SYNERGIZING LEAN MANUFACTURING AND MAYNARD OPERATIONAL SEQUENCE TECHNIQUE FOR ENHANCED LABOR PRODUCTIVITY IN SYNTHETIC FIBER MANUFACTURING

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ABSTRACT: In the era of Industrial Revolution 4.0, manufacturing sectors face intense competition requiring companies to consistently meet customer demands. However, labor-related process delays increasingly hinder timely delivery and reduce overall productivity. This study aims to improve workplace productivity by conducting a time study to establish standard times as a baseline for identifying activities while capturing inefficiencies and non-value-added tasks to support leaner processes and sustainable labor utilization. A case study was conducted in a synthetic fiber manufacturing facility, focusing on direct labor activities at critical processes. Lean Value Stream Mapping (LVSM) and the Maynard Operational Sequence Technique (MOST) were applied in line with the standard work procedures. MOST, known for enhancing productivity with minimal capital investment, was validated against video-recorded observations, with a t-test confirming results at 95% confidence level. The analysis identified significant improvement opportunities, particularly among packaging operators (highest utilization) and winding operators (lowest utilization). Implementation of targeted actions improved labor productivity by over 20%, exceeding management's initial target. Hence, this case study provides empirical evidence of the effectiveness of MOST in real-world manufacturing and offers practical insights for organizations seeking to optimize labor efficiency in competitive industrial environments.

KEYWORDS: *Labor Productivity; Lean Manufacturing; MOST; Synthetic Fiber Manufacturing*

1.0 INTRODUCTION

Improving productivity in manufacturing remains a critical challenge, especially in the era of rapid technological change and shifting customer demands [1]. To remain competitive, manufacturers must optimize production processes, address labor-related inefficiencies, integrate appropriate technologies, and ensure timely product delivery. Sustained production gains can yield higher profitability through better work organization, enhanced skills and training, advanced manufacturing technologies, and improved workplace environments.

Labor efficiency is a common partial productivity metric in macroeconomics, serving as a valuable indicator of economic growth, competitiveness, and living standards [2]. It reflects the ability of employees to complete tasks within a defined time frame while using minimal resources. Key factors influencing labor efficiency include work organization, skill level, training, and technological capabilities [3]. The primary goal is to increase output while minimizing resource consumption.

Synthetic fiber manufacturing involves both automated and manual processes, with labor playing a key role in packaging, winding, and inspection. For the synthetic fiber manufacturing under study, improving labor productivity is essential for reducing costs, enhancing quality, and meeting customer expectations in a competitive marketplace. However, the current operational framework lacks a quantitative reflection towards achieving the targeted 20% labour productivity improvement due to no established reference for standard time and baseline measurement for the manual task activities, leading to inefficiencies and inconsistencies in task execution.

To address this issue, this study applies VSM and MOST to develop standard times, identify improvement opportunities, and optimize worker performance. While MOST has demonstrated effectiveness in various industries, its application in the synthetic fiber manufacturing sector remains limited, highlighting a clear gap in empirical research. By integrating these tools, the study aims to detect inefficiencies and non-value-added activities, thereby providing a foundation for targeted interventions that are not only designed to streamline processes but also to ensure sustained labor comfort, health and safety.

1.1 Lean Manufacturing

Lean manufacturing (LM) has become a widely adopted approach for driving productivity gains by systematically identifying and eliminating waste across the value stream [4, 5]. Originating from Toyota in the mid-20th century, LM fosters a culture of continuous improvement involving active participation from all organizational levels. The lean journey begins with value identification, often through Value Stream Mapping (VSM), which distinguishes value-adding from non-value-adding activities. This mapping visualizes the flow of materials and information, enabling the detection of waste such as transportation, inventory, motion, waiting, overproduction, over-processing, and defects.

Lean manufacturing is a methodology that aims to enhance productivity by systematically identifying and eliminating waste within the production process. Lean manufacturing practices can boost an organization's productivity and competitiveness by maximizing production rate and efficiency without compromising product quality. Raktate et al. [6] emphasized that this approach reduces costs by eliminating product defects, reducing production times, and reducing labour and operation expenses.

