INNOVATIVE MECHANICAL ENGINEERING **ISSN 2812-9229 (Online)**
University of Niš, Faculty of Mechanical Engineering
VOL. 4, NO 3, 2025, PP. 51-64

Original scientific paper *

INTEGRATED APPLICATION OF LEAN TOOLS FOR PROCESS OPTIMIZATION IN SME MANUFACTURING: A CASE STUDY OF REFRIGERATION EQUIPMENT PRODUCTION

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Abstract. *Small and medium-sized enterprises (SMEs) often operate with resource constraints, high product variety, and informal processes that hinder systematic efficiency improvements. This paper presents a single-case study of an SME that manufactures customized refrigeration aggregates for industrial cooling applications and applies an integrated set of Lean tools for process optimization. The research follows an action-oriented approach and combines SIPOC (Suppliers-Inputs-Process-Outputs - Customers), process flowcharting, value stream mapping, eight-waste analysis, Pareto analysis, Ishikawa diagrams, and 5S-based proposals. The current-state Value Stream Mapping (VSM) reveals a total non-value-added time of 24 days and 170 minutes and a value-added time of 615 minutes, with major wastes arising from waiting, motion, inventory accumulation, and rework. Pareto analysis shows that waiting for chassis components and unnecessary operator movement account for more than 60% of recorded disruptions, while the Ishikawa diagram highlights structural causes linked to manpower, methods, materials, machinery, measurement, and the working environment. A future-state VSM, built on targeted improvements, reduces non-value-added time (NVAT) to 15 days and 170 minutes and increases value-added time (VAT) to 650 minutes, and an ideal-state design suggests further reductions to 6 days and 140 minutes. The paper demonstrates that a coordinated application of Lean tools can provide SMEs in specialized manufacturing sectors, such as refrigeration equipment production, with a practical roadmap for diagnosing inefficiencies and designing coherent, high-impact improvement strategies.*

Key words: *Lean manufacturing, SME, Refrigeration equipment, Value stream mapping, Process optimization, Waste reduction*

***Received: December 13, 2025 / Accepted December 17, 2025.**
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1. INTRODUCTION

SMEs form the basis of modern economies. Across OECD (Organisation for Economic Co-operation and Development) countries, they represent around 99% of all firms and generate about 50-60% of value added and employment [1]. In the European Union, micro and small firms make up 99% of enterprises and employ the majority of the workforce [2]. The performance of manufacturing SMEs therefore has a direct effect on productivity, competitiveness, and regional development. Production efficiency represents a major concern for these firms. Efficient processes help reduce operating costs, shorten lead times, and stabilize product quality [3-4]. Recent studies show that lean-based interventions in manufacturing can cut lead time and inventory and raise capacity utilization by several percentage points, even in resource-constrained settings [5-6]. For SMEs, such gains can translate into improved cash flow and greater resilience in volatile markets. Market conditions are increasingly shifting toward small, diversified orders and frequent design changes. Huang et al. note that many manufacturers now operate under high-mix, low-volume conditions and need strong internal capabilities to respond quickly [3]. SMEs often serve specific segments or supply customized components, which makes flexibility and agility as important as cost reduction. Refrigeration equipment production is a good example of this context. Industrial and commercial refrigeration systems support food storage, pharmaceutical logistics, and many process industries along the cold chain [7]. The global refrigeration system market was valued at about USD 41.5 billion in 2023 and is projected to reach around USD 61.9 billion by 2032 [8]. Cold chain equipment alone was estimated at USD 35 billion in 2024, with strong growth expected due to rising demand for fresh and frozen products [9]. Refrigeration also has a significant environmental footprint: recent assessments suggest that refrigeration uses roughly 20% of global electricity and contributes about 7.5% of global CO_2 emissions. Improving production efficiency and quality in this sector is therefore relevant not only for firm performance, but also for energy and climate goals. This paper analyses an SME that manufactures customized refrigeration aggregates for industrial cooling applications. The case reflects typical SME characteristics: limited resources, high product variety, and strong pressure to deliver reliable equipment with short lead times.

