HAS LEAN MANUFACTURING REMAINED RELEVANT IN THE LAST HALF A DECADE?

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ABSTRACT

The Lean Manufacturing (LM) approach is founded on two fundamental principles: producing high-quality products at low production costs and satisfying customer demands. Toyota Motor Company introduced LM in the 1940s. With the advancement of technology, a wide range of products need to be efficiently produced to contend with various organisations. This study attempts to determine the significance of LM application in the industries through the last 5 years (2018-2023), using "LM" as the keyword for searching the published studies. The researchers identified 119 research articles using the PRISMA literature review process. After reviewing the papers, they recognised that LM was still relevant even today since the traditional LM tools can resolve 8 waste-related issues noted in the manufacturing line. These problems could be solved by combining the Simulation (SM) process with the Internet of Things (IoT4.0).

Keywords: *IoT 4.0, lean manufacturing, PRISMA, simulation, waste*

1.0 INTRODUCTION

Manufacturing and service industries are constantly working to satisfy the standards for implementing the lean manufacturing practices. This is because they need to enhance the performance of different aspects of their triple bottom line, which includes the economy, environment, and society. Despite major efforts, increasing the LM implementation in different organisations has not displayed the desired results (Maware et al., 2022). Each manufacturing organisation would attempt to maintain a dominant market share, and nearly all market sectors would compete for dominance. The primary goal of the organisations is to increase their profits, which are entirely dependent on their product and service quality (Faishal et al., 2023). As a result, the data collected throughout the engineering procedure can help the manufacturing sector acquire a competitive advantage in the market (Abd Rahman et al., 2020b). The LM philosophy is categorised as a production approach as it attempts to maximise the product value and eliminate wastes generated throughout the manufacturing procedure (Mohamad et al., 2023). Although, many researchers support that lean improves performance, however it does not consistently true (Jacobs et al., 2015). Many industries struggled to achieve improvement in operational and financial performance by using lean manufacturing (Rosetti et al., 2023). This situation occurred due to the nature of the supply chain including the information flows are complex (Akin et al., 2022). A majority of Malaysian companies are still competitive in the market as they have applied the LM processes (Soufhwee et al., 2019). In this study, the researchers have investigated the significance of implementing the LM practices in the industry over the last half-decade. During World War II, Japanese mechanical companies were struggling to discover new ways to meet their resource shortages. As a result, the Lean Manufacturing (LM) process was first introduced by the Toyota Motor Company in Japan in the 1940s. This idea soon emerged as an effective technique for solving the problem of resource scarcity. When Toyota's founders assessed and determined the benefits and drawbacks of the large production framework applied by American organisations, they proposed the Toyota Production System as an alternative to the traditional one. Engineer Ohno primarily aimed to decrease the waste generated at every purchasing and production phase (Mady et al., 2020). This research study aimed to answer the below-mentioned questions:

1.1: Is LM still important in the industry?
1.2: How does LM influence LM performance and productivity?
1.3: How can LM expand within the industry?

2.0 METHODOLOGY

The PRISMA technique used in this study generated a total of 251 papers between 2018 and 2023. Figure 1 displays a systematic review of all the results acquired by the PRISMA literature review approach. Phase 1 involved identification, wherein 251 studies were noted in the Scopus database when the researchers used "lean manufacturing" as the keyword. Phase 2 involved screening, wherein the researchers reviewed the article's title and abstract sections, and thereafter determined its eligibility. Finally, 119 papers were shortlisted for the systematic review. Figure 1 depicts the flowchart of the complete reviewing process included in this study.

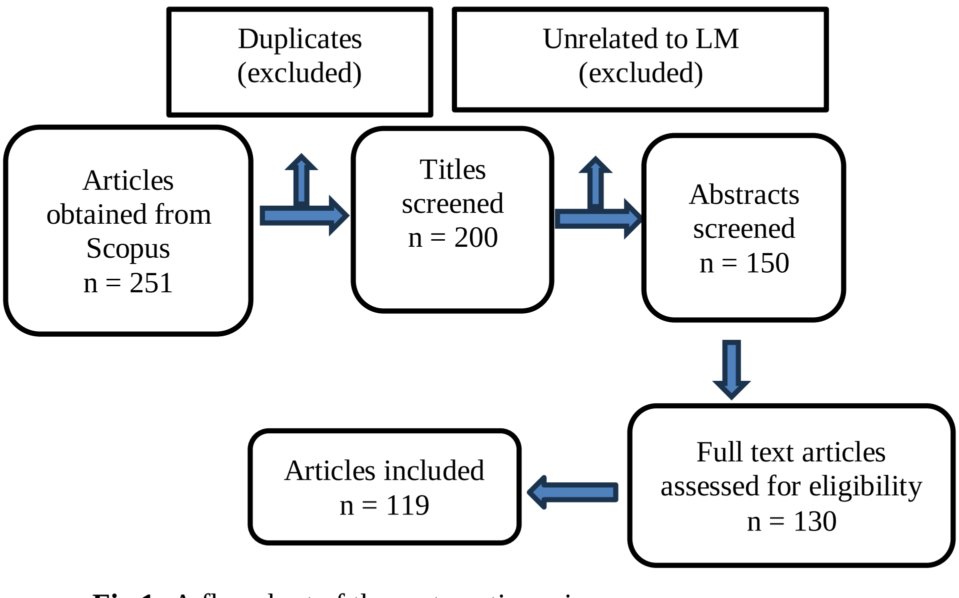

Fig 1: A flowchart of the systematic review process

3.0 FINDINGS AND DISCUSSION

The selection of research publications from 2018 to 2023 is to ensure that this research is relevant. Analysis has been done by answering three questions such as "What LM used, which type of waste identified in their research and does it combine LM tool with simulation or IoT". Hence, a summary of findings is as in Table 1 to Table 1.

Table 1: Summary of findings Value Stream Mapping (VSM)

Researcher	Type of Waste	Findings	Simulation	IoT
Fitri Ikatrinasari & Kosasih, 2018	M/W	The non- added value reduced by 46%		
Ahmad et al., 2018	UW/OP/M	The lead time reduced by 137 minutes		
Baby et al., 2018	W/I/M/T	The warehouse operations improved at least 40%	x	
Ikatrinasari et al., 2018	W/M	The lead time decrease by 15%		
Durakovic et al., 2018	W	VSM is used to identify waste and lean tools used to solve the waste issue		
Mubiena & Ma'Ruf, 2018	W/D/OVP	The sustainability of the product improved to 70%		
Kaiser et al., 2019	W/M/T/OVP	The takt time increase by 10%		
Amin et al., 2019	W/M/I/OVP	Improve the equipment efficiency, increasing productivity and reduced expenses		
Carvalho et al., 2019	W/I/OVP	Reduced the usage of inventory		
Mascarenhas et al., 2019	W/OVP	Waste reduced by 2.5% in a year		
Choudhary et al., 2019	W/M/OVP/T	The lead time decreased by 63% and the carbon footprint decreased by 77%		
Tarigan et al., 2019	W/M/T	The cycle efficiency increased by 34.15%		
Shams Bidhendi et al., 2019	W/I	Detect the bottleneck through VSM	x	
Abu et al., 2019	W/ OVP	VSM is capable to identify waste and eliminating waste by continuous improvement.		
Martin et al., 2020	W	Suggest an extension to the established VSM	x	x
Mahmood, 2020	D/OP	Lead time decreased by 45.19%	x	
Yang et al., 2020	W	Improved system performance by 6.42%	x	
Singh & Singh, 2020	I/OP/OVP	The cycle time reuduced by 87.59%	x	
Mishra et al., 2020	UW/D/ OVP	Reduce the cycle time by 30%	x	
Midilli & Elevli, 2020	W/ OVP	Stock level reduced by 50% while reducing the number of machines.	x	
Lin et al., 2020	OP/OVP	The total production lead time reduced by 11.10%	x	
Setiyawan et al., 2020	W/OVP	Increase the efficiency process by 22.81%	x	
Zahraee & Tolooie, et al., 2020	W/OVP	Reduced the production lead time from 17.5 days to 11 days	x	
Zahraee & Esrafilian, et al., 2020	W/OVP	Reduced the production lead time from 11 days to 7 days	x	
Mahmood et al., 2020	W	Applied Automated Ground Vehicle in manufacturing environment	x	
Arey et al., 2020	W	The lead time reduced from 6 days to 1 days		x
Mudgal et al., 2020	W/OVP	The efficiency of the production line increase from 43.48% to 70.7%		
Suryanti et al., 2020	W	79 minutes non value added time is been reduced		
Ngadono et al., 2020	W	Inventory in the building reduced from 7% to 3.2%		
Lamani et al., 2020	W/M	The lead time reduced by 29.06%		
Jasti et al., 2020	W	VSM can bring out positive impact toward process ratio, takt time ,process inventory level, total lead time and bottleneck time		
Lu et al., 2021	W	Value added time increased by 56.3%	x	

Lista et al., 2021	W	VSM is used to identify the flow of material for their materials	x	
Hernandez Marquina et al., 2021	W/M/I/OP/D	The transportation of the products reduced by 6.46 days		
Bouazza et al., 2021	W/M/I/OP	The resources usage reduced by 20%		
Acosta-Vargas et al., 2021	W	The efficiency improved by 76%	x	
Ferreira et al., 2022	W	Production lead time reduced from 12.81 minutes to 10.32 minutes	x	x
Miranda-López et al., 2022	W	Efficiency of the company increase by 24.39%	x	
Sullivan et al., 2022	W/OVP	VSM can be used to create the overview of the whole system to identify bottleneck of the system		x
Pekarcikova et al., 2022	W/M	Value added index increased from 0.0058% to 0.23%	x	
Hasnaoui et al., 2022	W	The total cycle time increased by 4.6%	x	
Gebeyehu et al., 2022	W	Process cycle efficiency is improved by 25.59%	x	
Poswa et al., 2022	W/D	Productivity improved by 4%	x	
Acosta-Ramirez et al., 2022	M	The net promoter score increase to 35.53%	x	
Zamalloa-Menacho et al., 2022	W/D/UW	Labor productivity increased by 23.91%	x	
Teriete et al., 2022	W	Proposed event based framework through digitalization of VSM	x	x
Guzel & Asiabi, 2022	W/D	The waiting times reduced to 65%		
Dinesh et al., 2022	W	The productivity of the process improved from 5.83% to 58.2%		
Naeemah & Wong, 2023	W/D	Used 12 lean manufacturing tool for improvements	x	
Chen et al., 2023	W/M/D	VSM used as a tool to visualize the system		x