Among the examples of successful implementation of the lean approach in the companies is a lean six sigma study conducted by Abdullah et al. [7] at an electronic component company and at a printer company [8] to help the company to optimize labour efficiency and achieve an ideal man-to-machine ratio. Similarly, Mulugeta [9] performed a productivity improvement study using lean manufacturing in an Ethiopian garment manufacturing company with overall productivity improvement by 17% through reduced production cycle time, workstation requirement, and lead time. In addition, a recent study to improve the rolling mill productivity using lean manufacturing was conducted by Rathi et al. [10], achieving a significant overall equipment efficiency (OEE) improvement of 30% by minimizing breakdowns and improving the equipment availability. Barot et al. [11] attempted to apply lean practices in the water heater manufacturing, which is a small and medium scale industry that initially avoided implementing lean due to financial factors. Value stream mapping was a primary tool used, and results showed that waiting time and material movement were drastically reduced, increasing productivity from 50% to 70%.

However, Ahmad et al. [12] criticized the use of traditional value stream map (VSM) leading to unsustainable long-term solutions because it focuses on addressing the symptoms rather than the root cause. They argued that there are still few works that provide a systematic and practical approach to this process and proposed a methodology called the VSM-Lean Thinking (VSM-LT) which guided the identification of the root cause of waste targeted to be solved. These authors proposed four basic steps in the VSM-LT; (i) waste identification, (ii) operation deficiency matching, (iii) possible root cause analysis, and (iv) opportunity for improvement identification. The model was then tested at a food-based industry, indicating various issues were the results of a common root cause.

1.2 Maynard Operational Sequence Technique (MOST)

A key technique for studying manual work within the lean framework is the Maynard Operational Sequence Technique (MOST). Developed by John W. Maynard in the mid-20th century, MOST breaks tasks into elemental motions with assigned time values, providing a faster, more consistent method than traditional time studies [13, 14]. MOST has been successfully applied in manufacturing, logistics, and healthcare to establish standard times and work processes. Comparative research shows MOST to be superior to other Predetermined Motion Time Standard (PMTS) methods such as Methods-Time-Measurement (MTM) in methodology, applicability, and accuracy [15]. Furthermore, the Maynard Operation Sequence Technique (MOST) is a specific work study tool that can be employed to analyse the root cause in the aspect of labour activities to optimize the work processes [16].

MOST are being applied in various areas and are used to measure the work content, which allows the company to balance the worker's workload and effectively perform manpower planning. For example, Jamil et al. [17] systematically optimized the manufacturing personnel's productivity while ensuring the ergonomics aspects at Tata Motors Ltd. by systematically analysing the time to accomplish basic tasks and accurately determining the manpower requirement. Pathak et al. [18] applied MOST in the garment industry successfully to achieve reduced work content and improved process productivity. Ganorkar et al. [19] further enhanced the use of MOST technique to apply to the time-driven activity-based costing (TDABC) for a clearer insight into the product cost performance. The various studies that integrate the lean and MOST methods include Buranasing and Choomlucksana [20], Kulkarni et al. [21], Gujar and Moroliya [22], and Deshpande [23] mainly for the purpose of reduction of working time, especially at the bottleneck process, and worker's productivity improvement. Other benefits observed from these studies include improved ergonomics and working conditions of the workers. Even in the most recent study from Mazareinezad et al. [24], MOST was the preferred PTMS used to develop a framework to implement time analysis in the digital human modelling systems (DHMS). This method was validated by the same authors using real-world manufacturing data with 95% of the MOST estimates and actual time values to be within the acceptable limits, demonstrating the reliability of the method to be used in the study of manufacturing to enhance productivity and operational planning [25].

In summary, MOST, as a predetermined motion time system, offers a structured method to set precise standard times by analyzing elemental motions, while lean methodologies such as Value Stream Mapping (VSM) help identify value-added activities and waste in the workflow. Combining these approaches ensures that the standard times established are not only technically sound but also aligned with broader process improvements, thereby addressing both human and process-related inefficiencies. By grounding standard time development in robust motion analysis and waste elimination, organizations can better respond to the critical labor efficiency factors, leading to sustained productivity gains without compromising worker well-being.