2. LEAN PRODUCTION IN THE SME CONTEXT

Lean production provides a systematic way to increase efficiency by eliminating waste and stabilizing processes. For SMEs, however, Lean implementation is not straightforward. Many studies report barriers such as limited financial resources, lack of internal expertise, dependence on tacit knowledge, and low levels of process standardization [3, 10]. Staff often perform multiple roles, documentation is incomplete, and improvement projects must compete with daily operational demands. Despite these constraints, evidence shows that Lean and Lean Six Sigma initiatives can improve operational performance in SMEs. Integrated Lean models for SMEs report higher productivity, fewer defects, and better delivery performance after the adoption of structured improvement programs [3, 6, 11]. The challenge is to select tools that are simple to apply, require modest investment, and still provide a clear view of process problems. In this context, an integrated set of Lean tools is particularly attractive. The SIPOC diagram helps define suppliers, inputs, process boundaries, outputs, and customers in a concise way, which is useful when processes are informal [12]. Value stream mapping (VSM) visualizes material and information flows, cycle times, waiting times, and inventories, and is widely used to detect waste and design improved process states [13]. Spaghetti diagrams map the physical movement of people and materials and reveal unnecessary motion and poor layout. Ishikawa (cause-and-effect) diagrams support structured root-cause analysis for quality and delivery problems. Pareto analysis helps teams focus on the "vital few" problems that generate most of the losses. Finally, 5S provides a simple framework for organizing and standardizing the workplace so that improvements are easier to sustain over time. Several recent case studies suggest that combining these tools yields better results than using them in isolation, because teams can move from high-level mapping to detailed diagnosis and then to standardized solutions in a coherent sequence [11, 14]. For SMEs in refrigeration equipment manufacturing, such an integrated Lean toolkit can provide a practical path toward higher efficiency, better quality, and more stable delivery performance.

Lean manufacturing is built around the systematic reduction of three types of loss: muda, muri, and mura. Muda refers to activities that consume resources without adding value for the customer. Mura denotes unevenness in workload, flow, or demand. Muri means the overburden of people, equipment, or systems [15]. The combined reduction of these three forms of loss improves quality, safety, and throughput, and is now a common foundation for modern efficiency programs in manufacturing and services. Within this framework, the concept of the "eight wastes" provides a more operational view of muda. Classical Lean literature identifies seven basic wastes: transport, inventory, motion, waiting, overproduction, over-processing, and defects [16]. Empirical studies in different sectors, including manufacturing and higher education services, confirm that these categories capture most non-value-adding activities observed in practice [16-18]. More recent work extends this list with an eighth waste: underutilized or non-utilized human talent [19]. This waste appears when organizations fail to use the skills, creativity, and improvement ideas of employees, and has been linked to missed innovation opportunities and persistent process problems. Several quantitative studies show that identifying and reducing these wastes can generate significant operational gains. Analysis in discrete manufacturing reports that unnecessary motion, excess inventory, and waiting often account for a large share of lost productivity and poor delivery performance [16-18]. Lean programs that explicitly target the eight wastes have achieved measurable reductions in lead time, defect rates, and work-in-process across different industries [15]. This evidence supports the use of waste-oriented diagnostics as a starting point for structured improvement in small and medium-sized firms.

Most existing Lean research has concentrated on applications in large, repetitive manufacturing environments, where processes are highly standardized and improvement programs have substantial managerial and financial support. Studies addressing SMEs are increasing, but they tend to focus on general manufacturing rather than on firms that produce customized or project-based equipment. As a result, there is limited empirical evidence on how Lean tools function in settings characterized by high product variety, short production runs, and informal workflows. The gap is even more pronounced in the refrigeration and HVAC sector. Although a few case studies examine specific improvements such as assembly balancing or cycle-time reduction, there is little research on integrated Lean applications in small or medium-sized refrigeration equipment manufacturers, particularly in Europe. The objective of this paper is to address this gap by applying a coordinated set of Lean tools, SIPOC, VSM, Pareto analysis, Ishikawa diagram, and 5S, to diagnose inefficiencies in the production of customized refrigeration aggregates. The paper aims to quantify major forms of waste, including transport, waiting, rework, motion, and inventory accumulation, and to evaluate improvement actions based on their operational impact. A further objective is to assess how suitable an integrated Lean approach is for SMEs that operate with high customization and limited resources, and to determine whether such an approach can support more stable, predictable, and efficient production in this type of environment.

3. METHODOLOGY

This analysis uses a single-case study methodology, which is appropriate when the goal is to understand real processes in depth and when the production environment has unique characteristics. The selected SME operates with high product customization and small production batches, making it a suitable setting for examining how Lean tools interact in a complex, low-volume manufacturing system. A single-case approach allows detailed mapping of process flows, workplace conditions, and decision-making practices that are often not documented in formal procedures. The paper follows an action research orientation, where analysis and improvement take place iteratively. The researcher works closely with engineers, operators, and managers to diagnose inefficiencies and propose solutions. This approach is consistent with Lean philosophy, which emphasizes learning from direct observation and collaborative problem-solving. Elements of design science are also present, because the research constructs, tests, and refines an integrated Lean toolkit tailored to the needs of the SME.

