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Time reduction of mudmee silk yarn manufacturing in the Khon-Mee process at the community level in Thailand

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Abstract

This research is aimed to reduce the average time spent on solving the delay in the Khon-Mee process that causes the delivery of silk yarn to customers to take longer than planned. The cause is broken yarn during manufacturing and the inability to stop the Khon-Mee machine immediately. The researcher created the broken yarn detector device, a new device at the community level; when detecting broken yarn, the light was turned on to show the Khon-Mee process status was stopped. Then the operator connected the silk yarn to continue to run the machine until finished. The results showed the average time spent on solving that problem decreased from 132.90 minutes to 67.85 minutes, and the time savings achieved as 65.05 minutes accounted for 48.95%. Maximum weekly productivity increased from 216 sets to 360 sets, and the productivity was accreted as 144 sets accounted for 66.67%. Consequently, the sufficient silk yarn for the required customer is 250 sets per week.

Keywords: Time reduction, Detector device, Silk fabric, Silk, Yarn, Weaving

1. Introduction

The Ban Sai community lives in the Ban Mi district, which is located in the western part of the province of Lopburi in Thailand. Most of the people are Phuan, also known as Thai Phuan or Lao Phuan, who migrated from Xiangkhouang in Laos between 1827 and 1890 [1]. The main occupation of the Ban Sai community is farming. Most people gathered to weave mudmee silk fabric when they were not on farms. Therefore, the village has been named "Ban Mi," which was named after a characteristic of the occupation that the whole village makes mudmee silk fabric, which is used as a symbol of the way of life of the Phuan people. Mudmee silk fabric is both a local handicraft that reflects the heritage of the Phuan people and a local product that Thai Phuan descendants have inherited from their grandparents [2]. Ban Sai villagers are known for weaving mudmee silk fabric by incorporating local knowledge into the weaving of the fabric, which features beautiful and colorful patterns that have been typed by the Thai Phuan people. The word "Mee" is called in term for bundling silk yarn into groups to provide a variety of colors [3-5]. Mudmee silk fabric weaving has been practiced by the Thai Phuan people for a long time, but it has been done in different ways. To improve the quality of life of the farmers, the Ban Mi District Agriculture Office has encouraged farmers to join together to weave cloth and make mudmee silk fabric as commercial products by integrating art, culture, and local wisdom. The farmers have created mudmee silk fabric products of good quality and diverse colors [6, 7].

The mudmee silk fabric is widely woven in mainly the Northeastern region, with the Northeast being a largely populated area. As a result, the popularity of mudmee silk fabric has grown widely. The process of weaving mudmee silk fabric has similarities and differences with general weaving. The difference is the mudmee silk fabric weaving, which must make a pattern before dyeing. Making a mudmee silk fabric pattern requires using a rope to bundle the silk yarn according to the pattern that has been designed. Bundling and dyeing silk yarn according to the pattern are done for both vertical and horizontal yarns, also known as the warps and wefts. The process of weaving mudmee silk fabric consists of the following: the process of preparing the yarn; the process of bundling the yarn; the process of dyeing; the process of solving silk yarn; and the process of weaving. The process of bundling the yarn can is separated into the procedure of bundling the yarn and the Khon-Mee process. The patterns and colors for the mudmee fabric are made by bundling silk yarn together. Therefore, the patterns are made by bundling a group of silk yarns on the weft yarn according to the desired patterns before dyeing the yarn. This bundle must be made of waterproof material. The bundling and dyeing of the mudmee silk yarn are done alternately many times to achieve the desired pattern and color. Before beginning the bundling of the yarn, the Khon-Mee process must be completed [8]. The Khon-Mee process involves preparing silk yarn and bundling it to the core of the machine first. Then wrap it around the Hong Khon-Mee and place the yarn on the yarn groove continuously, that is called the process of the Khon-Mee. It must

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be made from the bottom up or top to bottom until the desired cycle, which calls each of the yarn grooves as a group. The silk yarn is bundled on the right side, so it must circle left and right every time. Every silk yarn is bundled to separate each silk yarn from each other so that the silk yarn is not tangled. When the silk yarns are completely tied, they are removed from the Khon-Mee machine.

Mudmee silk fabric weaving nowadays has expanded to become an industry at the community level. The mudmee silk fabric manufacturing process in the Ban Sai community is separated into different work procedures under a particular house to speed up the manufacturing process. The working procedure is as follows: the first house is used for the Khon-Mee process, the second house is used for the dyeing of the yarn process, and the third house is used for the weaving of the silk process. The process of Khon-Mee in the Ban Sai community has been changed from being manual to a semi-automated system. The semi-automated Khon-Mee machine system was produced in 1995 by Mr. Wichian Champaduang, who lives in the Ban Sai community. The machine can proceed in the process of Khon-Mee according to the standard of mudmee silk fabric weaving for bundling a group of silk yarn as 7, 13, 17, and 25, in which the number of yarns in one group must be 40 pairs or 80 yarns. The Khon-Mee process in the Ban Sai community is manufactured by a maximum of 12 sets per cycle. Therefore, it has not been required to hire people to operate the Khon-Mee process anymore. However, the broken yarn during the Khon-Mee process is still the cause of the problem. Moreover, the broken yarn is not repaired immediately during the Khon-Mee process, which is not finished. One must wait until the process is completed before being able to repair a yarn that has broken completely, then keep the machine running until the process is completed according to the amount the customer has requested. Therefore, the process of Khon-Mee has been used for a lot of time.

After the literature review is done, the current Khon-Mee machine is semi-automated, where you can enter the number of spinning cycles of the yarn, control the rotation speed, and adjust the length of the yarn, but the manufacturer still must monitor the broken yarns, connect the broken yarns yourself, and keep the machine running until the process is completed. The Khon-Mee machine of the Ban Sai community in Lopburi Province is also semi-automated, but it can only enter the number of spinning cycles of the yarn and manufacturing under consistent rotation speed. The sample community found that the delay during the Khon-Mee process is caused by the broken yarn, but the machine cannot stop connecting the silk yarn. The researcher has found that the current Khon-Mee machine does not have a broken yarn detection system, no signal to order the machine to stop working, and no alarm of broken yarn during the Khon-Mee process. This research is aimed to solve the problem of the Khon-Mee process delay that is caused by broken yarn by reducing the Khon-Mee process time by creating a broken yarn detector that uses the principles of automation and control engineering to improve the Khon-Mee process by having a signal to order the machine to stop working and a signal for a broken yarn alarm during the Khon-Mee process to provide an action to solve the broken yarn during the Khon-Mee process without the operators monitoring the machine all the time.

