14th Annual International Conference on Industrial Engineering and Operations Management Dubai United Arab Emirates (UAE), February 12-14, 2024

Publisher: IEOM Society International, USA DOI: 10.46254/AN14.20240567
Published: February 12, 2024

Application of Lean in Maintenance Processes of Air Compressors and Diesel Welding Machines

Yasser Alahmad, Abdulla Aljaberi, Khwla Alkatheeri, and Maithah Alyaarbi
Students, Department of Management Science and Engineering
College of Engineering
Khalifa University
Abu Dhabi, UAE
Yasserammarsaid@gmail.com, a-aljaberi1@outlook.com, k7alkatheeri@gmail.com, maithabsa@gmail.com

Dr. Saed Amer
Assistant Professor, Department of Management Science and Engineering
College of Engineering
Khalifa University
Abu Dhabi, UAE
saed.amer@ku.ac.ae

Abstract

This report investigates the application of lean principles in preventative maintenance within the after-sale services industry, focusing on a GCC Engineering, Procurement, Construction company. The study addresses backlogs, delays, and various wastes in the maintenance facility, outlining objectives for lean processes. Methodology involves meetings, Gemba Walks, interviews, data collection, gap analysis, Kaizen improvements, and standardization. Numerical and contextual data reveal worker movements, waiting times, overprocessing, and a lack of standardization. Proposed improvements, such as tool belts, movable storage units, ERP systems, and Kanban boards, aim to mitigate these issues. Graphical representations illustrate the future state spaghetti diagram, standardized work, and 5S implementation. Results indicate substantial improvements, including an 84.31% to 92.16% decrease in lead time, an 83.33% to 340% increase in capacity, a 65% decrease in the number of steps, and a 66.67% to 75% decrease in inventory replenishment cycles. The conclusion emphasizes the achievement of all objectives and the unique contributions of the research, offering practical solutions aligned with industry needs. The organization anticipates positive shifts in operational dynamics and long-term success as these recommendations are implemented

Keywords
Lean principles, Preventative maintenance, Operational efficiency, Waste elimination, Continuous improvement.

1. Introduction
Lean is a systematic methodology that aims to identify and eliminate various sources of wastes within a process (Dhiravidamani et al. 2018). This methodology has originated from the Toyota Production System and has been vital in minimizing the manufacturing time, human effort, and product costs (Bakke and Johansen 2019). Moreover, it was observed that inefficiencies or activities lacking value could constitute over 90% of the entire manufacturing process (Dhiravidamani et al. 2018). Consequently, implementing continuous improvement strategies becomes crucial for organizations to maintain their competitiveness.

Lean methodologies have shown their effectiveness across many diversified industries, not only the manufacturing industry. Despite that, there is limited research on the context of the applicability of lean on the after-sale services industry, such as the preventative maintenance sector (Arlinghaus and Knizkov 2020). This case study explores the application of lean tools within the proactive maintenance industry. The company under study is a GCC

Engineering, Procurement, Construction company, focusing on its preventive maintenance facility for air compressors and diesel welding machines. The facility plays an vital role in maintaining and ensuring the functioning of the machines but has faced severe backlogs and delays in recent years and revealed major wastes, including significant motion, prolonged waiting times for parts and machine departure, and instances of overprocessing. Recognizing the impact of said inefficiencies, they set out to eliminate waste and streamlining its operations.

1.1 Objectives
The objectives of the project are crucial to ensuring that the maintenance processes machines are made more lean. They are aimed at achieving the project's overall goal, which is to reduce waste, improve efficiency, and achieve standardization while maintaining the highest standards of safety and quality. The following list will outline the objectives that will guide the project's implementation and evaluation.

1. To provide a standardized sequence of maintenance tasks that will decrease the lead time by 50%.
2. To decrease the movement required by workers to perform maintenance tasks by 50%.
3. To establish a maintenance management system that efficiently schedules the maintenance and reduces administrative tasks.
4. To increase the capacity of the facility to a level that could meet the demand.

