

AN INTEGRATED LEAN SIX SIGMA APPROACH TO MODELING AND SIMULATION: A CASE STUDY FROM CLOTHING SME

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Abstract:

To improve quality, production, and service delivery, clothing industries look toward continuous improvement approaches such as lean manufacturing, Six Sigma, and Lean Six Sigma (LSS). Simulation is one of the effective methods which aim to examine different solution scenarios. This study explores how LSS and simulation can be integrated based on the Sim-Lean approach, using a process improvement effort in clothing small-medium enterprises (SMEs). A structured framework integrating these research methodologies is developed, which might benefit a variety of future clothing process improvement efforts, and could inform quality improvement efforts in other industries. The aim is to allow a successful implementation of the approach in the clothing industry to improve the lead time, the daily output, the average staying times (min) of jobs waiting in queues, and the resource utilization.

Keywords:

Lean six sigma, discrete event simulation, modeling, sewing process, process improvement

1. Introduction

Taking into account the needs and problems of the textile industries, which they are facing enormous and multiple challenges and are forced to urgently adopt structural adjustment plans and raise their level of management and improve their processes [1–3]. Lean, Six Sigma, and Lean Six Sigma (LSS) are popular approaches in the continuous improvement of the production and the quality within manufacturing firms which can be ensured by the combination of the reduction in process variation used in Six Sigma and the elimination of non-added value by Lean approach [4]. Indeed, this method is widely used in manufacturing firms in the world and is applied in different industrial fields including manufacturing [5–9], services [10, 11], commercials [12], health care [3, 13], and logistics [14]. Many authors have started to identify the benefits that can be gained when combining lean, Six Sigma, LSS, and simulation as a new concept. Hahn *et al.* [15] use simulation with Six Sigma to evaluate and assess candidate decisions for difficult business problems and opportunities. While Ferrin *et al.* [16] discuss how the integration of Six Sigma and computer simulation can reduce the variation and improve a patient's experience in the hospital, Huang *et al.* [17], in the same context, discuss how simulation modeling and LSS together can facilitate problem identification and generation of suggestions to improve the phlebotomy process.

This paper shows the mutual benefits that can be gained when combining LSS and simulation. A study in clothing small-medium enterprises (SMEs) for this integration and a simplified sewing process are presented. This paper is organized as follows: Section 2 presents the experiments: The implementation of

our approach in clothing SMEs and results, while Section 3 presents the conclusion of our research.

2. Experiments

2.1 Methodology

In this work, the modeling and simulation of our process are achieved by integrating the Sim-Lean Model (Figure 1) developed by [18] with an enhanced LSS process based on Feld's streamlined method (Figure 2) [19] using Business Process Modeling Notation (BPMN) language to validate a certain number of indicators and avenues of the process improvement. We propose to support our LSS process by the Sim-Lean approach for the following purposes (Figure 3):

- **Educational purpose:** It can be a way to ensure the training of employees [20]. Also, it can have an educational function, which is to teach the lean, Six Sigma, and LSS concepts in a way that facilitates understanding of the dynamic of our process.
- **Facilitation purpose:** A simulation model is used to present a dynamic process map. In our model, the BPMN standard is used to offer better information.
- **Evaluation purpose:** With a discrete-event simulation model, it becomes possible to facilitate the transition of analytic and quantitative outputs to the current state. Also, to evaluate the future state, several scenarios are tested



to ascertain whether this opportunity and the change are feasible to apply to finally choose the best one to implement.

Each one of the Sim-Lean purposes described above is shown in their corresponding process steps. The process shows how LSS and simulation are supporting each process step. The Define, Measure, Analyze, Innovate, and Control (DMAIC) approach was used to solve the problem in the facilitate mode during our workshop.

First of all, the system is defined. Twenty measurements were taken for each operator to calculate the real process time of every task. Then, data were analyzed, and the distribution fit and goodness are used as inputs to drive the simulation model. Once we have determined the probability distributions for the processing times, the simulation model can be run.