2. Literature review

A literature review found that [9] studied the invention of the Khon-Mee machine, which was aimed to help the Khon-Mee, or the yarn preparation, in the process of weaving mudmee and was a device to reduce the fatigue of operators. The Khon-Mee machine was designed to have a power set by using the feet of an operator to force the rotation of the Hong Khon-Mee. Furthermore, it was designed to have a groove to hold the Hong Khon-Mee and then also serve to hold the Hong Khon-Mee and the Khon-Mee machine. Then, [9] was further improved by [10] studying the design of the transmission system with the linkage to the transmission shaft. Then, [10] was further improved and developed by [11], which focused on the process of preparing the warp yarn of the mudmee weaving process, such as cotton, silk fabric, etc. This further development controlled the speed and stop of the Hong Khon-Mee by designing the movement of the yarn to relate to the rotation of the Hong Khon-Mee and the placement of the yarn on the yarn groove. However, the operator still used their feet to control the movement of the Hong Khon-Mee to roll the yarn and then used their hands to hold the yarn to put it down on the yarn groove, according to [10]. The [12] studied the mudmee Khon-Cotton machine, which was unique in that it consisted of a wooden base frame in a square measuring 120x120 centimeters. On the one hand, the warp set of cotton yarns was made by cutting the wood into many 25 small grooves to help hold the cotton yarns in rows. On the opposite side was a set of yarns that were removed. At the center was an axle shaft to be used as a set for moving cotton yarn. The end of the axle shaft was the arm set of the crank. The arm set of the crank was used to spin the cotton yarn. [13] studied the development and construction of a silk yarn preparation machine for mudmee, that was designed to have a foot pedal similar to a sewing machine. A foot pedal was used to drive the 20-millimeter power transmission shaft. The crank would drive the silk reel frame to spin. Both [9-13] were Khon-Mee processes, which still had to use worker labor. The [14] studied the speed control system for the Khon-Mee machine. An improvement to the working process of the Khon-Mee machine by using automatic control was developed to be able to control the speed of rotation, speed detection, and adjustable speed. By creating a prototype of an automatic locating machine that could control two levels of speed to make it easier to use in real life and creating an automatic yarn slider instead of worker labor for convenience and safety in the process of Khon-Mee. [15] studied the development of an automatic handmade mudmee cotton machine that could control and count the number of cycles of yarn rotation and yarn length. The manufacturer was able to enter the number of cycles, each shift distance, and the number of yarn groups that you could arrange on the cotton wheel for mudmee by yourself. It was easy to use by programming a microcontroller with an encoder sensor system to detect cycles of motor rotations, making the system more accurate. Therefore, it could work more efficiently, faster, and more conveniently than using tools from traditional local wisdom. This automatic handmade mudmee cotton machine could reduce production costs by using the pulse width modulation (PWM) technique to control the speed of rotation. Then it could save a lot of labor without the manufacturer having to waste time carrying out the whole process. However, the manufacturer still had to check the broken yarn, connect the broken ones, and then continue to run the machine until the specified process was complete. This machine could efficiently increase the volume of production and also help increase the value of the fabric, according to local wisdom. The Khon-Mee machines [14] and [15] were semi-automated, similar to the sample community that the researcher studied, the Ban Sai community in Lopburi Province. However, these machines do not have a system to detect broken yarn during the manufacturing process. Therefore, the researcher is interested in studying and developing the broken yarn detector device with the sample community, which corresponds to the need for the use of the sample community studied as well.

The methods used include.

1: The manufacturer has used the foot to control the rotation of the Hong Khon-Mee.
2: The transmission system has been designed with a linkage to the transmission shaft.
3: The yarn has been moved on the yarn groove by manual labor.
4: The Khon-Mee machine was a semi-automatic system.
5: The yarn has been moved onto the yarn groove by the automation system.

6: The rotation of the Hong Khon-Mee has been controlled for consistent speed.
7: The Hong Khon-Mee has been controlled for stopping.
8: The rotation of the Hong Khon-Mee has been controlled for two-speed levels.
9: The rotation of the Hong Khon-Mee has been adjusted for speed.
10: The manufacturer could determine the number of cycles of rotation of the yarn.
11: The manufacturer could count the number of cycles of rotation of the yarn.
12: The manufacturer could determine the length of the yarn.
13: The manufacturer has kept monitoring the broken yarns.
14: The manufacturer has connected the broken yarns by yourself.

Table 1 The development of the Khon-Mee machine at the community level in the years between 2015 and 2021.

Authors	Years	1	2	3	4	5	6	7	8	9	10	11	12	13	14
[9]	2015	✓		✓										✓	✓
[13]	2015	✓	✓	✓										✓	✓
[10]	2016	✓	✓	✓										✓	✓
[11]	2017	✓	✓	✓			✓	✓						✓	✓
[12]	2018	✓	✓	✓										✓	✓
[15]	2020				✓	✓					✓	✓	✓	✓	✓
[14]	2021				✓	✓			✓	✓				✓	✓

✓ for the method that has been used.

In the evolution of the Khon-Mee machine at the community level, the yarn has been moved on the yarn groove by automation, controlled the stopping, adjusted the rotation speed, determined the number of cycles of rotations of the yarn, counted the number of cycles of rotation of the yarn, and determined the length of the yarn. However, the manufacturer still must monitor the broken yarns and connect the broken yarns himself because it takes skill and experience, as shown in Table 1.

3. Materials and methods

3.1 Methodology

The methodology of research is shown in the Figure 1.

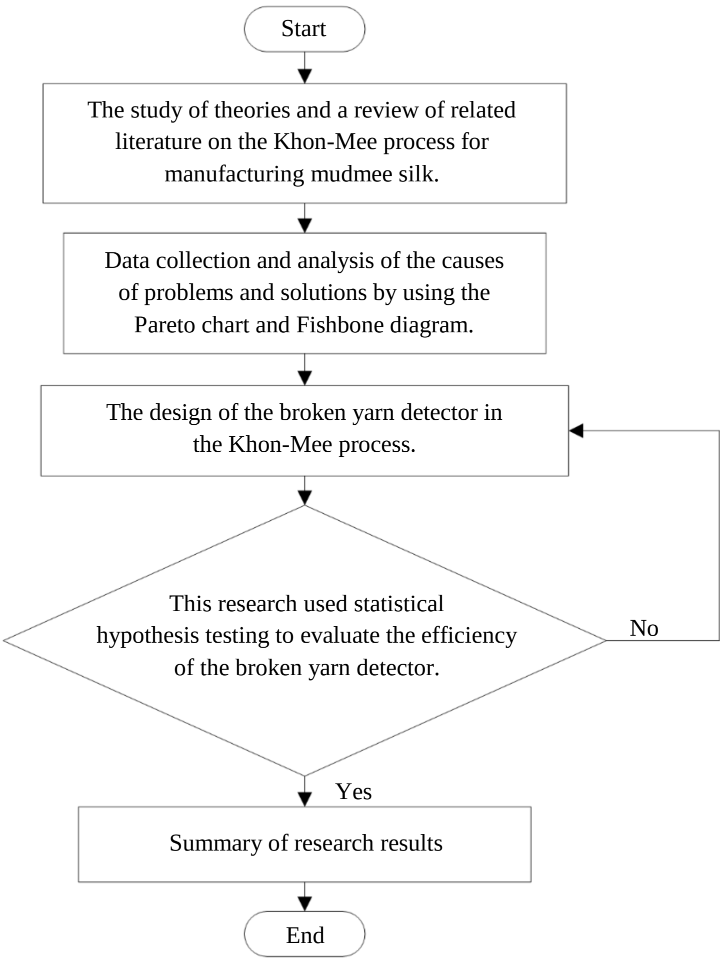


Figure 1 Methodology of research design.