Data were collected through several complementary methods to ensure a complete understanding of the production system. Direct observation was conducted on the shop floor during regular working hours. The researcher followed the production of refrigeration aggregates step by step, recording cycle times, walking distances, waiting periods, and movement patterns. Semi-structured interviews with engineers, operators, and managers provided qualitative insights into recurring problems, bottlenecks, and communication gaps. The interviews helped verify observations and clarify the reasons behind process deviations or delays. The paper also included a review of process documentation, such as internal procedures, technical drawings, bills of materials, and production schedules. These documents were used to compare the “intended” process with the actual one. SCADA and production data logs were analyzed to obtain objective measurements of testing durations, alarms, quality deviations, and component traceability. These data supported the quantitative elements of VSM and waste analysis.

The methodology applies an integrated sequence of Lean tools, designed to move from broad understanding toward detailed diagnosis and structured improvement. The analysis begins with a SIPOC diagram to define suppliers, inputs, main process steps, outputs, and customers. This establishes the boundaries and scope of the production system. A process flowchart is then created to visualize the high-level workflow and identify major activities in the assembly of the refrigeration aggregate. A current-state VSM is developed to measure cycle times, waiting times, material flow, information flow, and work-in-process inventory. Using VSM as a base, an 8 Wastes analysis is conducted to detect major sources of non-value-added activity. A Pareto analysis is applied to prioritize the most critical problems identified during observation and interviews. For high-impact issues, an Ishikawa diagram is created to identify root causes across categories such as manpower, machines, methods, materials, environment, and measurement. Improvement proposals are synthesized into a future-state VSM, which outlines an optimized production flow with reduced waste and more stable process conditions. To support long-term sustainability, 5S and standardization practices are introduced as foundational elements for maintaining order, clarity, and consistency.

The paper examines an SME in the mechanical and thermal engineering sector. For confidentiality, the company is anonymized and referred to as Company A. The firm specializes in the design and production of refrigeration equipment, with a focus on cooling aggregates for cold storage chambers operating at approximately -18 °C. These systems are used in food storage, logistics, and industrial refrigeration applications. Production is characterized by low-series, high-customization work, where product specifications frequently vary based on customer needs. Assembly activities are manual-intensive, requiring skilled handling of copper piping, compressors, electrical wiring, refrigerant charging, and system testing. The shop floor layout evolved gradually as equipment and product lines expanded, resulting in a workflow with several inefficiencies, including long walking distances, irregular material flow, and variable cycle times. This context makes the company a suitable environment for examining how an integrated Lean toolkit can help small manufacturers improve efficiency despite resource constraints, high variability, and a partially informal production system.

4. Results and Analysis

4.1 SIPOC and process mapping results

The SIPOC analysis clarified the operational boundaries of the refrigeration aggregate production process by identifying all suppliers, inputs, activities, outputs, and customers involved. For the selected SME, the SIPOC framework provided a structured understanding of how information, materials, and responsibilities flow across organizational units. The process begins with internal suppliers such as the design office, procurement, and the warehouse, which provide technical documentation, material requisitions, and component inventories. Inputs include technical drawings, work orders, bills of materials, and physical components sourced from the central warehouse and external vendors. According to the SIPOC table, the process owner is the general director, while the primary internal stakeholders are the engineering, procurement, production, and quality control teams. These actors contribute to the transformation of inputs into finished refrigeration aggregates prepared for installation at client facilities. The process outputs comprise fully assembled refrigeration units, final documentation, test reports, and outbound logistics documents such as invoices and delivery notes. The final customers are industrial firms that install or operate refrigeration systems. The SIPOC structure therefore establishes full visibility over the end-to-end production chain and highlights the interconnectedness of planning, procurement, manufacturing, and quality processes.