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A simulation model is supposed to be valid when the percentage of the difference between the simulation output and the actual output is <10%. The percentage of error is calculated as follows:

$$\text{Percentage of error} = \frac{\text{Simulation Output} - \text{Actual Output}}{\text{Actual Output}} \times 100 \quad (1)$$

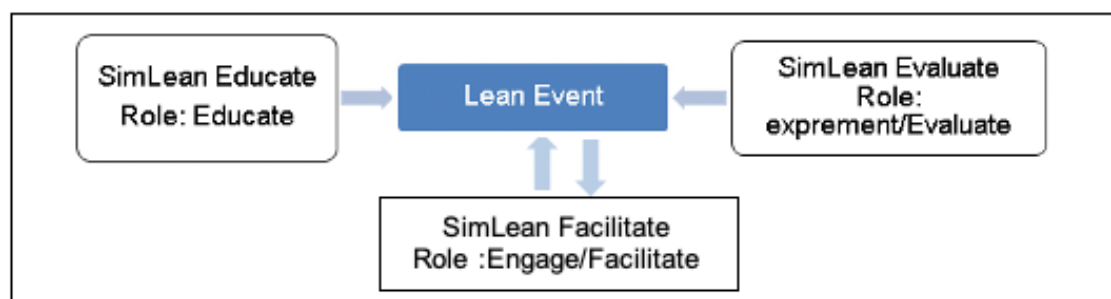


Figure 1. Sim-Lean model: the role of discrete-event simulation and lean in health care [18].

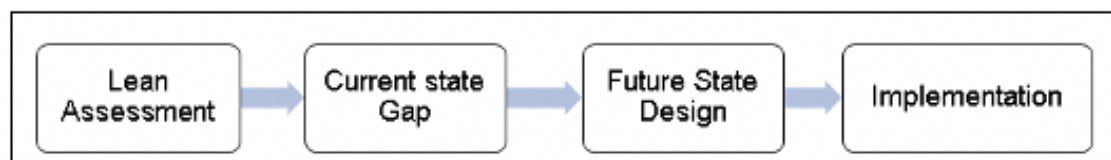


Figure 2. Feld's streamlined approach to lean manufacturing [19].

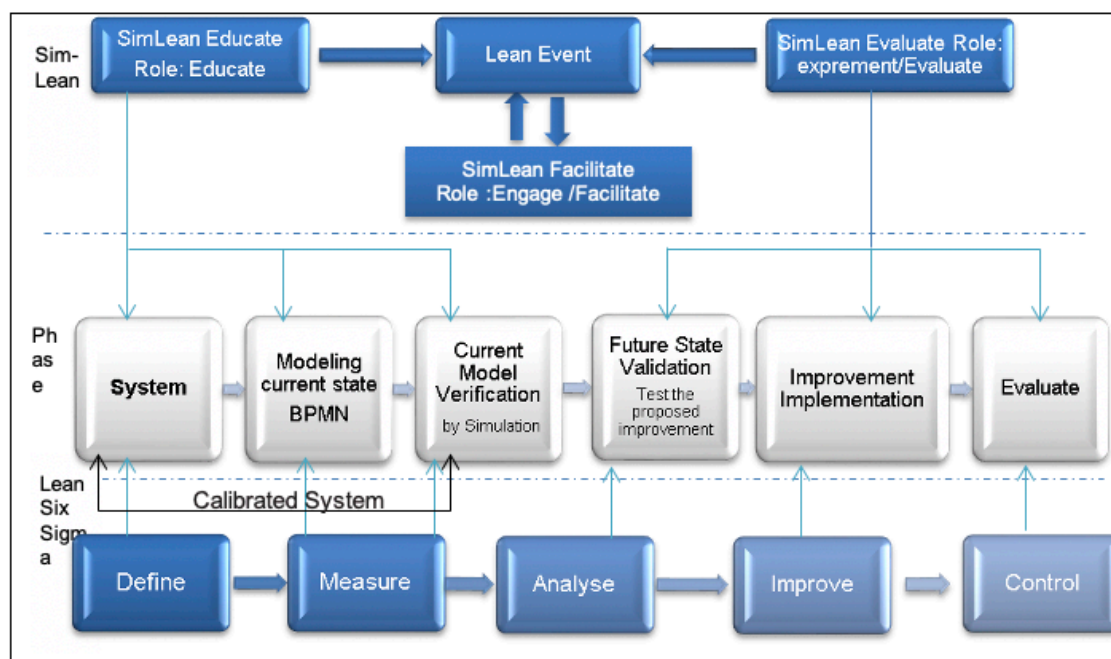


Figure 3. Steps of modeling and simulation method.

