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Original Article

Six sigma DMAIC for machine efficiency improvement in a carpet factory

Busaba Phruksaphanrat* and Naipaporn Tipmanee

Industrial Statistics and Operational Research Unit (ISO-RU), Department of Industrial Engineering, Faculty of Engineering, Thammasat University, Rangsit Campus, Khlong Luang, Pathum Thani, 12120 Thailand

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Abstract

In this research six sigma DMAIC was applied to improve machine efficiency in a case study factory representing textile industry. The company faced the problem of machine efficiency in its manufacturing process, especially with the most significant product that has the highest demand, Axminster carpet. The performance of Axminster carpet production has been lower than the target for a long time. The company anticipated a significant increase of the machine's efficiency. Therefore, Six Sigma DMAIC technique and improvement tools were applied to the prototype machine. Having divided the procedure into five phases: define, measure, analyze, improve and control, the solutions to the prototype machine's efficiency improvement were listed into six categories, training, designing new components, data analysis, improving documentation system, modifying some machine components and improving some material preparation methods. As a result, the final efficiency increased to 64.06%, which is 12.01%-point improvement from the initial 52.05% efficiency.

Keywords: six sigma, DMAIC, machine efficiency improvement, carpet industry

1. Introduction

Six Sigma is a management system that employs quality improvement techniques to reduce the number of defects and increase efficiency of machines and processes. It includes a systematic method based on statistics to dramatically reduce defect rates (Mast & Lokkerbol, 2012). It has been applied in many areas, such as process design, process improvement, plant improvement, and machine improvement, etc. (Brun, 2011; Goel & Chen, 2008; Han & Lee, 2002; Lin, Chen, Wan, Chen, & Kuriger, 2013; Sharma & Rao, 2014; Sokovic, Oavletic & Fakin, 2005; Srinivasan, Muthu, Devadasan, & Sugumaran, 2014). Benefits have been reported from many sectors such as manufacturing, finance, healthcare, engineering, construction, and research and development (Kwak & Anbari, 2006). Many studies have shown that knowledge creation positively affects a Six Sigma project, and a successful project improves organizational performances (Arumugam, Antony, & Kumar, 2013; Parast, 2011; Shafer & Moeller, 2012; Sin, Zailani, Iranmanesh, & Ramayah, 2015; Swink & Jacobs, 2012). Effective Six Sigma principles and practices will succeed by refining the organizational culture continuously with strong commitment (Kwak & Anbari, 2006). Six Sigma projects of continuous process improvement are led, from concept to completion, through 5 steps or phases named DMAIC. While we are familiar with elements of Six Sigma, we lack an understanding of the order of activities and implementation model. Practitioners have encountered tremendous difficulty in implementation, so many Six Sigma projects have failed in implementation (Chakravorty, 2009).

This study focuses on improving the efficiency of Axminster carpet machine that produces the main product for the case study factory. By utilizing the DMAIC techniques, the factory should be able to eventually expand its carpet production and sales to better meet customer demands in a competitive global market. This research demonstrates an application of Six Sigma DMAIC for machine efficiency improvement. This provides guidelines to practitioners in

*Corresponding author
Email address: lbusaba@engr.tu.ac.th

machine improvement based on DMAIC, step by step, with the necessary tools. This is a practical case study for carpet industry. While several prior studies have reported on successful implementation, they have not shown the full details of each step in the implementation.

2. Six Sigma DMAIC Process

Key characteristics of Six Sigma systems include a focus on processes as a fundamental building block (Easton & Rosenzweig, 2012). Among the most powerful processes is DMAIC, which emphasizes improving processes from their current level to a new higher level of performance (Arumu gam *et al.*, 2013). DMAIC has been used in evaluating the performance of systems (Srinivasan *et al.*, 2014; Yeh, Cheng, & Chi., 2007). It can help improve quality of products, increase yields, enhance productivity and reduce the costs to an organization, and improve customer satisfaction. Sin *et al.* (2015) has shown that six sigma projects tend to improve organization performance, and also influence the organizational sustainability (Freitas, Costa, & Ferraz, 2017)

The Six Sigma DMAIC process is defined as follows (Mast & Lokkerbol, 2012; Yeh *et al.*, 2007):

1. Define: Select problem and analyze the benefits.

2. Measure: Gather data to validate and quantify by translating the problem into a measurable form, and assess the current situation.

3. Analyze: Find root causes by identifying influence factors in detail, and enhance understanding of the process and the problem.

4. Improve: Design and implement adjustments to the process to develop the performance of the system.

5. Control: Adjust the process management and control system for making sustainable improvement.

3. Carpet Manufacturing Process and Axminster Machine

Woven by an Axminster machine, Axminster carpet is suitable for large areas such as ballrooms, lobbies, and corridors. It has long been the major product of the company.

