1 Improving the color sorting step

3.1.1 The overall process of two subsystem components in a color sorter

A color sorter structure is divided into two parts, the primary choice and the second choice. There are two subsystems. The first is the hue recognition subsystem with four main components, the rice flow speed control valve, the illumination lamp, optical lenses and cameras, and the hue decision processor. The second subsystem is the pressure nozzle subsystem which has two main components, the nozzle and compressors. When the grains of rice flow into the color sorting machine, the rice flow speed control valve of the hue recognition subsystem initializes. The grains vibrating in different rice chutes and are sequentially led into a 2/3 position on the left side of the primary groove. When the rice enters the primary groove, the grains of rice fall in a curtain-like waterfall from the groove of the subsystem, as shown in Figure 2. The amount of falling rice and the speed are controlled by the rice flow speed control valve. The higher (lower) the control valve setting, the closer (farther) the rice grains of the rice fall plane are, and the faster (slower) the rice flow. At the same time, the rice flow speed control valve controls the rice flowing into the color sorting machine from both the primary and second grooves.

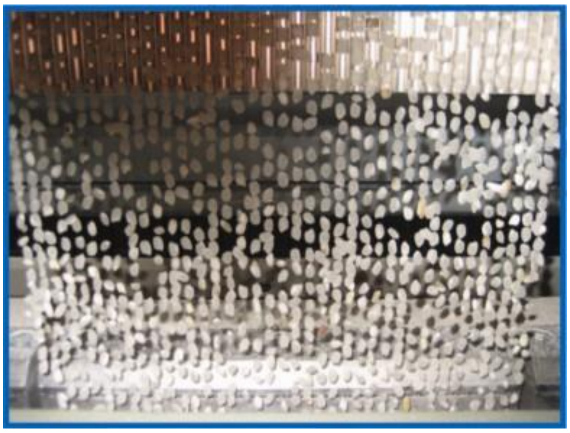

Fig. 3 The grains of rice fell down in a curtain-like waterfall manner from the groove of the color sorter.

At the moment the light was projected on falling rice waterfall plane by illumination lamp. Simultaneously each row of falling grains is imaged by the camera, and the resultant images sent to the hue decision processor. Based on the images, the hue decision processor identifies the color, transparency, and size of a grain of rice and determines whether the rice is acceptable. If the grains of rice are judged acceptable by the hue recognition subsystem, they fall into the acceptable rice collection area. This process is the primary choice process. If a row of grains is judged to be unacceptable, the pressure nozzle subsystem located at the bottom of the waterfall plane initiates and the nozzle blows the unacceptable rice into a temporary collection area using high-pressure air. When the unacceptable rice is blown out, acceptable rice may be blown into the temporary collection area. Therefore, a second color sorting known as the re-election is necessary.

Re-election begins when a bucket elevator machine sends the grains from the temporary collection area into the re-election groove that is on a 1/3 position of the right side of the groove. Again color sorting is conducted via the hue recognition subsystem and the pressure nozzle subsystem as in the primary choice. If the second choice also rejects the rice, the pressure nozzle subsystem blows them out into the unacceptable rice collection area. The primary choice groove is also used during the re-election process. The former was on the 2/3 of the left side, and the latter was on the 1/3 of the right side of the groove. Therefore, falling primary choice grains occupy in the 2/3 of the left side of the rice waterfall plane, while re-election rice grains fall on in the 1/3 of the right side.

Because of the different colors and translucencies of the rice varieties, before conducting color sorting, the hue decision processor should be adjusted to distinguish the color, transparency and size standard of the grains based on the variety of rice being processed. After the best grain color, transparency, and size standard of each variety of rice grains are determined, the color sorting can be performed. The overall flow diagram for judging the rice quality in the color sorting machine is shown in Figure 4.