We added the future state validation before implementation using the DES simulation. Once the future state is validated and the decision is taken, the implementation step is started and LSS is applied. The step is performed using discrete-event computer simulation by the BPMN model. DES ensures that the Sim-Lean approach can support the evaluation of this implementation. According to Huang *et al.* [17], if the object condition has not been achieved, the simulation model is used to analyze the reasons for failure and ascertain the requirements to ensure the success of the implementation. Consequently, when lean is supported by simulation, it becomes more powerful and makes great contributions to companies. For the current research, we choose the Bizagi Process Modeler to model and simulate our process using the BPMN standard [21].

2.2 Approach implementation within clothing SMEs

The approach was implemented in a clothing SME in Tunisia, specialized in workwear. Its products cover a wide range of areas: high-visibility clothing, basic models, professional and branded clothing, military clothing, non-flammable and waterproof clothing, kitchen clothing, hospitality clothing, and medical clothing, as well as custom clothing with options. The industry suffers from a high defect rate and productivity problems. The approach application must have gone through the DMAIC sequence of steps developed in detail in the rest of this work.

2.2.1. Define

This stage allows understanding the process and determining performance indicators. Interviews, meetings, observations, project charters, and spreadsheets were realized as primary tools to achieve this stage. The industry consists of a cutting unit, a manufacturing unit, and a finishing unit. To collect enough data, >100 h of observation were required, divided between these units. Four months were spent for the project application. As management commitment is the most important key to LSS implementation success, a meeting was prepared by the head managers to explain to the employees the importance and the need for the LSS project and its deliverables. Meetings were held before several observations. The team is composed of the leader (quality management manager), lean facilitator (the author), quality manager, and production manager. A project charter consists of detailing the problem statement: Project justification, objectives, definition, and risks were developed.

During the Sim-Lean Educate, the lean facilitator gives lean, Six Sigma, and LSS lessons to the participants. In addition, a brainstorming session was conducted, which focused on the means to understand and improve the current process.

At the end of the Define stage, the main objective of the project was determined: to reduce the “trousers” process flow time to 14 min. A project charter—including a problem statement and project scope—was developed.

2.2.2. Measure

In this step, data on measurable indicators of production processes are collected. The primary outputs from the Measure step were detailed process maps. In our case, we used the BPMN standard to model our process, process activities, and the current system simulation model. To achieve this, the methods used included interviews, observations, time studies, and summarizing data in a spreadsheet.

2.2.3. Process mapping

Since BPMN and BPSim are integrated into the BiZagi software, the analyzed process was the production flow of a Tunisian clothing SME. Using the BiZagi software, the draft process map is represented in the form of a belt in BPMN. Figure 4 shows the BPMN model: the chronological sequence of assembly operations needed to transform raw materials into sewed products. The “trousers” production cycle includes different steps of assembly operations to transform raw materials into the finished product, namely trousers. There are mainly four sequences of steps, namely: (i) pre-preparation of pockets; (ii) production of the back of trousers; (iii) production of the front of trousers; and (iv) assembling of fabric parts.

This model retains interviews, and observations were used initially to gain more insights into the process and determine which data were relevant for the time study. Informal interviews with the stakeholders were also carried out during the observation and even during the time study to gather information about the process, as well as staff activities between steps. The standard time can be calculated using the following formula:

$$\text{Standard time} = \text{normal time} * (1 + \text{allowance}) \quad (2)$$

The results of the reference layout model are shown in Table 1 according to the performance measures. From Table 1, it can be observed that the average time for the “trousers” process (lead time) is 14.77 min, the average number of finished trousers in a day is 419.5, and the average staying time of jobs in queues is 657.8 min.

Table 1. Results based on the current layout model.

Performance measures	Average	Std. Deviation	Min.	Max.
Lead time	14.77	0.2	14.2	14.95
Daily output	419.5	1.9	418.3	423.3
Waiting time	657.8	1.3	643.5	672.2

2.2.4. Analyze

In this stage, the causes of the non-value-added activities were determined, the time study was analyzed, and data were analyzed and tested for distribution fit and goodness. This latter is used as input to drive, verify, and validate the simulation model.

