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Waste Analysis in the Aluminum Extrusion Process utilizing Lean Six Sigma and Failure Mode and Effect Analysis (FMEA)

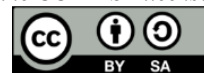
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Abstract— This study aims to identify the dominant types of waste, investigate the underlying causes of quality failures, and formulate improvement recommendations to enhance the efficiency of the production process. The research employs an integrated approach combining Lean Six Sigma and Failure Mode and Effect Analysis (FMEA) to systematically identify inefficiencies and prioritize corrective actions. In contrast to previous studies that primarily focus on a single Critical to Quality (CTQ) characteristic within aluminum extrusion processes, this study examines four dominant CTQs, thereby providing a more comprehensive framework for quality improvement. The findings indicate that defects constitute the most critical form of waste, with the highest weight value of 0.1206, followed by waiting (0.0905) and transportation (0.0854). Further analysis using fishbone diagrams and FMEA reveals that denting defects represent the most significant failure mode, yielding the highest Risk Priority Number (RPN) of 336. Based on the proposed improvement initiatives, the company has the potential to eliminate all non-value-added (NVA) activities and substantially reduce necessary non-value-added (NNVA) activities. The implementation of these recommendations decreases the total production lead time from 2,435.59 minutes to 1,870.41 minutes, while increasing the proportion of value-added (VA) activities from 40.86% to 46.34%. These results demonstrate that the integration of Lean Six Sigma and FMEA provides an effective and systematic approach to improving process efficiency and product quality in aluminum extrusion manufacturing.

Keywords—Aluminum Extrusion, Lean Six Sigma, FMEA, Seven Waste

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I. INTRODUCTION

The metallurgical industry constitutes a primary pillar of the national economy, with aluminum serving as a strategic commodity. The quality of the manufactured aluminum is fundamentally governed by extrusion process parameters, specifically extrusion force and velocity, processing temperature, and intrinsic factors such as material composition, billet dimensions, and preparation. Furthermore, it is influenced by profile geometry, die design, and die wear, as well as the tribological phenomena occurring during friction and lubrication [1]. Over a twelve-period observation, the total production of aluminum profiles reached 432,322 kg, with defective products totaling 33,281 kg. This indicates a significant

defect rate of 7.82%, leading to substantial defect waste. Furthermore, the analysis identified 'Waste of Unnecessary Inventory' due to the accumulation of profiles in the warehouse for several years, posing risks of material degradation and escalated holding costs. 'Waste of Overproduction' was also observed, where the extrusion process output exceeded actual demand. 'Waste of Inappropriate Processing' occurred through excessive immersion times in the coloring process and redundant purification of Iron (Fe) content. Additionally, 'Waste of Waiting' was identified due to idle time for waste division machinery and operators caused by limited waste tank capacity, equipment failure, and forklift shortages. 'Waste of Transportation' resulted from unstructured material flow due to poor workplace layout. Finally, 'Waste of Motion' was evident in inefficient operator movements stemming from inadequate material handling skills and suboptimal adherence to work procedures due to limited technical knowledge. Previous studies on Lean Six Sigma implementation in aluminum extrusion industries have predominantly focused on improving process capability based on a single critical-to-quality (CTQ) characteristic, particularly geometric dimensions. However, aluminum profile manufacturing in real production conditions is characterized by multiple dominant defects representing different CTQs. Therefore, a research gap exists in addressing multi-CTQ-based quality improvement that simultaneously considers various defect types affecting product performance. Accordingly, the novelty of this study lies in the application of Lean Six Sigma integrated with Failure Mode and Effect Analysis (FMEA) to analyze and prioritize four critical-to-quality (CTQ) characteristics representing dominant defects in aluminum profile production, enabling a more comprehensive and realistic quality improvement strategy.

II. RELATED WORDS

A. Aluminum Extrusion

Extrusion is a manufacturing process involving the compression of a material to induce plastic deformation, thereby producing components with a predefined geometric configuration. In metallurgical applications, extrusion is a process wherein a metal billet undergoes a reduction in cross-sectional area by being forced through a die orifice under high pressure [1]. In atmospheric conditions, aluminum readily undergoes oxidation, forming a tenacious, thin oxide film (Al_2O_3) that provides inherent corrosion resistance. Furthermore, aluminum exhibits amphoteric properties, enabling it to react with both acidic and alkaline solutions [3]. Aluminum extrusion is one of the primary manufacturing methods for producing various complex shapes that are widely utilized in the automotive, construction, energy, and other industrial sectors [4]. Aluminum possesses several advantages, including high hardness and ductility. However, certain aluminum alloys exhibit limitations, particularly an inability to withstand corrosion rates induced by destructive environmental influences. The toughness and mechanical strength of aluminum are subject to degradation as a consequence of corrosion. To mitigate the potential losses resulting from these environmental impacts, various protective measures are employed, one of the most prominent being surface treatment via the anodizing method [5]. Anodizing is a surface coating process utilizing an electrolytic method to transform the aluminum substrate into aluminum oxide (Al_2O_3) at the surface layer. The resulting thin oxide layer is characterized by a porous structure, exhibiting high hardness and superior corrosion resistance. These inherent pores are subsequently utilized for coloration through the impregnation of organic or inorganic dyes [6]. Coating, specifically powder coating, is a surface finishing process involving the application of powdered resin, where the coloration is customized according to customer specifications. The process initiates with the immersion of the substrate into an electrolyte solution containing metallic ions. In this electrochemical configuration, the substrate functions as the cathode connected to the negative terminal, while the anode is connected to the positive terminal and similarly

immersed in the solution. Upon the application of a direct current (DC) through the circuit, metallic ions are reduced and deposited onto the substrate surface, forming a cohesive coating layer [7].

B. Lean Six Sigma

The Lean method is utilized to eliminate waste within processes, thereby reducing costs and enhancing productivity [8]. Lean Manufacturing is a production approach that emphasizes speed, smoothness, and cost efficiency by focusing on customer demand [9]. Six Sigma is a business strategy aimed at eliminating waste, reducing costs associated with poor quality, and improving the effectiveness of all operational activities to meet customer needs and expectations [10]. Therefore, the integration of Lean Manufacturing and Six Sigma strategies is essential for the company to systematically eliminate identified wastes and optimize operational performance [8].

Lean Six Sigma is a collaborative methodology integrating Lean Thinking and Six Sigma principles, aimed at identifying and minimizing waste, optimizing processes, enhancing production or service quality, and increasing customer satisfaction. The Lean concept focuses on waste elimination, streamlining the flow of materials, products, and information, and fostering continuous improvement. Conversely, the Six Sigma component emphasizes the reduction of process variation and the attainment of operational excellence through systematic improvement [11].

In conducting an analysis to enhance production process efficiency, manufacturing activities are generally categorized into three distinct types of activities, namely Value Added (VA), Necessary Non-Value Added (NNVA), and Non-Value Added (NVA) [12]. The Lean Six Sigma method utilizes Process Activity Mapping (PAM) to illustrate all activities, including their respective durations, lead times, and the specific areas utilized for each activity [13]. There are five general stages in the Process Activity Mapping (PAM) approach, which include understanding the process flow, identifying waste, evaluating process reconfiguration, optimizing flow through layout and routing, and assessing necessity and elimination [14]. This is a technical method aimed at identifying waiting times and productivity, encompassing both physical product and information flows [15]. Subsequently, the process is visualized using Value Stream Mapping (VSM) to illustrate the production system, including the sequence of value-added activities within the company. There are two mapping conditions that must be conducted: the current state map and the future state map [16]. VSM is an essential tool in the implementation of Lean systems within a company to achieve sustainable improvements in productivity and quality [17]. The primary problem-solving methodology utilized in Lean Six Sigma is DMAIC (Define, Measure, Analyze, Improve, and Control), which serves to define, evaluate, and enhance process quality to drive profitability [18].

