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Advancing Safety, Efficiency, and Sustainability in Aluminum Casting: The Impact of the 5S+S Methodology

İbrahim Şahin[1,*] and Sezai Şen [2]

[1] The Graduate School of Natural and Applied Sciences, Dokuz Eylül University, 35390 İzmir, Türkiye; sahin.ibrahim@ogr.deu.edu.tr
[2] Department of Mining Engineering, Faculty of Engineering, Dokuz Eylül University, 35390 İzmir, Türkiye; sezai.sen@deu.edu.tr
*** Correspondence: sahin.ibrahim@ogr.deu.edu.tr**

Abstract: Ensuring workplace safety while maintaining operational efficiency is critical in high-risk industrial settings such as aluminum casting. This study investigates the implementation of the enhanced 5S+S methodology—comprising Sort, Set in Order, Shine, Standardize, Sustain, and Safety—in an aluminum casting factory over three years (2021–2023). The primary objective was to assess its effectiveness in improving occupational safety, operational efficiency, and employee engagement. The methodology was systematically introduced across the foundry, machining, and other departments, with quantitative safety performance indicators—including Accident Frequency Rate (AFR), Accident Severity Rate (ASR), and Combined Risk Index (CRI)—evaluated annually. Additionally, employee perception surveys were conducted in 2020 (pre-implementation) and 2023 (post-implementation) to assess changes in workplace satisfaction across four key domains: physical working conditions, health and safety improvements, training effectiveness, and management responsiveness. Statistical analysis revealed significant reductions in AFR, ASR, and CRI, with the foundry department—historically the highest-risk area—demonstrating the most substantial improvements. Blue-collar employees reported statistically significant enhancements in workplace satisfaction, while white-collar employees maintained consistently high satisfaction levels. The findings emphasize the transformative potential of integrating safety into Lean manufacturing frameworks, reinforcing the 5S+S methodology as a powerful tool for reducing workplace hazards, increasing employee engagement, and promoting sustainability in industrial environments. By embedding safety within structured Lean practices, this study contributes to the growing body of research on sustainable manufacturing, occupational health, and continuous improvement strategies in high-risk workplaces.

Keywords: Sustainability; 5S+S methodology; aluminum casting; lean manufacturing; occupational health and safety; employee engagement.

1. Introduction

The aluminum casting industry is vital to sectors such as automotive, heavy commercial vehicles, construction, and agricultural machinery. Aluminum alloys,

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strengthened with elements like silicon, copper, and magnesium, are highly valued for their superior mechanical properties [(1)]. Among the primary casting processes, low-pressure die casting (LPDC) minimizes defects such as air entrapment and shrinkage porosity, making it ideal for load-bearing applications. Conversely, high-pressure die casting (HPDC), while more prone to air and oxide film entrainment, excels in producing intricate geometries. Continuous advancements in die design, cooling technologies, and methods like counter-pressure casting (CPC) have further improved part quality, particularly in automotive applications. These innovations underscore the industry's commitment to both product quality and manufacturing efficiency [(2)].

To address industry challenges and boost productivity, many aluminum casting factories have adopted Lean manufacturing principles. The lean concept, introduced by John Krafcik in 1988 [(3)], gained widespread attention with Womack et al.'s book *The Machine That Changed the World* [(4)]. Rooted in the Toyota Production System (TPS), lean management aims to improve product or service quality while reducing costs and time by eliminating waste [(5, 6)]. Waste is broadly defined as any excess in equipment, materials, parts, space, or time that does not contribute to product value. Key types of waste include transportation, inventory, motion, waiting, overprocessing, overproduction, and defects, all of which diminish performance, quality, and efficiency [(5–7)].

Several lean tools and techniques, such as single-minute exchange of die (SMED), value stream mapping (VSM), just-in-time (JIT), 5S, kanban (Pull Systems), poka-yoke (error-proofing), total productive maintenance (TPM), and Gemba, are widely used to streamline processes and reduce waste across industries [(4, 5)]. SMED focuses on reducing changeover times, VSM optimizes workflow, and JIT ensures that production is aligned with demand. The 5S methodology emphasizes workplace organization and cleanliness, while Kanban manages workflows more efficiently. Poka-yoke prevents errors, TPM enhances equipment efficiency, and Gemba provides insights from the shop floor. Collectively, these methodologies improve operational efficiency, reduce costs, and increase stakeholder value [(4, 5)].

Among these tools, the 5S methodology, which originated in Japan, is notable for its structured approach to workplace organization. It consists of five core steps: sort, set in order, shine, standardize, and sustain (Seiri, Seiton, Seiso, Seiketsu, And Shitsuke) [(8)]. The 5S method promotes a clean, organized, and safe work environment, enhancing both productivity and reducing waste. By fostering discipline and standardized practices, 5S has become a cornerstone of Lean implementation strategies, boosting efficiency, productivity, and safety. The evolution of 5S into 5S+S, which adds safety as a core component, highlights the growing emphasis on safety in organizational frameworks. Jiménez et al. demonstrated the effectiveness of the 5S+S tool in a laboratory, improving both production efficiency and safety over four months. Initial audits showed successful implementation, with ongoing assessments planned to sustain improvements. Future efforts aim to expand this to a 7S approach to further embed safety standards across departments [(9)].

A study at Bezmialem Vakıf University's Pharmaceutical and Pharmacology Laboratory highlighted the integration of lean techniques into occupational health and safety practices. Using the fine Kinney method for risk analysis, the research identified and categorized 20 risk groups, focusing on mitigating high-risk areas. Lean methodologies, such as centralizing chemical storage and optimizing distribution practices, successfully improved workplace safety conditions [(10)].

