SMARTCrane Contributes to a Proactive Decision-Making and Optimization of Electrolysis Process

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https://doi.org/10.71659/icsoba2024-al008

Abstract

In smelters Pot Tending Machines (PTM) execute many and complex activities, such as anode change, tapping operation etc. Each anode change is a sequence of tasks: breaking the crust, gauging, traveling, scooping, anode placement and more. For one standard smelter it represents more than half million tasks to be executed correctly every year. To deliver production and ensure quality of aluminum, operations and maintenance teams face various challenges. Two major factors are: a full compliance with operating standards and very regular and respected workflow. These two parameters have a direct impact on the efficiency of the Aluminum process and operation stability. As well as on its environmental impact and greenhouse gas emissions, since, for example, poorly managed work can lead to over-consumption of anode. A IIOT solution SMARTCrane from Fives was implemented in various smelters and provided significant benefits for operations engineers and managers in taking proactive measures. Since it is running, it generated a vast amount of data and performance indicators. By analyzing this data and deriving actionable insights, operation and process teams made informed decisions regarding PTM availability and compliance with operating procedures. After several years of industrial use, this IIOT solution captured and analyzed worldwide more than 380 000 anode changes and made it possible to make a continuous control with loopback between the Key Performance Indicator (KPI) measured with operations and maintenance.

Keywords: Pot tending machines, IIOT field application platform, Overall equipment effectiveness.

1. Introduction

Many smelters have a wide range of equipment, layouts and processes with legacy devices, sensors, systems, and applications that span generations and periods. In addition, many of them likely use different operational technology providers for machinery, equipment lines and robotics technology. A smelter is mainly composed of machines, equipment lines and robots that are not always connected to the computer network.

The programmable logic controller (PLC), the monitoring and data acquisition system (SCADA) and the manufacturing execution system (MES) orchestrate the production flows and have demonstrated their contribution to the performance levels to be achieved.

The visible trend at the manufacturing level is to increasingly computerize the smelter's workshop; the convergence of operational and computer technologies is a reality. This creates more possibilities for achieving a common global architecture encompassing multiple dimensions: equipment, edge, workshop, and cloud.

In such a context, SMARTCrane has been developed by Fives ECL as an innovative new concept of IIOT (Industrial Internet of Things) field application platform for operations and maintenance for PTM and Furnace Tending Assemblies (FTA) [1]. It relies on technologies that can include analytics, big data and industrial content. This paper presents the implementation and impact of this IIOT platform in smelter operations and how it can help to improve Overall Equipment Effectiveness (OEE). It highlights the role of data analytics in optimizing PTM performance, improving compliance with Standard Operational Procedures (SOP), and ultimately enhancing the efficiency and sustainability of aluminium production processes. The findings underscore the importance of leveraging advanced computing technologies to drive operational excellence and achieve environmental objectives in industrial settings.

2. People and Challenges in Smelters with PTM

In a smelter, there are different roles, or profiles, which contribute to overall performance and quality of production. Roles are linked to the concept of person. A person is a stakeholder in the system (platform IIoT) which is responsible for ensuring that KPIs are met.

The table of people and challenges is depicted in Table-1 below.

Table 1. People in pot room and challenges.

People	Role	KPI	Challenges
Potline manager	- Monitor and organize the daily operations of the Plant Pot Lines. - Supervise employees, the production and efficiency to ensure that the plant is operating regularly, quickly, effective, and safe.	- Safety - Budget - OEE - Productivity	- Time to upskill personnel - Collaborative interaction - Supplier relations - Easy access to information
Maintenance manager (scheduled maintenance)	- Ensure that the facilities, development, and the machines are working with a yield and a maximum efficiency. - This includes maintenance total preventive, management equipment failures mechanical, electrical and automation (including the software programming). - Management of people and reports budgetary and financial.	- Safety - Budget - Equipment availability time OEE - Completed task	- Limited time to complete the maintenance tasks - Cost pressure (optimal profitability)
Maintenance engineer/ planner (operational maintenance)	- Ensure the optimization of the maintenance organization structure. - Analyze equipment repetitive failures. - Estimate the costs of maintenance and evaluate the alternatives. - Assess the needs of replacement of the equipment and	- Safety - Equipment availability time OEE - Budget	- The diagnosis takes time because of the system complexity. - Missing spare parts - Administration and analysis cause downtime longer - Tedious process to find related information

	establish replacement programs at the right time.		
Maintenance technician	- Assist in the installation of new manufacturing equipment. - Inspect and test regularly the equipment and the machines. - Respond to alerts and operating messages, in performing the procedures corrective and repairs in accordance with procedures standard operational (SOP)and the protocols of maintenance. - Clear documentation of routine checks and necessary repairs, in accordance with protocols and internal and external procedures.	- Safety - Duration of activities - Compliance	- Often under pressure and stress (work faster, improve the quality) - Insufficient support during the diagnostic phase - Complex documentation to understand - Absence of knowledge and expertise sharing
PTM operator	- Set up the PTM before executing the operation procedure - Operate the equipment in a effective and safe manner, and compliance with SOP, for the production processing.	- Safety - Levels of quality and performance	- Operational difficulties related to the pot and equipment availability - Dexterity - Respect of anode change and tapping schedule while ensuring quality - Insufficient support in case incident - Lack of information for the reporting

Two departments, Maintenance and Operations, are continuously engaged with the Pot Tending Machines (PTM) around the clock. Despite their separate roles, their interactions with the PTM are closely intertwined. If operators mishandle the cranes, it significantly impacts maintenance activities; likewise, poor maintenance performance affects crane availability, hindering operations from achieving production targets.