3.2 Root cause analysis of the problem

The Why-Why analysis, the Pareto chart, and the Fishbone diagram were used to find the root cause of the problem in this research [16, 17], which were used for analysis to determine the root cause affecting the delay problem in the Khon-Mee process and causing delivery of silk yarn to customers longer than planned.

3.2.1 Why-Why analysis

The delayed delivery problem is caused by broken yarn. The manufacturer does not have an inspection system to monitor manufacturing process errors; thus, a broken yarn detector device must be created, which may decrease the average time. However, for the other causes, the manufacturer adjusts its own manufacturing process without creating a device, as shown in Figure 2.

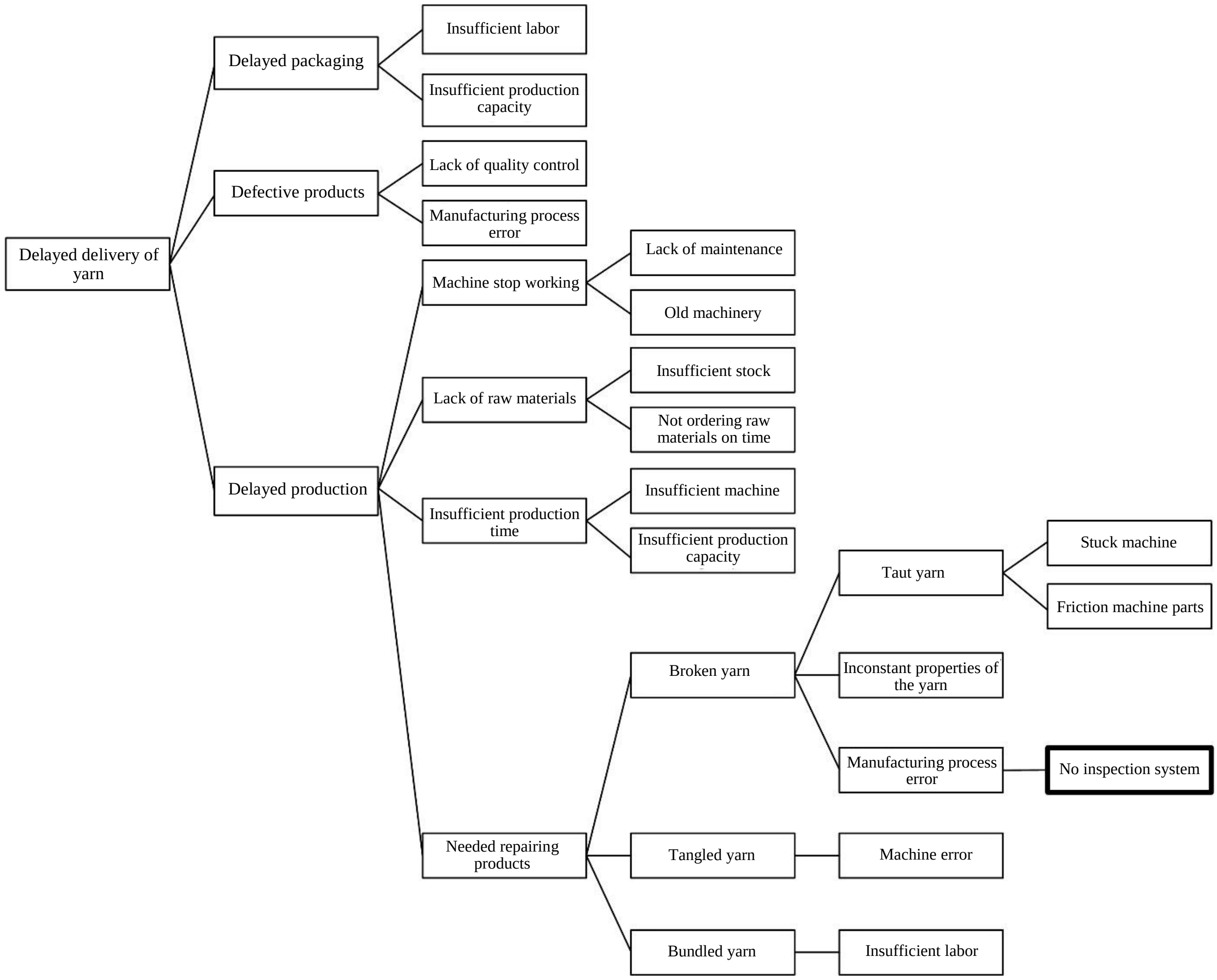


Figure 2 The possible causes of the problem in the Khon-Mee process by the Why-Why analysis.

3.2.2 Pareto chart

The Khon-Mee process was studied in detail via the Pareto chart, which was used to analyze the main causes affecting the delay problem in the Khon-Mee process. The researcher randomized the sample size to 20 cycles per cause of the silk weaving yarn in 25 groups, where one cycle of manufacturing equals 12 sets. Then, the root causes of the delay problem in the Khon-Mee process were identified using the average time used to resolve each cause as a consideration, as shown in Table 2. There were four root causes listed in descending order: broken yarn, bundled yarn, tangled yarn, and removed yarn. Then, the Pareto chart helps to identify the major cause of the delay problem in the Khon-Mee process was broken yarn, which must be resolved first, as shown in Table 3 and Figure 3.

The definitions of the causes affecting the delay problem in the Khon-Mee process.

1) Broken yarn means counting the time since finding the knotted yarn, connecting the yarn, and then releasing the Khon-Mee machine to continue running until the desired number of 25 groups per set.
2) Bundled yarn means counting the time after the Khon-Mee process is complete, the bundled yarn until the desired number of 25 groups per set.
3) Tangled yarn means counting the time spent solving tangled yarn between bundling a group of silk until the desired number of 25 groups per set.
4) Removed yarn means counting the time after the bundled yarn until the desired number of 25 groups per set, then removing yarn from the Khon-Mee machine one set at a time.

Table 2 Time spent on solving the causes of the problem in the process of Khon-Mee from the sample of 25 groups of 12 sets per cycle.

Sample (cycles)	Causes of the problem (min.)			
	Broken yarn	**Bundled yarn**	**Tangled yarn**	**Removed yarn**
1	52	13	22	3
2	47	11	0	2
3	125	9	17	4
4	54	10	0	2
5	83	12	13	5
6	64	8	0	3
7	96	11	9	3
8	73	10	0	4
9	48	11	0	5
10	35	9	0	2
11	39	13	0	3
12	54	14	0	2
13	78	11	15	3
14	44	10	0	4
15	117	12	0	2
16	69	10	11	3
17	84	11	0	3
18	105	13	14	2
19	58	9	0	4
20	93	12	0	3
Average	70.90	10.95	5.05	3.10
S.D.	26.14	1.61	7.45	0.97

The causes of the problem in the Khon-Mee process from Table 2 were arranged by the average time spent on solving the causes of the problem in descending order, as shown in Table 3. Then, calculating the cumulative percentage of the Pareto chart, as shown in Figure 3, a broken yarn was found with a cumulative percentage of 78.78, which complied with the 80/20 rule. The researcher aimed to solve the delay problem in the Khon-Mee process from the cause of the broken yarn, which has allowed the Khon-Mee process of the Ban Sai community to be developed further.

