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IMPROVING PRODUCTION EFFICIENCY AND QUALITY IN AN ALUMINUM PROCESSING COMPANY THROUGH LEAN PRACTICES

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Abstract.*This paper analyzes the application of Lean methodologies to improve the efficiency and quality of production in the aluminum foundry MTC "Nissal." The enterprise specializes in the manufacturing, refining, and shaping of aluminum and its alloys. It operates via two primary divisions: profile extrusion and aluminum rod manufacture. The main findings indicate a 14% decrease in production time mostly caused by equipment failures, and a significant rate of faults, with 71% of the defects being attributable to operator irresponsibility.By implementing Lean methods such as the 5S methodology and Statistical Process Control (SPC), the analyses showed areas that may be improved. The 5S audit revealed workplace organization and cleanliness, with an average score of 1.73 out of 5. The 5S shine phase had the lowest score of 1.38. The SPCanalysis conducted on the manufacture of billets in EN AW 2011 alloy revealed a process capability index (Cp) of 1.154 and a process capability performance index (Cpk) of 1.015. These values indicate that the process is incapable and exhibits some inconsistency.By implementing Lean techniques, the enterprise aims to decrease downtime, minimize defects, and improve overall production efficiency and quality. This will help establish MTC "Nissal" as a strong competitor in the aluminum market.*

Key words:*Lean, Quality improvement, 5S methodology, Statistical process control, Waste reduction*

1. INTRODUCTION

Metal production is very important to the world economy because metals are used as inputs in the building and manufacturing processes. The aluminum industry has an important position in the world economy because of the widespread utilization of

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aluminum in sectors such as the automotive industry, aircraft, construction, and packaging [1,2].Aluminum is highly valued for its characteristics, such as its low weight, exceptional strength, and ability to resist corrosion. The industry is categorized into primary production, which entails the extraction of aluminum from bauxite ore, and secondary production, which involves the recycling of aluminum scrap [3,4].Global aluminum output in 2022 amounted to over 68 million metric tons [5]. China is the leading producer, accounting for more than 55% of the worldwide production. It is followed by countries such as India, Russia, and Canada [6]. The demand for aluminum has continually increased due to the expansion of sectors reliant on aluminum products. It is projected that by 2025, the use of aluminium will increase by more than 2.5 times, reaching 120 million metric tons, compared to 45.3 million metric tons in 2006 [7].An important obstacle confronting the aluminum sector is its significant energy intensity and environmental footprint. The production of primary aluminum is highly energy-intensive, necessitating approximately 15 kWhof power for each kilogram of aluminum manufactured. This accounts for approximately 3% of global electricity use [8]. The smelting process also produces substantial carbon dioxide emissions, amounting to around 1.1 billion tons of CO2 each year [9].Another obstacle is the limited availability and high cost of basic materials. Bauxite ore, which serves as the main reservoir of aluminum, is extracted in substantial volumes, resulting in significant environmental deterioration and disputes around land utilization in prominent mining areas such as Australia, China, Guinea, and Brazil. The pricing of bauxite and its refined form, alumina, are subject to frequent changes due to geopolitical circumstances, supply interruptions, and shifting demand. These factors have a direct impact on the cost structure and profitability of companies involved in aluminum production.Recycling and promoting a circular economy are essential for the aluminum sector. Aluminum recycling necessitates a mere 5% of the energy required for initial production, resulting in economic and environmental advantages [10]. The current global Recycling Efficiency Rate (RER) for aluminium stands at 76% [11]. Nonetheless, the recycling process has challenges such as the presence of impurities in the scrap, inefficiencies in the collection process, and the requirement for improved sorting technology.

The aluminum sector is also confronted with regulatory and market challenges. Global governments are implementing more stringent environmental rules to decrease emissions and advance sustainability, which requires substantial investments in cleaner technology and procedures. The aluminum market is characterized by intense competition, as producers exert efforts to reduce costs, improve quality, and engage in ongoing innovation. The emergence of more rivals and the growth of current ones exacerbate these pressures even further.

The aluminum production industry has effectively applied Lean and Six Sigma approaches to optimize productivity, minimize waste, and improve quality. These approaches offer a systematic path to problem-solving and ongoing improvement, tackling major industry concerns such as excessive energy usage, environmental consequences, and market instability [12,13].An example is Alcoa, a prominent global aluminum manufacturer, which has attained substantial improvements by implementing Lean and Six Sigma methodologies. Alcoa has achieved a 20% boost in productivity and a 50% decrease in defects per million opportunities (DPMO) by specifically targeting the reduction of process variability and waste [14]. These improvements were accomplished through a range of measures, such as streamlining processes, providing training to workers, and upgrading equipment. Alcoa's Kaizen events, which were targeted, and brief initiatives designed to improveparticular processes, resulted in a 20% decrease in cycle times at their smelting plants. In addition, Alcoa was able to identify non-value-added processes and reduce lead times and inventory levels to a large extent by mapping value streams [14].Norsk Hydro, a prominent participant in the aluminum sector, has successfully adopted Lean and Six Sigma methodologies, yielding remarkable outcomes. They successfully attained a 15% decrease in energy usage per metric ton of aluminium manufactured throughout their operations. This was achieved by optimizing their smelting operations and enhancing equipment efficiency. Hydro's Six Sigma initiatives specifically targeted the reduction of defects and the standardization of processes, leading to a noteworthy 30% decrease in production costs and a commendable 25% improvement in product quality [15,16].Rio Tinto, a multinational mining and metals corporation, has announced comparable achievements. Rio Tinto's aluminum segment achieved a 25% increase in operating efficiency by implementing Lean principles. This encompassed optimizing production processes, minimizing periods of inactivity, and improving personnel competencies through ongoing training initiatives. Rio Tinto successfully employed the Six Sigma methodology to address particular quality concerns, resulting in a notable 40% decrease in defects and a 20% improvement in overall yield [17]. McKinsey & Company's analysis states that aluminium firms who adopted Lean and Six Sigma approaches achieved an average increase in productivity of 20-30% and a decrease in defect rates of 40-50%. The report emphasized that the most effective implementations entailed thorough employee training, rigorous data collecting and analysis, and a prominent emphasis on client requirements [18].