Keywords: W = Waiting, M = Motion, I = Inventory, D = Defects, OP = Over processing, UW = Unutilized Worker, OVP = Overproduction, T= Transportation

Table 2: Summary of findings Single Minute Exchange of Die (SMED)

Researcher	Type of Waste	Findings	Simulation	IoT
Martins et al., 2018	W	Setup time reduction reduced more than 50%		
Karam et al., 2018	W	The change over time at bottleneck process decreased by 30% in 12 months		
Leme et al., 2018	W	The idle time reduced up to 88%		
Almanei et al., 2018	W	SMED can help in quick changeovers		
Antosz & Pacana, 2018	W	The changeover time shortened by 64%		
Perico et al., 2019	W/D	The framework assists SMED by providing automatic line setup procedures		
Vieira et al., 2020	D	The average setup time reduced by 20%		
Silva et al., 2020	OP	Reduce number of workers from 3 to 2	x	
Brito et al., 2020	M	Reduce setup time by 15%	x	
Pena et al., 2020	W/M/I	The changeover process reduced by 14.9%		
Lora-Soto et al., 2021	W	The setup time reduced by 42%		
Sahin & Kologlu, 2022	W	Setup time reduced more than 45%		
Ribeiro et al., 2022	W	Reduction of setup time by 58%		x
Amiel-Reategui et al., 2022	W	The machine preparation times reduced by 35%		
Orellana-Nuñez et al., 2022	W	The setup times reduced from 17.4 minutes to 11.4 minutes		
Liza Ludeña et al., 2022	W/I	Reduced 22.05 minutes during tool change time		

Almanei et al., 2022	W	The setup times optimized through the kanban push system	x	
Afonso et al., 2022	W	55% of the setup time is reduced.		
Braglia et al., 2023	W	The author improved the support decision making for SMED implementation by creating a new framework		
Habib et al., 2023	W/M/D	The setup time improves by 10.6%		
Toki et al., 2023	W	Time consumption to finish the production reduced from 1.8 hour to 1.4 hour		

Keywords: W = Waiting, M = Motion, I = Inventory, D = Defects, OP = Over processing, UW = Unutilized Worker OVP = Overproduction, T= Transportation

Table 3: Summary of findings Kanban

Researcher	Type of Waste	Findings	Simulation	IoT
Rocha et al., 2018	I/ OVP	Kanban cards is used to organize the work information	x	
Tortorella et al., 2020	D	Kanban is used to during inspection session		
Ahmad et al., 2020	W/M	Kanban is used to establish pull system		
Hemalatha et al., 2021	I	The framework assist the author detect the bottleneck to implement Kanban		
Faisal & Karthigeyan, 2021	W	Utilized 81.3% by the improved production line	x	
Pekarcikova et al., 2021	W/T	Increase in production times by 5%	x	
Masmali, 2021	W	Non value added time reduced from 23 days to 2 days		
Eberlein & Freitag, 2022	W/I	Work In Progress reduced by 37%	x	
Naciri et al., 2022	OP	The maintenance time reduced from 13.8% to 5.1%	x	x

Keywords: W = Waiting, M = Motion, I = Inventory, D = Defects, OP = over processing, UW = Unutilized Worker OVP = Overproduction, T= Transportation

Table 4: Summary of findings Kaizen

Researcher	**Type of Waste**	**Findings**	**Simulation**	**IoT**
Hartmann & Metternich, 2020	W/M/OP/T	Kaizen opportunities obtained through VSM		x
Dossou et al., 2020	I/M/ OVP	Improve the efficiency of the worker rate	x	x
Barrientos-Ramos et al., 2020	W	The lead times improved by 32%	x	
Fortuny-Santos et al., 2020	W	Kaizen by applying line balancing to reduce the takt time		
Banga et al., 2020	D	The cycle time reduced from 58.64 seconds to 50.2 seconds	x	
de Assis et al., 2021	W/OP	Decrease the total cycle time by 46.7 hour in total of the production line	x	
McKie et al., 2021	W	The process improves by 76.4%		x
Mofolasayo et al., 2022	W/OVP	Includes IoT in Kaizen		x
Oliveira et al., 2022	W/M/I	The quality and cost of the product improve by 94.5% and 25.3%	x	

Mallikharjuna et al., 2022	W/T	Utilization increased by 12.58%	x	
Cáceres-Gelvez et al., 2022	W	The setup time increased to 50.65%	x	
Rajab et al., 2022	W/D/OP/M/I/ UW	IoT 4.0 can solve the lean manufacturing waste issues	x	x
Diaz et al., 2022	W	Order fulfilments increase from 59.9% to 90.1%		
Dias et al., 2022	M/T	The waiting time decreased by 18%	x	
Mamede et al., 2023	W/M/I/OP/D	Automation is used in Kaizen implementation		

Keywords: W = Waiting, M = Motion, I = Inventory, D = Defects, OP = over processing, UW = Unutilized Worker OVP = Overproduction, T= Transportation

Table 5: Summary of findings Plan Do Check Act (PDCA)

Researcher	Type of Waste	Findings	Simulation	IoT
Realyvásquez-Vargas et al., 2018	D/T	Defects decreased to 65%		
Pereira et al., 2020	OP	Waste reduced from 12% to 4%		
Tilahun et al., 2020	W/OVP	PDCA is used as check and balance to the system		
Peças et al., 2021	W	Created a framework consist of PDCA combining with IoT		x
Lai et al., 2022	UW	The success rate of training increase to 95%		

Keywords: W = Waiting, M = Motion, I = Inventory, D = Defects, OP = Overprocessing, UW = Unutilized Worker OVP = Overproduction, T= Transportation

Table 6: Summary of findings Total Quality Management (TQM)

Researcher	Type of Waste	Findings	Simulation	IoT
Akhmatova et al., 2022	OP	TQM used to reduce environmental risk		
Komal & Saad, 2022	D	TQM strategies need to be implemented to increase performance and gain competitive advantage.		

Keywords: W = Waiting, M = Motion, I = Inventory, D = Defects, OP = Over processing, UW = Unutilized Worker OVP = Overproduction, T= Transportation

Table 7: Summary of findings Total Productive Maintenance (TPM)

Researcher	Type of Waste	Findings	Simulation	IoT
Chen et al., 2019	W	Improve environmental sustainability performance		
Pinto et al., 2020	W/D	Reduce the number of breakdowns failures by 23%		
Klimecka-Tatar & Ingaldi, 2022	W	Improve the efficiency of work		x
Lagos et al., 2022	W	The OEE increased by 3.47%		

Keywords: W = Waiting, M = Motion, I = Inventory, D = Defects, OP = Over processing, UW = Unutilized Worker OVP = Overproduction, T= Transportation

Table 8: Summary of findings Poka Yoke

Researcher	Type of Waste	Findings	Simulation	IoT
Antonelli & Stadnicka, 2019	D	Implemented poka yoke by giving operator a robot to handle		
Bucko et al., 2022	W/D	Placed sensor to detect error at the production line		

Keywords: W = Waiting, M = Motion, I = Inventory, D = Defects, OP = Over processing, UW = Unutilized Worker OVP = Overproduction, T= Transportation

Table 9: Summary of findings 5s

Researcher	Type of Waste	Findings	Simulation	IoT
Veres et al., 2018	W	5s improved the cleanliness of the production, increase the safety of the operator and increase quality of the product		
Yik & Chin, 2019	I	The shipment preparation reduced by 50%		
Verma & Jha, 2019	D	5s minimized the time to identify, gather tools and materials for the processing work.		
Paucar et al., 2020	D/M/UW	Productivity improved by 38%	x	
Arbieto et al., 2020	W	The lead time reduced by 6.79%	x	
Lira-Aquino et al., 2021	W/D	Cycle time reduced by 68%	x	
Silvestre et al., 2022	W/D/M/UW	Productivity improves by 38%	x	
Shahriar et al., 2022	W	The total operational time reduced by 8%		

Keywords: W = Waiting, M = Motion, I = Inventory, D = Defects, OP = Over processing, UW = Unutilized Worker OVP = Overproduction, T= Transportation

Table 10: Summary of findings OEE

Researcher	Type of Waste	Findings	Simulation	IoT
Abd Rahman et al., 2020	W	Combined simulation with OEE to improve decision making	x	x
Silva et al., 2021	W	Improved the existing process chain	x	
Iyer et al., 2023	W	OEE is used for the system indicator		x

Keywords: W = Waiting, M = Motion, I = Inventory, D = Defects, OP = Over processing, UW = Unutilized Worker OVP = Overproduction, T= Transportation

3.1 Types of Waste Produced by the Manufacturing Industry

The term "Lean Manufacturing" was coined several years after the introduction of the Toyota Production System. LM's primary purpose is to obtain comparable results while using lesser inputs. For example, few resources are required regarding time, space, human labour, materials, machinery, and expenditures. Some waste elimination strategies include Kanban, JIT, Kaizen, Value Stream Mapping (VSM), poka-yoke, and Total Productive Maintenance (TPM) (Wong et al. 2009). Figure

2 depicts the percentage of waste products produced in the industries. The industries generally produce 8 kinds of wastes, which include overproduction, transportation, defects, overprocessing, waiting, inventory, underutilized talent, and motion. According to the data shown in the figure, 45% of studies identified 'waiting' as their primary waste issue. Waiting is regarded as a significant issue in industries because when any process forms a bottleneck, the remaining processes have to wait for a long time before they are implemented.

