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Application of digital twin technologies in mining industrial branch

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Abstract. Digital Twin technology became one of most popular and modern information technologies and at the same time operation technologies in the roadmap of increasing effectiveness and performance of industrial enterprise. This is already solid trend in many different scaled industrial facilities which belong to different industrial branches. This paper has objective to present how digital twin technology can help in optimization and effectiveness increase for mining industry. We will try to review the whole process and show advantages of digital twin technology implementation in dedicated sector or stage of mining and mineral beneficiation processes such as mine planning, mine operations, rom processing, ore processing, concentrate stockpiles managing, concentrate transportation and concentrate processing facilities such as refineries or smelting plants.

1 Introduction

Digital twin technology is already well established during past decade and have clear scientific theory, concept, and principles. Developed inside the trend of Industry revolution 4.0 and Industrial Internet of Things this technology absorbed most of scientific technologies and engineering solutions famous in engineering sector and became mutual framework and informational environment to connect and use all these solutions and technologies together for increasing of performance of industrial factory or plant.

There are a lot of investigations and research related to the digital twin technology conducted and presented also by authors of this paper [1,2,3,4,5] but authors previously mostly focused on implementation of these technologies in oil and gas, refinery and petrochemical, gas-chemical sector. However, several review research have also been done in mining sector to present most perspective advanced IT-solutions which now are effectively embedded to the digital twin infrastructure [6] and provide the high-level digest for digital twin trends which can be applied also in mining industry [7].

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As the next step, purpose of this paper to dive deeper and propose clear scientific-engineering plan of digital twin technologies implementation in mining sector focusing on exact applications of this industrial branch.

To find proper methodology and solutions for digital twin technology application we firstly need to find out and understand what most critical challenges are in operation of mining facility which can be driven for improvement or to be eliminated at all. These are usually more or less general for all industrial branches however some key differentiators are specific for specific industrial branch. These challenges are combined for clear illustration into below Figure 1.

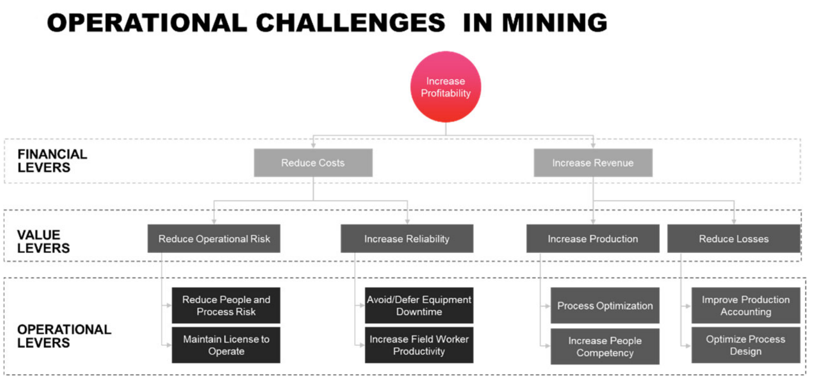

Fig. 1. Operation challenges and improvement roadmap in Mining industry.

People and process risks are mostly related to alarm noise and floods which make it impossible for operators to see genuine alarms, to assets being continually operated outside of safe operating windows impacts equipment health and operator error and equipment damage which can lead to 75% of all abnormal process situations.

Maintain license to operate is related to insurance requirements around alarm system audit and improvement, regulatory requirements mandate demonstrable practices around safety system audits, regulatory requirements around capture of environmental and safety related inspection data.

Avoiding or deferring equipment downtime is related to maintenance of mining equipment which averages 30-50% of operating costs, break-fix maintenance which can account for 92% of shutdowns, resulting in unplanned downtime, costing mining industry $60B/yr, extreme pressure on assets to from mineral boom-bust cycles.

Increasing field worker productivity is related to the decreasing number of experts on-site which makes troubleshooting difficult and issues take longer to resolve, lack of hands-on learning experience for incoming workforce and lack of timely availability of field data to make decisions within organizations.