Singh et al. suggest that certain lean tools, particularly 5S and poka-yoke, can enhance worker safety and health, based on existing evidence. However, the study also notes that the impact of other lean practices on occupational health and safety (OHS) remains unclear. The literature review highlights a lack of focus on the relationship between OHS and lean tools beyond 5S in manufacturing industries. Further research is recommended to explore how other specific lean tools affect worker safety and health outcomes [(11)].

Sá et al. demonstrate that implementing four selected lean tools—total productive maintenance, gemba walks, visual management, and yokoten—significantly improves both productivity and safety in an industrial setting involving manual labor. The study reports a notable reduction in cycle times across multiple areas, along with enhanced employee satisfaction due to streamlined processes. Most notably, there was a 50% decrease in monthly work accidents after implementing these lean tools, underscoring their positive influence on both productivity and safety outcomes, and affirming their applicability in industrial environments [(12)].

The implementation of 5S is widely recognized for improving productivity and efficiency, but few studies have focused on its impact on occupational safety and health (OSH) management and reducing workplace accidents. Tahasin et al. emphasize that 5S is essential for effective housekeeping and maintaining safety standards by eliminating unused materials (sort) and organizing spaces (set in order), leading to reduced clutter and improved employee discipline. Future research will evaluate the addition of safety as the sixth S in other departments, along with longitudinal studies on its long-term effects [(13, 14)].

Sá et al. found that lean tools not only reduce waste and costs but also significantly improve workplace quality and safety, as reflected in positive worker feedback (15). Muotka et al. integrated design thinking into the 5S process, resulting in an 80% reduction in required floor space and a significant decrease in unnecessary transport waste, demonstrating that design thinking enhances the effectiveness of 5S implementation (16).

Misiurek and Misiurek highlight that 5S is widely recognized for improving workplace organization across industries. By integrating safety into 5S, and creating the 5S+S system, its effectiveness is enhanced by prioritizing occupational safety. The safety step aligns with the plan-do-check-act (PDCA) cycle, and the study calls for future research to integrate 5S+S with occupational risk assessment [(17)].

Implementing 5S is often the first step in lean management, essential for boosting productivity by enhancing workplace cleanliness, safety, and product quality, and reducing waste and costs. Inefficiency and disorganization lead to wasted resources,

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lower product quality, and safety issues [18]. A study shows that implementing 5S in university organizations fosters a culture of continuous improvement, benefiting student learning and administrative activities. It transforms laboratories into efficient environments, justifying the extension of 5S across other services. Adding safety as the sixth "S" ensures a proactive approach to accident prevention and risk management, creating a safer and more productive workplace [19].
In a plastic bag manufacturing company, the 5S technique established standards through regular inspections. Key improvements included organizing blowing sizers and printing blocks in dedicated storage, reducing sizer searching time by 8% and block searching time by 18%. Sizer searching and lifting times fell to 4.40% of total blowing time (from 12.12%), and block searching and setting times decreased to 20.40% (from 34.78%). This reduction in unnecessary motion enhanced efficiency and cleanliness. Comparing data before and after implementing 5S, customer complaints about printing dropped from eight to one, showing improved quality and reduced waste. Worker safety was also prioritized by segregating heavy and small sizes ergonomically [20].

2. Materials and Methods

This study applies the 5S+S methodology to improve both operational efficiency and workplace safety within an aluminum casting factory. The traditional 5S methodology sort (Seiri), set in order (Seiton), shine (Seiso), standardize (seiketsu), and sustain (Shitsuke) was augmented by an additional focus on safety to form 5S+S. This enhancement addresses the unique hazards present in high-risk environments like foundries and machining departments.

2.1. The 5S+S Framework

The integration of the safety component into the 5S framework was key to enhancing occupational health and safety (OHS) outcomes. The following steps were implemented:
Sort (seiri): The initial step involved the removal of unnecessary items from the workspace to reduce clutter and hazards. The process included the identification of potential safety risks, such as defective tools or equipment that could cause accidents.
Set in order (seiton): Tools, equipment, and materials were organized for optimal efficiency and safety. Special attention was given to ergonomics, ensuring that frequently used tools were easily accessible, minimizing physical strain, and preventing accidents caused by improper handling.
Shine (seiso): Regular cleaning routines were established to ensure that workspaces remained free of debris, oil spills, and other contaminants. These efforts were directly linked to safety, as cleaner environments are less prone to accidents caused by slips, trips, or equipment malfunction.
Standardize (seiketsu): Safety protocols were formalized and standardized across the workplace. This included the creation of standard operating procedures (SOPs) for

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maintaining cleanliness and organization, ensuring that all employees adhered to consistent safety practices.

Sustain (shitsuke): Continuous monitoring and audits were conducted to ensure that 5S+S practices were maintained over time. Safety was embedded into routine checks and inspections, ensuring that improvements were sustained and adapted to evolving workplace conditions.

2.2. The 5S+S Framework

The implementation process followed a structured approach, beginning with training sessions for both management and employees to ensure understanding and buy-in. A multi-disciplinary steering committee was formed to oversee the process and monitor progress. The methodology was rolled out in phases over a three-year period, with key performance indicators (KPIs) including accident rates, report days, and employee satisfaction tracked to measure the impact.

