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Process improvement in apparel manufacturing through value stream mapping: A Bangladesh perspective

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ABSTRACT

Bangladesh being one of the largest textile producers in the world, the apparel manufacturing industry has to deal with the pressure to produce the maximum possible in the face of low product quality and sustainability standards. This paper examines a case of process improvement in a Bangladeshi apparel industry, which has a middle-scale, by implementing proper use of Value Stream Mapping (VSM), which is a strong Lean Manufacturing tool. A current-state VSM was established through careful time studies and data collection of a T-shirt production line and indicated the many non-value added activities that occurred such as the high waiting time, the unbalanced workflow, and the large amount of work-in-progress (WIP) inventory. On the basis of these observations, a future-state VSM has been put forward with the incorporation of lean intervention like line balancing, standardized work, and better information flow. Future state simulation has shown that there was the possibility that the total lead time would be reduced by 35 percent and overall production efficiency to improve by 25 percent. The current study demonstrates the empirical viability of VSM in the Bangladesh apparel manufacturing industry and gives recommendations that can be implemented by factory managers and policymakers to achieve competitive advantage in the rapidly-changing international market. The paper also fills a research gap in that it portrays an empirical documented case in academia to fill the gap hitherto, in the literature of Lean implementation in the apparel and other manufacturing industries in developing countries.

1. Introduction

World clothing business is crucial to the economies of third-world nations and Bangladesh is proving to be the second-largest clothing exporter after China. The readymade garment (RMG) industry alone accounts to over 80 per cent of the total export earnings of the country and employs over four million people mostly women. Even after making such a great contribution, Bangladesh apparel industry has a lot of challenges including the rising competition internationally, unstable market demands, the growing cost of production and the pressure exerted on it to maintain the production within the acceptable environmentally friendly and socially responsible manufacturing constraints. To keep up with this fast-changing environment, the garment manufacturers have no option but to keep on perfecting their production time, minimizing wastage, and maximizing on their production without reducing quality. Value Stream Mapping (VSM) among other lean tools has been identified as one of the lean tools that can be used to visualize the overall production process, pinpoint areas of bottleneck and wastes and which can also be used to base specific process improvements. Despite the popularity of using VSM in such industries as automotive and discrete manufacturing, the usage of VSM in apparel industry and especially in the industries of developing countries such as Bangladesh is rather scarce. Past research has skewed towards noting the possible affordability of lean practices on quality in the garment industry but has not emphasized on effective case studies that have research-based evidence on practical applications and changes that have a practical difference. This study is an attempt to fill this gap by imposing VSM in one of the sample apparel manufacturing companies in Bangladesh, on a T-

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shirt manufacturing line. This study aims at constructing a detailed current-state VSM, investigating current process inefficiencies, mapping a vision of a future target state and suggesting lean interventions, and estimating potential investments in terms of lead time decrease, efficiency growth, and waste reduction.

The paper contributes to the scholarly literature and industry experience by offering an empirical argument on the issue based on a Bangladesh perspective. The results should help the factory managers, policymakers, and the researchers in knowing the real benefits of VSM and lean adoption and the process is likely to lead to more sustainable and competitive manufacturing apparel practices in Bangladesh.

2. Literature review

The global apparel sector constitutes a substantial proportion of the world economy—estimated between 1.6 % and 2 % of global GDP—and faces mounting pressure due to volatile fashion trends, production complexity, and heightened competition. (UniformMarket, 2025; United Nations University, 2024). With the internationalization of business entering every production schedule, environmental responsibility, and consumer demand, there is an emerging requirement to be more responsive in leaner operations in the apparel manufacturing industry. The demands of the customer that he obtains the product at the earliest possible time and in numerous different manners like a mass ordering can make this challenge even more challenging and the manufacturers will have to trace and eliminate wastages in every single step of the process. To address these challenges, the apparel industry has increasingly embraced lean manufacturing principles—such as Value Stream Mapping, Just-In-Time, 5S, and Kaizen—which have been demonstrated to significantly improve production flow, eliminate waste, and enhance operational efficiency. (Limon & Sarker, 2023; Bashar et al., 2021, Ferdousi et al., 2009). The activity of increasing value is the key Lean issue which entails reduction of activities that add no value, flow of smooth operations and the empowerment of front-line workforces. One of the lean tools that can be applicable in visualizing the entire chain of the process and defining non-value adding activities as the efficiency meddler is Value Stream Mapping (VSM) (Hines & Rich, 1997; Seth & Gupta, 2005; Lasa et al., 2008; Alhuraish et al. 2017). VSM presents a capability of conjunct time, material, and information flow mapping within a unified framework, which sorts out a picture of production in the form of a supplier through customer. Most industries where VSM has been applied have been very successful. As an example, it has helped in waste reduction and smoothing the flow of operations in the automotive industry (Andrade et al., 2016; Abdulmalek at el., 2007; Behnam at el., 2018). Automotive manufacturing where there is complex component synchronization and high-level quality requirements set a standard on the success of VSM. Comparable improvements are also made in the electronic industries manufacturing sector whose products face rapid obsolescence and complex assembly making them to constantly be efficient (Chaurasia et al., 2016). Similarly in food processing industries that are very regulated in nature and face a perishable nature of crops and products, VSM has allowed persistent refreshment in product throughput and quality assurance (Dora et al., 2013).