The application of Lean and Six Sigma approaches in the aluminum production industry has resulted in significant improvements in both production efficiency and quality. The study [19] thoroughly examined the effects of these approaches at an aluminum firm in Nigeria.The use of Lean manufacturing methodologies revealed several forms of inefficiency, such as defects, excess inventory, transportation inefficiencies, and waiting periods, which had a negative impact on the company's overall performance. The implementation of Lean principles resulted in the manufacturing of tiny quantities of aluminum alloys (specifically AA3001, AA3105, and AA3110) without any problems. This was achieved by following the principle of pull production. Implementing takt time, a method that aligns production speed with customer demand, led to a significant decrease in production duration. The study measured this improvement by documenting a decrease in the average duration of production per shift from 3,168 seconds (equivalent to 52.8 minutes) to 2,304 seconds (equivalent to 38.4 minutes), which includes a 180-second activity that adds value, such as cleaning the workshop and equipment.The adoption of the 5S methodology, which includes the steps of sort, set in order, shine, standardize, and sustain, resulted in a workplace that is more structured and productive. The 5S approach's usage received a weighted mean score of 3.98, suggesting that it has been widely adopted by the workforce. Standard work and Kanban were both extensively utilized, with weighted mean ratings of 3.49 and 3.45, correspondingly. These approaches facilitated the optimization of production processes, minimized unnecessary movement, and improved overall operational effectiveness.

By incorporating Lean and Six Sigma approaches into the aluminum die casting operation in Portugal [20], notable improvements in both quality and efficiency were achieved. This project, following the Six Sigma DMAIC (Define, Measure, Analyze, Improve, Control) methodology, focused on addressing the issue of a high rejection rate of aluminum window handles caused by faults that are naturally present in the gravity die casting process.The project team initially found a problem: the rejection rate for the manufactured window handle model above 50%. Thorough examination conducted during production tests indicated that around 72% of the handles manufactured were found to be faulty. The primary flaws were classified as pores, filling mistakes, and solidification shrinkages, collectively constituting more than 50% of all problems. Furthermore, the presence of contaminants and mistakes in the grinding process were major factors that contributed significantly to the elevated rate of rejection.Four key controllable elements were discovered as having a major impact on defect rates: the quantity of molten alloy, the temperature of molten alloy, the speed at which the die casting machine rotates, and the type of die coat used. For example, it was discovered that the correlation between the amount of alloy and the rate of rotation significantly influenced the occurrence of pores. Similarly, the temperature of molten alloy and the kind of die coat had impacts on the solidification shrinkages and filling mistakes.In order to resolve these concerns, the team improved the process parameters. The most effective settings were determined to be employing a big die casting spoon, maintaining the molten alloy temperature at 730°C, setting the rotation speed at 42.5 Hz, and using the KS201 type of die coat. The manufacturing process showed a significant improvement in performance. The proportion of faulty handles decreased from around 79% to below 25%. The process capability, as measured by the Sigma level, increased from 2.3 to 3.1. In addition, the mean number of defects per unit (DPU) reduced from 1.47 to 0.36.

To address the scientific gap, it is important to highlight the lack of research on the use of Lean techniques in aluminumcompanies in Serbia, especially in smaller-scale operations such as MTC "Nissal." Although Lean and Six Sigma practices have been successful in larger corporations, there is a lack of empirical data on how these methodologies can be effectively applied in medium-sized enterprises that face distinct operational challenges. This paper illustrates how the use of certain Lean techniques, such as the 5S methodology and Statistical Process Control (SPC), may effectively tackle inefficiencies and elevated defect rates resulting from equipment failures and operator errors. The study demonstrates that by consistently implementing these methods, there is a 14% reduction in production time. This highlights the potential for improvements in production efficiency and quality. This research not only adds to the academic contribution on Lean adoption in the aluminum industry but also provides practical insights for similar businesses aiming to improve their competitive advantage through process optimization.The main aim of this paper is to examine the influence of Lean and Six Sigma approaches on the effectiveness and quality of aluminium production, and to offer a thorough analysis of their application in the aluminum industry.