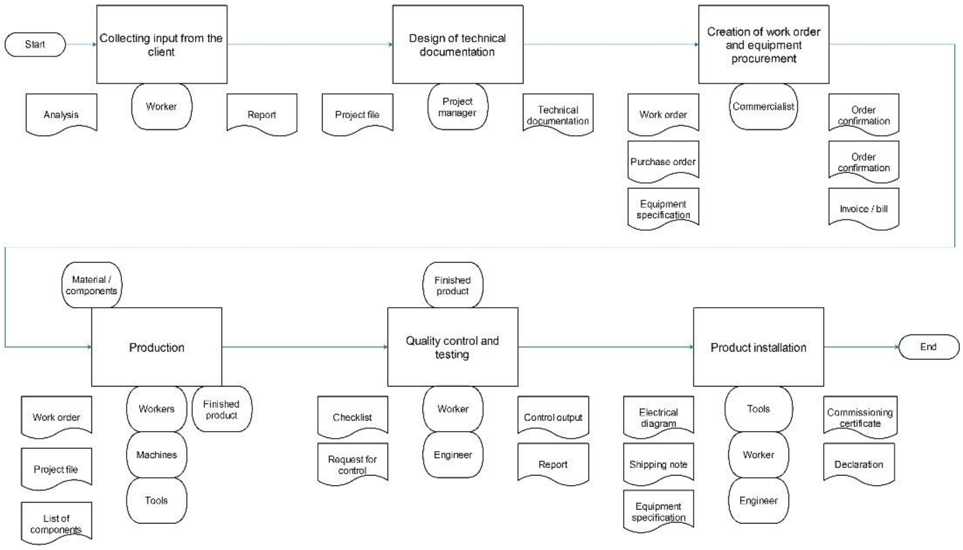

Fig. 1 Process flowchart of the end-to-end production process for refrigeration aggregates.

The process flowchart (Fig.1) provided further insight into how the intended process differs from actual operational practices. While the formal process map presents a linear progression, from receiving customer requirements, through design, procurement, production, testing, and installation, the observed workflow exhibits several deviations. The flowchart shows multiple feedback loops, informal communication channels, and recurrent rework steps that are not part of the designed process structure. For example, the flow frequently returns to the design stage due to incomplete initial specifications, and production activities are occasionally halted because components are not pre-positioned according to the defined schedule. These misalignments between the prescribed and actual flows suggest inconsistencies in documentation, coordination, and communication, particularly between engineering, procurement, and the production floor. Such discrepancies justify the subsequent application of VSM, and root-cause tools to identify inefficiencies. The flowchart confirms that while the process appears structured on paper, its real execution contains variability that leads to waiting times, excessive movement, and redundant confirmation steps, all of which impact throughput and reliability.

4.2 Current-state VSM analysis

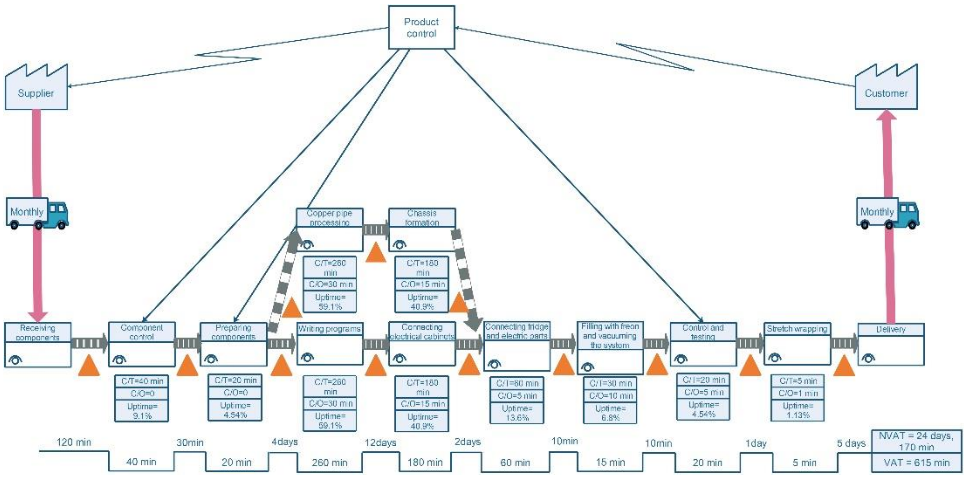

Fig. 2 Current-state VSM of the refrigeration aggregate production process

The current state VSM (Fig.2) provides a detailed overview of material and information flows across all major production stages. The mapped process includes component receiving, component control, preparation and processing, copper pipe bending, chassis formation, electrical preparation, mechanical-electrical integration, refrigerant charging, control and testing, and final packaging. The VSM quantifies both the value-adding time and the delays that occur between activities. The analysis shows that the total non-value-added time (NVAT) is 24 days and 170 minutes, while the total value-added time (VAT) is 615 minutes. This results in very low process efficiency, with value-adding activities representing only a small fraction of total throughput time. Long queue times appear between several stages, especially between chassis formation, electrical cabinet connections, and refrigerant charging. These waiting periods arise from scheduling mismatches, material unavailability, and limited workstation capacity. Work-in-process (WIP) inventories accumulate at multiple points in the flow. The highest WIP concentrations were observed before chassis formation and before system testing, reflecting bottlenecks caused by limited workstation availability and frequent disruptions. Machine uptime data embedded in the VSM (ranging from 4.54% to 59.1%) indicate that several operations are far below nominal utilization, reinforcing the presence of inefficiencies. Interpretation of the VSM also reveals significant walking distances, caused by dispersed workstations and non-linear movement of materials and workers. Rework loops were also identified, particularly where electrical and mechanical integration activities intersect. These loops add additional delays and increase operator load. Overall, the current-state VSM demonstrates that the system suffers from excessive waiting, motion waste, rework, and uneven workload distribution, conditions that are typical for high-mix, low-volume production environments. This baseline map served as the foundation for subsequent bottleneck identification and improvement planning.