2.0 METHODOLOGY

The case study at the synthetic fiber manufacturing followed the eight-step LP framework, as illustrated in Figure 1. In the first two steps, a Lean Value Stream Map (VSM) was developed to capture the overall process flow of the manufacturing operation and to detail the manpower planning for critical production stages. Subsequently, tasks for each position were identified based on the established Standard Operating Procedures (SOPs), using a tool referred to as the BLA ruler. To ensure completeness and accuracy, the process owner was engaged to verify that all activities were captured, and no SOP elements were overlooked.

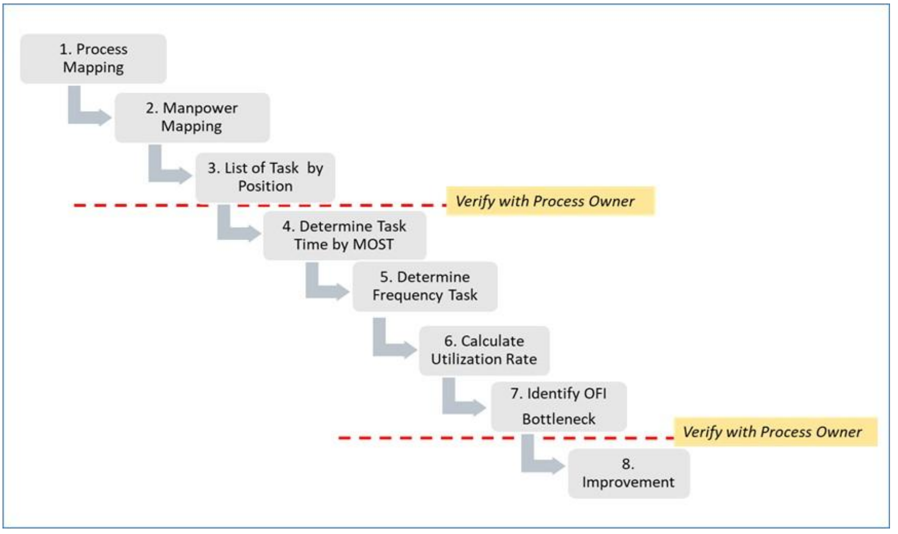


Figure 1: The 8-steps labour productivity framework

The fourth step comprised a comprehensive manual task study using MOST to determine the Task Time (TT). Direct observations were conducted on the shop floor, supplemented by video recordings to accurately capture workers' movements. Each activity sequence; general move, controlled move, and tool use was coded using a custom-designed Microsoft Excel template, which facilitated motion sequence documentation, TMU value assignment, and normal time calculation for each task. A paired t-test was performed to evaluate the statistical significance of the differences between the MOST calculated times and those measured from the video recordings. Next, an allowance factor, determined according to the International Labor Organization (ILO) standards and the nature of the work, was applied to compute the worker's utilization rate. The final TT was calculated using the following formula:

$$Task\ Time\ (TT) = \ Normal\ Time\ (MOST)\ x\ Allowance\ Factor\ (ILO) \tag{1}$$

The allowance factors obtained from the ILO standards are shown in Table 1. This fatigue allowance factor needed to observe the nature of work at the synthetic fibre manufacturing, which includes the working environment (heat, noise, lighting condition), the weight of the product needed to be lifted, and the working position (standing, bending).

Table 1: ILO allowance factors used in the study

Allowance Type	ILO factor (%)
Constant (Male)	9
Standing	2
Weightlifting	3
Light condition	2
Air condition (furnace)	5

Once the MOST values were validated, the fifth step involved determining the frequency of each task, defined as the number of times a specific activity is performed within the productive working time of a shift. This step is critical, as understanding task frequency supports workflow optimization, workload balancing, and overall efficiency improvement.

