

Applying Lean Six Sigma to Improve Garment Production Processes. A Case Study

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Abstract: - The company under study is specializing in producing garment products. The production process of the company has so much waste, long production time, high cycle time, high defect rate, leading to low productivity, low quality, then late deliveries, affecting competitive edge of the company. The paper applied Lean Six Sigma to improve the company production process to reduce waste, reduce the process production time, and cycle time, reduce the process defect rate, and then to improve productivity, improve quality, and finally increase on-time delivery rate, and the competitive edge of the company. Lean Six Sigma tools and techniques, according to the DMAIC procedure, has been used, helping the company reduce production lead time by 89.21% from 279 minutes to 30.1 minutes, reduce production cycle time by 36% from 25 sec. to 16 sec., reduce process defect rate by 37.45% from 14.9% to 9.32%, that improved the on-time delivery rate.

Keywords: Lean Six Sigma, DMAIC, SIPOC, VSM, Job design, SMED, Line Balancing, Kanban, FIFO, AM, Visual Management, DOE, Control Charts.

1. Introduction

The company under study is specializing in producing garment products. 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 doesn't meet the expectation of the company leaders. Through analysis, the cause of the problem is due to long production time, low productivity, and high defect rate.

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

2. Objectives

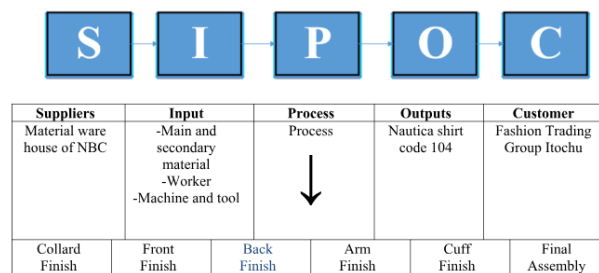
- To evaluate the DMAIC concepts in production technology
- To assess cycle time, lead time and defects per unit
- To evaluate the process planning and cost Estimation in production process under garments industries.

3. Methods

The research applied Lean Six Sigma to improve the sewing process through DMAIC procedure, including 5 steps: Define, Measure, Analyze, Improve and Control. These steps would be presented in the following section.

1 DEFINE

The problem that the company encounter is low percentage of on time delivery. The average on time delivery percentage of the company is 85% and need to be improved. Through analysis, the cause of the problem is due to long production time, low productivity, or high cycle time, high defect per unit rate. The research is carried out on a product family with highest demand. The SIPOC diagram of the product family is as follows.

**Figure 3.1** SIPOC diagram

This paper focused on the process of back finish with 6 stations as follows:

Table 3.1 Stations in back finish process.

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

The Defined stage is summarized in the Project charter as follows.

Table 3.2 Project charter.

PROJECT CHARTER	
Research	Applying Lean Six Sigma to improve sewing process of NBC' s NAUTICA 104 shirt
Problem	Low on time delivery rate
Objectives	Increase the on time delivery rate by: Reducing Lead time. Increasing productivity. Reducing the defects of sewing process.
Scope	NAUTICA104 ITOCHU shirt, Back finish process, line 2, Zone 4.
VOC	Increase the on time delivery rate.
CTQ	Defect per unit, Lead time, Cycle time.

2 MEASURE

The collected data in the back finish process, including number of worker n, change over time COT, Cycle time CT, Lead time LT, Defect per unit DPU, is shown in the following table.

Table 4.1 Collected data of back finish process

Station	n	COT (min)	CT (sec)	LT(sec)	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

Currently, the company works 6 days/ week, 1 shift/ day, 8 h/shift. Average break time is 40 min/day. Average change over time is 65 min/ day. The available producing time is as follows:

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

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

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

Work in process inventory WIP and time in process TIP are calculated and shown in the following table:

Table 4.2 Data of WIP and TIP

WIP	WI P	TIP (min)
WIP before 1	50	725
WIP between 1 – 2	112	1904
WIP between 2 – 3	16	272
WIP between 3 – 4	208	5200
WIP between 4 – 5	11	99
WIP between 5 – 6	283	5094
WIP after 6	25	411
Total		13705

With the data above, the Current state map of the process is as follows:

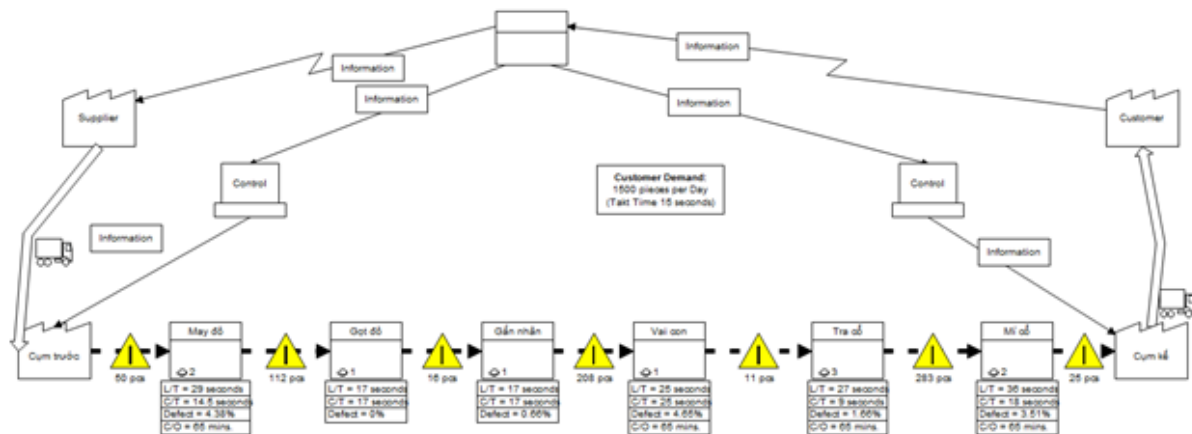


Figure 4.1 Current Value Stream Mapping

From the map, the current indexes, their values and performance assessment are as follows.

Table 4.3 Current indexes

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

The objectives of the research are set as follows

Table 4.4 The objectives of research

Index	Current value	Objectiv e
LT (min)	279	30
CT (sec)	25	16
DPU (%)	14.9	10

3 ANALYZE

3.1 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 follows.

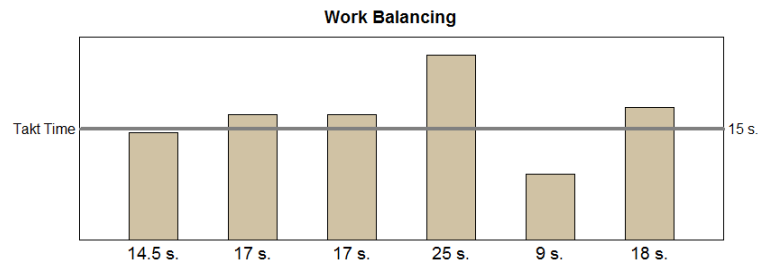


Figure 5.1 Current balance chart

The process is unbalanced, leading to the increasement of WIP inventory, causing long LT. Besides, CT of the process is 25 secs, higher than TT, which is 15 secs, the current production rate does not meet the demand rate. The causes of the problem are analyzed through fish bone diagram as follows:

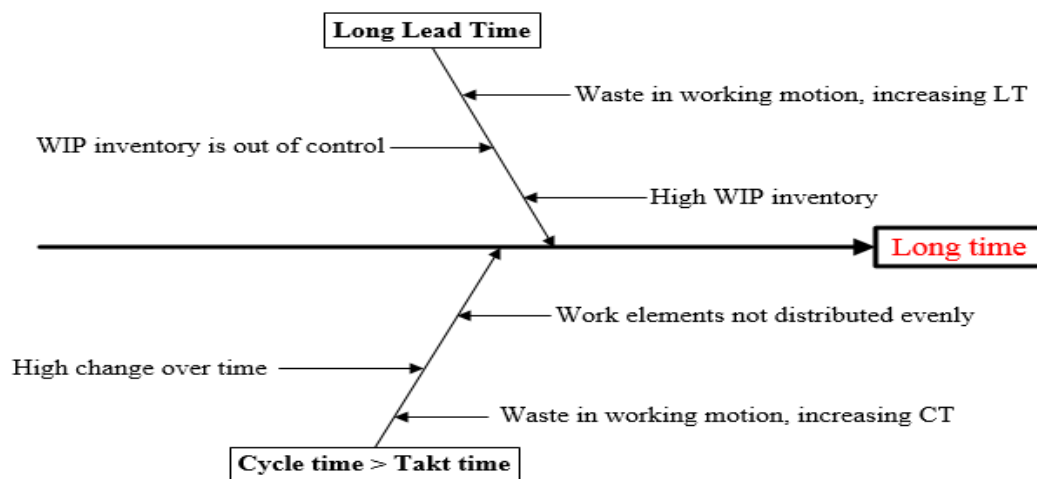


Figure 5.2 The Fish bone diagram shows the causes of long time problem

From the diagram, the causes, solutions and solving tools are demonstrated in the table below:

Table 5.1 Solutions and Tools for problems

Problem s	Causes	Solutions	Tools
Long LT	Iste in working motion, increasing LT	Eliminate iste in motion, standardize works	Work design
	High WIP	Balance the line	Line balancing
	WIP out of control	Control the WIP inventory	Kanban, FIFO
CT > TT	Iste in working motion, increasing CT	Eliminate iste in motion, standardizing work	Work design
	Work elements not distributed evenly	Reallocate work elements among stations	Line balancing
	Long change over time	Reduce the change over time	SMED

