Alumina Refinery 4.0: Digital Transformation and IIoT

J Berge[1*]

[1] *Emerson Automation Solutions, 1 Pandan Crescent, Singapore 128461, Singapore*

jonas.berge@emerson.com

ABSTRACT

Alumina refineries strive to improve reliability, safety, productivity, and throughput as well as reduce maintenance cost, energy usage, and other operations cost, and to meet environmental requirements.

Therefore, alumina refineries are now adopting digital transformation of how the plant is run and maintained to meet these goals, changing from manual and paper-based tasks to more digital automation and software.

Alumina refineries are deploying a second layer of automation, beyond the basic process control, with wireless sensors, purpose-built data analytics, industrially hardened tablet computers for digital document and software forms, real-time locating systems (RTLS) for personnel and assets, and connected services using cloud and the Industrial Internet of Things (IIoT). Applications reviewed in this paper include: pump condition monitoring, corrosion and erosion management, instrumentation and valve condition monitoring, switchgear monitoring, emergency safety shower and eyewash monitoring, manual valve position verification, caustic leak/spill detection, and time stamping on sampling valves, as well as digital mustering and digital document access. Case studies include Brazilian alumina refineries which improved throughput using wireless rectifier temperature monitoring, and reducing risk of red mud overflow with wireless level sensing. A related example from an aluminium smelter in Dubai reducing energy cost with wireless compressed air consumption monitoring will also be discussed.

1. INTRODUCTION

Alumina refineries face challenges such as process reliability, maintenance and energy cost, safety and compliance, and production output. The workforce may already be stretched. Many of these challenges stem from manual and paper-based work practices.

Reliability and Maintenance Challenges

A plant may struggle with unscheduled downtime due to unexpected equipment failures or excessive scheduled downtime for turnarounds losing several days of production every year. Personnel struggle to keep up with the preventive maintenance schedule and may not be able to complete required tasks within turnaround window. The plant may have escalating maintenance cost due to repair, and opportunity cost for lost production. Some process equipment may see premature end of life. This may be due to a reactive maintenance culture. Loss of containment due to aging piping and vessels is another challenge. Moreover, plants are expected to improve without increasing headcount.

Energy and Emissions Challenges

Plants see energy consumption going up, but not knowing why, compounded by increasing or unstable energy price. Again, plants can't hire more people to help energy conservation.

Safety and Compliance Challenges

Plant safety record has improved but incidents still occur, there are near misses, and the response time is sometimes too long. It is hard to keep up with inspection and verification requirements in new HS&E directives. There are fines for non-compliance. Again, manpower cannot be added to perform these tasks.

Production Challenges

Manual operation cause production bottlenecks. Operating cost may be escalating. As staff are retiring the remaining personnel are left with more to do.

2. METHOD

In spite of having a control system, plants still have many manual and paper-based tasks. To achieve operational excellence, alumina refineries are now digitally transforming how the plant is run and maintained. Plants are now switching to new automatic, digital, software-based and data driven ways of working. In a digital plant the personnel can carry out their daily duties more effectively. A digital plant also enables digital turnarounds thanks to these digital transformations.

2.1 Maintenance and reliability tasks

Imagine no routine manual collection of maintenance, reliability, and integrity data from equipment like pumps with portable testers or time-consuming interpretation. Instead vibration, acoustic, corrosion, and other data is collected automatically to detect early signs of problems ahead, transmitted digitally, and analyzed by software to predict and distinguish between various equipment failure modes. This prediction drives maintenance and asset management along the ISO 55000 guidelines. Notifications of developing issues sent to your smartphone or tablet wherever you are. Any remaining manual inspection rounds are not by clipboard and paper forms, but instead a tablet computer and software. A central pool of domain experts, company or external, use the information to support plant personnel.

No delays waiting for an expert to mobilize to site or trying to explain a problem in the field from the phone in the office or via email. Instead two-way digital video and audio between field technician with wearable camera at site, and subject matter expert seeing the problem up close and live in software from another location.

No carrying of papers or returning to the office to pick up additional documents. Instead open up any procedures, drawings, and manuals etc. in software on a tablet or browse information from the company Intranet or the Internet on-the-go in the plant.

