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APPLICATION OF LEAN TOOLS IN INDIAN SMALL SCALE AGRICULTURAL POLYPROPYLENE BAGS MANUFACTURING INDUSTRY – A CASE STUDY

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Abstract
This study focuses on the application of Lean manufacturing principles, specifically 5S, Kaizen, and Value Stream Mapping (VSM), to address operational inefficiencies and enhance productivity in the agricultural industry. The Polypropylene (PP) Leno Bags are crucial for packaging and protecting agricultural products. The production process of Leno Mesh Bags involves several steps, from material selection to final product packaging. However, the industry faces challenges related to unorganized plant’s tools, material and equipments, plant layout issues, lack of maintenance policies, and safety concerns. After conducting an extensive review of existing literature, this study leverages successful implementations of Lean manufacturing in various sectors, underscoring the efficacy of tools like 5S and Value Stream Mapping (VSM) in waste reduction and overall productivity improvement. VSM is implemented to map the entire production process, identifying value-added and non-value-added activities. The Current State VSM exposes a total lead time of 3 hours and 40 minutes for Leno bag production. The implementation of 5S techniques reduces searching time, while Kaizen focuses on minimizing setup time. Additionally, the suggested plant layout changes aim to improve overall workflow and reduce the total distance traveled during production. The Future State VSM reflects a reduced lead time of 2 hours after the implementation of Lean techniques. Plant layout analysis shows a significant reduction in the total distance traveled, from 80.8 meters to 66.8 meters.

Keywords: Application of Lean tools, Small Scale Manufacturing Industries, Agricultural Polypropylene bags, Leno Bags, 5S, VSM, Kaizen, Plant Layout Analysis.

Introduction
Polypropylene (PP) is a versatile thermoplastic polymer widely used in various applications such as packaging, textiles, and medical devices. In the context of Leno mesh bag production, PP's strength, durability, and resistance to moisture and chemicals make it ideal for creating the mesh material. Leno mesh bags have an open, net-like structure and are commonly used in agriculture for storing, transporting, and marketing crops. Leno mesh bags, play a crucial role in protecting and facilitating the handling of fruits, vegetables, and seeds in agricultural contexts.

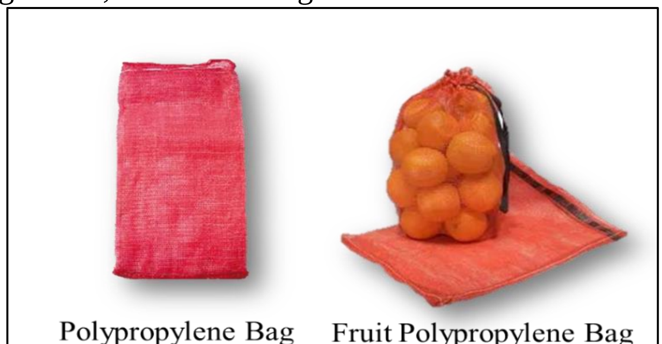

Fig.1. Polypropylene products

Leno Mesh Bags are a type of woven mesh fabric that is used for product packaging. They are made from polypropylene, a thermoplastic polymer, and are durable, breathable, and lightweight. L sewing

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Mesh Bags are designed to allow air to circulate around the produce, helping to reduce spoilage and prolong the shelf life of the product. Leno Bag is used for packing onions, potato, garlic, fruits vegetables & also for packaging flowers. Leno bag is available in numerous sizes so as to meet the demand of customers.

Production process for Leno mesh bags:

Step 1. Material Selection: Choose the appropriate mesh material, such as polypropylene, based on the bag's intended use and durability requirements.

Step 2. Grinding: The selected polypropylene material is broken into small pieces using a grinding machine and then heated to a pre-decided temperature.

Step 3. Mixing: After the polypropylene is ground, the material is mixed in the hopper and heated to the predetermined temperature, causing changes in its thermal and physical properties.

Step 4. Moulding: Molding is the process employed to melt the polypropylene material to temperatures ranging from 215°C to 238°C within the molding machine. It operates as a heat exchanger.

Step 5. Stretching: Following grinding, mixing, and molding of the polypropylene material, it is stretched to the predetermined thickness using a stretching machine, a pivotal step in crafting polypropylene bags.