3.2 Analyze the high defect problem

The causes of high DPU problem are analyzed through fish bone diagram as follow

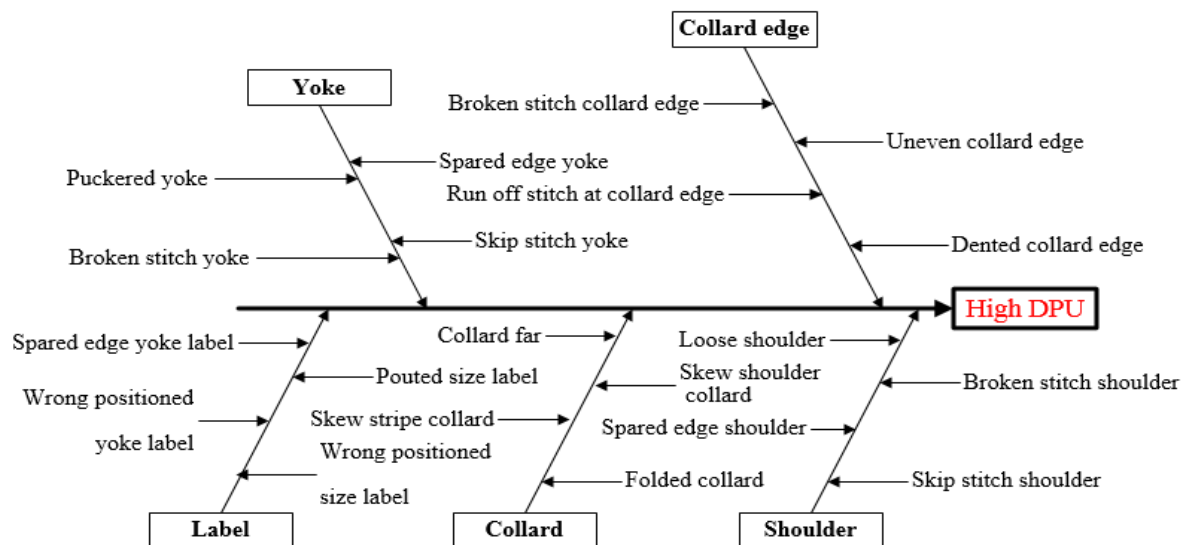


Figure 5.3 The Fish bone diagram shows the causes of defect problem

The Pareto charts for the causes are as follows.