3.1 Axminster machine

Axminster machines, highly popular for products with large volume, are capable of weaving high quality carpets with a variety of colors and patterns. There are 26 Axminster machines at the case study factory producing Axminster carpets of a width ranging between 2.0 and 4.5 meters. The carpet width determines the machine code, for example 2M, 3M or 4M that is followed by the running number of the machine, such as 2M/1, 3M/2, and 4M/3.

Axminster carpet consists of 3 main materials: weft, jute, and yarn. The materials are perpendicular to each other and are in a crossed-link structure. All materials are compressed together in the Axminster machine creating a high-endurance carpet, as shown in Figure 1.

3.2 Process

The manufacturing process of Axminster carpet can be divided into 2 stages:

(i) Preparation, comprising the processes of design and material preparation, and

(ii) Production, comprising the four processes of weaving, finishing, packing, and exporting.

4. Methodology

In improving the efficiency of the Axminster machine, the Six Sigma DMAIC tools were applied. In this section, the methodology and outcomes are demonstrated.

4.1 Define phase (D): Problem identification

According to the records of the company in the last 8 months (from January 2015 to August 2015) before the study was conducted, the average efficiency of all Axminster machines reached only 45.78% as shown in Figure 2. This indicated that improvement was essential because the Axminster carpet was the top-priority product for the company.

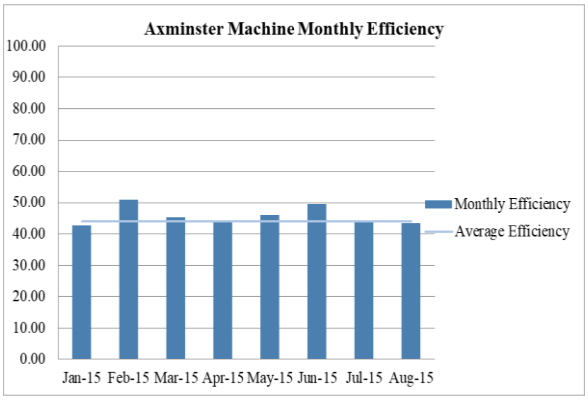

Figure 2. Axminster machine's monthly efficiency.

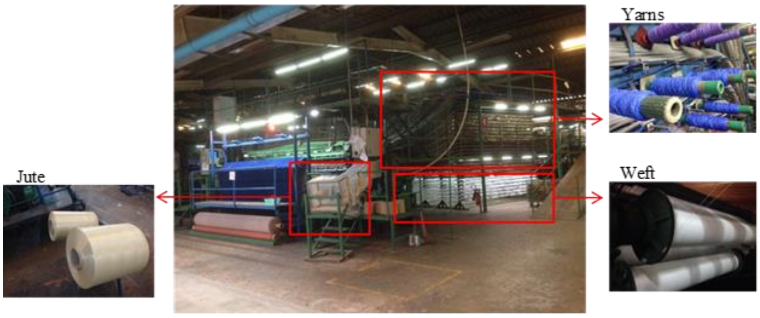

Figure 1. Positions of main materials at the Axminster machine.

The 3M/10 Axminster machine, which had been running at an average efficiency rate of 52.91% (average efficiency from the last 8 months before the study), was close to the overall average efficiency. It needed to operate continuously to satisfy orders throughout the study period. This machine unit was thus considered the most suitable prototype machine for the study.

4.2 Measure phase (M): Data collection and efficiency baseline

After having designated “3M/10” for this study, it was essential to know the situation and the efficiency before improvement at the work station. To do so, the activities occurring at the machine were listed and classified. Then, data were collected to define the baseline efficiency. The activities were divided into 2 main types as shown in Figure 3:

(i) Productive time: Time when the product was produced.

(ii) Non-productive time: Time not associated with product. In this case, all problems causing the machine to stop were categorized as non-productive time. There were 5 main problem sources as in Figure 3. The first three related to technical problems associated with the machine components and the 3 main manufacturing materials of jute, weft, and yarn, whereas the other two related to operators and lost time.

The accumulated productive time of the 3M/10 Axminster machine was 48.0% as calculated according to Equation (1);

Efficiency = Machine operating time/Total time (1)
= 23,213/48,374 = 48.0%

Based on the 10-day-average data collected after starting the project in each shift, the non-productive time was 52.0% deriving from the 5 main sources of stoppage (jute/machine tuning, weft, yarn/creel, operator waiting and resting at 23.2%, 8.0%, 4.8%, 2.4% and 13.6% respectively). From these 5 main sources, 31 causes associated with non-productive time were found.

4.3 Analyze (A): Major problems identification

From the data collected, information regarding the machine stoppage causes was also identified and used in the Analyze phase. The process was divided into two parts: identification of major problems and root cause analysis.

4.3.1. Major problems identification

This procedure aimed at identifying problems that had major effects on the 3M/10 machine’s efficiency. Problems were ranked as shown in Table 1.

