Enhancing Potline Productivity Through Implementation of In-House Automation Control System at Maaden Aluminium

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https://doi.org/10.71659/icsoba2025-al035

Abstract

At Maaden Aluminum, we are dedicated to enhancing potline productivity through the implementation of an automated inhouse system. Our commitment to continuous improvement is reflected in our focus on the best operational practices, which positively impact safety, process efficiency, and production outcomes. The Pot Tending Assembly (PTA) is a critical piece of equipment in the reduction process, responsible for major operational activities such as anode changes and Metal tapping. Traditionally operated by human operators following standard procedures, the potential for human error can lead to safety incidents, property damage, and negative effects on production.

To mitigate these risks, we made several upgrades in our Automation and Process OT environment to follow several operational activity-based Standard Work Instructions (SWIs) within the crane operations. These updates ensure that operators adhere to all required steps, reducing the likelihood of errors. Additionally, all crane movements are tracked through Level 2 Human-Machine Interface (HMI), with summary reports shared with employees on a shift basis. This transformation not only enhances safety and process reliability but also drives significant improvements in overall production efficiency.

Keywords: Potline digitalization, PLC system, Alpsys, Pot tending assembly, Anode change.

1. Introduction:

In the earlier phases of potline operations at Maaden Aluminium, the absence of a data interface between the PTA and Alpsys Pot Micro-System posed significant challenges. The lack of a tracking mechanism allowed unrestricted access to safety and configuration pages, limiting visibility into operator actions and hindering key performance indicators (KPIs) monitoring in the critical tasks such as anode changes and covering operations relied on manual confirmation through Pot Micro inputs, increasing dependency on ground operators and exposing the process to human error. Furthermore, inconsistent anode changes, particularly in breaking, shoveling, and gauging – compromised process stability and overall smelting efficiency.

2. Anode Change and Covering Operations

2.1 Identified Challenges During and After Anode Change

2.1.1 High Workload and Heat Stress Exposure

Anode change (AC) and covering is one of the most frequent and essential activities in the pot room at Maaden Aluminium, with approximately 600 anodes replacing daily to maintain optimal cell performance. These operations are structured around a 25.5-day anode change cycle, with each pot room/shift typically assigning a single operator (Figure 1) to perform the following tasks:

- Anode changes: 35–40 per shift
- Anode coverings: 35–40 per shift
- Anode re-coverings: 35–40 per shift

To execute these tasks effectively, a two-operator system is used: one operator stationed in the PTA cabin and the other operating on the pot room floor. This dual-role configuration is essential for ensuring both operational compliance and personnel safety. The floor operator is exposed to significant physical workload and environmental stressors, necessitating precise coordination with the PTA operator to achieve full procedural compliance and mitigate safety risks

The extreme summer temperatures in Ras Al Khair, often surpassing 45 °C, create substantial challenges for floor operators during anode changes. Those working in the pot room are exposed to both ambient heat and intense radiant heat from reduction pots and spent butts. This combination has been a major contributing factor to heat stress incidents in the reduction area.

Figure 1. Operator giving AC command.

2.1.2 Anode Effect Occurrences

According to the procedure, anode change commands should be issued 2–3 minutes before the removal of anode butts. However, due to timing mismatches when the ground operator sends the command too early or too late relative to the PTA operator's action the pot may register an anode effect, as the required actions are not achieved in time. Figure 2 shows the number of anode effects during anode change.

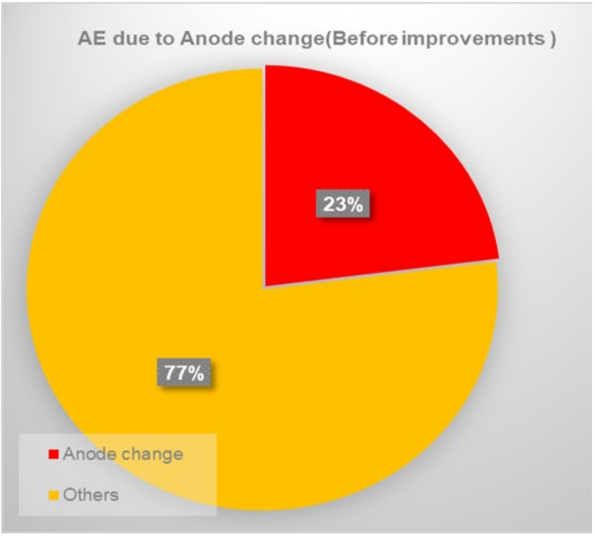


Figure 2. AE during anode change operation.

2.2 Gap Identification and Improvement Opportunities

A comprehensive gap analysis was conducted collaboratively by the internal operations team and the Alcoa Center of Excellence (COE) to evaluate the current practices and identify improvement opportunities in the anode change and covering operations.

Methodology for Anode Change and Cover Compliance Gap Analysis

1. Collaborative Planning

The gap analysis was initiated as a joint effort between the internal operations team and the Alcoa Center of Excellence (COE) to evaluate current practices and identify areas for improvement in anode change and covering operations.

2. Audit Team Formation

A team of five auditors was assembled to conduct live observations and assessments of operational practices.

3. Operator Sampling

Four different PTA operators were selected from various potrooms to ensure a representative evaluation across shifts and teams.