Using the TT (obtained from the MOST standard time), task frequency, and the total productive working time in a shift, the utilization rate (UR) for each operator was calculated in step six. UR represents the proportion of productive time spent performing assigned tasks and is expressed as:

$$Utilization\ Rate\ (UR) = \frac{Frequency\ x\ Task\ Time}{Productive\ Time}\ x\ 100 \tag{2}$$

In step seven, UR values for all manual tasks were analyzed using first and second level Pareto charts. The first-level Pareto identified the most significant contributors to inefficiency, while the second-level analysis examined these key contributors in greater detail. Consequently, a workload balance chart was developed to visualize task distribution, highlight overburdened or underutilized resources, and pinpoint bottleneck processes or operations that restrict or slow workflow.

The final step in the framework focused on identifying opportunities for improvement (OFI). Based on the identified bottlenecks, potential solutions such as task redistribution, process automation, resource reallocation were considered to enhance workflow efficiency and reduce process constraints.

3.0 RESULTS AND DISCUSSION

The case study was conducted at a synthetic fiber manufacturing facility located in West Malaysia. This facility is one of the seven within the same industrial compound and was selected as the pilot site for a labor productivity study, serving as a proof of concept for the remaining six facilities, each with different product portfolios and operational setups. Despite these differences, the challenge set by top management was uniform; all facilities were required to achieve a minimum of 20% improvement in labor productivity within a defined timeframe.

To meet this target, the synthetic fiber manufacturing operations used the developed LP framework capable of quantitatively assessing the labor productivity, establishing a reference standard time, and providing a baseline measurement for manual task activities. This would enable a clear and measurable strategy toward achieving the 20% improvement goal. The following sections detail the results obtained from each of the eight steps of the framework.

Step 1: Process mapping

To systematically capture and assess the overall operation and material flow, a Value Stream Map (VSM) was developed. Analysis of the VSM revealed four manual operations that exert a significant influence on throughput and labour utilization: (i) PET drying (extruder), (ii) spinning (winder), (iii) drawing, and (iv) packing. These operations were identified as critical due to their direct impact on cycle time, labour intensity, and potential to create bottlenecks. Their selection provided a focused scope for subsequent measurement, time study, and productivity optimization within the labour productivity framework.

Step 2: Manpower mapping

Once the critical operations were identified, manpower mapping was conducted to systematically capture the current workforce allocation and planning across the identified critical operations. An example of this mapping, summarized in the Excel spreadsheet shown in Figure 2, provided a structured view of labour distribution, shift coverage, and task assignments. The inclusion of detailed work descriptions extracted from the SOP and organized through the BLA ruler enabled a clear linkage between manpower deployment and specific operational requirements, serving as a baseline for identifying inefficiencies and potential optimization opportunities.

BLA Ruler

Manpower mapping

DUTY			TASK	Spinning				Drawing		
				Extruder	Winder			Drawing	Packing	
N	DESCRIPTION	NO2	DESCRIPTION3	Staff E	Staff (W3)	Staff (W2)	Subcon (W1)	Staff D	Staff P	Subcon 2
1	Utility	1.00	UTILITIES							
		1.01	Operate Startup or shutdown Utilities (Compressor,Main Exhaust Fan & Cooling Tower)							
		1.02	Monitor utilities performance							
		1.03	Aware and monitor fire fighting facilities prepareness							
2	Calibration & Verification	2.00	EQUIPMENT VERIFICATION & CALIBRATION							
		2.01	Perform oven temperature verification							
		2.02	Perform extruder feeder verification for PET,MB and Powder							
		2.03	Perform balance verification							
		2.04	Perform godet roll & spinning oil roll speed verification							
		2.05	Analyze & verify equipment verification result							
3	Raw Material	3.00	RAW MATERIAL PREPARATION							
		3.01	Understand production schedule & raw material planning							
		3.02	Carry out raw material calculation and issueance							
		3.03	Perform raw material transfer & storage	x					x	
		Open	MS-KIF-PRD-P010-001							
		3.04	Perform MB Preparation – Antistatic Mixing	x						
			MS-KIF-PRD-W020-019-00							
		3.05	Coordinate raw material preparation according to production schedule & requirement							
		4.00	MATERIAL GRADE CHANGE & CHARGING							
		4.01	Understand overall grade change procedure (MB, Powder etc)							
		4.02	Perform FR material grade change	x						
		Revised	MS-KIF-PRD-W010-010-00							
		4.03	Perform PET Preparation (Charging)				x			
			MS-KIF-PRD-W010-001-01							

Figure 2: The Manpower Mapping of the Synthetic Manufacturing Operation

Step 3: List of tasks by position

The list of tasks identified and agreed upon with the process owners to be further investigated involved activities described in the BLA ruler as "carry out or operate", "perform", and "conduct". Other descriptions such as "know", "describe" or "troubleshoot" will not be considered as the daily manual routine job.