4.3 Waste identification (Eight wastes analysis)

The current-state VSM and direct shop-floor observations enabled a systematic identification of the eight classical Lean waste types. Several forms of waste were found to dominate the production system. The most significant waste category was waiting, which appeared between major activities such as chassis formation, electrical cabinet assembly, refrigerant charging, and quality control. These delays are reflected in the long queue times in the VSM and contribute most heavily to the overall NVAT of 24 days and 170 minutes. A second major waste category was motion, resulting from extensive walking distances between dispersed workstations. Operators repeatedly backtrack between copper pipe processing, chassis preparation, and assembly stations, indicating inefficient workplace layout and poor material positioning. Inventory waste was also notable, as WIP accumulates before chassis formation, electrical connection, and control/testing. This buildup corresponds to the low uptime figures recorded in the VSM (ranging from 4.54% to 59.1%), which indicate uneven workload and capacity constraints. Rework waste was also detected in electrical and refrigerant-related tasks, where repeated adjustments and rechecks extend lead times and create additional operator workload. Together, these wastes explain the large discrepancy between total VAT (615 minutes) and overall throughput time, and they highlight the structural inefficiencies targeted in the improvement phase.

4.4 Pareto analysis of delay causes

The Pareto analysis quantifies the frequency of observed disruptions and identifies the "vital few" causes that account for most process delays. Based on the empirical records, six main categories of disruptions were identified. The highest frequency causes were: (1) Waiting for chassis - 11 occurrences (30.6%); (2) Unnecessary movement of people - 11 occurrences (61.1% cumulative). These two categories alone account for over 60% of all delays, placing them firmly in the "vital few" ranges. When adding poorly welded pipes (5 occurrences), the cumulative share reaches 75%, and with component backorders (4 occurrences), the cumulative total exceeds 86%. These results demonstrate that a relatively small set of issues creates most workflow interruptions. The Pareto chart clearly shows the steep cumulative curve characteristic of highly uneven distribution of problem sources. This validates the use of Pareto prioritization for focusing improvement efforts on chassis availability, layout optimization, and the reduction of operator movement.

		Cut-off point with cumulative percentage:	80%
#	Causes	Number	Cumulative line %
1	Waiting for the chassis	11	30.6%
2	Unnecessary movement of p	11	61.1%
3	Poorly welded pipes	5	75.0%
4	Backordering of component:	4	86.1%
5	Problems with probes	3	94.4%
6	Technical problems during d	2	100.0%

Fig. 3 Pareto table of delay causes.

Fig.3 shows the frequency and cumulative percentage of disruptions, identifying waiting for chassis and unnecessary operator movement as dominant causes. Fig.4 shows the "vital few" issues accounting for 80% of total delays, led by waiting for chassis and unnecessary movement of people.

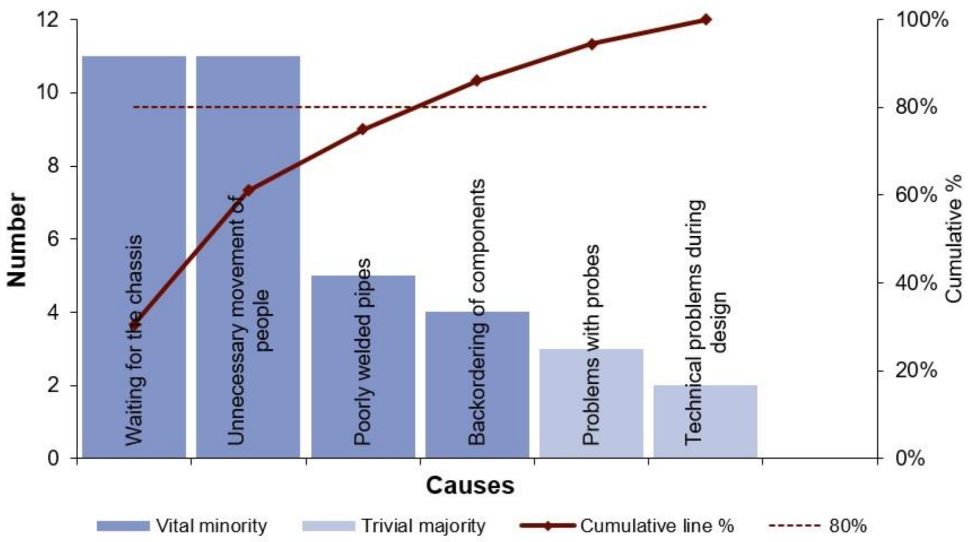

Fig. 4 Pareto chart of delay causes.