2. Literature Review
Lean methodology, which is derived from the Toyota Production System, has gained the interest of many organizations as a systematic approach to enhance efficiency, reduce waste, and improve overall organizational performance (Bai et al. 2019). The foundation of Lean thinking is formed around just-in-time production, continuous improvement, and respect for people (Bai et al. 2019). The primary focus of Lean is to establish an efficient flow of processes that produces finished products at the desired pace for customers while minimizing waste (Sanders et al. 2016). Lean methodology extends beyond manufacturing to service industries. Many of its principles have been adapted and implemented in areas such as healthcare, finance, and hospitality. Its application in various sectors has generated positive outcomes in many operational areas. Although Lean methodology has demonstrated considerable success, there are some criticisms and challenges associated with its implementation. These may include resistance to change, the need for sustained leadership commitment, and the potential difficulty in implementation (Abu et al. 2022).

In addition to the challenges associated with resistance to change and the need for sustained leadership commitment, Lean methodology implementation may encounter complexities related to the measurement and assessment of its impact. Quantifying the success of Lean initiatives poses a significant challenge for organizations seeking to gauge the effectiveness of their efforts (Belhadi et al. 2019). Some performance metrics may not fully capture the improvements brought about by Lean practices, making it crucial for organizations to develop tailored measurement systems (Ferrer et al. 2023). This involves establishing key performance indicators (KPIs) that align with the core principles of Lean, emphasizing not just cost reduction but also factors like cycle time, customer satisfaction, and employee engagement (Ferrer et al. 2023). By overcoming the measurement challenges and adopting a comprehensive assessment framework, organizations can more accurately evaluate the tangible benefits of Lean methodology and make informed decisions for continuous improvement.

3. Methods
The methodology followed in this case study was as follows:

3.1 Meetings with Management
Collaborative meetings with management were conducted to meticulously identify and define the strategic goals and objectives of the project.

3.2 Gemba Walks
Team members conducted several Gemba Walks to observe, engage, and gain a firsthand understanding of processes, operations, workplace dynamics, and spot wastes. Notes were shared amongst several stakeholders.

3.3 Interviews with maintenance workers
Several interviews were conducted with maintenance workers who have insights on day to day tasks to gain a clearer understanding of wastes.

3.4 Data Collection methodology

Gathering accurate data regarding the number and types of machines proved to be essential. This involved closely shadowing workers and employing stopwatches to accurately measure the duration of each task as well as capturing video footage of the maintenance activities.

3.5 Gap Analysis
After collecting data and identifying the present condition of operations. The disparity between current performance and goals, identifying the gaps that need to be addressed to achieve optimal outcomes.

3.6 Kaizen
Improvements were made over several key areas to reduce wastes and improve operational efficiency. These include 5S Implementation, Kanban Boards, Spare Parts Replenishment System, ERP System, and Worker Movement Reduction.

3.7 Standardization of Work
Standardized work charts were used to guide workers in order to maintain operational efficiency.

4. Data Collection
4.1 Numerical Data
Tables (1- 4) summarize the data collected throughout the duration of the project.

Table 1. Data collected from the maintenance tasks (Welding Machines)

Welding Machines (159 machines)		
Task	Work Element	Probability of Task Occuring
Drain Engine Oil	negligible work element (20 min waiting time)	100%
Fill Engine Oil	negligible work element (10 min waiting time)	100%
Replace Engine Air Filter	15 min	50%
Change Engine Oil Filter	10 min	100%
Change Primary Fuel Filter	15 min	33%
Change Secondary Fuel Filter	15 min	33%

Table 2. Data collected from the maintenance tasks (Air Compressor Type A)