Table 3 Average time spent on solving the causes of the problem in the process of Khon-Mee from the sample of 25 groups of 12 sets per cycle.

Causes of the problem (min.)	Average Time (AT)	%AT	%AT cum.
Broken yarn	70.90	78.78	78.78
Bundled yarn	10.95	12.17	90.95
Tangled yarn	5.05	5.61	96.56
Removed yarn	3.10	3.44	100.00
Total	90.00	100.00	

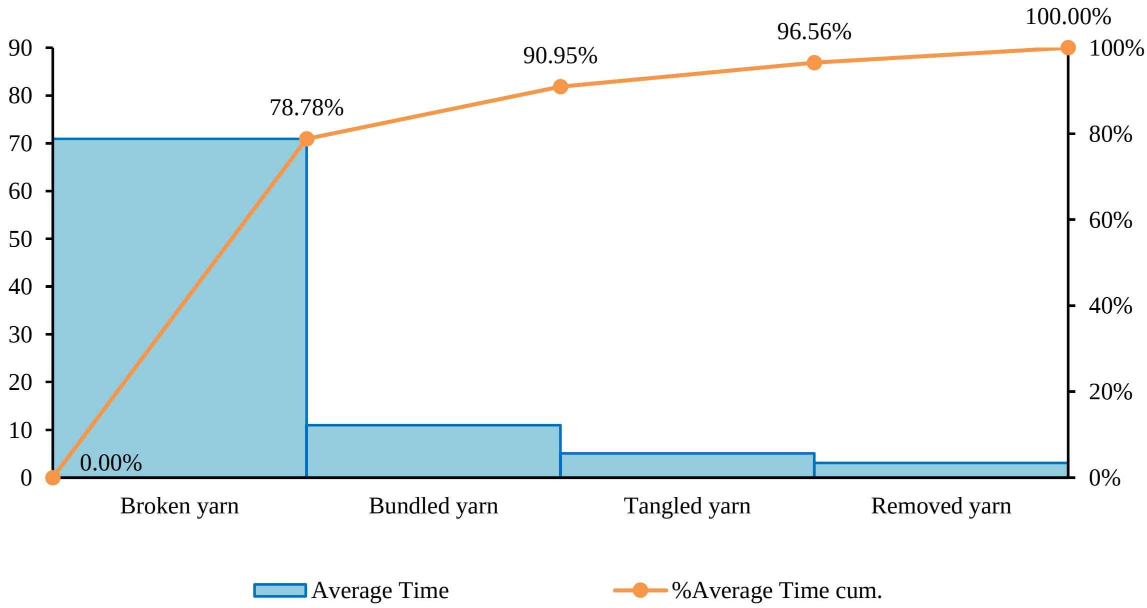


Figure 3 The cumulative average percentage of time spent on solving the causes of the problem in the Khon-Mee process by the Pareto chart.

3.2.3 Fishbone diagram

The fishbone diagram was used to identify the causes of the delay problem in the Khon-Mee process. The causes of the problem were classified into four categories: machines, methods, materials, and operators, called 3M1O principles, as shown in Figure 4.

Considering machines, operators, and methods, when the broken yarn was found to be the cause of the delay problem in the Khon-Mee process, but the operators could not stop the Khon-Mee machine during the manufacturing process to connect the yarn until after the manufacturing cycle has completed. The operators have not controlled the machines all the time. After the completion of the manufacturing cycle, it was found that the average time spent solving the cause of the delay in the Khon-Mee process was as follows: 70.90 minutes of broken yarn, 10.95 minutes of bundled yarn, 5.05 minutes of tangled yarn, and 3.10 minutes of removed yarn.

Considering materials when the community chose synthetic fiber yarn as the material. Therefore, the quality of silk yarn was not controlled because it was ordered from the manufacturer. In the 20th century, in the 10 years between 1960 and 1970, synthetic fiber yarn replaced natural fiber yarn and responded to the needs of today's consumers. Specific industrial processes and technologies were used in the manufacturing of yarns and new types of fiber. Both were newly invented and converted from the original fiber, in which natural fibers were mixed with synthetic fibers. There were many types that used both mechanical and chemical methods. The aim was to improve the quality of textile products according to the needs of consumers [18].

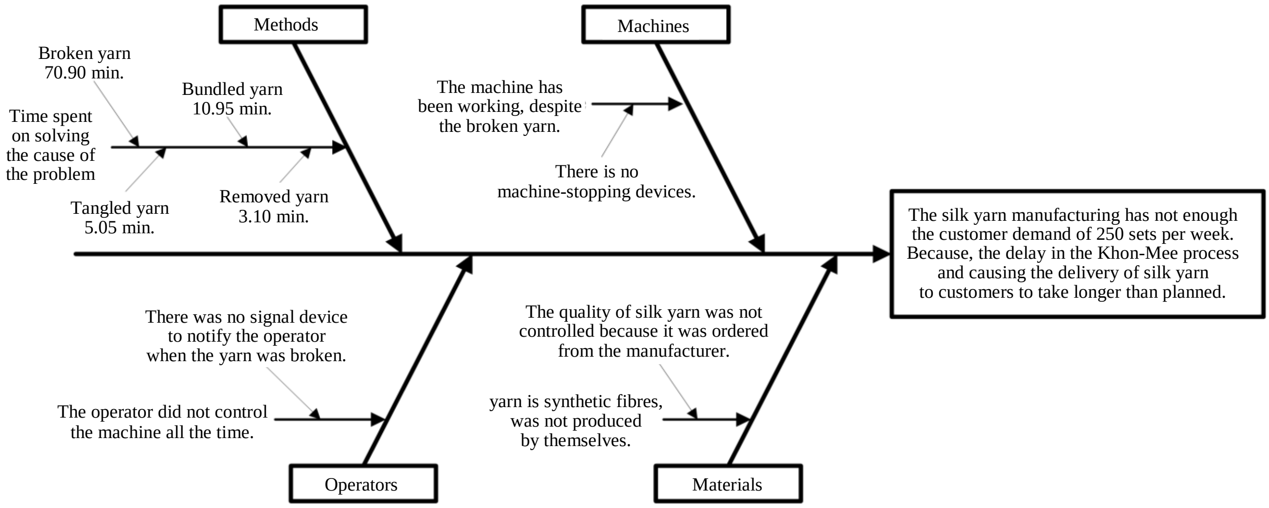


Figure 4 The possible causes of the problem in the Khon-Mee process by the Fishbone diagram.

