

# Industrializing Technology Solutions for Aluminium Reduction Lines: A Future-Ready Approach

Lucas S Oldfield<sup>1</sup> and Mike Pearman<sup>2</sup>

1, 2. Software Engineers

Rio Tinto Aluminium, Brisbane, Australia

Corresponding author: lucas.oldfield@riotinto.com

<https://doi.org/10.71659/icsoba2025-al025>

## Abstract

Implementing digital solutions in aluminum reduction lines is fraught with challenges stemming from extreme production conditions and intricate manual processes. Temperatures exceeding 900 °C, magnetic fields from currents over 100 kA, and pervasive dust complicate measurement device selection and integration, often requiring expensive engineering to align with recording systems. Manual tasks—measuring, interpreting for recording, and accurate data entry—demand rigorous training and validation, with errors risking disruptive process interventions. Transitioning from "paper and pencil" to digital systems is hindered by environmental stressors and device compatibility issues in such harsh settings. This paper proposes a hybrid solution: customized analog measurement devices, engineered for resilience and equipped with industry-standard Bluetooth LE, paired with an HTML5 web application. This approach ensures reliable data capture in adverse conditions, seamless real-time integration across devices, and reduced operator error, offering a robust, scalable path to digitize production while addressing adoption complexities.

**Keywords:** Measurement quality, Anode current density, Electrolyte temperature, Metal depth.

## 1. Introduction

Aluminum smelters operate under extreme conditions, including radiant heat sources from molten material temperatures above 900 °C, magnetic fields from riser and bus-bar currents exceeding 100 kA, and pervasive dust, which pose significant challenges to measurement processes. Manual methods, such as multimeter readings and paper-based recording, are susceptible to human error and lack robust validation, risking costly process disruptions. Transitioning to automated, algorithm driven systems can enhance data quality and operational efficiency, but it requires addressing technical difficulties in device durability, data integration, and long-term support. This paper outlines a framework for digitizing manual measurement processes, focusing on anode current density, bath dip, and bath temperature measurements.

## 2. Measurement Challenges in Aluminium Reduction Cells

Manual measurement processes in aluminium reduction cells are critical for process control but face significant limitations. The following subsections detail challenges and proposed solutions for three key measurements

### 2.1 Anode Current Density Measurement

Effective cell control hinges on monitoring anode current distribution, as non-uniform distributions can signal issues such as cracks, spikes, or inaccuracies in anode positioning. Traditional manual measurements using multimeters fall short, capturing only single-point data that misses high-frequency variations and lacks absolute timing information necessary to align with process control conditions. For example, a single reading might fail to detect peak currents

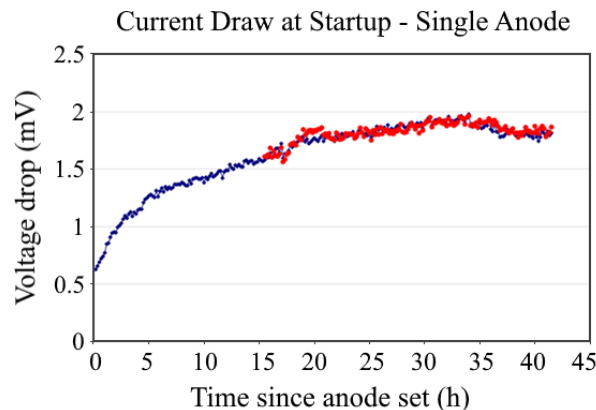
that indicate anode irregularities. By contrast, time-series data offers a dynamic view of high-frequency fluctuations and enables advanced statistical processing, such as Fast Fourier Transforms (FFTs), to uncover patterns and anomalies obscured by static measurements. This detailed insight is derived from cutting-edge technologies like Fiber Optic Current Sensors (FOCS) [1] or the anode rod millivolt (mV) method, both of which deliver high-resolution current data.

