Unlocking the Power of Intelligent Digital Twins in Mining

November 2023

Pieter Van Schalkwyk
CEO - XMPro
Chair – Natural Resources Working Group
Digital Twin Consortium
Australian-Owned Since 2009 with a Global Focus & Reach
Our Engineering and Software Teams Have Experience Working Across a Range of Industries

Mining

Oil & Gas

Manufacturing

Supply Chain & Logistics

Utilities

Environmental Services
Australian-Owned Since 2009 with a Global Focus & Reach
Our Engineering and Software Teams Have Experience Working Across a Range of Industries

Mining

Supply Chain & Logistics

Technology Innovators for Digital Twins: IT Providers

- Accenture
- Tata Consultancy Services
- XAUTOMATA TECHNOLOGY

Service Provider

Hyperscaler

Digital Twin

IT Provider

Digital Division

ET/OT Provider

- Alibaba Group
- AWS
- Google
- Microsoft
- Oracle

- Envision Digital
- GE Digital
- Hitachi
- Siemens
- XCMG HANYUN

- Braincube
- Cognite
- Cosmo Tech
- Element Analytics
- Software AG
- TADA
- Taidid
- XMPro
- e-Magic
- FORCAM
- PTC
- Unity
- Voovio

Source: Gartner
777302_C

September 2023
Weir Minerals announces new partnership with XMPro, a digital twin platform, to enhance its Synertrex® digital ecosystem and provide its customers with real-time decision support.
What is a Digital Twin?

Digital Twin Consortium Definition of a Digital Twin

A digital twin is a \{model-based\} virtual representation of real-world entities and processes, synchronized at a specified frequency and fidelity.

- Digital twin systems transform business by accelerating holistic understanding, optimal decision-making, and effective action.
- Digital twins use real-time and historical data to represent the past and present and simulate predicted futures.
- Digital twins are motivated by outcomes, tailored to use cases, powered by integration, built on data, guided by domain knowledge, and implemented in IT/OT systems.
Physical Twin vs Digital Twin

**Physical Environment**
- Physical Processes
- Physical operating State

**Virtual Environment**
- Virtual Processes
- Digital State Information

**Synchronization**
- Synchronization At Twinning Rate

**Data**
- Physical to Virtual Connection

**Information**
- Physical state
- Virtual Processes

Mathematical equation:

\[ x[k] = \sum_{i=0}^{N-1} x[i] e^{-\frac{2\pi ik}{N}} \]
DTP vs DTI vs DTA for pumps

Digital Twin Prototype (DTP)
Physical Entity
Digital Twin Instance (DTI)
Digital Twin Aggregate (DTA)
Scope and Scale of a Digital Twin

Composite Digital Twin
Assembly of Discrete Twins

Discrete Digital Twin
Single/Atomic Entity

Composite Digital Twin
System of Assembled Digital Twins
Digital Twins in Mining

- Ball Mill Unit
- Gearbox
- Composite Twin - Assembly
- Discreet Twin
- Composite Twin - System
- Ball Mill in Processing Plant
Without a Digital Twin

**Use Cases**
- **Operations**
  - Sensors for temp, pressure, speed
  - Operational data
  - OT Time series data
  - Production Optimization models
- **Maintenance**
  - Sensors for temp, vibration, speed
  - Maintenance data
  - Predictive models
  - PLM models, CAD
- **Safety/Governance**
  - Sensors for stress, temp, speed
  - Inspection records & data
  - Certification records
  - VR, AR models

**Capabilities (attributes & behaviors)**
- Sensors for temp, pressure, speed
- Operational data
- OT Time series data
- Production Optimization models
- Sensors for temp, vibration, speed
- Maintenance data
- Predictive models
- PLM models, CAD
- Sensors for stress, temp, speed
- Inspection records & data
- Certification records
- VR, AR models
With a Digital Twin

Capabilities (attributes & behaviors)

Use Cases

Operations

Maintenance

Safety/Governance

Sensors

Digital Twin as Proxy

Data Services
Integration
Intelligence
User Experience
Management
Trustworthiness
Digital Thread vs Digital Twin

Lifecycle Phases:
- Plan
- Design
- Construct
- Commissioning
- Operate
- Maintain
- Retire/Discard