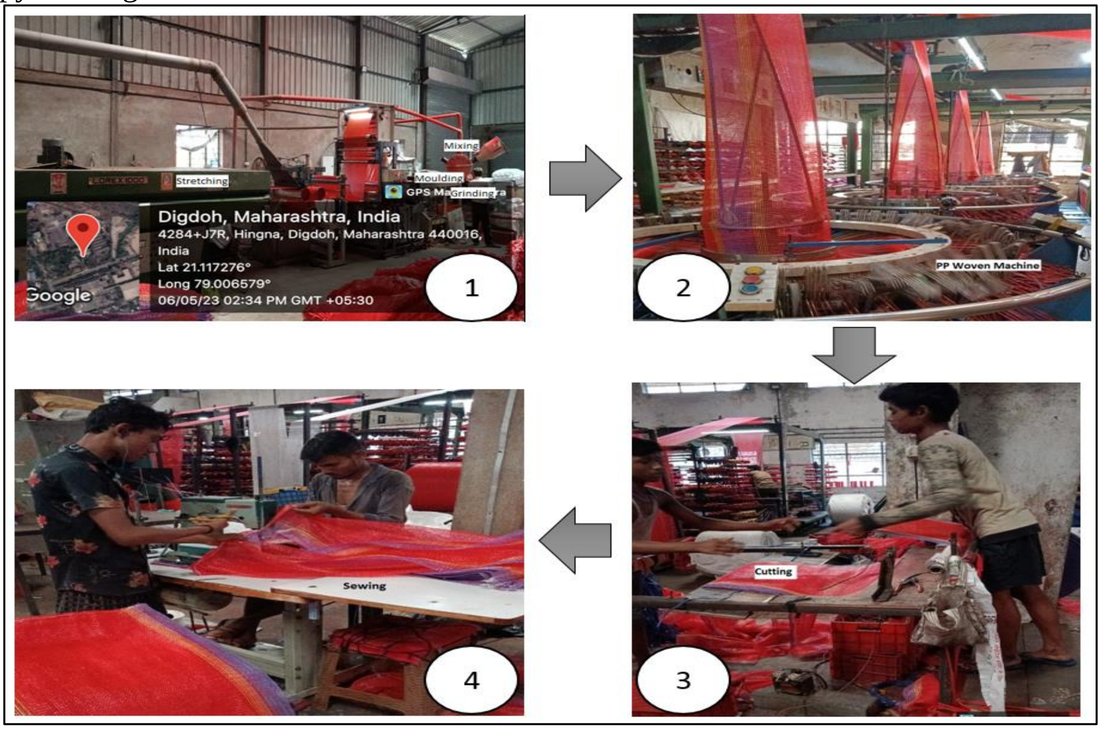

Fig.2. Production Process of making Leno bags

Step 6. Bobbin Rolling: The stretched polypropylene material is transformed into thin thread-like structures, which are then wound onto bobbins for storage. In this process, the bobbin rolling machine neatly rolls all the stretched polypropylene material into bundles.

Step 7. PP Woven : The bobbins are inserted into the PP woven machine, which is used to manufacture polypropylene bags. This machine utilizes 145 bobbins simultaneously to create sheets of polypropylene material for bag production. This process involves weaving thin polypropylene sheets using a woven technique.

Step 8. Cutting:- The woven polypropylene sheets proceed to the cutting operation, where employees cut the sheets according to the specifications outlined in the job card.

Step 9. Sewing : The cut polypropylene sheets are now sewn together to create the bags. Each roll of polypropylene material produces 1000 bags. Employees sew the bags continuously.

Process Sheet – Polypropylene Bags V K Agropack

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Process ID	Process Description	Workstation Name/ Machinery	Tool/ Equipment	Process Parameters/ Temperature	No. of Man	Process Time	Remarks
OP NO. 1	Grinding (Polypropylene material grind in the machine)	Grinding Machine	Grinding wheel	211°C	1	10 to 15min	The material should grind in proper temperature in the machine.
OP NO.2	Mixing	Hopper Machine	Mixing blade	225°C	1	5 to 6min.	The polypropylene material mixed in mixing machine properly.
OP NO.3	Moulding (Polypropylene material Melted in the machine)	Moulding Machine	Heater / T – Die	215°C to 238°C	1	10 to15min.	Take safety precautions.
OP NO. 4	Stretching (The polypropylene material stretch up to a decided thickness)	Stretching Machine	Rollers/Blade	136°C	1	1 hour.	Make sure that the machine stretch the material in pre-decided size.
0P NO. 5	Bobbin Rolling(The material rolled on the bobbin)	Bobbin Rolling Machine	Bobbin	–	1	1:30 Hour	The bobbin should be rolled in proper way.
OP NO. 6	PP Woven(In this process the material woven and make the sheets for bags)	PP Woven Machine	Cutting/Sewing	–	1	1 Day	Make Sure the machine produced proper sheets of polypropylene
OP NO. 7	Cutting(The sheet cut in decided size manually)	Cutting Machine	Cutting Blade	–	2	5 min.	Take safety precautions while cutting the sheets.
OP NO. 8	Sewing(The sheets are sewing and make the bags)	Sewing Machine	Sewing Needles	–	2	5min	Keep in mind that the machine can sewing the bag properly.

Fig.3. Process Sheet of Leno bags

The case industry has been facing lots of problems related to visual workplace management, plant layout issues, no maintenance policies and safety related issues. In the industry, there are instances of unused and underutilized areas where raw materials are stored randomly and carelessly throughout the workplace.

The equipment is placed randomly, resulting in workers spending more time searching for them, which negatively impacts their work efficiency. It has been observed that there is a lack of designated space for setting up the machining tools.

The worker does not use safety equipment while mixing the raw materials in a mixer, causing dust particles to enter the worker's eyes. The worker handles hot products in the stretching machine without wearing gloves. It has been observed that the raw materials are stored far away from the machine that needs to be used.