The Operations department faces various challenges, with operator management being the primary concern. Human operators control the PTM, and their driving methods vary between individuals. Despite training on standard operating procedures (SOP), operators may still make errors or forget steps in the process. High turnover rates among operators requires focus on training. Operations run continuously on three shifts (Morning, Afternoon, and Night), each with specific operational targets, such as anode changes and metal tapping. The success of operations heavily relies on PTM availability and efficiency.

Maintenance encounters challenges stemming from the diverse technologies employed in the cranes and the harsh operating environment. The pot room environment is characterized by high magnetic fields, dust, and extreme temperatures, exceeding 80°C in some regions during summer.

The SMARTCrane application already implemented, allows pot line managers, maintenance managers, engineers technicians, and PTM operators to get unique relevant and predictive information, that allows them to address challenges and achieve the factory goals, as shown in Figure 1. Prescriptive information can be provided through analysis by OEM experts that have access to the IIOT platform remotely.

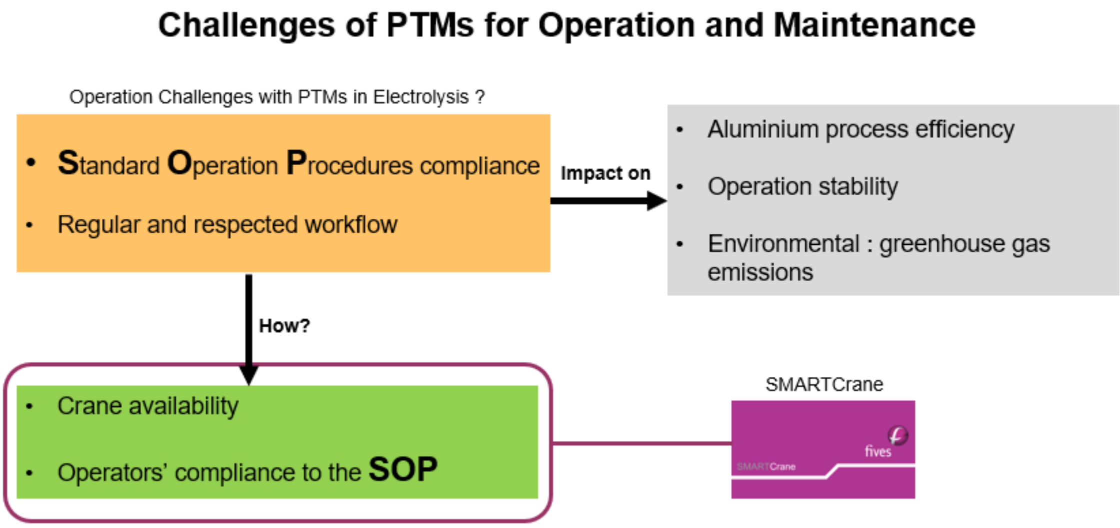

Figure 1. Challenges for operation and maintenance.

3. Genesis of the IIOT Solution SMARTCrane

The genesis of the solution begins with a set of unique challenges and requirements. First, there are special cranes (PTM), mobile equipment that is not directly connected by a network cable, which requires innovative solutions to capture and transmit data efficiently. Moreover, these machines are driven by humans, which implies that the machines themselves lack awareness of their own status, requiring specialized algorithms to interpret and analyze their performance.

To meet these challenges, the solution involves the installation of an embedded PC, using the principles of edge computing. This approach enables real-time processing and analysis of data directly on the machine, reducing latency and improving responsiveness, and minimizing the need to send large volumes of data to a central server or cloud for processing. In addition, the platform supports multiple connectivity options (e.g., Wi-Fi, 4G, Ethernet), ensuring smooth communication and data transfer. Hardware installation on a complete PTM fleet can be done in less than 4 weeks.

In terms of implementation, the industrialization of the embedded gateway is proven, involving the development of specialized acquisition modules and the separation of functions to optimize performance and efficiency. A local database is integrated into the system to store and manage data locally, minimizing dependence on external networks and improving data security. The WiFi connectivity implemented, facilitate communication with plant core systems and allow remote access and monitoring. The following sketch shows the main functional modules of a "remote equipment connection", the SMARTCrane hardware architecture as shown in Figure 2.