2. METHODOLOGY

MTC "Nissal" is a company that focuses on manufacturing, refining, and shaping aluminum and its alloys. The company began operations under this name in January 2020, carrying forward a tradition of aluminum manufacturing established by NISSAL in 1955 in Niš, southeastern Serbia. Over time, the company has transformed into an export-focused organization, with almost 75% of its income coming from international markets, mostly inside the European Union.The company's activities are categorized into two primary sectors: the profile extrusion sector, which involves the surface protection and machining of aluminum profiles, and the aluminum rod manufacturing sector, which comprises the foundry and drawing processes (Fig.1). The foundry, which is an essential element of the rod manufacturing industry, has a yearly production capacity of 7200 metric tons of aluminum billets. The billets have diameters measuring 6 and 8 inches (157mm and 203mm) and are manufactured utilizing various aluminum alloys from the 1xxx to 7xxx series.The "Nissal" company employs over 320 employees and operates on a location that covers an area of 11 hectares. The manufacturing program primarily emphasizes the processing of aluminum and its alloys, with the goal of optimizing the capabilities and resources of aluminum. It also incorporates other materials to generate a wide range of high-quality products.The production process in the foundry begins with the reception and inspection of aluminum scrap. The responsible people authenticate the quantity and quality of the incoming scrap by cross-checking it with the supporting documentation. Provided that the scrap passes the quality criteria, it is stored in a suitable manner to safeguard it from adverse weather conditions. The production process begins with the issuance of a work order by either the director or the head of the foundry. Subsequently, the foundry technologist formulates a precise alloy composition by taking into account the desired material and its chemical makeup. This recipe specifies the exact ratios of elements required to attain the desired alloy.The process of preparing materials for melting entails the precise measurement and gathering of the raw components in accordance with the specified recipe. The materials consist of aluminum blocks, in-house scrap, acquired scrap, pre-alloys (such as AlSi20 and AlCu30), and alloying elements (Si, Cu, Cr, Mg, Mn, Pb, Bi). The induction furnaces are filled with these ingredients in a meticulous manner, guaranteeing that every batch begins with a minimum molten base of 300kg to sustain optimal melting efficiency.After the ingredients are loaded, the melting process begins, with careful consideration given to the sequence in which components are added in order toimprove the efficiency of the melting process. The molten aluminum undergoes purification by the use of degassing salts, after which the purified molten metal is subsequently heated to the required temperature for casting.An electromagnetic casting machine is used for the casting of aluminum billets. The liquefied metal is introduced into the casting mold, where it solidifies and takes the shape of the mold. The resulting billets are then subjected to a regulated process to ensure uniformity and consistency. This process entails subjecting the billets to elevated temperatures ranging from 450°C to 600°C for durations ranging from 4 to 20 hours, depending on the specific alloy, in a homogenization furnace.Post-casting procedures encompass the act of severing the billets to the desired dimensions and performing meticulous examinations on the chemical composition, microstructure, and gas content. Defects discovered during these inspections are resolved by re-melting the billets, guaranteeing that the end products adhere to the necessary quality criteria.The production process at MTC "Nissal" is carefully structured to guarantee optimal efficiency and the production of output of superior quality. This entails the ongoing surveillance and regulation of multiple factors, including the duration of production, the caliber of the manufactured billets, and the adherence to production schedules. Although the organization encounters obstacles such as equipment malfunctions and the requirement for consistent raw material provision, it endeavors to uphold elevated levels of output by implementing stringent process management and quality control measures. The utilization of Lean approaches, such as

5S and SPC, has identified the effectiveness and excellence of the production process, tackling concerns associated with workplace arrangement, process fluctuation, and defect frequencies.