Optimizing production processes is related to suboptimal response to process disturbances which cause large losses, large volume of control assets that require consistent monitoring, lack of insight into economic impacts of controls decisions, poor controls coordination leading to lost profitability.

Increase people competency is related to high operator turnover where average tenure for employees age 25-34 is 2.8 years, aging operations staff approaching retirement, losing by industrial plant ~$8B per year due to operator-induced abnormal situation.

Optimizing process design is related to multiple tools needed for various simulation and process design requirements, process simulation models which are too slow for real-time digital twins, engineering teams which need flexibility to switch between simulation packages.

All these operational challenges are being resolved using digital twin technology the methods and results of which will be described in the next section.

2 Methods and results

Digital Twin technology applied in mining industry conceptually does not introduce new digital twin layers or representations. Focusing on process, assets, and people (worker) safety and efficiency optimization it refers to the same principal solutions already described and implemented [8,9,10].

Applying asset performance management (APM) digital twin technology, mining facility can achieve targeted results in operation and eliminate most of the challenges defined and described previously (refer to the Figure 2).

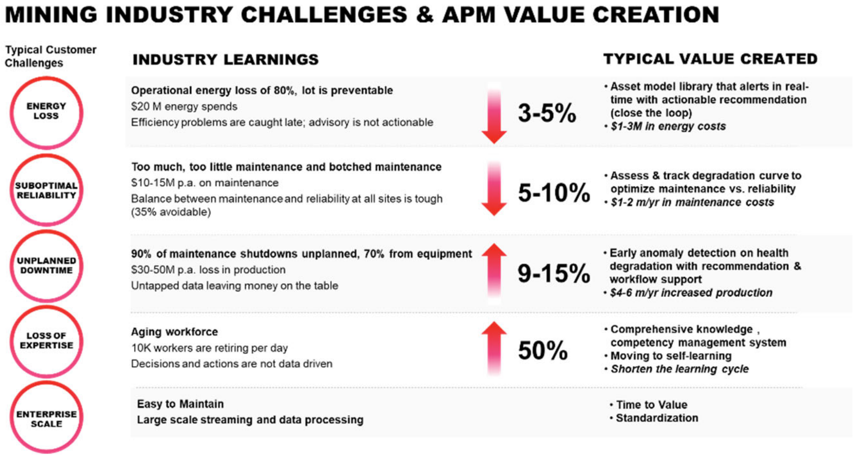

Fig. 2. Mining industry challenges & APM digital twin value creation.

APM digital twin works as an aggregator of data to make it useful for making decisions. This data is not just data from assets in the field, but also integration of data from surrounding enterprise systems like historians, computerized machine maintenance systems (CMMSs), and data from field operations. The goal here is to use all these data to have a complete view of operations produced by the highlights and insights from advanced analytics. In this holistic view companies should be able to measure their asset and process performance in real time. See how well they are doing regarding their specific key parameters indicators (KPIs) or overall equipment effectiveness (OEE). Get notification when assets or processes start deviating from normal behavior or present and anomaly. Get sufficient information to identify the source of such deviations and a clear path of action to bring them back to optimal performance.

APM digital twins are all about efficient use of data, timely notifications, and clear next steps to sustain performance. This strategy allows organizations to reduce their operational risk as they have a continuous measure and visibility of their operations and can adjust and make changes earlier. They also improve efficiencies in their operations as they can identify bad actors in a more efficient manner and kick off earlier corrective actions. This leads to assets that can be taken to their technical limits of operations for extended periods of time without compromising their integrity. This directly support production goals by pairing with dynamic maintenance asset strategies that are more efficient at identifying and solving issues.

Let's take a look at this simplified schematic that will take us from raw data to the detection and management of events (Figure 3). Events here refer to warnings of potential failures or deviations from normal operational states.