The researcher chose to use a fishbone diagram to present the 3M1O principles, which include machines, materials, methods, and operators, to see the causes that affected the delay problem in the Khon-Mee process more clearly. The fishbone diagram showed the broken yarn, which was the main cause that the operators spent the most average time solving the delay in the Khon-Mee process and causing the delivery of silk yarn to customers to take longer than planned.

After reviewing the literature related to the Khon-Mee machine at the community level development, a review of the patent applications of past the Khon-Mee machine at the community level, and a meeting with the Ban Sai community about the development approaches of the current Khon-Mee machine at the community level. In conclusion, the Ban Sai community wanted to create a broken yarn detector, focusing first on solving the cause of broken yarn that occurs during the manufacturing process to be able to stop the Khon-Mee machine immediately while finding the broken yarn. The operators can repair the broken yarn during the Khon-Mee process. The Khon-Mee operators in charge of the manufacturing process have not watched the machines all the time, and they have done other work while the Khon-Mee process was in progress. This broken yarn detector was expected to reduce production time and increase productivity to ensure the timely delivery of yarn to customers.

3.3 Broken yarn detector

A broken yarn detector consists of three main parts: 1) Broken yarn detector tool installed into each Khon-Mee process, as shown in Figure 5. Two turn yarns were wrapped around the yarn wheel (number 1) mounted on the shaft with support (number 2) to allow the yarn to transmit force through the yarn wheel mounted on the shaft to rotate the rotary encoder (number 3) [19] for rotation sensing. The rotary encoder received electrical power and transmitted electrical signals to the second part. 2) The secondary control box was responsible for regulating voltage [20] to supply electrical power to the rotary encoder and RS-485 communication system [21]. It was responsible for reading rotation signals from the rotary encoder and then sending the signal to the next part. 3) The primary control box had an Arduino microcontroller [22] to be the brain of the device. It read the signal from the four secondary control boxes and decided to run or stop the process. When one of the rotary encoders stopped spinning, a stop signal from the secondary control box was sent to the primary control box. After the primary control box received a stop signal for five seconds, it would stop the mudmee silk yarn preparation machine by disconnecting the signal from the contactor, which acted as the main switch to connect power to the mudmee silk yarn preparation machine and the indicated light turn on to show the stop process status. The stop of the Khon-Mee process was for employees to complete the repair of the yarn and press the start button when the repair was completed. The process of the broken yarn detector was shown in Figure 6.

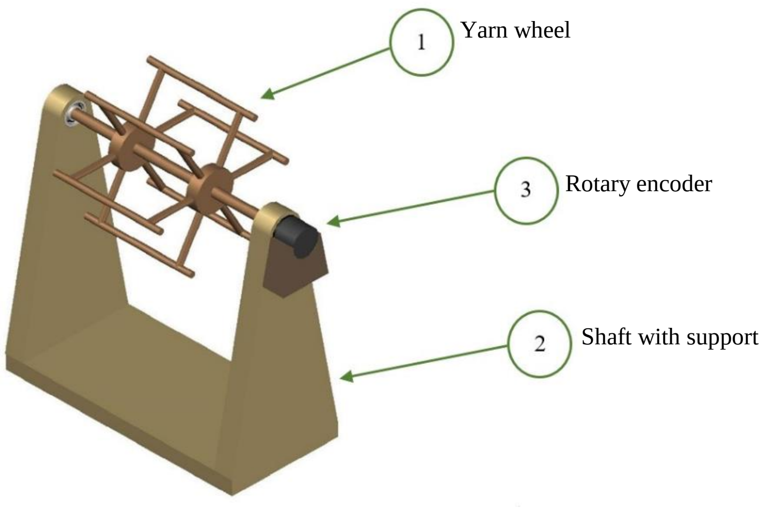


Figure 5 Broken yarn detector tool.

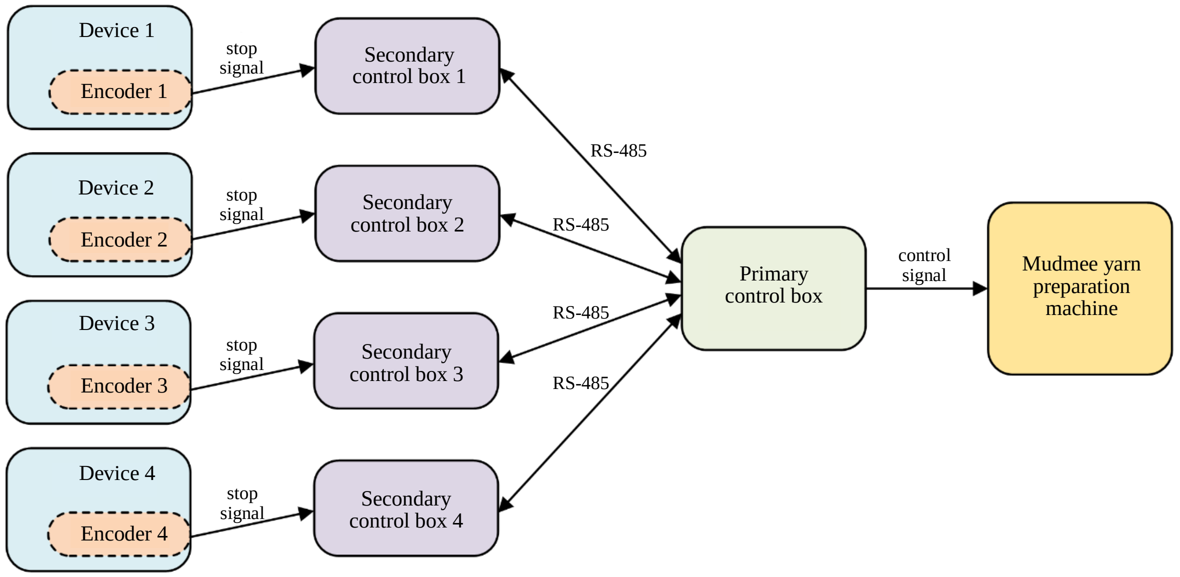


Figure 6 Process of the broken yarn detector.

In Figure 7, the broken yarn detector was installed in the Khon-Mee process. The four broken yarn detector tools worked with four mudmee silk yarn preparation machines to detect the stop signal from the rotary encoder when one of the yarns was broken.