Digital Twins based on Use Cases:
- Digital Twin based on Use Case
- Digital Twin based on Use Case
- Digital Twin based on Use Case
- Digital Twin based on Use Case
- Digital Twin based on Use Case
- Digital Twin based on Use Case
- Digital Twin based on Use Case

Digital Thread:
Transfer Ownership from Manufacturers or EPC contractor to owner/operator
Digital Twins Make **Implicit** Intellectual Property **Explicit** at Scale

**Business Intellectual Property**
- Institutional knowledge
- Internal & business processes
- Real-time event data and intelligence
- Contextual meta data and information

**Enterprise Intellectual Property**
- Better Decision Intelligence for **improved decisions**
  - Common operating picture
  - **integrated enterprise view**
  - Improved processes with recommendations

**Operationalize Enterprise Strategy**

**Composable at Scale**

**Technical Intellectual Property**
- Common DT models & taxonomy
- Integration and orchestration
- Intelligence and AI models
- UX for decision collaboration

**Deliver Digital Product and Services**
Digital Twins Make Implicit Intellectual Property Explicit at Scale

Digital Twin is a framework that unlocks Business Value and it is the only why to enable digital transformation at scale.

It makes implicit IP:
- Explainable (model-based)
- Useful (digitized and accessible)
- Scalable (beyond people capabilities)
Why Shift To Intelligent Digital Twins?

- Decision Support
  - Recognize changes in how we make decisions

- Intelligence
  - Make it smarter and more autonomous

- Scale Out
  - Think big, start small, scale fast
Decision-making is changing
Intelligent Twins: Decision-making is Changing

**Decision Intelligence**
Distributed Intelligence System – DIS

**Decision Support**
- Dashboards
- Business Intelligence
- Condition Monitoring

**Current Shift**
- AI Augmented Information
- Prescriptive Recommendations & FRS
- Closed-loop Feedback & Learning

**Decision Augmentation**

**Future Shift**
- Business Process Automation
- Distributed Intelligence System
- Algorithmic Business with DIS

**Decision Automation**

**Environment EI**
Supply Chain EI
Governance

**External Intelligence**

**Internal Intelligence**
Business Rules & AI IP
Process & IoT EI
Human Capital

EI: Event Intelligence
FRS: Front Running Simulation
Plant Automation (DCS) and Digital Twins (DIS)
DCS & DIS

Value Stream Focused Use Cases
DCS & DIS

Value Stream Focused Use Cases
Ecosystem of Vendors - Capabilities
# Digital Twin Use Cases – Across Value Chain

## Use Cases:
1. Underground Energy/Carbon Advisor
2. Energy Carbon Tracking
3. Freight Cost Optimization
4. Hoist Optimization Advisor
5. Conveyor Predictive Maintenance
6. Slurry Pump Predictive Maintenance
7. Crusher Predictive Maintenance
8. Ore Grading
9. Recovery Optimization
10. Operational Safety
11. Fan Condition Monitoring
12. Borer Predictive Maintenance
13. Cybersecurity threat monitor
14. Operator Fatigue Prediction and Monitor
15. Rope Condition Monitor
16. X
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27. X
28. X
29. X
30. X

## Digital Twin Type:
- **Design**
- **Asset**
- **Process**
- **Organization**

### Mining Value Chain

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<th>Mine &amp; Transport</th>
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<th>Stockpile</th>
<th>Ship</th>
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The Rise of Intelligent Digital Twins

It is not better technology, it is smarter digital twin
Dr. Michael Grieves – Father of Digital Twins
Digital Twin Evolution

Information Evolution

Physical to Virtual Maturity

Traditional

0

Transitional

1

Conceptual

2

Ad Hoc

3

DT Platform

4

FRS

Front Running Simulation

IDT Platform

© Michael W. Grieves, LLC 2003-2022
## Digital Twin (DT) vs Intelligent Digital Twin (IDT)

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<th>Digital Twin (DT)</th>
<th>Intelligent Digital Twin (IDT)</th>
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<td><strong>Passive</strong> Repositories</td>
<td><strong>Active</strong>, Always On Agents</td>
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<td><strong>Offline</strong>, wait for physical twin to actuate</td>
<td><strong>Online</strong> (real-time), scan and actuate</td>
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<td><strong>Goal Given</strong>, Measuring Performance</td>
<td><strong>Goal Seeking</strong> shared by human and twin</td>
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<td><strong>Predictive</strong>, but not optimizing</td>
<td><strong>Anticipatory &amp; FRS</strong> manipulate time</td>
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*Data vs Dataflow*

Intelligent digital twins and the development and management of complex systems [https://doi.org/10.12688/digitaltwin.17574.1](https://doi.org/10.12688/digitaltwin.17574.1)
Front Running Simulations (FRS)

Data-driven innovation starts at racing’s edge to improve race car aerodynamics — and speed

McLaren Racing continuously prototyped and streamlined its Formula 1 race cars supported with end-to-end solutions from Dell Technologies.