4. Criteria-Based Evaluation

Each operator was assessed against a comprehensive set of 20 criteria, covering technical execution, procedural adherence, and management systems. These included:

- Reference mark clarity
- Crew identification
- Crust breaking
- Hole cleaning and skimming
- Dunking anodes/butts
- C/Break-Set-Ore up timing
- Setting accuracy
- Perpendicularity
- Conformance to schedule
- Anode load-up
- Anode current balance
- Anode referencing system

- Set increment/anode burn-up rate
- Set pattern
- Use of large butts
- New pot anode setting
- Daily Management (mandatory)
- Practical Problem Solving (mandatory)
- Standardized Work (mandatory)
- Process Management (optional)

5. Scoring System Application

Each criterion was rated using a standardized 4-point scale:

0 – Does not exist, no minimum standards in place
1 – Exists but underdeveloped; less than 50% of minimum standards met
2 – Adequate and current; meets minimum standards and adds value
3 – Best-in-class; significantly exceeds standards and offers potential for broader application

6. Data Consolidation and Analysis

The audit results were compiled and analyzed to identify performance gaps, recurring issues, and opportunities for process optimization.

7. Visualization and Reporting

Findings were summarized in a visual chart to clearly communicate the distribution of compliance levels and highlight key areas for improvement.

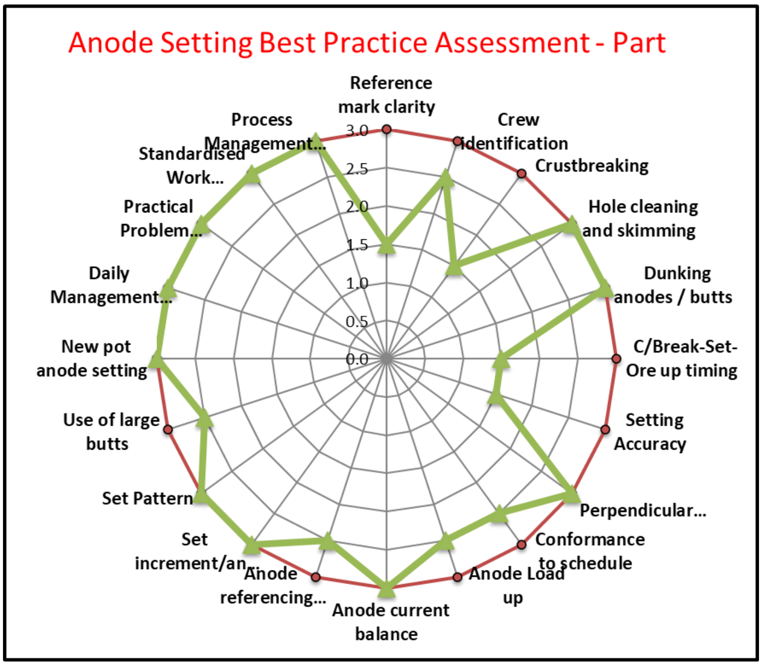


Figure 3. Anode change best practices gap analysis.

The findings, as illustrated in Figure 3, clearly highlight several operational gaps and areas with potential for process optimization and enhanced performance. Figure 3 shows the analysis of the current practice with respect to the best practice.

2.2.1 Crew Identification

The absence of a systematic tracking mechanism resulted in unclear attribution of anode change and covering operations to specific operators or teams. This lack of traceability hindered accountability and process evaluation.

2.2.2 Crust Breaking Deviations

To speed up operation, operators frequently omitted crust breaking prior to anode removal. This practice led to increased mechanical resistance in the anode stems, causing large crust fragments to fall into the cavity and generating oversized wings on the removed butts. Such deviations contributed to operational inefficiencies and potential equipment strain.

2.2.3 Shoveling Inconsistencies

Post-removal shoveling was intended to be performed based on cavity conditions. However, time-saving behaviors led operators to minimize shoveling efforts, which in turn compromised pot stability and increased the risk of process disturbances.

2.2.4 Anomalies in Anode Installation Practices

Despite the presence of step-by-step guidance within the Ma'aden PTA Diana system, operators occasionally failed to adhere to the prescribed sequence – either intentionally or inadvertently. These procedural lapses resulted in newly set anodes drawing excessive current, thereby destabilizing pot operations**.**

3. Embarking on Implementation of In-House Automation Solutions Journey to Bridge the Gap

3.1 Step-1: Anode Change and Cover Command from PTA HMI to Pot Mico

A project was undertaken to upgrade the exchange table system through an internally led initiative encompassing design, engineering, software development, and commissioning. The objective was to enable the execution of anode change and cover commands directly from the PTA HMI, thereby eliminating reliance on pot-level microcontroller inputs and enhancing operational integration and control. Figures 4–6 show Alpsys architecture and HMI anode change screen.

