BOHR International Journal of Operations Management Research and Practices
2023, Vol. 2, No. 1, pp. 53–63
DOI: 10.54646/bijomrp.2023.18
www.bohrpub.com

RESEARCH

Applying Lean Six Sigma to improve garment production processes-A case study

Phong Nguyen Nhu*, **Phuc Nguyen Huu, Phong Thieu Nam and Quang Nguyen Dang**

Industrial and Systems Engineering, Ho Chi Minh City University of Technology (HCMUT), National University, Ho Chi Minh City, Vietnam

***Correspondence:**
Phong Nguyen Nhu,
nnphong@hcmut.edu.vn

Received: 26 July 2023; **Accepted:** 08 August 2023; **Published:** 30 August 2023

The company under study specializes in producing garment products. The production process of the company has so much waste, a long production time, a high cycle time, and a high defect rate, leading to low productivity, low quality, and late deliveries, affecting the competitive edge of the company. In this article we have discussed how Six Sigma can be applied to improve the company production process to reduce waste, the process production lead time, the cycle time, and the process defect rate and then to improve productivity and quality and finally increase the on-time delivery rate and the competitive edge of the company. The research methodology is based on Lean Six Sigma theory, with the platform of DMAIC procedure, including five steps: define, measure, analyze, improve, and control. The tools used in the steps of DMAIC procedure include cause and effect diagram, Pareto diagram, value stream management, work design, SMED, line balancing, Kanban systems, FIFO, autonomous maintenance, visual management, design of experiments, and control charts. After applying Lean Six Sigma tools, the company has reduced the production lead time by 89.21% from 279 to 30.1 min, reduced the production cycle time by 36% from 25 to 16 s, reduced the process defect rate by 37.45% from 14.9 to 9.32%, and then improved the on-time delivery rate.

Keywords: Lean Six Sigma, DMAIC, SIPOC, cause and effect diagram CED, Pareto diagram, VSM, work design, SMED, line balancing, Kanban, FIFO, AM, visual management, DOE, control charts

1. Introduction

The company under study specializes in producing garment products. The main products of the company include men vestons, jackets, shirts, and trousers. According to statistics, the average on-time delivery percentage of the company in the past is 85%. It is low and does not meet the expectation of the company leaders. Through analysis, the cause of the problem is due to a long production time, low productivity, and a high defect rate.

This paper uses Lean Six Sigma tools to solve the problem of low on-time delivery through reducing the production time, increasing productivity, and improving the defect rate. The research is carried out on a product with the highest demand on a line of the shirt garment production area.

2. Literature review and research methodology

Lean Six Sigma is the fastest way to improve time and quality; therefore, we can minimize operation costs, minimize capital investment, increase value, and increase customer

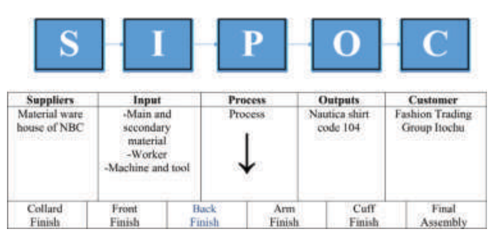

FIGURE 1 | SIPOC diagram.

TABLE 1 | Stations in back finish process.

Station	Station name
W1	Yoke assembly
W2	Press cut yoke
W3	Labeling
W4	Shoulder assembly
W5	Collar assembly
W6	Collar edging

TABLE 2 | Project charter.

Project charter	
Research	Applying Lean Six Sigma to improve the garment production process of product family X.
Problem	Low on-time delivery rate.
Objectives	Increase the on-time delivery rate by - Reducing the lead time. - Increasing productivity. - Reducing the defects of the garment production process.
Scope	X shirt, back finish process.
VOC	Increase the on-time delivery rate.
CTQ	Defect per unit, lead time, cycle time.

TABLE 3 | Collected data of back finish process.

Station	n	COT (min)	CT (s)	LT (s)	DPU (%)
W1	2	65	14.5	29	4.38
W2	1	0	17	17	0
W3	1	0	17	17	0.66
W4	1	65	25	25	4.65
W5	3	65	9	27	1.66
W6	2	65	18	36	3.51

TABLE 4 | Data of WIP and TIP.

WIP	WIP	TIP (min)
WIP before W1	50	725
WIP between W1 and W2	112	1904
WIP between W2 and W3	16	272
WIP between W3 and W4	208	5200
WIP between W4 and W5	11	99
WIP between W5 and W6	283	5094
WIP after W6	25	411
Total		13705

satisfaction. Lean Six Sigma is an integrated approach of Lean Manufacturing and Six Sigma. If we use Lean Manufacturing alone, we cannot control the process and solve quality problems in the best way. If we use only Six Sigma, we cannot minimize the time, cost, and capital investment.