The women responsible for packing the final product are working in the middle of the work area, and the final products are stored in front of the manager's table. The machines are placed too closely to each other. In order to cut the sheets of the propylene bag into the designed dimensions, two workers are required. However, in the current process, one person simply gives continuous directions to the sheet while the other person manually cuts the sheet. This results in significantly more time being taken for a single operation, which effects the efficiency of the industry.

Lean manufacturing can help to minimize the problems faced by the case industry. Lean Production development centers on defining 'value,' analyzing the entire 'value stream,' and eliminating wasteful steps while introducing flow. Lean tools such as 5S, kaizen and VSM have improved workplace and the productivity level effectively. [1] The tools of lean manufacturing such as 5S, Kaizen and VSM were developed for maximizing capacity utilization, reduction in cycle time, lead time and inventory, enhancing the product value. 'Kaizen' a Japanese philosophy that promotes continuous improvement in the workplace as a result of employees' involvement [25]

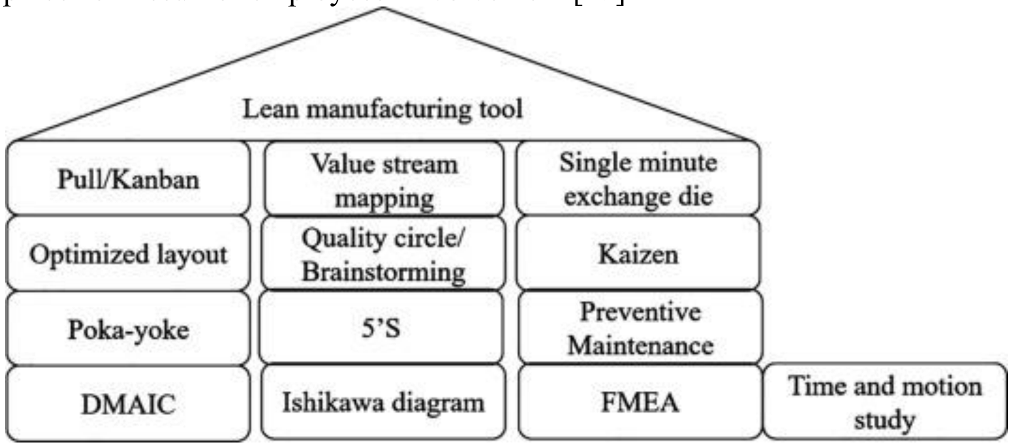

Fig.4. Lean manufacturing tools [25]

In recent decades, manufacturing companies have faced escalating pressures driven by heightened customer expectations and fierce competition. To meet these demands, manufacturers have sought to enhance product quality, reduce delivery times, and minimize production costs – or a combination of these objectives. [2] Value stream mapping (VSM) serves as a valuable tool for enterprise enhancement by providing a visual representation of the entire production process, encompassing material and information flow. It defines a value stream as a comprehensive collection of all activities, both value-added and non-value added, necessary for guiding products sharing resources from raw materials to end customers. VSM applications in an Indian industry case study, revealed the key findings. [5] Value stream mapping (VSM) has been used to reduce cycle times and achieve lean operations in order to meet hourly assembly line demands, fostering consistency in the supply of motorcycle frames from a dedicated supplier to an OEM. [3] The productivity of the edible cottonseed oil processing industry in India by applying the value stream mapping (VSM) approach. [4]

II. Literature review

A practical application of VSM through a case study conducted in a small manufacturing industry in Patiala, India. The study showcases substantial improvements, such as reduced lead time, processing time, work in process inventory, and manpower requirements. The literature review categorizes VSM-related work into four distinct types, highlighting its versatile global applicability. The provided case study in a Manufacturing Industry in India demonstrates the effectiveness of VSM in reducing waste. However, it also identifies potential areas for future research, including cost-benefit analysis, vendor management, the human factor impact, and comparisons with alternative waste reduction methods. [5] Author utilizes Value Stream Mapping (VSM) to rectify inefficiencies and waste within the supply chain of the Indian cottonseed oil industry, primarily in processing. Through observations, interviews, and VSM analysis, the study aims to uncover non-value-adding activities, excess inventory, and technological obstacles hindering productivity The paper proposes applying lean manufacturing principles and VSM to identify, analyze, and eliminate these inefficiencies, ultimately improving the competitiveness of the cottonseed oil industry in India. The methodology involved extensive sampling, data collection, supply chain and process activity mapping, and stakeholder interviews, with the aim of identifying and addressing inefficiencies to enhance industry competitiveness. The proposed solutions include capacity utilization improvement, policy advocacy, lean manufacturing, and the use of tools like Value Stream Mapping. Implementing these measures will enhance efficiency, reduce costs, and improve the competitiveness of the cottonseed oil industry in India. These insights have applicability to other edible oil sectors, aiding in addressing similar challenges in different contexts. [4]