Air Compressor Type A (96 machines)		
Task	Work Element (Min)	Probability of Task Occuring
Drain Engine Oil	Negligible work element (25 min waiting time)	100%
Fill Engine Oil	Negligible work element (15 min waiting time)	100%
Replace Engine Air Filter	15 min	100%
Change Engine Oil Filter	20 min	100%
Replace Compressor Air Filter	15 min	100%
Change Fuel Filter	30 min	50%
Change Fuel Water Separator	25 min	50%
Flush Radiator and Refill	30 min	50%

Table 3. Data collected from the maintenance tasks (Air Compressor Type B)

Air Compressor Type B (59 machines)		
Task	Time (Min)	Probability of Task Occuring
Drain Engine Oil	Negligible work element (25 min waiting time)	100%
Fill Engine Oil	Negligible work element (15 min waiting time)	100%
Replace Engine Air Filter	15 min	100%
Change Engine Oil Filter	20 min	50%
Replace Compressor Air Filter	15 min	50%
Change Fuel Filter	30 min	50%

Table 4. Other relevant data

Number of Workers	4 Workers
Available Production Time	510 minutes/day available
Lead Time for all machines	510 minutes
Maintenance Capacity	7 machines per day
Approximate Number of Steps Per Worker Per Hour	200 steps
Number of inventory replenishment cycles	4 trips
Frequency of maintenance for all machines	Every 3 Weeks

4.2 Contextual Data
The following section underscores other non-numerical data and observations from Gemba walks, meetings, and interviews.

4.2.1 Worker Movements
Worker motion constitutes a significant portion of non-value-added activities, requiring frequent walks across the facility to retrieve essential tools, parts, and equipment between each step as depicted by the spaghetti diagram below for 1 hour of work resulting in approximately 200 steps (Figure 1).

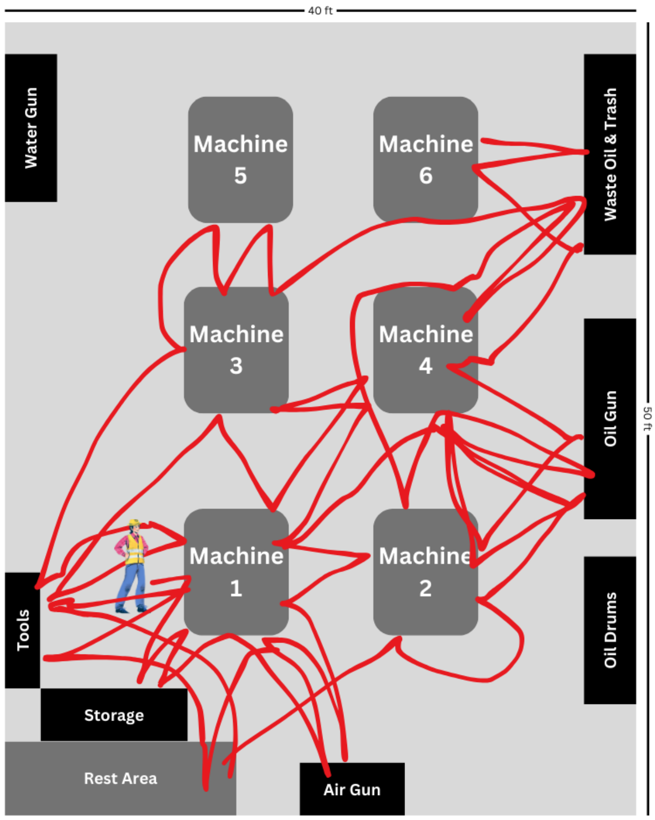

Figure 1. Spaghetti Diagram

4.2.2 Waiting Times

Waiting times stem from spare parts replenishment issues. Lack of access to daily machine lists and corresponding vocab numbers leads to frequent visits to the storage facility, causing significant time wastage. In addition, idle time persists even after early completion of machine maintenance tasks. Despite a worker finishing tasks within an hour, the machine remains idle until the end of the shift, taking up space.