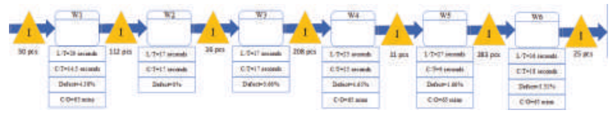

FIGURE 2 | Current value stream mapping.

TABLE 5 | Current indexes.

Index	Values	Assessment
LT (min)	279	Rather high and need to be reduced
PCE (%)	0.906	Very low due to waste, need to be increased.
CT (s)	25	Not meet TTc, need to be reduced
DPU (%)	14.9	Rather high and need to be reduced

TABLE 6 | Objectives of research.

Index	Current value	Objective
LT (min)	279	30
CT (s)	25	16
DPU (%)	14.9	10

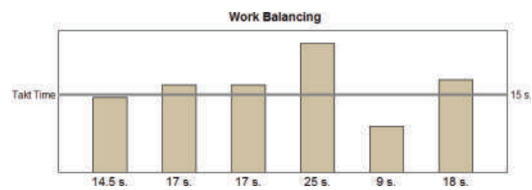

FIGURE 3 | Current balance chart.

FIGURE 4 | The fish bone diagram shows the causes of long-time problems.

Simultaneous use of Lean and Six Sigma tools helps us achieve high quality, high-speed production, and low cost with breakthrough improvements in a short time. Lean Six Sigma gives faster results than either Six Sigma or Lean Manufacturing.

The research methodology is based on Lean Six Sigma theory, with the platform of DMAIC procedure (1), including five steps:

(1). Define
(2). Measure

TABLE 7 | Solutions and tools for problems.

Problems	Causes	Solutions	Tools
Long LT	Waste in working motion	Eliminate waste in motion	Work design
	High WIP	Balance the line	Line balancing
	WIP out of control	Control the WIP inventory	Kanban, FIFO
CT > TT	Waste in working motion	Eliminate waste in motion	Work design
	Work elements not distributed evenly	Reallocate work elements among stations	Line balancing
	Long COT	Reduce the COT	SMED

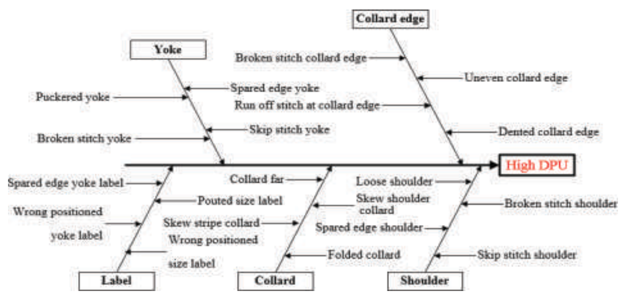

FIGURE 5 | The fish bone diagram shows the causes of defect problems.

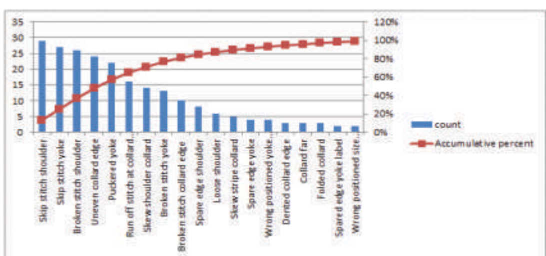

FIGURE 6 | The Pareto chart analyzes the causes of high-defect problems.

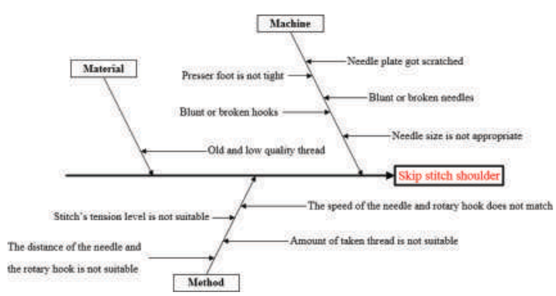

FIGURE 7 | The fish bone diagram shows the causes of skip stitch shoulder defects.