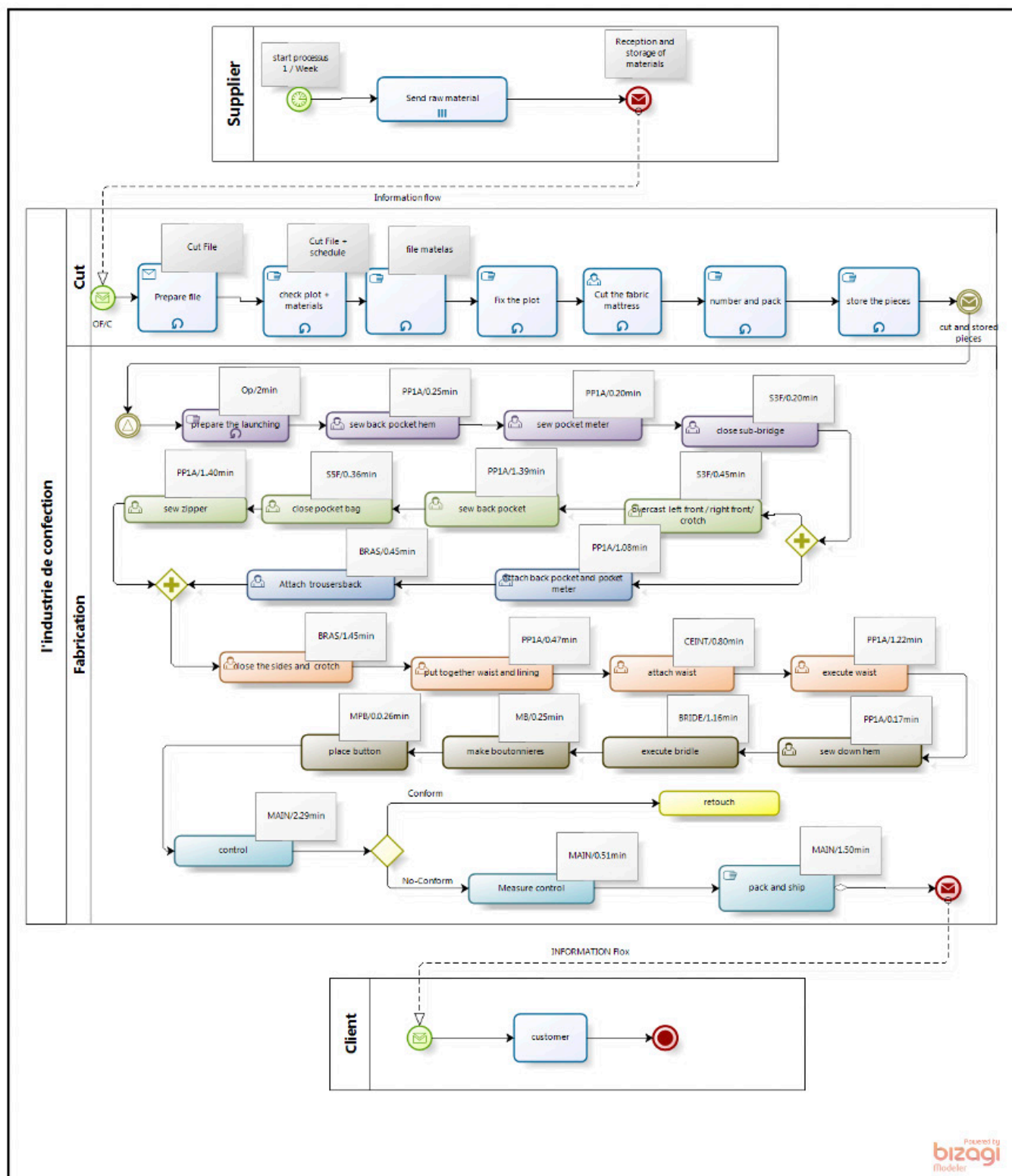


Figure 4. BPMN diagram model of trousers' sewing processes. BPMN, Business Process Modeling Notation.

2.2.5. Current state verification by simulation

Our simulation model was developed to be as near as possible to the real process to ensure the calibration of our system. The Stat fit Student Version program is used to determine the statistical distributions. Figure 5 shows the histogram of this process distribution. Table 2 summarizes the distributions estimated for all tasks.