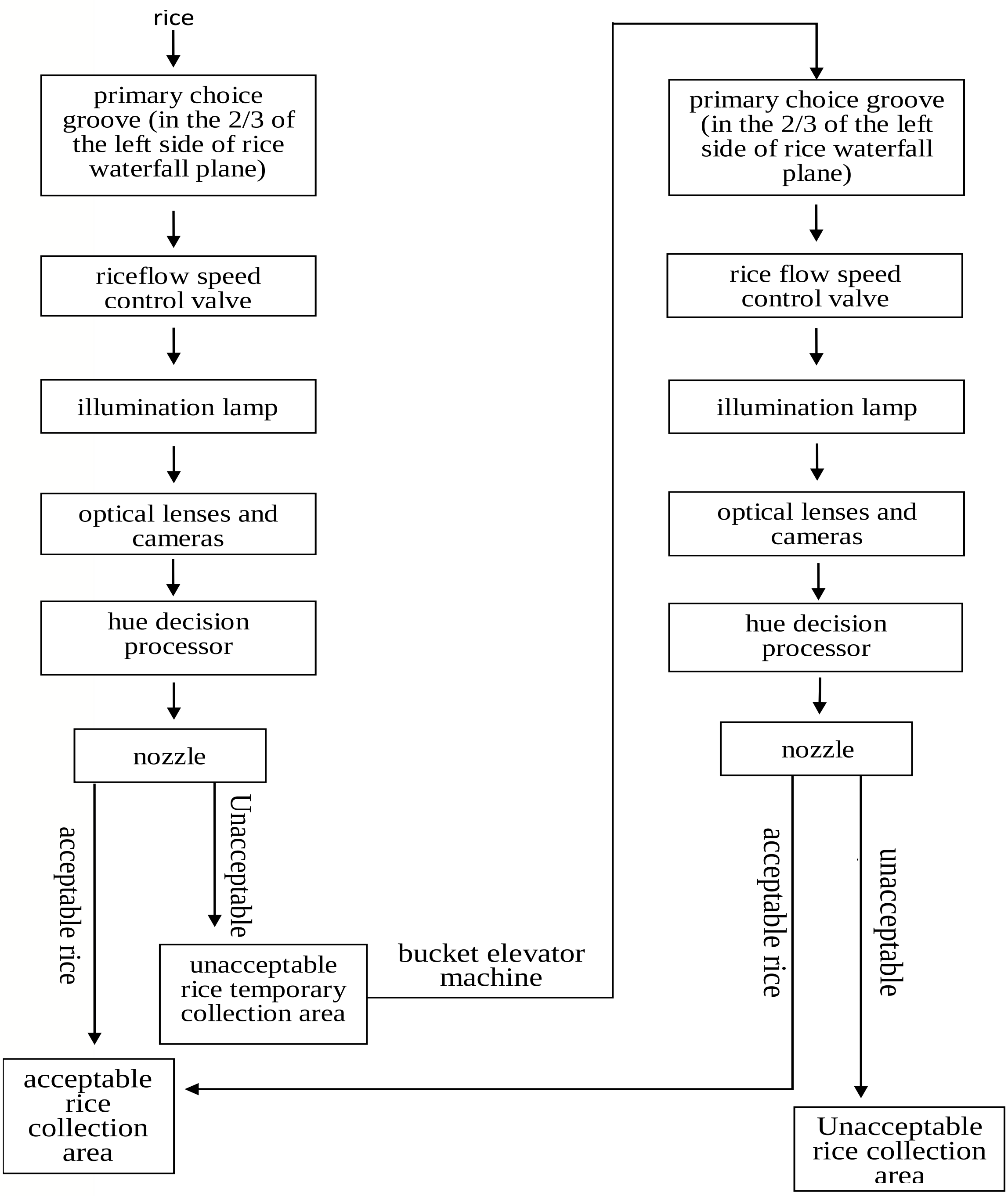

Fig. 4 Flow diagram for rice quality evaluation via color sorting machine.

3.1.2 Causal chain of functional attributes of the components of the color sorter

We next analyze the functional attributes of the components in the hue recognition subsystem and the pressure nozzle subsystem of the color sorting machine to determine the causal chain. During function attribute analysis (FAA), the components of the system or subsystem are dismantled to identify the relationships between the components and the main function or subsidiary functions of components. This enables determination of which relationships are helpful and which are functional, inadequate, or harmful. Functions that are over-functional, inadequate, or harmful are called negative functions. Using the negative functions of the relationship among the various components, we can find the conflicts among the functions and resolve them (Kowalick, 1996).