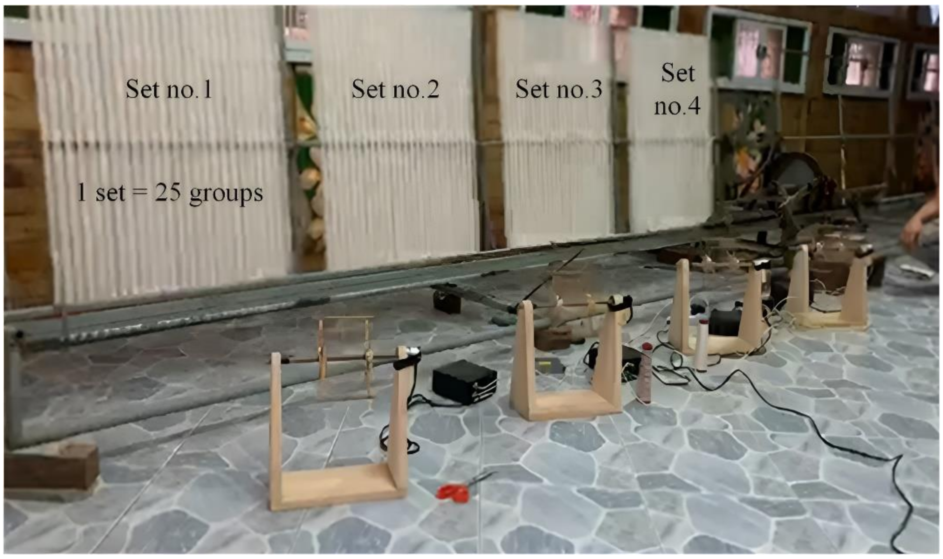


Figure 7 The testing of the broken yarn detector with the Khon-Mee process for 25 groups and 4 sets.

3.4 Data analysis

This research used the percentage improvement value and the independent two-sample t-test, which was a statistical method used to compare the means of two independent samples under the conditions of statistical testing to determine if there was a significant difference between them. In this research, the mean of time spent solving the causes of the problem was obtained from the traditional process to compare with the mean was obtained from the new process that was installed the broken yarn detector, and both processes were independent of each other.

The conditions of statistical testing were that the dependent variables must not be correlated, the dependent variable should be normally distributed, the independent variable should have two or more groups, and the variance of the dependent variable must not be equal.

1) Percentage improvement is the ratio of positive (or negative) change from the initial number to a higher (or lower) number, as expressed by a percentage.

The formula for finding the Improvement percentage is:

$$P = a/b \times 100 \qquad (1)$$

where P is the percentage improvement, a is the amount of positive (or negative) change, and b is the initial number that was increased (or decreased).

2) Independent two-sample t-test is used to compare the means of two independent samples [23-26] to determine whether there is statistical evidence that the sample means are significantly different. It is a parametric test. For the independent two-sample t-test, two variables are required. The first variable defines the two groups. The second variable is the measurement of interest. The null hypothesis (H_0) and alternative hypothesis (H_1) of the independent two-sample t-test are expressed as follows:

H_0: $\overline{X}_1 = \overline{X}_2$, the two-sample means are equal.
H_1: $\overline{X}_1 \neq \overline{X}_2$, the two-sample means are not equal.

The independent two-sample t-test statistic is computed as:

$$t = \frac{\overline{x}_1 - \overline{x}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \qquad (2)$$

Where $\overline{X}_1$ is the mean of the first sample.
$\overline{X}_2$ is the mean of the second sample.
n_1 is the sample size (i.e., number of observations) of the first sample.
n_2 is the sample size (i.e., number of observations) of the second sample.
s_1 is the standard deviation of the first sample.
s_2 is the standard deviation of the second sample.

The critical t value from the t distribution table with degrees of freedom is computed as:

$$df = \frac{\left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)^2}{\frac{1}{n_1 - 1}\left(\frac{s_1^2}{n_1}\right)^2 + \frac{1}{n_2 - 1}\left(\frac{s_2^2}{n_2}\right)^2} \qquad (3)$$

and choose the 95% confidence level. If the calculated t-test statistic > critical t value, then we reject the null hypothesis.

The conditions of the independent two-sample t-test as in items are as follows:

2.1) The independent samples or independent groups, i.e., independence of observations. There is no correlation between the dependent variables in each group. Thus, the dependent variables in the first group are not also in the second group. No, the dependent variable in either group can influence the dependent variable in the other group. However, no group can influence the other group. Violation of this condition will yield an inaccurate statistical test significance level. This is calculated by the Pearson correlation coefficient that the null hypothesis (H_0) and alternative hypothesis (H_1) are expressed as follows:

H_0: $\rho = 0$; the sample correlation coefficient is equal to zero or there is no correlation between variable x_1 and variable x_2.
H_1: $\rho \neq 0$; the sample correlation coefficient is not equal to zero or there is a correlation between variable x_1 and variable x_2.

2.2) The dependent variables should be normally distributed; they should also measure on a continuous scale, i.e., interval or ratio level. The Shapiro-Wilk test requires the sample size to be between 3 and 50 [27, 28]. Moreover, Shapiro and Wilk did not extend their test beyond a sample size of 50 [29]. The null hypothesis (H_0) and alternative hypothesis (H_1) in the Shapiro–Wilk test are expressed as follows:

H_0: The variables are normally distributed.
H_1: The variables are not normally distributed.

2.3) The independent variable should collect the categorical groups., i.e., two or more groups.

2.4) The variances of the dependent variable are unequal or called equal variances are not assumed (i.e., $s_1^2 \neq s_2^2$), thus the null hypothesis of equal sample variances (i.e., $s_1^2 = s_2^2$) is rejected. There is a difference between the sample variances in the two independent samples by Levene's test that the null hypothesis (H_0) and alternative hypothesis (H_1) are expressed as follows:

H_0: $s_1^2 = s_2^2$, equal sample variances or equal variances assumed.
H_1: $s_1^2 \neq s_2^2$, unequal sample variances or equal variances are not assumed.

Consequently, the researcher created the broken yarn detector, which is our new device. However, using the Pareto chart, Fishbone diagram, and independent two-sample t-test methods to support the results of the new device installation to solve the broken yarn, which was the main cause, affected the delay problem in the Khon-Mee process and caused the delivery of silk yarn to customers to take longer than planned. The broken yarn detector was created to be used at the community level to develop the community, similar to the Mudmee silk industry level.

4. Results

For comparing the two methods namely, the traditional method and the one with the broken yarn detector added, a sample size equal to 20 cycles per method from the silk weaving yarn of 25 groups was randomly chosen, as shown in Table 4. Because only four broken yarn detectors were fabricated as shown in Figure 7, the experimental sample was used to manufacture 4 sets per cycle.

Therefore, this study had two independent variables that were the traditional method and the method with the broken yarn detector, which variables were already in categorical groups, as shown in Table 4. Both variables were checked according to the three conditions of the independent two-sample t-test statistic as follows: 1) The Pearson correlation coefficient test was used to establish that there was no correlation between the dependent variables in each group, as shown in Table 5; 2) the Shapiro–Wilk test was used to establish that the dependent variable was normally distributed, as shown in Table 6; and 3) The equal and unequal variances of the dependent variable by Levene's test, as shown in Table 7. The research hypothesis was tested at a significant level of 0.05.

In Table 4, the average time spent manufacturing the silk yarn using the traditional method was 132.90 minutes, and with the broken yarn detector was 67.85 minutes. Using the broken yarn detector reduced the time spent on manufacturing the silk yarn in the Khon-Mee process by 48.95%, which was a reduction like a straight line parallel to the X-axis and tends toward one of the constants of time spent on manufacturing, as shown in Figure 8.