This research paper's primary objective is to employ Value Stream Mapping (VSM) as a means to boost productivity within the automotive supplier network. By scrutinizing the existing and desired states of supplier shopfloor processes, the study identifies areas for enhancement, calculates takt times, and addresses factors conducive to increased production output and reduced inventory levels. The literature review centers on lean manufacturing and VSM, emphasizing waste reduction and operational efficiency. It covers lean manufacturing's origins in Japan, principles stressing waste reduction, various lean tools, VSM's role, and the paper's significance in applying VSM to enhance supplier-side productivity in India's motorcycle industry. Implementing VSM-based changes led to significant enhancements, such as the introduction of a Kanban system, reduced inventory levels, optimized manpower, and process improvements. These improvements resulted in increased production output, reduced lead times, and cost savings in the supply chain, ultimately achieving a lean and responsive operational environment. VSM, within a holistic lean framework, proves essential for genuine lean transformation by improving flow to the customer and reducing waste effectively. [3]

This paper introduces an innovative framework called "Improved Value Stream Mapping" (IVSM) that combines Value Stream Mapping with industrial engineering tools to enhance lean production in intricate manufacturing processes with merging flows, addressing the limitations of traditional VSM application. The paper discusses the core principles of Lean Production, emphasizing waste reduction and customer-centric manufacturing. The paper outlines a structured seven-step methodology for applying VSM to complex production systems with nonlinear value streams. This systematic approach aims to improve manufacturing processes and reduce lead times in intricate production environments. A case study in refrigerator manufacturing demonstrates the successful application of IVSM. By identifying critical value streams, creating current and future state maps, and implementing lean solutions, the authors achieved an impressive 68% reduction in production lead time, enhancing efficiency and customer responsiveness. The IVSM framework offers an advanced approach for implementing Lean Production in complex manufacturing processes, handling diverse product routings, and managing complex Bills of Materials and merging flows effectively. Future research avenues include economic measures and statistical/fuzzy analysis of manufacturing process variances. [1]

This research paper aims to present a case study on the implementation of lean principles at a small manufacturing company in the United States. The study focuses on identifying obstacles hindering progress toward lean transformation, utilizing the "5 whys" method to pinpoint root causes, and proposing solutions through kaizen events, Taguchi experiment design, and rabbit chasing techniques for process improvement. The literature review underscores the growing pressure on manufacturing firms to improve product quality, reduce delivery times, and minimize costs. It discusses lean manufacturing as a response to the shortcomings of mass production, emphasizing waste reduction and increased productivity through various lean tools and strategies. The study applies a structured approach, including kaizen, process mapping, value-stream mapping, waste identification, and design of experiments, to enhance manufacturing processes. This case study serves as a valuable reference for implementing lean systems in small manufacturing operations, showcasing its potential to enhance competitiveness. [2]

The primary objective is to apply the principles of 5S lean manufacturing to reduce non-value-adding operational time in a plastic bag manufacturing company based in Bangladesh. The study focuses on the blowing and printing operations within the manufacturing process. Through the meticulous application of the 5S methodology, the authors successfully achieved an 8% reduction in operational time in the blowing operation and an 18% reduction in the printing operation. The research underscores the importance of lean manufacturing principles, particularly the 5S approach, as a means to streamline processes, boost productivity, and cultivate a culture of efficiency and safety. The case study centers on a company engaged in plastic bag production for garment packaging, which faces challenges due to variable raw material costs and the need for efficient production. The results highlight reduced search times, enhanced workplace safety, and a cleaner working environment. [7]

This research delves into Lean Six Sigma, a data-driven philosophy aimed at preventing defects, enhancing quality, and achieving customer satisfaction. It combines Lean, focused on eliminating waste, with Six Sigma, which reduces process variation. The synthesis of these principles enhances process efficiency and quality. Researchers have empirically investigated these principles and their impact on organizational performance. This paper systematically compiles their work and explores future research aspects in Lean manufacturing. Value Stream Mapping (VSM) was a widely used tool, often in combination with others like DMAIC, SMED, and 5S. Integrated Lean Six Sigma and Total Quality Management (TQM) approaches to enhance customer satisfaction and profitability remain relatively unexplored, especially in small and medium enterprises. [8]

The study in plastic bag manufacturing industries systematically employs methodologies like Value Stream Mapping (VSM), 5S, Visual Control, Kaizen, and Reduced lot size to identify and eliminate waste in the plastic bag manufacturing process. The successful application of these methods results in increased productivity, a 10.4% reduction in Manufacturing Lead Time, and a significant 35% decrease in the cycle time for the "Cutting/Packaging" process. The study employs Lean methodology and Value Stream Mapping to address issues related to waste, setup delays, and inadequate packaging, aiming to enhance manufacturing productivity. In the implementation phase, the study addresses identified waste sources through lean principles and techniques, leading to a more efficient "future state" production system, reducing manufacturing lead time and enhancing overall productivity. The results show the successful implementation of lean tools and techniques, reducing cycle times, setup times, and manufacturing lead times, while increasing weekly productivity. [9]

Table 1: Literature review on the use of Lean tools by the various Authors

Author	*5S*	*Kaizen*	*Kanban*	*TPM*	*TQM*	*7 Waste*	*VSM*	*Poka Yoke*	*SMED*	*QMS*	*JIT*
Roriz and Nunes [10]	✓						✓	✓	✓		
Rosa and Silva [11]				✓		✓	✓				
Oliveira and Sá [12]					✓	✓	✓				
Costa and Silva [13]											
Cheung, Leong, and Vichare [14]	✓		✓		✓		✓				✓
Khawale [15]											✓
Lucherini and Rapaccini [16]							✓				
Alves, Junior, and Mendes [17]				✓							
Akhil Khajuria [18]											✓
Alaa Alshammari [19]											✓