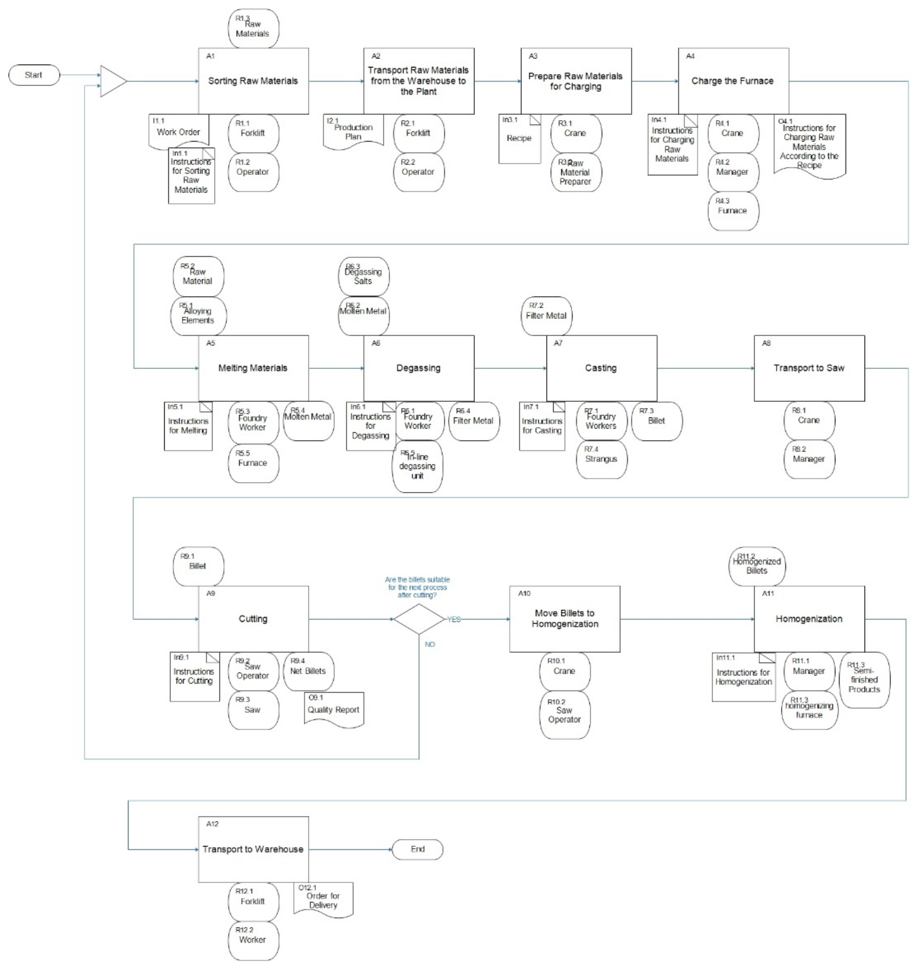

Fig. 1 Process map in the foundry production plant of the company MTC 'Nissal

In order to examine the implementation of Lean approaches and their effect on the productivity and quality of production at MTC "Nissal," a systematic data collection methodology was done. The main data collection methods employed were direct observations, structured interviews, and quantitative data analysis.Direct observations were made by conducting regular site visits to observe the production processes in real-time. This facilitated the recognition of inefficiencies, bottlenecks, and prospective areas for improvement. The observations were centered on the workflow within the profile extrusion and aluminum rod manufacturing divisions, with a particular emphasis on the utilization of equipment, activities performed by operators, and procedures related to handling materials.Structured interviews were carried out with key staff, such as production managers, line supervisors, and machine operators. The purpose of these interviews was to collect information regarding the current difficulties in production, the efficiency of current protocols, and the employees' knowledge and expertise in Lean approaches such as 5S and SPC. Quantitative data analysis was conducted using historical production data to evaluate the performance both before and after the application of Lean methods. The data encompassed many measures, including production time, defect rates, downtime, and process capability indices (Cp and Cpk). The SPC analysis specifically examined the production of billets using alloy EN AW 2011, with the aim of assessing the process's consistency and capacity.

This study usedLean tools to examine the inefficiencies in production and improve the quality of the aluminum foundry processes at MTC "Nissal." The main approaches employed were the application of Lean concepts to identify waste, conducting 5S audits, utilizingSPC, Pareto analysis, and Ishikawa (fishbone) diagrams.

3. Analysis of Current State

The effective implementation of Lean methodologies relies on identifying and eliminating different types of waste. An investigation was carried out in the aluminum foundry at MTC "Nissal" to classify and examine these inefficiencies. This section provides a detailed explanation of the various forms of waste that can be identified in the manufacturing process. These include wasteful transportation, excessive inventory, duplicate motions, overproduction, excessive processing, waiting periods, defects, and untapped human potential. In addition, the 5S audit, which is a fundamental part of Lean techniques, was used to evaluate and improve the organization, cleanliness, standardization, and maintenance of the workplace. Thorough audits, SPCand Pareto analysis were used to provide important insights into the underlying reasons for production inefficiencies and faults. These findings not only identify the specific areas that need immediate attention, but also offer a clear plan for making systematic improvements that will improve both the overall production efficiency and quality at MTC "Nissal."

3.1 List of basic wastes in the production process

1. **Transport -** Waste occurs due to unnecessary movement of raw materials during reception and selection at the raw material yard. Frequently, due to a shortage of forklifts, raw materials are moved multiple times, reducing the efficiency of forklift operation and the workers responsible for the yard.
2. **Inventory -** Waste occurs in the form of unnecessary stockpiles of raw materials, as production plans change daily. Consequently, the yard contains materials of varying quality, often sufficient for a month's production of billets. Accumulating unnecessary raw material inventory often increases production costs.
3. **Unnecessary movements – walking-** This waste occurs daily in the foundry. Workers often walk unnecessarily and leave their workstations outside of

scheduled breaks. Additionally, there is unnecessary movement of cranes and forklifts. Due to the distance of the laboratory, the technologist must walk about 500 meters back and forth for sample testing, which would not be the case if the spectrometer were closer to the production plant.

4. **Overproduction -** There is no overproduction, as the foundry's capacity is lower than the capacity of its internal customers.
5. **Overprocessing -** Overprocessing usually does not exist in the foundry as all processes are standardized. In certain cases, when a customer demands specific quality, overprocessing occurs (improved chemical composition and filtration of the melt). However, due to the specific nature of production, these additional activities often do not affect the quality that the customer can recognize.
6. **Waiting -** This waste occurs frequently, especially at the positions of raw material preparers and melters. Due to frequent forklift breakdowns, the raw material preparer must wait for the raw material. This waiting also causes delays for the melter, who, due to a lack of raw materials at the preparer's station or furnace breakdowns, cannot add the prescribed raw materials to the melting furnace. This waste significantly slows down and jeopardizes the planned daily production schedule.
7. **Defects -** Defects are a part of the business and occur frequently. The advantage in the production of aluminum semi-finished products is that all defects can be reused or "remelted." This waste manifests as a reduction in planned production and an increase in product costs due to the reprocessing of unplanned scrap. Defects can arise from poor billet casting (cold shuts, poor billet surface, poor degassing) or inappropriate chemical composition.
8. **Underutilized human potential-** The workforce structure is such that older, experienced workers predominate. Due to the company's turbulent past, workers are insufficiently motivated to use their knowledge and skills in the most productive manner. This waste is very visible and striking but is not addressed for elimination.