4.5 Root-cause analysis (Ishikawa results)

The Ishikawa (fishbone) diagram was used to explore underlying causes of extended production time, particularly delays associated with chassis formation and the integration of mechanical and electrical components. The analysis grouped root causes into six standard categories: (1) Man: operator inexperience, fatigue, insufficient number of assembly workers, and inconsistent adherence to procedures. (2) Machine: outdated or insufficient equipment, poor tool maintenance, and operational errors due to equipment wear. (3) Method: inefficient process flow, inadequate work procedures, and lack of standardized work instructions. (4) Material: incorrect component dimensions, inconsistent material quality, and supplier delivery delays. (5) Environment: poor lighting conditions, messy workspace, and unfavorable factory layout contributing to disorganized flow. (6) Measurement: insufficient quality-control instrumentation, uncalibrated tools, and lack of real-time monitoring. These roots causes correspond directly with the bottlenecks identified in the VSM. For example, material delays reinforce the long waiting times seen before chassis formation; inadequate methods and workspace organization contribute to high motion waste; and measurement gaps explain rework loops and extended test durations. The Ishikawa analysis therefore provides the causal foundation for targeted improvement interventions. In Fig.5 root causes are categorized into man, machine, method, material, environment, and measurement, showing the systemic drivers of waiting, rework, and process variability.

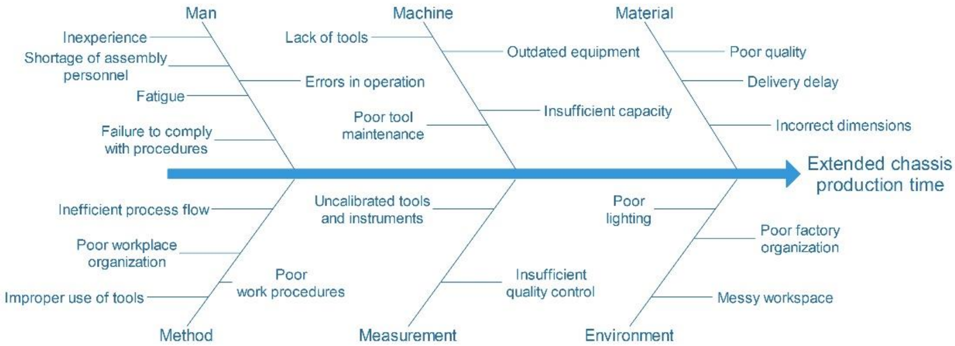

Fig. 5 Ishikawa diagram for extended chassis production time.

4.6 Future-state VSM

The future-state VSM was developed based on the bottlenecks, waste patterns, and root causes identified in the current-state analysis. The improved map reflects the expected performance after introducing targeted Lean interventions, including layout adjustments, improved material staging, reduction of unnecessary movement, and enhanced coordination with suppliers. The future-state VSM (Fig.6) shows a measurable reduction in total NVAT, decreasing from 24 days and 170 minutes to 15 days and 170 minutes. This improvement is primarily achieved through reduced waiting between chassis assembly, electrical integration, and testing, supported by more consistent material availability and improved internal scheduling. The VAT increases from 615 minutes to 650 minutes, reflecting smoother workflow and fewer disruptions that previously caused repeated rework or delays.