McLaren race cars are expertly driven faster than 200 miles per hour. They act as edge devices streaming as many as 100,000 data points a second. Engineers continuously prototype them to get the most performance and competitive advantage, using a wide range of secure IT solutions from Dell Technologies.

Transformations

- McLaren’s trackside edge data center is securely tied to HPC at headquarters for closed-loop performance analysis.
- McLaren streamlines race car aerodynamics using data-driven 3D digital twin and 3D printing models.
- McLaren’s continuous rapid prototyping to improve car performance helps boost its standings from race to race.

Outcomes

- Accelerates time to innovation with HPC aerodynamic simulations.
- Enables simulations via digital twins to validate car enhancements.
- Addresses race restrictions on speed and aerodynamic testing.
- Optimizes race performance and speed for innovation with data analytics.

XMPro is a Dell Validated Design For Manufacturing Edge.
More F1 Front Running Simulations - AWS

IT STARTS WITH THE DATA

Every F1 car contains 300 sensors which generate 1.1 million telemetry data points per second. This real-time data is combined with over 70 years of historical race data stored on Amazon S3 to educate and enrich the fan experience on the track.

AWS powers F1 Insights

The new ‘Undercut Threat’ graphic launching this weekend, the latest in the F1 Insights series powered by AWS, will provide fans and broadcasters an opportunity to understand which cars are at threat from an ‘undercut’ i.e. if the car behind them pits at the end of the lap, will they lose a position to this car, or more positively which cars have the possibility of making an undercut.

Learn more

Car Sensor Data

Race Strategy

Competitor Analysis

Car Performance

Qualifying Pace

Projected Race Time

Start Analysis

Track Dominance
Traditional Digital Twin

- **Physical Environment**: Physical Processes, Physical Twin, Physical operating State
- **Virtual Environment**: Synchronization At Twinning Rate, Passive Repositories, Offline, wait for physical twin to actuate
- **Data**: Physical to Virtual Connection
- **Information**: Synchronization At Twinning Rate, Goal Given, Measuring Performance
- **Digital Twin**: Virtual Processes, Predictive, but not optimizing

Equation: \[ x[k] = \sum_{n=0}^{N-1} x[n]e^{-\frac{n^2}{2\sigma^2}} \]
Intelligent Digital Twin

Physical Environment

Synchronization At Twinning Rate

Virtual Environment

Decision Management

- Expert Knowledge
- Central Business-rules
- Math & Physics Models
- Conventional AI & ML
- Generative AI & LLMs
- Deep Learning & Neural
- Goal-seeking & Learning
- Front-running Simulation

Physical Processes

Physical to Virtual Connection

Data

Physical Twin

Digital Twin

Prescription

Physical operating State

Synchronization At Automation Rate

Mathematical equation:

\[ x[k] = \sum_{j=1}^{N} x[j] e^{-\frac{t[k]}{\tau}} \]

Virtual Processes

Digital State Information
“It makes sense, but how do I do this?”

Physical Environment

Synchronization At Twinning Rate

Virtual Environment

Data

Physical to Virtual Connection

Prescription

Synchronization At Automation Rate

Virtual Processes

Digital Twin

Decision Management

Active, “Always on” Agents

Expert Knowledge

Central Business-rules

Math & Physics Models

Conventional AI & ML

Generative AI & LLMs

Deep Learning & Neural

Goal-seeking & Learning

Front-running Simulation

Physical Processes

Physical operating State
XMPro I³C - Intelligent Digital Twins Framework

INTEGRATED
Real-Time and Contextualized

INTELLIGENT
Analytics and Simulation

INTERACTIVE
Decisions and Visualizations

COMPOSABLE
No-Code Modular Digital Twin Platform & Marketplace

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XMPro I³C - Intelligent Digital Twins Framework