In discrete manufacturing firms, VSM implementations resulted in deep reduction of both lead times and work-in-process (WIP) inventory, which is noted in observational studies by Rahani and al-Ashraf (2012) and Albliwi et al. (2014). These findings carry weight on the fact that VSM can be applied universally in simplification of the production process. It should be stressed that these two case studies indicate not only the advantage in terms of operations but also improved communication in the group and visual controls along with methodology of solving problems. It also enhances the application of VSM in strategic operations management through the synergy of VSM with the continuous improvement models, including PDCA (Plan-Do-Check-Act). VSM has also presented great gains in the clothing industry as well. Studies conducted by Hussain (2023), Manupati et al. (2019), and Behnam et al. (2018) have emphasized that VSM can be used to streamline assembly lines, reduce the operational bottlenecks, and enhance the performance of delivery. VSM is especially beneficial in an industry with seasonal changes, poor product life cycles and with a lot of required labor. According to Choudhury (2019) product variety and constantly changing fashion trends in the apparel industry suggest that the industry should be one of the targets of lean interventions, particularly the VSM approach. The interactivity of the changes of style and the flexibility of production requires such a tool as VSM that can identify the most critical bottlenecks and adjust itself to the fast-changing workflows. The positive influence of VSM has been confirmed by a set of systematic literature reviews on various sectors (Singh & Sharma, 2009; Forno et al., 2014; Pakdil & Leonard, 2015). Close examinations performed on the applications of the cases indicate that VSM does not merely come up with savings in time and costs but does come up with cultural change within organizations. Other writers state that VSM is especially successful in labor intensive processes such as garment production in which periodic flow breakdowns can be overcome with visual process management applications (Vinodh et al., 2010; Dora et al., 2013). Where the number of involved workforces is significant, and where variations in the implementation of transferring work are in general, VSM helps to standardize the operations, shortcut the processes of training, and rationalize the roles. Nevertheless, the authors like Shah & Ward (2007) warn that perfectly working VSM may need to be realized in collaboration with other lean tools, and one should deploy them to achieve maximum effects.

India has been on the forefront in the implementation of VSM in the textile and apparel sector in South Asia. The mentioned results were reported in terms of improving the cycle time with 30-50 percent and on-time delivery measurement with 20-25 percent (Seth & Gupta, 2005; Jasti et al., 2014). The improvements are not only operational but also strategic to enable firms to achieve buyer expectations, minimize costs of production, and satisfy international standards. Kumar and Kumar

(2014) demonstrated why the integration of VSM with simulation methods is useful to pre-test improvement scenarios and Dal Forno et al. (2014) highlighted real-world issues such as data accuracy and involvement of stakeholders. Such insights prove imperative in providing practitioners who need to reconcile between the theoretical models and the application on the field. As was the case with Bangladesh, there has been growing academic interest in lean manufacturing, above all VSM, during the last several years (Hasan et al., 2020). Bangladesh is having readymade garments as the second-largest exporter, thus making it a highly stakeful environment where inefficiencies in operations translate immediately to the economy and jobs. Nonetheless, empirical studies that tend to study VSM directly are few. Tyagi (2015), and Iqbal (2015) conducted pioneer work introducing VSM in sequentially product manufacturing process and ready-made garment (RMG) factories and reported lead time decreases and decreased rework levels. All these pilot studies demonstrate that the implementation of VSM, even in part, can result in a significant increase in productivity and delivery conformance. As indicated by prior research published in the case of New Zealand (Pearce et al., 2013), confirmed cultural resistance, insufficient technical training, and implementation incompetence to be critical barriers to a lean implementation effort. The barriers will show surface-level trouble but are connected to greater internal systemic problems like hierarchical organizational cultures, inadequate data infrastructure, and insufficient investments on human capital. A significant outstanding trend is including digital technologies in the VSM, involving Bangladesh RMG sector under-resourced area. Such researchers as (Buer et al., 2018; Lasi et al., 2014; Kamble et al., 2020) promote the usage of Digital Value Stream Mapping (DVSM) approach as it facilitates the monitoring in real-time, makes the operation more accurate, and allows testing the situations prior to the implementation. DVSM has the capability to increase traceability, feedback loops can be automated, and predictive analytics can take place-all of which are valuable in an Industry 4.0 environment in terms of competitiveness. The presented integration is particularly pertinent since the Bangladeshi factories intend to meet the standards of Industry 4.0 (Buer et al., 2018; Antony et al., 2021).

The idea that the key to successful lean implementation with VSM included is the top-management commitment, employee empowerment, and constant training is supported by a meta-analysis by Albliwi et al. (2014). However, the mentioned factors continue to be poorly implemented in the Bangladesh manufacturing environment (Bashar et al., 2021; Hasan et al., 2020; Sharif., 2019). Additionally, it is stated in literature that it is necessary to modify VSM frameworks to fit local operations and cultures (Pearce et al., 2013; Jasti et al., 2014). The usage of VSM in the context-sensitive form will guarantee higher adoption rates and sustainability of the improvements. Altogether, the literature studied is sufficient to prove the theoretical validity and practical efficiency of VSM (Vasanth at el., 2020; Romero at el., 2017). Nevertheless, they still lack a significant longitudinal, economically impactful and context-relation study to evaluate the long-term effect of VSM in the RMG sector of Bangladesh (Chowdhury et al., 2021; Hasan et al., 2020; Sharif., 2019). Filling that gap is the goal of the given research that considers the way VSM can be tailored and successfully implemented into the peculiarities of the apparel manufacturing industry in Bangladesh and can give insights useful to policymakers and other stakeholders.