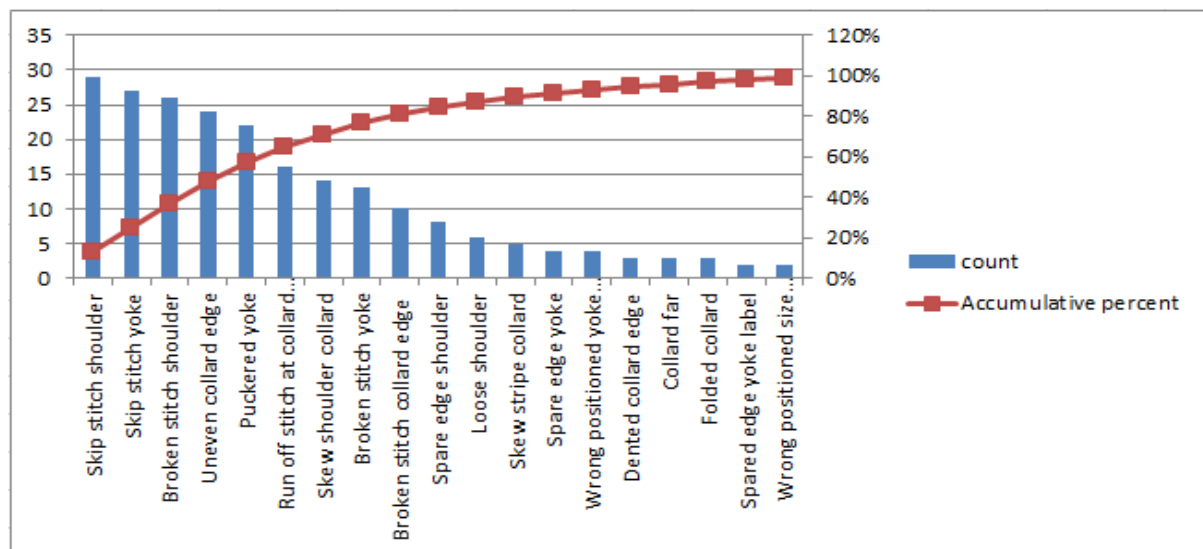


Figure 5.4 The Pareto chart analyzes the causes of high defect problem

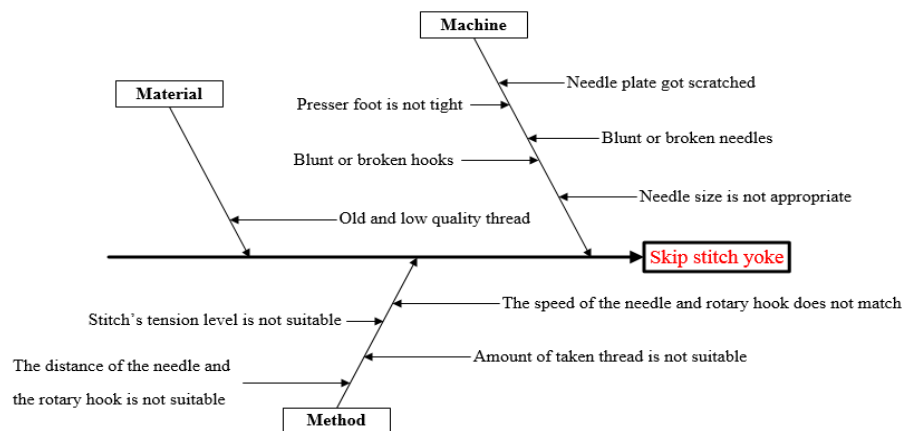


Figure 5.5 The Fish bone diagram shows the causes of skip stitch yoke defects

The fish bone diagram for the broken stitch shoulder effect is as follows.

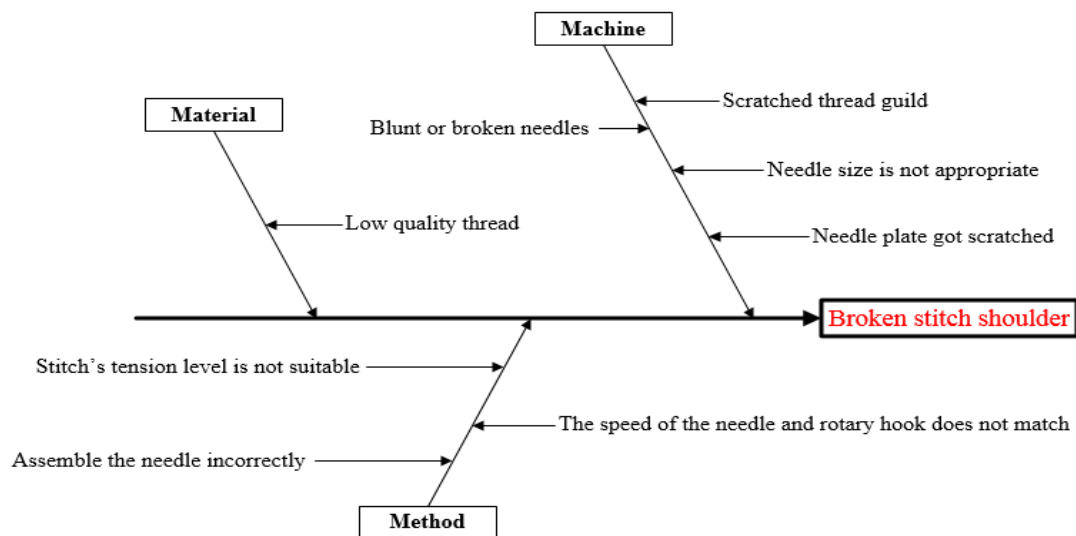


Figure 5.6 The Fish bone diagram shows the causes of broken stitch shoulder defects
The fish bone diagram for the *skip stitch shoulder* effect is as follows.

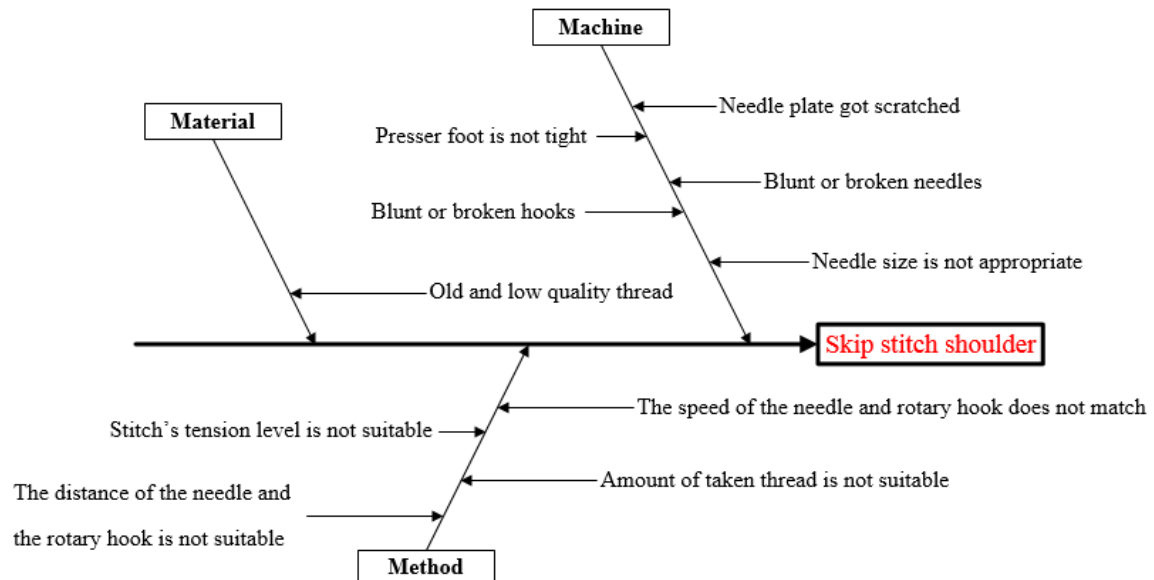


Figure 5.7 The Fish bone diagram shows the causes of skip stitch shoulder defects
From the fish bone diagrams, the causes, solutions and solving tools for each causes are presented in the table below.