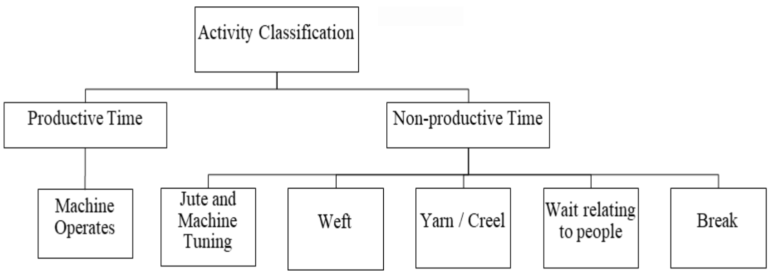

Figure 3. Activity classification.

Table 1. Ranking of problems affecting 3M/10 Axminster machine efficiency.

No.	Description	Time (cmn)	Percent	Acc. Percent
1	Weft is broken	3,861	23.0%	23.0%
2	Jute is torn	3,572	21.3%	44.3%
3	Yarn falls off from behind the machine	2,012	12.0%	56.3%
4	Brass plate bends	1,834	10.9%	67.2%
5	Sharpen cutter	862	5.1%	72.3%
6	Shuttle does not tie up	723	4.3%	76.6%
7	Jacquard controller dysfunctions	633	3.8%	80.4%
8	Weight control switch breaks	615	3.7%	84.1%
9	Change gripper	561	3.3%	87.4%
10	Refill thread into shuttle	450	2.7%	90.1%
11	Gripper pulls wrong color of yarn	440	2.6%	92.7%
12	Gripper pulls out the yarn	432	2.6%	95.3%
13	Talk to supervisor	403	2.4%	97.7%
14	Move the carpet produced	389	2.3%	100.0%
	Total	16787	100.0%	

According to Table 1, problems number 1 to 4 were the significant problems, which were approved by the company, totaling about 68% of the 3M/10 machine's stoppages. These four problems were weft broken, jute torn, yarn fell off the machine, and brass plate bent.

4.3.2 Root cause analysis

The tool used in this procedure is the Fishbone diagram which considers 5 factors of a manufacturing process: man, machine, method, material, and environment. The information was acquired from two sources: observations during the data collection process and brainstorming together with the technicians and experts at the company. An example of Fishbone diagram of the problem weft frequently breaks and requires a long time to fix was shown in Figure 4. From 5 days data collection of the causes of problems, average waste time for each cause of "weft is broken" per shift was collected, as shown in Table 2. The major causes of the problem were from the machine and the man, such as wires at the weft hanger have sharp edges, grippers pull weft too much, operators do not correctly arrange the weft causing the weft to break etc. The major causes analyzed by Fishbone diagram of the problem types "jute is torn", "yarn falls from behind the machine" and "brass plate bends" were also mainly from the machine and the man.

4.4 Improve: Lists of solutions and implementation plan

After obtaining root causes of each of the four problems from Fishbone diagrams, it was time to come up with solutions, estimate gains from the actions, and select the most beneficial ones for implementation. The phase Improve was divided into two sections: solution proposal and selection, and implementation.

4.4.1. Solution proposal and selection

The root causes together with solutions acquired from brainstorming with the factory manager and team of experts in the factory were summarized. An example of solutions approved is shown in Table 3. The time gained from each solution was estimated and converted to equivalents in product and cost. Time gained refers to the time improved or saved after implementing the proposed solution. Time gained can be calculated from

$$\text{Time gained} = \text{Current time} - \text{Expected time} \quad (2)$$

The product gained represents the amount of product gained from time that is saved if the solution is implemented. The product gained can be computed based on