3. Model formulation

3.1 Methodology

This paper uses a mixed-method, single- case research method where it explores the use of Value Stream Mapping (VSM) in the process of improving processes in the ready-made garment (RMG) industry in Bangladesh. The study is based on a purposefully chosen small-to-medium-sized apparel factory within Dhaka, which attracts a wide picture of an export-oriented and labour-intensive manufacturing sector in the country. The research methodology followed in this study is illustrated in the flowchart below, which outlines each sequential step taken to analyze, improve, and validate the production process using Value Stream Mapping (VSM) in the selected apparel industry.

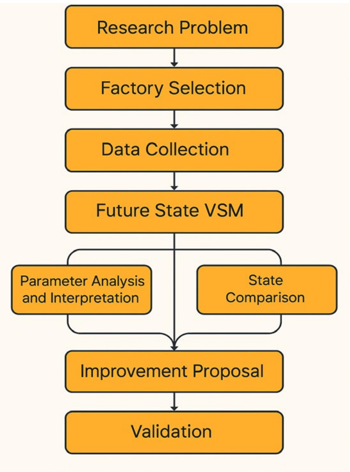

Fig. 1. Methodology Flowchart

Research Problem: The research commences with the process of finding any fundamental working inefficiencies in an apparel manufacturing enterprise located in Bangladesh. According to the initial observations and the previous research, it was pointed out that the factory was facing the variety of production-related issues, such as late shipment, uneven workloads, and a stall-out in the processes. The causes of these problems were not found in some technological breakdowns but in the inefficiencies of the system. The issue was addressed with a lean manufacturing viewpoint especially in the perspective of Value Stream Mapping (VSM) which provides the total manner of visualizing and enhancing the manufacturing operations. The aim was to see the whole picture of the production process, identify the problems of the delay or redundancies, and create a systematic plan of the improvement, which is in line with the lean principles.

Factory Selection: After the identification of the problem, an appropriate factory was selectively identified to conduct the case study. Some of the factors considered during the selection process were the kind of products produced, the size of operation and the willingness of the management to embrace an improvement initiative which would be based on research. The chosen apparel factory was meant to capture elements common in most of the factories in the local economy that consist of a linear production flow, deployment of semi-skilled labor force, a combination of manual and mechanized processes, and a high-pressure production system with looming export deadlines. Such circumstances predisposed it to be an appropriate candidate in which lean tools like VSM could be applied to provide on-ground experience and a possible opportunity to generalization in other similar facilities in the region.

Data Collection: Once the factory was selected, the study entered the phase of intensive data collection. This involved direct engagement with the factory floor through site visits, observational studies, interviews with supervisors and line workers, and review of production records. The focus of this stage was to gain a detailed understanding of how the production system currently operated. Information was gathered on the sequence of processes, how materials moved through the system, the interaction between human and machine, and where delays or hold-ups occurred. All activities were documented to construct a complete picture of the existing operational flow, which formed the basis for developing the current state visual model.

Future State VSM: Having a clear view of what was going on in the system, there was now the need to complete the process by imagining a more efficient production process which was the same one. The Future State VSM was achieved through reconsideration of the staff of the information and the material flow, the reduction of waste, streamlining of operations, and adjustment of activities to a true demand. This rethought form was not abstract in form or idealistic; it was based in realistic conditions and materials constraints of the factory. The proposed future state entailed modification in sequencing of tasks, coordination of workers and machines and internal communication that could be enhanced. It aimed to build a simplified process which was realistic and could provide a far superior performance in terms of its operations.

Parameter Analysis and Interpretation: After coming up with the conceptualization of the future state, the full interpretation of the current and recommended systems was conducted. This meant an examination of the differences in the working of each stage of the production line comparing the current and future structures. The idea of the interpretation was to ascertain areas of improvement as the major point and learning how the suggested changes would affect the overall behavior of production as a whole. The delays, redundancies, and other kinds of redundant complications present within the original system were reviewed by contrasting with the simplified, more responsive model. This hermeneutic contribution gave a considerable logic on taking necessary actions related to the alterations depicted in the future state design.

State Comparison: Following the interpretation of the two process states a comparative evaluation was done. This step was meant to show distinct differences between the real and proposed systems and how the new system addressed most of the challenges witnessed in the former systems of operation. The similarity was not cosmetic but was between the structural reason of flow of process. The comparison of the two states allowed delineating the areas where a positive change could be made. As an example, the easier flow of the operations, shortened wait times between operations, and a more predictable production pace were identified as the main advantages of the suggested system. The comparison provided a basis of decision-making particularly in communicating the improvement plan to the stakeholders of the factory.