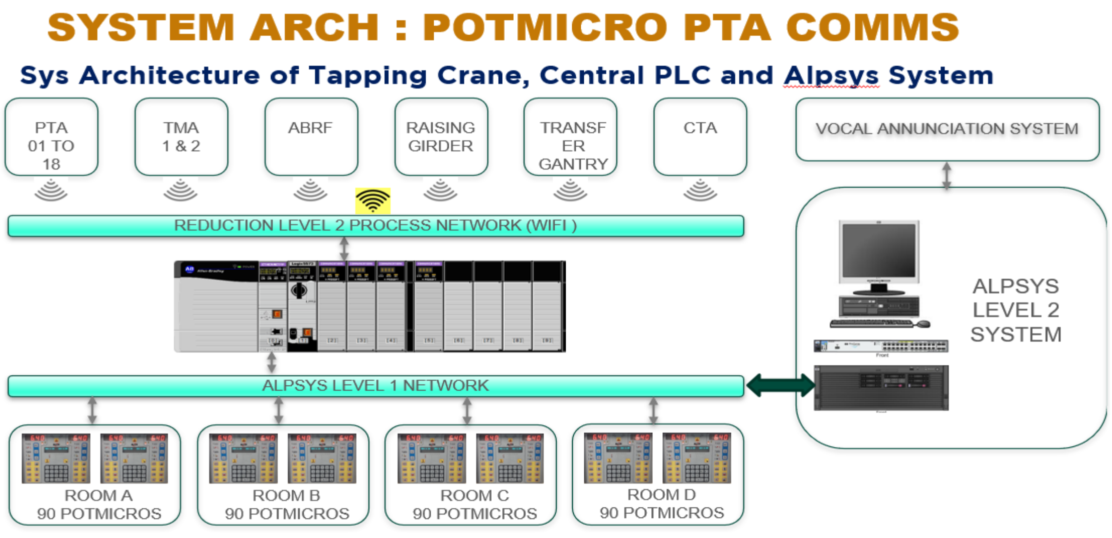


Figure 4. Central PLC and Alpsys architecture.

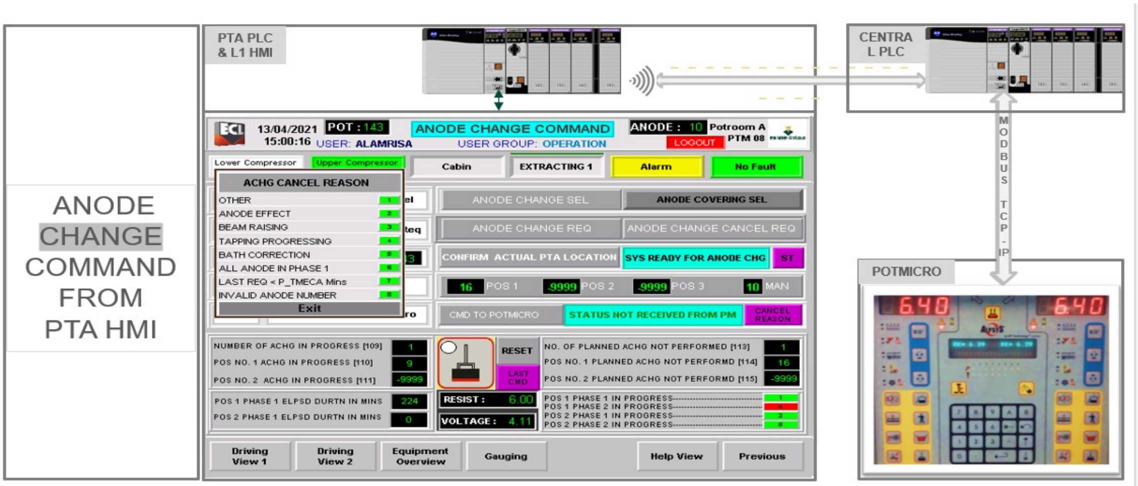


Figure 5. PTA HMI anode change screen.

Figure 6. PTA cabin HMI to pot micro.

3.2 Step-2: Anode Change Compliance Enhancement by Adding Process Automation Model

A detailed study was conducted to understand operator behavior and decision-making patterns during anode change and cover operations using the PTA system. The investigation revealed a tendency among operators to adopt time-saving shortcuts at various stages of the process, often bypassing critical procedural steps. These deviations, while aimed at improving efficiency, posed risks to both process stability and operator safety.

To address these challenges, a series of interlock-based control logics were developed and integrated into each step of the anode change sequence. These logics were designed to enforce strict adherence to the Standard Work Instructions (SWIs), thereby eliminating the possibility of procedural shortcuts. As a result, operators are now required to follow the defined sequence of operations, with the system preventing progression unless each step is completed as prescribed. Figures 7–9 show HMI screens for AC operations.

3.2.1 Crust breaking

To calculate the crust breaker counts,we are capturing the data from the Long travel, Cross travel, and Tools rotation encoders coordinates, along with the Crust breaked coordinates and crust breaker command. By tracking these parameters, we can accurately monitor the number of crust breaker counts. Additionally, all this data is being stored in our Pi historian, as illustrated in Figure 7.1. We are utilizing this stored data to generate comprehensive reports, as demonstrated in Figure 7.2. This ensures that we have a robust and reliable system for tracking and reporting the crust breaker counts.