C. FMEA

Failure Mode refers to the failure of a product or process to perform its intended function, or the underlying cause of such failure, whereas Effect Analysis involves analyzing the potential consequences resulting from each failure mode. The objective of employing FMEA is to determine corrective actions that can eliminate or mitigate the causes of failure and minimize hazardous risks, particularly for those identified as high priority. The failure risk and its impact are quantified by three primary factors [19]:

1. Severity (S): The degree of impact or seriousness of the failure should it occur.
2. Occurrence (O): The frequency or probability with which a specific failure cause is expected to happen.
3. Detection (D): The probability of identifying the failure or its cause before it reaches the customer or subsequent process stage

The Risk Priority Number (RPN) is a numerical ranking utilized to quantify the risk associated with potential failure causes. It is calculated by multiplying the scores of three

parameters: Severity (S), Occurrence (O), and Detection (D) [20]. To obtain the Risk Priority Number (RPN), a questionnaire utilizing a Likert scale will be employed. The Likert scale is used to measure the attitudes, opinions, and perceptions of individuals or groups regarding social phenomena [21]

D. Waste

Waste refers to any activity that does not provide value added during the production process, spanning from small components to the final product [22]. The following are types of waste commonly encountered in production lines [23] :

1. Overproduction: A type of waste caused by excessive production volumes, occurring when the output exceeds the initial production schedule or actual demand.
2. Waiting: Waste resulting from process bottlenecks or disruptions, where subsequent stages are delayed while awaiting the completion of preceding operations.
3. Transportation: Excessive movement of materials or products, which leads to unnecessary expenditures in terms of costs, time, and physical effort.
4. Inappropriate Processing: Waste stemming from redundant or overly complex process steps, including unnecessary operations such as avoidable rework.
5. Inventory: Waste associated with the accumulation of excessive raw materials or finished goods. The 'Just-In-Time' (JIT) concept is typically implemented to eliminate this category of waste.
6. Motion: Unnecessary physical movements by operators that do not add value, consequently slowing down the process and extending the overall lead time.
7. Defects: Waste arising from the production of non-conforming products. Defects are a critical concern in manufacturing as they directly impact production costs and operational profitability.
8. Underutilized People: The failure to leverage employees' skills and intellectual potential optimally, or assigning tasks that are significantly below their actual capabilities.

III. METHOD

This research employs questionnaires, interviews, and observation methods to collect data. The obtained data were analyzed using the Lean Six Sigma approach to measure the defect rate and identify various types of waste in the production process. The root causes of defects and high-priority failure risks were identified using the Failure Mode and Effects Analysis (FMEA) method. Based on the analysis results, improvement proposals were formulated to increase process efficiency and minimize defective products through both quantitative and qualitative perspectives.

Table 1. Production and Defect Data for the 2025 Period

Month	Total Production (kg)	Types of Defect (kg)				Total Defective Products (kg)
		Discoloration	Dents	Dullness	Mold	
January	13.149	192	250	128	132	702
February	108.812	1.814	2.472	1.277	1.514	7.077
March	14.218	300	427	216	323	1.266
April	8.758	76	152	55	94	377
May	6.234	91	113	36	109	349
June	11.179	325	512	232	231	1.300
July	11.463	315	412	112	219	1.058
August	11.064	200	321	108	257	886
September	5.533	125	227	124	181	657
Oktober	17.010	207	341	116	172	836
November	8.848	43	61	39	56	199
December	216.054	5.302	6.742	3.358	3.712	19.114
Total	432.322	8.990	12.030	5.801	7.000	33.821

IV. RESULT AND DISCUSSION

In the Results and Discussion section, waste reduction is illustrated using Value Stream Mapping (VSM) following the elimination of Non-Value-Added (NVA) activities and the reduction of cycle times in Necessary But Non-Value-Added (NNVA) activities. To manage product defects, the DMAIC framework is employed, encompassing the Define, Measure, Analyze, and Improve phases. However, the Control phase is excluded from this study, as the research objective is limited to providing proposed improvement recommendations for the company.

A. Current State Value Stream Mapping

The identification of the Current State Value Stream Mapping (CVSM) was conducted by mapping the primary production flow of aluminum profiles, encompassing both information and physical flows. The production process at the company is illustrated for each station, supplemented by a classification table distinguishing Value Added (VA), Necessary Non-Value Added (NNVA), and Non-Value Added (NVA) activities. Based on this mapping, the initial production lead time was identified as 2,435.63 minutes, consisting of a total VA time of 1,154.18 minutes, NNVA time of 866.27 minutes, and NVA time of 415.18 minutes.

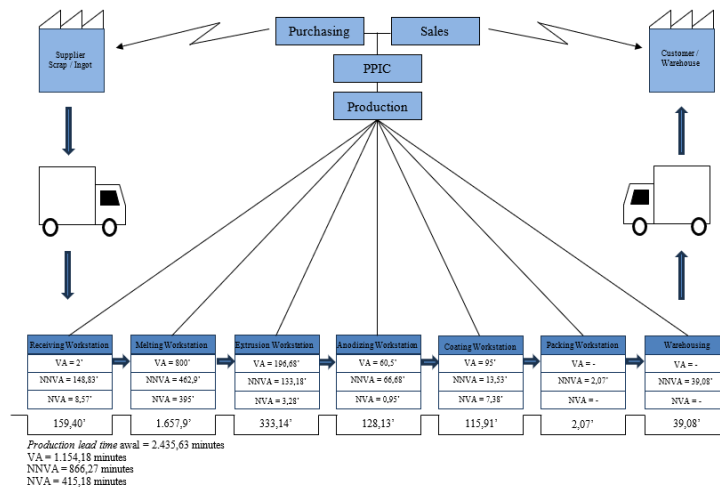


Figure 1. Current State Value Stream Mapping

Subsequently, calculations were performed to determine the Process Cycle Efficiency (PCE) value as follows:

$$PCE = \frac{VA}{\Sigma t} \times 100\%$$

$$PCE = \frac{1.154,18}{2.435,63} \times 100\% = 47,38\%$$

The Process Cycle Efficiency (PCE) value of 47.38% indicates that the efficiency of the aluminum extrusion process remains suboptimal. Consequently, strategic improvement efforts are required to enhance the overall production efficiency within the facility.