Table 5.2 Solutions and Tools for causes of defects

Main Causes	Causes	Solutions	Tools
Skip stitch (Yoke + Shoulder Station)	The speed of the needle and rotary hook does not match	Define suitable speed for needle and rotary hook	Design of Experiments
	Stitch's tension level is not suitable	Adjust stitch's tension level	
	Amount of taken thread is not suitable	Adjust suitable amount of taken thread	
	The distance of the needle and the rotary hook is not suitable	Adjust suitable distance of the needle and the rotary hook	

	Presser foot is not tight	Check and tighten presser foot	Autonomous Maintenance
	Blunt or broken hooks	Check and replace hooks	
	Blunt or broken needles	Check and replace needles	
	Needle plate got scratched	Check and sand-papering needle plate	
	Old and low quality thread	Sort out thread depend on their expiration	Thread Storage System Design
	Needle size is not appropriate	Select the suitable needle size	Visualization
Broken stitch (Shoulder Station)	Stitch's tension level is not suitable	Adjust stitch's tension level	Design of Experiments
	The speed of the needle and rotary hook does not match	Define suitable speed for needle and rotary hook	
	Scratched thread guild	Check and sand-papering thread guild	Autonomous Maintenance
	Needle plate got scratched	Check and 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 thread depend on their expiration	Thread Storage System Design
	Needle size is not appropriate	Select the suitable needle size	Visualization

4 IMPROVE

4.1 Quick change over SMED

Change over time need to be reduced to lift up TT, based on [3]. SMED is used by the following steps.

Step 1: Identify Time Elements.

Elements and their time are collected as in the following table.

Table 6.1 Time of elements

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

Step 2: Separate External Elements

The internal and external elements are separated as in the following table.

Table 6.2 Separate External Elements

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

Step 3: Convert Internal Elements to External.

The internal elements are converted to external elements as in the following table.

Table 6.3 Convert Internal Elements to External

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

Step 4: Streamline remaining elements

The remaining elements are streamlined as in the following table.

Table 6.4 Streamline remaining elements

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

After using SMED, COT, APT and TT change as in the following table.

Table 6.5 Comparisons between before and after applying SMED

	Before	After
COT (sec)	3905	1240
APT (sec)	23095	25760
TT (sec)	14.98	16.77

The balance chart of the process after using SMED is as follows.

Figure 6.1 Balance chart after applying SMED

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

4.2 Work design

Collecting the working elements of each station and their processing time is as follows:

Table 6.6 The collected data of working elements

Station	No. worker	Element	Time (sec)	CT (sec)
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	
		Isted 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
		Isted thread cutting	4	

By analyzing and removing isted motion, reallocating the work load of the right and left hand, designing support tools, rearranging station layout, then the results are that, the CT reduced while the number of workers remained unchanged, as shown in the following table

Table 6.7 The working elements after the improvement

Station	No. worker	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	
		Isted 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
		Isted thread cutting	4	

The balance chart after using work design is as follows:

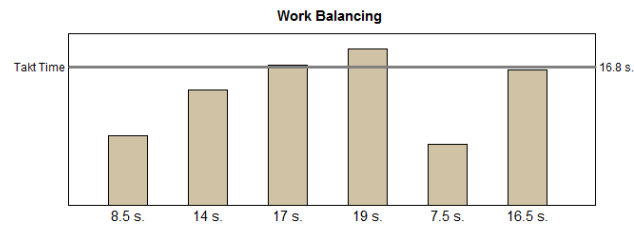


Figure 6.2 Balance chart after applying work design

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

4.3 Line balancing

Applying the line balancing model in [5], 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 the following table.

Table 6.8 The working elements data

Station	Element	Time (sec)	No. worker	CT (sec)
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		
	Isted 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
	Isted thread cutting	4		

The balance chart after using line balancing is as follows:

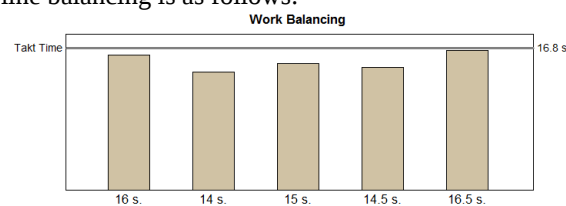


Figure 6.3 Balance chart after applying line balancing

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

4.4 WIP inventory control

Refer to [1], 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.