2.3. The 5S+S Framework

To evaluate the effectiveness of the 5S+S methodology, data were collected on a range of metrics:

The accident severity rate (ASR) is used as the primary indicator to assess the severity of accidents, while the accident frequency rate (AFR) measures the occurrence of accidents. Both metrics are combined into a combined risk index (CRI) to provide a comprehensive view of the risks associated with each department. By analyzing data from 2021 to 2023, we aim to highlight how safety improvements have impacted different departments.

To evaluate departmental risks, the following metrics were calculated:

Accident severity rate (ASR): Measures the impact of accidents based on lost workdays per thousand working hours:

$$AFT = ((\text{Number of accidents} \times 1{,}000{,}000)/(\text{Working Hours})) \quad (1)$$

Accident frequency rate (AFR): Measures the occurrence of accidents relative to working hours:

$$ASR = ((\text{Number of Report Days} \times 1{,}000)/(\text{Working Hours})) \quad (2)$$

Combined risk index (CRI): Integrates both AFR and ASR to provide an overall risk score for each department:

$$CRI = AFR \times ASR \quad (3)$$

2.4. Statistical Analysis

To evaluate the impact of the 5S+S methodology on employee perceptions of workplace conditions and management practices, an employee perception survey was conducted before implementation in 2020 and after implementation in 2023. The primary objective was to determine whether there were statistically significant differences in employee responses between 2020 and 2023. To achieve this, the Chi-Square Test of Independence was employed for each survey question within the four key areas: Physical Working Conditions, Health and Safety Improvements, Training's Contribution to Development, and Management's Attention to Feedback.

A structured questionnaire was administered to employees in both 2020 and 2023. Each question was rated on a four-point Likert scale: "Agree", "Partially Agree", "Partially Disagree", and "Disagree". However, as there were zero responses for "Disagree" across all survey areas, the "Partially Disagree" and "Disagree" categories were combined into a single "Disagree" category to enhance analytical robustness and meet the assumptions of the Chi-Square Test, particularly regarding minimum expected cell frequencies.

The Chi-Square Test was selected for its suitability in analyzing categorical data and its ability to identify associations between survey responses and time points. Given the ordinal nature of the Likert scale data, this test provides a robust framework for evaluating distributional changes without assuming normality or interval scaling. While the simplification of ordinal data into categorical variables may obscure finer nuances, this approach ensures methodological integrity, particularly for analyzing trends within the context of small group sizes.

The sample sizes were 48 white-collar employees and 215 blue-collar employees in 2020, and 45 white-collar employees and 235 blue-collar employees in 2023. Statistical computations were performed using SPSS Statistics Version 26. P-values and chi-square statistics were analyzed to determine the significance and strength of any observed differences.

By employing this approach, the analysis provides an accessible yet rigorous means of evaluating changes in employee perceptions, offering insights into the effectiveness of the 5S+S methodology while addressing limitations related to data structure and sample size.

3. Implementation

The implementation of the 5S+S methodology in the aluminum casting factory was conducted in several phases, with each phase building on the progress of the previous one. The structured approach ensured a systematic transformation of the workplace, leading to significant improvements in both operational efficiency and safety.

3.1. Planning and Preparation

The initial phase focused on raising awareness of the 5S+S methodology among both employees and management. Training sessions were organized to explain the principles and benefits of the methodology, laying the foundation for a disciplined and systematic implementation process. A steering committee was established to oversee the implementation, ensuring active involvement from both management and workers.

This phase was crucial in securing buy-in from all organizational levels, setting the tone for a successful and sustainable application of the 5S+S framework.
With the foundation laid through planning and preparation, the first operational phase of the 5S+S methodology, sort (seiri), was initiated to declutter the workspace and eliminate unnecessary items.

3.2 Sort (Seiri)

The seiri (sort) phase started by designating area managers and mapping work zones. The goal was to remove unnecessary items, reduce clutter, and organize the workspace to improve both efficiency and safety. Items were marked with red tags and sorted according to their usage. The sorting process was conducted collaboratively between area employees and managers, ensuring that workers' knowledge and experience were effectively utilized. Unused items were moved to a designated red tag area for potential redistribution to other departments, while faulty or damaged items were marked with a yellow tag to indicate they required repair or replacement, enabling quick identification and action. A sample assessment for 5S sort (seiri) implementation is shown in Table 1, detailing specific criteria and scoring for evaluating this phase's effectiveness.

Table 1. Sample assessment for 5S sort (seiri) implementation.

1S	No	Questions	1	2	3	4	5
Sort	1	Are the materials and parts (such as equipment, tools, molds, etc.) to be used in the work area defined?	☐	☐	☐	☐	☒
	2	Have the materials that are used most frequently been placed closest to the point of use, and those used least frequently been positioned farther away, as determined by the users?	☐	☐	☐	☒	☐
	3	Is there a red label application? Are the red-tagged parts removed from work centers and areas according to the plan?	☐	☐	☐	☒	☐
	4	Are work instructions and 5S instructions up to date and accessible?	☐	☐	☒	☐	☐
	5	Are preventive activities carried out to prevent unnecessary materials from entering the area?	☐	☐	☐	☐	☒
		1S score (%)	21/25=84				

Once unnecessary items were removed and the workspace decluttered, the next phase, set in order (seiton), focused on organizing tools and equipment for optimal accessibility and workflow.