**Proposed Solution:** To overcome these limitations, a sophisticated data logging system that integrates multiple capabilities is required. This system should record absolute date-time stamps and high-frequency time-series data, while providing a versatile display showcasing single-point values, peak measurements, time-series plots, and FFT analyses. By incorporating live cell operating conditions – such as cell voltage and historical sample data – this solution empowers operators with a comprehensive, real-time understanding of cell performance. Together, the data logger, recorded data, time-series insights, and statistical tools provide the foundation for precise, data-driven decision-making. Figure 1 shows a time-series plot of a potential anode spike, along with a per stall representation of the cells anode current distribution.



**Figure 1. Anode current distribution. Left: User interface, Right: Rio Tinto CAT CD probe.**

Careful consideration must be given to the interpretation of anode current take-up after anode setting, when evaluating anode setting accuracy, which is made possible via the absolute date-time recorded against the measurement. Early intervention optimizes anode profile and improves cell stability. Anode adjustment thresholds are a function of time, relative to when the anode was installed, commonly known as “anode setting”, and must be calibrated to a plant anode current take-up profile. In Figure 2, red dots indicate data from the secondary measurement device, offline from 0–16 hours.



**Figure 2. Anode current (drop in stem in mV) from hour since anode setting.**

## 2.2 Metal and Bath Depth Measurements

Metal and Bath depth measurements are vital for tracking the levels of molten metal and electrolyte in aluminium smelters. The amount of metal held in the metal-pad influences the heat-mass balance and is used to project the next metal tap weight, while bath levels impact feed cycles based on the volume of molten material impacting alumina concentration. Errors in measurement can disrupt cell stability by removing or transferring incorrect amounts of material, leading to higher power use or a shorter cell lifespan.

Traditionally, operators measure bath levels by dipping a thick steel rod to the cathode's base. As the rod cools, bath material freezes onto it, marking the interfaces between molten metal and electrolyte. These frozen points are then measured with a tape or ruler. However, this method lacks precision. Operators must visually judge the interface points, often at odd angles against a glowing, hot rod, introducing errors. Additionally, cathode erosion at the tap hole can inflate the measured levels, further reducing accuracy.

To overcome these issues, a measurement trolley equipped with a digital slide rule is proposed. Operators position the steel rod against the slide rule, which provides a stable, flat surface for measurement. The digital slide rule quickly and accurately captures the interface points, calculating the metal level (lower interface) and bath level (higher interface) upon pressing the red capture button (Figure 3). Its alignment with the operator's viewing angle eliminates errors from ruler interpretation or transcription.



**Figure 3. Bath metal dip trolley. Left: interface and slide rule, Right: side view.**

The digital slide rule also logs the exact date and time of each measurement. This timestamp allows normalization of the bath level to account for changes in the Anode-Cathode Distance (ACD) due to varying cell conditions. The normalization follows this equation:

$$\text{Bath Level} = (\text{Total Height} - \text{Bath Interface}) \cdot \left( \sum_{[t_m-5min, t_m]} R_{\mu\Omega, i}(t) \right) \cdot \text{bath\_modifier} \quad (1)$$

where:

<i>Total Height</i>	Total measured height from the dip rod, mm
<i>Bath Interface</i>	Height of the bath interface, mm
<i>bath_modifier</i>	adjustment factor based on anode/cavity ratio, mm/ $\mu\Omega$
$R_{\mu\Omega, i}(t)$	Additional resistance parameter at time t, $\mu\Omega$
$t_m$	Absolute measurement time

In this equation, *Total Height* is the full measured height, *Bath Interface* is the bath interface height, additional resistances account for extra resistances in  $\mu\Omega$ , and *bath\_modifier* adjusts anode to surrounding cavity ratio. The sum covers a 5-minute window before the sample time to handle

sample capture lag. This time-stamped approach ensures bath level data reflects real-time conditions, improving process control and supporting stable, efficient cell operation.