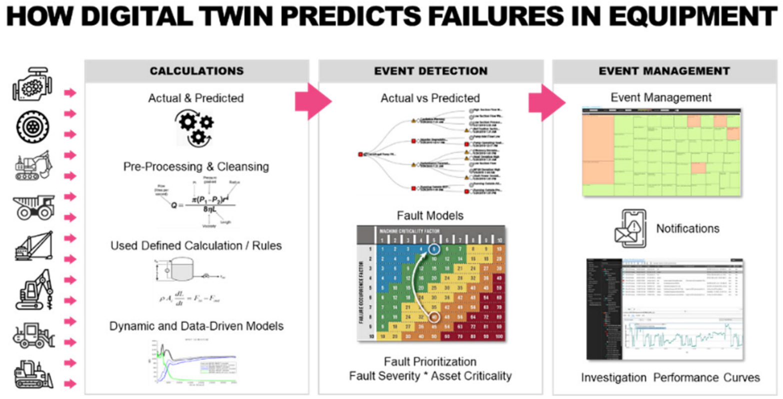

Fig. 3. APM digital twin running principle.

First, in order to use all these aggregated data, we need to prepare it, what data scientists call data cleaning, which is essentially a pre-processing step to eliminate missing data points, remove bad readings, normalize the data if it has different units, scales, etc. This is essential for models to work properly. As mentioned before these could be performance models that quantify efficiency, fault models that detect scenarios based on pre-define limits, or machine learning models that detect correlations between variables and patterns.

So this way using the performance models we can compare the actual performance of the equipment versus the expected performance, using the fault models and current operating conditions will decide what the performance should be to raise or not a particular fault.

If a fault is raised, all this data an information goes to the event management infrastructure, here notifications are generated and visualized with the fault variable. Also all the events generated for the fleets you may have are organized and visualized based on priority depending on the criticality of the event. This is very important, because it helps subject matter experts (SMEs) and operators focus in the most important work to be done first and efficiently navigate all the warnings and alarms they need to work on. To further expedite this process, we provide historical trends to understand why alarms are being generated and the main contributors of such alarms, this last one is a natural outcome of machine learning models that allow the easy identification of signals triggering specific behaviors. Finally, in addition to all the features that allow the investigation of problems, we associate faults with recommended actions that are included in the notifications that go to the rest of the enterprise systems so this way maintenance teams can solve the problem with the correct guidance in a timely fashion.

And assets library for mining APM digital twin can be applied to whole process of product extraction as illustrated in Figure 4.

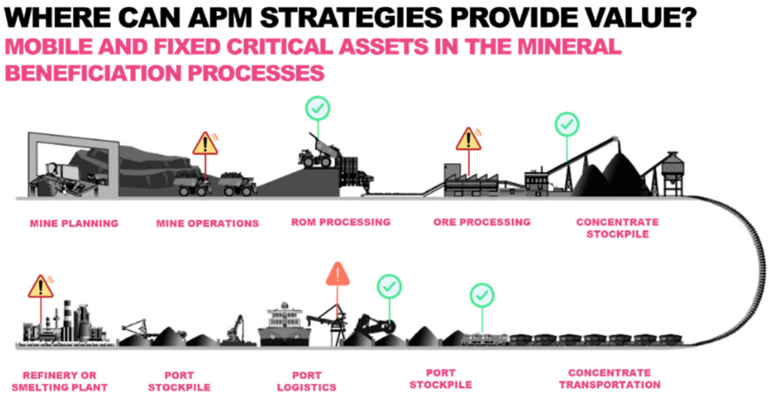

Fig. 4. APM digital twin application in whole mining and minerals beneficiation chain.

Another digital twin representation focused on process control optimization is based on well-known advanced process control (APC) and model-predictive control (MPC) solutions. But here digital twin technology presented allows to embed process control application into digitization infrastructure and to synchronize in online running mode with physical mining facility. Implementation of APC digital twin provides following effectiveness increase results (refer to Figure 5).