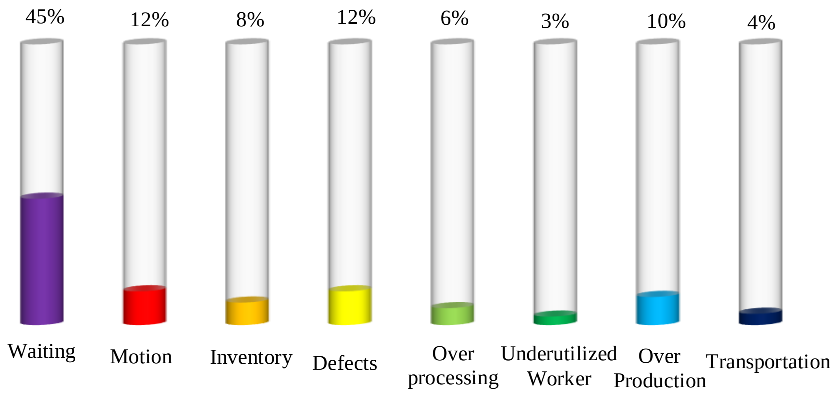

Fig 2: The types of waste produced by the manufacturing industry

3.2 The Effects of LM on Lean Manufacturing Performance (LMP) and Productivity

This study has investigated how LM helps in reducing waste within the industries. Studies have highlighted 10 kinds of LM strategies that can be applied for reducing wastes, which include poka-yoke, TPM, Total Quality Management (TQM), Overall Equipment Effectiveness (OEE), Kaizen, VSM, sort, straighten, shine, standardise, and sustain (5s), Plan-do-check-act (PDCA), Single-Minute Exchange of Die (SMED), and Kanban. Figure 3 illustrates the use of the LM tools in different organisations. It was noted that VSM was the most popular technique used for waste reduction, i.e., while OEE was the least popular, i.e., 2%. In their study, Durakovic et al. (2018) applied VSM to detect wastes and develop a waste-reduction solution. Other advantages of employing VSM as an LM tool include better process ratio, process inventory, overall lead times, takt time, and bottleneck time (Jasti et al., 2020).

Almanei et al. (2018) employed SMED to reduce waiting time by enhancing the changeover times. Another study developed a framework to support SMED by offering automated line setup processes to eliminate waiting delays and flaws (Perico et al., 2019). Hemalatha et al. (2021) developed a framework for detecting bottlenecks using Kanban and resolving inventory issues. Kanban can also be utilised as the pull system to address waiting and motion waste problems (Ahmad et al., 2020). In their study, Tilahun et al. (2020) applied PDCA as a check and balance in the system. Another study found that using PDCA to conduct training to resolve the unemployed worker issues increased the training success rate by 95% (Lai et al., 2022).

Pinto et al. (2020) employed TPM to reduce breakdown failures by 23% while addressing delay and defect problems. A different study found that TPM can increase environmental sustainability performance by minimising breakdown failure time (Chen et al., 2019). Komal & Saad (2022) mentioned that TQM was used to improve performance and achieve a competitive advantage within the industry. According to Akhmatova et al. (2022), TQM was adopted to minimise environmental risks by avoiding trash overprocessing.

Bucko et al. (2022) installed a sensor to identify errors in the production line to address the waiting and defect issues. Subsequently, poka-yoke could be used as a guideline by the operator for handling a robot with minimal material faults (Antonelli & Stadnicka 2019). According to Veres et al. (2018), 5s improves production cleanliness while also boosting operator safety and product quality. The 5s method can also be implemented to reduce the time required to locate and acquire tools and materials for processing tasks (Verma & Jha 2019).

LM emphasises the flexibility, efficiency, and improvement of the manufacturing process. To reduce waste, LM practitioners have to control their resources. Hence, the tools are powerful enough to be used without the addition of other technology. As a result, LM tools are still applicable and can be used in industries today.

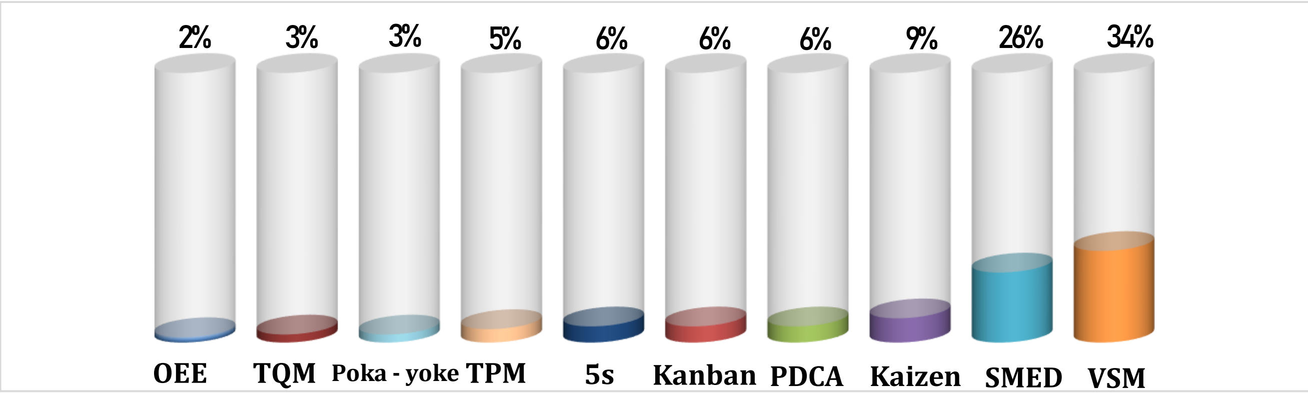

Fig 3: Types of LM tools

3.3 How Does the Industry Combine Lean Manufacturing (LM) with Simulation (SM)?

Figure 4 depicts the use of LM tools combined with SM to reduce industrial waste between 2018 and 2023. According to Figure 5, VSM was the most frequently used LM tool that helped in reducing industrial waste, whereas OEE was the least popular found in the reviewed paper. It was noted that 42 studies applied LM tools with SM to reduce industrial waste.

SM such as Arena, Flexsim and Simio was used in the reviewed studies as a decision support in the industry (Zahraee et al., 2020). SM was employed to model and recreate specific parts of the manufacturing procedure (Kelton, 2002). Data such as machine parameters and cycle times is needed for each operation to conduct the SM (Kelton, 2002). To develop SM model, data collection can be done by “stop-watch” method then a probability of distribution function can be fitted in each activity by the data collected to complete a SM model (Zahraee et al., 2021).

The researcher applied VSM and SM, reducing the value-added time from 3412 to 2415 s and the production lead time from 17.5 to 11 days. Takt time was also decreased from 250 to 192 s, resulting in increased output that was both timely and cost-effective (Zahraee et al., 2021). Paucar et al. (2020) used 5s to enhance the SM and process to develop a new scenario after applying the improvements, which resulted in increased profits and sales, and also satisfied the customer demands on time.

By combining SM and LM, a researcher can investigate hypothetical situations and "what if" inquiries without testing the changes, lowering the possibility of failure or improvement at the existing production line. It also aids in identifying production bottlenecks and determining which variables are essential for the manufacturing process.

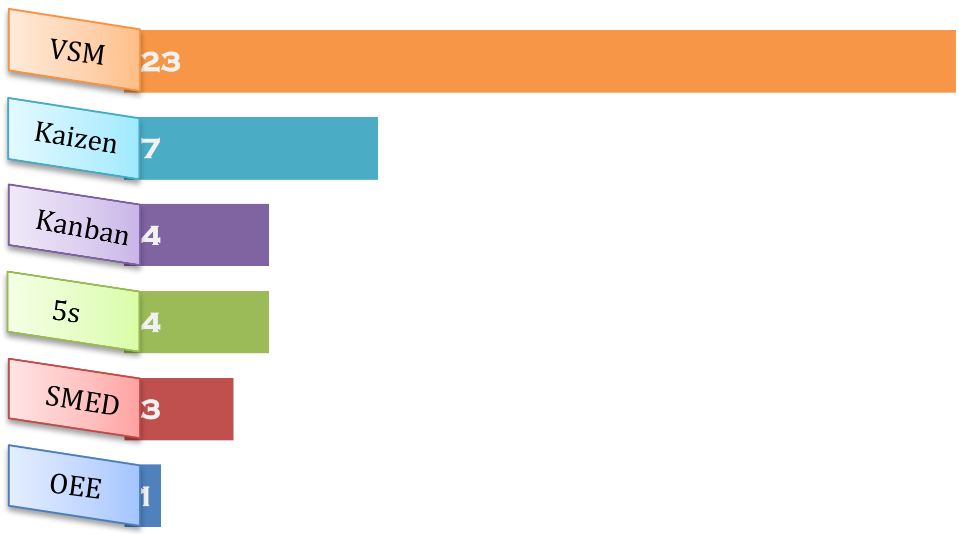

Fig 4: The combinations of LM tools with SM

3.4 Can the Internet of Things (IoT) 4.0 be implemented in lean manufacturing (LM)?

Figure 5 depicts the use of LM tools combined with IoT to reduce industrial waste between 2020 and 2023. According to Figure 6, VSM combined with IoT is the most popular LM tool that was used by researchers to overcome industrial wastes, while the TPM, SMED, Kaizen, PDCA, and OEE technologies were each employed by one researcher to overcome industrial waste. It was noted that 12 researchers employed the LM technique in combination with IoT to reduce industrial wastes.