3.3 Set in Order (Seiton)

Building on the progress made in the seiri phase, the set in order (seiton) phase emphasized organizing the workspace to enhance efficiency. Frequently used tools and materials were placed in easily accessible areas, while less frequently used items were stored further away. Visual management techniques, such as labeling and shadow boards, were introduced to ensure quick access to necessary tools. This step minimized unnecessary movement and time wastage, while also improving safety by organizing items logically. A sample assessment for implementing 5S set-in-order (seiton) practices is shown in Table 2, with a focus on efficient placement, visual identification, and accessibility standards.

Table 2. Sample assessment for 5S set in order (seiton) implementation.

2S	No	Questions	1	2	3	4	5
Set in Order	1	Are all the needed parts in the production area? Are the parts listed by frequency of use?	☐	☐	☐	☐	☒
	2	Are holding/storage areas appropriately labeled and visual identification used? Are minimum and maximum quantities defined?	☐	☐	☐	☐	☒
	3	Is there an up-to-date layout plan? Are corridors and walkways marked? Have obstacles been avoided? Is emergency equipment easily accessible? Can emergency exits be used?	☐	☐	☐	☐	☒
	4	Are only these designated materials available in areas where “instant-urgently needed” materials are kept for abnormal needs?	☐	☐	☐	☒	☐
	5	Have all movable or immobile machines, equipment, tools, cabinets, drawers, cages, tables, chairs, caissons, carts, boxes, etc., been located and identified/labeled? Can the needed equipment be accessed within 30 seconds?	☐	☐	☐	☒	☐
	2S score (%)		23/25= 92 %				

With the workspace now organized for efficiency, the next step, shine (seiso), focused on maintaining cleanliness to ensure safety and further enhance productivity.

3.4 Shine (Seiso)

The shine (seiso) phase centered on keeping the workspace clean and free of hazards. After creating contamination maps (Figure 1), actions were taken to address identified risks, including installing protective covers, containers to prevent liquid spills, and measures to control the spread of metal shavings. Employees were assigned cleaning tasks during scheduled breaks, and a dedicated cabinet with the necessary cleaning equipment was set up. Regular maintenance of machines and safety equipment also played a key role in maintaining cleanliness, reducing the need for repetitive cleaning. With these practices embedded into daily routines, the next step, standardize (seiketsu), ensured that cleanliness protocols were formalized and standardized across the factory.

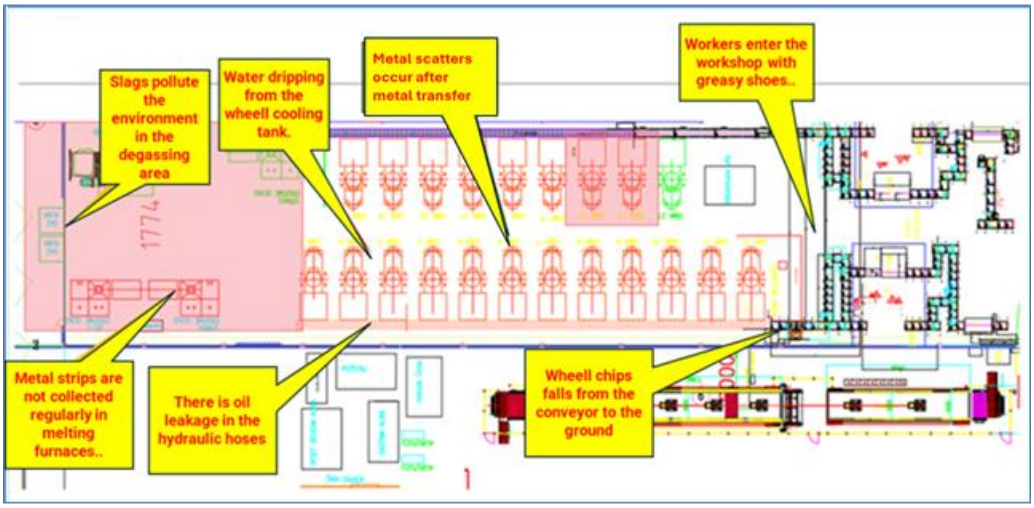

Figure 1. Example of a factory contamination map highlighting high risk zones for spillage, dust, and debris.

Table 3 provides a sample assessment for 5S shine (seiso) implementation, highlighting the criteria used to evaluate cleanliness and organization efforts.

Table 3. Sample assessment for 5S shine (seiso) implementation.

3S	No	Questions	1	2	3	4	5
	1	Are all floors clean and waste (industrial waste, glass, paper, batteries etc.,) collected in separate defined containers?	☐	☐	☐	☐	☒
	2	Are the machines on site clean and dry? Is it cleaned from waste such as oil, sawdust etc.? Does the comfort of the working environment (temperature, noise, dust and lightning) meet the standards?	☐	☐	☐	☒	☐
Shine	3	Do operators perform cleaning and sweeping operations without warning?	☐	☐	☐	☒	☐
	4	Are people responsible for cleanliness and order in the work area identified and are cleanliness and order ensured with schedules?	☐	☐	☐	☒	☐
	5	Is the cleanliness, organization and order of the work area considered a part of the work and is a preventive action system implemented for possible problems?	☐	☐	☐	☒	☐
	3S score (%)		21/25= 84 %				

3.5 Standardize (Seiketsu)

The standardize (seiketsu) phase established standard operating procedures (SOPs) to ensure consistency in practices from previous phases. Visual controls, such as

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standardized labeling, color coding of pipes, and designated quarantine areas, were introduced to make processes safer and easier to follow. Floor markings, display boards, and separated pedestrian and forklift paths were added to reduce accidents, while yellow-and-black handrails enhanced visibility, lowering risks around machinery. Additionally, hydraulic and pneumatic fittings were marked for quick leak detection, and gauges displayed clear operational limits with automated alerts for high pressure situations (Figure 2). This phase also included the development of clear safety protocols to ensure that the 5S+S principles were upheld consistently by all employees.