INTEGRATED
Real-Time and Contextualized

- Standards-based APIs and Packaged Business Capabilities
- Model-driven development and integration
- Bi-directional active connection between physical and digital twin

INTELLIGENT
Analytics and Simulation

- Executable AI and Machine Learning (Algorithmic Business)
- Innovation AI for experimentation and Front Running Simulation
- Augmented AI for self-learning Digital Twins

INTERACTIVE
Decisions and Visualizations

- AI enabled Recommendations for Prescriptive Analytics
- Collaborative, XR UI as basis for future industrial metaverse
- Autonomous “Operate by Wire” Capabilities in a safe envelope

COMPOSABLE
No-Code Modular Digital Twin Platform & Marketplace

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One Way To Create Intelligent Digital Twins
How to make Digital Twins Connected

- Integrated
- Real-Time and Contextualized

Standards-based APIs and Packaged Business Capabilities

Model-driven development and integration

AI integrated and executable in data flow

Bi-directional active connection between physical and digital twin
How to make Digital Twins Smarter

XMPRO AI
Jupyter Notebooks embedded and integrated
Make Digital Twins Accessible

Generative & collaborative, multi-experience user interfaces
Integrated IT/OT/ET systems - better decisions
Closing The Loop

**INTERACTIVE**
Decisions and Visualizations

AI enabled Recommendations for Prescriptive Analytics
Composable Digital Twins, built on an ecosystem of capabilities

Framework to Scale
Make Digital Twins Scale

Digital Twin Composition Platform
Integration | Composition | Orchestration | Development | UX Development

Digital Twin PBC Catalog/Marketplace

Composed Digital Twin Experiences
Blast Furnace Casting Guidance Simulation Twin
Smart Water Leak Detection and Monitoring Twin
Intelligent Building Energy Optimizing Twin
Supply Chain Short Term Inventory Planning Twin
Blockchain Certified Inspection Monitoring Twin

Long Conveyor Predictive Maintenance Twin
Centrifugal Pump Predictive Maintenance Twin
CHPP Throughput Loss Optimization Twin
First Pass Yield Optimizing Twin
Tailings and Environmental Monitoring Twin

Physics-based models
Thermo, FEM, Geological etc.

Analytical models
Predictive, statistical, math

IoT and Temporal data
Sensor and Time series

Transactional data
ERP, EAM, CMMS, CRM

Visual models
CAD, 3D, VR, BIM, GIS, BPM

Master data
EAM, MDM, BPM

Legacy Business and IT Applications

Legacy OT and Engineering Applications

Technology Services to Composable Business Capabilities
Physic-based models
Analytical models
IoT and Temporal data
Transactional data
Visual models
Master data

Data Fabric
Source Data | Metadata | Derived Data | Internal Processes | Rationalization | Logs | Model Repository

User Interface
API/Event Interfaces

Adapted by XMPro Inc. from “Reference Model for Intelligent Composable Business Applications”
https://www.gartner.com/doc/3991699
At Twinning Rate

Physical Twin

Physical Processes

Physical to Virtual Connection

2. Integration

4. UX

Digital Twin

Virtual Processes

5. Management

6. Trustworthiness
Collaboration framework is a framework to facilitate collaboration in multidisciplinary or fusion teams who need to create Digital Twins requirements specifications in large scale complex environments.
Periodic Table Groups

Data Services
Integration
Management
Intelligence
Trustworthiness
User Experience
# Digital Twin Capabilities Periodic Table

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- Integration
- Intelligence
- UX
- Management
- Trustworthiness
# Windfarm Condition Monitoring Use Case

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- **1** Data Acquisition & Ingestion
- **2** Synthetic Data Generation
- **3** Any other relevant service or integration
- **4** Enterprise System Integration
- **5** Edge AI & Intelligence
- **6** Machine Learning ML
- **7** Machine Learning AI
- **8** Prescriptive Recommendations
- **9** Real-time Monitoring
- **10** BPM & Workflow
- **11** Gaming Engine Visualization