Step 4: Determine TT using MOST

The task time for each process was determined using two approaches: the direct observation using video capture and the breakdown of the work motion sequence to perform the MOST coding. MOST Excel template (Figure 3) served as the primary tool for capturing, classifying, and quantifying the motion elements involved in each manual task. Using Equation (1), the normal time (column A) for each task was computed by multiplying the TMU derived from the MOST activity sequence by a constant factor of 0.0006 minutes per TMU. This conversion factor reflects the standardized definition in the Maynard system, where 1 TMU equals 0.036 seconds or 0.0006 minutes, thereby enabling the translation of motion-based observations into actual time values.

A paired t-test was conducted to determine whether there is a statistically significant difference between the task time estimates using MOST method and those measured from the video analysis. The t-value of 1.53 and corresponding p-value of 0.145 are above the conventional significance threshold (α = 0.05), leading to a failure to reject the null hypothesis. This suggests no statistical difference between MOST-based and video-based time measurements, implying that MOST method provides time estimates comparable to direct video observations in this study.

				A	B			C	D	E
IMS Procedure	BLA Task No.	No. Step	Work Instruction	Normal Time (min)	ILO & Fatique Allowance Time (%)	ILO & Fatique Allowance Time (min)	Standard Time (min)	Frequency/ Shift	Total Standard Time/Shift	Utilization Rate
(IMS-KIF-PRD-W010-004-01)	4.04		Perform SR-T charge in and refill	12.45	13%	1.62	14.07	1	14.07	2%
Memo G16 - Bag Filter Cleaning	5.05		Perform periodical maintenance/servicing for PET& FR Transport System - Bag Filter	0.00	13%	0.00	0.00	0.02	0.00	0%
Memo G16 - Line Filter Cleaning	5.06		Perform periodical maintenance/servicing for PET& FR Transport System - Bag Filter	0.00	13%	0.00	0.00	0.02	0.00	0%
Memo G13 - PET dryer Panel Information	5.07		Operate PET & FR tranportation panel operation	0.74	13%	0.10	0.83	0.02	0.02	0%
(IMS-KIF-PRD-W010-008-00)	6.01		Operate crushing Machine	27.71	11%	3.05	30.76	1	30.76	5%
(IMS-KIF-PRD-W010-009-00)	6.02		Cleaning crusching machine	0.00	13%	0.00	0.00	0.02	0.00	0%
(IMS-KIF-PRD-W010-011-00)	6.03		Operate Scrap Portable lifter	4.22	13%	0.55	4.77	4	19.09	3%
(IMS-KIF-PRD-W020-008-01)	8.12		Perform grade change type A - MB Measurement Equipment Cleanin	10.03	17%	1.71	11.74	0.5	5.87	1%
(IMS-KIF-PRD-W031-001-03)	12.04		Operate to startup No.3 Extruder Godet and Winder	6.31	13%	0.82	7.13	0.5	3.57	1%
(IMS-KIF-PRD-W031-002-01)	12.05		Operate to shutdown No.3 Extruder Godet and Winder	0.00	13%	0.00	0.00	0.02	0.00	0%
(IMS-KIF-PRD-W030-005-01)	12.06		Preparation of spinning oil	3.89	11%	0.43	4.32	1	4.32	1%
Memo S28	12.07		Prepare bobbin label sticker & printing follow production schedule	6.17	13%	0.80	6.97	1	6.97	1%
Internal WI -Winder Empty bobbin for production	12.08		Prepare winder empty bobbin for production	2.45	11%	0.27	2.72	4	10.90	2%
Memo S15 - Fiber End Handling At Winder	12.09		Perform fiber end finish goods handling (1527)	1.28	11%	0.14	1.43	21	29.93	5%
(IMS-KIF-PRD-W030-004-01)	13.03		Verify bobbin Weight Measurement (Winding Process)	0.67	13%	0.09	0.75	86	64.72	10%

Figure 3: MOST excel template for LP study

Column B calculates the task's standard time by applying the allowance factor (ranging between 13% and 17% per Table 1) based on the work type. The standard time was then determined by multiplying the normal time with the allowance factor.