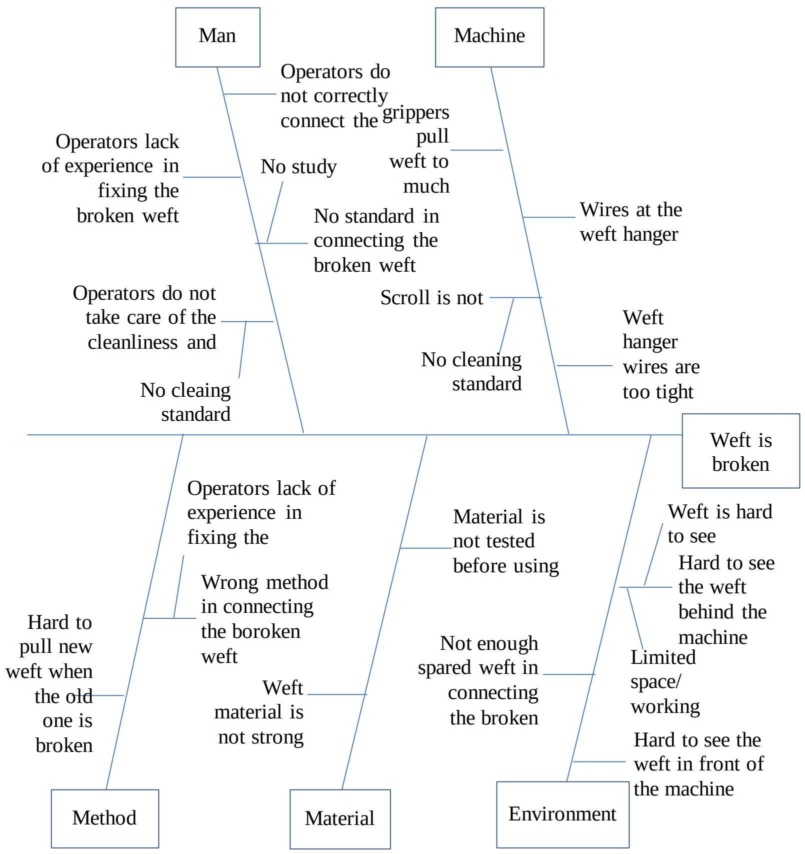

Figure 4. Fishbone diagram of the problem "weft is frequently broken and requires long time to fix".

Table 2. Average waste time for weft is broken per shift for each cause.

	Causes	Average waste time per shift (cmn)
Man		
1	Operators do not correctly arrange the weft causing the weft to break	1158.30
2	Operators do not correctly connect/tie the weft causing the weft to break	386.10
3	Operators lack of experience in fixing the broken weft correctly	193.10
4	Operators do not take care of the cleanliness and working environment	193.00
	sub total	1930.50
Machine		
5	Wires at the weft hanger have sharp edges	472.97
6	Grippers pull weft too much	472.97
7	Weft hanger wires are too tight	405.41
	sub total	1351.35
Method		
8	Hard to pull new weft when the old one is broken	192.05
Material		
9	Weft material is not strong enough	135.14
10	Material is not tested before using	57.92
	sub total	193.05
Environment		
11	Not enough spared weft in connecting the broken weft	115.83
12	Weft is hard to see	57.92
13	Limited space/working area	20.31
	sub total	194.05
Total		3,861

Table 3. Summary of approved solutions ranked in descending order of cost gained [Top 10 examples].

Problems	Main Factors	No.	Causes	Solutions	Current Time (cmn)	Expected Time (cmn)	Time Gained (cmn)	Product Gained (m²)	Cost Gained (Baht)
Approved Solutions									
Weft is broken	Machine	1	Wires at the weft hanger have sharp edges	Add to Monthly PM checklist	472.97	0	472.97	0.98	984.54
Weft is broken	Machine	2	Grippers pull weft to much	Add to Monthly PM checklist	472.97	0	472.97	0.98	984.54
Weft is broken	Man	3	Operators do not correctly arrange the weft causing the weft to break	Training	1158.30	694.98	463.32	0.96	964.44
Brass plate bends	Machine	4	Number of magnets are not suitable	Change number of magnets at the machine	440.16	0	440.16	0.92	916.23
Jute is torn	Man	5	Waste time to connect 2 jutes as the operators do not follow the procedure	Training	428.64	0	428.64	0.89	892.25
Weft is broken	Machine	6	Weft hanger wires are too tight	Fix the hangers at the machine	405.40	0	405.41	0.84	843.89
Jute is torn	Machine	7	The needle speed is not appropriate	Use ANOVA to find the appropriate speed	857.28	514.37	342.91	0.71	713.80
Brass plate bends	Machine	8	No sponge supporter	Add to Monthly PM checklist	330.12	0	330.12	0.69	687.18
Brass plate bends	Machine	9	Collar is not installed	Install collar at the machine	330.12	0	330.12	0.69	687.18
Brass plate bends	Man	10	Operators do not check brass plate condition	Add to Monthly PM checklist	275.10	0	275.10	0.57	572.65

Note: Expected time equals to zero means the problem will not exist after the solution is implemented.

the following assumptions. One shot takes 6.38 centiminutes, 7 shots equal to 1 inch or 0.0254 meter and width of the product is 3.66 meters.

$$\text{Product gained} = \frac{\text{time gained x } 0.0254 \text{ x } 3.66}{7 \text{ x } 6.38} \quad (3)$$

Cost gained refers to the cost saved from the implementation of the proposed solution. Saving cost per square meters is estimated to be 1,000 Baht. Then, the cost gained is

$$\text{Cost gained} = \text{Product gained x } 1{,}000 \quad (4)$$

For example, the current time and expected time of the problem 1 in Table 2 are 472.97 and 0, then from equation (2) the time gained is 472.97 cmn. Product gained and cost gained are 0.98 m^2 and 984.54 Baht by equations (3) and (4).

All of the 49 solutions were presented to the company management team. The decision of the company management team was based on 3 factors: cost gained, investment, and time for implementation, respectively. Almost all of the selected solutions had no extra cost, except the cost of a new rapier rail that was approved by the company. Expected time for implementation of all the solutions was less than 6 months, which was acceptable. So, cost gained is the main factor to rank the priority of solutions. The costs gained were calculated from equations (2)-(4). After cost gained items had been selected, investment cost and time for implementation were evaluated. As a result, 28 out of 49 solutions were approved. The total time gained from these 28 approved solutions was equal to 5,747.57 centiminutes, while the time of the whole shift was 48,374 centiminutes. Therefore, the efficiency gained from the approved solutions was estimated according to the equation (2) below. The expected gain of efficiency of 11.9% confirmed the possibility for achieving the agreed objective of efficiency improvement of the 3M/10 Axminster machine by 10%.

$$\text{Percent efficiency gained} = \frac{\text{Total time gained}}{\text{Total time in one shift}} \quad (5)$$

$$= \frac{5{,}747.47}{48{,}374} = 11.9\%$$

4.4.2. Implementation

The 28 approved solutions were categorized into 6 types of actions. These actions were created to prevent problems, as shown in Table 4.