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Brito and Ramos [20]											
Al-Akel Karam [21]									✓		✓
Veres and Marian [22]									✓		
Santosa and Sugarindra [23]			✓	✓			✓				
Ben Ruben and Vinodh [24]											✓

Note: TQM = Total quality management, VSM = Value stream mapping, TPM = Total productive maintenance, JIT = Just-in-Time, DMAIC = Define, measure, analyse, improve and control, SMED = Single minute exchange of die, QMS = Quality management system.

III. Application of Lean manufacturing tools

Through exhaustive literature survey based on the problems identified in the case industry 5S, Kaizen, VSM and Plant layout optimization tools has been selected for the implementation in the case industry. Firstly, VSM implemented to understand the current process and total value added and non-value added time for the production process. Through application of VSM, it is found that there is a lot of scope of improvement in terms of reducing the searching, transportation and setup time. For the reduction of searching time, 5S and workplace management principles were implemented in the industry. To reduce the transportation, Plant layout optimization tool were implemented and Kaizen were implemented to reduce the setup time and overall operations.

Implementation of Value stream mapping

Value stream mapping (VSM) has been implemented to map the entire process of production of Leno bags at the case industry. The process starts with the Raw Material inventory then Grinding, Mixing, Moulding, Stretching, Bobbin rolling, PP woven, Cutting, Sewing, Prepackaging, Packaging and Finish Product Inventory. The VSM uses various icons/ symbols for representation of various entities. In the implementation of VSM process, first we have to map the existing or current process and their associated time. The Current State VSM or CVSM provides a pictorial view of the entire production process flow. Also, CVSM gives us the scope of improvement possible in the production process.

Create a Current state VSM

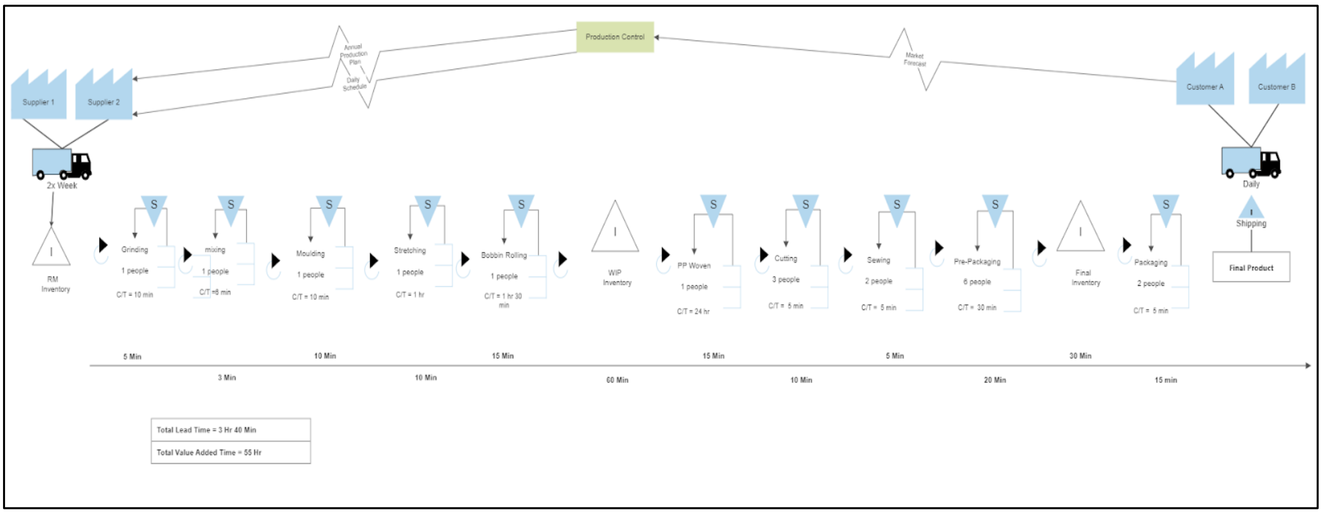

Fig.5. CSVSM of Leno bags

The implementation of VSM involved creating a Current State Value Stream Map (CVSM), which visually represented the entire Leno mesh bag production process. This map identified each step, from raw material selection to the final product's packaging and storage. The total lead time for the production process was measured and found to be 3 hours and 40 minutes. This served as a baseline to understand the efficiency of the existing workflow. The CVSM highlighted areas for improvement, such as excessive searching time, inefficient transportation, and prolonged setup times. It also brought attention to challenges related to the existing plant layout and organization of materials.