3.2 5S audit in the foundry production plant

To determine the level at which a specific category is evaluated during the 5S audit, ratings are entered into the checklist. This provides insight into which category needs improvement, and which is at an acceptable level.

Table 1 Definition of characteristics of ratings during the 5S audit

Rating	Category	Description
0	No effort	There are no 5S activities in the work area based on this criterion.
1	Minimal effort	Any effort in 5S is likely the result of 1-2 people. There is no organized effort from all, and there are many opportunities for improvement.
2	Moderate effort	There are attempts to implement 5S, but efforts are sporadic and superficial.
3	Minimally acceptable level	The entire team works on improving 5S implementation.

		Previous improvements become standards.
4	Above-average results	The level of 5S in the work area is excellent. Although there is still room for improvement, work areas become examples of "world-class."
5	Outstanding results	The level of 5S in the work area is "world-class," an example for the industry. 5S is fully implemented at the workplaces.

The following tables present the results of the 5S audit conducted in the semi-finished aluminum products production sector at MTC "Nissal."

Table 25S Audit Results by Individual Phases

Step	Result	Average
Sort	22	2.75
Organize	18	2.25
Clean	11	1.38
Standardize	14	1.75
Maintain	4	0.5
Total	**69**	**1.73**

Since the 5S methodology is not implemented at MTC "Nissal," the audit revealed significant room for improvement and identified critical points that can have a substantial impact on overall operations. The biggest issue is the cleanliness of the production plant, which is at a very low level and directly affects the execution of other phases of the 5S methodology. This problem is difficult to solve because, despite cleaning the production plant on a shift basis, the casting technology is extremely dirty. Aluminum dust appears constantly during the production process due to a semi-closed filtration system, making it nearly impossible to ever fully clean the production plant, offices, and other auxiliary areas. Additionally, due to years of inadequate maintenance, oil stains appear around the equipment. Another identified issue is the accumulation of unnecessary items, documentation, and materials that are not used, without designated places or methods for disposal. In the offices, unnecessary documents are not properly archived, unnecessary tools are found on work surfaces, and unnecessary raw materials are present in the plant. Since the first 3S's were rated poorly, it is impossible to standardize the process, and a non-standardized process is pointless to maintain. The reason for not implementing the 5S methodology is the lack of interest from higher management in the company. Proper waste selection, essential for the correct production process, is the only phase in the 5S methodology that is adhered to at the highest level. Waste is sorted and marked according to aluminum alloy types.

3.3 Statistical Process Control (SPC)

Statistical Process Control, as a quality tool, is not implemented at MTC "Nissal." For the SPC analysis in this paper, one order from the Extrusion Plant was used. The analysis was conducted during March in the Extrusion Plant for the production of 3000 kg of aluminum billets in alloy EN AW 2011. The required length of the cut aluminum billets is 300 cm. Each of the 25 samples had five measurements. The control limits for cutting billets, determined based on measured values, are an upper limit of 301.938 cm and a lower limit of 298.062 cm.

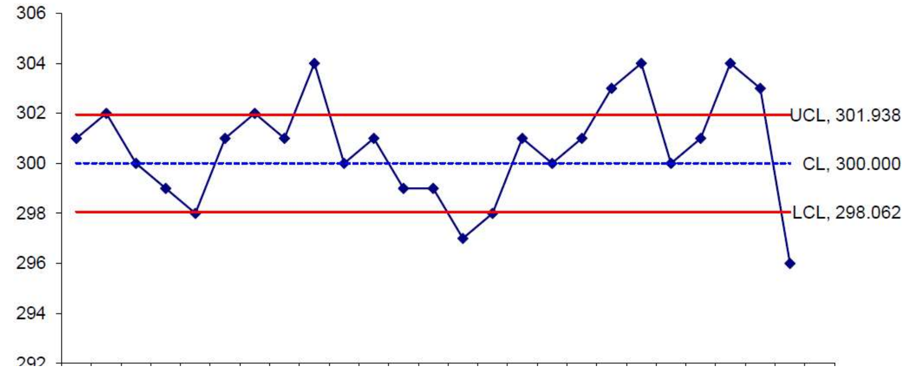

Fig. 2X-bar Chart

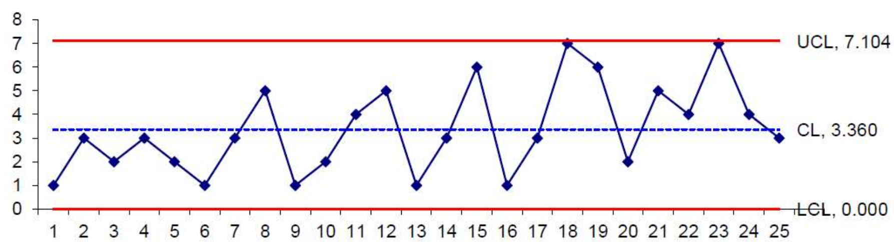

Fig. 3R Chart

Statistics from Data Table	
R-bar	3.360
Process Mean, μ-hat	300.600
Process St.Dev., σ-hat	1.445
$\sigma_{X\text{-bar}}$	0.646

Process Capability	
Upper Spec Limit, USL	305.000
Lower Spec Limit, LSL	295.000
C_p	1.153
CPU	1.015
CPL	1.292
C_{pk}	1.015
Percent Yield	99.88%

Fig. 4 Cp and Cpk Coefficients

After performing measurements and using the SPC method, the following results were obtained (Fig.2-Fig.4):
Cp = 1.154
Cpk = 1.015

These results show that the value of the Cp coefficient (potential index) is in the range of $1 < Cp < 1.33$, indicating that the process is uncapable but there are certain variations that can affect the quality of the products. The value of the Cpk coefficient (process capability index) is in the range of $1 < Cpk < 1.33$, indicating that the process is critically accurate.