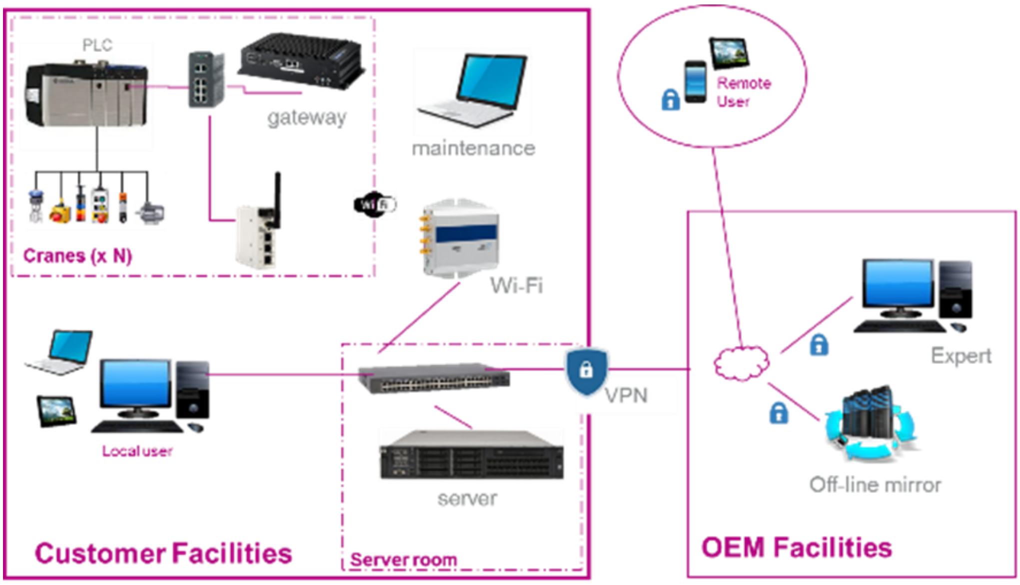

Figure 2. Data acquisition architecture.

This platform can be adopted for proactive decision making and optimization of the electrolysis process via logical steps of value gradation.

Digitizing the Electrolysis workshop through the IIoT filed application platform involved different steps integrated into a timely and sequential roadmap to ensure value, as the following:

- Data collection: Data come directly from PTM equipment/sensors and algorithmic calculations through an intelligent gateway. Data may also come from other systems such as Enterprise Resource Planning (ERP) used for maintenance management.
- Model visualization: This is done through real time dashboards, user interface and other representations to view the data. The operator monitors the operation practices and equipment health using different score card.
- Developing a vision informed by analysis: This includes treatment of data with statistical analysis, such as correlations, root cause research and predictive maintenance.

A crucial aspect of the solution is the co-design process with the customer, involving close collaboration with the operations and maintenance teams. This collaborative approach facilitates the enrichment of the solution with valuable information and requirements specific to the operational environment, ensuring that the final solution aligns closely with the needs of end users.

Cybersecurity and safety are paramount concerns for smelters and their partners, as the platform operates as a "consulting only" tool, through an IOT gateway integrating the technologies to ensure higher level of security. It is capable of reading, processing, and disseminating corresponding information. Its unidirectional data stream (upload) prevents any interference with equipment operation.

Finally, the solution highlights the importance of ritualizing the analysis of the collected data, highlighting the need for regular and structured evaluation of performance indicators. By establishing a systematic approach to data analysis, information can be collected more efficiently, enabling operational adjustments, proactive maintenance and optimization of machine performance.

4. The IIOT Solution

PTMs are vital assets within an aluminium smelter and face numerous challenges, underscoring the importance for operation and maintenance teams to have comprehensive knowledge of their equipment's status. In recent years, several smelters have opted to invest in IIOT field application platforms such as SMARTCrane and upgraded their existing PTMs fleets with it.

The objective is to provide a software with different Applications such as OEE, Dry-run, Statistical Process Control, machine health monitoring, cycle time, remote diagnostics, and tools to enhance smelters' operation and maintenance activities. This system collects, processes, and utilizes data from the entire PTM or specific components, delivering actionable insights regarding best practices associated with processes in reduction cells, such as anode changing cycles and adherence to SOP. As illustrated in Figure 3 below the user can see on the dashboard various information such as: if anode change work started at the beginning of the shift and how it progressed over the shift to reach production target, offset between anode change and covering, consistency between anode change quantity and anode covering quantity etc. It can prioritize critical components such as compressors, insulation monitoring systems, hydraulic units, and hoists, each with distinct characteristics. User-friendly interface allows operators and maintenance personnel to visualize data, configure settings, and interact with the system in real-time.

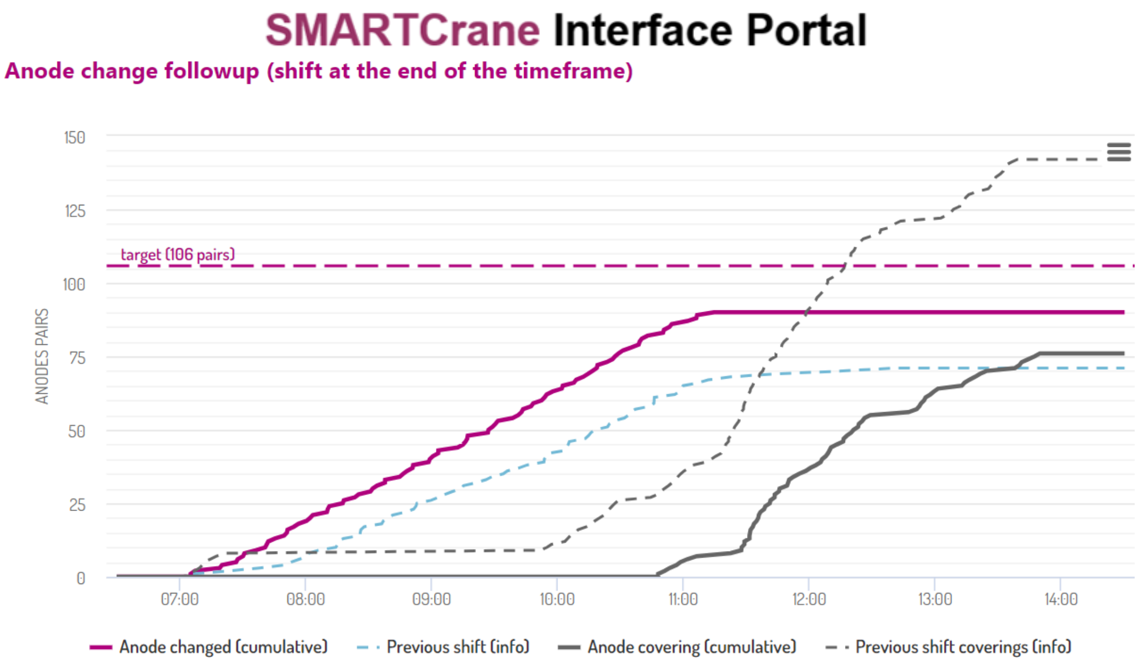

Figure 3. Anode change efficiency follow-up.