2.2 Energy management and loss control tasks

Imagine no manual collection of energy meter readings or tallying of consumption report. Instead consumption data is collected automatically, transmitted digitally, and overconsumption alarmed by software also generating the ISO 50001 reports. This could be further supported by equipment performance monitoring and steam trap health monitoring.

2.3 Health, safety, and environment management tasks

Imagine no walkie-talkie required for distress calls. Instead automatic detection, digital transmission, and alarm on safety shower activation or man-down, not moving, in operator software and locating software.

No ad-hoc visits to the plant to check if a manual valve was closed, dipping to see if tank is nearly full, or inspect for leaks and spills. Instead automatic detection, digital transmission, and indication in control room software, as well as use in interlocks. HS&E applications include for instance, detecting leaks of the caustic sodium hydroxide, and time stamping on opening and closing of the manual valves used for product sampling.

No mustering cards, paper lists, and walkie-talkie for headcount during emergency evacuation mustering and no search parties required to find missing personnel. Instead the geolocation of every person is sensed digitally in real-time and automatically tallied in software. Contractors are managed and with geofencing alarm issued if personnel wander beyond permitted work areas or into a high-risk area.

2.4 Production process tasks

Imagine no routine manual collection of operations data on clipboard and paper forms. Instead data is collected automatically and transmitted digitally to historian and operator software etc. Any remaining manual rounds are instead by tablet with software.

No paper notebooks for jotting down near misses, incidents, hazards, and maintenance needs etc. Instead notes and digital photos of incidents, hazards, leaks, and damaged equipment is captured digitally on tablets with software and shared with relevant parties.

Tagging along experienced staff is not the only way to teach newcomers how to perform manual tasks. Field operators can also learn new tasks in a very immersive virtual plant environment with virtual reality.

3. RESULTS AND DISCUSSION

Alumina refineries are deploying additional digital operational infrastructure as the enabler for digital transformation of work practices for many tasks around the plant to achieve operational excellence

3.1 Digital operational infrastructure

Existing operational infrastructure in plants include plant historian, the control system, underlying field instruments like transmitters, flow meters and valves. The digital operational infrastructure is expanded with digital automation to transform how work is carried out in the plant (Figure 1).

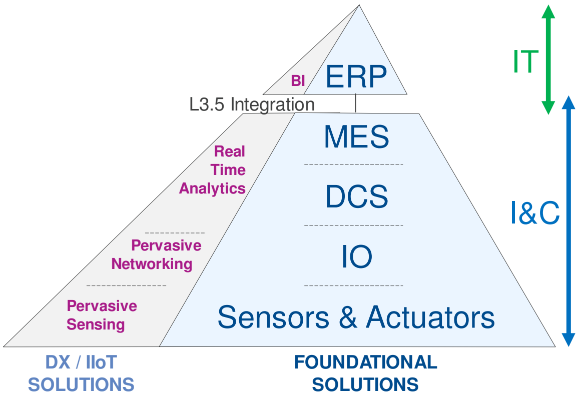

Figure 1. Digital Operational Infrastructure

There is no need to replace the existing control system. The operational infrastructure is compatible with existing automation. There is no need to add another analytics platform layer, the existing historian can be used as a platform.

The principal building blocks for expanding the digital operational infrastructure are:

- Mobility
- Predictive analytics
- Pervasive networking
- Pervasive sensing
- Connected services

Mobility

In a digitally transformed plant, work by everyone from the plant manager down is data driven. Each person needs data relevant to their responsibility to do their job better. For instance, the reliability manager has a dashboard very different from the safety manager and they don't get the same notifications (Figure 2).

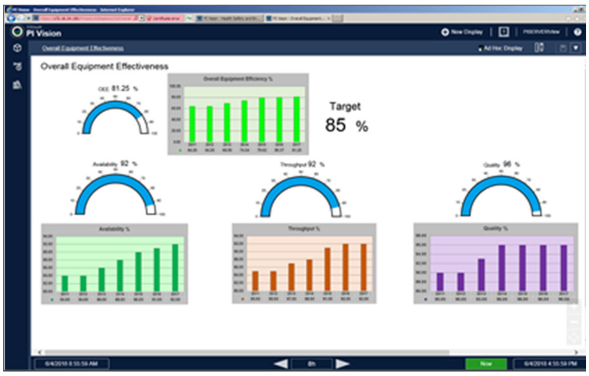

Figure 2. Dashboard

A key success factor for digital transformation is that the information must be easily accessible in a timely manner. In the infancy of digital transformation of instrument and valve maintenance practices more than 20 years ago, the software was installed on a computer located in the control room or an equipment room where instrument technicians could not easily access it. It quickly fell into disuse. Instead data must go to the desk and pocket of the person responsible. For instance, predictive instrument alarms and information goes to the laptop and smartphone of the instrument technician.