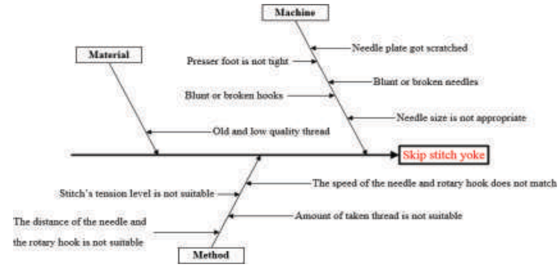

FIGURE 8 | The fish bone diagram shows the causes of skip stitch yoke defects.

TABLE 8 | Solutions and tools for skip stitch shoulder and yoke.

Causes	Solutions	Tools
The speed of the needle and rotary hook does not match	Define a suitable speed for the needle and rotary hook	Design of experiments
The stitch's tension level is not suitable	Adjust the stitch's tension level	
Amount of taken thread is not suitable	Adjust a suitable amount of taken thread	
The distance of the needle and the rotary hook is not suitable	Adjust a suitable distance of the needle and the rotary hook	
The presser foot is not tight	Check and tighten the presser foot	Autonomous maintenance
Blunt or broken hooks	Check and replace hooks	
Blunt or broken needles	Check and replace needles	
The needle plate got scratched	Check and use a sand-papering needle plate	
Old and low-quality thread	Sort out threads depending on their expiration	Thread storage system design
The needle size is not appropriate	Select the suitable needle size	Visualization

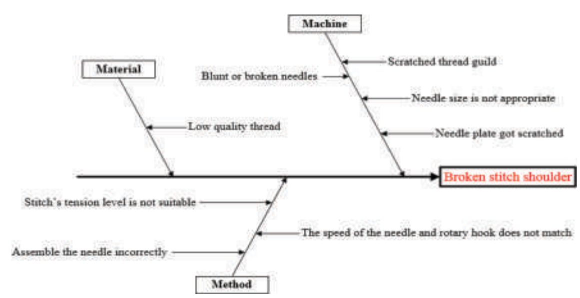

FIGURE 9 | The fish bone diagram shows the causes of broken stitch shoulder defects.

(3). Analyze
(4). Improve
(5). Control.

The define step defines the problem, objective, and scope of the study. In this step, the objective is defined qualitatively. The measurement step collects data, maps the current state

TABLE 9 | Solutions and tools for causes of defects.

Causes	Solutions	Tools
The stitch's tension level is not suitable	Adjust the stitch's tension level	Design of experiments
The speed of the needle and rotary hook does not match	Define a suitable speed for the needle and rotary hook	
Scratched thread guild	Check and use a sand-papering thread guild	Autonomous maintenance
Needle plate got scratched	Check and use a sand-papering needle plate	
Blunt or broken needles	Check and replace needles	
Assemble the needle incorrectly	Check needle installation and give installation instruction	
Low-quality thread	Sort out threads depending on their expiration	Thread storage system design
The needle size is not appropriate	Select the suitable needle size	Visualization

TABLE 10 | Time of elements.

Elements	Time (s)
Changing thread	149
Changing needle	59
Positioning needle	116
Cleaning machine	302
Changing presser foot	125
Getting required resources	598
Returning previous resources	605
Getting instruction for new order	124
Preparing required documents	55
Preparing material	783
Running first test	301
Adjusting thread tension	183
Adjusting rotary hook	329
Adjusting sewing step	176
Total	3905

TABLE 11 | Separate external elements.

Internal		External	
Elements	Time (s)	Elements	Time (s)
Changing thread	149	Getting required resources	598
Changing needle	59	Returning previous resources	605
Positioning needle	116	Getting instruction for new order	124
Cleaning machine	302	Preparing required documents	55
Changing presser foot	125	Preparing material	783
...	...	...	...
Total	1740	Total	2165

TABLE 12 | Convert internal elements to external.

Internal		External	
Elements	Time (s)	Elements	Time (s)
Changing thread	119	Putting thread spool on rack	30
Changing needle	59	Getting required resources	598
Positioning needle	116	Returning previous resources	605
Cleaning machine	302	Getting instruction for new order	124
Changing presser foot	125	Preparing required documents	55
Running first test	301	Preparing material	783
...	...	...	...
Total	1710	Total	2195

TABLE 13 | Streamline remaining elements.

Internal		External	
Elements	Time (s)	Elements	Time (s)
Changing thread	119	Putting thread spool on rack	30
Changing needle	59	Getting required resources	598
Positioning needle	72	Returning previous resources	605
Cleaning machine	302	Getting instruction for new order	124
Changing presser foot	125	Preparing required documents	55
Running first test	301	Preparing material	783
Adjusting thread tension	135		
Adjusting rotary hook	157		
Adjusting sewing step	95		
Total	1240	Total	2195

value stream, identifies current performance indexes, and sets objectives quantitatively. The analysis step finds out the root causes of the problem and then identifies solutions and tools to solve the problems. The improvement step implements solutions to improve the process in order to achieve the objectives. The control step controls the improved process to maintain improved results.