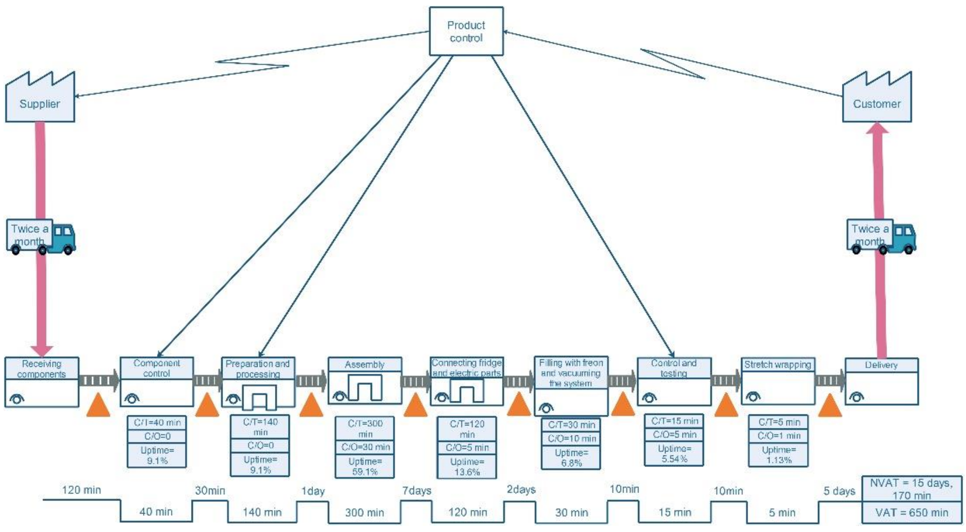

Fig. 6 Future-state VSM after implementing targeted Lean improvements.

Workstation data in the improved VSM indicate higher uptime levels and more evenly distributed workloads, particularly in stages where interruptions and queues were dominant in the baseline map. The improved delivery frequency, which remains twice per month but is better aligned with material scheduling, supports more stable inventory flow. The revised process flow shortens lead times and reduces WIP accumulation across the main stages, addressing the main inefficiencies identified in previous sections. Together, the future-state VSM provides a realistic operational target that can be achieved within the current organizational and technical constraints of the SME, forming the basis for long-term improvements.

4.7 Improvement proposals

Based on the findings from the current-state VSM, waste analysis, Pareto prioritization, and Ishikawa root-cause analysis, a set of comprehensive improvement proposals was developed. These proposals are designed to enhance process stability, reduce motion and waiting waste, improve material availability, and support long-term Lean sustainability within the SME. The improvement concept is represented in the ideal-state VSM (Fig.7), which illustrates the envisioned production system once all major inefficiencies are addressed. In this scenario, total NVAT is reduced to 6 days and 140 minutes, and total VAT stabilizes at 600 minutes, indicating a significantly more balanced and efficient workflow. Weekly supplier deliveries further reduce material shortages and eliminate long waiting periods observed in the current state.

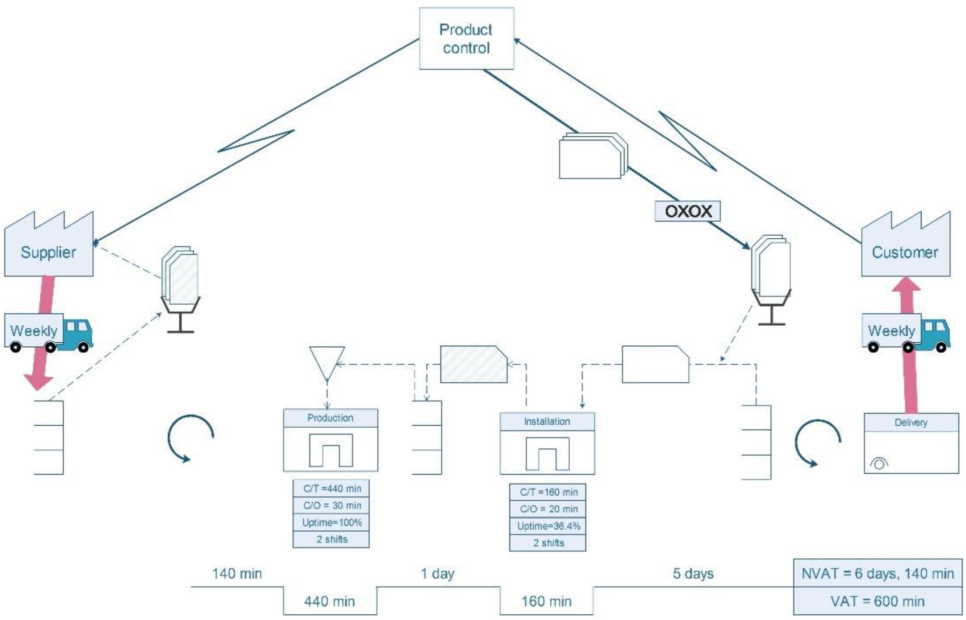

Fig. 7 Ideal-state VSM representing the long-term optimized production system.