Table 4 Time spent on manufacturing the silk yarn in the process of Khon-Mee from the sample of 25 groups of 4 sets per cycle.

Sample (cycles)	Methods (min.)	
	Traditional	Adding the broken yarn detector device
1	114	70
2	109	68
3	187	67
4	116	65
5	145	73
6	126	66
7	158	65
8	135	69
9	110	68
10	97	66
11	101	71
12	116	66
13	140	72
14	106	64
15	179	65
16	131	76
17	146	66
18	167	69
19	120	67
20	155	64
Average	132.90	67.85
S.D.	26.14	3.22

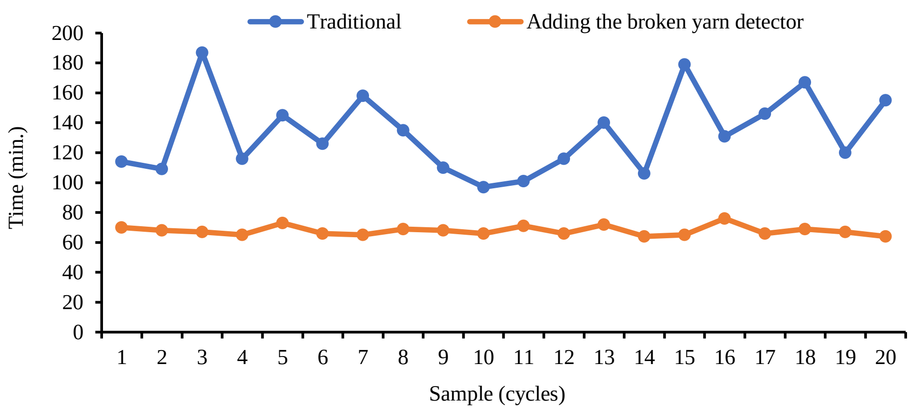


Figure 8 Comparison of the time spent on manufacturing the silk yarn of two methods from the sample of 25 groups of 4 sets per cycle.

For the hypothesis test of the correlation between the time spent on manufacturing the silk yarn using the traditional method and the one using the broken yarn detector obtained using the Pearson correlation coefficient test, the sig. (2-tailed) value equals 0.762, which was more than the significance level of 0.05. Consequently, the null hypothesis (H_0) could not be rejected, and it was concluded that the two methods did not have a statistically significant correlation. The time spent on manufacturing the silk yarn using the traditional method did not correlate with that of the method using the broken yarn detector, as shown in Table 5.

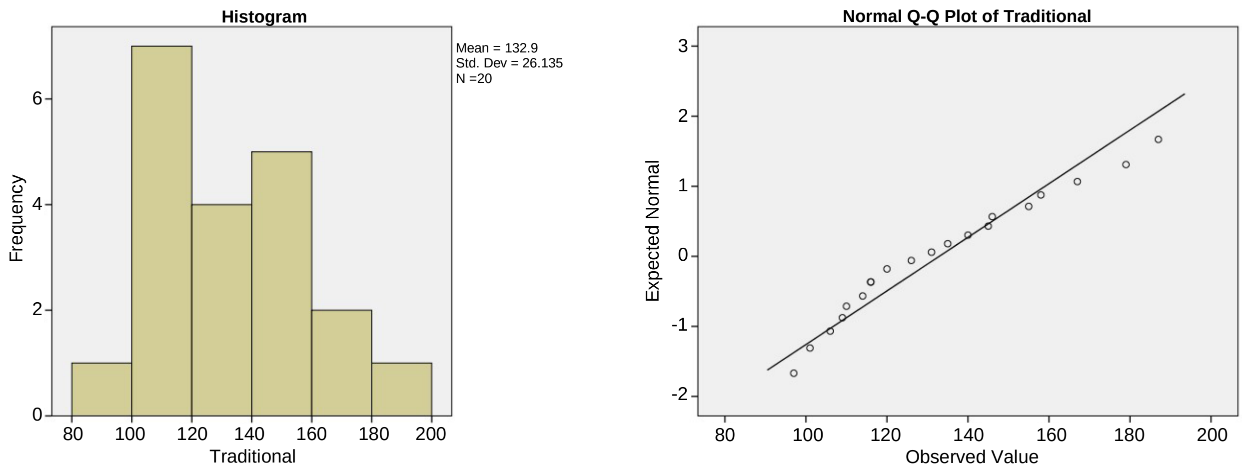
Table 5 Comparing the correlation of the time spent on manufacturing silk yarn between the two methods using the Pearson correlation coefficient test.

Methods	**Pearson Correlation**	**Methods**	
		Traditional	**Adding the broken yarn detector device**
Traditional	Correlation coefficient (r)	1	-0.072
	Sig. (2-tailed)		0.762
	n	20	20
Adding the broken yarn detector device	Correlation coefficient (r)	-0.072	1
	Sig. (2-tailed)	0.762	
	n	20	20

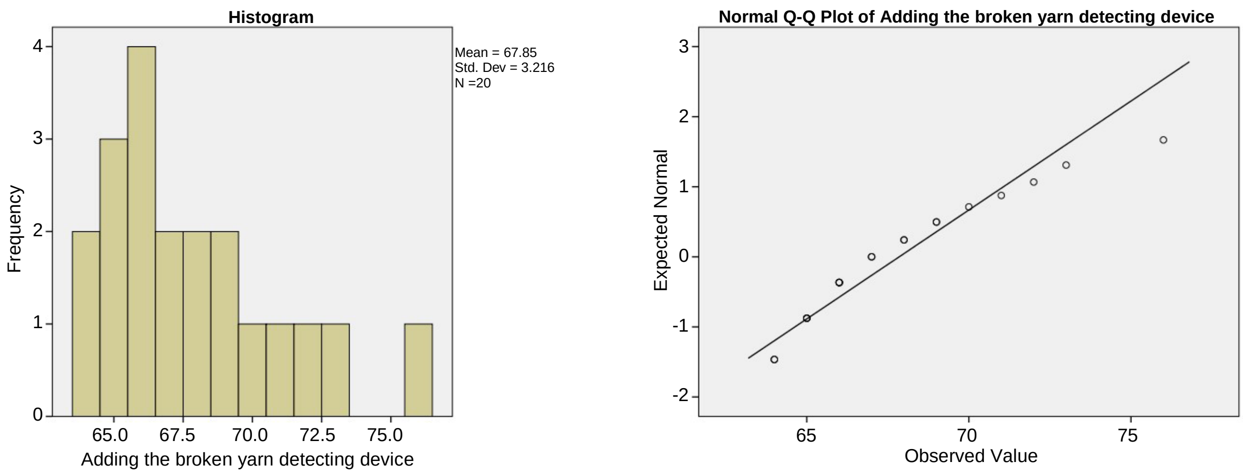
In Table 6 and Figure 9, the hypothesis that the time spent on manufacturing the silk yarn using the traditional method and that with the broken yarn detector was of normal distribution was determined by the Shapiro-Wilk test. The sig. value using the traditional method was 0.293, and the sig. value by the method using the broken yarn detector was 0.071. Both sig. values were more than the significance level of 0.05. Consequently, the null hypothesis (H_0) could not be rejected, and it was concluded that the two methods had a normal distribution that was statistically significant. Therefore, the sample size that the researcher randomly collected for studying 20 cycles per cause of the problem was sufficient according to the statistical principle with a significance level of 0.05.