The tools used in the steps of DMAIC procedure include value stream management, work design, SMED, line balancing, Kanban, FIFO, autonomous maintenance, visual management, design of experiments (DOE), and control charts. All tools used can be found in references (1) and (2), along with articles (3) and (4).

3. Define

The problem that the company encounters is a low percentage of on-time delivery. The average on-time delivery percentage of the company is 85% and needs to be improved.

TABLE 14 | Comparison of parameters before and after applying SMED.

	Before	After
COT (s)	3905	1240
APT (s)	23,095	25,760
TT (s)	14.98	16.77

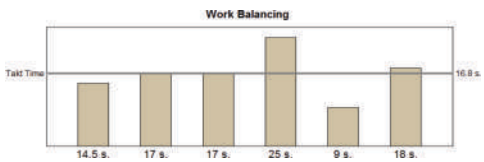

FIGURE 10 | Balance chart after applying SMED.

TABLE 15 | Collected data of working elements.

Station	No. of workers	Element	Time (s)	CT (s)
W1	2	Yoke assembly + folding	23	14.5
		Peel back	3	
		Stitching size label	3	
W2	1	Press cut yoke	15	17
		Check	1	
		Mark shoulder	1	
W3	1	Stitch main label	6	17
		Mark	3	
		Wasted thread cutting	2	
		Make button hole x 2	6	
W4	1	Shoulder assembly	25	25
W5	1	Neck assembly	27	9
W6	1	Collar edging	32	18
		Wasted thread cutting	4	

Through analysis, the cause of the problem is due to a long production lead time, low productivity, a high cycle time, or a high defect per unit rate. The research is carried out on a product family with the highest demand (5, 6). The SIPOC diagram of the product family is as in Figure 1.

This paper focuses on the process of back finish with six stations as in Table 1.

The defined stage is summarized in the project charter as in Table 2.

4. Measure

The collected data in the back finish process, including number of workers n, change over time (COT), cycle time (CT), lead time (LT), and defect per unit (DPU), are shown in Table 3.

Currently, the company works 6 days/week, 1 shift/day, 8 h/shift. The average break time is 40 min/day. The average

TABLE 16 | Working elements after the improvement.

Station	No. of workers	Element	Time (sec)	CT (sec)
W1	2	Yoke assembly + folding	12	8
		Peel back	2	
		Stitching size label	2	
W2	1	Press cut yoke	12	14
		Check	1	
		Mark shoulder	1	
W3	1	Stitch main label	6	17
		Mark	3	
		Wasted thread cutting	2	
		Make button hole x 2	6	
W4	1	Shoulder assembly	19	19
W5	1	Neck assembly	22.5	7.5
W6	1	Collar edging	29	16.5
		Wasted thread cutting	4	

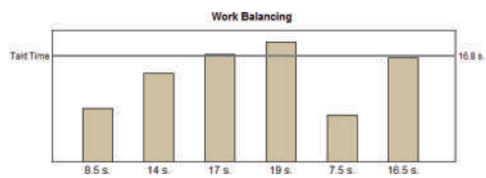

FIGURE 11 | Balance chart after applying work design.

TABLE 17 | Working elements data.

Station	Element	Time (s)	No. of workers	CT (s)
W1	Yoke assembly + folding	12	1	16
	Peel back	2		
	Stitching size label	2		
W2	Press cut yoke	12	1	14
	Check	1		
	Mark shoulder	1		
W3	Stitch main label	6	1	15
	Mark	3		
	Wasted thread cutting	6		
W4	Make button hole x 2	2	3	14.5
	Shoulder assembly	19		
	Neck assembly	22.5		
W5	Collar edging	29	2	16.5
	Wasted thread cutting	4		

COT is 65 min/day. The available producing time is as follows:

$$APT = 8 \times 60 - 40 - 65 = 375(\text{min})$$

with the demand of 1500 pcs/day. The talk time TT is calculated as follows:

$$TT = 375 \times 60/1500 = 15(\text{s})$$

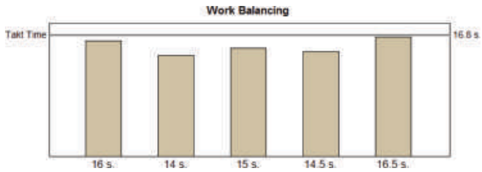

FIGURE 12 | Balance chart after applying line balancing.