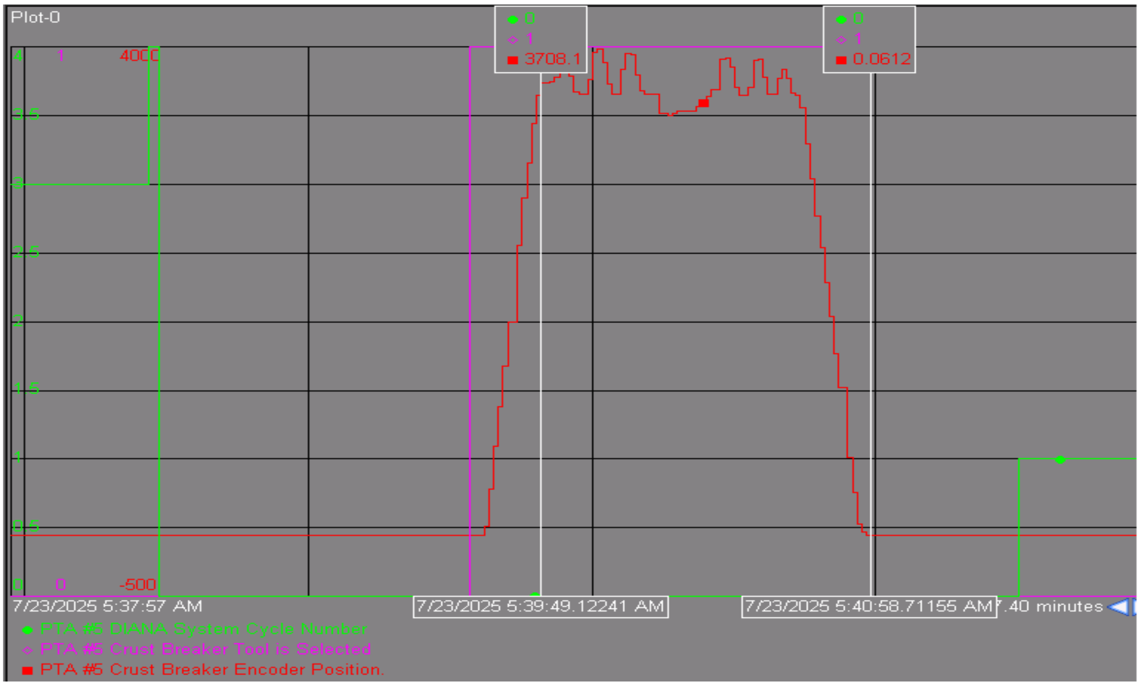
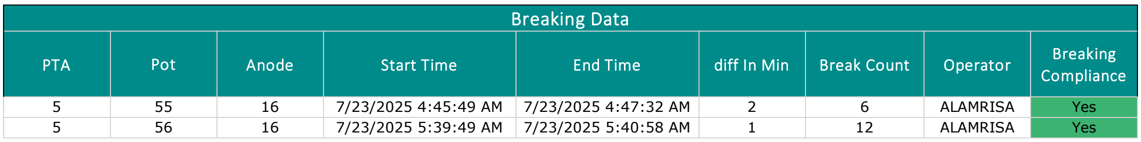


Figure 7.1 Data from Pi Historian to monitor Crust breaking operation



Breaking Data

PTA	Pot	Anode	Start Time	End Time	diff In Min	Break Count	Operator	Breaking Compliance
5	55	16	7/23/2025 4:45:49 AM	7/23/2025 4:47:32 AM	2	6	ALAMRISA	Yes
5	56	16	7/23/2025 5:39:49 AM	7/23/2025 5:40:58 AM	1	12	ALAMRISA	Yes

Figure 7.2 Report generated from Pi Historian to track the crust breaking operation

3.2.2 Shovelling

To ensure that the shovelling operations are followed meticulously, we are capturing data from several key parameters. These include the Long travel, Cross travel, Tools rotation, and Shovelling encoder coordinates, along with the Shovel Up, Down, Open, and Close commands. By tracking these parameters, we can accurately monitor shovelling counts and ensure that the shovelling operation is conducted as per the procedures. Moreover, all this data is being stored in our Pi historian, as illustrated in Figure 8.1. This stored data is pivotal for generating comprehensive reports, as demonstrated in Figure 8.2. This process ensures that we have a robust and reliable system for tracking and reporting shovelling counts and operations in accordance with the procedures.

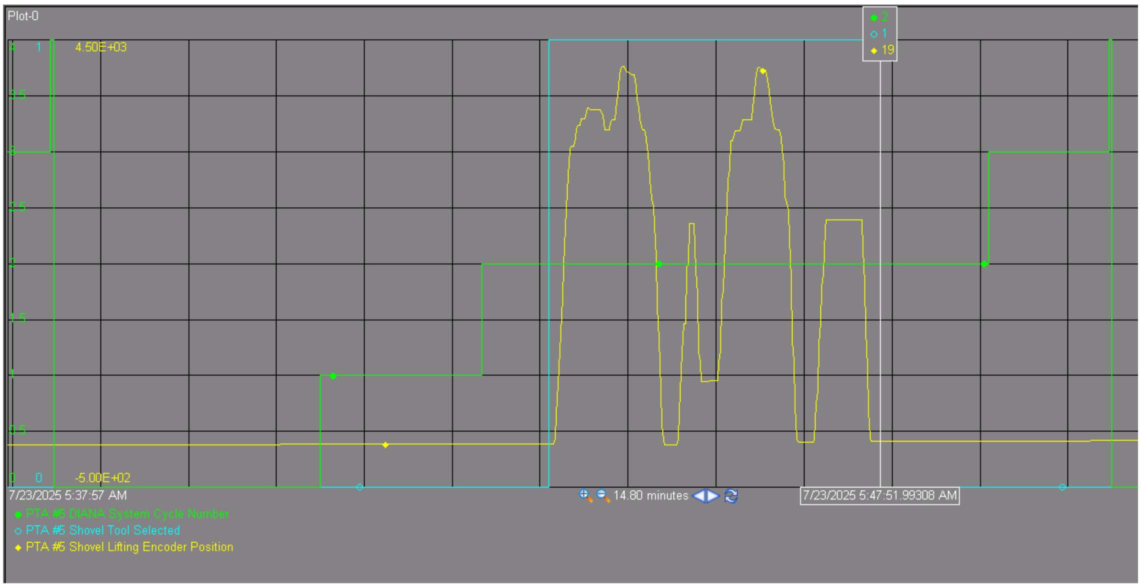
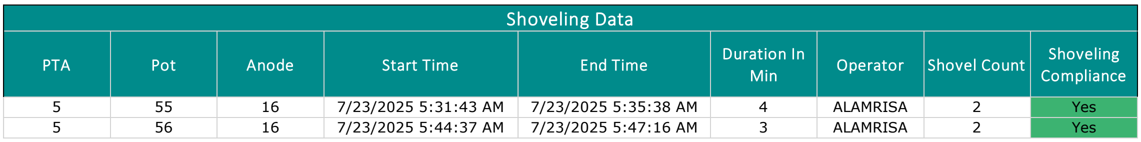