Future state VSM

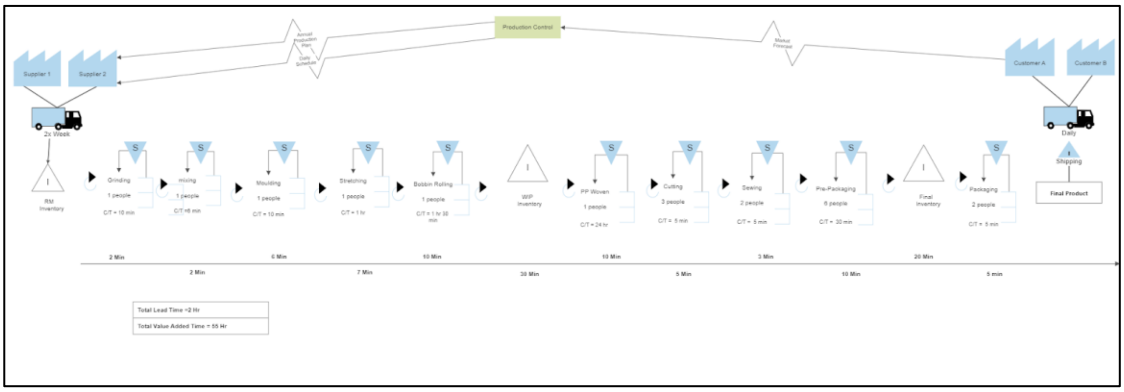

Fig.6. FSVSM of Leno bags

To address the identified issues, a series of lean manufacturing interventions were introduced, including 5S, Kaizen, and Plant Layout Optimization. These interventions aimed to enhance efficiency, reduce waste, and create a more organized and streamlined production environment.

After the implementation of lean interventions, a Future State Value Stream Map (FSVSM) has developed. The FSVSM indicated a significant reduction in lead time from 3 hours and 40 minutes to 2 hours, showcasing the positive impact of the implemented lean practices. The suggested plant layout, combined with 5S practices, was projected to reduce the total distance traveled within the plant, indicating improved material flow and accessibility.

Plant Layout Analysis

The examination of the current plant layout revealed that the total distance traveled within the facility was approximately 80.8 meters. This measurement provided insights into the movement of raw materials, work in progress, and finished products throughout the production process. It was observed that the arrangement of machinery, storage, and workstations could be a contributing factor to inefficiencies and longer lead times.

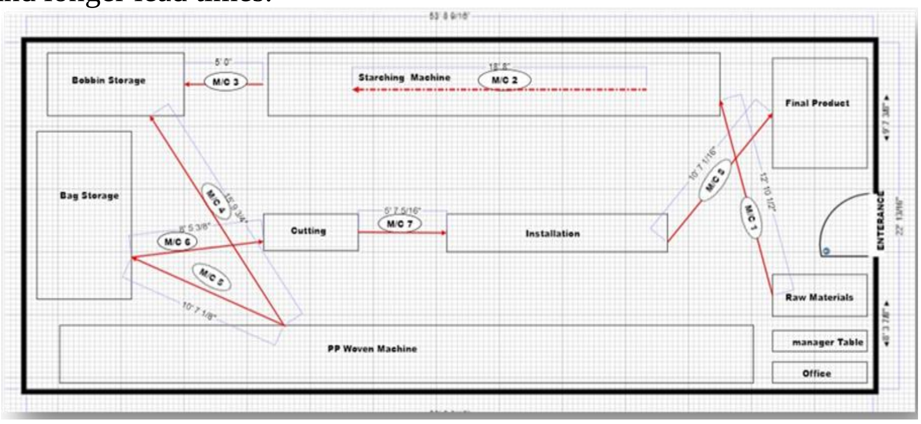

Fig.7. Current Plant Layout

A suggested plant layout was proposed with the aim of optimizing the arrangement of key elements in the production process. This involved considering the positioning of machinery, workstations, raw material storage, and finished product storage. The proposed layout was designed to minimize unnecessary movement and streamline the flow of materials, addressing the identified issues from the Value Stream Mapping (VSM) analysis.

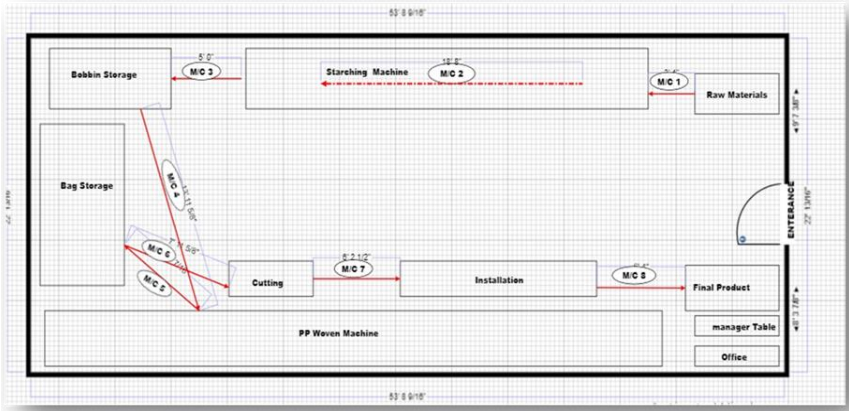

Fig.8. Suggested Plant Layout

The suggested plant layout, combined with the implementation of 5S practices, aimed to create a more streamlined and visually organized workspace. The total distance traveled within the plant was projected to decrease from 80.8 meters to 66.8 meters. This reduction in travel distance indicated a potential improvement in material flow and accessibility. By exchanging the positions of raw material and final product storage, the new layout aimed to create a more efficient and ergonomic workspace. This change was expected to contribute to overall operational efficiency, reducing lead times and enhancing the overall production process.