Table 3 shows that the difference between the simulation model and the real process is almost 6%, which is lower than the maximum allowable error ($\pm 10\%$), confirming the validity and calibration of the model to be used to test scenarios.

It was observed that post 2 "Sew back pocket hem" and post 12 "Put together waistband and lining" blocked the system. Machines are busy with 98.9% and 98.3%, respectively.

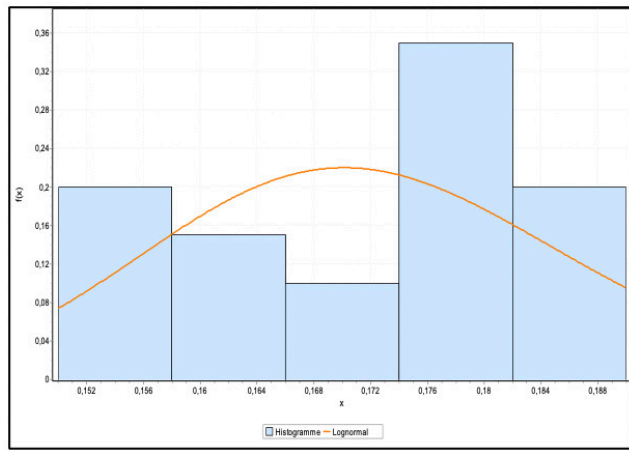


Figure 5. Examples of estimated distributions.

Therefore, in the current model, post 2 and post 12 were identified as a bottleneck. The usage of the resources indicates some sub-utilization and over-utilization. Therefore, we confirm the hypothesis about a possible problem of resource capacity.

2.2.6. Improve

To improve the process efficiency, LSS techniques were applied. A Kaizen activity event was planned and directed to ensure that each team member could participate in finding solutions and propose suggestions for the implementation.

The improvement activities begin with the presentation of the objectives by the team members. LSS approach and the results obtained after the measure phase were presented to ensure that

all the Kaizen members received the same information; then, models were run, the results were analyzed, and the developed system was validated. The modification of the process mapping can be possibly made when necessary. Several scenarios of the sewing process were tested and are tried by what-if analysis to check if the model still performs adequately. Among the considered decision factors in suggestions, we list the resource utilization, the average waiting time for each sewing process, and the total production. In addition, bottlenecks and weaknesses were determined to construct alternative models to improve the system's performance. Several suggestions from Kaizen members are identified for improving the system. For brevity, only three are listed and tested for the sewing process as given in the following. The results of the three scenarios are provided in Table 4.

Scenario 2 has the largest positive impact on the fabrication process. As seen in Table 5, the daily production of trousers has increased to 450.3 with Scenario 2 (up by according to the reference system). Also, with the same scenario, the lead time was lower than that of the reference layout, and the average staying times (min) of work waiting in queues were observed to be lower than those of the reference layout.

The daily output of the system has increased to 422.5 with Scenario 1 and 435.7 with Scenario 3. Furthermore, the average staying time with Scenario 3 has decreased to 635.7 min from 657.8 min. To sum up, with these scenarios, the efficiency of the line has increased. Results were presented to the group members, who are interested in the projected flow time. The last step in the improvement stage is implementation.

Table 2. Estimated distributions for tasks.

No.	Task	Fit distribution	No.	Task	Fit distribution
1	Prepare the launching	Lognormal (1.25; 0.12)	11	Close the sides and crotch	Lognormal (1.45; 0.3)
2	Sew back pocket hem	Lognormal (0.17; 0.014)	12	Put together waist and lining	Uniform (0.47; 0.21)
3	Sew pocket meter	Uniform (0.17; 0.020)	13	Attach waist	Weibull (0.80; 0.54)
4	Close sub-bridge	Normal (0.15; 0.01)	14	Execute waist	Gamma (1.22; 0.54)
5	Overcast left front/right front/crotch	Uniform (0.14; 0.2)	15	Sew down hem	Lognormal (0.17; 0.03)
6	Sew back pocket	Uniform (0.7; 1)	16	Make boutonnieres	Uniform (1.16; 0.2)
7	Close pocket bag	Poisson (0.3)	17	Place button	Lognormal (0.25; 0.12)
8	Sew zipper	Beta (1.20)	18	Control	Uniform (2.29; 0.1)
9	Attach back pocket and pocket meter	Lognormal (1; 0.13)	19	Measure control	Lognormal (0.51; 0.43)
10	Attach trousers back	Gamma (0.45; 0.21)	20	Pack and ship	Exponential (1.50; 0.54)

Table 3. Validation of the discrete-event simulation model.