Improvement Proposal: Based on the findings and analysis, a set of concrete recommendations was prepared and submitted to factory management. These suggestions were designed to be realistic, minimally disruptive, and implementable within the factory's existing capacity. The proposal emphasized process simplification, better utilization of human and machine resources, and improvements in workflow layout. It also suggested procedural changes that would require little to no capital investment but could generate noticeable improvements in performance. The recommendations were presented in a structured format, with step-by-step guidance on how to integrate the changes into daily operations.

Validation: The ultimate step of the methodology was the necessity to validate the proposed changes in the real life conditions. Some of these changes were made in the sphere of the production environment, and their influence was observed during this period. The execution of this validation process also acted as a confirmation that the suggested improvements listed on the Future State VSM were not only possible but safe enough to remedy the inefficiencies that had been noticed earlier on. The factory personnel participated in the feedback loop and could ensure that the interventions were modified to meet the realities in the floor. The new reality brought about ease of flow in the processes, improved utilization of time and resources as well as observable increase in operational confidence on both the part of the workers and supervisors.

3.2 Problem formulation

VSM Factors: To quantify the improvements and assess the performance of the production system before and after Value Stream Mapping (VSM) implementation, a set of analytical formulas and performance metrics were applied. These formulas enabled a structured evaluation of process flow, operational efficiency, and overall effectiveness across multiple production stages in the apparel manufacturing environment. The following section outlines the key equations used in the study, along with precise definitions of all relevant variables and subscripts. The metrics include Takt time, Effective cycle time, Total lead time, Value stream efficiency, Process stream efficiency, Process efficiency ratio, Throughput yield, overall process effectiveness, each metric played a critical role in analyzing the current state, designing the future state, and validating the impact of lean-based improvements;

Takt time: Takt time represents the pace at which products must be completed to meet customer demand within the available production time.

$$T = \frac{\mathrm{Ap}}{D} = \frac{\mathrm{H\_s} \times \mathrm{M\_s} \times \mathrm{D\_s}}{D} \tag{1}$$

Effective Cycle Time: Effective Cycle Time reflects the total time required to produce one unit, accounting for setup, processing, delays, and inspection activities.

$$\mathrm{CT} = \frac{S}{B} + P + W + I \tag{2}$$

Total Lead Time (Multi-stage): Total Lead Time captures the overall time a product spends within the production system, from the start of the first process to the end of the last.

$$\mathrm{LT} = \frac{\mathrm{WIP}}{\mathrm{Rp}} \; or \; \mathrm{LT} = \sum_{i=1}^{n} \frac{\mathrm{WIP}_i}{\mathrm{R\_p}_i} \tag{3}$$

Value Stream Efficiency (VSE): Value Stream Efficiency measures the proportion of time that adds value to the product relative to the total lead time.

$$\mathrm{VSE} = \frac{\mathrm{VAT}}{\mathrm{LT_{total}}} \times 100 \tag{4}$$

Process Efficiency Ratio (PER): Process Efficiency Ratio evaluates the share of value-added time within the total process time, including both value-added and non-value-added activities.

$$\mathrm{PER} = \left(\frac{\sum_{i=1}^{n} T_{\mathrm{VA},i}}{\sum_{i=1}^{n} \left(T_{\mathrm{VA},i}{'} +{'} T_{\mathrm{NVA},i} \right)} \right) \times 100 \tag{5}$$

Throughput Yield (TY): Throughput Yield indicates the overall quality performance of the process by measuring the probability of a unit passing through all stages without defects.

$$\mathrm{TY} = \prod_{i=1}^{n} Y_i,\; Y_i = \frac{\text{Good Units Output}}{\text{Units Input}} \tag{6}$$

Overall Process Effectiveness (OPE): Overall Process Effectiveness combines flow efficiency and quality to provide a comprehensive measure of the production system's performance.

$$\mathrm{OPE} = \mathrm{VSE} \times \mathrm{TY} \tag{7}$$

This section defines all parameters and variables used in the Equations and Performance Metrics for Value Stream Mapping (VSM) in apparel manufacturing, with proper subscripts.

T : Takt Time (min/unit): time available per unit to meet customer demand
A_p : Total Available Production Time (min/period)
D : Customer Demand (units/period)

H_s : Working hours per shift
M_s : Minutes per hour (typically 60)
D_s : Number of shifts per period
CT : Effective Cycle Time (min/unit)
S : Setup Time per batch (min)
B : Batch Size (units)
P : Processing Time per unit (min)
W : Average Waiting Time per unit (min)
I : Inspection Time per unit (min)
LT : Lead Time (days or min)
WIP : Total Work-In-Process inventory (units)
R_p : Average Production Rate (units/day)
n : Number of stages/processes
WIP_i : Work-In-Process at stage i
R_{pi} : Production Rate at stage i (units/day)
VSE : Value Stream Efficiency (%)
VAT : Value-Added Time (min/unit)
LT_{total} : Total Lead Time (min/unit)
LT_{VA} : Value-Adding Lead Time
LT_{NVA} : Non-Value-Adding Lead Time
PER : Process Efficiency Ratio (%)
$T_{VA,i}$: Value-Added Time at stage i
$T_{NVA,i}$: Non-Value-Added Time at stage i
TY : Throughput Yield (fraction or %)
Y_i : Yield at stage i
OPE : Overall Process Effectiveness (%)