APC DIGITAL TWIN IN COPPER CONCENTRATOR PROCESSES

Processs	% Utilization	Results
Crushing	80% – 95%	Less equipment stops. Production stabilization -> **increased production**
Unitary grinding	85% - 95%	**3% - 6% higher throughput**, 3% - 11% less Specific Energy Consumption (SEC)
Conventional grinding	80% - 90%	**3% - 7% higher throughput**, 4% less SEC
SAG grinding	95% - 100%	**Between 2,3% and 5,8% higher throughput**, 0,3% to 2,4% less SEC, strong stabilization of bearing pressure
Flotation	60% – 80%	Process stabilization, better flotability condition, **more than 1% increase in copper recovery**
Thickening	60% - 80%	5% - 10% less variability in slurry % solids, almost no high torque events
Roasting	90% - 100%	Improved process continuity and temperature stabilization inside roaster. **Production increased by 38%**

Fig. 5. APC digital twin value creation in mining and minerals beneficiation chain.

Figures 6 and 7 illustrates tangible and intangible benefits of APC digital twin application.

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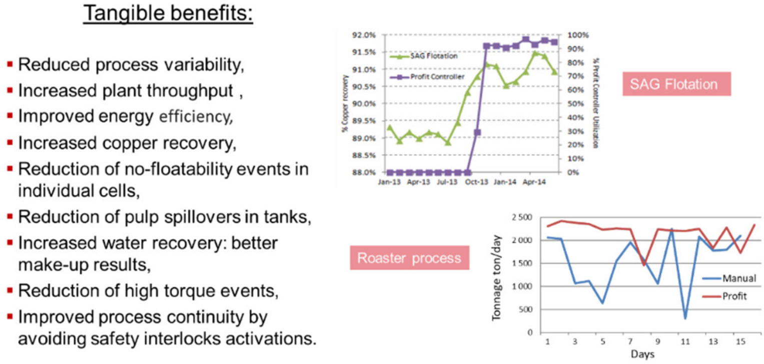

Fig. 6. Tangible benefits of APC digital twin application in concentrator plants.

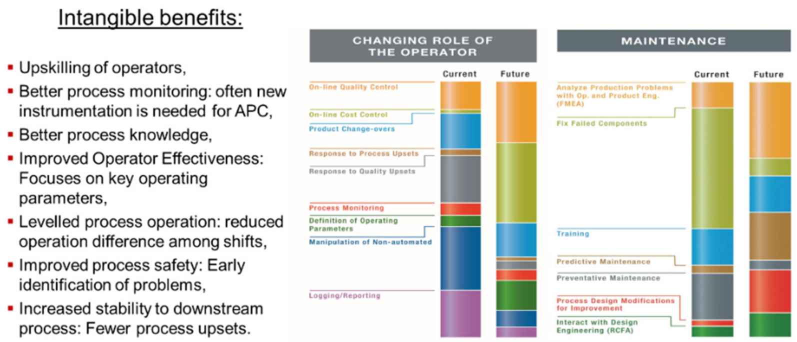

Fig. 7. Intangible benefits of APC digital twin application in concentrator plants.

3 Conclusion

Application of digital twins in industry generally and in mining, mineral processing branch namely brings tremendous source of new mechanisms of optimization and new ideas for effectiveness increase which are not discovered or not conceptually implemented yet. Vivid example is unique opportunity to combine different digital twin representations and find the additional values from the process of their interaction. For example below is one of combination which currently implemented in one of existing mining facilities (refer to Figure 8).