4.2.3 Overprocessing

Machines arriving for maintenance with minimal use in the 3 week period results in unnecessary cleaning and inspection, wasting time, effort, and shop space, as many spare parts remain in good condition. Instead, focusing on machines in need of full maintenance would optimize resources and space in the workshop.

4.2.4 Standardization

There exists a severe lack of standardized work in the facility with workers working in a random manner with the tasks mentioned earlier in the report done in no particular order and no coordination among workers.

5. Results and Discussion

5.1 Proposed Improvements

The Table 5 summarizes the proposed improvements to bridge the gap between the current and future states. The improvements minimize waste, increase efficiency, productivity, and capacity. As well as reduce related costs and significantly cut lead time. These improvements address the wastes and issues mentioned earlier.

Table 5. Proposed Improvements

Improvement	Problem addressed	Description
4 Tool belts	Motion Wastes	Tool belts for workers minimize trips to the tool shed
2 Movable storage units	Motion Wastes	Movable storage units reduce trips to the storage cabinet and the storage facility. Placed between machines.
3 Drum dollies	Motion Wastes	Eliminates the need to carry heavy oil pans to the disposal site, results in less movement and injuries. Placed between machines.
Planning and Scheduling ERP System	Overprocessing and Waiting Times	An ERP system to aid planning and scheduling of machines, this would confirm if machines do in fact need maintenance and provides vocab numbers for spare parts in advance which reduces trips to the storage facility
Inventory supermarket and replenishment system	Motion Wastes and Waiting Times	In coordination with the ERP system, minimizes trips to the storage facility.
Sequence of work	Lack of Standardization	Provides clear responsibilities, sequence, and ownership of tasks, eliminating random work (Medyński et al. 2023).
Application of 5S	Waiting Times	An application of 5S for tool and parts cabinets to increase accessibility of items.
Kanban board	General visual management	Increases workflow visibility and efficiency. Provides a visual representation of tasks, promoting collaboration, and clear ownership of tasks (Naufal et al. 2012).

5.2 Graphical Results
5.2.1 Future State Spaghetti Diagram
The future state spaghetti diagram below illustrates 1 hour of worker movement after the proposed improvements in section 5.1, reducing the steps from 200 to 70 (Figure 2).

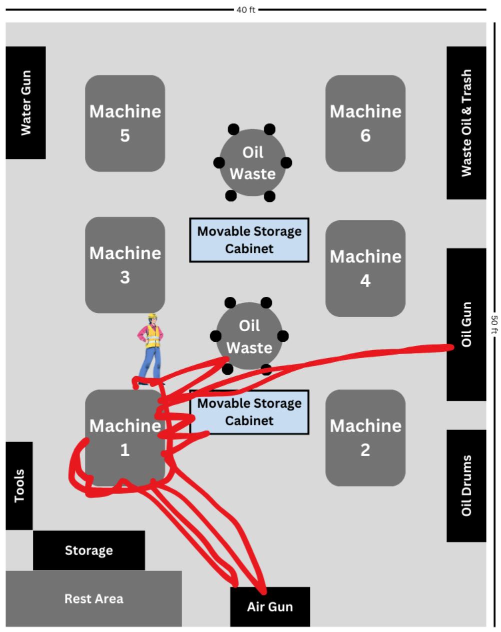

Figure 2. Future Spaghetti Diagram

5.2.2 Standardization of Work

Graphs (Figures 3-5) were created in order to simplify task sequencing for operators in all possible scenarios of each machine. This provides clear responsibilities, sequence, and ownership of tasks, eliminating random work and wastes.

Machine Type A: Requires 1 operator for all cases.