Table 4. Summary table of solutions and related problems.

Summary table of solutions and related problems			
Training			
	1	Jute is torn	Waste time to connect 2 jutes as the operators do not follow the procedure
	2	Jute is torn	Wrong method in fixing the torn jute (Not follow the standard)
	4	Weft is broken	Operators do not correctly arrange the weft causing the weft to break
	5	Weft is broken	Operators do not correctly connect/tie the weft causing the weft to break
	7	Yarn falls from behind the machine	Operators lack of experience in arranging yarns properly
	9	Yarn falls from behind the machine	Operators lack of experience in connecting yarns correctly
	10	Yarn falls from behind the machine	Method of connecting yarns are not standard (Not follow the standard)
	11	Yarn falls from behind the machine	Wrong method in hooking yarns with hanger (Not follow the standard)
Design			
	1	Jute is torn	Jute path is not appropriate
Data Analysis			
	1	Jute is torn	The needle speed is not appropriate
	2	Jute is torn	Feeder speed is not appropriate
	3	Jute is torn	Angle and distance of jute is not appropriate
Checklist			
PM checklist			
	1	Brass plate bends	No sponge supporter
	2	Brass plate bends	Operators do not check brass plate condition
	3	Jute is torn	Needle is too sharp
	4	Jute is torn	Jute system is barely checked
	5	Weft is broken	Wires at the weft hanger have sharp edges
	6	Weft is broken	Grippers pull weft too much
Daily Checklist			
	1	Weft is broken	Operators do not take care of the cleanness and working environment
Machine Installation			
	1	Weft is broken	Weft hanger wires are too tight
	2	Brass plate bends	Collar is not installed
	3	Brass plate bends	Number of magnets are not suitable
Material Preparation			
	1	Jute is torn	No spared jute at the machine
	2	Weft is broken	Hard to pull new weft when the old one is broken
	3	Weft is broken	Not enough spared weft in connecting the broken weft

1) Training

Out of the 49 solutions, 12 were from human error. To minimize errors and improve lost time cause by “the man”, training is required for operators to work correctly and efficiently with less lost time. Two main problems related to the operators are weft is broken and yarn falls from behind the machine. Areas of training are installation, connecting and tying the weft, fixing the broken weft and torn jute, arranging connecting hooking and installation of yarns.

2) Designing more suitable components

Jute path consists of 2 components: the rapier and its rail. Rapier is a component that runs the jute through the carpet. It moves along the metal rail which guides the rapier to move smoothly in the direction of x-axis. The rail had been utilized for over 10 years and was very rusty, thus causing the rapier to not move smoothly. Although the clearances between the rapier and the two sides of the rail have to be as small as possible, the spaces between the two components were too tight and more effort was required to overcome friction, causing movement of the rail to be inconsistent and resulting in torn jute. Therefore, a new component was designed as shown in Figure 5.

The major advantage of the new rapier rail is friction reduction. The additional parts modified in the new design are the rollers, which enable the rapier to move smoothly on the plate. By adding the rollers, stoppage due to unsmooth movement of the rapier should be reduced and hence, the lost time from torn jute should be less than when using the old design. Stainless steel was used for the new rapier rail to help prevent the rail corroding. Also dust, either from the air or the yarns used to produce Axminster carpet, was another factor causing unsmooth movement of the rapier. The top part of the rail was modified to solve this problem by changing from an open-top rail to a closed-top rail. The lid prevents dust from falling into the rapier path and the jute system; it is also easier for cleaning and maintenance

3) Determining suitable level of machine tuning by using design of experiments

Torn jute had been the second biggest problem causing lost time from stoppage of the machine. The design of experiments followed a 2^5 full factorial design with 2 replications to avoid inconsistency from the machine and random effects of uncontrollable external factors such as experimenter, materials, environment, etc. The experiment was processed by the Minitab 18 software.

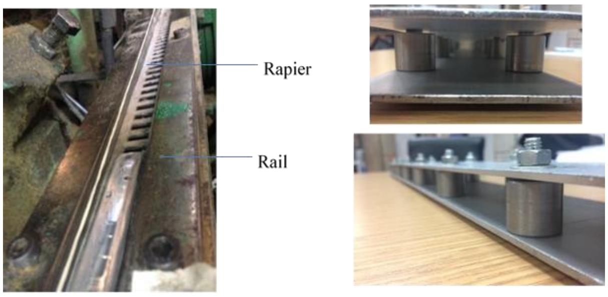

Figure 5. Rapier and the rail; (a) Before improvement (b) After improvement.