Linking Value Stream Parameters to Cost Savings: The This research has helped to synthesize an overall framework between lean performance measures and cost savings by establishing a multifactorial view of lean performance and its relate to cost savings in situations involving apparel manufacturing. Essential parameters, which include Takt Time (T), Cycle Time (CT), Lead Time (LT), Value Stream Efficiency (VSE), Process Efficiency Ratio (PER), Throughput Yield (T Y), and Overall Process Effectiveness (OPE) were also computed to Standardize the operational impact of the Value Stream Mapping (VSM) interventions adopted. Not only are this performance measures used to target the flow of the process, purge of waste and enhancement of quality, but they also act as inputs in terms of estimating the direct financial effects. As an illustration, reduction in Cycle Time allows establishing labor productivity, reduction in Lead Time and WIP bring down the cost of holding inventory, and increase in Throughput Yield result in the decrease of the cost of scrapping and reworking. The systematic overview of these metrics coupled with standard formulas of calculating costs clearly shows how, in quantitative terms, process improvements can be transformed into a direct improvement in profits, which could be an interesting development even in practice to justify the lean program in the ready-made garment industry (RMG). In order to measure the direct monetary effect of the process improvements the standard formulas of calculating standard cost were used as shown below. Each formula correlates the perceived operational alterations which include reducing the cycle time, decreasing the level of work in progress (WIP) and enhancing the defect rates with their equivalent monetary outcomes in the form of daily and monthly savings. These equations make the estimated profit increases completely transparent and replicable and can easily be adopted in productions of the same nature in the apparel business.

Table 1
Cost Saving Parameters overview

Cost Calculation	Linked Performance Parameter(s)	Explanation
Labor Savings	Directly uses **Cycle Time (CT)**	**Cycle Time (CT):** Affects labor productivity → When CT decreases, the same number of units are produced in less time, lowering labor costs.
WIP Inventory Savings	WIP is derived from **Lead Time (LT)** calculation	**Lead Time (LT) and WIP:** WIP is calculated from LT → When WIP is reduced, holding costs drop, saving money.
Scrap/Rework Savings	Related to **Throughput Yield (TY)**	**Throughput Yield (TY):** TY shows defect levels → Fewer defects mean lower scrap/rework costs, resulting in direct savings.

Labor Savings: Calculates the reduction in direct labor cost due to improved cycle time efficiency.

$$\mathbf{Ls} = \frac{(\mathbf{CT_{before}} - \mathbf{CT_{after}}) \times \mathbf{N}}{\mathbf{60}} \times \tag{8}$$

WIP Savings: Estimates the cost saved by lowering work-in-process inventory holding expenses.

$$\mathbf{WIPs} = (\mathbf{WIP_{before}} - \mathbf{WIP_{after}}) \times \mathbf{WIPc} \tag{9}$$

Scrap Savings: Quantifies the cost reduction achieved by decreasing defective units and rework.

$$\mathbf{SRs} = (\mathbf{Defects_{before}} - \mathbf{Defects_{after}}) \times \mathbf{SRc} \tag{10}$$

Total Monthly Saving: Represents the sum of labor, WIP, and scrap savings, showing the overall financial gain per month.

$$\mathbf{Ts} = \mathbf{Ls} + \mathbf{WIPs} + \mathbf{SRs} \tag{11}$$

This section defines all parameters and variables used in cost Metrics for Value Stream Mapping (VSM) in apparel manufacturing, with proper subscripts.

N= Units/Day
CT_{before} = Cycle time before the VSM
CT_{after} = Cycle time after the VSM
WIP_{before} = WIP before the VSM
WIP_{after} = WIP after the VSM
$Defects_{before}$ = Defects before the VSM
$Defects_{after}$ = Defects after the VSM
Ls = Labor Savings
Lc = Labor Cost/hr
WIPs = WIP Savings
WIPc = Holding Cost/unit/day
SRs = Scrap savings
SRc = Scrap Cost/unit
Ts = Total Monthly savings

These cost functions, in addition to complementing the performance indicators (like CT, LT and TY) offer a convenient linkage between improvement of the processes and financial performance. The combination of operational measures, and economic appraisal makes the methodology ensure that VSM & lean interventions are technically as well as economically rational.

4. Model Interpretation and analysis

4.1 Model implementation

Data Collection: carried out time-motion studies, structured interviews, and floor observations to obtain information about the processes in high detail and to obtain current performance indicators.

Current-State Mapping: Created a current-state VSM that has pointed out inefficiencies, such as the presence of too much WIP, unbalanced workloads, out-of-sync flow and misalignments in information.

Waste and Bottleneck Analysis: Applied the TIMWOOD framework to map all of those non value adding activities and recognized the bottlenecks particularly on the finishing and sew operation.

Future-State Design: Future lean solutions involved: Line balancing, Uniformed work processes, Increased information circulation (system visual control, standard reporting).

These tools are suggested to implement in the production line and the changes observed which are directed as the future state condition. Noticeable changes in the production system happen and which influences the parameters of the production and efficiency.

***Change Management & Training*:** After analyzing between the future state and the current state, industry individuals are Introduced lean training, implemented visual control devices (e.g. Andon lights, performance boards), and coordinated the leaders through structured engagement and review meetings to effect long-term changes.