The connected PTM also offer intelligence for benchmarking fleet performance across a smelter, enabling prompt identification and correction of underperforming process cranes. Additionally, a link can be established with Virtual Technology Simulators to integrate data collected by the field application platform, enabling real-time adjustments based on changing usage conditions.

5. Continuous Improvement Facilitated Using Data Collected and Processed

The IIOT solution includes a set of analysis devices and solutions delivered as end-user applications. They cover operations and maintenance use cases across different deployment models.

It enables cost savings, improvement on aluminium process efficiency and operations stability throughout the Pot line value chain (described in chapter 6). This is done by analyzing a variety of information from crane availability, operators' compliance with Standard Operating Procedures (SOP), PTMs operator regular workflows, context, environment to improve quality, operations up to decision-making.

Processed data produced (Figure 4) enables management transformation through a better understanding of the Overall Equipment Effectiveness (OEE) such as anode change operation, calculated by multiplying the three factors: Availability, Performance and Quality.

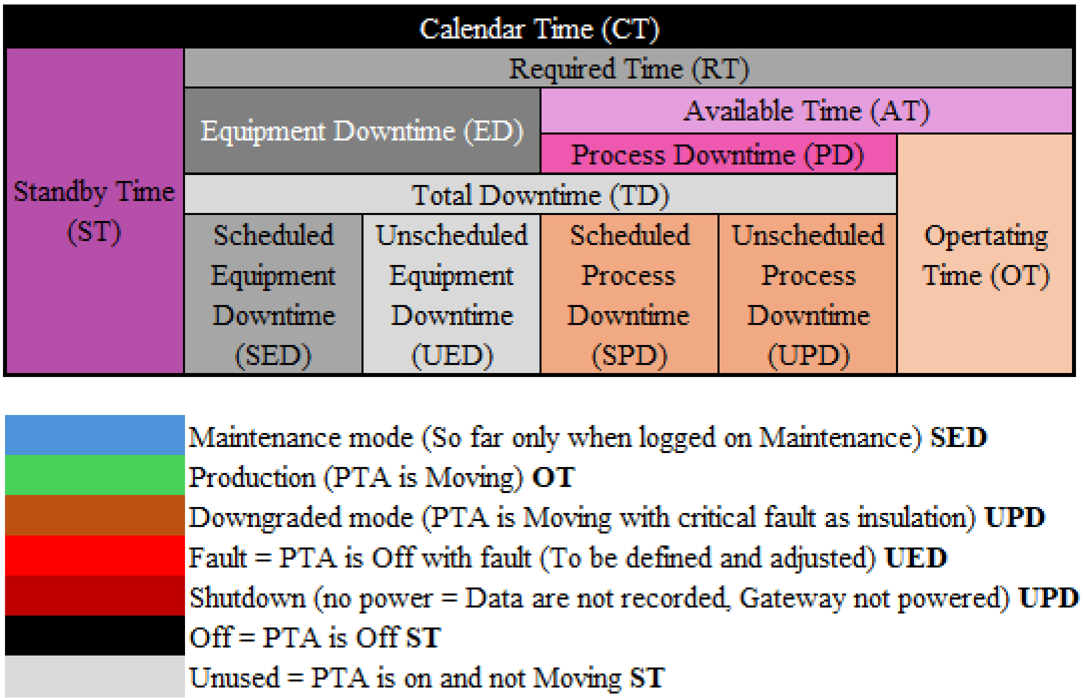

Figure 4. Example of smelter time model versus data available in SMARTCrane.

5.1 Availability of PTM

Availability as shown in Figure 5, considers all events that stop planned production long enough where it makes sense to track a reason for being down (example several minutes). This typically custom-made module to be developed to end users' field application cases. Availability is calculated by taking the ratio of Run Time to Planned Production Time as follow:

- Availability = Run Time / Planned Production Time
- Run Time is simply Planned Production Time less Stop Time, where Stop Time is defined as all-time where the manufacturing process was intended to be running but was not due to Unplanned Stops (e.g., Breakdowns) or Planned Stops (e.g., Changeovers).
- Run Time = Planned Production Time − Stop Time