	Lead time (waiting and service)			Waiting time		
	Real (min)	Simulated (min)	Gap (%)	Real (min)	Simulated (min)	Gap (%)
Total process time	14.77	15.86	5.73	657.8	698.34	6.1

Table 4. Different proposed scenarios.

Scenario1	Change the layout of the sewing process (the sew pocket meter hem post is transferred in parallel with post 2)
Scenario 2	Add one extra sewing machine operator for post 12. Train the workers to improve their efficiency.
Scenario 3	Add two extra sewing machine operators to the reference layout for post 11 and post 13.

Table 5. The results based on different scenarios.

Scenario	Performance measures	Average	Std. Deviation	Min.	Max.
Scenario 1	Lead time	14.5	0.2	14.1	14.6
	Daily output	422.5	1.9	420	424.1
	Staying times (min) of jobs waiting in queues	653	1.3	652	654
Scenario 2	Lead time	14.2	0.1	14	14.5
	Daily output	450.3	1.8	419	458.3
	Staying times (min) of jobs waiting in queues	650.6	1.2	648	655
Scenario 3	Lead time	14.6	0.3	14.2	14.95
	Daily output	435.7	1.7	430.6	438.3
	Staying times (min) of jobs waiting in queues	653.7	1.1	655.7	659

Scenario 2 is implemented because of its features such as high daily output, low waiting time, and low lead time. The group members conducted an action plan to quickly implement those changes with other lean tools in 30 working days. Lean tools like 5S and FMEA were implemented. Based on the analysis of the spaghetti plot diagram, physical flow is proposed to create a new handling tool by the realization of a finished product evacuation sheath that eliminates the movement of workers and accelerates the flow in all security aspects. Twenty weeks after implementing the modifications, new data were collected. The results before and after improvement are presented in Table 6.

Table 6. Results before and after improvement.

	Before improvement	After improvement
Lead times (min)	14.77	14
Daily production (piece)	419.5	450
Waiting time (min)	657.8	560

Trousers' production lead times were reduced from 14.77 min to 14 min (a 5% reduction). The daily production of trousers is increased to 450. (Up by according to the reference system), the average staying time (min) of jobs waiting in queues was found to be 560 min. The gap between what was estimated and the real value after implementation can be explained by limits of the discrete-event simulation model, which did not take into account machine breakdowns, changing apparatus, and the fabric loss.

2.2.7. Control

The applied improvements have been fully integrated into the training regime and the process documentation, and the

information related to company performance was shared among the employees. Visual management, total productive maintenance, and process FMEA are to be implemented after completion of the project to provide a visual aid for controlling the relevant key input and output variables and to ensure that the team could not revert to old habits. The control charts are a powerful tool for achieving process control and stability.

3. CONCLUSION

The sewing process affects several improvement outcomes, but it has rarely been studied in the literature. In addition, LSS and simulation have rarely been combined and used in a single sewing process improvement study. This study aimed to understand and improve the trousers' sewing process, as well as provide an integrated framework by using three approaches. The simulation models and statistical results showed that all scenarios can result in a significant improvement in the sewing processes. The "trousers" process flow time achieves an improvement from 14.77 min to 14 min—a 5% reduction—which is considered important in clothing SMEs. Therefore, the framework was created to guide future sewing process improvement efforts in textile industries. There are a few limitations to this study. Other major stochastic variables (machine breakdown, repair, absence rate, absenteeism, the work of the supervisor, maintenance, etc.) are not used to detail the model in this study. Future work could investigate a wider range of performance measures and developments to be implemented in other SME clothing industries.