3.4 Pareto analysis

To identify the critical causes that result in production losses, a Pareto analysis was conducted. The losses were tracked monthly and included work process stoppages and defects. These categories need improvement to make the production process more efficient and effective. The data for stoppages are presented in minutes for the period from February 1 to February 29, 2024, and for defects in kilograms for the same period.The production stoppages and their durations in minutes were as follows: furnace breakdowns accounted for 2100 minutes, making up 34.6% of the total stoppage time. Crane malfunctions caused 1550 minutes of downtime, cumulating to 60.2% when added to the furnace breakdowns. Forklift breakdowns resulted in 1200 minutes of downtime, bringing the cumulative total to 80.0%. Cleaning the furnace lining took 445 minutes, accumulating to 87.3%. Washing the furnace coils required 315 minutes, resulting in a cumulative total of 92.5%. Shortages of alloying elements accounted for 155 minutes, adding up to 95.1%. Raw material shortages caused 125 minutes of downtime, bringing the cumulative total to 97.1%. Cleaning workstations took 80 minutes, accumulating to 98.4%. Water supply interruptions caused 60 minutes of downtime, resulting in a cumulative total of 99.4%. Power outages accounted for 35 minutes, bringing the cumulative total to 100.0% (Fig.5).

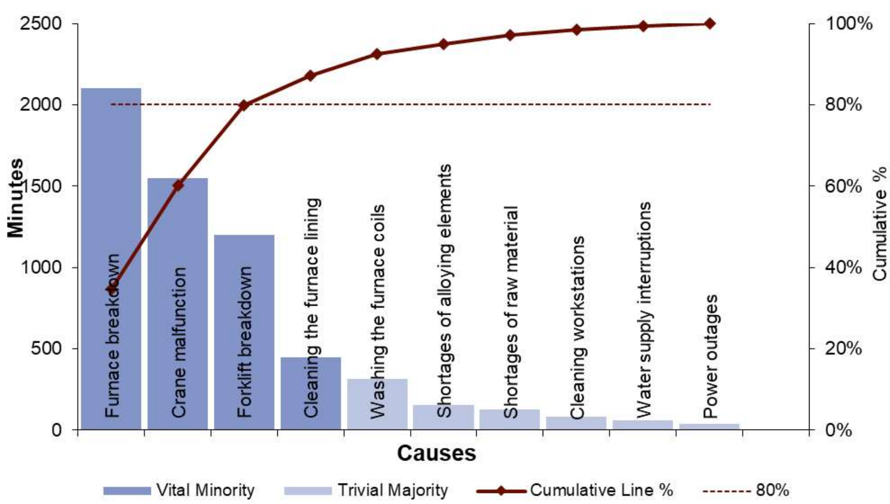

Fig. 5 Pareto diagram for production downtime in the foundry

The Pareto diagram analysis showed that 14% of the total time, the foundry was in downtime. The primary cause of stoppages was furnace breakdowns, followed by crane and forklift malfunctions. Addressing these issues would significantly improve process performance, reduce costs, and increase production volume.

For defects, the observed values were measured in kilograms. The primary cause was operator negligence, which accounted for 35450 kg of defects, making up 71.0% of the total defects. Poor cooling of the crystallizer resulted in 7550 kg of defects, cumulating to 86.1% when added to operator negligence. Poor chemical composition caused 2980 kg of defects, bringing the cumulative total to 92.0%. Defective casting accounted for 1800 kg of defects, adding up to 95.6%. Inadequate training of the cutters resulted in 1345 kg of defects, accumulating to 98.3%. Equipment failure caused 836 kg of defects, bringing the cumulative total to 100.0% (Fig.6).

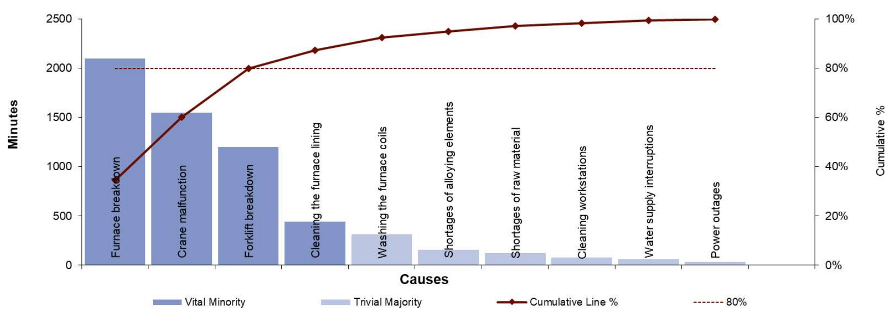

Fig. 6 Pareto diagram for defects (scrap)

The Pareto diagram for defects revealed that the primary cause of defects was operator negligence. Addressing this issue would significantly reduce defects in the production of aluminium semi-products and increase production volume with the same amount of effort.