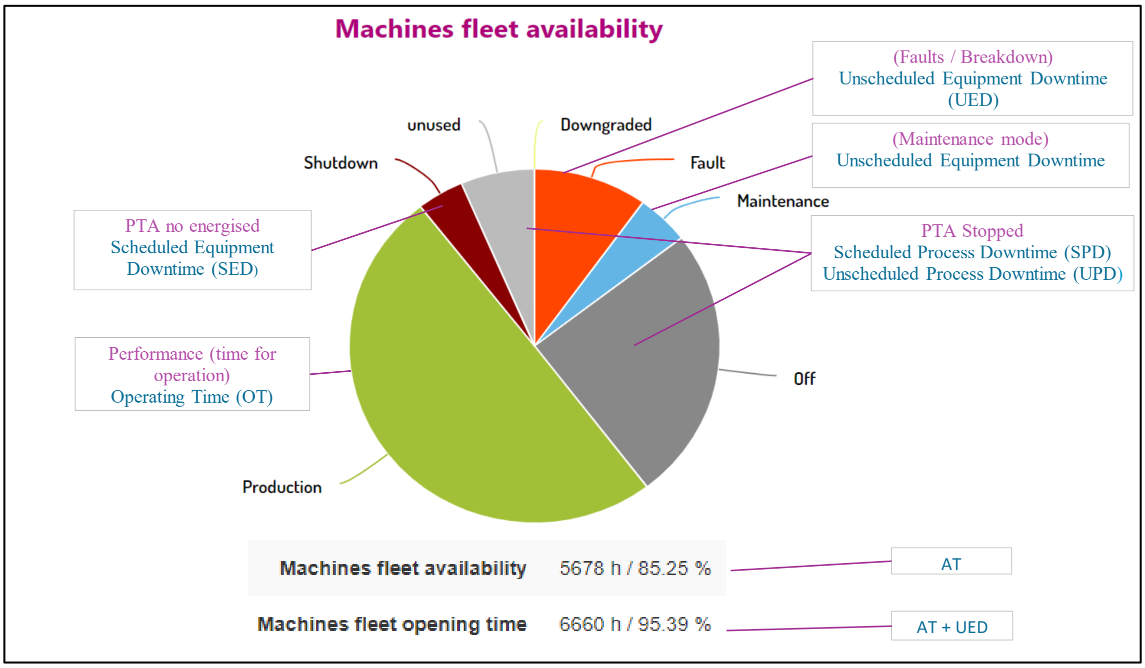

Figure 5. Typical PTA fleet availability dashboard.

5.2 Performance of Anode Change and Other Operations on Field

Performance of anode change considers anything that causes the manufacturing process, to operate less than the maximum possible speed when it is running, including both slow cycles and small stops). Performance is based on different data provided by the IIOT platform as shown in Table 2.

Table 2. Typical data selected for scoring performance of one shift.

Detail Breakdown per shift one PTM					
Type	**Shift**	**Quantity**	**Average duration**	**Max duration**	**Min duration**
Anode change	Night	16	11 min 56 s	30 min 3 s	6 min 27 s
Anode change	Total	16	11 min 56 s	30 min 3 s	6 min 27 s

Performance is the ratio of Net Run Time to Run Time. It is calculated as:

- Performance = (Ideal Cycle Time × Total Count) / Run Time
- Ideal Cycle Time is defined by the process and operations, it is the fastest cycle time, or standard time frame, that specific process operation, can achieve in optimal circumstances. Therefore, when it is multiplied by Total Count the result is Net Run Time (the fastest possible time to anode change).

Since rate is the reciprocal of time, Performance can also be calculated as:

- Performance = (Total Count / Run Time) / Ideal Run Rate
- Performance should never be greater than 100 %. If it is, it could indicate that Ideal Cycle Time defined by process is incorrect (Table 3).

Table 3. Typical KPIs used to analyze performance.

Ideal cycle time (input)	Total count anode change (output)	Total ideal cycle time	Run time anode setting (output)	Perfor-mance	Good or bath performance of PTM operator
15 min	16	240 min	192 min	125 %	Over performing but still need to check Quality KPI
10 min	16	160 min	192 min	83.3 %	Under performing but it must be seen if the quality KPI is good, it may necessary to improve the dexterity of the operator

The Ideal Cycle Time defined by the process can be redefined over the machine life, for example when there are evolutions with the design of tools of the PTM or the process.

For anode change analysis, if the performance is bad, a chronogram, as shown in Figure 6, will provide details for deep analysis of sequences of cycles for following operations:

- Travel to the Anode Stem Pot.
- Crust Breaking around the anode.
- Anode Removal.
- Cavity cleaning.
- New anode setting.

It enables to monitor if sequences followed the reference anode change procedure. Helps to understand why the PTM operator performed or not and see if we were too optimistic or pessimistic about the Ideal Cycle Time.

