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Outlining a Roadmap for the Deployment of a Digital Twin System for the San Xavier Mine Laboratory

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Implementing a Digital Twin at the San Xavier Mine Laboratory (Sahuarita, AZ), requires a network redesign with a robust architecture. The goal is to create an ecosystem in where all personnel and equipment can be monitored in real-time from the University of Arizona campus, visualizing the site in a digital terrain model. A wireless mesh will help to test robots with autonomous features. Expected outcomes include data retrieval and analytics, the evolution of communications and safety protocols, tele-operation, and an innovated approach for managing the site with new supervision challenges. A timeline with expected commissioning benchmarks is also included.

INTRODUCTION

In recent years, computer technologies for underground mines have experienced a major development in terms of versatility, effectiveness, and information management. Internet of Things can be found virtually everywhere, allowing conventional equipment to provide essential data for analysis and process improvement. Combining hardwired and wireless network configurations, it is possible to overcome the classic limitations of data/signal transmission in underground works, and in turn boost up operations with supervision, surveillance teleoperation and autonomous systems for the benefit of safety, productivity and cost reduction. From all these solutions, Digital Twins appear as a highly useful solution for not only observe operations remotely, but to actively participate in the excellent of operations. Implementing Digital Twin technologies may sound easy in theory, however it may take several steps and trial attempts for a seamless configuration, until extending our reach from a control room to a remote mine operation, and effectively improving the overall performance of equipment and personnel, while keeping safety levels and achieving production goals. This paper center in the required steps to implement from scratch a Digital Twin system for the supervision of the San Xavier Mine Laboratory, located in Sahuarita, AZ, from the University of Arizona Campus, in Tucson, AZ. Several challenges include identifying the proper technologies required, the network-to-network communications protocols, the supervision, safety of operations and the adequate asset management, so that the model produced could be sustained effectively, and later scaled to planned future expansions in the site.

THE SAN XAVIER MINE LABORATORY

With one of the nation's most sophisticated research hoisting systems, two declines for access of rubber-tired vehicles and legacy rail haulage access, the mine features four levels of underground workings to a depth of 250 feet. This unique site has attracted projects critical to national defense, geosciences, mine safety and miner rescue. (LIMR (2023). In 2020, a major expansion included a decline with a portal of 15 × 15 feet section, and a total projected length of 1,000 feet. In recent times, many sensors have been placed along the excavation, opening the possibilities of remote reading of changes in the rock behavior, associated with temperature variations, micro-displacement of the host rock, and potential for asset and personnel follow up. Drones have also successfully been sent along the decline and through the existing levels of the mine.

TOWARDS A DIGITAL TRANSFORMATION

The process of implementing a Digital Twin in an underground mine brings up three major key points (Miskinis, 2018): 1. Improving Mining Machinery Productivity; 2. Developing Digital Twin Mining Simulations; and 3. Automating Ore Extraction Processes. Although the completion of these steps may take time and investment, as well as training for the operators, it becomes a favorable proving ground for testing technologies. At the beginning, it may encompass controlling one machine at a time; however, given the nature of digital technologies, this can be done either at the line of sight, from the safety and convenience of a site control room, or from a remote place, such as the University campus, 23 miles away from San Xavier.

BENEFITS

According to Nemes (2023), digital twins offer a range of advantages to the mining sector, revolutionizing traditional practices and enabling more efficient and sustainable operations. Digital twins:

- Enable real-time monitoring and predictive maintenance in mining equipment, allowing operators to assess performance, detect anomalies, and prevent breakdowns.
- Enhance safety and risk mitigation by creating virtual environments for training, simulating mining scenarios, and operate equipment remotely.
- With the addition of simulations, they can optimize mining processes like drilling, blasting, and ore extraction, improving productivity and reducing waste by virtually testing parameters.
- Help to improve mining sustainability by integrating real-time environmental data, optimizing resource utilization, reducing emissions, and mitigating environmental footprint through optimization of air quality, water consumption, and energy usage.
- The supply chain is simplified by projecting market conditions, client preferences, and price variations, synchronizing supply, demand, inventory tracking, and logistics management.

According to Andritz (2023), the creation of a digital twin gives a deeper understanding of real-time processes. It offers valuable insights into how to improve efficiency and product quality or reduce maintenance and waste. Digital twins also enable virtual support, without an engineer having to be on site. Experiments can be carried out with much less risk and a lot more return on investment.

Figure 1 shows a conceptual layout for an industrial digital twin, where the components for decision making rely solidly in technological readiness, and situational awareness.