Figure 2. Example of a marking system for monitoring fitting looseness to prevent leaks

Table 4 provides a sample assessment for 5S standardize (seiketsu) implementation, illustrating the criteria used to evaluate adherence to standardized practices. After the establishment of standards, the sustain (shitsuke) phase focused on ensuring that the gains from previous phases were maintained over the long term.

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Table 4. Sample assessment for 5S set in order (seiton) implementation

4S	No	Questions	1	2	3	4	5
Set in order	1	Are 5S boards, layouts, work instructions and job cards organized and used, are they up-to-date and orderly?	☐	☐	☐	☐	☒
	2	Can employees define specific standards for labeling, control and quantification?	☐	☐	☒	☐	☐
	3	The team has identified and documented the parts needed, work methods, and work area controls. Documents can be easily accessed in the field.	☐	☐	☐	☒	☐
	4	Are standard work instructions and work methods routinely applied? Are employees at a level where they can introduce standard practices to customers and visitors?	☐	☐	☐	☒	☐
	5	Are field controls and operating practices disseminated as part continuous improvement?	☐	☐	☐	☒	☐
	4S score (%)		20/25= 80 %				

3.6 Sustain (Shitsuke)

The sustain (shitsuke) phase embedded 5S+S practices into the culture of the organization, ensuring continuous improvement through regular audits, inspections, and employee engagement. Team leaders conducted daily inspections, while monthly and quarterly audits were performed to ensure adherence to established standards. Employee involvement was further encouraged through suggestion schemes and recognition programs, reinforcing accountability and ongoing engagement. Table 5 provides a sample assessment for 5S sustain (shitsuke) implementation, detailing key criteria used to evaluate the integration and ongoing commitment to 5S practices. With the practices embedded into daily routines, the final phase, safety, ensured that safety was systematically addressed throughout every phase of the 5S+S process.

Table 5. Sample Assessment for 5S Sustain (Shitsuke) Implementation

5S	No	Questions	1	2	3	4	5
Sustain	1	Are all employees trained according to an established procedure? Do employees understand their role in 5S efforts? Is 5S explained during orientation?	☐	☐	☐	☐	☒
	2	Are all materials stored properly?	☐	☐	☐	☐	☒
	3	5S targets exist and are understandable to employees. There is visual control panel and the applications are reflected.	☐	☐	☐	☒	☐
	4	Are audits performed routinely to ensure 5S? Are the work done on the 5S dashboard shared with the staff? Are problems documented with their sources and frequencies?	☐	☐	☐	☐	☒

5	Is the information on the control panel a decision-making source for daily work? Have the root causes of the problems been generally eliminated and the preventive action implementation phase has been concentrated on?	☐ ☐ ☐ ☒ ☐
5S score (%)		23/25= 92 %

3.7 Safety (Safety)

Safety was not treated as a separate phase but was integrated into every aspect of the 5S+S methodology. Continuous risk assessments were conducted, and immediate corrective actions were taken to eliminate hazards. Regular safety audits ensured compliance with safety protocols, and emergency preparedness was emphasized through drills and training.

Basic safety measures, such as signage and personal protective equipment (PPE) compliance, were enforced, while regular inspections ensured that machinery and equipment were well maintained. Chemical safety protocols were also established to ensure the safe handling and storage of hazardous materials. In addition, zero accident teams were created to share safety data and foster a culture of safety within the organization. Emergency preparedness was an integral part of this phase, with drills and training ensuring that employees were equipped to handle various emergency scenarios, including natural disasters, fires, and chemical spills. By embedding safety into every aspect of the 5S+S process, the organization significantly reduced accidents and hazards, creating a safer and more efficient working environment.

4. Results

To provide a comprehensive understanding of the factory’s structure and the varying levels of occupational risk, this section introduces the three main departments analyzed in this study: the foundry, the machining department, and other departments. Each department plays a crucial role in production, and their inherent risk levels vary based on the nature of their operations.

The foundry production directorate, which includes the foundry, melting, heat treatment, and mold maintenance departments, is considered the most hazardous area within the factory. With an average of 65 employees, representing 17% of the total workforce, the Foundry handles high-risk processes involving molten metal at temperatures exceeding 750°C and products reaching 350°C. Employee seniority is balanced, with 60% of employees having 0-3 years of experience and 40% having over three years. These departments have historically faced hazards such as molten metal splashes and contact with hot surfaces.

The machining departments handle post-casting processes, including CNC robotic lines and quality control machines such as sealing and balancing. These departments are considered the second most hazardous in the factory, with approximately 110 employees, accounting for 28% of the factory's workforce. CNC machines, metal shavings, cutting oils, and hydraulic leaks contribute to the risks in this department.

The workforce is composed of 65% workers with 0 3 years of experience, and 35% with over three years. Addressing contamination and organizational challenges in these departments has been essential to reducing workplace incidents.
Other departments within the factory include finishing, powder and wet painting, Incoming quality control, X-ray control, measurement control, final control, maintenance, auxiliary facilities, administrative staff, shipment, material warehouse, and security. These areas are crucial for product quality and operational efficiency. With approximately 230 employees, representing 59% of the workforce, these departments have dealt primarily with slips, trips, and falls due to cluttered workspaces. Maintaining cleanliness and organization is critical to minimizing such incidents and ensuring operational safety.