IV. Results and discussion

The implementation of Value Stream Mapping (VSM) in V.K Agropack's Leno mesh bag production process provided a comprehensive analysis of the existing workflow. The Current State VSM (CVSM) visually represented the production stages, revealing critical insights into both value-added and non-value-added activities. The total lead time for manufacturing Leno bags in the current state was identified as 3 hours and 40 minutes, serving as a baseline for assessing the effectiveness of subsequent lean manufacturing interventions. The CVSM highlighted several areas of improvement, including excessive searching time, inefficient transportation, and prolonged setup times. Additionally, issues related to the existing plant layout and organization of materials were identified as significant contributors to workflow inefficiencies.

To address these challenges, a combination of lean manufacturing tools, including 5S, Kaizen, and Plant Layout Optimization, was implemented. The introduction of 5S principles aimed to reduce searching time and enhance workplace organization through sorting, setting in order, systematic cleaning, standardizing, and sustaining. This intervention contributed to a more organized and visually efficient workplace. Plant Layout Optimization involved proposing a new arrangement for machinery, workstations, raw material storage, and finished product storage. This optimization aimed to minimize unnecessary movement and streamline material flow through the production process, addressing inefficiencies identified in the CVSM.

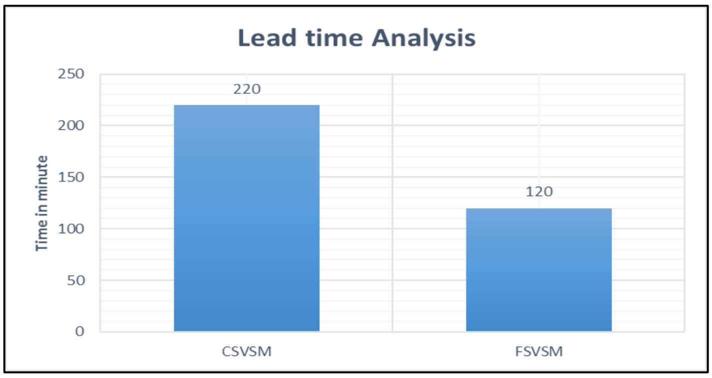

Fig.9. Comparison analysis of lead time through VSM

Kaizen principles were applied to streamline setup processes, particularly in the cutting and sewing stages. Continuous improvement initiatives were undertaken to reduce setup times and enhance overall operational efficiency. Following these lean manufacturing interventions, a Future State VSM (FSVSM) was created to visualize the expected improvements in the production process. The FSVSM projected a significant reduction in lead time from 3 hours and 40 minutes to 2 hours, demonstrating the positive impact of the implemented lean practices on overall efficiency. The suggested plant layout, combined with 5S practices, was projected to contribute to a more streamlined and visually organized workspace. The total distance traveled within the plant was expected to decrease from 80.8 meters to 66.8 meters, indicating a substantial improvement in material flow and accessibility.

V. Conclusions

Implementing lean manufacturing tools like 5S, Kaizen, and Value Stream Mapping made a significant positive impact on V.K Agropack's Leno mesh bag production. These changes led to real improvements in how quickly products were made, how the workplace was organized, and how materials moved through the process. Overall, it showed that with these tools, the production process could become more efficient, well-organized, and sustainable. The lessons learned from this study can be valuable for other manufacturing situations looking to improve productivity and operations through similar lean practices.

References

[1] Braglia, M., Carmignani, G., & Zammori, F. (2006). A new value stream mapping approach for complex production systems. International Journal of Production Research, 44(18–19), 3929–3952. https://doi.org/10.1080/00207540600690545

[2] Chen, J. C., Li, Y., & Shady, B. D. (2008). From value stream mapping toward a lean/sigma continuous improvement process: An industrial case study. International Journal of Production Research, 48(4), 1069–1086. https://doi.org/10.1080/00207540802484911.

[3] Seth *, D., & Gupta, V. (2005). Application of value stream mapping for lean operations and cycle time reduction: An indian case study. Production Planning & Control, 16(1), 44–59. https://doi.org/10.1080/09537280512331325281

[4] Seth, D., Seth, N., & Goel, D. (2008). Application of value stream mapping (VSM) for minimization of wastes in the processing side of supply chain of cottonseed oil industry in Indian context. Journal of Manufacturing Technology Management, 19(4), 529–550. https://doi.org/10.1108/17410380810869950

[5] Singh, B., Garg, S. K., & Sharma, S. K. (2010). Value stream mapping: Literature review and implications for Indian Industry. The International Journal of Advanced Manufacturing Technology, 53(5–8), 799–809. https://doi.org/10.1007/s00170-010-2860-7