Dashboards and alarms are generated by mobility software using information from underlying analytics apps like equipment condition monitoring. Dashboards contains KPIs specific to the person's responsibilities displayed on tablet computers or smartphones, making information immediately available wherever you are, be it in a meeting in the administration building, in the canteen, or on your way to or from work. Tablets and smartphones are available in industrially hardened models for use in the plant.

Predictive Analytics

Many digital transformation solutions are simple monitoring such as corrosion (metal loss), temperatures, and pressures that need no analytics. Predictive equipment analytics apps which encode subject matter expertise are used for performance and condition monitoring of complex process equipment using multiple measurements to anticipate problems, allowing failures to be averted. Such equipment include compressors, blowers, fans, pumps, heat exchangers, cooling towers, and air-cooled heat exchangers. Raw data from sensors is distilled into actionable information. When problem arises the technician already knows what to do and what to bring before going to the field. And it is not just vibration, the fault models also uncover early signs of trouble and distinguishes between many types of equipment specific failures. The disruptive 'learning periods' associated with Machine Learning technologies is not required. Equipment analytics can feed into level 4 enterprise dashboards KPIs, Business Intelligence software, and ERP work order management. Software provide predictive analytics to predict failure as well as prescriptive analytics recommended action. The analytics software can be installed on servers on-premises or on virtual machines in the cloud. A layered open architecture has real-time analytics at the sensor level, edge analytics done in higher level devices and servers, feeding up to big data analytics at level 4.

Web-based analytics apps are platform agnostic, not depending on any particular control system or historian. The plant's existing historian remains in place for Big Data storage, it need not be replaced by another middleware platform, and there is no need to add another middleware platform thus protecting the plant's investment and keeping the administration cost low. The analytics uses data aggregated from multiple sources; the new wireless sensors, existing sensors, package unit PLCs, control systems, safety system, machinery protection systems, intelligent device management (IDM) software, and any historian or future platform etc. through OPC-UA regardless of vendor. Conversely, analytics from equipment apps can feed into other analytics apps for the whole unit or plant. Similarly, information can be integrated in augmented reality (AR) visualization solutions.

Use apps purpose built for real-time equipment monitoring; easy for maintenance and reliability professionals including managers, engineers, and technicians to use with overview dashboards, alarm summary with simple health index, priority, plain text problem description, and ability to zoom into detail and history trend to see accelerated degradation and estimate remaining life (Figure 3).

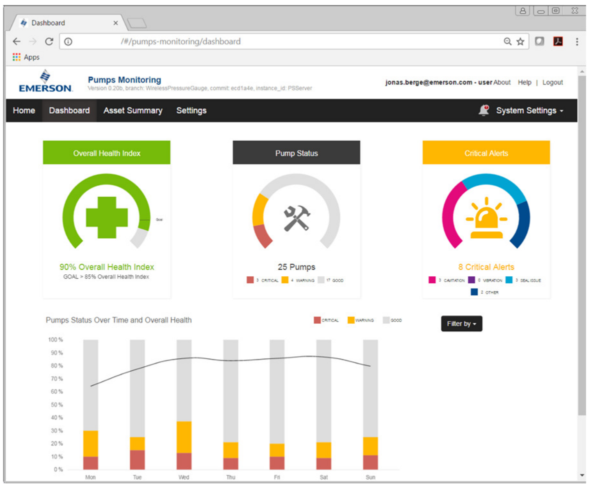

Figure 3. Easy-to-use analytics apps

Some software providers have pre-built years of process equipment experience and domain knowledge is built into the apps. Apps for steam trap analytics, pump, and heat exchanger analytics help drive maintenance management. The analytics uses verifiable first principle models and statistical algorithms to detect signs of developing equipment issues, predicting failure and providing an early warning on these leading indicators so breakdown can be prevented. These apps are pre-engineered based on years of experience so no long algorithm learning periods are required, just capture the baseline. These are readymade apps, no custom programming or code maintenance required. Digital transformation need not cost many million dollars.