Step 5: Determine the task frequency

The amount of repetitive work that a worker needed to perform or frequency tasks was also taken into consideration and is shown in column C of Figure 3. The process owners were involved in the verification of the frequency data. With the frequency task information, a total standard time for the task (column D) can be obtained by multiplying the standard time by the task frequency.

Step 6: Calculate the utilization rate (UR)

The UR in column E is the result from Equation (2). The productive time was set to be at 645 minutes (750 minutes of available time minus 75 minutes of break time). The summary of the UR for each of the processes is presented using a workload balance chart as shown in Figure 4. The bottleneck process was identified at the packing process with 101% UR. Conversely, winder 3, winder 1, and winder 2SC process worker's URs were found to be low at 58%, 46%, and 46%, respectively.

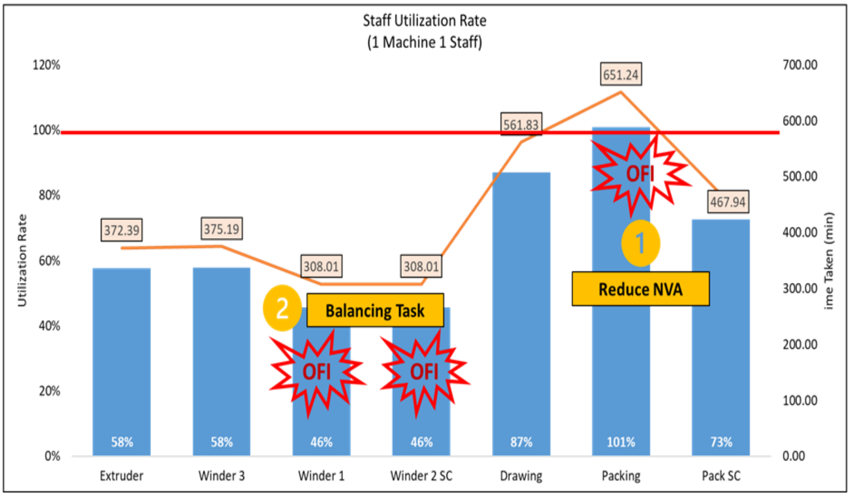
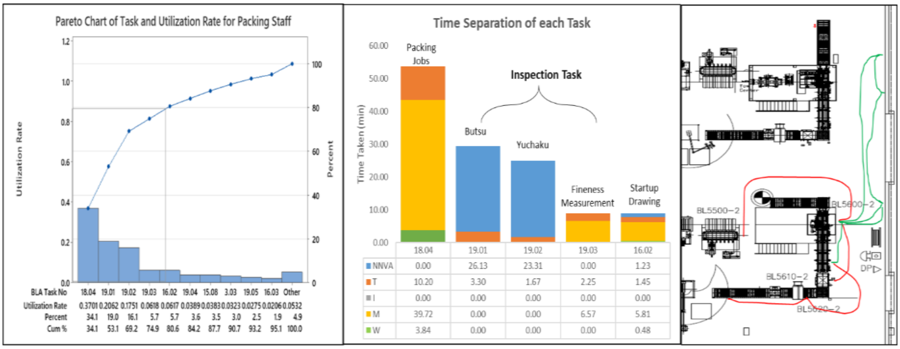


Figure 4: Summary of Process Utilization Rate (UR)

Step 7: Identify opportunities for improvement (OFI)

The packing and winding were identified to be the two critical processes for the OFI activities. By analysing the workers' work content at the packing process using the Pareto chart (Figure 5a) showed that the BLA tasks no 18.04, 19.01, 19.02, 19.03, and 16.02 contributed to 80% of the operator's workload. Further lean waste analysis (Figure 5b) indicated that 50% of the waste occurred due to the transportation and motion waste. This information is further confirmed through the use of a spaghetti diagram as shown in Figure 5c.