[6] Chen, Y., Zhou, H., Huang, P., Chou, F., & Huang, S. (2019). A refined order release method for achieving robustness of non-repetitive dynamic manufacturing system performance. Annals of Operations Research, 311(1), 65–79. https://doi.org/10.1007/s10479-019-03484-9

[7] Shahriar, M. M., Parvez, M. S., Islam, M. A., & Talapatra, S. (2022). Implementation of 5s in a plastic bag manufacturing industry: A case study. Cleaner Engineering and Technology, 8, 100488. https://doi.org/10.1016/j.clet.2022.100488

[8] Makwana, A. D., & Patange, G. S. (2019). A methodical literature review on application of Lean & Six Sigma in various industries. Australian Journal of Mechanical Engineering, 19(1), 107–121. https://doi.org/10.1080/14484846.2019.1585225

[9] Issa, T. N. (2018). Lean manufacturing implementation in fused plastic bags industry. Proceedings of the 2018 10th International Conference on Information Management and Engineering. https://doi.org/10.1145/3285957.3285958

[10] Roriz, C., Nunes, E., & Sousa, S. (2017). Application of lean production principles and tools for quality improvement of production processes in a carton company. Procedia Manufacturing, 11, 1069–1076. https://doi.org/10.1016/j.promfg.2017.07.218

[11] Rosa, C., Silva, F. J. G., Ferreira, L. P., & Campilho, R. (2017). SMED methodology: The reduction of setup times for steel wire-rope assembly lines in the automotive industry. Procedia Manufacturing, 13, 1034–1042. https://doi.org/10.1016/j.promfg.2017.09.110

[12] Oliveira, J., Sá, J. C., & Fernandes, A. (2017). Continuous improvement through “Lean tools”: An application in a mechanical company. Procedia Manufacturing, 13, 1082–1089. https://doi.org/10.1016/j.promfg.2017.09.139

[13] Costa, T., Silva, F. J. G., & Pinto Ferreira, L. (2017). Improve the extrusion process in tire production using Six sigma methodology. Procedia Manufacturing, 13, 1104–1111. https://doi.org/10.1016/j.promfg.2017.09.171

[14] Cheung, W. M., Leong, J. T., & Vichare, P. (2017). Incorporating lean thinking and life cycle assessment to reduce environmental impacts of plastic injection moulded products. Journal of Cleaner Production, 167, 759–775. https://doi.org/10.1016/j.jclepro.2017.08.208

[15] Khawale, Y. S. (2017). “Implementation of Six Sigma Methodology for Piston Rod Manufacturing.” Global Research and Development Journal for Engineering 2 (3), February 2017, 14–18.

[16]Lucherini, F., & Rapaccini, M. (2017). Exploring the impact of lean manufacturing on flexibility in smes. Journal of Industrial Engineering and Management, 10(5), 919. https://doi.org/10.3926/jiem.2119

[17] Pinto Junior, M.J. and Mendes, J.V. (2017) ‘Operational practices of Lean Manufacturing: Potentiating environmental improvements’, Journal of Industrial Engineering and Management, 10(4), p. 550. https:// doi.org/10.3926/jiem.2268

[18] Akhil Khajuria, A. R. 2018. “Implementation of DMAIC Six Sigma Principle in Thermoforming for Improving Rate of Production.” International Journal For Research In Mechanical & Civil Engineering 4 (1): 13–22.

[19] Alaa Alshammari, S. R. 2018. “Quality Improvement in Plastic Injection Molding Industry: Applying Lean Six Sigma to SME in Kuwait.” Proceedings of the International Conference on Industrial Engineering and Operations Management, Bandung, Indonesia, March 6–8, 2018.

[20] Brito, M., and A. L. Ramos. 2017. “Combining SMED Methodology and Ergonomics for Reduction of Setup in a Turning Production Area.” Manufacturing Engineering Society International Conference 2017, MESIC 2017, Procedia Manufacturing 13: 1112–1119.

[21] Karam, A.-A. et al. (2018) ‘The contribution of Lean Manufacturing Tools to changeover time decrease in the pharmaceutical industry. A SMED project’, Procedia Manufacturing, 22, pp. 886–892. doi:10.1016/j.promfg.2018.03.125

[22] Veres (Harea), C. et al. (2018) ‘Case study concerning 5s method impact in an automotive company’, Procedia Manufacturing, 22, pp. 900–905. doi:10.1016/j.promfg.2018.03.127.

[23] Santosa, W.A. and Sugarindra, M. (2018) ‘Implementation of Lean Manufacturing to reduce waste in production line with value stream mapping approach and Kaizen in division sanding upright piano, case study in: Pt. X’, MATEC Web of Conferences, 154, p. 01095. doi:10.1051/matecconf/201815401095.

[24] Ben Ruben, R., Vinodh, S. and 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), pp. 1193–1211. doi:10.1080/09537287.2017.1357215.

[25] Atul Palange, Pankaj Dhatrak, ‘Lean manufacturing a vital tool to enhance productivity in manufacturing’, Materials Today: Proceedings, Volume 46, Part 1, 2021, pp. 729-736, ISSN 2214-7853, https://doi.org/10.1016/j.matpr.2020.12.193.