4.1. Workforce, Working Hours, and Safety Performance Analysis (2021–2023)

The analysis encompasses data from three primary departments; foundry, machining, and those classified under “other departments” alongside overall factory metrics spanning 2021 to 2023. Table 6 provides an overview of the total workforce and working hours for each department foundry, machining, and other departments from 2021 to 2023.

Table 6. Workforce and working hours by year.

Category	**2021**	**2022**	**2023**
Total workers	410	431	329
Foundry workers	57	70	52
Machining workers	113	110	71
Workers of other departments	240	251	206
Total working hours	977.383	1.001.840	698.977
Foundry working hours	155.550	173.669	126.766
Machining working hours	253.317	247.577	116.690
Other department's working hours	568.516	580.594	455.521

Table 7 provides a detailed breakdown of the overall factory accident and report day data across the foundry, machining, and other departments from 2021 to 2023. This table highlights the trends in the number of accidents and the corresponding report days in each department, reflecting the impact of the implemented safety interventions over the years.

Table 7. Number of accidents and report days by department for the entire factory (2021-2023).

Year	Department	Number of accident	Number of report day
2021	Foundry	21	307
	Machining	18	138
	Other departments	30	192
2022	Foundry	15	200
	Machining	20	85
	Other departments	10	169
2023	Foundry	10	176
	Machining	6	31
	Other departments	5	66
2021	Entire factory	69	637
2022		45	454
2023		21	273

Following the examination of workforce and working hours data, along with safety performance trends across the factory from 2021 to 2023, a more detailed exploration of key safety metrics is necessary. The Accident frequency rate (AFR), Accident severity rate (ASR), and Combined Risk Index (CRI) are used to provide a deeper understanding of the frequency and severity of accidents, allowing high-risk areas to be identified. In the next section, these metrics will be analyzed across different departments to assess the effectiveness of the safety initiatives and the reductions in workplace risks.

Table 8 provides the overall accident and report day data, along with AFR and ASR, CRI index values, for the entire factory from 2021 to 2023. Based on the integrated analysis of ASR, AFR, and CRI, the Foundry Department emerges as the high-risk area within the factory. However, improvements are observable, particularly in 2023, where there was a notable decrease. Similarly, the Machining and Other Departments show significant reductions in both the number of accidents and report days, pointing to the success of the implemented risk reduction strategies.

Table 8. Entire factory accident frequency, accident severity rate, and combined risk index values.

Department	Year	AFR	ASR	CRI (AFR × ASR)
Foundry	2021	135.00	1.97	266.45
	2022	86.37	1.15	99.47
	2023	78.89	1.39	109.52
Machining	2021	71.06	0.54	38.71
	2022	80.78	0.34	27.74
	2023	51.42	0.27	13.66

Other departments	2021	52.77	0.34	17.82
	2022	17.22	0.29	5.01
	2023	10.98	0.14	1.59
Entire factory	2021	70.06	0.65	46.01
	2022	44.92	0.45	20.36
	2023	30.04	0.39	11.73

Figure 3 illustrates the trends in accident frequency rate (AFR), accident severity rate (ASR), and the combined risk index (CRI) across the foundry, machining, and other departments from 2021 to 2023. The foundry department consistently shows the highest AFR and CRI values, marking it as the most hazardous area, although improvements are visible over time. AFR in the foundry decreased from 135.00 in 2021 to 78.89 in 2023, with the CRI following a similar downward trend from 266.45 to 109.52, indicating that safety interventions have reduced both accident frequency and risk severity. However, the ASR shows a slight increase to 1.39 in 2023, suggesting that while accidents are fewer, some remain severe. The machining department displays a significant improvement, particularly between 2022 and 2023, where AFR declines from 80.78 to 51.42. ASR also steadily decreases, indicating that both the frequency and severity of accidents have been minimized. By 2023, machining's CRI is 13.66, showing that the department has transitioned into a low-risk category. Other departments exhibit the most dramatic improvements, with AFR dropping from 52.77 in 2021 to 10.98 in 2023, and CRI falling from 17.82 to 1.59. The consistent decline in ASR from 0.34 to 0.14 indicates that safety risks in these departments have been effectively mitigated.

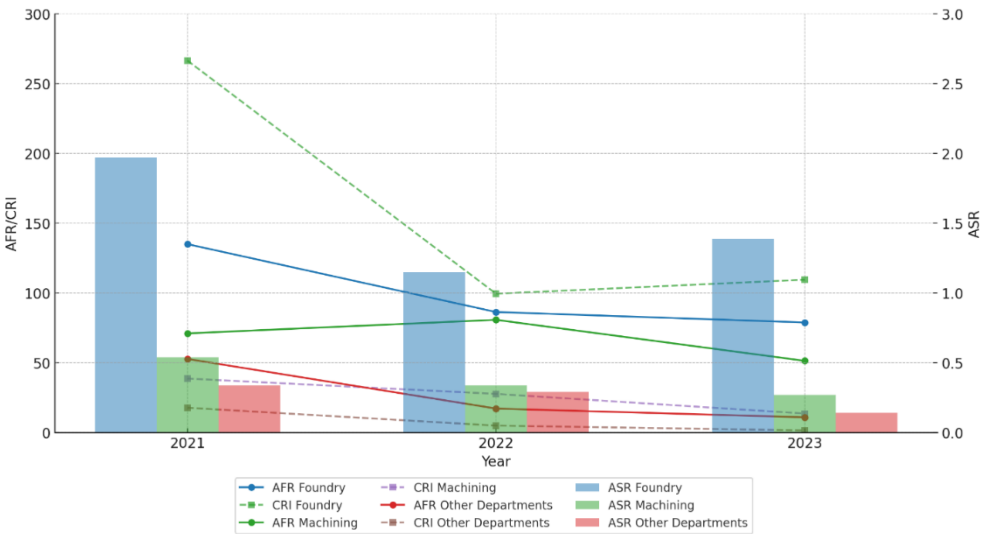

Figure 3. Trends of AFR, ASR, and CRI across departments (2021-2023).