Table 6 Testing for normality of the time spent on manufacturing the silk yarn of the two methods using the Shapiro-Wilk test.

Methods	**Shapiro-Wilk test**		
	Statistic	**df**	**Sig.**
Traditional	0.945	20	0.293
Adding the broken yarn detector device	0.912	20	0.071



(a) Traditional



(b) Adding the broken yarn detector

Figure 9 Histogram and normal Q-Q plot of two methods as (a), and (b).

The hypothesis of the equal and unequal variances of the time spent on manufacturing the silk yarn using the traditional method and that with the broken yarn detector was tested using Levene's test. The sig. value equals 0.000. It was less than the significance level of 0.05. Consequently, the null hypothesis (H_0) was rejected, and it was concluded that the variances of the two methods were not equal, which was statistically significant. The variances between the time spent on manufacturing the silk yarn for the traditional method and that with the broken yarn detector were not equal, as shown in Table 7.

Table 7 Comparing the variances of the time spent on manufacturing the silk yarn between the two methods using Levene's test.

Comparing the two methods' variances	Levene's test for equality of variances	
	F	Sig.
Equal variances assumed Equal variances not assumed	37.058*	0.000

The hypothesis of equal and unequal average times spent on manufacturing the silk yarn using the traditional method and the broken yarn detector was tested using the independent two-sample t-test. The sig. (2-tailed) value was 0.000. It was less than the significance level of 0.05. Consequently, the null hypothesis (H_0) was rejected, and it was concluded that the averages of the two methods were not equal, and that is statistically significant. The average time spent on manufacturing the silk yarn by adding the broken yarn detector was less than the average time spent on manufacturing the silk yarn using the traditional method, as shown in Table 8.

Table 8 Comparing the difference in the average time spent on manufacturing the silk yarn between the two methods using an independent two-sample t-test.

Methods	T-Test for equality of Means						
	n	Mean	S.D.	t	df	Sig. (2-tailed)	Mean Difference
Traditional	20	132.90	26.14	11.048*	19.575	0.000	65.05
Adding the broken yarn detector device	20	67.85	3.22				

For this case study, the manufacturing conditions were as follows: The Khon-Mee process could manufacture a maximum of 12 sets per cycle. Operators would work for 6 days, with 1 day off. Customers had an average silk yarn requirement of 250 sets per week.

As seen in Table 9, adding the broken yarn detector helps to improve the Khon-Mee process, thereby increasing productivity as follows: 1) The average time spent on manufacturing the silk yarn in the process of Khon-Mee reduced from 132.90 to 67.85 minutes, and the time savings achieve 65.05 minutes, which was a decrease of 48.95%. This resulted in 2) the maximum manufacturing capacity increasing from 3 cycles per day to 5 cycles per day, which was a 66.67% increase in productivity per day. 3) Maximum manufacturing capacity increased from 216 sets per week to 360 sets per week, which was a 66.67% increase in productivity per week. 4) The number of days for manufacturing the silk yarn reduced from 6.94 to 4.17 days, which decreased by 39.91%; the process could deliver sufficient silk yarn for an average order of 250 sets per week.

Table 9 Comparison of key performance indicators of the Khon-Mee process after adding the broken yarn detector.

Key performance indicator	The methods		Key results
	Traditional	Adding the broken yarn detector	
1. Average time spent on manufacturing the silk yarn in the process of Khon-Mee from the sample of 25 groups of 4 sets per cycle, averaging 20 cycles. (minutes)	132.90	67.85	The average time spent on manufacturing the silk yarn was decreased by 48.95%.
2. Maximum manufacturing capacity. (cycles per day)	3	5	Productivity was increased by 66.67% per day.
3. Maximum manufacturing capacity. (Sets per week)	216	360	Productivity was increased by 66.67% per week.
4. To order 250 sets, how many days does it take? (day)	6.94	4.17	The number of days in manufacturing the silk yarn was decreased by 39.91% per order of 250 sets.

5. Discussion

Most of the Khon-Mee machines at the community level still have used worker labor [9-13]. Thus, when manufactured for a long time, the manufacturer causes fatigue, which results in the Khon-Mee process being a mistake. Subsequently, the Khon-Mee machines at the community level are developed in a semi-automatic manner [14, 15]. However, the Khon-Mee processes at the community level still take longer than industrial machines, so they cannot respond to market demands on time.

The sample Khon-Mee machine in the Ban Sai community is a semi-automatic system able to determine the number of cycles of rotation of the yarn, the same as [15], and when installed with the broken yarn detector, the average time spent manufacturing yarn decreased. This is consistent with the hypothesis of this research. The procedures and processes of this research have been studied and are applicable to practical work, and the researcher has tested their use in the sample community successfully. The broken yarn detector device will be able to be used in other communities, and the Khon-Mee process must have similar characteristics. Besides, the broken yarn detector device has also been registered as a license for petty patent number 17766 in 2021 on the topic of the broken yarn detector in the Khon-Mee process [8]. However, it still should be further developed by adding a function to adjust the speed obtained from research [14] and by adding a function to count the number of cycles of rotation of the yarn and determine the length of yarn obtained from research [15].

6. Conclusions

The estimated cost of creating the broken yarn detector device is equal to 2,000 baht per device. After using the broken yarn detector device, we still have found the causes of the problem with broken yarn, bundled yarn, tangled yarn, and removed yarn. However, the average time spent on manufacturing the silk yarn in the Khon-Mee process has been decreased, that provided maximum daily productivity increased, weekly productivity increased, and the number of days spent manufacturing silk yarn per week decreased. The broken yarn detector is suitable for a semi-automatic Khon-Mee process at community level use only because the Khon-Mee process at a community level is usually similar. The user should train to use the device before actually using it. When detecting broken yarn, the light is turned on to show the Khon-Mee process status is stopped. The broken yarn detector device only detects broken yarn. However, the operators still have had to waste time connecting the yarn because it has taken skill and experience to connect the yarn correctly, and beautifully by not tearing it apart.

The limitation of this research is that it is mainly aimed at responding to the needs for use of the sample target community by creating the broken yarn detector. A guideline for the future development of the Khon-Mee machine of the local wisdom should develop with a level of functionality equal to the manufacturing of industrial machines and has responded to the community market demands in time. Therefore, it should combine the principles of the Khon-Mee machine in the Ban Sai community that is already installed the broken yarn detector device with the addition of functions: controlling the speed of rotation, speed detection, adjustable speed, counting the number of yarn rotation cycles, and controlling yarn length by yourself. Importantly, connecting the broken yarn should be automatic. Ready to install a display via the IoT system to monitor the manufacturing process from anywhere, continuously monitor the manufacturing process, and be up to date.

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