In an earlier study, the researchers developed a framework for Digitalisation Support Environmental Sustainability based on LM principles, which applied VSM as the visualisation tools with IoT to achieve zero emissions by maximising energy and resource utilisation (Chen et al., 2023). The researcher developed the PDCA 4.0 framework wherein the IoT was used for applying data analytics using the real time data acquired from the machine to generate the PDCA database (Peças et al., 2021). In their study, Iyer et al. (2023) integrated IoT4.0 into OEE by developing a novel software that determines efficacy using OEE strategies.

IoT4.0 offers novel advantages to the LM tool, like process efficiency *via* automation, which increases production and streamlines industrial processes. In addition, it provides real-time data monitoring, which could help LM practitioners make better decisions and enhance the manufacturing line.

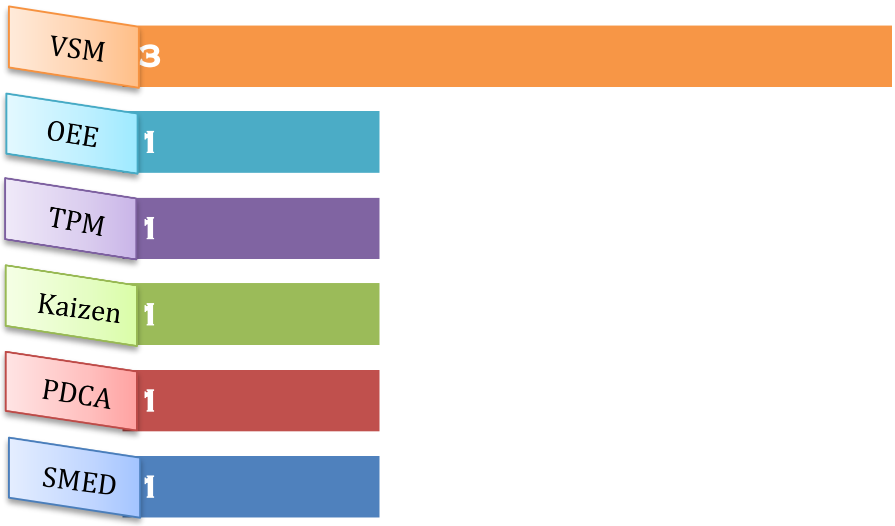

Fig 5: The combinations of LM tools with IoT between 2020 to 2023

3.5 Can Lean Manufacturing (LM) Be Combined with Simulation (SM) and the Internet of Things (IoT) 4.0?

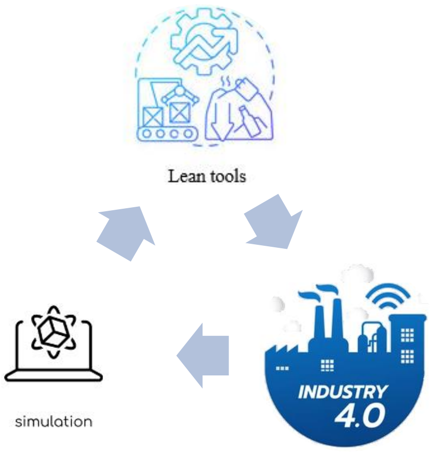

Fig 6: The combinations of LM, SM, and IoT4.0

Figure 6 depicts the use of LM tools, SM, and IoT to reduce industrial wastes between 2020 and 2022. Figure 7 depicts the use of LM tools when combined with SM and IoT, demonstrating that VSM is the most popular LM tool that was combined with SM and IoT strategies by researchers for overcoming industrial wastes. On the other hand, Kanban and OEE were employed by one researcher each for overcoming the industrial wastes. It was noted that 7 researchers applied LM tools in combination with the SM and IoT techniques for reducing industrial waste.

The article review identified 6 different frameworks that were combined with LM, SM, and IoT. The researcher suggested a framework known as the cyber-physical production system, which encompasses data collection, feedback, cyber world, and the actual world. Sensors will collect data and use it instantly for SM in the cyber world while generating feedback that enhances the efficiency of machines. Additional VSM analysis will be conducted using the examined data to improve the technique further (Martin et al., 2020). In an earlier study, the researcher integrated hybrid SM with VSM, which blends the discontinuous vent and agent-based modelling SM processes (Ferreira et al., 2022). In a different study, the researchers designed an event-based structure to digitalise VSM that includes an interface between collection and processing, which leads to the development of multiple VSM apps with customisable reports (Teriete et al., 2022). In an earlier study, the researcher used Jidoka principles to halt the production line if they noted a problem immediately, and the machine would directly alert engineers to the problem. The researcher also employed arena SM for simulating the improvement and applied SMED as a solution for improving the production line (Naciri et al., 2022). The researcher used Kaizen to improve the healthcare system by increasing the collaboration between humans and robots to deliver food and medicine. Dossou et al. (2020) used FlexSim SM to model automated intelligent vehicle actions. The author develops a framework model-driven decision support system that uses data simulation and communication technology to optimise industrial processes. An earlier study collected OEE data using an internet networking system and simulated the predictions of the improved outcomes (Abd Rahman et al., 2020b).

The combination of SM, LM, and IoT4.0 technologies offers major advantages to the industry since IoT4.0 may offer real-time data to LM practitioners. Then, using LM tools, they can employ SM to model "what if" scenarios and implement changes in the manufacturing line. Hence, precise data and SM will reduce the likelihood of failure.

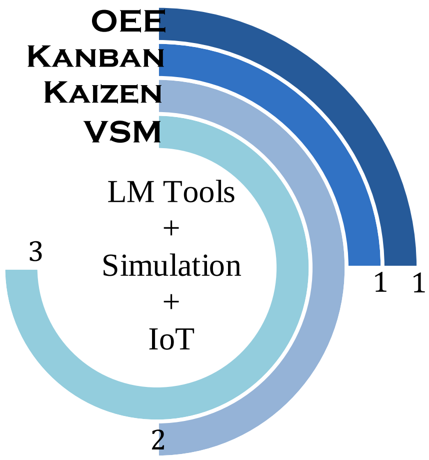

Fig 7: The combinations of LM tools with SM and IoT between 2020 to 2022

4.0 CONCLUSIONS

In this study, the researchers reviewed several research papers that implemented LM. They reviewed 119 research articles related to the LM production process that were published between 2018 and 2023. This review focuses on the use of LM tools, waste generated during the production process, findings for improvement, and determined the relevance of LM even today. Traditional LM techniques are still useful for reducing waste in a manufacturing line, where 52% of the researchers applied LM tools to resolve industrial bottlenecks between 2018 and 2023. In future, LM would be integrated with digital technologies to optimise the manufacturing line by integrating the LM tools with SM and IoT technologies. 6% of the researchers have already stated that the LM tool can be utilised with SM and IoT strategies, while 42% of the researchers have already integrated SM with LM tools. According to this study, the LM tools can eliminate all kinds of industrial waste and promote environmental sustainability by lowering waste generation during the production process. For instance, when production decreases, less energy is required to manufacture a product, enhancing environmental sustainability. By combining LM with modern SM and IoT4.0 tools and technologies, LM practitioners can address real-time issues and adapt to complicated production lines. It was noted that LM was compatible with IoT4.0 technology as it offers metrics and outcomes for monitoring the production line, resulting in an accurate perspective of the production line. In future, LM should be integrated with the SM and IoT4.0 technologies as they propel LM to new heights. IoT4.0 provides real-time data to LM practitioners, which is essential since real-time data shows a higher accuracy compared to the time study data. Thereafter, LM can be used as an effective tool for improving production by utilising real-time data, and subsequently, SM will offer 'what if' scenario data to the LM practitioners.

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REFERENCES

Abd Rahman, M. S., Mohamad, E., & Abdul Rahman, A. A. (2020a). Enhancement of Overall Equipment Effectiveness (OEE) Data by Using Simulation as Decision Making Tools for Line Balancing. *Indonesian Journal of Electrical Engineering and Computer Science*, *18*(2), 1040–1047.

Abd Rahman, M. S., Mohamad, E., & Abdul Rahman, A. A. (2020b). Enhancement of Overall Equipment Effectiveness (OEE) Data by Using Simulation as Decision Making Tools for Line Balancing. *Indonesian Journal of Electrical Engineering and Computer Science*, *18*(2), 1040–1047.

Abu, F., Gholami, H., Mat Saman, M. Z., Zakuan, N., & Streimikiene, D. (2019). The Implementation of Lean Manufacturing in The Furniture Industry: A Review and Analysis on the Motives, Barriers, Challenges, and The Applications. *Journal of Cleaner Production*, *234*, 660–680.

Acosta-Ramirez, D., Herrera-Noel, A., Flores-Perez, A., Quiroz-Flores, J., & Collao-Diaz, M. (2022). Application of Lean Manufacturing Tools Under DMAIC Approach to Increase The NPS in A Real Estate Company: A Research in Peru. *ACM International Conference Proceeding Series*, 70–76.

Acosta-Vargas, P., Chicaiza-Salgado, E., Acosta-Vargas, I., Salvador-Ullauri, L., & Gonzalez, M. (2021). Towards Industry Improvement in Manufacturing with DMAIC. *Advances in Intelligent Systems and Computing, 1273 AISC*, 341–352.

Afonso, M., Gabriel, A. T., & Godina, R. (2022). Proposal of an Innovative Ergonomic SMED Model in an Automotive Steel Springs Industrial Unit. *Advances in Industrial and Manufacturing Engineering, 4,1000075.*

Ahmad, A. N. A., Ahmad, M. F., Hamid, N. A., Ngadiman, Y., Pakir, M. I., Nawanir, G., Bakri, A., & Rahim, M. A. (2020). Green Lean Practices Towards Increasing Operation Value of Manufacturing Company. *International Journal of Integrated Engineering*, *12*(7), 128–133.