In this study, the functional attributes of the color sorter's components were plotted into a causal chain of functional attributes in frames, based on the overall sorting process. The functional attribute causal chain was analyzed as shown in Figure 5. In Figure 5, where the process contains negative functions, they are marked as with symbols representing insufficient, over-functional, and harmful. Components possessing negative functions are termed "color sorter important functional components" and marked with double borders. Five components, the rice flow speed control valve, illumination lamps, optical lenses and cameras, the hue decision processor, and the nozzles were so marked. The remaining components were termed secondary components and are covered by a single border.

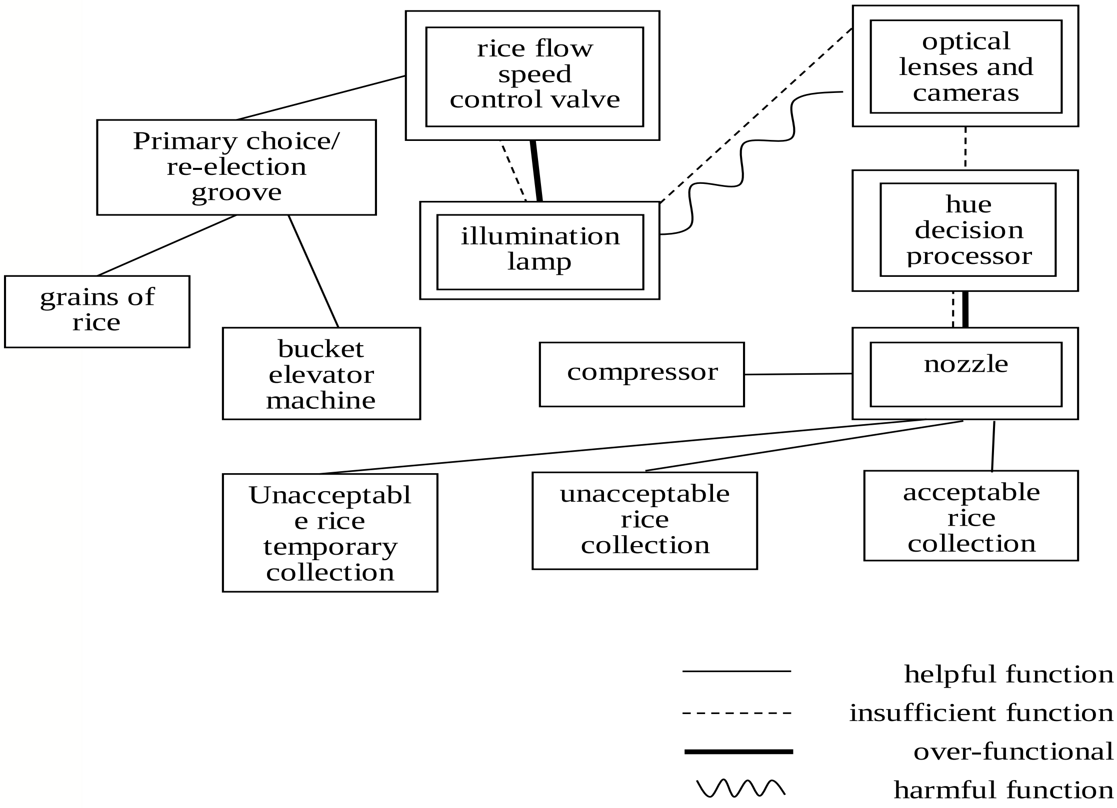

Fig.5 Analysis of functional attributes of the color sorter components.

3.1.3 FAA-based improvement plan for the color sorter

(1) Rice flow speed control valve

The rice flow speed control valve controls the flow of grains in the primary choice groove and the re-election groove. If the flow of rice is mishandled, the distance between the rice grains in the rice waterfall plane would be wrong, and insufficient/over-function would occur, involving the illumination lamps. Therefore, before the grains of rice enter the primary choice groove, a small portion of rice should be tested to determine the valve opening size to ensure the quality of color sorting.