B. Process Activity Mapping

This section presents the comprehensive sequence of activities within the aluminum extrusion process flow, utilizing the initial Process Activity Mapping (PAM) at the company. Through this mapping, each stage is identified in detail based on its activity category to evaluate overall process efficiency. The initial Process Activity Mapping is presented below

Table 1. Process Activity Mapping

No	Activity Description	Activity Type	Time (minute)	Activity Category		
				VA	NNVA	NVA
RECEIVING WORKSTATION						
1	Security receives raw material truck at the gate	O	0,48		✓	
2	Driver submits delivery note to security	O	4,95		✓	
3	Driver waits for call from raw material division	D	5,07			✓
4	Delivery note verification by security	I	3,50			✓
5	Driver waits for call from raw material division	I	5,85		✓	
6	Truck enters the weighbridge for first weighing	O	3		✓	
7	Initial unloading of raw materials from the truck	O	51		✓	
8	Truck enters the weighbridge for second weighing	O	3,55		✓	
9	Truck enters the weighbridge for the second weighing	O	47		✓	
10	Operator sorts raw materials based on their specific types	O	30		✓	
11	Truck undergoes the third weighing (tare weight/empty load)	O	3		✓	
12	Staff inputs raw material weight data into the system	O	2		✓	
MELTING WORKSTATION						
13	Operator performs preheating of the melting furnace	O	180	✓		
14	Operator loads raw materials into the furnace for melting	O	360	✓		
15	Operator performs dross skimming on molten aluminum	O	90	✓		
16	Operator uses a heavy-duty magnet to extract Fe contaminants	O	15	✓		
17	Operator performs flux injection into the furnace	O	20	✓		
18	Operator performs secondary dross skimming	O	60	✓		
19	Laboratory staff performs testing to check Fe content	I	15		✓	
20	Operator repeats flux injection due to high Fe content	O	15	✓		
21	Laboratory staff repeats Fe content testing	I	15			✓
22	Operator performs re-melting due to high Fe content	O	360			✓
23	Operator performs additional flux injection due to high Fe content	O	20			✓

24	Operator performs standardization to reduce Fe content	O	15	✓	
25	Laboratory staff performs final Fe content testing	I	15		✓
26	Operator casts the billet using a casting machine	O	45	✓	
27	Lifting and transferring the casted billets	O	120		✓
28	Operator performs billet weighing	O	5		✓
29	Operator performs billet cutting	O	300		✓
30	Operator transfers billets to the external production area using a forklift	T	7,85		✓
EXTRUSION WORKSTATION					
31	Operator transfers billets to the rack using a forklift	T	3,35		✓
32	Operator performs billet reheating	O	120		✓
33	<i>Billet</i> diekstrusi dengan mesin melalui <i>die</i> untuk membentuk profil aluminium	O	2,18	✓	
34	Formed profiles are transported by a puller machine	O	2,37		✓
35	Operator performs stretching on the profiles	O	0,42	✓	
36	Aluminum profiles wait for temperature reduction (cooling)	D	13,90	✓	
37	Operator performs profile cutting	O	0,18	✓	
38	Operator cleans cutting residues	O	0,35		✓
39	Supervisor performs inspection of aluminum profiles	I	0,95		✓
40	Operator arranges profiles onto the rack	O	0,28		✓
41	Aluminum profiles wait for forklift transfer	D	2,93		✓
42	Profiles are transferred to the aging oven via forklift	O	3,12		✓
43	Aging treatment for aluminum profiles	O	120	✓	
44	Cooling of aluminum profiles	D	60	✓	
45	Profiles are transferred to the coloring station	T	3,12		✓
ANODIZING WORKSTATION					
46	Admin performs paperwork verification	I	3,02		✓
47	Workers perform profile racking	O	14,38		✓
48	Lifting profiles using a crane	O	2,52		✓
49	Profiles are immersed into the degreasing tank	O	5	✓	
50	Profile immersion in degreasing rinse tank	O	1,2	✓	

51	Profile immersion in caustic (soda) tank	O	5	✓	
52	Profile immersion in first caustic rinse tank	O	0,95	✓	
53	Profile immersion in second caustic rinse tank	O	0,9	✓	
54	Profile immersion in third caustic rinse tank	O	0,95		✓
55	Profile immersion in desmutt tank	O	5	✓	
56	Profile immersion in first desmutt rinse tank	O	1,58	✓	
57	Profile immersion in second desmutt rinse tank	O	1,75	✓	
58	Profile immersion in anodizing (micron forming) tank	O	25	✓	
59	Profile immersion in first anodizing rinse tank	O	1,55	✓	
60	Profile immersion in second anodizing rinse tank	O	1,52	✓	
61	Profile immersion in sealing tank	O	5,7	✓	
62	Profile immersion in first sealing rinse tank	O	2,42	✓	
63	Profile immersion in second sealing rinse tank	O	2,93	✓	
64	Profile drying using a blower	O	20		✓
65	Workers arrange racks for unloading	O	2,48		✓
66	Workers remove wires from the rack	O	15		✓
67	Profile inspection by QC supervisor	I	4,08		✓
68	Workers transfer profiles to the packing station	T	5,20		✓
COATING WORKSTATION					
69	Admin performs paperwork verification	I	3,2		✓
70	Workers perform profile racking for coating	O	1,18		✓
71	Lifting profiles using a crane	O	2,45		✓
72	Profile immersion in degreasing tank	O	10	✓	
73	Profile immersion in first degreasing rinse tank	O	3,32	✓	
74	Profile immersion in second degreasing tank	O	3,35	✓	
75	Profile immersion in third degreasing rinse tank	O	3,48		✓
76	Profile immersion in chromating tank	O	11,63	✓	
77	Profile immersion in first chromate rinse tank	O	3,55	✓	
78	Profile immersion in second chromate rinse tank	O	3,52	✓	
79	Profile immersion in third chromate rinse tank	O	3,9		✓
80	Profiles enter the drying oven	O	30	✓	

81	Workers transfer profiles to the rack	T	0,98	✓
82	Workers perform profile racking for coloring/painting	O	2,05	✓
83	Workers install baggles/attachments	O	0,4	✓
84	Profiles undergo spray gun process via conveyor	O	6,48	✓
85	Profiles pass through the curing oven via conveyor	O	23,15	✓
86	Workers transfer profiles to the packing rack	T	0,72	✓
87	Workers transfer profiles to the packing station	T	2,55	✓
PACKING WORKSTATION				
88	Workers put profiles into plastic packaging	O	1,02	✓
89	Workers perform final packaging using sacks/bags	O	0,85	✓
90	Workers move packaged aluminum profiles to the stack	T	0,20	✓
WAREHOUSING				
91	Workers move profile stacks to the truck	T	15,25	✓
92	Truck transports profiles to the storage warehouse	T	3,5	✓
93	Workers perform the final arrangement of aluminum profiles in the warehouse, organized by profile type	S	20,33	✓

C. Determination of Critical Waste Based on Questionnaire Results

To identify the waste occurring within the production process, a questionnaire based on the Seven Waste concept was utilized. This questionnaire was distributed to five respondents, who are the heads of their respective divisions at the company. The assessment was conducted using a Likert scale.

Table 2. Recapitulation of Waste Ranking Based on Questionnaire Results

Code	Waste Attribute	Total	Weight	Ranking
D1	Aluminum profiles undergo physical defects such as discoloration, dents, dullness, and surface oxidation	24	0,1206	1
W1	Waste division machinery and operators experience downtime due to limited waste tank capacity and equipment malfunction	18	0,0905	2
W2	Waiting time occurs for both billets and aluminum profiles due to a limited number of forklifts	18	0,0905	3
T1	Unstructured movement of billets and aluminum profiles due to poor workplace layout	17	0,0854	4
M2	Operators fail to implement optimal work procedures due to a lack of technical knowledge	17	0,0854	5
I1	Profile immersion time during the coloring process exceeds standard requirements	16	0,0804	6
O1	The extrusion process produces aluminum profiles in quantities exceeding actual demand	16	0,0804	7
M1	Inefficient operator movements due to a lack of material handling skills	15	0,0754	8

T2	Time loss and potential material damage during inter-station transfer processes	15	0,0754	9
U1	Accumulation of aluminum profile stock in the warehouse for extended periods (years)	15	0,0754	10
I2	Repeated refining processes necessitated by high iron (Fe) content	14	0,0704	11
U2	Potential risk of material damage and increased holding costs due to excessive stock levels	14	0,0704	12