Ahmad, R., Masse, C., Jituri, S., Doucette, J., & Mertiny, P. (2018). Alberta Learning Factory for Training Reconfigurable Assembly Process Value Stream Mapping. *Procedia Manufacturing*, *23*, 237–242.

Akhmatova, M. S., Deniskina, A., Akhmatova, D. M., & Kapustkina, A. (2022). Green SCM and TQM for Reducing Environmental Impacts and Enhancing Performance in The Aviation Spares Supply Chain. *Transportation Research Procedia*, *63*, 1505–1511.

Akin Ateş M, Suurmond R, Luzzini D, Krause D. (2022). Order from Chaos: A Meta-Analysis of Supply Chain Complexity and Firm Performance. *J Supply Chain Manag 58*(1), 3–30

Almanei, M., Oleghe, O., Afy-Shararah, M., & Salonitis, K. (2022). Implementing Pull Manufacturing in Make-To-Order Environments. *Advances in Transdisciplinary Engineering*, *25*, 334–341.

Almanei, M., Salonitis, K., & Tsinopoulos, C. (2018). A Conceptual Lean Implementation Framework Based on Change Management Theory. *Procedia CIRP*, *72*, 1160–1165.

Amiel-Reategui, G., Vargas-Tapia, E., & Viacava-Campos, G. (2022). Increase The Efficiency of the Machine Production Process in Textile Companies Through a Model Based on TPM and SMED. *Proceedings of The LACCEI International Multi-Conference for Engineering, Education and Technology*, *2022-July,186*.

Amin, A. N. M., Wan Mahmood, W. H., Kamat, S. R., & Kamalrudin, M. (2019). Continuous Improvement Through Lean Using VSM for Application in Machining Based Product Company. *International Journal of Recent Technology and Engineering*, *8*(2 Special Issue 11), 778–784.

Antonelli, D., & Stadnicka, D. (2019). Predicting and Preventing Mistakes in Human-Robot Collaborative Assembly. *IFAC-Papersonline*, *52*(13), 743–748.

Antosz, K., & Pacana, A. (2018). Comparative Analysis of the Implementation of The SMED Method On Selected Production Stands. *Tehnicki Vjesnik*, *25*, 276–282.

Arbieto, M., Vasquez, J., Altamirano, E., Alvarez, J., & Marcelo, E. (2020, September 30). Lean Manufacturing Tools Applied to The Metalworking Industry in Perú. *2020 Congreso Internacional De Innovacion Y Tendencias En Ingenieria, CONIITI 2020 - Conference Proceedings*.

Arey, D., Le, C. H., & Gao, J. (2020). Lean Industry 4.0: A Digital Value Stream Approach to Process Improvement. *Procedia Manufacturing*, *54*, 19–24.

Baby, B., Prasanth, N., & Jebadurai, S. S. (2018). Implementation of Lean Principles to Improve the Operations of a Sales Warehouse In The Manufacturing Industry. *International Journal of Technology*, *9*(1), 46–54.

Banga, H. K., Kumar, R., Kumar, P., Purohit, A., Kumar, H., & Singh, K. (2020). Productivity Improvement in Manufacturing Industry By Lean Tool. *Materials Today: Proceedings*, *28*, 1788–1794.

Barrientos-Ramos, N., Tapia-Cayetano, L., Maradiegue-Tuesta, F., & Raymundo, C. (2020). Lean Manufacturing Model of Waste Reduction Using Standardized Work to Reduce the Defect Rate in Textile Mses. *Proceedings Of The 18th LACCEI International Multi-Conference for Engineering, Education and Technology virtual edition.*

Bibliographic Data: Rewers, P., Trojanowska, J., & Chabowski, P. (2016). *Tools and Methods of Lean Manufacturing-A Literature Review*. *PLoS ONE 16*(12).

Bouazza, Y., Lajjam, A., & Dkhissi, B. (2021). The Impact of Lean Manufacturing on Enviromental Performance in Moroccan Automotive Industry. In *Management Systems in Production Engineering* (Vol. 29, Issue 3, Pp. 184–192).

Braglia, M., Di Paco, F., & Marrazzini, L. (2023). A New Lean Tool for Efficiency Evaluation in SMED Projects. *International Journal of Advanced Manufacturing Technology*, *127*(1–2), 431–446.

Brito, M., Vale, M., Leão, J., Ferreira, L. P., Silva, F. J. G., & Gonçalves, M. A. (2020). Lean and Ergonomics Decision Support Tool Assessment in A Plastic Packaging Company. *Procedia Manufacturing*, *51*, 613–619.

Bucko, M., Schindlerova, V., & Krupova, H. (2022). Application of Lean Manufacturing Methods in the Production of Ultrasonic Sensor. *Tehnicki Vjesnik*, *29*(5), 1671–1677.

Cáceres-Gelvez, S., Arango-Serna, M. D., & Zapata-Cortés, J. A. (2022). Evaluating the Performance of a Cellular Manufacturing System Proposal for the Sewing Department of a Sportswear Manufacturing Company: A Simulation Approach. *Journal of Applied Research and Technology*, *20*(1), 68–83.

Carvalho, C. P., Carvalho, D. S., & Silva, M. B. (2019). Value Stream Mapping as a Lean Manufacturing Tool: A New Account Approach for Cost Saving in A Textile Company. *International Journal of Production Management and Engineering*, *7*(1), 1–12.

Chen, P. K., Fortuny-Santos, J., Lujan, I., & Ruiz-De-Arbulo-López, P. (2019). Sustainable Manufacturing: Exploring Antecedents and Influence of Total Productive Maintenance and Lean Manufacturing. *Advances in Mechanical Engineering*, *11*(11).

Chen, X., Kurdve, M., Johansson, B., & Despeisse, M. (2023). Enabling The Twin Transitions: Digital Technologies Support Environmental Sustainability Through Lean Principles. *Sustainable Production and Consumption*, *38*, 13–27.

Cherrafi, A., Elfezazi, S., Hurley, B., Garza-Reyes, J. A., Kumar, V., Anosike, A., & Batista, L. (2019). Green and Lean: A Gemba–Kaizen Model for Sustainability Enhancement. *Production Planning and Control*, *30*(5–6), 385–399.

Chiarini, A. (2015). Improvement of OEE Performance Using A Lean Six Sigma Approach: An Italian Manufacturing Case Study. *International Journal of Productivity and Quality Management*, *16*(4), 416–433.

Chiarini, A., & Baccarani, C. (2016). TQM and Lean Strategy Deployment in Italian Hospitals: Benefits Related to Patient Satisfaction and Encountered Pitfalls. *Leadership in Health Services*, *29*(4), 377–391.

Chong, J. Y., & Perumal, P. A. (2020). Conceptual Framework for Lean Manufacturing Implementation in SMEs with PDCA Approach. *Lecture Notes in Mechanical Engineering*, 410–418.

Choudhary, S., Nayak, R., Dora, M., Mishra, N., & Ghadge, A. (2019). An Integrated Lean and Green Approach for Improving Sustainability Performance: A Case Study of a Packaging Manufacturing SME in the U.K. *Production Planning and Control*, *30*(5–6), 353–368.

Das, T. K. (2020). *Industrial Environmental Management: Engineering, Science, and Policy, First Edition.*

De Assis, R. F., De Santa-Eulalia, L. A., Ferreira, W. De P., Armellini, F., Anholon, R., Rampasso, I. S., & Santos, J. G. C. L. Dos. (2021). Translating Value Stream Maps into System Dynamics Models: A Practical Framework. *International Journal of Advanced Manufacturing Technology*, *114*(11–12), 3537–3550.

Deshmukh, M., Gangele, A., Gope, D. K., & Dewangan, S. (2022). Study and Implementation of Lean Manufacturing Strategies: A Literature Review. *Materials Today: Proceedings*, *62*, 1489–1495.

Dias, A. S. M. E., Antunes, R. M. G., Abreu, A., Anes, V., Navas, H. V. G., Morgado, T., & Calado, J. M. F. (2022). Utilization of The Arena Simulation Software and Lean Improvements in The Management of Metal Surface Treatment Processes. *Procedia Computer Science*, *204*, 140–147.

Diaz, M. I., Dioses, G., & Ramos, E. (2022). Lean Manufacturing Model to Improve the Order Fulfillment in a Company in the Wine Sector. *Proceedings of The LACCEI International Multi-Conference for Engineering, Education and Technology, 2022-December*.

Dinesh, S. N., Shalini, M., Vijay, M., Vijey Mohan, R. C., Saminathan, R., & Subbiah, R. (2022). Improving the Productivity in Carton Manufacturing Industry Using Value Stream Mapping (VSM), volume 66, part 3, 1221- 1227.

Dossou, P. E., Rafael, P., Cristiane, S., & Joao, C. J. (2020). How to Use Lean Manufacturing for Improving a Healthcare Logistics Performance. *Procedia Manufacturing*, *51*, 1657–1664.

Durakovic, B., Demir, R., Abat, K., & Emek, C. (2018). Lean Manufacturing: Trends and Implementation Issues. *Periodicals of Engineering and Natural Sciences*, *6*(1), 130–139.

Eberlein, S., & Freitag, M. (2022). A Pull Principle for The Material Supply of Low-Volume Mixed-Model Assembly Lines. *Procedia CIRP*, *107*, 1385–1390.

Faisal, A. M., & Karthigeyan, L. (2021). Data Analytics Based Prescriptive Analytics for Selection of Lean Manufacturing System. *Proceedings of The 6th International Conference On Inventive Computation Technologies, ICICT 2021*, 464–466.