After the procedure of the experiment was designed, possible factors were identified and levels of adjustment for each possible factor were determined. The data were then collected and analyzed with the confidence interval of 95%. There were 64 experiments. Normal probability plot was used to verify that the residuals from the experiment were normally distributed. Plot between residuals and observation order was used to assess independency of the data, and the plot of residuals and the fitted values indicated constant variance, or homoscedasticity. Table 5 shows the factors and their levels.

From the results of 2^5 full factorial design with significance level 0.05, A, B, C, D and E were all possible factors associated with the performance of the jute system. P-values indicate that adjustments of factors A, B, D and E significantly affect the jute system performance as the P-values are less than 0.05, as shown in Table 6. There were no interactions between factor C and the other factors. The main effects plot is shown in Figure 6.

As the existing adjustments of factors A, B and E were already suitable with the jute system, only adjustment of factor D was suggested for a change, from the current height of 160 cm to 200 cm.

4) Reducing error from human and machine by creating checklists

The aim of creating checklists was to ensure that operators clean the working area and check conditions of safety devices as well as the regularly used materials before starting work. Moreover, conditions of parts of the machine should be checked, repaired, and maintained after one order of production is completed, which usually takes one month. Therefore, the checklists were divided into 2 forms: daily machine checklist and monthly machine preventive maintenance checklist, shown in Table 7 and Table 8.

Table 5. Factors and their levels.

Factors	Symbol	low	high	current level	appropriate level
Needle speed (times/hour)	A	700	900	900	900
Feeder speed (Level)	B	7	9	9	9
Horizontal distance of feeder to jute stand center (cm.)	C	60 (to the left)	60 (to the right)	60 (to the right)	60 (to the right)
Height of jute stand (cm.)	D	160	200	160	200
Distance between feeder and jute stand (cm.)	E	120	320	120	120

Table 6. Result of analysis of variance.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	10354238	1150471	58.99	0.000
Linear	5	10179828	2035966	104.39	0.000
needle speed	1	4606389	4606389	236.18	0.000
feeder speed	1	1301881	1301881	66.75	0.000
Horizontal distance	1	46333	46333	2.38	0.129
height of jute stand	1	3459600	3459600	177.38	0.000
distance b/w feeder and jute stand	1	765625	765625	39.26	0.000
2-Way Interactions	4	174410	43603	2.24	0.077
needle speed*horizontal distance	1	68121	68121	3.49	0.067
feeder speed*horizontal distance	1	31064	31064	1.59	0.212
horizontal distance*height of jute stand	1	12600	12600	0.65	0.425
horizontal distance*distance b/w feeder and jute stand	1	62625	62625	3.21	0.079
Error	54	1053196	19504		
Total	63	11407434			
where R^2 = 89.23%					

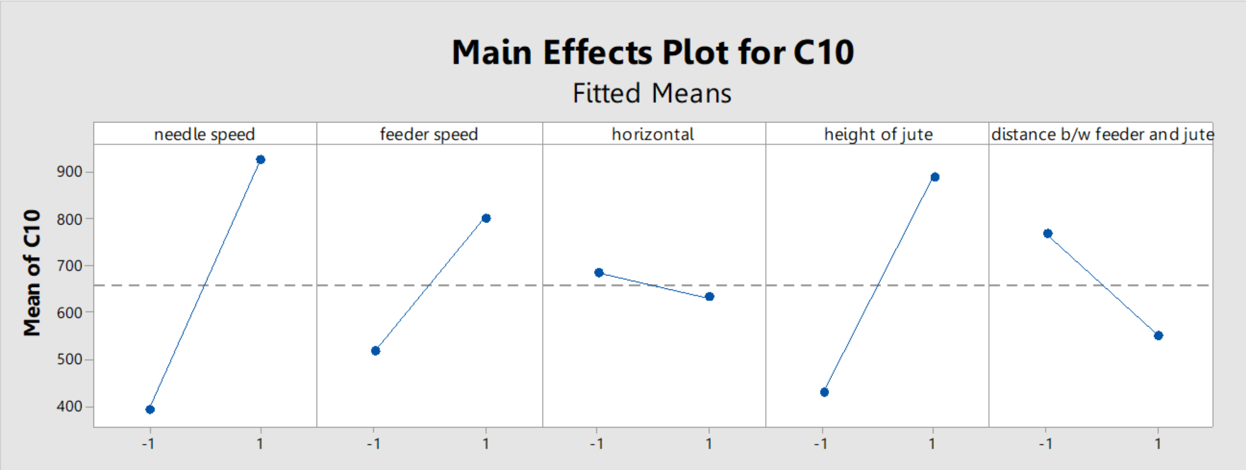

Figure 6. Main effects plot.