Figure 4 illustrates the trends in accident frequency rate (AFR), combined risk index (CRI), and accident severity rate (ASR) for the overall factory from 2021 to 2023. The AFR shows a significant downward trend, decreasing from approximately 70.06 in 2021 to around 30.04 in 2023, indicating a marked reduction in workplace accidents. Similarly, the CRI demonstrates a substantial decline, falling from 46.01 to 11.73, signifying a considerable decrease in overall risk levels associated with accidents. The ASR remains relatively stable but shows a slight decrease, indicating that while the frequency of accidents is declining, the severity of these incidents is also being effectively managed. Collectively, these trends highlight significant improvements in workplace safety, reflecting the effectiveness of implemented safety interventions and emphasizing the importance of maintaining a culture of safety within the factory.

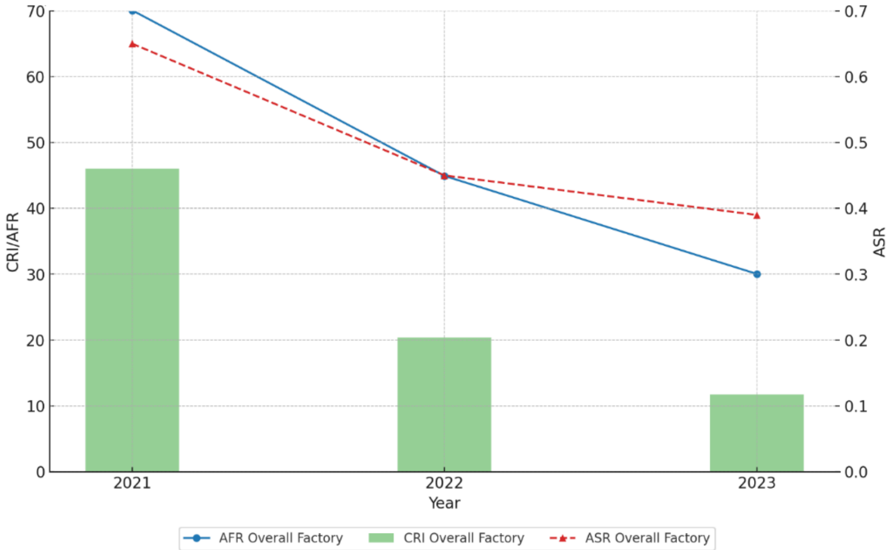

Figure 4. Trends of AFR, ASR, and CRI for the entire factory (2021-2023).

4.2. Statistical Analysis of Employee Survey Results (2020 vs. 2023)

In addition to quantitative safety performance metrics, an employee survey was conducted to understand the impact of the 5S+S methodology on workplace satisfaction in 2020 (pre-implementation) and again in 2023 (post-implementation). The survey focused on four key areas: physical working conditions, health and safety improvements, training's contribution to job and personal development, and management's attention to employee feedback (Table 9).

A chi-square test of independence was used to assess differences between 2020 and 2023 responses for each employee group and survey area. A P value of less than 0.05 was considered statistically significant. It is important to note that high initial satisfaction among white-collar employees in 2020 may have limited observable improvements due to the ceiling effect.

Table 9. Survey results on employee perceptions: 2020 vs. 2023

Survey Area	Group	2020				2023			
		Agree	Partially Agree	Partially Disagree	Disagree	Agree	Partially Agree	Partially Disagree	Disagree
Physical Working Conditions	White Collar	32	12	4	0	34	10	1	0
	Blue Collar	77	73	65	0	129	64	42	0
Health and Safety Improvements	White Collar	30	11	7	0	34	9	2	0
	Blue Collar	121	62	32	0	171	45	19	0
Training's Contribution to Development	White Collar	29	14	5	0	35	9	1	0
	Blue Collar	133	62	20	0	188	45	2	0
Management's Attention to Feedback	White Collar	31	11	6	0	35	8	2	0
	Blue Collar	107	43	65	0	157	47	31	0

Across all areas, white-collar employees maintained high satisfaction levels from 2020 to 2023. In terms of physical working conditions, positive responses remained high, increasing slightly from 91.7% in 2020 to 97.8% in 2023; however, this change was not statistically significant (P=0.384). For health and safety improvements, positive responses rose from 85.4% to 95.6%, but again without statistical significance (P=0.210). Satisfaction with training's contribution to development persisted at high levels, with positive responses increasing from 89.6% to 97.8%, yet the change was not significant (P=0.127). Similarly, perceptions of management's attention to feedback remained high, with positive responses increasing from 87.5% to 95.6%, without a statistically significant change (P=0.273).