Faishal, M., Mohamad, E., Mukti Asih, H., Rahman, A. A. A., Zul Ibrahim, A., & Adiyanto, O. (2023). The Use of Lean Six Sigma to Improve the Quality of Coconut Shell Briquette Products. *Multidisciplinary Science Journal*, Volume *6* issue 1.

Ferreira, W. De P., Armellini, F., Santa-Eulalia, L. A. De, & Thomasset-Laperrière, V. (2022). Extending The Lean Value Stream Mapping to The Context of Industry 4.0: An Agent-Based Technology Approach. *Journal of Manufacturing Systems*, *63,* 1–14.

Fitri Ikatrinasari, Z., & Kosasih, D. (2018). Improving Quality Control Process Through Value Stream Mapping. In *International Journal of Engineering & Technology* (Vol. 7, Issue 2, 219-225).

Fortuny-Santos, J., Ruiz-De-Arbulo-López, P., Cuatrecasas-Arbós, L., & Fortuny-Profitós, J. (2020). Balancing Workload and Workforce Capacity in Lean Management: Application to Multi-Model Assembly Lines. *Applied Sciences (Switzerland)*, *10*(24), 1–21.

Gebeyehu, S. G., Abebe, M., & Gochel, A. (2022). Production Lead Time Improvement Through Lean Manufacturing. *Cogent Engineering*, *9*(1).

Gunduz, M., & Naser, A. F. (2017). Cost Based Value Stream Mapping as A Sustainable Construction Tool for Undergraound Pipeline Construction Projects. *Sustainability (Switzerland)*, *9*(12),2184.

Guzel, D., & Asiabi, A. S. (2022). Increasing Productivity of Furniture Factory with Lean Manufacturing Techniques (Case Study). *Tehnicki Glasnik*, *16*(1), 82–92.

Habib, M. A., Rizvan, R., & Ahmed, S. (2023). Implementing Lean Manufacturing for Improvement of Operational Performance in A Labeling and Packaging Plant: A Case Study in Bangladesh. *Results in Engineering*, *17, 100818*.

Hartmann, L., & Metternich, J. (2020). Waste in Value Streams Caused by Information Flow: An Analysis of Information Flow Barriers and Possible Solutions. *Procedia Manufacturing*, *52,* 121–126.

Hasnaoui, F. Z., Attni, S., & Aboueljinane, L. (2022). Improving and Optimizing Industrial Performances of a Fertilizer Producer: Application of the Value Stream Mapping Tool and the Discrete Event Simulation Method on a Chemical Treatment Plant. *ACM International Conference Proceeding Series*, 85–91.

Helleno, A. L., De Moraes, A. J. I., & Simon, A. T. (2017). Integrating Sustainability Indicators and Lean Manufacturing to Assess Manufacturing Processes: Application Case Studies in Brazilian Industry. *Journal of Cleaner Production*, *153*, 405–416.

Hemalatha, C., Sankaranarayanasamy, K., & Durairaaj, N. (2021). Lean and Agile Manufacturing for Work-In-Process (WIP) Control. *Materials Today: Proceedings*, *46*, 10334–10338.

Hernandez Marquina, M. V., Zwolinski, P., & Mangione, F. (2021). Application of Value Stream Mapping Tool to Improve Circular Systems. *Cleaner Engineering and Technology, volume 5, 100270*.

Ikatrinasari, Z. F., Hasibuan, S., & Kosasih, K. (2018). The Implementation Lean and Green Manufacturing Through Sustainable Value Stream Mapping. *IOP Conference Series: Materials Science and Engineering, volume 1,453.*

Iyer, S. V, Sangwan, K. S., & Dhiraj. (2023). Digitalization: A Tool for the Successful Long-Term Adoption of Lean Manufacturing. *Procedia CIRP*, *116*, 245–250.

Jacobs BW, Swink M, Linderman K. (2015) Performance Effects of Early and Late Six Sigma Adoptions.

Jasti, N. V. K., Kota, S., & Sangwan, K. S. (2020). An Application of Value Stream Mapping in Auto-Ancillary Industry: A Case Study. *TQM Journal*, *32*(1), 162–182.

Kaiser, J., Urnauer, C., & Metternich, J. (2019). A Framework for Planning Logistical Alternatives in Value Stream Design. *Procedia CIRP*, *81*, 180–185.

Karam, A. A., Liviu, M., Cristina, V., & Radu, H. (2018). The Contribution of Lean Manufacturing Tools to Changeover Time Decrease in The Pharmaceutical Industry. A SMED Project. *Procedia Manufacturing*, *22*, 886–892.

Kelton WD. (2002). Simulation with ARENA: McGraw-Hill.

Klimecka-Tatar, D., & Ingaldi, M. (2022). Digitization of Processes in Manufacturing SMEs - Value Stream Mapping and OEE Analysis. *Procedia Computer Science*, *200,* 660–668.

Komal, S., & Saad, S. M. (2022). The Role of Total Quality Management in Textile Industry. *Advances in Transdisciplinary Engineering*, *25*, 207–214.

Koskela, L. J., & Koskela, L. (2004). *Moving On-Beyond Lean Thinking Integrating Planning and Control Activities Between Design and Construction Stages in Overlapped Projects View Project Energy and Cost Efficient Design of Buildings View Project Moving-On-Beyond Lean Thinking*. *Lean Construction Journal, Volume 1,1.*

Kumar, N., Shahzeb Hasan, S., Srivastava, K., Akhtar, R., Kumar Yadav, R., & Choubey, V. K. (2022). Lean Manufacturing Techniques and Its Implementation: A Review. *Materials Today: Proceedings*, *64(3), 1188-1192.*

Lagos, M., Luis, K. N., & Ramos, E. (2022). Applying Lean Manufacturing Tools to Minimize Waste in A Mass Consumption Food Company. *Proceedings of The LACCEI International Multi-Conference for Engineering, Education and Technology*, *2022-December*.

Lai, F., Xie, D., Weng, Y., Mai, S., Du, J., Han, Y., & Zhang, Y. (2022). Application of Plan-Do-Check-Act Management to Improve First-Attempt Insertion Success Rates of Internal Jugular Vein Catheterization for Standardized Training Residents in an Intensive Care Unit. *BMC Medical Education*, *22(1),420.*

Lamani, E., Ahmad, A. N. A. Bin, & Ahmad, M. F. Bin. (2020). Lean Manufacturing Implementation to Reduce Waste On Weighing Scale Assembly Line. *International Journal of Emerging Trends in Engineering Research*, *8*(1 1.2 Special Issue), 40–51.

Leksic, I., Stefanic, N., & Veza, I. (2020). The Impact of Using Different Lean Manufacturing Tools on Waste Reduction. *Advances in Production Engineering and Management*, *15*(1), 81–92.

Leme, R. D., Nunes, A. O., Message Costa, L. B., & Silva, D. A. L. (2018). Creating Value with Less Impact: Lean, Green and Eco-Efficiency in a Metalworking Industry Towards a Cleaner Production. *Journal of Cleaner Production*, *196*, 517–534.

Lian, Y. H., & Van Landeghem, H. (2007). Analysing The Effects of Lean Manufacturing Using a Value Stream Mapping-Based Simulation Generator. *International Journal of Production Research*, *45*(13), 3037–3058.

Lin, C. K. X., Helmi, S. A., Hisjam, M., & Ali, A. (2020). Implementation of Lean Manufacturing in an Electronic Assembly Company. *AIP Conference Proceedings*, *2217, 030198*.

Lira-Aquino, A., Miranda-Poccori, E., Altamirano-Flores, E., & Cardenas-Rengifo, L. (2021). Improving Production Process Efficiencies at A Peruvian Company Through a Lean Manufacturing Implementation Model. *ACM International Conference Proceeding Series*, 117–122.

Lista, A. P., Tortorella, G. L., Bouzona, M., Mostafad, S., & Romeroe, D. (2021). Lean Layout Design: A Case Study Applied to the Textile Industry. *Production, 31, e20210090*.

Liza Ludeña, B., Paulino Fierro, G., & Altamirano Flores, E. (2022). Design of a Lean Manufacturing Model to Reduce Order Delivery in A Textile Mype. *Proceedings of The LACCEI International Multi-Conference for Engineering, Education and Technology, 2022-December,93*.

Lora-Soto, A., Morales-Silva, C., Llontop-Jesus, J., & Mamani, N. (2021). Process Improvement Proposal for The Reduction of Machine Setup Time In A Copper Transformation Company Using Lean Manufacturing Tools. *Advances in Intelligent Systems and Computing, 1253 AISC*, 585–591.

Lu, Y., Liu, Z., & Min, Q. (2021). A Digital Twin-Enabled Value Stream Mapping Approach for Production Process Reengineering in SMEs. *International Journal of Computer Integrated Manufacturing*, *34*(7–8), 764–782.

Mady, S. A., Arqawi, S. M., Al Shobaki, M. J., & Abu-Naser, S. S. (2020). Lean Manufacturing Dimensions and Its Relationship in Promoting the Improvement of Production Processes in Industrial Companies. *International Journal On Emerging Technologies*, *11*(3), 881–896.

Mahmood, A. (2020). Smart Lean in Ring Spinning—A Case Study to Improve Performance of Yarn Manufacturing Process. *Journal of The Textile Institute,111(11), 1681-1696*.

Mahmood, K., Otto, T., Kangru, T., & Kuts, V. (2020). An Approach to Analyze the Performance of Advanced Manufacturing Environment. *Procedia CIRP*, *93*, 628–633.

Mallikharjuna, V., Ivatury, K., & Bobe Bonsa, K. (2022). *Productivity Improvement of a Garment Assembly Line Using Simulation and Model Driven Decision Support System*. *17*(4), *407-415*.

