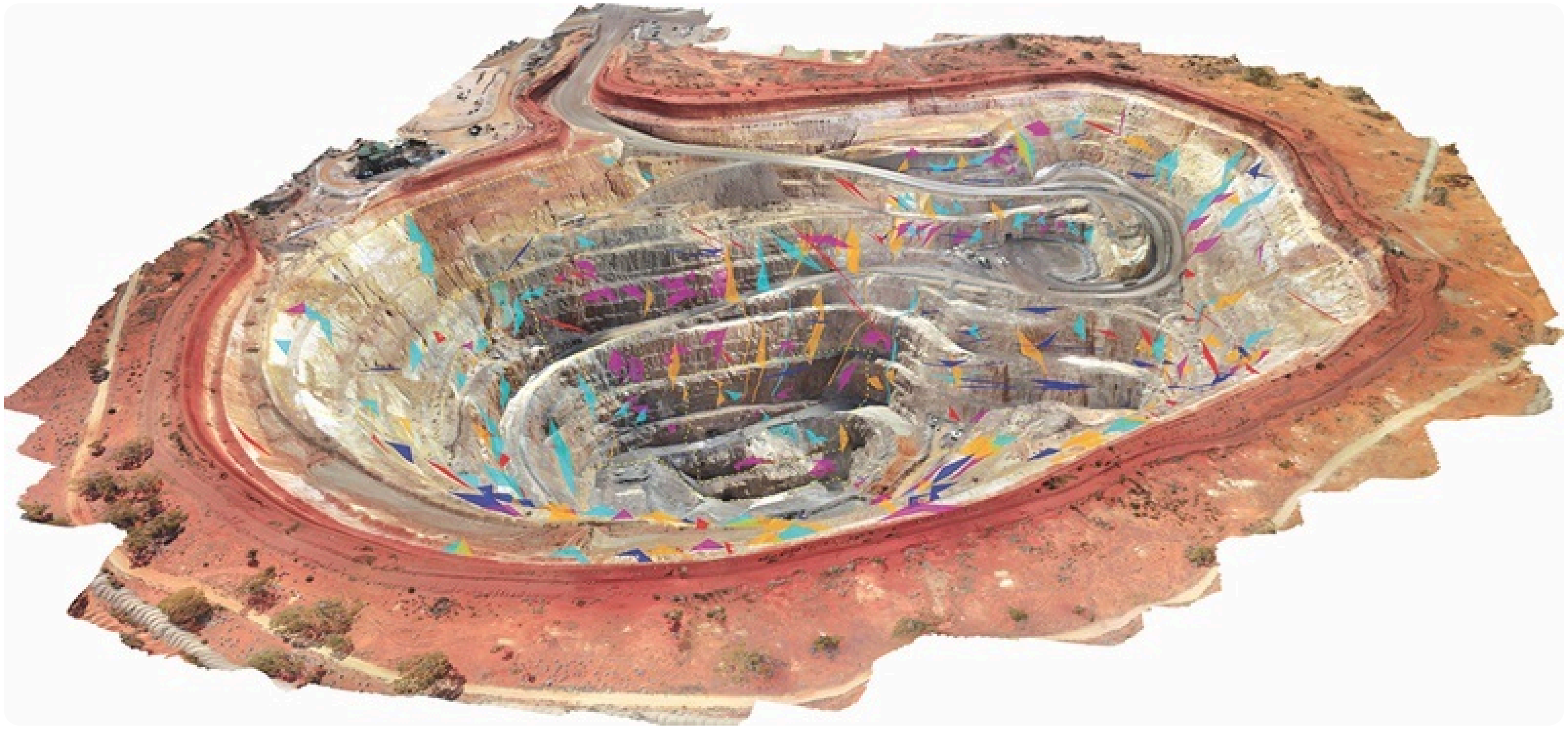

Mine Digital Terrain and Geology Shared Services - Business Requirements

Executive Summary	This initiative aims to centralize the creation, maintenance, and usage of the Digital Terrain Model and Digital Geology Model used by all MTS applications (embedded and central). This is a critical milestone in fulfilling MTS's vision for the Mine Platform as the *Single Source of Truth* and *Guarantor of Data Quality*. Currently, the data, models, technologies, and geographic services used by the applications are significantly different from each other and require different teams to manage. Limitations in how we store and access is also impacting our ability to enhance our application capabilities. The Digital Terrain Twin is a virtual spatial representation of the mine's physical terrain and associated land features of interest to MTS applications (road network, locations). The Digital Terrain Twin is continuously updated with near-real-time data to reflect changes in the real world. It's a specific type of digital twin focused