(2) Illumination lamps

The illumination lamps project light onto the rice waterfall plane. Over time their illumination falls as their lamps wear out. Thus the optical lenses and cameras may not have enough light, producing a frequency spectrum shift. Moreover, the lamps, lenses, and cameras should not be placed too closely to one another. If the distance is too close, interference may occur, resulting in insufficient/harmful function. Our improvement plan involved regular checking and testing of the brightness of illumination lamps to ensure their output was 990 to 1100 lumens as specified.

(3) Optical lenses and cameras

The function of optical lenses and cameras is to image the rice waterfall plane. As the grains of rice fall, they throw off bran fiber. Over time this makes the lenses dirty and causes the hue decision processor to generate false judgments, an insufficient function. The improvement plan involved regularly cleaning the optical lenses to ensure that the camera is functioning properly.

(4) Hue decision processor

The hue decision processor identifies the color, transparency, and size of the rice grains in based on the imagery generated by the imaging system. If it is malfunctioning, it may produce false judgments of the rice color or quality, which in turn may cause the nozzles to function improperly. Our improvement plan was to make appropriate color adjustments for the quality of each batch of rice and test a small portion of rice first to ensure that the processor is functioning properly.

(5) The nozzles

Using high-pressure air produced by the compressor, the nozzle blows grains judged unacceptable by the hue decision processor into the poor rice temporary collection area or the unacceptable rice collection area. If the pressure of the nozzle is too high, acceptable rice around unacceptable rice may also be removed. Conversely, if it is too low, not enough unacceptable rice will be removed from the stream of rice, an over-/insufficient function problem. Our improvement involved checking and testing the nozzle and the compressor to ensure they were at the recommended pressure of 2.6kg/cm² to 2.8kg/cm².