Mamede, H. S., Gonçalves Martins, C. M., & Mira Da Silva, M. (2023). A Lean Approach to Robotic Process Automation in Banking. *Heliyon*, *9*(7), *e18041*.

Martin, N. L., Dér, A., Herrmann, C., & Thiede, S. (2020). Assessment of Smart Manufacturing Solutions Based On Extended Value Stream Mapping. *Procedia CIRP*, *93*, 371–376.

Martins, M., Godina, R., Pimentel, C., Silva, F. J. G., & Matias, J. C. O. (2018). A Practical Study of the Application of SMED to Electron-Beam Machining in Automotive Industry. *Procedia Manufacturing*, *17*, 647–654.

Mascarenhas, R. F., Pimentel, C., & Rosa, M. J. (2019). The Way Lean Starts - A Different Approach to Introduce Lean Culture and Changing Process with People's Involvement. *Procedia Manufacturing*, *38*, 948–956.

Masmali, M. (2021). Implementation of Lean Manufacturing in a Cement Industry. In *Technology & Applied Science Research* (Vol. 11, Issue 3,7069-7074).

Maware, C., Okwu, M. O., & Adetunji, O. (2022). A Systematic Literature Review of Lean Manufacturing Implementation in Manufacturing-Based Sectors of the Developing and Developed Countries. In *International Journal of Lean Six Sigma* (Vol. 13, Issue 3, pp. 521–556).

Mckie, M. G., Jones, R., Miles, J., & Jones, I. R. (2021). Improving Lean Manufacturing Systems and Tools Engagement Through the Utilisation of Industry 4.0, Improved Communication and A People Recognition Methodology in A UK Engine Manufacturing Centre. *Procedia Manufacturing*, *55*(C), 371–382.

Midilli, Y. E., & Elevli, B. (2020). Value Stream Mapping with Simulation to Optimize Stock Levels: Case Study. In *Jordan Journal of Mechanical and Industrial Engineering* (Vol. 14, Issue 3,295-302).

Miranda-López, Y., Toledo-Loza, F., & Altamirano-Flores, E. (2022). Optimization Model to Increase the Efficiency of the Flexible Packaging Production Process Applying the Johnson Method, SMED and TPM in a SME in The Plastics Sector. *Proceedings of The LACCEI International Multi-Conference for Engineering, Education and Technology*, *2022-July, page 748*.

Mishra, A. K., Sharma, A., Sachdeo, M., & Jayakrishna, K. (2020). Development of Sustainable Value Stream Mapping (SVSM) for Unit Part Manufacturing: A Simulation Approach. *International Journal of Lean Six Sigma*, *11*(3), 493–514.

Mofolasayo, A., Young, S., Martinez, P., & Ahmad, R. (2022). How to Adapt Lean Practices in SMEs to Support Industry 4.0 In Manufacturing. *Procedia Computer Science*, *200*, 934–943.

Mohamad, E., Afif, M., Resa, E., Rizal, M., Salleh, B., Syafiq, A., Yunos, M., Salleh, M. R., Yuniawan, D., Larasati, A., Oktavianty, O., & Pembuatan, F. K. (2020). *A Proposal of Overall Equipment Effectiveness (OEE) Simulation Decision Support Tools for Lean Practitioners, 6th International Forum on Advanced Technologies*.

Mohamad, E., & Ito, T. (2022). *Implementation of Overall Equipment Effectiveness (OEE) In Textile Manufacturing Company, 22(6)*.

Mohamad, E., Ito, T., Ain Qistina MUHAMMAD SHAFEE, N., Soufhwee ABD RAHMAN, M., & Yuniawan, D. (2023). *Big Data and Simulation in Lean Manufacturing from The Industry 4.0 Perspective, 23(10)*.

Mohamad, E., Ito, T., Oktavianty, O., Ain Qistina MUHAMMAD SHAFEE, N., Syuhadah HALIM, A., & Soufhwee ABD RAHMAN, M. (2023). *Kanban Apps for Lean Practitioners,23(10)*.

Mohamad, E., Ito, T., Ridzuan Jamli, M., Akramin Bin Mohamad, N., Azizi TUKIRAN, M., Ridzuan JAMLI, M., Akramin MOHAMAD, N., Rizal SALLEH, M., Yuniarti, R., Amri SULAIMAN, M., & Kejuruteraan Pembuatan, F. (2020). *Improving Overall Equipment Effectiveness Using Lean Six Sigma in Lube Blending Plant: A Case Study,20(14)*.

Mohamad, E., Ito, T., Soufhwee, M., Rahman, A., Qistina, A., Shafee, M., Salleh, R., Rahman, A. A., Aishah, S., Aziz, A., Teknologi, F., Mekanikal, K., Pembuatan, D., & Pembuatan, F. K. (2023). *Application of Kaizen in Proposing a Hood Placement Design for The Milling Machines' Exhausting Ventilation System, number 3*.

Mubiena, G. F., & Ma'Ruf, A. (2018). Development of an Assessment Model for Sustainable Supply Chain Management in Batik Industry. *IOP Conference Series: Materials Science and Engineering*, *319*(1),012073.

Mudgal, D., Pagone, E., & Salonitis, K. (2020). Approach to Value Stream Mapping for Make-To-Order Manufacturing. *Procedia CIRP*, *93*, 826–831.

Naciri, L., Mouhib, Z., Gallab, M., Nali, M., Abbou, R., & Kebe, A. (2022). Lean and Industry 4.0: A Leading Harmony. *Procedia Computer Science*, *200,* 394–406.

Naeemah, A. J., & Wong, K. Y. (2023). Sustainability Metrics and A Hybrid Decision-Making Model for Selecting Lean Manufacturing Tools. *Resources, Environment and Sustainability*, vol. *13, 100120.*

Ngadono, T. S., Rokhim, M., & Ikatrinasari, Z. F. (2020). Lean Manufacturing Implementation On Extrude Process with Value Stream Maping: Study Case in Tyre Manufacture. *IOP Conference Series: Materials Science and Engineering*, *852*(1),012104.

Nicholas, J. (2016). Hoshin Kanri and Critical Success Factors in Quality Management and Lean Production. *Total Quality Management and Business Excellence*, *27*(3–4), 250–264.

Noto, G., & Cosenz, F. (2021). Introducing a Strategic Perspective in Lean Thinking Applications Through System Dynamics Modelling: The Dynamic Value Stream Map. *Business Process Management Journal*, *27*(1), 306–327.

Nunes Mariz, R., Picchi, F. A., Granja, A. D., Savio, R., & De Melo, S. (2018). *A Review of the Standardized Work Application in Construction, vol. 196, 517-534.*

Oliveira, J., Sá, J. C., & Fernandes, A. (2017). Continuous Improvement Through "Lean Tools": An Application in a Mechanical Company. *Procedia Manufacturing, 13*, 1082–1089. 139

Oliveira, M., Tavares, A., Dos Santos, I., & Veroneze, G. (2022). Improvement of The Process Performance of a Tire Manufacturing Company Through the Implementation of Management Tools Based on the Michelin Manufacturing Way Philosophy (MMW). *Proceedings On Engineering Sciences*, *4*(4), 397–406.

Orellana-Nuñez, N., Puerta-Girón, M., & León-Chavarri, C. (2022). Production Management Model to Reduce Late Deliveries in A Metal-Mechanical SME Using Lean Tools. *Proceedings of The LACCEI International Multi-Conference for Engineering, Education and Technology, 2022-December, vol. 2,133*.

Palange, A., & Dhatrak, P. (2021). Lean Manufacturing a Vital Tool to Enhance Productivity in Manufacturing. *Materials Today: Proceedings*, *46*, 729–736.

Paucar, V., Munive, S., Nunez, V., Marcelo, G. E., Alvarez, J. C., & Nallusamy, S. (2020). Development of a Lean Manufacturing and SLP-Based System for a Footwear Company. *IEEE International Conference on Industrial Engineering and Engineering Management, 2020-December*, 1112–1116.

Peças, P., Encarnação, J., Gambôa, M., Sampayo, M., & Jorge, D. (2021). Pdca 4.0: A New Conceptual Approach for Continuous Improvement in the Industry 4.0 Paradigm. *Applied Sciences (Switzerland)*, *11*(16),7671.

Pekarcikova, M., Trebuna, P., Kliment, M., & Dic, M. (2021). Solution of Bottlenecks in the Logistics Flow by Applying the Kanban Module in the Tecnomatix Plant Simulation Software. *Sustainability (Switzerland)*, *13*(14),7989.

Pekarcikova, M., Trebuna, P., Kliment, M., & Schmacher, B. A. K. (2022). Milk Run Testing Through Tecnomatix Plant Simulation Software. *International Journal of Simulation Modelling*, *21*(1), 101–112.

Pena, R., Ferreira, L. P., Silva, F. J. G., Sá, J. C., Fernandes, N. O., & Pereira, T. (2020). Lean Manufacturing Applied to a Wiring Production Process. *Procedia Manufacturing*, *51*, 1387–1394.

Pereira, T., Neves, A. S. L., Silva, F. J. G., Godina, R., Morgado, L., & Pinto, G. F. L. (2020). Production Process Analysis and Improvement of Corrugated Cardboard Industry. *Procedia Manufacturing, 51*, 1395–1402.

Perico, P., Arica, E., Powell, D. J., & Gaiardelli, P. (2019). MES as an Enabler of Lean Manufacturing. *IFAC-Papersonline*, *52*(13), 48–53.

Pinto, G., Silva, F. J. G., Baptista, A., Fernandes, N. O., Casais, R., & Carvalho, C. (2020). TPM Implementation and Maintenance Strategic Plan - A Case Study. *Procedia Manufacturing*, *51*, 1423–1430.