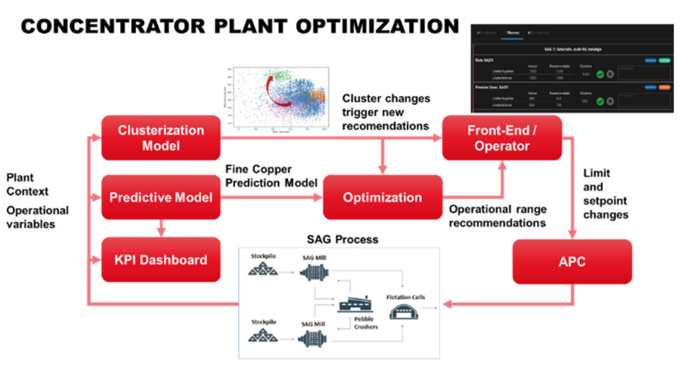

Fig. 8. Concentrator plant optimization based on combination of running digital twins.

This is the general architecture, consisting in a customized machine learning recommendation system, from back-end to front-end developed with open-source software and tools. At the bottom center, with the Semi-Autogenous Grinding (SAG) process in concentrator plant. Plant has two SAG mills with ball mills for secondary grinding, and a centralized pebble crusher plant, that recirculates the crushed pebbles back to the ball mills for the most part. Then there is a flotation stage with rougher and scavenger floating cells. And all this equipment interacts with APC digital twin deployed in digital infrastructure. What we do is feed the plant context and operational variables into our predictive and clusterization models. The predictive models are gradient boosted models that aim to predict the plants processing capability at any given time and are trained with historical data. So: given those things we can't control, and the current values for the things we can control, we ask ourselves: what does our mineral rate capacity look like? what copper recovery can we expect? The clusterization model uses key process variables to identify operating modes. These variables are stockpile conditions, granulometry, crushed pebble recirculation, mill lifter wear, among others. If we detect a cluster change, we trigger an optimization routine that aims to adapt to new conditions using Markov-chain Monte-Carlo to find optimum ranges and setpoints for APC applications that maximize fine copper production. The output of the optimization stage is a set of recommendations that we display to operations. They validate the recommendations, which we accompany with time series information and cluster descriptions, and any validated recommendations are automatically implemented to APC applications involved. We also monitor model performance and impact of implemented recommendations with a KPI dashboard and generate executive reports for stakeholders.

A few key results of this combination are shown in Figure 9.

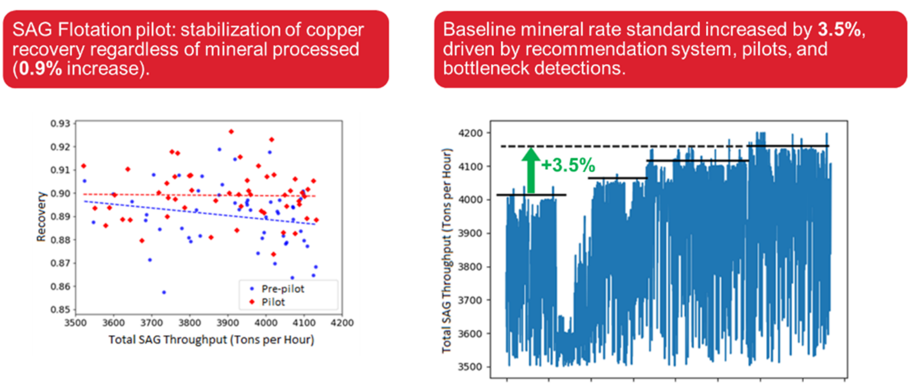

Fig. 9. Key results of combined Digital Twin for Concentrator plant.

On the left-hand side, we show results for our initial flotation model pilot, which generated recommendations for flotations cells, aiming to maximize copper recovery. The chart shows copper recovery vs SAG rate over a 2-month period, with pre-pilot values in blue and pilot values in red. You can see we stabilized recovery across all SAG rates, attributed to the dynamic ranges used in APC digital twin, in contrast with sticking to static operational standards. Overall, we saw an average increment of .9% in copper recovery. On the right we have a time series of SAG rate spanning over one calendar year, and showing how incremental use of the recommendations application, driven by pilots as well as bottleneck detections, led to a 3.5% increment of baseline mineral rate.

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