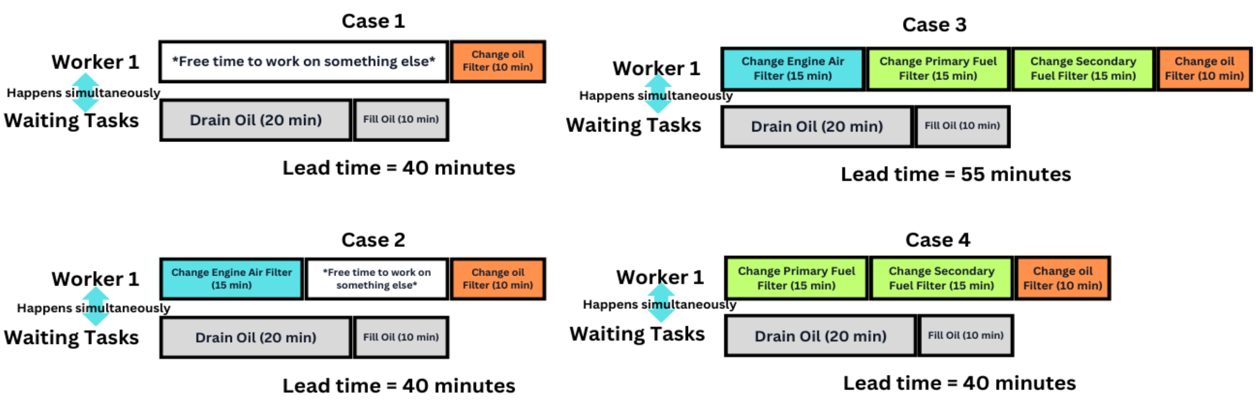

Figure 3. Standardized Work Sequence for Welding Machines

Machine Type B: Requires 2 operators to accommodate all cases.

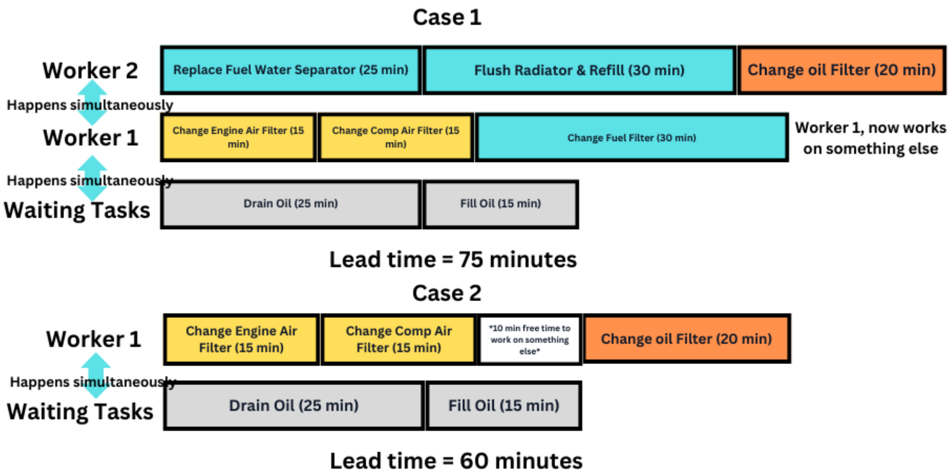

Figure 4. Standardized Work Sequence for Air Compressor Type A

Machine Type C: Requires 2 operators to accommodate all cases.