By pairing the digital slide rule with a trolley, this solution refines the traditional dipping method, boosting precision and efficiency without requiring entirely new technology other than an industrialised slide mechanism capable of surviving the alumina dust, magnetics and impacts from hot material.

### 2.3 Bath Temperature Measurements

Bath temperature stability is crucial for evaluating pot thermal balance, typically maintained below 975 °C during normal operation. Manual multimeter measurements of thermocouples often fail to account for calibration tolerances or ensure temperature stability, as operators may rush to estimate endpoints. Compromised thermocouple insulation or open circuits further undermine measurement quality.

**Proposed Solution:** Automated measurement tools validate thermocouple condition, ensure temperature stability, and record metadata like date-time, improving data reliability. These systems compensate for calibration tolerances and detect faults, ensuring accurate temperature readings. Figure 4 demonstrates how an automated capture device determines a stable thermocouple value, ensuring full end-temperature before allowing the operator to move on.

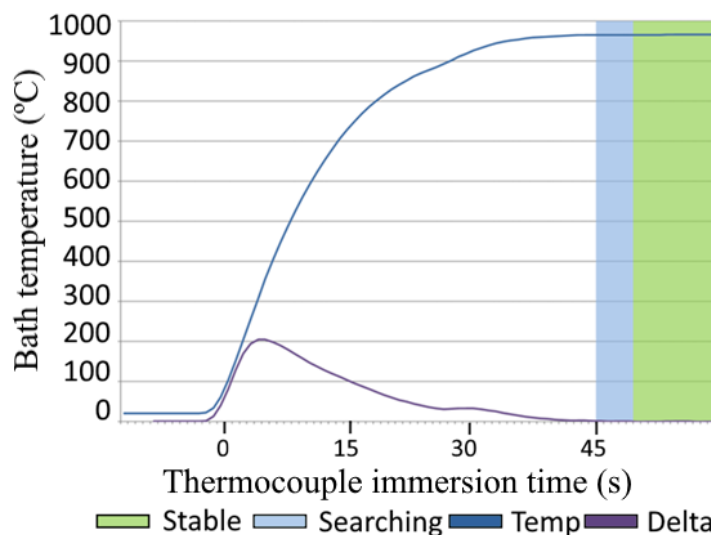


Figure 4. Bath temperature K-type thermocouple sampling.

### 3. Importance of Metadata and Validation

The quality of measurement data depends on its context and validation. A single sampled value without metadata – such as sampling device, username, date-time, or probe condition – lacks the context needed for validation or compensation. For instance, a faulty thermocouple with incorrect calibration can induce common-mode failures across multiple cells, detectable only through metadata analysis. Automated systems capture this contextual data, enabling regression analysis to identify group offsets and invalidate erroneous measurements, thus preventing unintended process control impacts.

**Absolute Date-Time Case Example:** Cell operating condition data invalidation – Corner block near taphole recently set causing localized cooling affecting bath temperature readings. Recording data values along with absolute date-time is essential for ensuring high measurement quality.

Local and real-time validation at time of measurement rejects false data from being used to make process control decision. Two methods are proposed to ensure the sensor data is valid at time of capture by assessing the probe input resistance along with the sampled data. The methodology differs between a thermocouple and voltage while using the same underlying electrical technology.

**Thermocouple Validation Case Example:** Thermocouple degradation data invalidation – An immersed thermocouple with a melted end still allows a temperature to be sampled. On removal of the thermocouple from the molten bath an online impedance check verifies that the thermocouple is now open-circuit, and invalidates the last sampled measurement.

**Voltage Validation Case Example:** Online Impedance surface contact validation – A voltage measurement is captured alongside an online impedance measurement between the two probe ends [2]. The purpose of the impedance measurement is to ensure that the probe ends are in contact with a low source impedance i.e. a bus-bar, cathode surface, anode rod or any internal/external component of a reduction cell.