Poswa, F., Adenuga, O. T., & Mpofu, K. (2022). Productivity Improvement Using Simulated Value Stream Mapping: A Case Study of the Truck Manufacturing Industry. *Processes*, *10*(9),1884.

Rajab, S., Afy-Shararah, M., & Salonitis, K. (2022). Using Industry 4.0 Capabilities for Identifying and Eliminating Lean Wastes. *Procedia CIRP*, *107*, 21–27.

Realyvásquez-Vargas, A., Arredondo-Soto, K. C., Carrillo-Gutiérrez, T., & Ravelo, G. (2018). Applying The Plan-Do-Check-Act (PDCA) Cycle to Reduce the Defects in The Manufacturing Industry. A Case Study. *Applied Sciences (Switzerland)*, *8*(11),2181.

Ribeiro, M. A. S., Santos, A. C. O., De Amorim, G. Da F., De Oliveira, C. H., Braga, R. A. Da S., & Netto, R. S. (2022). Analysis of the Implementation of the Single Minute Exchange of Die Methodology in an Agroindustry Through Action Research. *Machines*, *10*(5).

Ribeiro, P., Sá, J. C., Ferreira, L. P., Silva, F. J. G., Pereira, M. T., & Santos, G. (2019). The Impact of the Application of Lean Tools for Improvement of Process in a Plastic Company: A Case Study. *Procedia Manufacturing*, *38*, 765–775.

Rocha, H. T., Ferreira, L. P., & Silva, F. J. G. (2018). Analysis and Improvement of Processes in the Jewellery Industry. *Procedia Manufacturing*, *17*, 640–646.

Roh, P., Kunz, A., & Wegener, K. (2019). Information Stream Mapping: Mapping, Analysing and Improving the Efficiency of Information Streams in Manufacturing Value Streams. *CIRP Journal of Manufacturing Science and Technology, 25*, 1–13.

Rossetti, C. L., Warsing, D. P., Flynn, B. B., & Bozarth, C. C. (2023). Complex and Lean or Lean and Complex? The Role of Supply Chain Complexity in Lean Production. *Operations Management Research*, *16*(3), 1382–1412

Sahin, R., & Kologlu, A. (2022). A Case Study on Reducing Setup Time Using SMED on a Turning Line. *Gazi University Journal of Science*, *35*(1), 60–71.

Setiyawan, D. T., Nugrahandi, K., & Effendi, M. (2020). Design of Lean Production System with Simulation Model Approach in Agar Powder Production. *IOP Conference Series: Earth and Environmental Science*, *475*(1),012060.

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*, vol. *8,100488*.

Shams Bidhendi, S., Goh, S., & Wandel, A. (2019). Development of A Weighted Leanness Measurement Method in Modular Construction Companies. *Journal of Industrial Engineering International*, *15*(4), 603–625.

Silva, A., Sá, J. C., Santos, G., Silva, F. J. G., Ferreira, L. P., & Pereira, M. T. (2020). Implementation of SMED in a Cutting Line. *Procedia Manufacturing*, *51*, 1355–1362.

Silva, G. V., Thomitzek, M., Abraham, T., & Herrmann, C. (2021). Bottleneck Reduction Strategies for Energy Efficiency in The Battery Manufacturing. *Procedia CIRP*, *104*, 1017–1022.

Silvestre, S. E. M., Chaicha, V. D. P., Merino, J. C. A., & Nallusamy, S. (2022). Implementation of a Lean Manufacturing and SLP-Based System for a Footwear Company. *Production*, vol. *32, e20210072*.

Singh, J., & Singh, H. (2020). Application of Lean Manufacturing in Automotive Manufacturing Unit. *International Journal of Lean Six Sigma*, *11*(1), 171–210.

Sivaraman, P., Nithyanandhan, T., Lakshminarasimhan, S., Manikandan, S., & Saifudheen, M. (2020). Productivity Enhancement in Engine Assembly Using Lean Tools and Techniques. *Materials Today: Proceedings*, *33*, 201–207.

Skaar, J. (2019). The Power of Lean Principles. *27th Annual Conference of the International Group for Lean Construction, IGLC 2019*, 393–404.

Soufhwee, A. R., Mohamad, E., & Abdul Rahman, A. A. (2019). Enhancement of Time-Driven Activity–Based Costing (TDABC) By Using Simulation in Manufacturing Process Towards Industry 4.0. *International Journal of Innovative Technology and Exploring Engineering*, *8*(10), 1895–1900.

Sulaiman, M. A., Ito, T., Rahman, M. A. A., Ishak, A., Salleh, M. R. Bin, & Mohamad, E. (2019). Cleaner Production Value Stream Mapping at A Chromium Plating Plant: A Case Study. *International Journal of Agile Systems and Management*, *12*(3), 245.

Sullivan, B. P., Yazdi, P. G., Suresh, A., & Thiede, S. (2022). Digital Value Stream Mapping: Application of UWB Real Time Location Systems. *Procedia CIRP*, *107*, 1186–1191.

Suryanti, F., Sudiarno, A., & Sudarni, A. A. C. (2020). Combination of Value Stream Mapping and House of Risk Methods to Eliminate Waste in Productivity Enhancement in Production Area of Fertilizer Company. *IOP Conference Series: Materials Science and Engineering*, *847*(1).

Tarigan, U., Tarigan, U. P. P., & Sukirman, V. (2019). Integration of Lean Manufacturing and Group Technology Layout to Increase Production Speed in The Manufacture of Furniture. *IOP Conference Series: Materials Science and Engineering*, *528*(1).

Teriete, T., Böhm, M., Sai, B. K., Erlach, K., & Bauernhansl, T. (2022). Event-Based Framework for Digitalization of Value Stream Mapping. *Procedia CIRP*, *107*, 481–486.

Tilahun, S., Berhan, E., & Kitaw, D. (2020). Enhancing Competitiveness Through Innovative Lean Manufacturing (In Cases of Ethiopian Metal and Steel Industries). *Proceedings On Engineering Sciences*, *2*(3), 247–258.

Toki, G. F. I., Ahmed, T., Hossain, M. E., Alave, R. K. K., Faruk, M. O., Mia, R., & Islam, S. R. (2023). Single Minute Exchange Die (SMED): A Sustainable and Well-Timed Approach for Bangladeshi Garments Industry. *Cleaner Engineering and Technology*, *12*.

Tortorella, G., Cómbita-Niño, J., Monsalvo-Buelvas, J., Vidal-Pacheco, L., & Herrera-Fontalvo, Z. (2020). Design of A Methodology to Incorporate Lean Manufacturing Tools in Risk Management, to Reduce Work Accidents at Service Companies. *Procedia Computer Science*, *177*, 276–283.

Veres, C., Marian, L., Moica, S., & Al-Akel, K. (2018). Case Study Concerning 5S Method Impact in an Automotive Company. *Procedia Manufacturing*, *22*, 900–905.

Verma, R. B., & Jha, S. K. (2019). Implementation of 5s Framework and Barriers Modelling Through Interpretive Structure Modelling in a Micro Small Medium Enterprise. *International Journal of Recent Technology and Engineering*, *8*(3), 7010–7019.

Vieira, A. M., Silva, F. J. G., Campilho, R. D. S. G., Ferreira, L. P., Sá, J. C., & Pereira, T. (2020). SMED Methodology Applied to the Deep Drawing Process in The Automotive Industry. *Procedia Manufacturing*, *51*, 1416–1422.

Wang, P., Wu, P., Chi, H. L., & Li, X. (2020). Adopting Lean Thinking in Virtual Reality-Based Personalized Operation Training Using Value Stream Mapping. *Automation in Construction*, vol. *119*, *103355*.

Womack, J. P., & Jones, D. T. (1997). Lean Thinking—Banish Waste and Create Wealth in Your Corporation. *Journal of The Operational Research Society*, *48*(11), 1148–1148.

Wong, Y. C., Wong, K. Y., & Ali, A. (2009). A Study on Lean Manufacturing Implementation in the Malaysian Electrical and Electronics Industry. In *European Journal of Scientific Research* (Vol. 38, Issue 4,521-535).

Yang, T., Wen, Y. F., Hsieh, Z. R., & Zhang, J. (2020). A Lean Production System Design for Semiconductor Crystal-Ingot Pulling Manufacturing Using Hybrid Taguchi Method and Simulation Optimization. *Assembly Automation*, *40*(3), 433–445.

Yik, L. K., & Chin, J. F. (2019). Application of 5S and Visual Management to Improve Shipment Preparation of Finished Goods. *IOP Conference Series: Materials Science and Engineering*, *530*(1),012039.

Zahraee, S. M., Esrafilian, R., Kardan, R., Shiwakoti, N., & Stasinopoulos, P. (2020). Lean Construction Analysis of Concrete Pouring Process Using Value Stream Mapping and Arena Based Simulation Model. *Materials Today: Proceedings*, *42*, 1279–1286.

Zahraee, S. M., Tolooie, A., Abrishami, S. J., Shiwakoti, N., & Stasinopoulos, P. (2020). Lean Manufacturing Analysis of a Heater Industry Based on Value Stream Mapping and Computer Simulation. *Procedia Manufacturing*, *51*, 1379–1386.

Zamalloa-Menacho, A., Manani-Rojas, R., Flores-Perez, A., & Collao-Diaz, M. (2022). Proposal of Production Model Based On Lean and Continuous Improvement to Improve the Productivity in Smes of Baking: An Empirical Investigation in Peru. *ACM International Conference Proceeding Series*, 66–71.

Zahraee SM, Mokhtar AA, Tolooie A, Mohd Asri NA. Performance Evaluation of EFB Biomass Supply Chain for Electricity Power Generation Based on Computer Simulation: Malaysia Case Study. Lecture Notes in Mechanical Engineering. 2020: 363-75.