Pervasive networking

Data-driven practices requires sensors to collect the missing data. It would be impractical to hardwire hundreds or thousands of sensors using 4-20 mA and on-off signals point-to-point. Plants built with FOUNDATION fieldbus networking can simply add instrumentation to existing field junction boxes with minimal wiring to the sensors. All plants should deploy wireless infrastructure for sensors.

Plants deploy a plant-wide wireless sensor network and optionally also a wireless LAN (WLAN) infrastructure depending on which operations tasks will be digitally transformed. The wireless network infrastructure consists of wireless gateways for the wireless sensor networks, and wireless access points for the Wi-Fi network as the central nervous system of a digital plant. The wireless gateways can be embedded inside the wireless access points when WirelessHART and Wi-Fi are deployed together. Since these networks are used for operational functions, both wireless networks integrate with the control system, historian, machinery protection system, safety system, and other operations systems.

Real-Time Locating System (RTLS) for geolocation of people and assets including digital mustering headcount, rescue locating, and geofencing in restricted or high-risk areas, wearable video collaboration (Figure 4), using handheld, and tablet computers in the field to assist in various tasks such as retrieving maintenance history or documents, data collection and reporting, are examples of functionality which make use of industrial Wi-Fi at level 1 (L1). The wearable ID tags used for location detection optionally include a panic button and sensor for no movement (man-down).

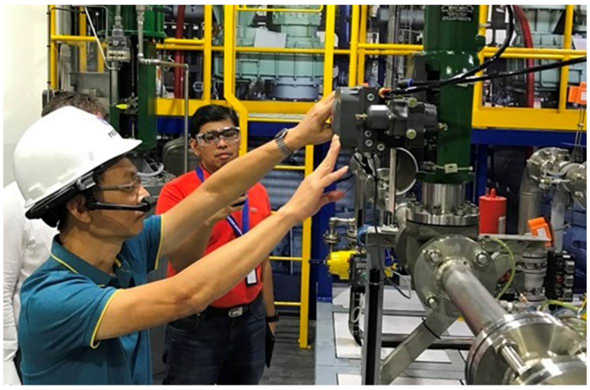

Figure 4. Wearable video conferencing

Pervasive Sensing

Data-driven work practices starts with the raw data from sensors. Sensors bridge the gap between the physical and digital world. Without sensors there can be no analytics and no Big Data. Process equipment like pumps, compressors, heat exchangers, blowers, cooling towers, air cooled heat exchangers, manual valves, tanks even steam traps have process sensors but usually have no sensor for condition monitoring. This equipment is instrumented with additional sensors to cover these missing measurements thus yielding smart connected equipment. The automatic data collection is much faster, providing early detection of "markers" of developing problems, thereby making the asset management more predictive, and far more productive.

Wireless sensors often take the place of mechanical instruments, portable testers, and clipboards. Wireless sensors include pressure, flow, level, position, on-off contact, vibration, temperature, corrosion, acoustic noise, electric power, and sand as well as level switch which can be deployed without having to lay more cable and installing more I/O for 4-20 mA and on-off signals. Control valves and flow meters not already digitally integrated are fitted with wireless adapters. Many of these sensors are non-intrusive or reuse existing process connections meaning they can be installed while the plant is running without shutting down the process. Wireless sensors can be deployed without opening cable trays or junction boxes avoiding the risk of damaging existing cable. Some transmitters such as for vibration include edge analytics pre-processing the raw data.

Connected services

Often there is not enough experts at site. Some plants opt for an IIoT-based solution with subject matter experts in a central location monitoring equipment across multiple sites. It can be the company's own fleet management center to manage process equipment in the company's fleet of plants around the world, or it can be a third-party connected service provider monitoring process equipment in multiple companies' sites globally. The service provider's IIoT center has a pool of experts in the areas of rotating machinery vibration, control valves, analyzers, static process equipment and steam traps to guide the personnel at site with expert advice.

In the cloud, analytics software monitors the equipment in the plant. Staff extracts reports listing equipment condition and what actions are required. The reports are reviewed by domain experts before sending to plant personnel. The report format has been created specifically for each kind of equipment including the relevant information allowing plant personnel to act immediately. The reporting frequency depends on the type of equipment.