D. Define

The Define phase in this research aims to clarify the existing quality issues at the company. At this stage, the problems are defined and visualized using a histogram to analyze the frequency of defect occurrences and to identify the Critical to Quality (CTQ) attributes

- Critical To Quality

Table 3. Identification of Critical to Quality (CTQ) Attributes

Critical To Quality	Profile Defect Type	Description
CTQ-1	Discoloration	The presence of discoloration (<i>belang</i>) on the surface of aluminum profiles negatively impacts product aesthetics and market value. This defect is frequently caused by pH instability in chemical agents during the coloring process and poor wire adhesion during racking, which disrupts the electrical current flow into the profile. Aluminum profiles with discoloration exceeding tolerance limits result in inconsistent visuals, ultimately decreasing customer satisfaction. If products with these defects are delivered to consumers, it potentially triggers complaints and diminishes consumer trust in the company, leading to financial losses
CTQ-2	Dents	Physical deformation or dents (<i>pesok</i>) in aluminum profiles represent a major obstacle to achieving quality targets at PT URD. Based on recapitulation data, dent defects are the largest contributor to the company's DPMO (Defects Per Million Opportunities) value. This physical damage typically occurs due to negligent material handling during the stretching process, racking, or transport via forklift. Beyond being unusable, dented products diminish functional quality during assembly and increase scrap volume, necessitating re-melting. Consequently, this leads to energy and production time inefficiencies that directly impact the increase in the company's operational costs
CTQ-3	Dullness	A dull appearance on the aluminum surface indicates a failure to meet the glossiness standards desired by customers. This issue can occur due to excessively high temperatures in the chemical tanks and an overextended etching process duration. Although the profile remains structurally sound, dullness defects downgrade the product's quality class in the market. If the level of dullness exceeds the established quality standards, the product may still be used for certain functional purposes; however, the company loses the opportunity to sell it as a premium product, resulting in financial losses due to the diminished market value of the goods
CTQ-4	Mold	The occurrence of surface oxidation, commonly referred to as mold or white rust, on aluminum profiles is a serious quality issue as it permanently damages the aesthetic appearance. This defect is characterized by white or grayish spots resulting from oxidation reactions when profiles are exposed to excessive moisture for extended periods. Mold often appears due to rainwater exposure from leaking roofs, causing dampness, while poor air circulation accelerates the oxidation process. These uncontrolled environmental conditions cause water trapped between profile stacks to evaporate slowly, triggering a chemical reaction that forms a permanent aluminum hydroxide layer. If such oxidized profiles reach consumers, it will severely damage the reputation of the manufacturer as a provider of high-quality aluminum

- Histogram

The following histogram is constructed based on the data presented in Table 1

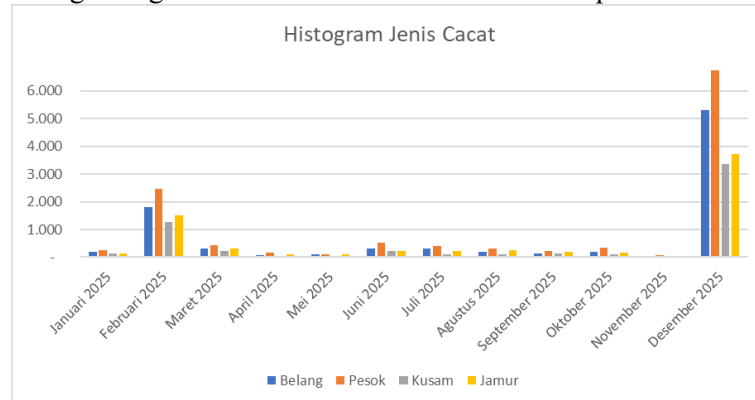


Figure 2. Histogram of Defect Types

Based on the quality data collected for aluminum profiles from January 2025 to December 2025, four primary types of defects have been identified as Critical to Quality (CTQ) parameters. Observations conducted throughout the year indicate that dents (*pesok*) are the most dominant defect type, with a total accumulation of 12,030 units.

The peak frequency of defects occurred in December 2025, where a high production volume of 216,054 units was directly proportional to a drastic surge in defects, reaching 19,114 units. During that month, dents (*pesok*) also recorded the highest figure at 6,742 units, followed by discoloration (*belang*) with 5,302 units, surface oxidation (*jamur*) with 3,712 units, and dullness (*kusam*) at 3,358 units

Conversely, the lowest defect rate within this year was recorded in November 2025, with a total of 199 defects, representing only 2.25% of that month's production volume. This identification indicates that the company's average annual defect percentage stands at 7.28%. These findings provide a solid foundation for the company to prioritize improvements in the physical aspects of the product

E. Measure

At this stage, process performance is measured by calculating the Defects Per Million Opportunities (DPMO) and the Sigma level, based on the total defective products collected during the period from January to December 2025

$$DPO = \frac{\text{Total of Defects}}{\text{Total of Production} \times \text{CTQ}}$$

$$DPMO = 13.347,30$$

Table 4. Recapitulation of DPMO and Sigma Level Calculation (2025)

Month	Production (kg)	Defects (kg)	CTQ	DPO	DPMO	Sigma Level
January	13.149	702	4	0,0133	13.347,30	3,72
February	108.812	7.077		0,0163	16.259,69	3,64
March	14.218	1.266		0,0223	22.260,98	3,51
April	8.758	377		0,0108	10.761,59	3,80
May	6.234	349		0,0140	13.995,83	3,70
June	11.179	1.300		0,0291	29.072,37	3,39
July	11.463	1.058		0,0231	23.074,24	3,49
August	11.064	886		0,0200	20.019,88	3,55

September	5.533	657	0,0297	29.685,52	3,39
Oktober	17.010	836	0,0123	12.287,14	3,75
November	8.848	199	0,0056	5.622,43	4,03
December	216.054	19.114	0,0221	22.117,16	3,51
Average	36.026,80	2.818,42	0,0182	18.208,68	3,62

F. Analyze

This stage aims to identify the primary root causes of the quality issues occurring at the company. This phase utilizes several analytical tools, including the p-control chart, process capability analysis, and fishbone diagram

• **P-Control Chart**

The p-control chart serves as a tool to visualize quality control limits. Based on the data in Table 1, calculations will be performed to determine the proportion, Upper Control Limit (UCL), Central Line (CL), and Lower Control Limit (LCL) as follows

a. Value of Proportion

$$P = \frac{\text{Total of Defect in January}}{\text{Total of Production in January}} \quad (1)$$

b. Value of Center Line

$$CL = P = \frac{\sum np}{\sum n} \quad (2)$$

c. Value of Upper Control Limit

$$UCL = P + 3\sqrt{\frac{p(1-p)}{n}} \quad (3)$$

d. Value of Lower Control Limit

$$LCL = P - 3\sqrt{\frac{p(1-p)}{n}} \quad (4)$$

Table 5. P-Chart Control Limit Data for Aluminum Profile Defects

Period	Production (kg)	Defect (kg)	Proportion	UCL	CL	LCL
January	13.149	702	0,053	0,079	0,078	0,077
February	108.812	7.077	0,065	0,079	0,078	0,077
March	14.218	1.266	0,089	0,079	0,078	0,077
April	8.758	377	0,043	0,079	0,078	0,077
May	6.234	349	0,056	0,079	0,078	0,077
June	11.179	1.300	0,116	0,079	0,078	0,077
July	11.463	1.058	0,092	0,079	0,078	0,077
August	11.064	886	0,080	0,079	0,078	0,077
September	5.533	657	0,119	0,079	0,078	0,077
Oktober	17.010	836	0,049	0,079	0,078	0,077
November	8.848	199	0,022	0,079	0,078	0,077
December	216.054	19.114	0,088	0,079	0,078	0,077