Applied Kanban models in [1], the number of Kanban cards, N , are calculated as in the following table. With the demand D of 1500 products, lot size Q of 5 and $\alpha = 0.1$. Formular of N as below:

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

Table 6.9 The calculation of Kanban cards quantity

Stations	LT = ST + PT + QT + MT				LT	N
	ST	PT	QT	MT		
W2- W3	23	75	15	20	0.005 0	2
W4- W5	16	82.5	15	20	0.004 9	2

According to models in [4], the FIFO lane sizes, S, are calculated as in the following table below.

Table 6.10 The calculation of FIFO lane size

Stations		CT	Std. Dev.	Processing time	S
W1- W2	W 1	16	3.2	120s	8
	W 2	14	2.7		
W3- W4	W 3	15	4.5	120s	8
	W 4	14. 5	3.1		

4.5 Autonomous maintenance

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

- Standard checklist for routine cleaning, inspection and lubrication activities are established:

Table 6.11 The standard checklist for routine cleaning, inspection and lubrication

Symbols  Inspection  Cleaning  Lubrication			
Items inspected	Item pictures	Inspection Objects	Tools
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

- Establish needle and thread inspection standards.

Table 6.12 The 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 transfigured	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

- Design checking note for cleaning, inspection and lubrication.

Table 6.13 The checking note for cleaning, inspection and lubrication

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

4.6 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. Depend on needle sizes, the storage capacity of each box is determined.

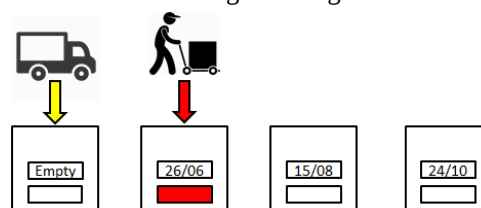
Table 6.14 The needle sizes and storage capacity of each box

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

4.7 Thread storage system design

Low quality thread is one of the most important cause which brings to broken stitch problem. By using 5-Why analysis, the root cause is identified, that is the storage time of thread. 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. This system contains 3 types of cards:

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

**Figure 6.5** Balance chart after applying SMED

The operational process is as follows.

- Import materials are stored in the empty batch (with Empty card).
- Then, replace Empty card with Time card with storage date of the batch.
- Attach Emergency card with the longest storage time batch.
- In case of stocking out batch (with Emergency card), replace it with Empty card.

4.8 Design of Experiments - DOE

Refer to [1], DOE is implemented in Yoke Station to minimize skip stitch errors, and in Shoulder Station to minimize skip stitch and broken stitch errors.

6.8.1 Yoke station

The input and output variables are defined as in the following figure.

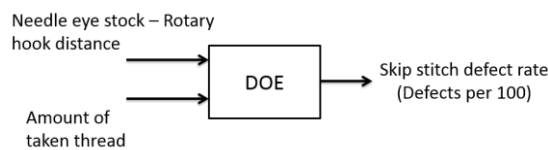


Figure 6.6 The input and output variables for DOE

The levels of factors are defined as in the following table.

Table 6.15 The levels of factors for DOE

Factors	Levels				Unit
Amount of taken thread	2	3	4	5	Level
Needle eye stock – Rotary hook distance	1	2	3		mm

With the number of repetition of 3, the number of experiments is 36. The data is collected. From the collected data, the ANOVA is shown as follows.

General Linear Model: Tỷ lệ lỗi versus Khoảng cách, Lượng khâu chỉ

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value
Khoảng cách	2	0.176906	91.60%	0.176906	0.088453	995.09
Lượng khâu chỉ	3	0.009567	4.95%	0.009567	0.003189	35.87
Khoảng cách*Lượng khâu chỉ	6	0.004517	2.34%	0.004517	0.000753	8.47
Error	24	0.002133	1.10%	0.002133	0.000089	
Total	35	0.193122	100.00%			

Source	P-Value
Khoảng cách	0.000
Lượng khâu chỉ	0.000
Khoảng cách*Lượng khâu chỉ	0.000

Error Total

Model Summary

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)
0.0094281	98.90%	98.39%	0.0048	97.51%

Figure 6.7 The result of ANOVA

Through ANOVA analysis, both factors and their interaction have affected defect rate. The contour plot is shown as follows.

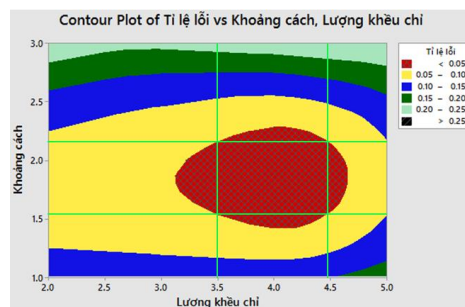


Figure 6.8 The display of the contour plot

From the plot, the distance of needle eye stock and rotary hook should be between 1.6 mm and 2.1 mm, the amount of thread taken should be setup 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 and output variables are defined as in the following figure.