(a) Pareto Chart (b) Lean Waste Analysis (c) Spaghetti Diagram

Figure 5: Packing worker workload analysis

As for the winding process, theoretically the quick win will be to combine the winder 1 and winder 2SC workloads and free up one worker from this process. By doing so, the UR of the winding worker will improve to 91%. However, there is an issue with the back pain, although back support could be provided to the worker. Another study was conducted to evaluate the current scenario of having two winding workers compared to if the workloads were combined to only one operator. Figure 6 shows the result of the study where if the workloads were combined to only one operator, there would be a double in increase on the bending frequency, causing a high risk for back pain issues. With the advice from the occupational health and safety department, the option to combine the workload could not be materialized and requires further investigation.

CURRENT SENARIO:

Level of Weight	Bending Frequency
1 (With load – 20kg)	183
2 (No load – 1kg)	140
3 (With Load – 12.5kg)	167
4 (With Load – 5kg)	32
Grand Total	522

AFTER COMBINE SENARIO:

Level of Weight	Bending Frequency
1 (With load – 20kg)	366
2 (No load – 1kg)	280
3 (With Load – 12.5kg)	334
4 (With Load – 5kg)	64
Grand Total	1,045

Figure 6: Winding worker workload analysis

Step 8: Improvement plan

To reduce the packing operator UR, a quick win solution proposed include the duplication of the workstation and to install a sensor at the conveyor to minimize having the worker to assist in the material movement along the conveyor. The packing operator UR will be able to improve from 101% to 89% (12% LP improvement). The long term proposed solution include the automation of the packing process which could further reduce the packing operator UR to only 31%. As for the winding process, there was already an ongoing automation project to modify the winder 2 which may further reduce the UR for the winders and allow for the opportunity to reduce the number of workers. Hence, there will be a high possibility to achieve the 20% LP challenge once the automation project is completed.

In Summary, the benefits observed from using lean tools and MOST work study technique concur with many previous studies conducted in other manufacturing industries. For instance, comparable to Abdullah et al. [7, 8], Mulugeta [9] and Barot et al. [11], the case study with the synthetic manufacturing company resulted in an improved productivity and successful reduction, especially in terms of the lean transportation and motion wastes. Moreover, the application of MOST was able to identify the bottleneck process and reduce the worker's workload effectively while still observing the ergonomic factor, similarly to the studies conducted by Jamil et al. [17], Buranasing and Choomlucksana [20], Kulkarni et al. [21], Gujar and Moroliya [22] and Deshpande [23].

4.0 CONCLUSION

In conclusion, the impactful combination of the use of lean tools and MOST technique presents a valuable opportunity for manufacturers to improve labour productivity and drive leaner operations. The study objective was achieved using the eight-step framework to systematically gather the required data and perform the analysis on the work processes. The synthetic manufacturing company now has baseline data to work on and a clear strategy on labour productivity improvement to achieve above the company's 20% improvement target. Furthermore, the company was also able to reap the benefits of being able to identify the opportunity and realize their company's goal to eliminate waste, increase efficiency, and enhance their overall competitiveness. In addition, this pilot study serves as a guideline on the implementation of a similar study with the other six facilities and adds to the body of knowledge on the impactful use of lean tools and MOST technique to enhance the labour productivity.

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AUTHOR CONTRIBUTIONS

R. Abdullah: Conceptualization, Methodology, Writing Original Draft; N.F.H. Abu Sulaiman: Conceptualization, Data Validation, Supervision; N. Mohamad: Data Curation, Data Analysis; A.H. Abdul Rasib, and H.O. Mansoor: Reviewing and Editing.

CONFLICTS OF INTEREST

The manuscript has not been published elsewhere and is not under consideration by other journals. All authors have approved the review, agree with its submission and declare no conflict of interest on the manuscript.

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