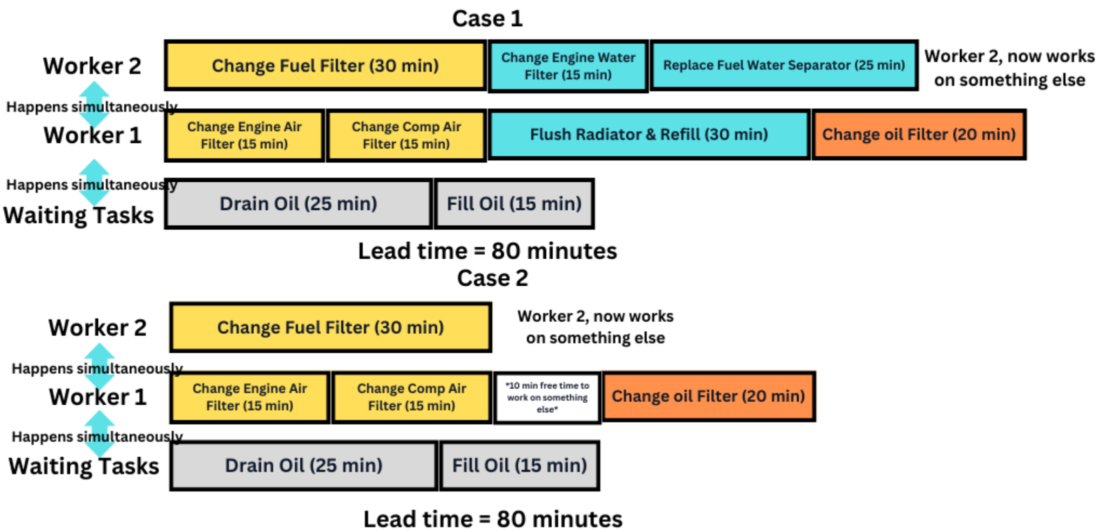

Figure 5. Standardized Work Sequence for Air Compressor Type B

5.2.3 5S Implementation

Implementing 5S in the storage and tool cabinets involves organizing tools and spare parts in a systematic and efficient manner, ensuring easy accessibility and minimizing waste in searching or handling. By employing visual cues, such as clearly labeled compartments, the cabinets become a streamlined and productive asset, contributing to a lean and efficient facility.

5.3 Numerical Results

5.3.1 Calculated Demand

The Table 6 shows the calculated daily demand for each machine type.

Table 6. Demand Per Day for Each Machine Type

	Welding Machines	Air Compressors Type A	Air Compressors Type B
No. of Machines to be serviced every 3 weeks	159	96	59
No. of Machines to be serviced every week	159/3 = 53	96/3 = 32	59/3 = 19.67
No. of Machines to be serviced every day (Demand Per Day)	53/5 = 10.6 = 11	32/5 = 6.4 = 7	19.67/5 = 3.9 = 4

5.3.2 Takt Time Calculations

The Table (7-9) below show the calculated takt time for each machine type.

Table 7. Welding Machines Takt Time Calculation

Welding Machines Takt Time Calculation	
Available production time	510 minutes/day available
Demand	11 machines/day
Takt time	510 min / 11 machines = 46.36 minutes/machine

Table 8. Air Compressors Type A Takt Time Calculation

Air Compressors Type A Takt Time Calculation	
Available production time	510 minutes/day available
Demand	7 machines/day
Takt time	510 min / 7 machines = 72.86 minutes/machine

Table 9. Air Compressors Type B Takt Time Calculation

Air Compressors Type B Takt Time Calculation	
Available production time	510 minutes/day available
Demand	4 machines/day
Takt time	510 min / 4 machines = 127.5 minutes/machine

5.3.3 Number of Operators Needed

The below calculations identify the optimal number of operators for each machine type (Table 10-Table 12)

Table 10. Number of Operators Needed for Welding Machines

Welding Machines: Number of Operators Needed	
Total work content	40 minutes
Takt time	46.36 minutes/machine
Number of operators needed	40/46.36 = 0.863 = 1 operator

Table 11. Number of Operators Needed for Air Compressors Type A

Air Compressors Type A: Number of Operators Needed	
Total work content	135 minutes
Takt time	72.86 minutes/machine
Number of operators needed	135/72.86 = 1.853 = 2 operators

Table 12. Number of Operators Needed for Air Compressors Type B

Air Compressors Type B: Number of Operators Needed	
Total work content	150 minutes
Takt time	127.5 minutes/machine
Number of operators needed	150/127.5 = 1.176 = 2 operators

5.3.4 Supermarket Capacity

Establishing an on-site spare parts supermarket with just-in-time inventory management will significantly improve efficiency and operational performance by eliminating the need for operators to travel 15 minutes to an external storage location. This system, replenished daily, ensures smooth workflow, minimizes walking and waiting times, and enhances visibility and control over spare parts usage (Table 13).