Furthermore, the data from the table above is visualized into a p-chart control diagram, as presented below

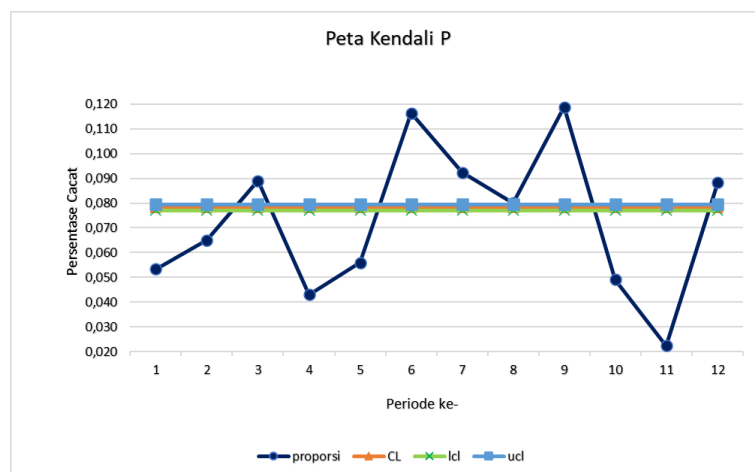


Figure 3. P-Chart Control Diagram

Based on the diagram above, it is evident that the production of the 30209 U-channel aluminum profile is in a statistically out-of-control condition. Out of the 12 observation periods, the majority of the defect proportion values fall outside the Upper Control Limit (UCL) of 0.079 and the Lower Control Limit (LCL) of 0.077. Only the August 2025 period approached the Center Line (CL) with a proportion value of 0.080, while other periods experienced extreme fluctuations.

• **Capability Process Analysis**

The following presents the process capability analysis calculations for the production of U-Channel 30209 aluminum profiles

$$C_p = 1 - \bar{p} \quad (5)$$

The calculated value of 0.92177 indicates that the current process capability at the company remains below 1.00 ($C_p < 1$). This suggests that the production process exhibits high variability, meaning the company is not yet capable of consistently producing defect-free products. This figure correlates with the 7.28% average defect percentage previously identified in the control chart analysis. Although the company's average Sigma level has reached 3.62, a capability value below 1 serves as a critical indicator that further improvements are necessary. Future improvement efforts must focus on mitigating the root causes of defects to reduce the average defect proportion and elevate the process capability value to 1.00 or higher

• **Fishbone Diagram**

To identify the causes of defects within the aluminum profile production process, several primary defect types are analyzed as in Critical To Quality (CTQ)

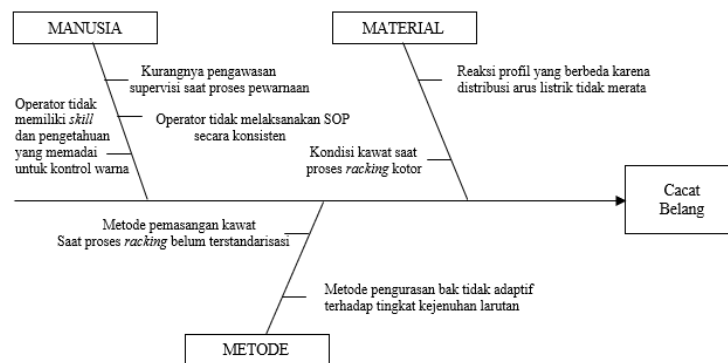


Figure 4. Fishbone Diagram for Discoloration Defect

The following factors summarize the primary causes of discoloration defects as identified in the fishbone diagram analysis:

- a. **Human Factor:** A lack of supervisory oversight during the coloring process leads to undetected deviations in process parameters, allowing minor errors in current settings or immersion timing to persist and result in high defect volumes. Furthermore, operators lack the necessary skills and technical knowledge for color control, making it difficult to implement rapid corrective actions when visual changes occur before the sealing process. The inconsistent execution of Standard Operating Procedures by

operators also creates technical variations between shifts, leading to non-uniform color quality and an increase in defect-related waste.

- b. **Material Factor:** Contaminated or dirty racking wires obstruct electrical conductivity, preventing even current distribution across the aluminum profile surface. This uneven distribution causes a load imbalance at specific points, resulting in inconsistent oxide layer formation and the appearance of discoloration (*belang*).
- c. **Method Factor:** The lack of standardization in racking wire installation methods leads to unstable electrical contact between the wires and the profiles, disrupting the stability of the coloring process. Additionally, non-adaptive tank drainage methods which fail to account for solution saturation levels cause contaminant accumulation, destabilizing pH levels and inhibiting the complete absorption of color pigments into the aluminum pores.

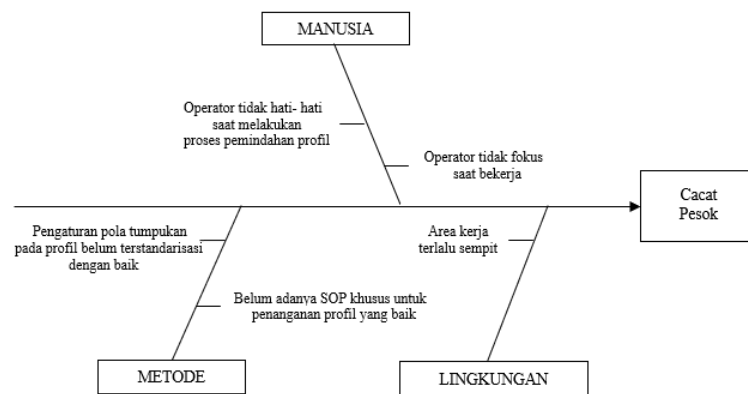


Figure 5. Fishbone Diagram for Dent Defect

The following factors summarize the primary causes of dent defects as identified in the fishbone diagram analysis:

- a. **Human Factor:** Operator negligence during material handling leads to physical collisions between profiles or with hard objects such as walls. Furthermore, a lack of focus during work results in improper profile placement, which triggers excessive pressure and causes physical deformation in the form of dents
- b. **Method Factor:** The lack of standardized stacking patterns results in uneven load distribution, causing the bottom profiles to endure excessive pressure. Additionally, the absence of specific Standard Operating Procedures (SOPs) for proper profile handling leads to inconsistent handling and arrangement procedures, increasing the probability of physical damage or denting
- c. **Environmental Factor:** A workspace that is too narrow restricts the operator's range of motion while transporting profiles, thereby increasing the risk of collisions between the profiles and work facilities or other materials

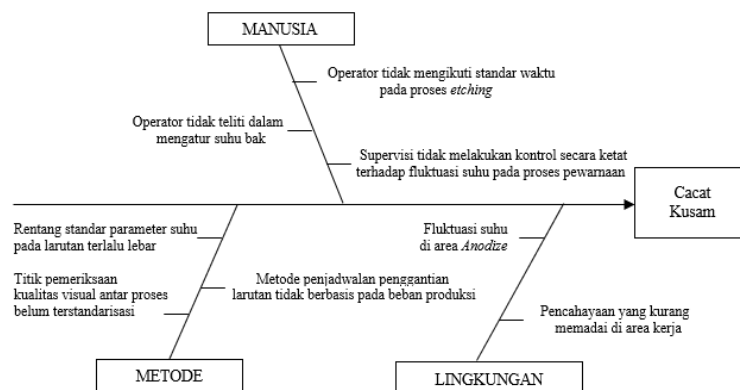


Figure 6. Fishbone Diagram for Dullness Defect

The following factors summarize the primary causes of dullness defects as identified in the fishbone diagram analysis:

- a. **Human Factor:** Operators failing to adhere to standardized timing during the etching process leads to excessive surface erosion, which diminishes gloss levels and creates a dull appearance. Furthermore, a lack of precision in regulating tank temperatures results in operational inconsistencies that trigger incomplete chemical reactions on the aluminum surface. This is exacerbated by a lack of strict supervisory control over temperature fluctuations, allowing technical deviations in the solution to go undetected
- b. **Method Factor:** The standardized temperature parameter ranges for the solution are currently too broad, making it difficult to maintain precise chemical control and leading to unstable solution activity. Additionally, the absence of standardized visual quality checkpoints between processes allows sub-standard products to bypass early screening. The current solution replacement scheduling is also not production-load based, leading to contaminant saturation that inhibits the formation of a clear, glossy layer during coloring
- c. **Environmental Factor:** Temperature fluctuations within the Anodize area cause instability in the chemical solutions' operational temperatures, disrupting the consistency of the protective layer formation. Moreover, inadequate lighting in the workspace impairs operator visibility during visual inspections, making it difficult to detect early signs of surface dullness accurately



Figure 7. Fishbone Diagram for Mold Defect

The following factors summarize the primary causes of mold defects as identified in the fishbone diagram analysis:

- a. **Human Factor:** A lack of responsiveness to weather changes prevents immediate protection of materials when environmental humidity rises. Additionally, operator inefficiency in deploying tarps results in the direct exposure of aluminum profiles to water splashes or damp air, triggering the formation of mold spots
- b. **Material Factor:** Sub-standard raw material quality makes the aluminum surface highly reactive and sensitive to moisture when stored in areas with high water vapor levels. Furthermore, the presence of raw, uncoated surfaces leads to direct contact between the profiles and humid air without a protective layer, while surface roughness allows water particles to adhere easily, creating an ideal environment for oxidation within surface crevices

- c. **Method Factor:** The absence of a First In First Out (FIFO) system causes profiles to remain in storage for excessive periods, leading to prolonged exposure to humidity. Additionally, drying methods that rely solely on air blowing result in uneven evaporation, while the lack of an optimal moisture absorption system leaves the air around the profile stacks saturated, accelerating mold growth
- d. **Environmental Factor:** Leaking roof tiles allow water droplets to wet the aluminum profiles directly. Moreover, extreme temperature fluctuations lead to condensation on the profile surfaces, providing a medium for rapid oxidation. Poor air circulation further exacerbates the issue by causing air saturation, which hinders natural evaporation and prevents residual water within the profile stacks from drying completely

G. Improve

In this stage, various efforts are undertaken to reduce product defect rates in the aluminum profile production process by formulating process improvement plans based on the root causes identified in the fishbone diagram, alongside prioritizing these improvements to minimize defects

- **FMEA**

Given the company's policies regarding the implementation of improvement efforts, this stage is conducted solely as a proposed framework. To calculate the RPN value, the following example is provided

$$RPN = S \times O \times D \quad (6)$$

Table 6. Risk Priority Number (RPN) Analysis and Mitigation Strategies

Failure Mode	Cause of Failure	Value				RPN	Calculation Level	Recommended Improvements
		S	O	D				
Dents	Workspace is too narrow	8	7	6	336	Very High	Redesign the workspace layout to optimize operator range of motion, separate material handling paths, and reduce collision potential by enforcing careful handling procedures.	
Dullness	Inadequate workspace lighting	7	7	5	245	Very High	Enhance the lighting system to meet standard light intensity requirements (lux) and install additional lamps at critical visual inspection points.	
Dullness	Inter-process visual quality	7	7	5	245	Very High	Implement standardized	

	inspection points are not yet standardized							inter-process visual quality inspection points equipped with inspection checksheets so that defects can be addressed before the next process.
Mold	Drying method only utilizes air blowing	7	8	4	224		<i>Very High</i>	Improve drying methods by adding controlled-temperature warm air to allow surface moisture to evaporate more quickly and evenly.
Discoloration	Racking wires are dirty during the process	8	5	5	200		<i>Very High</i>	Establish a schedule for routine maintenance and cleaning of racking wires and perform visual inspections of wire cleanliness before use.
Mold	Lack of implementation of systems and methods for optimal moisture absorption	7	7	4	196		<i>High</i>	Implement moisture absorption tools (dehumidifiers) to ensure measurable humidity control in the workspace.
Discoloration	Tank drainage method is not adaptive to solution saturation levels	8	8	3	192		<i>High</i>	Develop standard tank drainage protocols based on solution saturation parameters, supported by periodic recording of solution conditions.
Dullness	Solution replacement is not based on production load	7	9	3	189		<i>High</i>	Implement a solution replacement schedule based on production volume and operating hours.
Mold	Poor raw material quality	7	5	5	175		<i>High</i>	Tighten the acceptance of scrap raw materials and

								increase the composition of ingot raw materials in the melting process.
Discoloration	Operators lack adequate color control skills	8	7	3	168	High		Conduct specialized training for color control and perform periodic evaluations.
Discoloration	Variable profile reactions due to uneven electrical current	8	7	3	168	High		Re-engineer the profile binding wires during racking to ensure even electrical current distribution.
Dents	Careless material handling	8	7	3	168	High		Conduct ergonomic work training and provide direct supervision.
Dullness	Lack of precision in regulating tank temperature	7	6	4	168	High		Implement automated temperature controls and utilize a temperature setting checklist for the process.
Mold	No FIFO method implementation	7	6	4	168	High		Implement a visual FIFO system using date labels, batch markers, and storage layout adjustments.
Mold	Leaking roof tiles	7	8	3	168	High		Repair the roof structure in the workspace to prevent water entry.
Discoloration	Racking wire installation method not yet standardized	8	4	5	160	High		Establish standardized racking methods and re-engineer wire installation using auxiliary jigs.
Dullness	Operators do not follow standard timing during the etching process	7	7	3	147	High		Use audible alarms and perform real-time recording during the coloring process.
Discoloration	Operators do not consistently follow the operational standard	8	6	3	144	High		Conduct routine briefings and strengthen the role of supervision.

Mold	Extreme temperature changes	7	5	4	140	High	Control temperature and humidity by improving air circulation.
Dullness	Standard range of solution temperature parameters is too wide	7	6	3	126	High	Tighten the range of temperature parameters
Dents	Lack of specific operational standard for proper profile handling	8	5	3	120	High	Develop and implement specific SOPs for profile handling, including training and compliance audits.
Mold	Aluminum surface is still raw without coating	7	4	4	112	Medium	Use temporary plastic covers while waiting for further processing to prevent exposure to humid air that can trigger mold.
Dullness	Temperature fluctuations in the Anodizing area	7	5	3	105	Medium	Increase temperature control in the workspace and monitor environmental conditions.
Discoloration	Lack of supervision during the coloring process	8	6	2	96	Medium	Increase supervision frequency and implement a coloring process supervision checklist.
Dullness	Supervision does not strictly control temperature fluctuations	7	4	3	84	Medium	Mandate a review of process temperature logs by supervisors for every shift.
Mold	Operators are slow to deploy tarps	7	4	3	84	Medium	Conduct weather readiness training and standardize work response procedures.
Mold	Poor air circulation	7	4	3	84	Medium	Improve ventilation systems and airflow in the workspace.