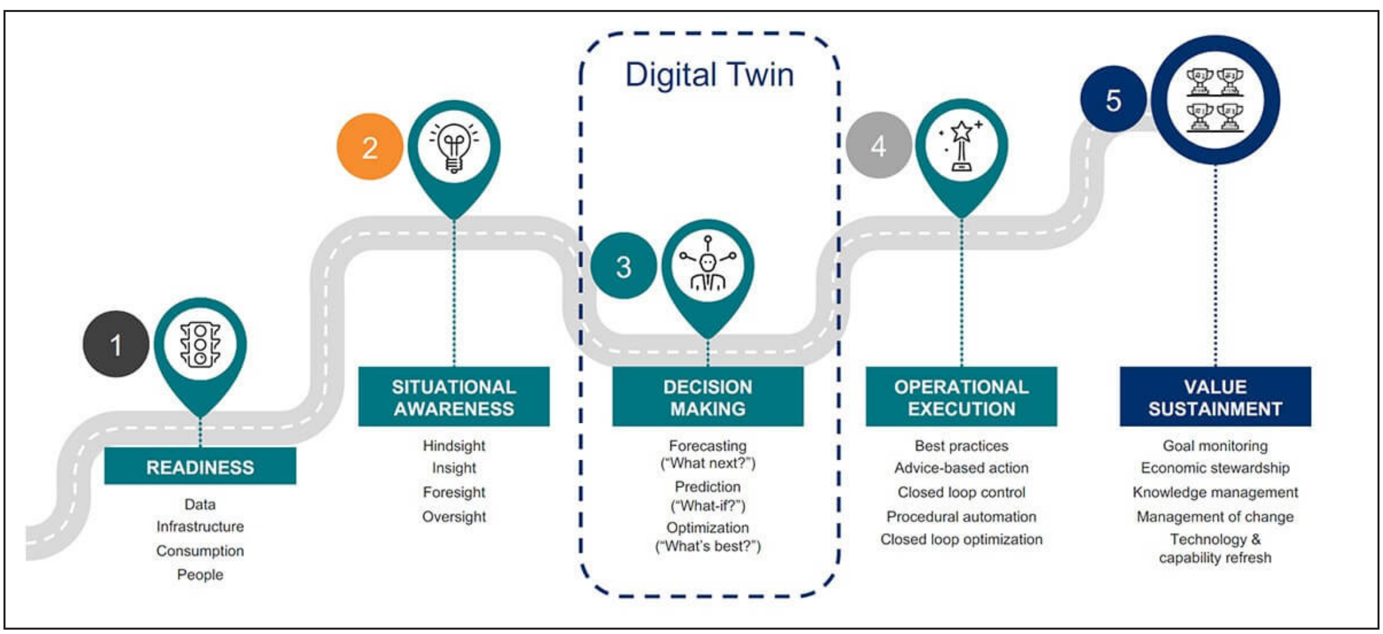

Figure 1. A Digital Twin Concept (Tokogawa, 2020)

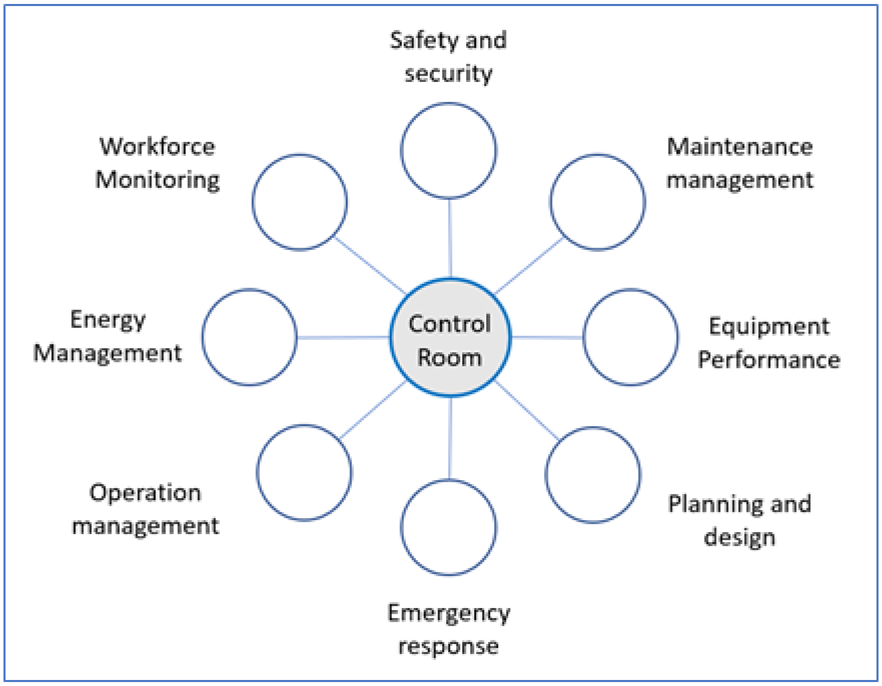

Figure 2. Control room scope (Pacheco et al., 2020)

radio waves having two advantages: mobility and flexibility of the system in general.

CONTROL ROOM

Control rooms are designed to carry out all the Digital Twin tasks in an optimal way for remote visualization, control, and management. As a result, it is possible to monitor and follow up all the personnel and equipment used in a mine. It involves the recording and analysis of several processing variables. A scheme of a control room and its scope is shown in Figure 2.