Figure 8.1 Data from Pi Historian to monitor Shovelling operation



Shoveling Data								
PTA	Pot	Anode	Start Time	End Time	Duration In Min	Operator	Shovel Count	Shoveling Compliance
5	55	16	7/23/2025 5:31:43 AM	7/23/2025 5:35:38 AM	4	ALAMRISA	2	Yes
5	56	16	7/23/2025 5:44:37 AM	7/23/2025 5:47:16 AM	3	ALAMRISA	2	Yes

Figure 8.2 Report generated from Pi Historian to track the Shoveling operation

3.2.3 Gauging

As part of this anode change procedure, it's crucial that we complete all the steps outlined in the Gauging procedure. Missing out on any particular step can significantly impact the quality of the anode change.

To ensure that operators adhere strictly to the Gauging procedure, we are now capturing data from several key parameters. These include Long travel, Cross travel, Tools rotation, Extractor encoder coordinates, along with data from the Cross travel, Extractor tool. By closely tracking these parameters, we can accurately monitor the anode change activity and ensure it is conducted as per the set procedures. Additionally, all of this data is being stored in our Pi historian, as depicted in Figure 9.1. This stored data is pivotal for generating comprehensive reports, as shown in

Figure 9.2. This process ensures that we have a robust and reliable system for tracking and reporting gauging operations in accordance with the procedures.

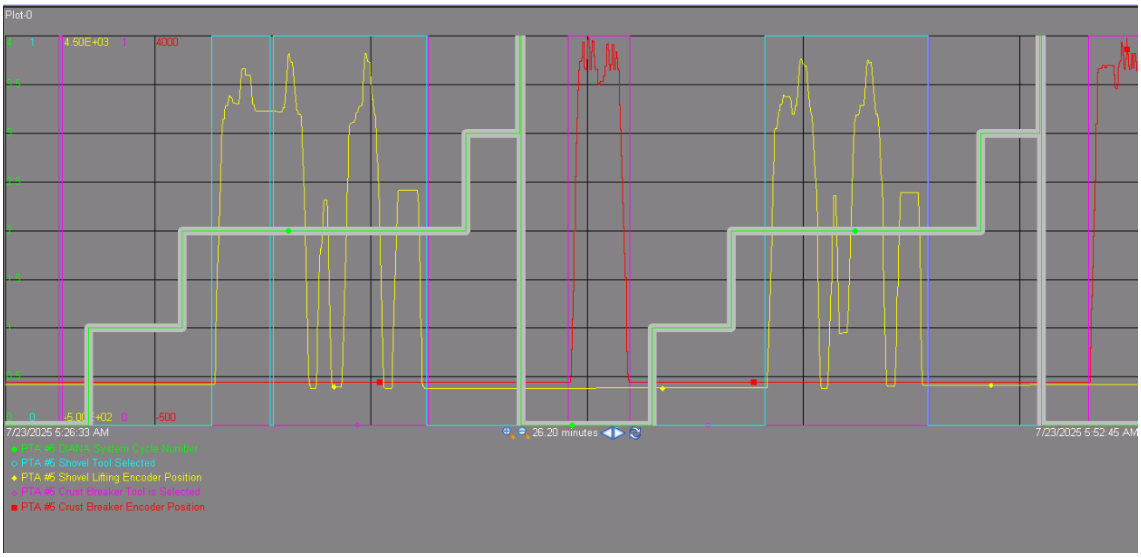
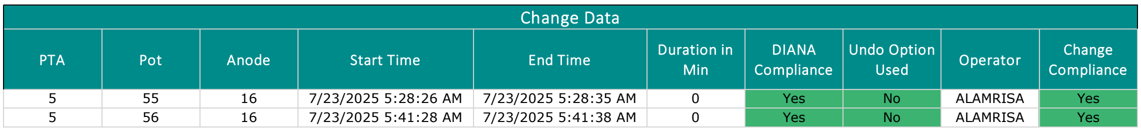


Figure 9.1 Data from Pi Historian to monitor anode change operation



Change Data

PTA	Pot	Anode	Start Time	End Time	Duration in Min	DIANA Compliance	Undo Option Used	Operator	Change Compliance
5	55	16	7/23/2025 5:28:26 AM	7/23/2025 5:28:35 AM	0	Yes	No	ALAMRISA	Yes
5	56	16	7/23/2025 5:41:28 AM	7/23/2025 5:41:38 AM	0	Yes	No	ALAMRISA	Yes

Figure 9.2 Report generated from Pi Historian to track the anode change operation

4. Post-Automation Outcomes

4.1 Implementation of PTA-Based Anode Change and Cover Commands

Following the deployment of automated command functionality via PTA, several operational improvements were observed across the potline.

4.1.1 Reduction in Floor Operator Workload

Prior to automation (Figure 10), floor operators were required to manually initiate anode change and cover commands at individual pot microcontrollers, averaging approximately 80 manual interventions per shift per operator. With the integration of command execution through the PTA Human-Machine Interface (HMI) (Figure 11), this task has been fully centralized, reducing manual workload from 80 to zero.