4.2 Data collection

To provide the accuracy of the analysis of the process performance as well as to guarantee the transparency of the current state, the complete data of the time study was extracted and structured into two different Excel workbooks which can be considered as Current State and Future State conditions. At every important process stage (Cutting, Sewing, Finishing, Inspection and Packing), 100 individual observations were taken to get real life variation in processing time, waiting time, and percentage of yield. That kind of high frequency sampling can support strong statistical calculations, such as average and standard deviation which is fundamental to both the baseline and enhanced performance measures. The Current State workbook captures the actual performance of the line including the number of units that run down the line, the current production time etc., whereas the Future State workbook demonstrates the future state including the projected improvement totally on real-time performance. In every file, there are systematically organized raw data sheets, a summary table that contains the formulas and calculation sheets that connect observations to the most important performance outcomes provided in this study. In this way, all the empirical elements of the discovery become fully traceable and can easily be replicated by other researchers or practitioners too.

4.3 Model execution

In To provide the accuracy of the analysis of the process performance as well as to guarantee the transparency of the current state, the complete data of the time study was extracted and structured into two different Excel workbooks which can be considered as Current State and Future:

Supplementary Files: Current State Time Study.xlsx Future State Time Study.xlsx

Current State: Detailed data of time study was used in calculating in the current state model and 100 observation details were taken on each step of the process (e.g., cutting, sewing and finishing, inspection and packing). The data was recorded on the number of the individual components of the setup time, active processing time, wait time, inspection time and the numbers of defects per entry. All these raw stops were averaged to get the mean of the processing time at each stage. The summation of each of the average setup (converted to per unit), processing time, inspection time and waiting time of each of the stages was used to determine the total cycle time. Value-added time was taken as the addition of pure processing times only without the non-value-adding delays. The lead time was calculated using the documented number of works in process inventory and average daily production output. Throughput yield was calculated as a product of the performance of each stage using violations yield at each stage. The model connected all these metrics through use of excel formulas, to give automated calculations with the input of time study.

Table 2

Current state summary

Process Step	Avg Processing Time (min/unit)	Std Dev Processing	Avg Waiting Time (min/unit)	Std Dev Waiting	Yield (%)	WIP (units)	Setup Time (min/batch)	Batch Size (units)
Cutting	0.7948	0.0452	0.2011	0.0474	98.04	200.00	15.00	100.00
Sewing	1.2107	0.0880	0.6944	0.1058	94.77	400.00	0.00	
Finishing	0.5012	0.0531	0.1998	0.0290	99.10	100.00	0.00	
Inspection	0.1006	0.0193	0.0000	0.0000	100.00	50.00	0.00	
Packing	0.2009	0.0199	0.0000	0.0000	100.00	50.00	0.00	

Future State: Future state calculations were performed according to the same structure as the current model whereas the same set of 100 entries per process was replicated but with changes such that proper improvements were anticipated after lean interventions were implemented. In every step, new data on the time was inserted to reflect shorter wait times, improved cycle times and less defects. The delays, the processing time and set ups were averaged to recompute the future cycle time. Better first-pass yield was used to make modifications in the throughput yield value. The lead time was recalculated through input of lower levels of WIP. The structure of Excel workbook made it possible to automatically recalculate value-added time, cycle time, lead time and the related efficiency ratios employing the embedded formulas, and each of the metrics reacted dynamically with the changed data set without re-entering the formulas itself.

Table 3

Future state summary

Process Step	Avg Processing Time (min/unit)	Std Dev Processing	Avg Waiting Time (min/unit)	Std Dev Waiting	Yield (%)	WIP (units)	Setup Time (min/batch)	Batch Size (units)
Cutting	0.7959	0.036	0.1007	0.0285	98.03	150	10	100
Sewing	1.1086	0.070	0.3972	0.0529	97.88	300	0	
Finishing	0.5010	0.042	0.09984	0.0194	99.11	80	0	
Inspection	0.1006	0.019	0	0.0000	100.00	30	0	
Packing	0.2009	0.020	0	0.0000	100.00	30	0	

In order to assess the effects of lean implementation in terms of Value Stream Mapping (VSM), two parallel models depicting current and future states of production line were prepared based on the structured time study data. In each case, 100 observational data were obtained with respect to process step including time taken set up, processing time, waiting time, and quality performance. Calculation of these parameters comprises the following key operational parameters; cycle time, lead time, value-added time, and yield using these datasets. The Excel model relied on a set of formulas, and through it, it was possible to automatically generate performance measures. The comparisons of the results were conducted straight away in the form of quantification of time efficiency gains, process flow gains, as well as gains in output quality.