Dents	Operators do not focus while working	8	5	2	80	Medium	Implement workload management, job rotation, and direct supervision.
Dents	Unstandardized profile stacking patterns	8	4	2	64	Low	Develop standard stacking patterns and visual guides in the workspace
Mold	Initial profile surface is still rough	7	3	3	63	Low	Add an initial surface inspection point before subsequent processing.
Mold	Operators do not respond to weather changes	7	4	2	56	Low	Provide weather information and standard operating procedures for changing weather conditions.

• **Proposed Improvements for Waste Reduction**

After formulating improvement proposals for defect waste through FMEA analysis, the subsequent step involves developing comprehensive recommendations for each identified type of waste

Table 7. Improvements for Waste Mitigation

Rank Priority	Waste Code	Waste Type	Improvement Recommendations
1	D1	Aluminum profiles exhibit physical defects, such as discoloration, dents, dullness, and fungal growth.	Solutions to mitigate defect rates include optimizing workspace layout, enhancing lighting systems, and standardizing visual inspection points between coating processes. Implementation of controlled-temperature warm air drying methods, scheduled maintenance of racking wires, and humidity control using dehumidifiers are required. Furthermore, establishing tank drainage standards based on solution saturation, scheduling solution replacement based on production volume, optimizing ingot raw material composition, and tightening scrap material acceptance criteria are recommended. Technical measures involve specialized color control training, engineering profile tie wires during racking, ergonomic training, automated temperature control, and FIFO system implementation. Additionally, standardizing racking methods, utilizing auxiliary jigs, implementing audible alarms with real-time recording, conducting routine briefings, strengthening supervisory roles, tightening temperature parameter ranges, and developing specific SOPs for profile handling complemented by compliance audits are essential.
2	W1	Machines and operators in the waste division experience idle time due to limited	Expanding waste tank capacity to prevent process flow bottlenecks. Additionally, implementing scheduled machine maintenance is necessary to reduce downtime and minimize operator idle time.

		waste tank capacity and equipment malfunctions.	
3	W2	Waiting time occurs for both billets and aluminum profiles due to the limited number of available forklifts.	Investing in additional forklift units based on rigorous requirement calculations and reorganizing internal logistics flows to reduce material waiting time.
4	T1	The movement of billets and aluminum profiles is unstructured due to poor workspace layout.	Redesigning the production area layout based on Lean Manufacturing principles to minimize the distance and frequency of material handling. Establishing clear and standardized transportation paths to enhance material flow efficiency and reduce transport waste.
5	M2	Operators fail to implement work procedures optimally due to a lack of technical knowledge.	Implementing periodic technical training programs and SOP socialization for operators, complemented by regular competency evaluations and direct supervision. By enhancing operator understanding and skills, the application of work procedures can be executed more consistently and effectively.

• **Process Time Adjustments**

Following the implementation of the proposed improvements, the details of the time efficiency achieved by eliminating waste activities, as outlined in Table 6, are as follows

Table 8. Process Time Adjustments

Activity Number	Activity Name	Activity Type	Process Time Before Improvement	Process Time After Improvement
3	Driver waits for call from raw material division	NVA	5,07 minutes	0 minutes
4	Delivery note verification by security	NVA	3,50 minutes	0 minutes
21	Laboratory staff repeats Fe content testing	NVA	15 minutes	0 minutes
22	Operator performs remelting due to high Fe content	NVA	360 minutes	0 minutes
23	Operator performs additional flux injection due to high Fe content	NVA	20 minutes	0 minutes
29	Operator performs billet cutting	NNVA	300 minutes	150 minutes
38	Operator cleans cutting residues	NVA	0,35 minutes	0 minutes
41	Aluminum profiles wait for forklift transfer	NVA	2,93 minutes	0 minutes
54	Profile immersion in third caustic rinse tank	NVA	0,95 minutes	0 minutes
75	Profile immersion in third degreasing rinse tank	NVA	3,48 minutes	0 minutes
79	Profile immersion in third chromate rinse tank	NVA	3,9 minutes	0 minutes

Table 9. Proposed Improvements for NVA and NNVA

Activity Name	Activity Type	Proposed Improvement
Driver waits for call from raw material division	NVA	To eliminate the 5.07-minute queuing time, the company will implement a Time Slot Management (TSM) system. This system is supported by active coordination from the Customer Service (CS) team to confirm schedules, provide reminders, and handle instantaneous schedule adjustments in the event of supplier technical issues.

			<p>Technically, the system synchronizes warehouse loading/unloading capacity with fleet arrivals by assigning specific appointment windows for each vendor. Through proactive communication and fleet leveling, truck accumulation during peak hours can be avoided, ensuring the unloading area is prepared upon arrival and effectively reducing NVA time to 0 minutes</p>
Delivery verification security	note by	NVA	<p>By implementing document digitalization, the verification process is conducted via a centralized system where vendors upload electronic documents prior to arrival. Technically, security personnel only need to perform a QR Code scan to validate data, eliminating manual input and redundant physical inspections. This stage can also be integrated into the initial security gate check upon entry to optimize time. Data integration between security and the logistics division ensures that security protocols remain robust while simultaneously eliminating this non-value-added activity to 0 minutes.</p>
Laboratory staff content testing	repeats Fe	NVA	<p>The repetition of laboratory testing activities constitutes waste within the inappropriate processing category, arising from high variability in the Iron (Fe) content of raw materials. This issue is particularly prevalent when a significant proportion of scrap (secondary aluminum) is utilized, as it is inherently more difficult to sort manually. To eliminate this 15-minute non-productive interval, the proposed improvement focuses on material composition engineering (input mixing) by increasing the ratio of ingots (primary aluminum) relative to scrap to ensure chemical stability from the outset.</p> <p>Technically, the use of ingots—which possess standardized low Fe-content specifications—acts as a diluter for contaminants potentially introduced via scrap, making the final melt composition in the furnace more predictable. By combining a cleaner raw material ratio with the implementation of stringent Incoming Quality Control (IQC) standards, the risk of Fe-content non-conformity can be significantly mitigated. Consequently, the requirement for laboratory re-testing can be entirely eliminated, reducing the process time to 0 minutes.</p>
Operator performs re-melting Fe content		NVA	<p>Re-melting represents a critical form of rework waste, consuming massive production cycle time and incurring high energy costs. To eliminate the 360-minute NVA time, the company will implement preventive chemical composition control by optimizing the material mix ratio prior to the melting process. By increasing the proportion of primary aluminum ingots relative to scrap, Fe-content stability can be maintained, thereby eliminating the possibility of specification failures that necessitate re-melting. Technically, this raw material input standardization ensures that each melting cycle produces molten metal that immediately meets quality standards on the first pass yield, successfully reducing redundant re-melting activities to 0 minutes.</p>
Operator performs additional injection due to high Fe content	flux	NVA	<p>To eliminate this 20-minute non-productive interval, the proposed improvement focuses on standardizing injection parameters and implementing real-time chemical composition monitoring. Technically, by utilizing more controlled raw materials—predominantly primary aluminum ingots—the workload required for the flux to bind Iron (Fe) impurities becomes lighter and more quantifiable, allowing for precise flux dosing from the beginning of the process. By ensuring the effectiveness of the chemical reaction during the initial stage, the requirement for subsequent flux injections can be entirely eliminated. This optimization automatically accelerates the furnace work cycle and reduces Non-Value Added (NVA) time to 0 minutes</p>
Operator performs cutting	billet	NNVA	<p>To significantly reduce process time from 300 minutes to 150 minutes, the proposed improvement involves investing in an additional billet-cutting machine (a second unit) and transitioning the workflow from a serial system to a parallel system. Technically, by operating two cutting lines simultaneously, the company can double the throughput speed without altering the technical cutting parameters themselves. This asset acquisition not only cuts process time by 50% but also minimizes the accumulation of Work-in-Process (WIP) inventory</p>