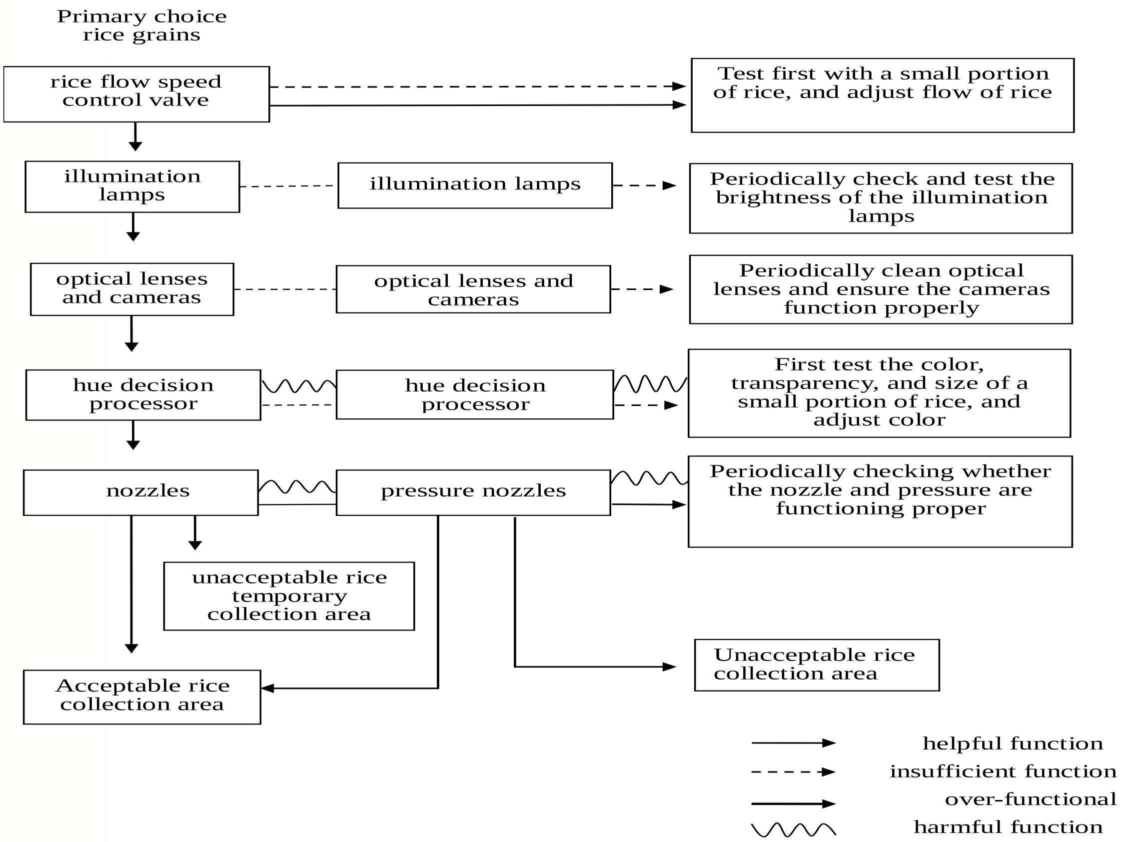

Fig. 6 Improvement plan of five problematic functional components in a color sorter.

3.2 Using TRIZ to improve the cold storage structures and ventilation pipelines

There are two kinds of contradiction matrices, technical and physical contradiction. A technical contradiction occurs when improving a parameter in a system negatively affects another parameter. For example, increasing lamp brightness contradicts the need to save electricity. Physical contradiction occurs when arrangements conflict, such as when an umbrella must be large yet space is lacking. Technical contradictions can be analyzed and resolved through a contradiction matrix, while physical contradictions can be resolved by using a different separation principle. The solution is the use of 40 invention principles (Hsia, Huang, and Chen, 2011).

Our study found that two other key factors in the quality of rice milling are the refrigerated barrel structure (A) and the ventilation facilities (C). The technical contradiction approach may be used to solve problems, as described below.

3.2.1 Refrigerated barrel structure (A)

Each refrigerated barrel consists of four large soldered steel plates and can hold 100,000 kg of rice. Over time, the weight of the grains deforms the cold storage barrels. Cracks are produced at the seams and some of the rice is not refrigerated properly. This problem is a typical technical contradiction in a systematic innovation technique (TRIZ), specifically described as follows: "A refrigerated barrel saves more rice but does not exhibit structural deformation of the chilled barrel." Some of 39 engineering parameters were reviewed to solve this problem. The parameters which might improve the problem were item 11 "tension, pressure" and item 13, "object stability", while item 2, "fixed object weight", may reduce the problem. On the basis of this analysis, a technical contradiction matrix table was created as shown in Table 2. In Table 2 the helpful innovative principles were principles 1, 10, 13, 18, 26, 29, 39, and 40.

Table 2 Technical contradiction matrix table for the refrigerated barrel structure (A).

parameters that cannot be changed / parameters that may changed		Fixed object weight item 2
pressure, tension	item 11	13, 29, 10, 18
object stability	item 13	26, 39, 1, 40

Based on the above-mentioned eight innovative principles, the problem resolution plan was:

(1) Principle 10: pre-action: making changes before problems occur.

The problem resolution plan for this principle was that the internal steel plates of the four sides of the refrigerated barrel were riveted and the plates bound tightly with steel cables to reinforce the structure.

(2) Principle 26: copy: replacing the objects or systems which are expensive and have defects with simplified or inexpensive copies.

The plan called for the seams of the barrels to be welded to reinforce the structure.

(3) Principle 39: inert environment: to add a neutral substance or blunt additives in objects or in the system.

The problem resolution plan using this principle was to eliminate rust in the steel plate joints and to paint the exteriors of the steel plate to prevent rusting."

(4) Principle 40: composite materials: replace homogeneous materials with composite materials. The company installed Teflon insulation inside the four plates of the refrigerated barrel to ensure energy savings.

(5) Four additional innovative principles were segmentation, reverse, vibration, and hydraulic. Because they had no significant application to the problem, they were not put to use.