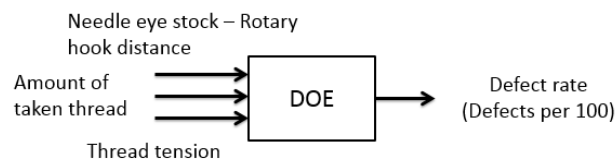


Figure 6.9 The input and output variables for DOE

The levels of factors are defined as in the following table.

Table 6.17 The levels of factors for DOE

Factors	Levels				Unit
Amount of taken thread	2	3	4	5	Level
Needle eye stock – Rotary hook distance	1	2	3		mm
Thread tension	3	4	5		Level

With the number of repetition of 2, the number of replicas is 36. The data is collected. From the collected data, the ANOVA is shown as follows.

General Linear Model: Tỷ lệ lỗi versus Lượng khâu chỉ, Khoảng cách, Lực căng

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value
Lượng khâu chỉ	3	0.025937	4.35%	0.025938	0.008646	80.84
Khoảng cách	2	0.336953	56.55%	0.336953	0.168476	1575.36
Lực căng	2	0.218711	36.71%	0.218711	0.109356	1022.55
Lượng khâu chỉ*Khoảng cách	6	0.004892	0.82%	0.004892	0.000815	7.62
Lượng khâu chỉ*Lực căng	6	0.001700	0.29%	0.001700	0.000283	2.65
Khoảng cách*Lực căng	4	0.001981	0.33%	0.001981	0.000495	4.63
Lượng khâu chỉ*Khoảng cách*Lực căng	12	0.001808	0.30%	0.001808	0.000151	1.41
Error	36	0.003850	0.65%	0.003850	0.000107	
Total	71	0.595832	100.00%			

Source	P-Value
Lượng khâu chỉ	0.000
Khoảng cách	0.000
Lực căng	0.000
Lượng khâu chỉ*Khoảng cách	0.000
Lượng khâu chỉ*Lực căng	0.031
Khoảng cách*Lực căng	0.004
Lượng khâu chỉ*Khoảng cách*Lực căng	0.207
Error	
Total	

Model Summary

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)
0.0103414	99.35%	98.73%	0.0154	97.42%

Figure 6.10 The result of ANOVA

Through ANOVA analysis, both factors and their 2-factor interaction have affected defect rate. The interaction plot is shown as follows.

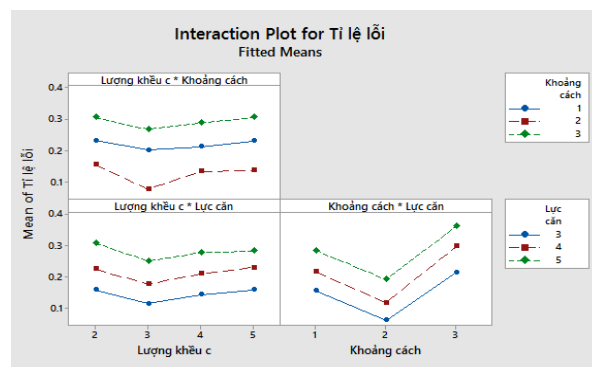


Figure 6.11 The display of the interaction plot

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

The results of applying DOE are shown in the following table.

Table 6.19 The 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	<0.00	Defect rate	0.02
	5		

4.9 The future state map

After applying Lean Six Sigma tools, the future state map is as follows.

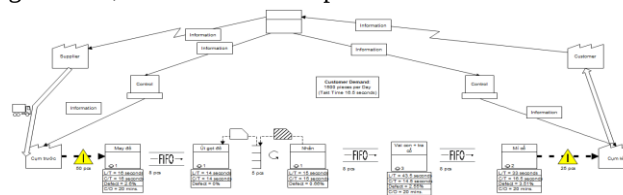


Figure 6.12 The future state map

From the map, the system indexes are presented as follows.

Table 6.20 Index of the system

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

Comparing the performance indexes of the current state map CSM and the future state map FSM is shown in the following table

Table 8.1 Comparing the performance indexes of CSM & FSM

Index	CFM	FSM	% Improve
Lead Time (min)	279	30.1	89.21%
PCE (%)	0.903	6.73	745.29%
Cycle Time (sec)	25	16.5	34%
DPU (%)	14.9	9.32	37.45%

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

5 CONTROL

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

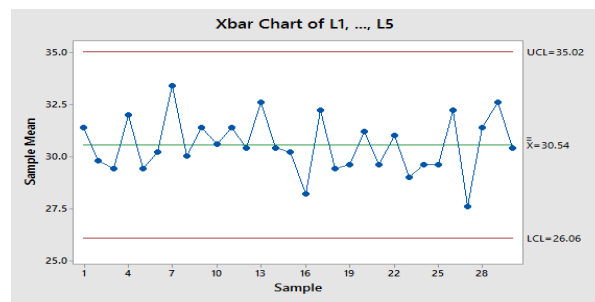


Figure 7.1 LT control chart

The CT control chart is as follows.