5) Reinstalling the parts of the machine that were in inappropriate condition

Tuning of the machine is a significant factor in producing Axminster carpet. In observing unusual tuning or condition of machine components, 3 problems were found. The first problem was broken weft, which was solved by improving weft hanger wires to become less tight. The other two problems were from bent brass plate. These were solved by installing the collars and re-installing the correct number of required magnets.

6) Preparing materials used in weaving Axminster carpet

Implementation concerning material preparation consists of preparation of spare jute and spare weft. Wefts were cut into suitable lengths ready for operators to use when the old one was broken. The number of rolls was increased and installed at 3 locations: left side, right side, and in the middle of the machine.

4.5 Control (C): Results and suggestions on standard maintenance

The purpose of this step is to measure and sustain the gains. A control plan should be created and documents, business process, or training records should be utilized.

4.5.1 Result evaluation

After the implementation, the machine's efficiency must be measured again. The data were obtained from 3 main sources:

1) Data collected by researchers

The data were collected for 5 days with exactly the same method and duration of time as in the Measuring Phase. The time that the machine operates (or productive time) was 60.2%, meaning that the machine's efficiency was improved by 12.2%-points from the efficiency baseline at start of the project (48% in ten days of data). By considering the four

Table 7. Daily machine checklist.

Machine Daily Checklist

Machine Number **Month** **Year**

	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	29	30	31
1. Cleanness																															
1.1 No yarn waste or dust in nooks and crannies of gripper																															
1.2 No yarn waste or dust on yarn carrier																															
1.3 No yarn waste or dust in the lower guide comb																															
1.4 No obstructing objects throughout passage before the machine																															
1.5 Cleaning of passage before the machine																															
1.6 Cleaning of area underneath the machine																															
1.7 Cleaning of area behind the machine																															
2.Tensioning Weight																															
2.1 Even weights on both sides																															
3. Jumbo Switch																															
3.1 Being in the right and appropriate position																															
3.2 Complete power cut for all 6 switches																															
4. Raw Material																															
4.1 Quantity of pile yarns being enough for the weaving job																															
4.2 Yarns being correctly inserted and not crossed																															
4.3 Having more than 2 spare jute cones at the machine																															
4.4 Wefts being correctly inserted and not crossed																															
Operator's Signature																															
Supervisor's Certification																															

Table 8. Monthly machine preventive maintenance checklist.

Machine Preventive Maintenance Checklist Machine Number Date / /			
Checklist Item		Problems detected	Results after maintenance
1. Gripper & Carrier			
1.1	Check for loose gripper		
1.2	Check for loose reed		
1.3	Check for breast comb damages		
1.4	Check gripper's movements		
1.5	Check new gripper's pressure		
1.6	Check if gripper completely goes into yarn carrier		
1.7	Check if yarn carrier is correctly aligned with gripper		
1.8	Check carrier fulcrum stud		
1.9	Check if carrier of each yarn color levels with the others		
2. Safety Switch			
2.1	Check jumbo switches		
2.2	Install knock-off switch for weaving shuttles		
2.3	Install knock-off switch against pulling from uncut yarns		
2.4	Install device preventing yarn carrier's retraction		
3. Jacquard			
3.1	Check for correct number of magnet (1 thick and 2 thin magnets)		
3.2	Check if collar's installed position being at 10 mm.		
3.3	Check sponge support condition		
4. Wire			
4.1	Check for protuberances on wires and mend, if any		
4.2	Check for normal wire bending		
5. Roller			
5.1	Check spikes on roller (all to be the same for 8 mm.)		
5.2	Check center support bearing behind spike roller		
6. Oil			
6.1	Check if oil can be properly pumped out in all locations		
6.2	Check for correct oil level in oil pan		
7. Cam			
7.1	Check lay cam and stud		
7.2	Check threading cam and stud		
8. Carpet bow and skew			
8.1	Check all items for prevention of bow and skew		
SUMMARY			
Number of shots weavable:	Shots	Checker's Signature :	
Time for weft and plain jute weaving:	Minutes	Supervisor's Certification :	

major problems, the time lost due to broken weft, torn jute, fallen yarns and bent brass plate were improved by 4.9%, 4.4%, 1.5%, and 2.9%, respectively, as shown in Figure 7.

2) Daily efficiency and Monthly efficiency record from the company

The post-implementation daily efficiency was obtained from the Axminster Production Department. The average efficiency for both night and day shifts from January 2015 to June 2015 of 64.06% was equivalent to 12.01%-point efficiency increase from the efficiency before improvement (52.05%).

The Monthly efficiency record was tracked and recorded by Axminster Production Department. The benefit of displaying the monthly trend was to track and interpret the long-term efficiency progress. Figure 8 shows that the monthly efficiency of the 3M/10 Axminster machine before conducting the study fluctuated quite randomly with lowest and highest efficiencies of 39.2% and 62.04%. The efficiency of the machine before improvements was not stationary due to the lack of continuous maintenance and problem analysis. Moreover, during August 2015 to December 2015, demands on the machine had increased, so the factory increased the working time of the machine. Then, problems at the machine occurred after a long run.