TABLE 18 | Calculation of Kanban card quantity.

Stations	LT = ST + PT + QT + MT				LT	N
	ST	PT	QT	MT		
W2–W3	23	75	15	20	0.0050	2
W4–W5	16	82.5	15	20	0.0049	2

TABLE 19 | Calculation of FIFO lane size.

Stations		CT	Standard deviation	Processing time	S
W1–W2	W1	16	3.2	120 s	8
	W2	14	2.7		
W3–W4	W3	15	4.5	120 s	8
	W4	14.5	3.1		

TABLE 20 | Standard checklist for routine cleaning, inspection, and lubrication.

Items inspected	Item pictures	Inspection objects	Tools
Symbols Inspection Cleaning Lubrication			
1/ Sewing needles		Rust	Observe
2/ Rotary hooks		Dusts Errors Lubricant Rust	Observe Lubricant Wiper Grinder brush
3/ Needle plate sets		Dusts Errors Lubricant Rust	Observe Lubricant Wiper Grinder brush
4/ Feed dogs		Dusts Errors Lubricant	Observe Lubricant Wiper Grinder brush
5/ Threads		Errors	Observe

Work in process inventory WIP and time in process TIP are calculated and shown in **Table 4**.

With the data above, the current state map of the process is as in **Figure 2**.

From the map, the current indexes, their values, and performance assessment are as in **Table 5**.

The objectives of the research are set as in **Table 6**.

TABLE 21 | Needle and thread inspection standards.

Needle inspection	Inspection	Qualified	Unqualified	Solutions
Pinhead	Pinhead's sharpness	Normal	Curved or broken	Remove
Body	Straightness and roughness	Normal	Curved or broken or rusted	Remove
Eye	Roughness and transfiguration	Normal	Broken or rusted or transfigurated	Remove
Thread inspection	Inspection	Qualified	Unqualified	Solutions
Fraying thread	Observe and touching	Normal	Fraying thread	Mark errors and replaces
Fastening color	Touching	Normal	Bleeding or shading color	Mark errors and replaces

TABLE 22 | Checking note for cleaning, inspection, and lubrication.

Machine				
Standard information for cleaning, inspection, and lubrication				
No.	Abnormal condition	Dates	Condition after solving problems	Worker's name
1				
2				
3				

TABLE 23 | Needle sizes and storage capacity of each box.

No.	Needle size	Color	Storage capacity
1	65/9	Yellow	972
2	75/11	Red	660
3	90/14	Blue	330
4	100/16	Green	300

5. Analyze

5.1. Analyze the long-time problem

The long-time problems are demonstrated by long LT and long CT, exceeding the TT. The balance chart is as in **Figure 3**.

The process is unbalanced, leading to the increase of WIP inventory, causing long LT. Besides, CT of the process is 25 s, higher than TT, which is 15 s; the current production rate does not meet the demand rate. The causes of the problem are analyzed through the fish bone diagram as in **Figure 4**.

From the diagram, the causes, solutions, and solving tools are demonstrated in **Table 7**.

5.2. Analyze the high-defect problem

The causes of high-DPU problems are analyzed through the fish bone diagram as in **Figure 5**.

The Pareto charts for the causes are as in **Figure 6**.

The fish bone diagram for the *skip stitch shoulder* effect is as in **Figure 7**.

The fish bone diagram for the *skip stitch yoke* effect is as in **Figure 8**.

From the fish bone diagrams, the causes, solutions, and solving tools for skip stitch shoulder and yoke defects are presented in **Table 8**.

The fish bone diagram for the broken stitch shoulder defects is as in **Figure 9**.

From the fish bone diagrams, the causes, solutions, and solving tools for broken stitch shoulder defects are presented in **Table 9**.

6. Improve

6.1. Quick change over SMED

Change over time needs to be reduced to lift up TT. Based on (2), SMED is used by the following steps.

Step 1: Identify time elements.

Elements and their time are collected, as in **Table 10**.

Step 2: Separate external elements

The internal and external elements are separated as in **Table 11**.

Step 3: Convert internal elements to external elements.

The internal elements are converted to external elements as in **Table 12**.

Step 4: Streamline remaining elements

The remaining elements are streamlined as in **Table 13**.

After using SMED, COT, APT, and TT change as in **Table 14**.

The balance chart of the process after using SMED is as in **Figure 10**.

The process CT is 25 s, still higher than TT. Work design needs to be used to reduce the CT of each station to meet the TT.

6.2. Work design

Collecting the working elements of each station and their processing time is as in **Table 15**.