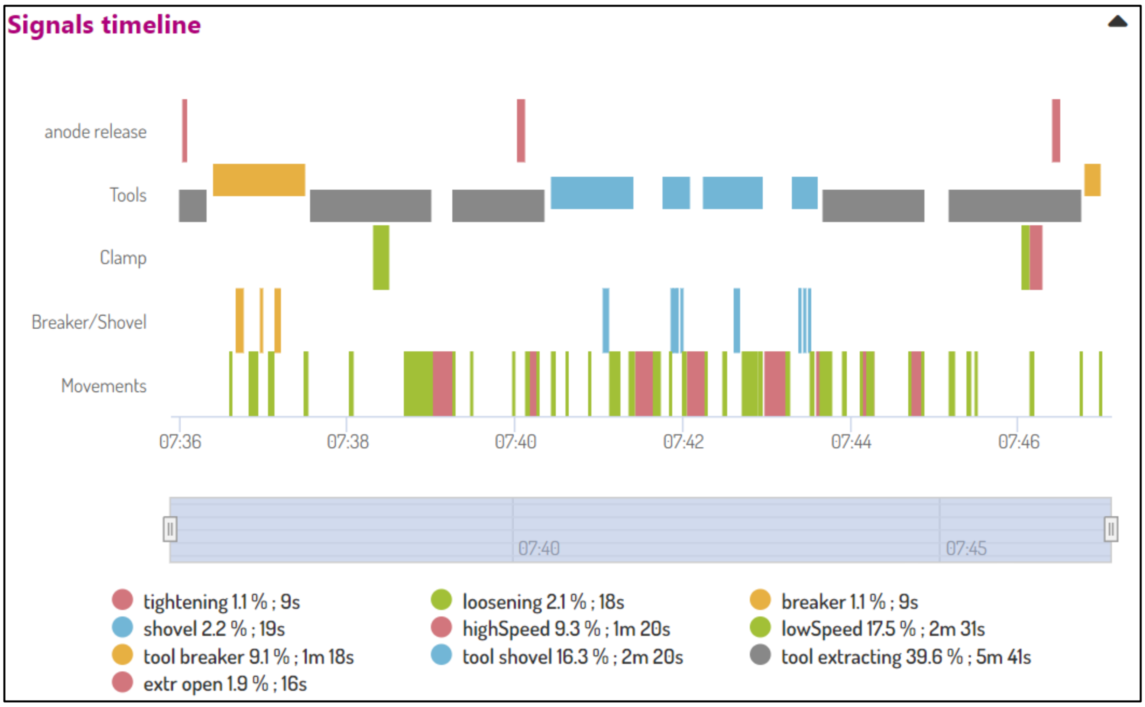

Figure 6. Chronogram available from SMARTCrane for performance.

5.3 Quality of Anode Change

Quality indicator considers measuring manufactured parts that do not meet quality standards, including parts that need rework. Remember, OEE Quality is like First Pass Yield, in the way that it defines Good Parts as parts that successfully pass through the manufacturing process the first time without needing any rework.

Quality is calculated as: Quality = Good Count / Total Count.

This is the same as taking the ratio of Fully Productive Time (only Good Parts manufactured as fast as possible with no Stop Time) to Net Run Time (all parts manufactured as fast as possible with no stop time). Quality is based on different data provided by the IIOT platform as shown in Table 4.

Table 4. Typical data used for scoring quality displayed in dashboards.

Detail Breakdown per shift			
Average breaking points quantity	**Average shovel quantity**	**N° breaking quantity**	**N° gauging quantity**
3.75	1.5	12	14

Quality indicator of operations done by a PTM can be defined by measuring the ratio Reality versus SOP best practice (see examples in Table 5).

- Number of Breaking per anode as a minimum (one side, in front) and quantity more on accessible anodes (corner / no positive raiser)
- Number of shoveling
- Gauging of new anode, place new anode over the hole by lifting in adjustment speed before tightening the connector.
- Positioning new anode low speed up

Table 5. Typical KPI used to analyze quality.

Quality	Breaking points	Shoveling	Gauging	Positioning new anode low speed	Overall Quality (unweighted)
Measured real	3.75	1.5	14	0	
SOP	7	2	16	1	
Quality KPI	53.6 %	75 %	87.5 %	0	**54 %**

6. Team Performance and Quality Compliance

6.1 How People in Electrolysis Interact with SMARTCrane and Use its OEE Components

The nature of anode change activities in a typical potline with two pot rooms is very intensive, almost 120 000 changes annually, with more than 50 changes per room per shift. This results in one anode change every 4.5 minutes at different locations of a potline, during day and night, which is impossible for humans to monitor thoroughly.

The use of SMARTCrane in smelters changed how these anode operations are monitored and optimized by teams in electrolysis sector.

Pot line managers are responsible for achieving the target of metal quality and volume. They get better visibility into the factors that contribute to productivity loss and must also be able to assess the potential impact on downstream operations.

They are also interested in the performance of their team in following SOPs, their efficiency, and their relative variability. They particularly focus on the parameters of OEE components such as: activities cycle times and KPIs of different machines, which can be compared and analyzed.

Moreover, they are responsible for reducing waste and anode set-up retouching. OEE components provide early warning of equipment process variations and quality failures and thus help engineers who monitor quality to reduce problems, as well as scrap and retouching. Thus, ensure that good practices will contribute to best stabilize the electrolysis process.

Maintenance engineers ensure that service is completed on time, allowing the PTM to operate without interruption. The OEE component must anticipate machine problems, provide information that enable to better prioritize maintenance tasks and recommend the best times for repairs. Therefore, it helps field engineers to perform the necessary maintenance tasks within the given time frame.

This IIOT solution is not merely an operator tracking device, as it may be perceived. Rather, our experience demonstrates that operators autonomously adjust their practices to align with Standard Operating Procedures (SOPs). The introduction of this digital technology has provided valuable insights into daily tasks, facilitating constructive feedback on operations. Previously, without monitoring tools, operators lacked visibility into their performance, resulting in varying approaches to tasks based solely on individual interpretation, as illustrated in Figure 7.