3.2.2 Ventilation facilities (C)

There are 33 refrigerated barrels in the refrigerator. Cold air is generated by the refrigeration unit and circulated from each ventilation pipe to each refrigerated barrel. If the ventilation pipes become clogged or the ventilation gates fail to control the flow of cold air, cold air cannot enter barrels when needed. This is a typical technical contradiction, described as "barrels maintain long-term temperature, and ventilation facilities do not allow exceptions." The 39 engineering parameters were again used to review the problem. The parameter which may address the problem was item 13, "the stability of object" and the parameters which might prevent further deterioration were item 17, "temperature" and item 23, "material loss." The technical contradiction matrix table was created on the basis of the problem as shown in Table 3. The helpful innovative principles were principles 1, 2, 14, 30, 32, 35, and 40.

Table 3. Technical contradiction matrix table of ventilation facilities (C)

Parameters that cannot be changed / parameters that can be changed		temperature item 17	material loss item 23
stability of object	item 13	35, 1, 32	2, 14, 30, 40

On the basis of the above-mentioned seven innovative principles, the problem resolution plan was:

(1) Principle 1: the role of segmentation: A composite object was made. Principle 2: separation/ extraction: involves refining, removing, or separating the beneficial parts or attributes out of an object. The temperature inside the refrigerated barrel should be controlled at 14-18 °C. If too high, rice quality declines. Based on these two principles, the problem resolution plan was to install temperature sensors in the 33 refrigerated barrels and a networked computer system was used in the monitoring room for displaying the temperature of each refrigerated barrel.

(2) Principle 30: flexible films and thin films: replacement of solid structures by flexible shells and thin films. Using this principle, the resolution plan was when the temperature sensors were installed inside the refrigerated barrels, automatic gate controllers replaced less accurate manual turning on/off to ensure refrigeration quality.

(3) Principle 32, changing color: Color additives or light emitting elements are put to use to improve the visibility of objects. Based on this principle, the resolution plan was to install temperature stickers on common pipelines. If the temperature was unusual, staff can inspect the different colored temperature stickers to determine which ventilation pipeline has abnormal air supply.

(4) Principle 40, composite materials: replacement of homogeneous materials with composite materials. The problem was resolved by installing insulating films on the ventilation pipe exteriors to keep pipe air from leaking during the pipeline transportation process.

(5) Two innovative principles, “spherizing” and “physical or chemical state change” had no significant application to the problem and were not adopted.

4. Conclusion and Suggestions

This study has investigated the rice milling production process of Taiwan Yixing Rice Milling Company. The eight steps of rice milling production process were first analyzed using risk assessment theory to determine the three steps with the greatest risk, drying, refrigeration, and color sorting. Next, using a cause-and-effect diagram, we identified eight factors that cause poor quality rice milling in the three steps. We then analyzed the eight vital factors using quality functional deployment techniques to determine the four key factors: the hue recognition subsystem, the refrigerator structure, the ventilation facilities, and the air pressure nozzle subsystem. Finally, we used TRIZ to address the problems of the four key factors. This study emphasizes the four key factors involved in color sorting and refrigeration. We recommended that Yixing Rice Milling Company address them to enhance rice milling quality. We made five recommendations for color sorting (1) a small portion of grains entering the color sorting system should be checked first to test the rice flow speed control valve, and to adjust the size to ensure the quality of color sorting; (2) the brightness of illumination lamps should be periodically checked and tested to maintain them at the recommended 990 to 1100 lumens; (3) the optical lenses and cameras should be cleaned and proper camera function checked periodically; (4) the hue decision processor should be tested with a small amount of grain first to ensure that the processor can correctly identify the grain color, transparency, and size of the grain; and (5) the nozzles and the compressor pressured need to be periodically checked.

Two recommendations were made for the refrigeration system: (1) to reinforce the refrigerated barrel, its steel plates of the four sides of each refrigerated barrel were tightly bound with steel cables. Rust should be regularly removed from the plate joints, and Teflon insulation lining installed inside the four side steel plates of the refrigerated barrel to ensure no leakage of cold air. (2) Networked temperature sensors were installed in 33 refrigerated barrels. These enable temperature monitoring in the control room. Automatic gate controllers were used to replace less accurate and slower manual turning on/off. (3) Temperature stickers were affixed on common pipelines. If the temperature was outside normal parameters, the colors change, which staff can see.

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