By analyzing and removing wasted motion, reallocating the work load of the right and left hands, designing support tools, and rearranging station layout, the results are that

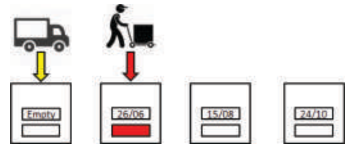

FIGURE 13 | Thread storage system.

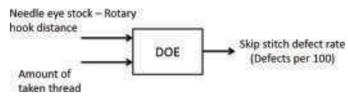

FIGURE 14 | Input and output variables for DOE.

TABLE 24 | Levels of factors for DOE.

Factors	Levels				Unit
A	2	3	4	5	Level
D	1	2		3	mm

the CT reduced while the number of workers remained unchanged, as shown in **Table 16**.

The balance chart after using work design is as in **Figure 11**.

The process CT is now 19 s, which still exceeds the TT, 16.8 s. Line balancing is used to reallocate work load of each station to meet demand.

6.3. Line balancing

Applying the line balancing model in (3), we reallocate the work load and worker for the stations with constraints of the element order and the goal of meeting TT. The results are as in **Table 17**.

The balance chart after using line balancing is as in **Figure 12**.

The process CT now is 16.5 s, which meets the TT, 16.77 s. On the other hand, the number of workers has reduced to 8, the number of stations has reduced to 5, and the line balancing efficiency has increased to 92.12%. The process is more balanced, but we still have to control WIP inventory.

6.4. WIP inventory control

With reference to (1), in order to control WIP, Kanban systems would be placed between stations 2 and 3 and between stations 4 and 5. FIFO lanes would be placed between stations 1 and 2 and between stations 3 and 4.

Applying Kanban models in (1), the numbers of Kanban cards, N, are calculated, as in **Table 18**, with the demand D of 1500 products, a lot size Q of 5, and $\alpha = 0.1$. The formula of

TABLE 25 | Result of ANOVA of Yoke Station.

General linear model							
Analysis of variance							
Source	**DF**	**Seq SS**	**Contribution**	**Adj SS**	**Adj MS**	**F-Value**	**P- value**
A	2	0.1769	91.60%	0.1769	0.0084	995.09	0.00
D	3	0.0095	4.95%	0.0095	0.0031	35.87	0.00
AD	6	0.0045	2.34%	0.0045	0.0007	8.47	0.00
Error	24	0.0021	1.10%	0.0021	0.000089		
Total	35	0.193	100.00%				
S	**R-sq**	**R-sq (adj)**	**PRESS**	**R-sq (pred)**			
Model summary							
0.0094281	98.90%	98.39%	0.0048	97.51%			

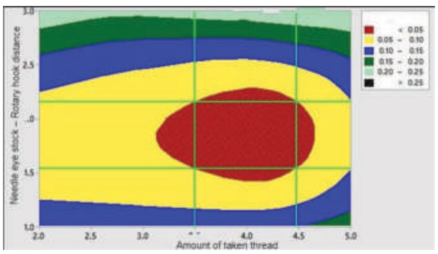

FIGURE 15 | Contour plot of defect rate DR.

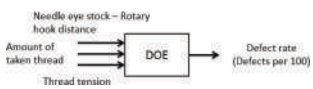

FIGURE 16 | Input and output variables for DOE.

TABLE 26 | Levels of input factors for DOE.

Factors	Levels				Unit
A	2	3	4	5	Level
D	1	2	3		mm
T	3	4	5		Level

N is as below:

$$N = \frac{DL(1 + \alpha)}{Q}$$

According to models in (4), the FIFO lane sizes, S, are calculated as in Table 19.

6.5. Autonomous maintenance

In order to solve the causes of machine failures, machines have been restored to their basic conditions. AM activities are then established by the following steps.

Step 1: A standard checklist for routine cleaning, inspection, and lubrication activities is established as in Table 20.

Step 2: Establish needle and thread inspection standards as in Table 21.

Step 3: Design checking notes for cleaning, inspection, and lubrication as in Table 22.

6.6. Visual control

In order to solve needle-size-not-appropriate problems, a visual tool has been used by matching size needles with colors. Also, we put them in the same color boxes. Depending on needle sizes, the storage capacity of each box is determined as in Table 23.

6.7. Thread storage system design

A low-quality thread is one of the most important causes which lead to broken stitch problems. By using 5-Why analysis, the root cause is identified, that is, the storage time of the thread. The quality of long-time-storage threads has been reduced. To solve the problem, a thread storage system has been designed to determine the storage time as in Figure 13. This system contains three types of cards:

- Time card: Cards indicate the storage date of the material.
- Empty card: Cards attached on empty batches.
- Emergency red card: This is the only card that is attached on the longest storage time batch, which is priority for using.