Table 13. Supermarket Capacity Calculation

Welding Machines	Air Compressors Type A	Air Compressors Type B
Daily demand: 11 machines/day	Daily demand: 7 machines/day	Daily demand: 4 machines/day
Needed: 4 spare parts	Needed: 7 spare parts	Needed: 6 spare parts
Total: 11*4 = 44 parts	Total: 7*7 = 49 parts	Total: 4*6 = 24 parts
Supermarket capacity = 44 + 49 + 24 = 117 spare parts		

5.4 Summary of Results

Table 14 below summarizes the results of the proposed improvements for the lean project (Table 14).

Table 14. Summary of Results

	Before	After	Improvement and Description
Lead time	510 minutes	40 to 80 minutes, depending on the machine type and case	84.31% to 92.16% decrease in lead time as a result of suggested improvements
Capacity	5 to 12 machines	22 machines minimum	83.33% to 340% increase in capacity as a result of suggested improvements
Number of steps	200 steps	70 steps	65% decrease in number of steps as a result of suggested improvements
Number of inventory replenishment cycles	3 to 4 trips	1 trip	66.67% to 75% decrease in number of trips as a result of suggested improvements
Planning/scheduling	Unorganized / adhoc	ERP aided decisions	Previously the planning and scheduling was done by the supervisor based on his experience and with little coordination between the teams. The

			ERP system allows constant and clear communication between all stakeholders at all times, showing which machines are arriving at what date and time, as well as what maintenance and parts are required. Crucially, it also allows the supervisor to view the run times of each machine, allowing him to decide whether or not to maintain the machine.
Demand	Not met – severe backlog	Demand met	Backlogs used to have a contant presence in day to day operations. After improvements that decreased lead time and increased capacity, backlogs are no longer a concern
Data collection	No data collection	Data collection through Kanban Board & ERP systems	One of the major challenges of this project was the lack of historic data. The Kanban Board would provide accurate process times as workers are required to list the tasks for each machine and the respective processing times of the tasks. The ERP System would provide data on what machines were processed in what days and the running times of the machines. Paving the way for further Kaizen.
Standardization	Random	Standardized sequence of work	Figure 3. Figure 4. and Figure 5. Act as guides for maintenance workers to follow when conducting maintenance tasks. This system acts as a framework for standardized work and provides further opportunities for Kizen.
Motion wastes	Severe motion waste	Minimal motion wastes due to new facility layout	As depicted in Figure 2., the future spaghetti diagram clearly illustrates the decreased worker movements and waste.

6. Conclusion

In summary, this study undertook a thorough examination of the facility's existing operational landscape, pinpointing significant inefficiencies and highlighting avenues for enhancement. Improvements including the implementation of tool belts, movable storage, and a revamped layout, were proposed to enhance efficiency and minimize waste in the forthcoming operational phase. Moreover, the integration of 5S principles, alongside advanced technologies such as ERP and Kanban, is envisioned to reinforce the suggested enhancements. Beyond diagnosing current challenges, this research provides pragmatic, industry-aligned solutions, accomplishing the company's objectives in this lean project.

References

Abu, F., Saman, M., Garza-Reyes, J, Gholami, H. and Zakuan, N., Challenges in the Implementation of Lean Manufacturing in the Wood and Furniture Industry, *Journal of Manufacturing Technology Management*, vol. 33, no. 1, pp. 103–23, 2022.

Arlinghaus, J. and Knizkov, S., Lean Maintenance and Repair Implementation - A Cross-Case Study of Seven Automotive Service Suppliers, *Procedia CIRP*, vol. 93, pp. 955–64, 2020.

Bakke, A. and Johansen, A., Implementing of Lean – Challenges and Lessons Learned, *Procedia Computer Science*, vol. 164, pp. 373–80, 2019.