The high initial satisfaction levels among white-collar employees suggest a ceiling effect, limiting the potential for statistically significant improvements. Maintaining such high satisfaction levels over time is a positive outcome, reflecting consistent organizational performance in meeting the needs of white-collar staff.

Significant improvements were observed in all areas for blue-collar employees. Positive responses regarding physical working conditions increased from 69.8% in 2020 to 82.1% in 2023, with the change being statistically significant ($p<0.001$). For health and safety improvements, positive perceptions rose from 85.1% to 91.9% ($p<0.001$). Satisfaction with training's contribution to development saw positive responses increase from 90.7% to 99.1% ($p<0.001$). Perceptions of management's attention to feedback improved markedly, with positive responses rising from 69.8% to 86.8% ($p<0.001$).

The 5S+S methodology effectively addressed the needs of blue-collar employees, leading to significant improvements in their perceptions across all surveyed areas. These enhancements suggest increased engagement and may contribute to better organizational performance.

The analysis demonstrates that the 5S+S methodology had a significant positive impact on blue-collar employees' workplace satisfaction from 2020 to 2023. White-collar employees maintained high satisfaction levels, indicating sustained organizational performance in meeting their needs. These findings highlight the importance of targeted interventions and considering initial satisfaction levels when assessing organizational changes.

5. Discussion

The findings from the study reveal the significant impact of implementing the 5S+S methodology in an aluminum casting factory, highlighting notable improvements in workplace safety, operational efficiency, and employee satisfaction. These results offer critical insights into the intersection of lean practices and sustainability in industrial settings, addressing key economic, environmental, and social dimensions. This section contextualizes these findings within the broader literature and discusses their implications for advancing safety and operational frameworks in high-risk industries.

5.1. Workplace Safety and Operational Efficiency

Quantitative analysis of safety metrics, including the Accident Frequency Rate (AFR), Accident Severity Rate (ASR), and Combined Risk Index (CRI), underscores the efficacy of the 5S+S methodology in mitigating workplace risks. Among the factory departments, the foundry exhibited the highest baseline risk, characterized by hazardous processes involving molten metals at extreme temperatures. By 2023, AFR in the foundry decreased from 135.00 in 2021 to 78.89, and CRI dropped from 266.45 to 109.52. While ASR slightly increased in 2023, likely due to the severity of residual incidents, these improvements signify a systematic reduction in both accident frequency and associated risks.

The machining departments, which faced risks related to CNC machinery, cutting oils, and hydraulic leaks, also demonstrated significant progress. AFR declined from 71.06 in 2021 to 51.42 in 2023, and CRI dropped to a low-risk category of 13.66. Similarly, the improvements in other departments, with AFR decreasing from 52.77 in 2021 to 10.98 in 2023, highlight the methodology’s adaptability to diverse operational contexts. These outcomes align with existing literature emphasizing structured lean methodologies in reducing workplace hazards [9, 12, 15].

5.2. Employee Satisfaction and Organizational Engagement

Employee surveys revealed statistically significant improvements among blue-collar employees in all surveyed areas: physical working conditions, health and safety enhancements, training contributions, and management’s attention to feedback. Positive responses increased significantly, with physical working conditions improving from 69.8% in 2020 to 82.1% in 2023 ($p<0.001$). White-collar employees, who exhibited high baseline satisfaction levels, showed consistent positive responses, albeit with non-significant changes. This ceiling effect reflects the need for differentiated strategies to sustain engagement among white-collar employees.

The statistically significant improvements in blue-collar employee perceptions align with the active involvement of these employees in the 5S+S implementation process. This participatory approach fosters ownership and accountability, echoing findings from studies linking employee involvement with enhanced organizational performance and satisfaction [11, 13, 17]. Moreover, the observed improvements in both safety and satisfaction highlight the dual benefits of integrating lean methodologies with safety frameworks, suggesting pathways for enhanced operational resilience.

5.3. Sustainability Dimensions

The study findings also underscore the 5S+S methodology's alignment with sustainability principles:

Economic sustainability: Reductions in workplace accidents and associated report days directly translate to lower costs related to downtime, medical expenses, and insurance claims. The methodology's emphasis on operational efficiency and waste reduction enhances profitability and resource optimization.

Environmental sustainability: Structured organization and cleanliness fostered by the methodology reduce material waste and contamination, contributing to greener manufacturing practices. For example, the introduction of contamination maps and measures to manage metal shavings align with sustainable production standards and environmental stewardship.

Social sustainability: Enhanced safety and employee satisfaction reflect the methodology's role in promoting social responsibility. The creation of safer work environments and increased employee engagement supports long-term workforce retention, morale, and community trust. These outcomes resonate with broader societal goals of workplace equity and well-being.

6. Conclusions

The successful implementation of the 5S+S methodology in this study underscores its effectiveness as a structured approach to enhancing workplace safety, operational efficiency, and employee engagement, while simultaneously advancing sustainability objectives. By systematically embedding safety within Lean manufacturing principles, the 5S+S framework not only reduces workplace hazards but also fosters a culture of continuous improvement and accountability. The significant reductions in accident rates and improvements in employee satisfaction highlight its transformative impact on industrial settings. Beyond its immediate operational benefits, this methodology aligns with broader sustainability imperatives, contributing to economic efficiency by minimizing downtime and operational risks, promoting environmental responsibility through waste reduction and resource optimization, and strengthening social sustainability by improving worker well-being and engagement. These findings reinforce 5S+S as a strategic tool for industries striving to balance productivity, safety,

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and sustainability, offering a replicable model for high-risk manufacturing environments worldwide.

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