AI-POWERED BUSINESS INTELLIGENCE APPLICATIONS

Createasoft (2023) is a comprehensive solution for Digital Twins based in advance Business Intelligence application, power by AI and Machine Learning tools. Some of the highlights include the constant learning that the software achieves from the environment variables, on-the-fly adjustments, and the capability of performing hands-off analysis and validation.

Figure 3 shows an example of a Digital Twin configuration, using AI-based applications, producing self-adaptive Models and Historical Replay.

Smart Real-Time Location Systems

One of the powerful capabilities of Digital Twins that could be of great value for the Mining Laboratory is the implementation of Smart Real-Time Location Systems (Createasoft, 2023)

The purpose is to extend our visualization capabilities from the training center or even from the campus control room to track personnel and equipment, and manage productivity goals, verify safety levels for operators, and visualize areas of difficult access. Some of the features to achieve are:

- Real-Time visualization of the operation in 2D, 3D, and VR
- Lookup and display of all entity properties, interactively
- Connection to a tracking system
- Entity connection with traceability capabilities
- Generation of heat maps, congestion maps, and collision points.
- Highlighting of bottlenecks in Real-Time

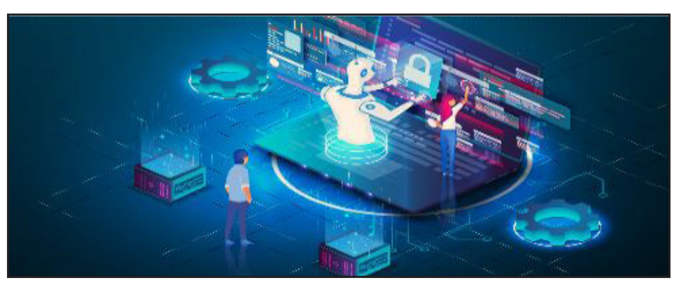

Figure 3. Digital Twin Model with AI, for Predictive Analysis and Scheduling (source. Createasoft)

This solution is achieved by combining the capabilities of GPS (with all the steps required for achieving the geo-positioning functions in an underground environment), Active and Passive RFID, and the implementation of Industrial-type Bluetooth. The major goal is to monitor personnel, materials and equipment on a daily basis, with proper visibility in Real-Time.

IOT SENSORS

For this project, the Digital Twin becomes a "precise digital replica"(Andritz, 2023) of the actual mine site. It can help monitoring a process, a machine, or the location of personnel. Internet of Things (IoT) sensors gather data from the physical world and send it to the campus computers to reconstruct. The digital twin is continuously updated to mirror the state of its physical counterpart.

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24-070

Perceptive Track Projection—Creating Context Sensitive Path, Velocity, and Auxiliary Activity Projections for Use in Autonomous Safety Intervention Systems

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ABSTRACT

Machine Situational Awareness (MSA) requires the ability to efficiently evaluate the probability of interaction of objects within the environment, without creating false alarms or ignoring materializing hazards. To do this, an MSA system needs to assign context to observed object activity and integrate as much information about object identity, kinematics, behavior, and current state as possible. This paper describes how known object characteristics, attributes, and activities (drilling, dumping, driving, etc.) can refine interaction probabilities and help identify rogue actors that introduce anomalous risks to the health and safety of miners. Path projections need to incorporate velocity and direction as a function of time while accounting for terrain, safety response, environmental factors, current assigned activity, etc. This paper also describes the methodology for properly prioritizing responses to place the highest value on human safety.

MACHINE SITUATIONAL AWARENESS (MSA)

The ISO 17757 [1] refers to situational awareness (SA) as an overall concept of humans and highly automated / autonomous (A/A) equipment working together. The standard covers many considerations for human factors and roles in situational awareness. While there has been a great deal of study and development on the human side of this structure, the equipment contribution is in its infancy. Given the absence of a formal definition, we found that the existing terminology fell short in effectively expressing the essence of our work. As a result, we introduced the term "machine situational awareness," which encapsulates the equipment's capacity to perceive its surroundings, assess potential interactions within that context, and recognize both existing and emerging hazards.

Humans have the innate ability to constantly evaluate their environment and make millions of risk-reduction decisions a day (some trivial, some lifesaving). The downside is that humans lose focus for a myriad of reasons such as fatigue, boredom, distraction, etc. [2]. Machines equipped with safety intervention controllers (parallel to machine control) that employ MSA can potentially perform these same functions without the shortcomings of humans, but they will have to be nearly infallible to be trusted to operate in the presence of humans. Some events are tolerable in a human-controlled environment that would not be in an autonomous world (requiring mines to build new exclusion zones, etc.). For a number of reasons, the expectation for equipment far exceeds that of humans [3]. Within that paradigm, MSA must be substantially more robust than humans. There are three critical elements to MSA, a) redundant, consistent, and reliable perception of objects