4.1.2 Elimination of Heat Stress Incidents

The automation significantly minimized operator exposure to the potroom environment, particularly during peak summer periods when ambient temperatures exceed 45°C. As a result, no heat stress cases have been reported post-implementation, indicating a substantial improvement in occupational health and safety (see Figure 12).

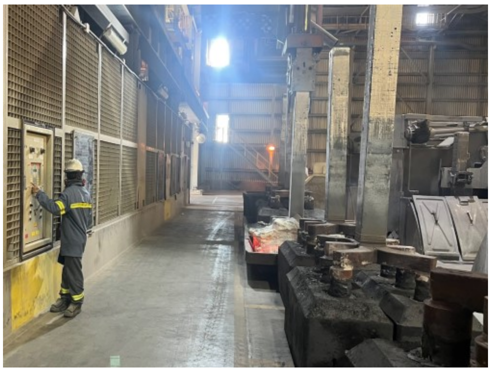


Figure 10. Command given by pot micro.

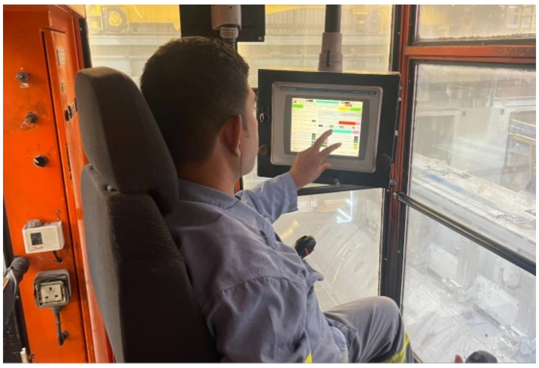


Figure 11. Command given by PTA.

Achieved

Zero

Heat Stress Case - 2024

Congratulations & Thank You All.

Smelter Management Appreciated Everyone's Contribution

On This Achievement.

Figure 12. Maaden heat stress committee announcement.

4.1.3 Reduction in Anode Effect Occurrences

Timely execution of anode changes commands via PTA ensured that the required electrical resistance setpoint was delivered to the pots without delay. This eliminated the risk of anode effects typically caused by mis synchronizations of manual interventions, thereby enhancing pot stability and energy efficiency (Figure 13).

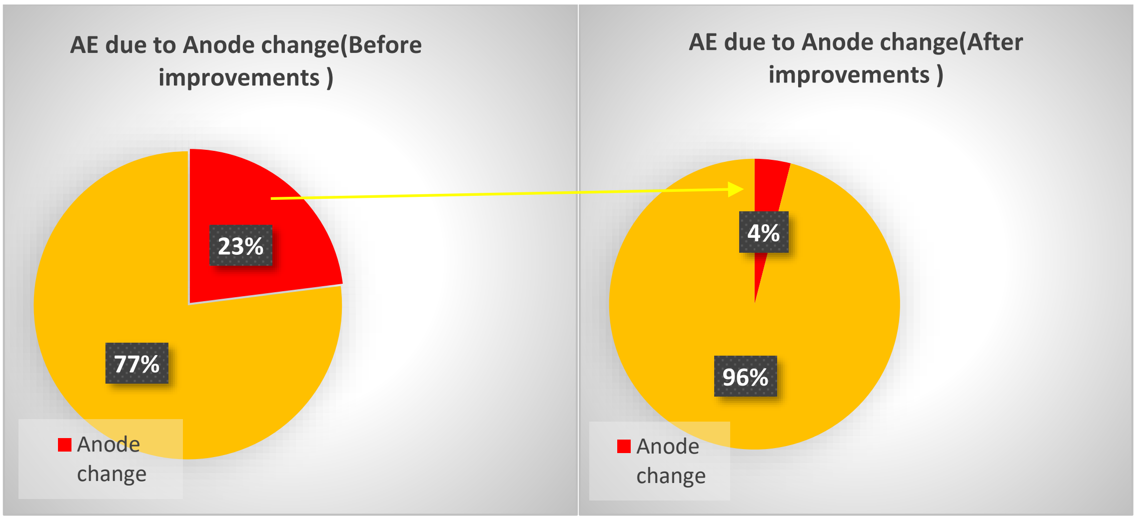


Figure 13. Anode effects before and after improvements.

4.2 Results by Following Compliance Enhancement Through Process Automation

4.2.1 Operator Empowerment Through Credential Integration

To enhance operational discipline and accountability, user credential integration was implemented within the PTA system. This allowed for real-time tracking of operator activities and enabled the monitoring of key performance indicators (KPIs) related to anode change and covering operations. The initiative fostered a culture of ownership and responsibility among operators, contributing to improved safety and productivity.

Key benefits of the implemented solution:

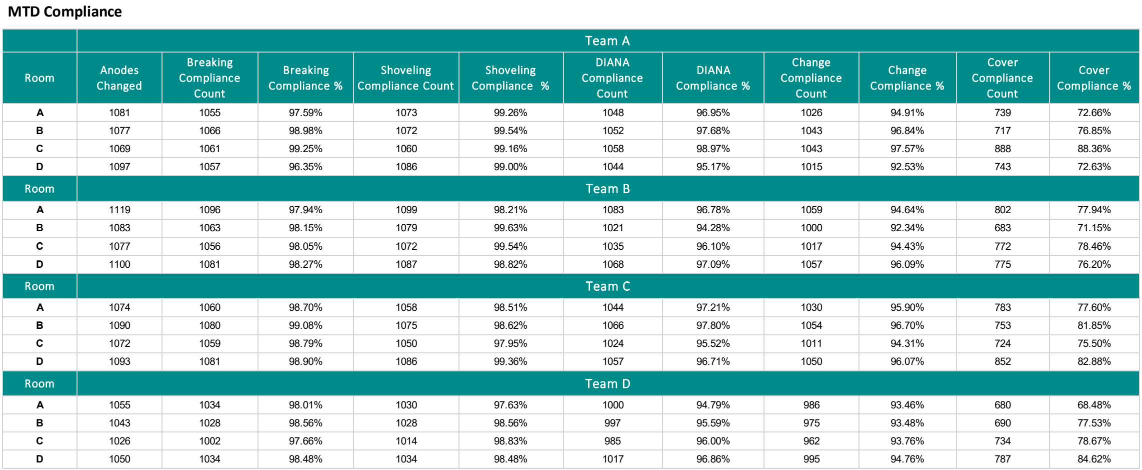
- User activity tracking: Enabled identification and monitoring of individual PTA users during operations (Table 1) and by teams (Figure 14).
- KPI monitoring: Facilitated the generation of performance reports, including AC KPIs and bypass reports.
- Enhanced accountability: Strengthened operator ownership by linking actions to user credentials.
- Utilization insights: Provided visibility into PTA idle time through login activity analysis.

Table 1. PTA operator's compliance tracking report.

Operator	Anodes Changed	Breaking Compliance Count	Breaking Compliance %	Shoveling Compliance Count	Shoveling Compliance %	DIANA Compliance Count	DIANA Compliance %
Operator 1	553	547	98.92%	548	99.10%	546	98.73%
Operator 2	510	502	98.43%	496	97.25%	498	97.65%
Operator 3	489	487	99.59%	489	100.00%	488	99.80%
Operator 4	487	473	97.13%	469	96.30%	456	93.63%
Operator 5	461	459	99.57%	461	100.00%	449	97.40%
Operator 6	447	444	99.33%	445	99.55%	443	99.11%
Operator 7	460	457	99.35%	455	98.91%	441	95.87%
Operator 8	439	432	98.41%	436	99.32%	428	97.49%
Operator 9	438	432	98.63%	435	99.32%	416	94.98%
Operator 10	416	414	99.52%	416	100.00%	413	99.28%
Operator 11	427	424	99.30%	418	97.89%	419	98.13%
Operator 12	426	418	98.12%	426	100.00%	417	97.89%
Operator 13	419	417	99.52%	417	99.52%	412	98.33%
Operator 14	423	419	99.05%	422	99.76%	413	97.64%
Operator 15	426	414	97.18%	417	97.89%	418	98.12%

Table 1. Continued.

Operator	Change Compliance Count	Change Compliance %	Coverings Done	Cover Compliance Count	Cover Compliance %	Overall Score
Operator 1	536	96.93%	481	425	88.36%	536
Operator 2	488	95.69%	232	182	78.45%	488
Operator 3	486	99.39%	402	366	91.04%	486
Operator 4	448	91.99%	399	297	74.44%	448
Operator 5	447	96.96%	306	275	89.87%	447
Operator 6	438	97.99%	375	311	82.93%	438
Operator 7	437	95.00%	368	271	73.64%	437
Operator 8	423	96.36%	296	255	86.15%	423
Operator 9	412	94.06%	351	249	70.94%	412
Operator 10	411	98.80%	322	264	81.99%	411
Operator 11	410	96.02%	310	254	81.94%	410
Operator 12	410	96.24%	375	264	70.40%	410
Operator 13	409	97.61%	365	316	86.58%	409
Operator 14	408	96.45%	297	235	79.12%	408
Operator 15	403	94.60%	372	313	84.14%	403



MTD Compliance

Room	Anodes Changed	Breaking Compliance Count	Breaking Compliance %	Shoveling Compliance Count	Shoveling Compliance %	DIANA Compliance Count	DIANA Compliance %	Change Compliance Count	Change Compliance %	Cover Compliance Count	Cover Compliance %
	Team A										
A	1081	1055	97.59%	1073	99.26%	1048	96.95%	1026	94.91%	739	72.66%
B	1077	1066	98.98%	1072	99.54%	1052	97.68%	1043	96.84%	717	76.85%
C	1069	1061	99.25%	1060	99.16%	1058	98.97%	1043	97.57%	888	88.36%
D	1097	1057	96.35%	1086	99.00%	1044	95.17%	1015	92.53%	743	72.63%
Room	Team B										
A	1119	1096	97.94%	1099	98.21%	1083	96.78%	1059	94.64%	802	77.94%
B	1083	1063	98.15%	1079	99.63%	1021	94.28%	1000	92.34%	683	71.15%
C	1077	1056	98.05%	1072	99.54%	1035	96.10%	1017	94.43%	772	78.46%
D	1100	1081	98.27%	1087	98.82%	1068	97.09%	1057	96.09%	775	76.20%
Room	Team C										
A	1074	1060	98.70%	1058	98.51%	1044	97.21%	1030	95.90%	783	77.60%
B	1090	1080	99.08%	1075	98.62%	1066	97.80%	1054	96.70%	753	81.85%
C	1072	1059	98.79%	1050	97.95%	1024	95.52%	1011	94.31%	724	75.50%
D	1093	1081	98.90%	1086	99.36%	1057	96.71%	1050	96.07%	852	82.88%
Room	Team D										
A	1055	1034	98.01%	1030	97.63%	1000	94.79%	986	93.46%	680	68.48%
B	1043	1028	98.56%	1028	98.56%	997	95.59%	975	93.48%	690	77.53%
C	1026	1002	97.66%	1014	98.83%	985	96.00%	962	93.76%	734	78.67%
D	1050	1034	98.48%	1034	98.48%	1017	96.86%	995	94.76%	787	84.62%

Figure 14. Anode change and covering compliance tracking report.