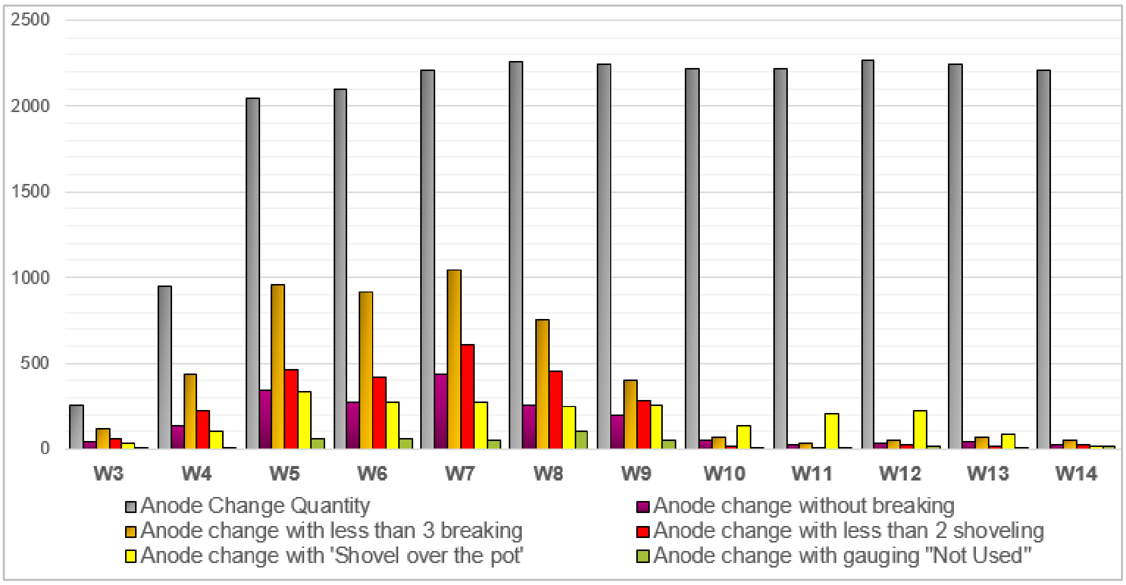

Figure 7. Chart with impact on operational behavior from the arrival of IIOT in week 7.

After week 7 there is a positive evolution of detected operational discrepancies monitored on a week-to-week basis. The grey portion of the graph represents the total quantity of anode change activities performed in each week. Highlighted in purple, orange, red, yellow, and green are instances of operational discrepancies, including anode changes:

- Performed without proper braking.
- With fewer than 3 breakings
- With fewer than 2 shoveling actions.
- Involving "Shovel over the pot" incidents.
- Where gauging was not utilized.

Another chart, in Figure 8 presents data from different teams categorized by colors representing data before and after the adoption of IIOT in PTM. Purple denotes average crust breaking counts, while green represents average shoveling counts. The shift from lighter to darker shades in both colors signifies the positive impact of IIOT on performance metrics.

Thanks to the insights derived from machine monitoring data, teams have been able to refine practices and achieve closer alignment with the optimal standards for anode change operations.

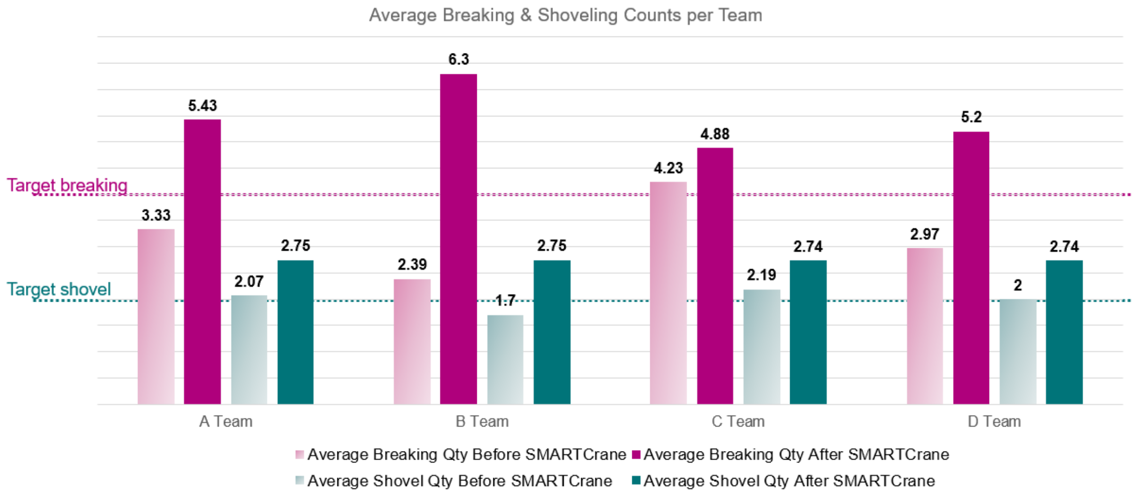

Figure 8. Chart with breaking and shoveling data before and after set-up of IIOT.

6.2 Precise Monitoring of Crane Process through Advanced Algorithms

At the core of this monitoring system are sensors and encoders integrated into the machines, capturing detailed data, with advanced algorithms it generates insightful visualizations, as shown in Figure 9 diagram. This diagram meticulously tracks every tool on the machine, utilizing a color-coded representation to signify specific functions. With this, operators' precise trajectories during tasks like anode changes are revealed, offering a comprehensive view of operational processes.

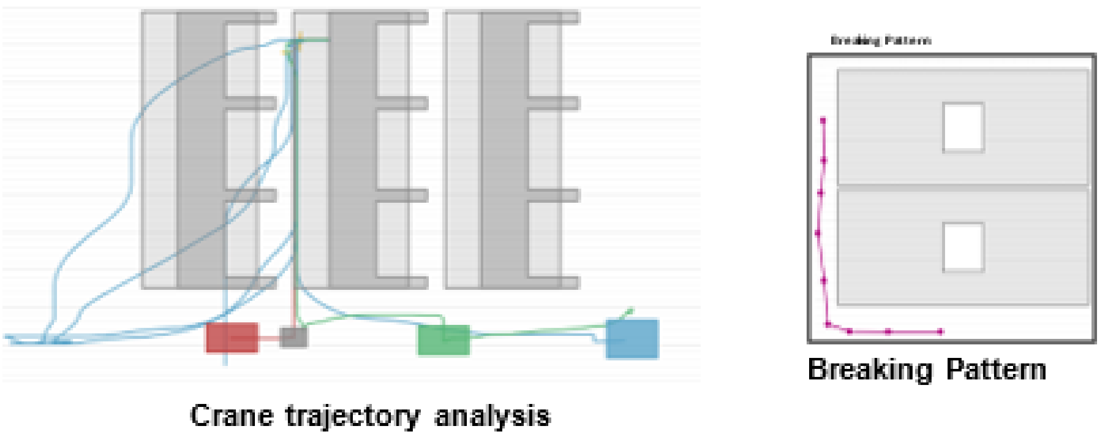

Figure 9. Monitoring focus on crane trajectory, anode breaking pattern.