Table 4
Comparison between present and future state and changes

Metric	Formula	Present	Future	% change
Value-Added Time (VAT)	Sum Processing Only	2.81 min	2.71 min	↓ 3.6%
Available Time (A_p)	$H_s \times M_s \times D_s$	480 min	480 min	— (Same)
Takt Time (T)	A_p / D	1.2 min/unit	1.2 min/unit	— (Same)
Cycle Time (CT)	Setup/unit + Σ(Proc) + Σ(Wait) + Inspect	4.25 min	3.60 min	↓ 15%
Lead Time (LT)	Σ(WIP) / Prod Rate	2 days	1.48 days	↓ 26%
Value Stream Efficiency (VSE)	VAT / LT_ total	0.29%	0.38%	↑ 31%
Process Efficiency Ratio (PER)	VAT / CT	66.02%	75.10%	↑ 14%
Throughput Yield (TY)	Π Yields	92.07%	95.10%	↑ 3.3%
Overall Process Effectiveness (OPE)	VSE × TY	0.27%	0.36%	↑ 33%

4.4 Interpretation of the analysis

In To Value-Added Time (VAT) records a small drop (~3.6%), which means that standardization and quality workflow have led to the fact that value-adding activities are more homogeneous and deducible.

The reduction of the Cycle Time (CT), which is about 15%, proves that it is possible to eliminate the non-value-added time spent waiting and setup waste with improved line balancing and SMED.

Lead time (LT) is also reduced by approximately 26%, evidently reducing work-in-process (WIP) levels, and thus a better process flow, leading to faster delivery performance.

Value Stream Efficiency (VSE) enhances by approximately 31 percent which brings out the fact that a larger proportion of the total time is spent on value addition as opposed to waiting and non-value-added handling.

The update in Process Efficiency Ratio (PER) represents more than 75 percent indicating that there is less non-value-added time per unit compared to the value-added time per unit now.

The Throughput Yield (TY) goes up to about 95 percent, a significant improvement over the 92 percent previous figure, and this means fewer units lost to defects and rework, with quality costs correspondingly reduced.

The overall process effectiveness (OPE) rises by approximately 33% and it is confirmed that once the whole value stream applies VSM, the improvement will lead to more efficiency, wastes reduction and increased quality of products.

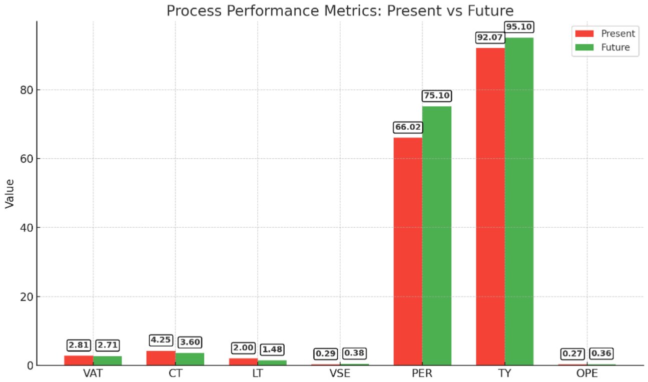

Fig. 2. Process performance metrices comparison

5. Economic Perspective and outcome

In order to assess the direct financial value of the suggested process improvements, economic impact analysis was carried out with realistic production and cost figures of the chosen T-shirt line. It takes into account three major sources of savings: higher labor productivity because of a reduction in cycle time, the reduced cost of holding inventory since the work-in-process (WIP) inventories will be decreased, and lower manufacturing scrap and reworking costs because of the increased throughput yield. The assumptions made on the input, the calculation equations applicable and the savings obtained per source per day and per month have been tabulated as below.

Table 5

Economic Outcome

Parameter	Value
Units per day	400
CT Before (min/unit)	4.25
CT After (min/unit)	3.6
Labor Cost ($/hr)	2
WIP Before (units)	800
WIP After (units)	592
Holding Cost ($/unit/day)	0.05
Defects Before (units/day)	32
Defects After (units/day)	20
Scrap/Rework Cost ($/unit)	1
Production Days per Month	25

Table 6 shows estimated direct cost savings in relation to the advantageous Value Stream Mapping (VSM) improvements proposed of the chosen T-shirt manufacturing line. Simulations are performed with realistic assumptions of production and cost with changes observed in the cycle time, work-in- process (WIP) inventory level and defect rates. The table indicates individual large items of savings, their daily and monthly financial effect and the formula (law) used to be certain and reproduced.

Table 6

Periodic cost saving

Impact Source	Daily Saving ($)	Monthly Saving ($)	Law
Labor Productivity Gain	8.67	216.67	Labor Savings = ((CT_before - CT_after) * Units/day / 60) * Labor Cost/hr
WIP Inventory Cost Reduction	10.40	260.00	WIP Savings = (WIP_before - WIP_after) * Holding Cost/unit/day
Scrap/Rework Reduction	12.00	300.00	Scrap Savings = (Defect_before - Defect_after) * Scrap Cost/unit
Total Monthly Saving	31.07	776.67	Total = labor Savings+ WIP Savings + Scrap Savings

Based on the explanations provided above, the estimated total savings that will be achieved through the proposed improvements will be around about USD4776.67 per month in a single production line. Particularly, the decrease in cycle time increases productivity of labor giving opportunity to the workforce to produce more goods during the table work hours, hence reducing the direct labor cost and later requirements of overtime. The reduction in inventory associated with the work in progress (WIP) directly decreases the capital-holders tied up by the incomplete inventory and is highly beneficial in the reduction of holding costs through storage, handling, and possible obsolescence of these incomplete goods. Besides the increase in the throughput yield will be that a smaller number of faulty units will be produced/manufactured, thus fewer units will be wasted, reworking, and raw materials used. These savings, when stretched to the annual context, or used over a set of production lines can have a huge impact on the overall profitability and competitiveness of the factory. Furthermore, the concrete cost savings shown in this paper are the reality about the financial feasibility of implementing lean manufacturing practice by means of the Value Stream Mapping (VSM) in the context of the apparel industry in Bangladesh where the efficiency of resources and cost competitiveness has been major concerns in terms of its sustainability in the long-term.