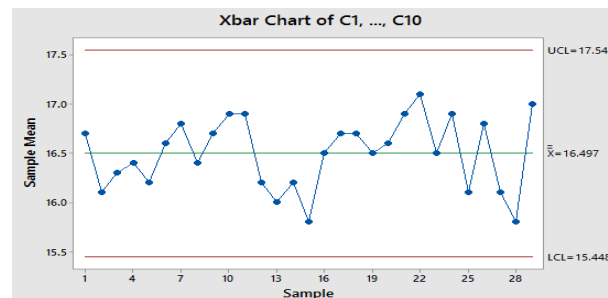


Figure 7.2 CT control chart

The DPU control chart is as follows.

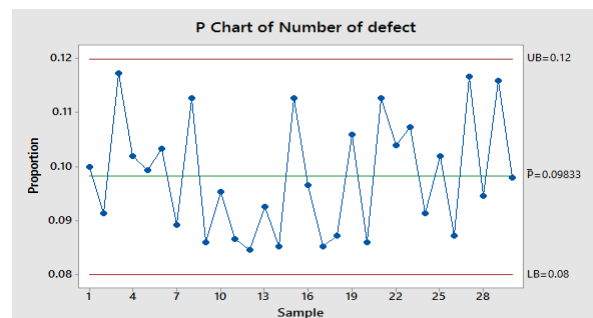


Figure 7.3 DPU control chart

4. Results

The results are tabulated comparing the defective rates under various criterion of DMAIC. Time taken for Inspect, lubricate and to recharge the working mechanisms in garment industry is witnessed with DMAIC principles.

5. Discussion

The paper has implemented Lean Six Sigma through DMAIC process to improve sewing process. The results show that the research has met the objectives with the advantages of following strict and scientific methodology, using many tools, among them are strong tools like DOE. The research still had some disadvantages:

- The number of collected samples use in DOE is small
- Control phase has not built up Standard Operating Process SOP for controlling the whole process.
- The improvements has not been applied to verify the effectiveness of research.

These restrictions would guide the way for future research.

References

- [1] Phong Nguyen Nhu. Lean Six Sigma. *National University of HCMC Publisher*. 2012. ISBN: 978-604-73-1454-6.
- [2] Phong Nguyen Nhu, N.H. Phuc, V.V. Thanh, N.V. Sang, N.V. Hai, N.V. Hoa. Applying Lean Six Sigma to Improve Productivity and Quality of Production Systems - A Case Study In The Kia Cabin Welding Line,

Model K2700ii & K3000s. Journal of Science & Technology Development, Vol 18, No.K1- 2015. ISSN 1859-0128.

[3] Jonalee D. Bajpai, SMED (Single-Minute Exchange of Die) methodology in Garment manufacturing industry: Case study in reducing Style Change Over Time, National Institute of Fashion Technology, Bangalore 560102.

[4] Christoph Roser, Determining the Size of Your FIFO Lane – The FIFO formular. Available at <https://www.allaboutlean.com/fifo-size/#comment-1693> (accessed August 24, 2014).

[5] William J. Stevenson, Operations Management, The United States of America, The McGraw – Hill Companies, Inc, New York City, 2012.

[6] Nguyễn Như Phong, Nguyễn Hữu Phúc, Lê Quốc Bảo, Nguyễn Huỳnh Thái Thuận. Ứng dụng Lean Six Sigma cải tiến quy trình sản xuất thép lá mạ. Một trường hợp nghiên cứu ở công ty TNHH ST. Hội nghị toàn quốc máy và cơ cấu NCOMM 10/2015.

[7] Nguyễn Như Phong, Trần Minh Trí, Nguyễn Khắc Minh Tuấn, Đỗ Thái Bình, Lưu Minh Chiến. Ứng dụng Lean Six Sigma cải tiến quy trình sản xuất công ty LEPS. Hội nghị Khoa học Công nghệ CK 7, 03/2016.

[8] Nguyễn Như Phong, Lê Mạnh Quân, Nguyễn Hồng Thiên Kim, Đỗ Thái Bình, Phạm Quang Anh Tuấn. Ứng dụng Lean Six Sigma cải tiến quy trình sản xuất công ty FB. Hội nghị Khoa học Công nghệ CK 7, 03/2016.

[9] Nguyễn Như Phong, Nguyễn Đại Minh, Hoàng Thiện Mỹ. Ứng dụng Lean Six Sigma cải tiến quy trình sản xuất công ty NBC. Hội nghị Khoa học Công nghệ CK 8, 03/2017.

[10] Er.G.V.Hariharan, Dr.L.Prakash, Dr.A.Vikraman, Inventory Planning for Continuous Demand Materials in Chip Manufacturing Industry available at <https://gradivareview.com/volume-9-issue-9-2023/> ISSN 0363-8057, pp 398-409.