An analog DC measurement circuit with coupled AC components for the impedance measurement allows both voltage sampling and contact validation performed simultaneously across the entire sampling windows. Figure 5 illustrates an AC coupled current injection while maintaining a low frequency DC voltage measurement. The AC frequency should exceed the DC measurement frequency by at least 100 times.

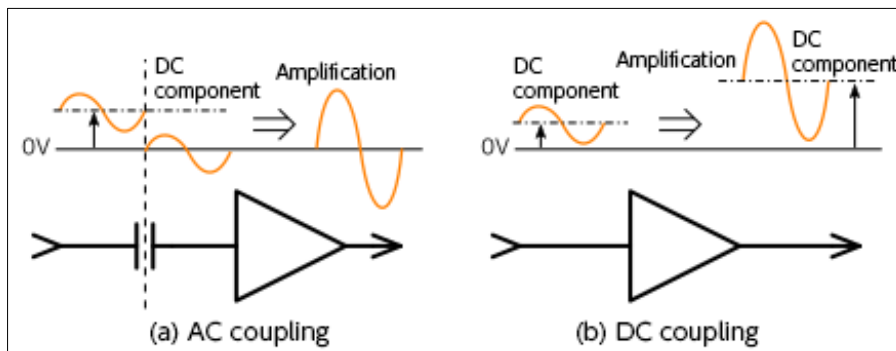


Figure 5. AC and DC coupling [3] of current and voltage measurements.

#### 4. Device Durability and Connectivity

Measurement devices in aluminum smelters must withstand extreme conditions, including molten material splashes, physical impacts, and pervasive dust. Furthermore, the rapid obsolescence of mobile devices, with lifecycles of 2–3 years, necessitates futureproof designs to ensure long-term system viability. Legacy systems, reliant on installed client applications developed for platforms such as Windows CE.NET, iOS, or Android, posed significant challenges. These systems required complex device and software management, involving multiple disconnected development and deployment pathways. Such approaches demanded extensive local site support for updates and maintenance, increasing operational costs and complexity.

In contrast, modern design practices leverage web-based applications built with HTML5, enabling seamless integration with measurement probes via Bluetooth Low Energy (BLE) and direct access to online systems through universally accessible web URLs. This architecture eliminates the need for platform-specific development, reducing the burden of managing disparate

software ecosystems. Moreover, HTML5 web applications support local data processing and connectivity, ensuring reliable operation in the harsh smelter environment.

The shift to modern system architectures also transforms software deployment. Legacy systems relied on manual processes, requiring on-site personnel to handle updates, as illustrated in Figure 6. By contrast, contemporary systems employ continuous integration and continuous deployment (CI/CD) pipelines, enabling automated updates and integration with production environments. This approach, depicted in Figure 7, minimizes manual intervention, enhances scalability, and ensures rapid delivery of new features and bug fixes. Together, these advancements provide a robust, future-proof solution for digitizing measurement processes.

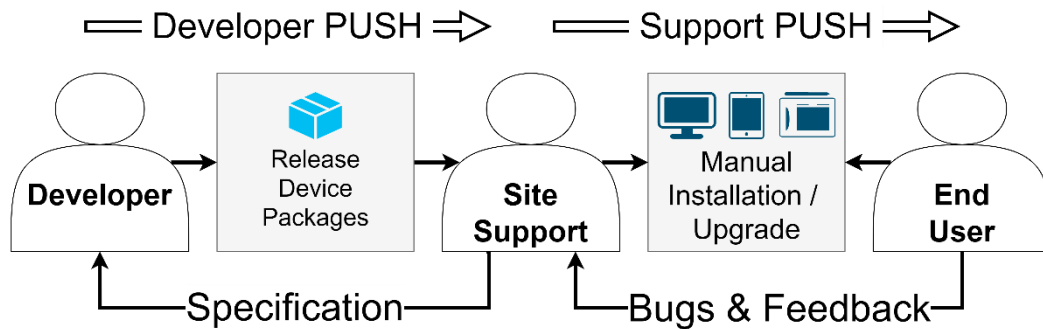


Figure 6. Legacy Rio Tinto production systems release pipeline.