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**Use Case Description:**

The Windfarm Energy Prediction Use Case involves various data services and integrations to support the prediction of energy output from windfarms. The use case focuses on leveraging data from various sources to improve operational efficiency and predictive analytics. Key components include the collection and ingestion of data, advanced analytics using machine learning, and real-time monitoring to ensure safety and reliability. The integration of systems such as Enterprise System Integration and Edge AI & Intelligence is crucial for real-time decision-making and predictive insights.
Digital Twin Capabilities Periodic Table

Excel Toolkit

Periodic Table

User Guide

Capabilities Periodic Table - Digital Twin Consortium

A Digital Twin Consortium Technical Document
Examples of Intelligent Digital Twins
Real-time Event Intelligence at Operational Level

**Challenge**
Reduce long conveyor (underground) downtime by 30%

**Solution**
XMPro monitor 52 (80+km) conveyors and predict fluid coupling and lagging failures

**Benefits**
~184hrs of preventable borer downtime identified worth ~44k product tonnes
Real-time Event Intelligence at Operational Level

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November 2019

[Image showing conveyor system with recommendations and resolution times]

May 2020
CUSTOMER STORY - Mining

$4m PdM - Underground Long Conveyor

Measures of Success

Time to value - 30 days to deploy initial release
- Integration with OSIsoft Historian and Oracle EAM
- Complex Engineering models and predictive analytics executed at 2 sec intervals
- 30% reduction in conveyor downtime due to fluid coupling failures add $+4m in revenue

Always On, Situational Awareness
- 52 long conveyors in series monitored and analyzed every 2 seconds
- Real-time dashboards with notifications and drill-down for decision-support and automation

Expert Knowledge Capture
- XMPro Recommendations capture expert knowledge on maintenance best practices
- Replaced ad-hoc BI style Excel spreadsheet analysis with continuous analysis and notifications for reliability engineers to prescribe appropriate actions
- Recommended actions incorporated into predictive/prescriptive maintenance processes

Challenge
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Messages Per Day
42m

Data signals per day
340m
Model-based Digital Twin approach makes it scalable

Scaling out with own Engineers in six months
Pilot at first mine, rolled out to six mines
Think Big, Start Small, Scale Fast
Real-time Enterprise Intelligence for GM
Real-time Enterprise Intelligence for Operations

Gold Processing Plant

Live Process Health

Operating Metrics

Throughput (QTD)
579 Tons

Tonnage Processed (QTD)
873 Tons

Recovery
Total Gold Recovery (QTD)
95 %

Gold Recovered (QTD)
80 Tons

Executive Recommendations
1. Crusher 2 RUL has reached 24 hours
   Schedule urgent liner change-out work order
   08/15/2021 09:50 AM

2. Crusher 3 RUL has reached 48 hours
   Schedule liner change-out work order
   08/15/2021 12:40 PM

Crushing, Screening & Conveying
Tonnes Crushed (QTD)
1000 Tonnes

SAG and Ball Milling
Tonnes Milled (QTD)
985 Tonnes

Crushing, Screening & Cyclones, Trash Screening
Tonnes Screened (QTD)
924 Tonnes

Flotation
Tonnes Processed (QTD)
892 Tonnes

Leaching & Metal Recovery
Gold Head Grade (QTD)
2.35 %

Tails & Cyanide Destruction
Tails Grade Gold (QTD)
12 gpt
Real-time Enterprise Intelligence for Operations
Real-time Decision Intelligence for Planning
HT20002 - High Main Hydraulic Pressure

Recommendation Details
Elevated main hydraulic pressure levels detected, check the hydraulic system.

Event Data
- Tire Back Left Inner Pressure: 99.3714444
- Tire Back Right Inner Pressure: 103.3810014
- Hydraulic fluid quality water: 0.62687799
- Tire Back Left Outer Pressure: 100.316457
- Hydraulic pressure aux: 1963.329096
- Tire Back Right Outer Pressure: 105.3329592

Notes

Did this recommendation solve the problem? [ ] [ ]

Options:
- Assign to me
- Share
- Save
- Mark as Positive
- Mark as Resolved

Work Request Number

Work Order Number

Work Order Status

Request Type

Special Instructions for Work Request

Create Work Request
Activate and Accelerate more miners and OEMs to be competitive in a digital-enabled landscape through intelligent digital twins that:

- Support new decision-making processes
- Are Intelligent and augment tasks
- Enable more autonomous operations
- Can scale fast
- Support regulatory and other compliance