		awaiting cutting, thereby ensuring a smoother and more responsive material flow toward the extrusion stage.
Operator cleans cutting residues	NVA	The activity of cleaning residual chips or shavings from billet cutting is classified as motion waste (unnecessary movement), arising from the use of manual methods that are decoupled from the primary process. To eliminate this 0.35-minute non-productive interval per cycle, the proposed improvement involves implementing an integrated automated cleaning system within the new cutting unit. Technically, the machine is equipped with a chip extractor or an automated air-blast system that operates simultaneously with the saw blade during the cutting process. This ensures that residual material is immediately discharged into a collection bin without requiring manual intervention from the operator. By converting manual activities into parallel mechanical functions, the risk of occupational accidents due to direct contact with sharp shavings is mitigated, and Non-Value Added (NVA) time is successfully reduced to 0 minutes.
Aluminum profiles wait for forklift transfer	NVA	To eliminate this 2,93-minute waiting time, the proposed improvement involves a fleet capacity expansion strategy by adding dedicated forklift units for the transfer of billets to the extrusion line. Technically, the addition of these units enables the implementation of an area-dedication system, where each forklift is responsible for a specific zone to prevent task overlapping, which frequently causes material pickup delays. By combining an adequate fleet size with precise scheduling, the material flow achieves a continuous flow state. This effectively reduces Non-Value Added (NVA) time to 0 minutes, as every cut profile can be immediately transferred without any waiting process.
Profile immersion in third caustic rinse tank	NVA	To eliminate this 0.95-minute interval, the proposed improvement focuses on enhancing the filtration and water circulation efficiency of rinsing tanks one and two to consistently maintain low contamination levels. Technically, by tightening the control of pH values and the overflow rate in the initial two tanks, residual caustic soda solution can be completely dissolved without necessitating an additional rinsing stage in the third tank. This workflow redesign ensures that the cleaning process continues to meet surface treatment quality standards while utilizing a shorter trajectory. Consequently, the redundant activity in the third tank is successfully eliminated, reducing the time to 0 minutes.
Profile immersion in third degreasing rinse tank	NVA	To eliminate this 3.9-minute Non-Value Added (NVA) interval, the proposed improvement focuses on increasing the frequency of tank drainage and cleaning from once a week to twice a week, or dynamically adjusting it based on the production workload. Technically, more intensive drainage scheduling ensures that the concentration of chemical contaminants in rinsing tanks one and two remains at a minimal level, thereby drastically increasing rinsing effectiveness. By maintaining rinsing water clarity through disciplined tank sanitation management, the quality of the chromate coating remains optimal without necessitating a third rinsing stage. Consequently, this redundant activity is successfully reduced to 0 minutes, resulting in a more efficient process flow.
Profile immersion in third chromate rinse tank	NVA	To eliminate this 3.9-minute interval, the company has implemented a workload-based maintenance policy for tank cleaning, whereby the frequency of tank drainage is increased from once a week to twice a week. Technically, a higher drainage frequency prevents the excessive accumulation of residual chromate chemicals in the initial rinsing tanks, ensuring that the rinsing water remains effective in neutralizing the profile surfaces. By maintaining water clarity in tanks one and two through disciplined cleaning schedules, the requirement for a third rinsing stage becomes irrelevant. Consequently, this activity can be entirely eliminated to 0 minutes without compromising the quality of chromate layer adhesion on the final product.

• **Future State Value Stream Mapping**

Based on the calculated efficiency increase of 23.20%, a Future State Value Stream Mapping was developed to design a more efficient workflow by eliminating or reducing NVA (Non-Value Added) and NNVA (Necessary Non-Value Added) activities. The mapping is constructed based on the improvement proposals and simplifications outlined in Tables 7 and 8. The Future State Value Stream Mapping is presented as follows

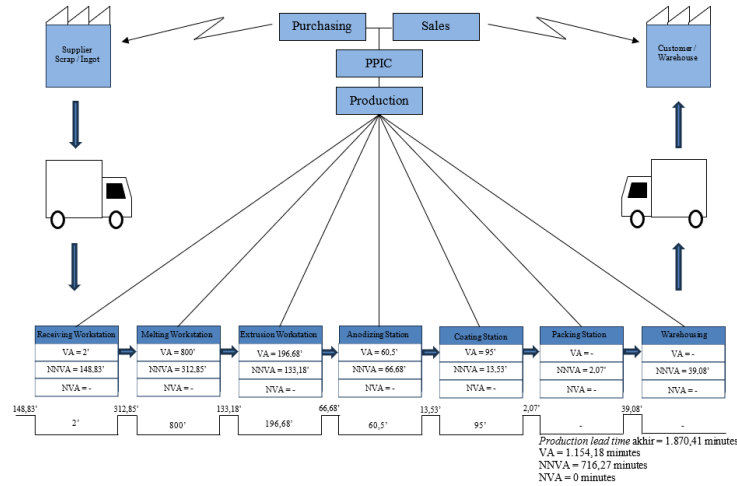


Figure 8. Future State Value Stream Mapping

Based on the analysis, the production lead time for the 30209 U-channel aluminum profile significantly accelerated. The initial production lead time was recorded at 2,435.63 minutes, which, following further identification and improvement, was reduced to 1,870.41 minutes. The calculation for this improvement is as follows:

$$PCE = \frac{Value\ Added}{Lead\ Time} \times 100\% = \frac{1.154,18}{1.870,41} \times 100\% = 61,70\%$$

The calculation of the Process Cycle Efficiency (PCE) after improvement reached 61.70%, indicating a substantial enhancement in production efficiency compared to the previous value of 47.38%.

V. CONCLUSION

Lean Six Sigma Analysis Results Based on the waste analysis of the aluminum extrusion production process at the company using the Lean Six Sigma approach, Defects (D1) were identified as the most critical waste with the highest weight of 0.1206. This is followed by Waiting (W1 and W2) at 0.0905, Transportation (T1) at 0.0854, Inappropriate Process (I1) and Overproduction (O1) at 0.0804, and Motion (M1) and Unnecessary Inventory (U1) at 0.0754 each. Activity mapping shows that the initial production lead time reached 2,435.63 minutes. Following the proposed improvements specifically the elimination of Non-Value Added (NVA) activities from 10 to 0 and the reduction of time in Necessary Non-Value Added (NNVA) activities the lead time was successfully reduced to 1,870.41 minutes. This results in a process time saving of 565.22 minutes, indicating a significant increase in production flow efficiency. Based on the causal factor identification, several strategic improvements were formulated to mitigate the identified waste across the production line. To address Defect (D1), the company implemented a comprehensive approach involving workspace layout redesign, lighting optimization, and the standardization of visual inspection points between coloring processes. Technical interventions included the installation of temperature-controlled drying systems, scheduled

racking wire maintenance. Regarding Waiting (W1 & W2), the strategy focused on preventive maintenance for waste treatment machinery and optimizing forklift allocation based on production loads. Additionally, Transportation (T1) waste was reduced by redesigning the layout according to Lean Manufacturing principles to minimize travel distances, while Motion (M2) was addressed through periodic technical training, SOP socialization, and strengthened supervision to ensure consistent and effective work procedures

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