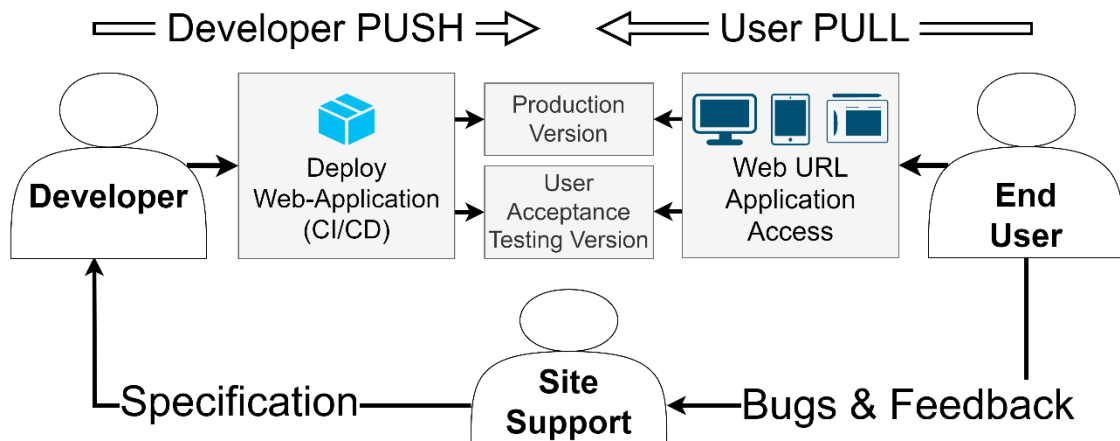


Figure 7. Modern Rio Tinto production systems CI/CD pipeline.

## 5. Proposed Framework

The proposed framework combines customized analog measurement devices with digital interfaces to digitize manual processes. Key components include:

- **Ruggedized Devices:** Engineered to withstand high temperatures, magnetic fields, and physical impacts.
- **Bluetooth LE Communication:** Ensures compatibility and future-proofing through industry-standard protocols.
- **HTML5 Web Application:** Provides a user-friendly interface for real-time data capture and integration.
- **Algorithm-Driven Validation:** Incorporates metadata and automated checks (e.g., contact resistance, thermocouple impedance) to ensure measurement quality.

- Continuous Development and Integration: Deliver the web-application via automated processes to ensure all end-users experience the latest version without site-support individual device management.

This framework addresses the technical difficulties of digitization, offering a scalable solution for aluminum smelters.

## 6. Conclusion

Digitizing manual measurement processes in aluminum reduction lines is essential for improving measurement quality and operational efficiency. By addressing challenges in anode current distribution, bath dip, and bath temperature measurements through automated systems, smelters can reduce errors and enhance process control. The proposed hybrid solution, combining ruggedized devices with Bluetooth LE and digital interfaces, provides a robust path forward.

## 7. References

1. Beijing SIO Technology Co., Ltd. (2025). FS210 Fiber Optic Current Clamp Meter. Available at: <http://sio-cn.com/212.html>, (Accessed: 1 June 2025).
2. Lazanas, A. C., & Prodromidis, M. I. (2023). Electrochemical Impedance Spectroscopy—A Tutorial, *ACS Measurement Science Au*, 3(3), 162–193, <https://doi.org/10.1021/acsmesuresciau.2c00070> (Accessed: 1 June 2025).
3. NF Corporation. (n.d.). Measurement Lecture: Input Coupling. *NF Corporation Technical Information*, (Accessed:20 June 2025) <https://www.nfcorp.co.jp/english/techinfo/measurementlecture/vamp/lecture9.html>.