Moreover, algorithms enable the verification of the metal tapping speed is regular, events that are not normally discoverable can be viewed through this specific dashboard (Figure 10) such as spikes in tapping speed or tapping overspeed and find root causes that impact quality of metal by vacuum of bath [2].

Tapping details

Date/ Time	PTM N°	OP id	Pot N°	Duration	Tapping metal weight	Metal weight in laddle	Average speed tapping	Max speed tapping
25/07/2024 16:03:05	PTM 10	22	N120	4m 52s	4420 kg	14010 kg	21.5	28.61

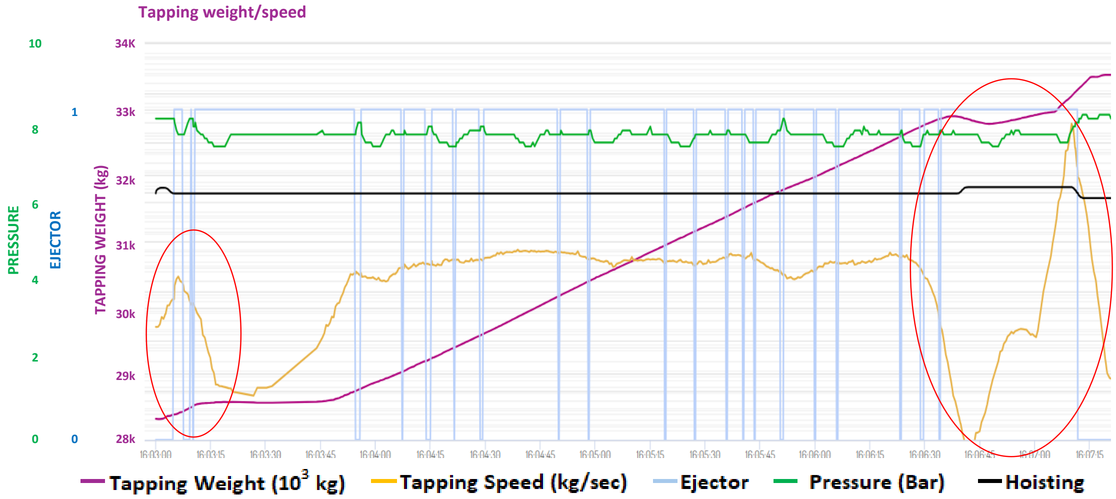

Figure 10. Metal tapping monitoring.

7. Next Steps: Increasing Environmental Initiatives and Enhancement with Image Analysis Covering Additional Equipment in Electrolysis Sector

Smelters want to produce more by using less and that is why industry 4.0 technologies such as SMARTCrane can help to identify where, when, and how to precisely reduce energy consumptions and emissions in pot lines by correlating machine data with meter records. Increasing environmental initiatives can be achieved by focusing on PTM energy efficiency during different activities in pot room. PTM play a significant role, and improving their energy efficiency can lead to several environmental benefits such as: Reduced Energy Consumption, compliance with regulations…Installing devices such as an energy meter on PTM crane will provide energy-related KPIs to employees, empowers businesses to make data-driven decisions, optimize energy usage, reduce costs, minimize environmental impact, and foster a culture of energy efficiency within the organization.

Moreover, roof emissions of fluoride gases are a challenge, especially during creeping where pots are in start-up mode [3]. Crossing data from SMART Crane with data from online gaseous fluoride analyzers can determine the contribution of PTM workflow on each operational activity on roof gaseous fluoride emissions. This approach benefits both operational performance and sustainability objectives.

Further steps for digitizing the Electrolyse workshop through the IIoT platform could involve additional steps such as:

- Data collection from other mobile equipment such as Anode Beam Raising Frane (ABRF), crucibles or pot controller system.
- Developing a further analysis-informed vision: with prescriptive analytics, and sector-specific analytics models.
- Cognitive: This could involve new ways of processing unstructured information, including imaging, video, and audio, as well as machine learning algorithms.

8. Conclusions

IIOT filed application platform SMARTCrane serves as a critical tool that supports Smelter operations and maintenance by providing comprehensive monitoring and analysis.

Firstly, this system enhanced the quality of operation realization by meticulously tracking and evaluating the execution of millions of elementary tasks. This level of scrutiny ensured that operations adhered to strict standards, fostering consistent quality and reliability in anode change processes.

Secondly, the system contributed to equipment availability by conducting detailed analyses of sub-functions and detecting performance degradation. This proactive approach enabled timely interventions to maintain equipment uptime and reliability, ultimately optimizing operational efficiency [1].

Moreover, the insights gained from the solution facilitated transparency between customers internal departments operations and maintenance. By uncovering previously unseen details and performance metrics, this collaborative effort led to informed decision-making and continuous improvement initiatives.

9. References

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