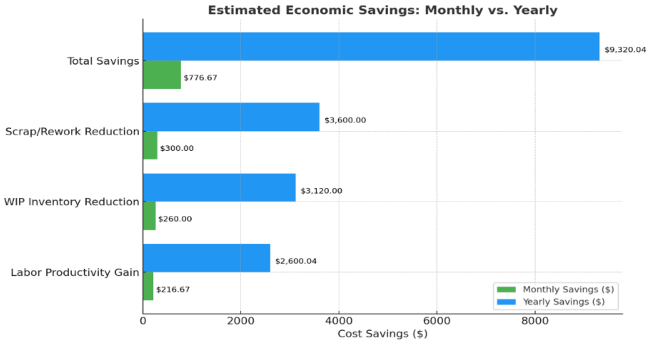

Fig. 3. Estimated Economic Savings

6. Results and outcome

After introducing Value Stream Mapping (VSM) to the chosen T-shirt production line, a comparison between the baseline and the improved conditions was performed with respect to the most important operating and financial indicators.

6.1 Operation Performance Indicators

The future-state VSM and the other lean tools have been implemented and the improvement of various process parameters was measured. Cycle Time (CT) improved or decreased to 3.60 minutes per unit, where Lead Time (LT) decreased to 1.48 days. Such gains show the improvement of flow efficiency and decrease in the time of waiting or adding no value to the process. Further, Value Stream Efficiency (VSE) jumped up by 31% and Process Efficiency Ratio (PER) at more than 75%, which means a leaner flow of processes. The increase in the percentage of Throughput Yield (TY) by 92.07% to 95.10% still indicates improvement of defects and rework.

6.2 Financial Impact Assessment

In order to quantify the operational gains and in effect translate them into savings 3 cost saving indicators have been assessed:

Labor Productivity Gain: There was an achievement of labor savings of $216.67/month with reduced CT.

Inventory holding reduction: A decrease of WIP ranging 800 to 592 produced 260.00/mo in inventory reduction.

Scrap/Rework Cost Reduction: As a result of the improved yield, we also realized a monthly saving of 300.00/month scrap cost.

Cumulatively these amount to an average of 776.67 dollars monthly; that is about 9,320.04 dollars yearly.

It is this kind of finding that strongly supports the economic case of using lean intervention, beyond the process efficiency.

7. Discussion

As the results of this paper reveal, the implementation of the Value Stream Mapping (VSM) in a labor-intensive environment with apparel production can bring visibly appreciable results in the efficiency of working processes and the development of the economy. By making use of the same principle, methodically culling non-value-added processes throughout the course of a T-shirt production line, organization succeeded in decreasing the cycle time (15%), the lead time (26%) and an even larger jump in the process-related efficiencies that include VSE (31%) and PER (14%). Such enhancements can be associated with the lean philosophy, which focuses on the waste removal, the flow optimization, and defects decrease. The smaller, yet statistically significant increase in throughput yield (TY: 3.3%) also shows a more consistent and error-proofed flow of production. The benefits of these gains are not only to enhance customer satisfaction due to short delivery delays but also make lines reliable and cut the rework cycles. In financial terms, it can be said that rear-ending performance indicators into revised costs will facilitate economic readability of lean efforts. A total monthly saving of about 776.67 dollars can be saved and therefore the improvements add up to over 9000 dollars yearly which is also a huge increment to a one line intervention. Notably, reduction of the cost of scrap and rework was the biggest source of savings, which further shows the importance of quality improvements in a labor-intensive environment. The results confirm the validity of the existing reports recommending lean integration in textile and RMG industry (e.g., Kumar et al., 2018; Vinodh et al., 2010), yet this study contributes to this field, since quantitative comparisons between the specific performance measures and the resulting monetary savings are usually not provided in case studies on lean implementation.

8. Conclusion

Based on this study, it is possible to see that Value Stream Mapping (VSM) may become an effective method to help improve both the efficiency of the processes and the economic activities in the industry of the ready-made garments (RMG) in Bangladesh. Through use of lean diagnostics in a T-shirt production line, the study was able to realize substantial changes in important performance indicators including cycle time, lead time, value stream efficiency and throughput yield. The systematic translation of such process gains into realizable dollar savings provides a negotiating grounds to manufacturers and policy-makers willing to sketch out the cost benefit of such lean exercise with dollars. In addition, the findings validate the assumption that despite such small and local process enhancements and implementation, when expanded to all production lines, would have given significant financial payoffs. Finally, it suggests the possibility of replicating this particular model of using VSM as a method of diagnosing and strategic planning in other settings labor-intensive environments of the manufacturing sector.

Declaration of Competing Interest

All the authors state that they have no known competing financial interests or personal relationships that may have made an appearance to have an impact on the work reported in this paper.

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