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References

- [1] Caputo, A. C., Palumbo, M. (2005). Manufacturing re-insourcing in the textile industry: A case study. *Industrial Management and Data systems*, 105(2), 193-207.
- [2] Chan, K. C., Hui, P. C., Yeung, K. W., Ng, F. S. (1998). Handing the assembly line balancing problem in the clothing industry using a genetic algorithm. *International Journal of Clothing Science and Technology*, 10, 21-37.
- [3] RajaKumar, S., Arunachalan, V. P., Selladurai, V. (2005). Simulation of work flow balancing in assembly shop-floor operations. *Journal of Manufacturing Technology Management*, 16, 265-281.
- [4] Smith, B. (2003). Lean and Six Sigma-a One-two Punch. *Quality Progress*, 36(4), 37-41.
- [5] Ben Ruben, R., Vinodh, S., Asokan, P. (2017). Implementation of Lean Six Sigma framework with environmental considerations in an Indian automotive component manufacturing firm: A case study. *Production Planning & Control*, 28(15), 1193-1211.
- [6] Krueger, D. C., Mellat Parast, M., Adam, S. (2014). Six sigma implementation: A Qualitative Case Study Using Grounded Theory. *Production, Planning & Control*, 25(10), 873-889.
- [7] Timans, W., Antony, J., Ahaus, K., van Solingen, R. (2012). Implementation of Lean Six Sigma in small- and medium-sized manufacturing enterprises in the Netherlands. *Journal of the Operational Research Society*, 63(3), 339-353.
- [8] Anderson, N. C., Kovach, J. V. (2014). Reducing welding defects in turnaround projects: A Lean Six Sigma Case Study. *Quality Engineering*, 26(2), 168-181.
- [9] Kumar, M., Antony, J., Singh, R. K., Tiwari, M. K., Perry, D. (2006). Implementing the Lean Sigma framework in an Indian SME: A Case Study. *Production Planning and Control*, 17(4), 407-423.
- [10] Sunder, V., Antony, J. (2015). Six-sigma for improving top-box customer satisfaction score for a banking call centre. *Production, Planning and Control*, 26(16), 1291-1305.
- [11] Sunder, M. V. (2016). Rejects reduction in a retail bank using Lean Six Sigma. *Production Planning & Control*, 27(14), 1131-1142.
- [12] Garza-Reyes, J. A., Flint, A., Kumar, V., Antony, J., Soriano-Meier, H. A. (2014). A DMAIRC approach to lead time reduction in an aerospace engine assembly process. *Journal of Manufacturing Technology Management*, 25(1), 27-48.
- [13] Zhang, M., Wang, W., Goh, T. N., He, Z. (2015). Comprehensive six sigma application: A Case Study Production, Planning & Control, 26(3), 219-234.
- [14] Garza-Reyes, J. A., Al-Balushi, M., Antony, J., Kumar, V. (2016). A Lean Six Sigma framework for the reduction of ship loading commercial time in the iron ore pelletising industry. *Production Planning & Control*, 27(13), 1092-1111.
- [15] Hahn, G. J., Doganaksoy, N., Hoerl, R. (2000). The evolution of six sigma. *Quality Engineering*, 12(3), 317-326.
- [16] Ferrin, D. M., Miller, M. J., Muthler, D. (2005). Lean sigma and simulation, so what's the correlation? V2. In *Proceedings of the 2005 Winter Simulation Conference*, 2005, 5.
- [17] Huang, Y., Klassen, K. J. (2016). Using six sigma, lean, and simulation to improve the phlebotomy process. *Quality Management Journal*, 23(2), 6-21.
- [18] Robinson, S., Radnor, Z. J., Burgess, N., Worthington, C. (2012). SimLean: Utilising simulation in the implementation of lean in healthcare. *European Journal of Operational Research*, 219(1), 188-197.
- [19] Feld, W. M. (2001). *Lean manufacturing: Tools, techniques, and how to use them*. Boca Raton: St. Lucie Press: APICS.
- [20] Adams, M., Componation, P., Czarnecki, H., Schroer, B. J. (1999). Simulation as a tool for continuous process improvement. In *Proceedings of the 1999 Winter Simulation Conference*, edited by P. A. Farrington, H. B. Nembhard, D. T. Sturrock, and G. W. Evans, 766-773.
- [21] OMG. (2011). *Business Process Model and Notation (BPMN): OMG available specification, version 2.0* Retrieved 14 June 2016, from www.omg.org/spec/BPMN/2.0