3.5 Ishikawa method

The manufacturing of aluminum semi-products is modeled by the Ishikawa diagram (Fig. 7). This figure shows the reasons of production stoppages and flaws using the 4M technique (Machines, Manpower, Methods, Materials). Work stoppages are mostly caused by people and machines. On the other hand, materials and techniques constitute the main sources of manufacturing flaws. Among the machine-related problems are obsolete tools, limited capacity, poor handling and upkeep. Many times, these issues cause manufacturing stops. Work stoppages also greatly influence manpower problems including worker indiscipline, inadequate training, regular absences, and general discontent. Reducing these problems by modernizing tools, changing maintenance schedules, and raising worker satisfaction and training could help to lower production disruptions.

Conversely, flaws in the final goods are mostly resulting from the materials and techniques applied throughout the manufacturing process. Inappropriate use of materials and poor techniques might cause flaws, therefore lowering the quality of the aluminum semi-products. While material-related problems could involve poor quality raw goods or improper handling, methods can include inadequate procedures, lack of standardizing, and insufficient control mechanisms. Many advantages in productivity can be obtained by only partially removing these factors. Reduced downtime and improved efficiency would result from better-trained, more contented staff and higher dependability of machines.

Likewise, improving the general quality of the items by means of better manufacturing techniques and guaranteeing premium materials will help to reduce flaws. Constant improvement and operational excellence in the manufacturing of aluminum semi-products depend on this method of spotting and fixing fundamental reasons.

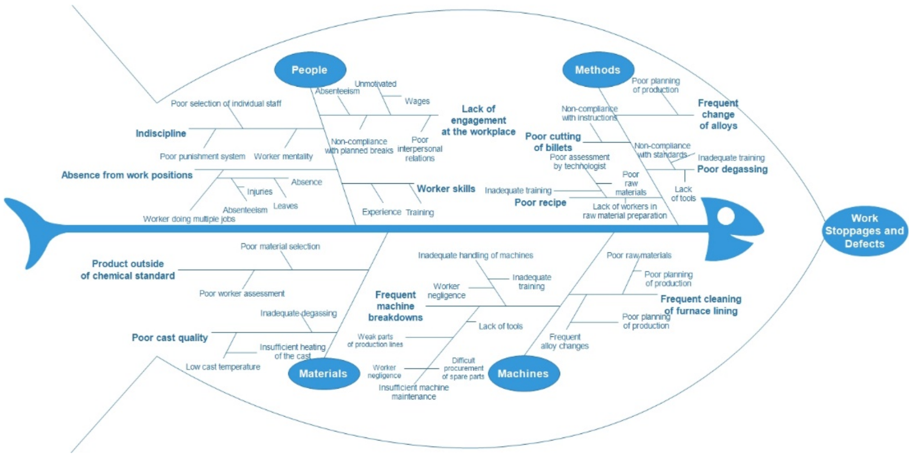

Fig. 7 Ishikawa diagram of work stoppages and defects

4. DISCUSSION

Lean approaches' examination and application at MTC "Nissal" exposed numerous important areas for development. Frequent equipment breakdowns, poor personnel utilization, and uneven quality control techniques all hinder the foundry's operations. These problems cause major production interruptions and high failure rates, which eventually influences the general effectiveness and quality of products of the company. Using the 5S approach brought attention to the manufacturing plant's poor cleanliness and organization. Particularly in the "Shine" phase, which scored the lowest at 1.38, the average score of 1.73 out of 5 from the 5S audit shows great opportunity for development. This low score implies that the general efficiency and safety of the production environment are affected by inadequate attention to cleanliness and maintenance of the workspace.

The SPC study gave important new perspectives on the foundry's process capacity. It is clear from a process capability index (Cp) of 1.154 and a process capability performance index (Cpk) of 1.015 that, the process is uncapable, it shows variability that can compromise product quality. These results highlight the need for more severe process control strategies and ongoing monitoring to lower variability and raise output consistency. The Pareto study also helped to pinpoint the main factors of ineffective manufacturing. The bulk of production stoppages—34.6%, 60.2%, and 80.0% of the total downtime—were equipment failures, especially furnace breakdowns, crane malfunctions, and forklift breakdowns. By means of consistent maintenance and prompt repairs, addressing these equipment-related problems will help to greatly lower downtime and increase production efficiency. With regard to flaws, operator ignorance came out as the main one causing 71.0% of all the ones. With 86.1% and 92.0% respectively, poor cooling of the crystallizer and insufficient chemical composition were also major factors causing the flaws. These results underline the requirement of changes in the cooling process and chemical composition control as well as the need forimproved training and operator monitoring. Analysed using the Ishikawa diagram study, these results show that both manpower-related and machine-related problems are crucial ones needing attention. Reducing production interruptions and increasing efficiency depend on updating equipment, streamlining maintenance schedules, and raising worker training and satisfaction. Minimizing flaws and improving product quality depend also on improving manufacturing techniques and guaranteeing premium materials.

Using Lean techniques and approaches methodically will help one to reach these gains. By teaching management, the value of Lean techniques and progressively implementing them in phases, MTC "Nissal" will be better able to change into a more competitive and efficient company. The business may make major increases in production efficiency and product quality by concentrating on ongoing development and tackling the underlying causes of inefficiencies and flaws, therefore enhancing its position in the aluminium market.