The operational process is as follows:

- Import materials are stored in the empty batch (with empty cards).

TABLE 27 | Result of ANOVA of Shoulder Station.

General linear model							
Analysis of variance							
Source	**DF**	**Seq SS**	**Contribution**	**Adj SS**	**Adj MS**	**F-Value**	**P-value**
A	3	0.0259	4.35%	0.0259	0.0086	80.84	0.000
D	2	0.3369	56.55%	0.3369	0.1684	1575.4	0.000
T	2	0.2187	36.71%	0.2187	0.1093	1022.6	0.000
AD	6	0.0048	0.82%	0.0048	0.0008	7.62	0.031
AT	6	0.0017	0.29%	0.0017	0.0002	2.65	0.004
DT	4	0.0019	0.33%	0.0019	0.0004	4.63	0.207
ADT	12	0.0018	0.30%	0.0018	0.0001	1.41	
Error	36	0.0038	0.65%	0.0038	0.0001		
Total	71	0.5958	100.00%				
S	**R-sq**	**R-sq (adj)**	**PRESS**	**R-sq (pred)**			
Model summary							
0.0094281	98.90%	98.39%	0.0048	97.51%			

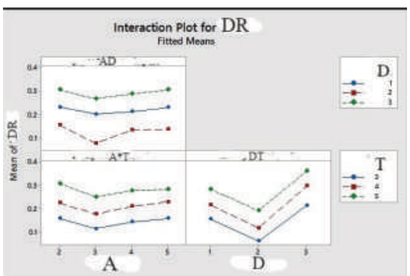

FIGURE 17 | Display of the interaction plot.

TABLE 28 | Results of applying DOE.

Yoke station		Shoulder station	
Distance	2 mm	Distance	2 mm
Taken thread	Level 4	Taken thread	Level 3
		Tension level	Level 3
Defect rate	< 0.005	Defect rate	0.02

- Then, empty cards are replaced with time cards with storage dates of the batch.
- Emergency cards with the longest storage time batch.
- In case of stocking out batches (with emergency cards), they are replaced with empty cards.

6.8. Design of experiments

With reference to (1), DOE is implemented in the Yoke Station to minimize skip stitch errors and in the Shoulder Station to minimize skip stitch and broken stitch errors.

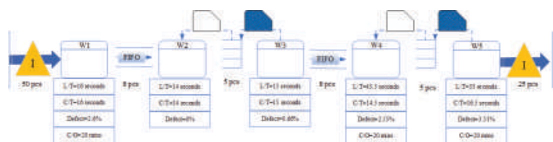

FIGURE 18 | Future state map.

TABLE 29 | Index of the system.

Index	Value
LT (min)	30.1
PCE (%)	6.73
CT (s)	16.5
DPU (%)	9.32

TABLE 30 | Comparing the performance indexes of CSM and FSM.

Index	CFM	FSM	% Improvement
Lead time (min)	279	30.1	89.21%
PCE (%)	0.903	6.73	745.29%
Cycle time (s)	25	16.5	34%
DPU (%)	14.9	9.32	37.45%

6.8.1. Yoke station

The input variables are needle eye stock, rotary hook distance D, and amount of taken thread A. The output variable is the skip defect rate DR. The variables are shown in **Figure 14**.

The levels of factors are defined as in **Table 24**.

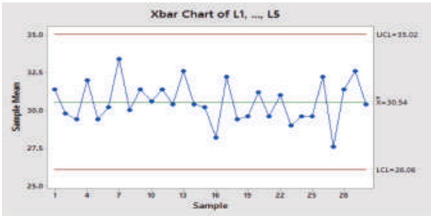

FIGURE 19 | LT control chart.

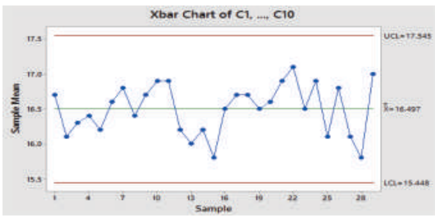

FIGURE 20 | CT control chart.

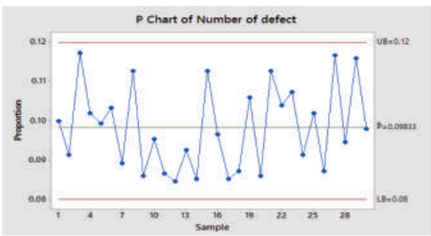

FIGURE 21 | DPU control chart.