In a new business model for connected services, instrumentation such as acoustic and vibration sensors are included as part of the subscription fee. That, is little or no upfront investment for the plant.

For process equipment like pumps, compressors, heat exchangers, cooling towers, air-cooled heat exchangers, fans and blowers, sensors installed on the equipment in the plant send data into the cloud. If the equipment already has instrumentation, this data is used. Often there is insufficient data for condition monitoring in which case wireless sensors are added for the missing measurements.

For digitally connected devices like control valves, flow meters, level transmitters, as well as the control system additional sensors are not required. These devices are digitally networked through to the cloud.

3.2 Digital transformation from the aluminium industry

Alumina refineries and smelters around the world are already digitally transforming how work is done.

Switchgear monitoring

An alumina refinery in Brazil was operating their rectifier stacks well below the rated 100kA due to operating temperature uncertainty because they were relying on infrequent IR thermography for temperature checks.

Surface Acoustic Wave (SAW) temperature sensors were installed on 9 rectifiers, providing continuous temperature measurement at the control switch incoming and outgoing buses.

The sensors are self-powered requiring no power cables or signal wires thus avoiding potential arcing and flashover. The data is transmitted from the access point in the field to the monitoring system using a digital communication network allowing any increase in operating temperature is captured early. Despite of the high magnetic field, the wireless sensors and digital communication network functions flawlessly.

The solution allowed a 10% increase in operating current and total material throughput without fear of catastrophic failure as the gear is continuously monitored.

Energy management and loss control

An aluminium smelter in Dubai had problem with the compressed air consumption. Air demand is varying through the day but they don't know why, where, or when air consumption increases because they relied on daily manual compressed air flow meter readings. Because of this they were unable to optimize air usage and production.

20 flow meters with wireless transmitters on the compressed air headers continuously measure the compressed air consumption of each plant area covering a total plant of 480-hectare. The wireless transmission is unaffected by the extremely strong magnetic field. The measurements are integrated with the MES system which allows the company to know in which area and at what date/time air consumption increases. Based on this, each area is reviewing its processes and procedures to optimize air usage. The same wireless network is also used for temperature monitoring in substations.

The solution has eliminated the need for daily visits to air flow meters. Continuous monitoring shows spikes and trends in air use, allowing improved management. They now have a better understanding of the compressed air consumption in the plant with improved ability to plan and control cost. As a result, they have reduced energy use by 13 percent and has created a plant-wide awareness of the importance of compressed air.

Overfill and spill

An alumina refinery in Brazil had problems with their red mud stacking residue storage area. In the past level inspection and was manual, and any safety valves only opened after inspecting in person, which is infrequent. There is a risk of overflow into the surroundings environment; an environmental hazard.

Level switches with wireless transmitters were installed in multiple points around the red mud basins to detect high level at critical points. Due to the dynamics of red mud stacking a mobile sensing solution was provided such that the level sensors can be moved around as needed. Wireless sensor networks provide the required mobility. Running wires to sensors in such a geographically large site, and moving the sensors and cables around when needed, would not be practical, so a wireless sensor networking infrastructure was deployed instead. Other types of sensors now share the same wireless network.

As a result, they were able to reduce the risk of red mud overflow thus protecting the environment.

4. CONCLUSION

Alumina plants are striving to achieve operational excellence. Digital transformation of how the plant is run and maintained is a new initiative to achieve this. Therefore alumina plants expand their digital operational infrastructure with more software and sensors. As a result alumina plants have managed to improve production, energy efficiency, safety, as well as reliability.

5. REFERENCES

"*Enabling electrical power asset predictive maintenance with the IntelliSAW CAM™ platform*", Jonathan P. Murray – Emerson, 2016 Emerson Global Users Exchange, Session ID: 6-10309

"*Dubai Aluminium ('DUBAL') implementation and benefits of plantwide wireless compressed air flow monitoring system*", Ahmad Dowaymeh – Dubal and Nadeem Memon – Emerson, 2013 Emerson Global Users Exchange, Session ID: 12-4642, 2013

"*Monitoring of the basins of RMS using Wireless Sensor Network*", Márcia Ribeiro - Alunorte, 2010 Emerson Global Users Exchange, Session ID: 12-205, 2010