Proposed improvements: (1) Layout redesign and workstation consolidation. Consolidating related workstations (such as chassis assembly and electrical integration) and implementing clear material flow paths will reduce motion waste and operator fatigue. (2) Standardized work procedures and 5S application. Poor workplace organization contributes to rework, delays, and inconsistent performance. Introducing standardized work instructions, visual controls, and structured 5S routines will improve repeatability and reduce variation across operators and shifts. (3) Improved supplier coordination and material staging. Waiting for components, especially chassis materials, was one of the dominant causes of delay. Weekly or synchronized material deliveries, supported by improved forecasting and communication with suppliers, will reduce interruptions and WIP accumulation. (4) Equipment upgrades and maintenance planning. Low uptime values in several stations indicate capacity and reliability issues. Improving tool availability, implementing preventive maintenance, and upgrading outdated equipment will reduce operational errors and idle times. (5) Improved quality-control procedures. The Ishikawa analysis highlighted insufficient quality control and uncalibrated tools as contributors to rework. Strengthening in-process quality checks and ensuring calibration will minimize rework loops and reduce deviations from specifications.

These proposals collectively guide the SME toward the ideal-state VSM, where process flow becomes more continuous, interruptions are minimized, operator movement is optimized, and production lead time is reduced.

5. Discussion

The results show that the integrated application of Lean tools provides a structured and effective methodology for diagnosing and improving process performance in a small manufacturing enterprise. The current-state VSM revealed significant process inefficiencies, including extended waiting times, high WIP accumulation, and low workstation utilization. These findings align with prior studies indicating that SMEs often struggle with unstable material flow, fragmented processes, and inconsistent work practices [10, 20]. In this case, the low proportion of VAT relative to total lead time illustrates a system heavily burdened by NVAT activities. The waste analysis further clarified the practical sources of these inefficiencies. Excessive operator movement, poorly structured work sequences, and irregular layout patterns were found to be significant contributors to motion waste, one of the most dominant categories identified. These results are consistent with observations in high-mix, low-volume environments, where layout constraints and frequent transitions between tasks amplify motion and waiting waste. The Pareto analysis confirmed that a small number of issues, such as waiting for chassis components and unnecessary movement, were responsible for the majority of disruptions, supporting the Pareto principle commonly observed in Lean diagnostics. The Ishikawa diagram provided deeper insights into the systemic causes of delays, revealing interrelated problems across manpower, methods, machinery, materials, measurement, and the working environment. These findings reinforce the idea that performance challenges in SMEs are rarely isolated; rather, they reflect structural deficiencies in planning, coordination, training, and resource allocation. Understanding these root causes was essential for constructing a viable future-state VSM.

The improved future-state and ideal-state VSMs illustrate the potential impact of targeted Lean improvements. Reducing NVAT from 24 to 15 days in the future-state scenario demonstrates that meaningful gains can be achieved even within existing organizational constraints. The ideal-state map further shows the long-term potential for an optimized, continuous-flow system, if supplier coordination, layout redesign, standardization, and equipment improvements are fully implemented. These findings contribute to the broader literature by demonstrating how an integrated sequence of Lean tools, rather than individual techniques in isolation, can generate actionable and transformative insights for SMEs in specialized manufacturing sectors such as refrigeration equipment production.

6. Conclusion

This paper applied an integrated set of Lean tools to analyze and optimize production processes within a small refrigeration equipment manufacturing company. The sequential use of SIPOC, process mapping, VSM, waste analysis, Pareto prioritization, and Ishikawa root-cause analysis provided a comprehensive understanding of existing inefficiencies and their underlying drivers. The current-state assessment revealed a production system characterized by long waiting times, extensive operator motion, material shortages, rework, and unbalanced workloads. The future-state and ideal-state VSMs demonstrated that significant reductions in non-value-added time (NVAT) are achievable through targeted Lean interventions. Improvements such as workstation consolidation, standardized work procedures, enhanced material flow, and strengthened supplier coordination offer clear pathways for reducing lead times, stabilizing workflow, and improving overall process reliability. These insights emphasize the value of using Lean as a holistic diagnostic and improvement framework, specifically in SMEs that face resource limitations and customization-driven variability. The main limitation of this paper is its single-case design, which may restrict the generalizability of the findings. However, the methodological approach and the identified waste patterns are common in many SMEs and provide a basis for broader application. Future research should explore long-term performance monitoring after Lean implementation, comparative studies across different SME sectors, and the integration of digital tools such as real-time tracking and simulation models to support continuous improvement. This research shows that even modestly resourced SMEs can achieve meaningful performance gains through a structured Lean approach. The integrated use of Lean tools not only identifies where inefficiencies occur but also clarifies why they persist, enabling managers to design interventions that are both effective and sustainable.

Acknowledgement: *This research was financially supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Contract No. 451-03-137/2025-03/200109).*

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