With the number of repetitions of 3, the number of experiments is 36. The data are collected. From the collected data, the ANOVA is shown as in **Table 25**.

Through ANOVA analysis, both factors and their interaction have affected defect rate. The contour plot of defect rate DR according to the amount of taken thread A and the distance of needle eye stock and rotary hook D is shown in **Figure 15**.

From the plot, the distance of needle eye stock and rotary hook D should be between 1.6 mm and 2.1 mm, and the amount of thread taken A should be set up from the level of 3.5 to 4.5. The value of the distance of 2 mm and the amount of thread taken of level are chosen.

6.8.2. Shoulder station

The input variables are needle eye stock, rotary hook distance D, amount of taken thread A, and thread tension T. The output variable is the skip defect rate DR. The variables are shown in **Figure 16**.

The levels of input factors are defined as in **Table 26**.

With the number of repetitions of 2, the number of replicas is 36. The data are collected. From the collected data, the ANOVA is shown as in **Table 27**.

Through ANOVA analysis, both factors and their 2-factor interaction have affected the defect rate. The interaction plot is shown in **Figure 17**.

From the plot, the lowest defect rate would be attained with a distance of 2 mm, a tension level of 3, and a thread taken level of 3.

The results of applying DOE are shown in **Table 28**.

6.9. Future state map

After applying Lean Six Sigma tools, the future state map is as in **Figure 18**.

From the map, the system indexes are presented as in **Table 29**.

A comparison of the performance indexes of the current state map CSM and the future state map FSM is shown in **Table 30**.

The result shows that all the performance indexes have been improved.

7. Control

In order to maintain improved results, the control charts of important system parameters, LT, CT, and DPU, would be developed. With the current data, the control charts are constructed and operated. The LT control chart is as in **Figure 19**.

The CT control chart is as in **Figure 20**.

The DPU control chart is as in **Figure 21**.

8. Conclusion

The research has implemented Lean Six Sigma to improve a garment production process. The research methodology is based on the platform of DMAIC procedure, including five steps: define, measure, analyze, improve, and control. The tools used in the steps of DMAIC procedure include CED, Pareto diagram, value stream management, work design, SMED, line balancing, Kanban, FIFO, autonomous maintenance, visual management, DOE, and control charts.

After applying Lean Six Sigma tools, the company has reduced the production lead time by 89.21% from 279 to 30.1 min, reduced the production cycle time by 36% from 25 to 16 s, reduced the process defect rate by 37.45% from 14.9 to 9.32%, and then improved the on-time delivery rate. The results show that the research has met the objectives with the advantages of following strict and scientific methodology and using many tools; among them are strong tools like DOE.

The research still had some disadvantages. The number of collected samples used in DOE is small. The control phase has not built up standard operating processes for controlling the whole process. The improvements have not been implemented to verify the effectiveness of research. These restrictions would guide the way for future research.

Conflict of interest

The research is conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author contributions

PNN is the thesis advisor of PH, PTN, and QD. PN has developed the models for the thesis. PH, PTN, and QD have collected and analyzed the data and run the models. PNN has composed the article based on the thesis. All authors contributed to the article and approved the submitted version.

Acknowledgments

We extend our heartfelt appreciation to everyone who has contributed to the completion of this research article, especially our families, Ho Chi Minh City University of Technology (HCMUT), and the scientific community, for their invaluable support.

References

1. Phong NN. *Lean Six Sigma*. Ho Chi Minh: National University of HCMC Publisher (2012).
2. Bajpai JD. *SMED (Single-Minute Exchange of Die) methodology in Garment manufacturing industry: Case study in reducing Style Change Over Time*. Bangalore: National Institute of Fashion Technology (2014).
3. Stevenson WJ. *Operations Management*. New York City, NY: The United States of America (2012).
4. Roser C. *Determining the Size of Your FIFO Lane – The FIFO formula*. Zürich: FIFO (2014).
5. Phong NN, Phuc NH, Thanh VV, Sang NV, Hai NV, Hoa NV. Applying lean six sigma to improve productivity and quality of production systems – A case study in the Kia Cabin Welding Line, Model K2700ii & K3000s. *J Sci Technol Dev*. (2015) 18.
6. Phong NN, Phuc NH, Quoc BL, Huynh TT. Applying Lean Six Sigma to improve productivity and quality of production systems - A case study in ST Company. *Proceedings of the National Conference on Machine and Machinery NCOMM 10/2015*. Atlanta, GA (2015).