4.2.2 Improved Compliance in Crust Breaking

A logic-based interlock was introduced to ensure that operators could not proceed to subsequent steps in the anode change sequence without completing crust breaking as prescribed in the Standard Work Instructions (SWIs). This intervention led to a measurable improvement in compliance with crust breaking protocols (Figure15. Wings on anode butts have been reduced (Figure 16).

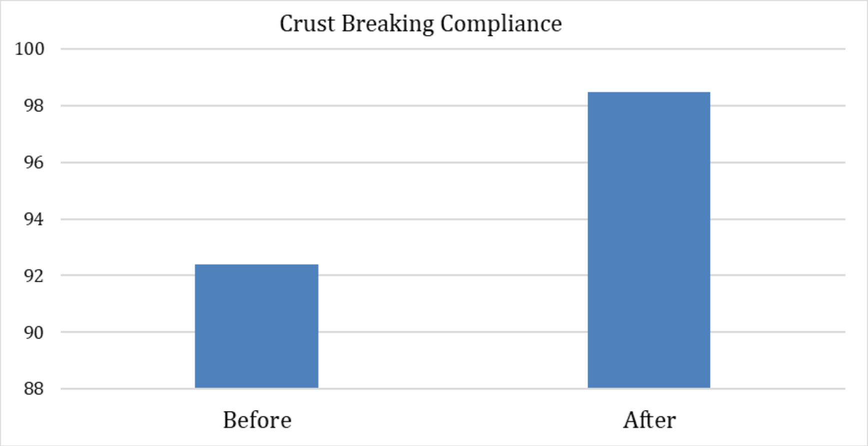


Figure 15. Crust breaking compliance before and after interlock implementation.

Figure 16. Wings compliance before and after interlock implementation.

4.2.3 Enhanced Shoveling Practices

A logic-based interlock was introduced to ensure that operators could not proceed to subsequent steps in the anode change sequence without completing the number of required shoveling based on the set points from level 2 HMI. This practice significantly improved the removal of crust and carbon dust, thereby reducing pot instability following anode changes (Figure 17).

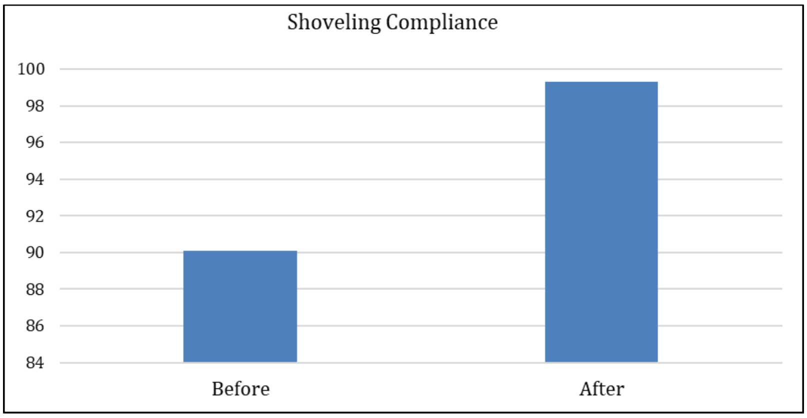


Figure 17. Shoveling compliance before and after interlock implementation.

4.2.4 Standardisation of Anode Setting Heights

The integration of the DIANA gauging interlock ensured that new anodes were set at the correct height, in accordance with process specifications (Figure 18). This eliminated occurrences of high or low anode-cathode distances (ACD), contributing to improved electrical stability and pot performance.

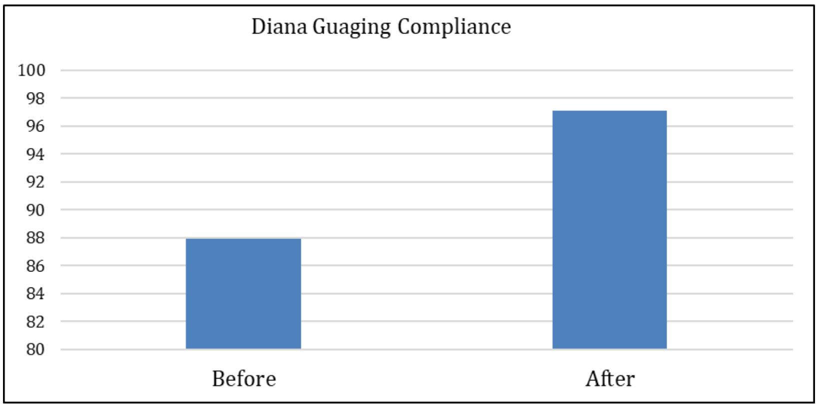


Figure 18. Diana compliance before and after interlock implementation.

5. Conclusions

The automation logic improvements of anode changes and covering operations at Maaden Aluminium have significantly enhanced operational efficiency, safety, and process stability. Centralizing command execution through the PTA HMI eliminated manual interventions, reducing operator workload and human error. Interlock-based logic and credential tracking enforced strict compliance with Standard Work Instructions, improving consistency in crust breaking, shoveling, and anode setting. These changes minimized pot instability and eliminated anode effects during changeovers. Additionally, reduced floor exposure led to zero heat stress incidents, marking a major safety milestone. Overall, the initiative has strengthened process control and positioned Maaden as a transformation leader.