Bai, C., Satir, A. and Sarkis, J., Investing in Lean Manufacturing Practices: An Environmental and Operational Perspective, *International Journal of Production Research*, vol. 57, no. 4, pp. 1037–51, 2019.

Belhadi, A., Touriki, F. and Elfezazi, S., Evaluation of Critical Success Factors (CSFs) to Lean Implementation in SMEs Using AHP: A Case Study, International Journal of Lean Six Sigma, vol. 10, no. 3, pp. 803–29, 2019.

Dhiravidamani, P., Ramkumar, A., Ponnambalam, S. and Subramanian, N., Implementation of Lean Manufacturing and Lean Audit System in an Auto Parts Manufacturing Industry – an Industrial Case Study, *International Journal of Computer Integrated Manufacturing*, vol. 31, no. 6, pp. 579–94, 2018.

Ferrer, M., Calvo, E. and Santa, R., The Key Success Factors to Adopting Lean Practices: The Case of South American Manufacturing Firms, TQM Journal, vol. 35, no. 7, pp. 2068–91, 2023.

Medyński, D., Bonarski, P., Motyka, P., Wysoczański, A., Gnitecka, R., Kolbusz, K., Dąbrowska, M., Burduk, A., Pawelec, Z., and Machado, J., Digital Standardization of Lean Manufacturing Tools According to Industry 4.0 Concept, *Applied Sciences*, vol. 13, no. 10, pp. 6259, 2023.

Naufal, A., Jaffar, A., Yusoff, N. and Hayati, N., Development of Kanban System at Local Manufacturing Company in Malaysia–Case Study, *Procedia Engineering*, vol. 41, pp. 1721–26, 2012.

Sanders, A., Elangeswaran, C. and Wulfsberg, J., Industry 4.0 implies lean manufacturing: research activities in industry 4.0 function as enablers for lean manufacturing, *Journal of industrial engineering and management*, vol. 9, no. 3, pp. 811–33, 2016.

Biographies

Yasser Alahmad completed his Industrial and Systems Engineering BSc from Khalifa University in December 2023 with High Honors. He was awarded the presidents list in four separate semesters and the deans list once. He was awarded Second Place in a United Nations Sustainability Development Goals Competition. He served as as the President of the IISE Student Chapter at KU for over 2 years, during which he was awarded the as the First Place Winner of IISE IAB Youtube Video Competition, as well as leading the chapter to be awarded the Gold Award by the IISE. He has professional experience as a Management Consultant intern at PwC and a Project Controls intern at Hatch Ltd.

Abdulla Aljaberi is a 2023 graduate from Khalifa University with a Bachelor's in Industrial and Systems Engineering. Throughout his academic journey, Abdulla demonstrated a passion for optimizing processes and a commitment to excellence by engaging in many projects. Through his active participation as an officer in the IISE Student Chapter, Abdulla took part in many events and activities that were organized by the chapter.

Khwla Alkatheeri is a graduate from Khalifa University. She was granted her Bachelor's degree in Industrial and Systems Engineering in 2023

Maithah Alyaarbi graduating from Khalifa University, she earned her Bachelor's degree in Industrial and Systems Engineering in the year 2023.

Dr. Saed Amer earned his Doctorate of Philosophy in Computer and Information Systems Engineering in August 2012 from Tennessee State University, USA. Dr. Amer is currently a faculty in the Department of Industrial and Systems Engineering at Khalifa University and leading research endeavors on the advances in Health Safety and Environment engineering, training, and HSE education. Other research fields that Dr. Amer is involved in are

Human Factors simulation and validation, Seat comfort analyses, and the assimilation of the human into Industry 4.0. Previous work includes sustainability assessments, systematic measures to enforce engineering sustainability education, and autonomous solutions for Unexploded Ordnance (UXO) remediation. Finally, Dr. Amer worked on simulation solutions for hybrid renewable energy research.