From January 2016 to June 2016, however, the efficiency of the 3M/10 Axminster machine consistently improved. It turned to 64.06% on average. To sustain this improvement, the company must further maintain the machine and monitor its efficiency consistently.

4.5.2 Suggestions on standard maintenance

During the project, it was found that the efficiency was never systematically checked, although Axminster machines had been utilized for over 40 years. Conditions of the machines together with mistakes by the operators significantly affected the machines' efficiency. To monitor and improve an Axminster machines' efficiency, 4 main suggestions were proposed.

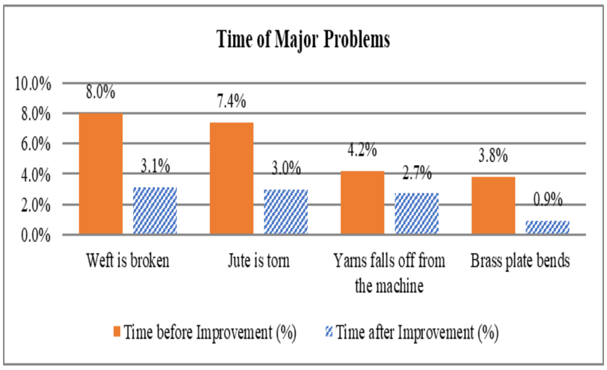

Figure 7. Comparison of time taken by the major problems.

- The company should frequently examine the performance of the machines, major causes affecting the machines' efficiency, and find proper solutions for implementation. Daily machine checklist and monthly machine preventive maintenance should be used to analyze and report monthly about the problems. Then, the steps in DMAIC can be repeated again to solve new problems.

- Efficiency or productivity of Axminster carpet relies highly on the condition of the machine. Therefore, the use of machine checklists used in the implementation process should be continuously reinforced.

- Human error was another significant factor affecting the efficiency of the machine. The operators' method of work must be observed. Training and workshops could improve an operator's performance.

- To monitor and maintain the results, the management system at the company should allow and encourage supervisors at each level to work together with the operators more, in order to examine problems in production and improve the documentation system. Machine running time before stoppage of each machine should be monitored and compared. Control charts may be used to track the efficiency of each machine. Then when something goes wrong, the operators can immediately know and report to their supervisors.

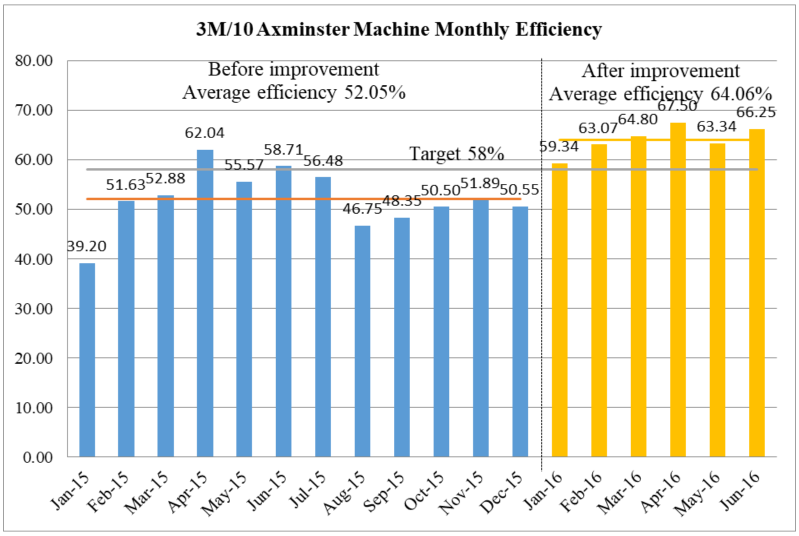

Figure 8. Pre- & Post-implementation Axminster machine monthly efficiency.

5. Conclusions and Suggestions

This research focused on improving the efficiency of a machine in a carpet factory by applying the technique of Six Sigma DMAIC. Statistical tools and techniques were useful to solve quality and other improvement problems. Firstly, the problems of the prototype 3M/10 Axminster machine were defined. The average efficiency before improvement was 52.05%. Non-productive time was also analyzed to find the problems and their causes by means of problem ranking, fishbone diagrams, and cause analysis of wasted time. Then, an improvement plan was constructed. It included training, designing more suitable components, determining the suitable level of machine tuning by using 2^5 factorial design, and reducing human errors by creating checklists, reinstalling the parts of the machine that were in inappropriate condition, and preparing materials used in weaving the Axminster carpet. Finally, the efficiency of the 3M/10 Axminster machine was re-assessed and suggestions on monitoring were proposed. After applying Six Sigma DMAIC, the performance of the machine was increased to 64.06%, a gain of 12.01%-points. Currently, the average efficiency of the machine from January to December, 2016, was improved to 65%. The company also used the same techniques to investigate and improve other machines. This case study can be used as a guideline for practitioners, who are facing the problem of low efficiency in machines or processes.

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