5. PROPOSED IMPROVEMENTS AND IMPLEMENTATION PLAN

Further investments are required to reach specific targets; in this scenario, they would have many favorable results: higher production volume, greater product quality, and better adherence to production standards. The forklift, crane, melting furnace, and casting machine are the most important foundry tools needing investment. The foundry requires another forklift because of continuous breakdowns and wear and tear on the present one. Waiting times between the raw material yard and the manufacturing hall would be much shortened by a new forklift. The crane presents still another waiting problem. Because of its important function, the crane is quite worn out and daily electro-mechanical problems happen. The crane has to be repaired. First, accumulated aluminum dust has to be wiped from the crane bridge and tracks. The crane tracks ought then to be leveled. The crane wheels should have new "braids" fitted; the "trolleys" should be totally rebuilt; and the so-called "cat" should be extensively overhauled. This suggested renovation would speed up manufacturing itself and eliminate waiting times resulting from breakdowns. The induction melting furnaces currently in use are technologically outdated and inefficient. Purchasing new gas furnaces represents the largest investment. This action would lower the production cost per unit, cut the number of operators required, lower the electricity usage, and raise the melting volume, thereby improving the quality of the products. Another tool that restricts output is the casting machine. Buying a new casting machine—more especially, the so-called Wagstaff—would boost production volume, raise the quality of products, cut the number of operators (casters), and lessen the likelihood of human error during the semi-finished product manufacturing.

The recommendation to invest in new machinery and overhaul existing ones at MTC "Nissal" is aimed at addressing the bottlenecks in the production process, which are primarily caused by equipment failures and inefficiencies.These investments are expected to yield significant improvements in production capacity, product quality, and operational efficiency.

First, adding a new forklift is really important. Constant breakdowns and too much wear and tear cause the present forklift to be often out of use. This causes major delays in transporting raw materials from the storage yard to the production hall, therefore creating production flow congestion. Apart from lowering these delays, a second forklift would improve the general foundry logistics effectiveness. Second, the crane—needed for many lifting and transportation tasks in the foundry—badly needs a thorough overhaul. Because of its great use and inadequate maintenance, the crane suffers everyday electro-mechanical faults. Cleaning the crane bridge and tracks to eliminate accumulated aluminum dust, leveling the tracks, placing new braiding on the crane wheels, totally restoring the trolleys, and extensively refurbishing the cat—the main lifting mechanism—is part of a complex overhaul plan. By removing regular breakdowns these steps will help to lower downtime and accelerate the manufacturing process. The melting furnaces currently in use are technologically outdated and inefficient, leading to high electricity consumption and limited production capacity. Although the replacement of ancient induction furnaces with new gas furnaces requires a large outlay of funds, it promises great advantages. New gas furnaces would minimize manufacturing costs per unit, cut energy usage, boost melting capacity, improve product quality, and cut operator needed numbers. This upgrade would modernize the melting process, making it more efficient and cost-effective. At last, an essential component of the manufacturing of aluminum billets, the casting machine needs replacing as well. The current machine is prone to mistakes influencing product quality and restricts manufacturing capacity. The recommendation to purchase a new Wagstaff casting machine aims to address these issues. By lowering faults, improving product quality, increasing production volume, and minimizing the need of operators, this new machine would also reduce the possibility of human mistake. The production capacity and general efficiency of the foundry should be improved by this investment.

Overcoming the present production difficulties at MTC "Nissal" depends on both the planned expenditureon new machinery and the examination of current equipment. These steps will raise production capacity, improve product quality, and boost operational efficiency, orienting the foundry toward more competitiveness in the aluminum market.

6. Conclusion

Application of Lean tools at MTC "Nissal" has exposed areas for development that, if addressed, would greatly increase production efficiency and product quality. The results underline that the main obstacles to lean foundry operations include equipment breakdowns, underused staff, and inconsistent quality control policies. These problems cause significant production downtime and high defect rates, which eventually influences the general quality and efficacy of the company's products. Aiming at clearing these obstacles are the suggested expenditures in new machinery and the thorough overhaul of current equipment at MTC "Nissal". Significant increases in production capacity, product quality, and operating efficiency are anticipated from adding a new forklift, renovating the crane, substituting new gas furnaces for old induction furnaces, and obtaining a new Wagstaff casting machine.

Lean methods applied methodically and gradually, teaching management on their value, will help MTC "Nissal" become a more competitive and efficient company. Emphasizing ongoing development and tackling the underlying causes of flaws and inefficiencies would help the business to significantly increase production efficiency and product quality, thereby strengthening its position in the aluminum market. Future work should focus on the continuous application and refinement of Lean methodologies at MTC "Nissal." Long-term research should be carried out to evaluate Lean methods' continuous impact on product quality and production efficiency. Additionally, exploring the integration of advanced technologies such as automation and digitalization in the production process can further improve operational efficiency.

Publishing the presented results is important for several reasons. First, it contributes to the existing state of the art on the application of Lean methodologies in the aluminum processing industry, particularly in medium-sized enterprises. This research fills a gap in the literature by providing empirical data on the effectiveness of Lean techniques in improving production efficiency and quality in a Serbian aluminum foundry.Second, distributing these results to the larger academic and commercial communities can be a great source of reference for like companies trying to improve their competitive edge by means of process optimization. At last, these findings emphasizes the need for ongoing development as well as the acceptance of Lean ideas in the manufacturing sector. They emphasize the real advantages that can be attained by methodically trying to lower waste, minimize flaws, and improve general operational efficiency.

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