on the Earth's surface, encompassing features like spatial geometry, elevation, slope, shape, semantic objects, and metadata, and is created/enhanced using various data sources like aerial surveys, satellite imagery, CAD drawings, sensors, equipment dot traces, and LiDAR.

The Digital Geology Twin, similarly, is a virtual representation a mine's surface and subsurface geology, created using GIS and 3D modeling, and updated using real-time data from sensors, geophysical and geochemical surveys, remote sensing, and other sources.

The work done by LuxModus recently will form the basis for the development of these solutions.

Digital Terrain and Geology Twins will be utilized in the future across all Modular Ecosystem applications, driving key benefits to the customers as listed below:

- Improved Resource Management and Reduced Environmental Impact: By accurately mapping and modeling the ore body and surrounding geology, they help optimize extraction processes, leading to better resource utilization and reduced waste.
- Enhanced Safety: Allow for the simulation of hazardous scenarios like slope instability or potential rock bursts, enabling proactive safety measures and emergency response planning.
- Enhanced Visualization: Creating immersive and interactive visualizations for better understanding and communication.
- Improved Decision-Making: By providing a realistic and interactive virtual environment, they empower better decisions.
- Cost Savings: Reducing the need for physical site visits and streamlining workflows.
- Increased Efficiency: Automating tasks, accelerating processes, and improving productivity.
- Data-Driven Insights: Providing valuable insights through data analysis and simulation capabilities.

It will also increase data consistency and reduce MTS development and support costs by:

- Eliminating the need for applications to internally store geographic information, and unifying the way that geographical objects are represented.
- Reducing the amount of legacy code to support over time, by replacing internal code and databases with a modern external service.
- Providing a singular source of truth, by replacing legacy and out-of-date implementations within applications, and creating an external service to handle the object lifecycle of geographic data.

Description	Currently, geographic and geologic data is managed using various methods and technologies in isolated systems and file shares, which causes:
	• Duplication of storage and memory, each application holds copies/multiple copies of its own and other applications' data.
	• Limited access to accurate, up-to-date geospatial datasets
	• Inconsistencies in terrain models and geology interpretations
	• High manual effort to integrate datasets into software applications
	• Inefficiencies in mine design, compliance reporting, and field collaboration
	• Manual reconciliation of terrain and geology data
	• Limited support for AI and analytics-based optimization
	
	<u>Highlights of current challenges</u>
	
	• **Dispatch:**
	  ◦ Spatial data is represented using coordinate arrays, with road segments stored as indexed X/Y coordinate pairs across several normalized tables.
	  ◦ This requires time-intensive coordinate-based calculations for rendering road paths and distance computations for truck routing operations, proximity analysis etc.
	  ◦ Transition to a industry standard mapping platforms using spatial geometry types, such as LINESTRING, would make this significantly more efficient and quicker.
	  ◦ <u>Uses</u>:
	    ▪ Microsoft SQL Server (MS-SQL)
	    ▪ MySQL
	• **Provision**:
	  ◦ Material block modeling
	    ▪ Voxel grid with metadata
	  ◦ Terrain data for machine positioning and grade from Intellimine and Dispatch.
	  ◦ <u>Uses:</u>
	    ▪ binary geometry format
	    ▪ specialized libraries
	• **Replenish and Simulate**:
	  ◦ Coordinate XY instead of spatial types

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missing spatial topology
<u>Uses</u>:
Microsoft SQL Server (MS-SQL)

Roadways:

Bridges Dispatch based geometry to GIS to create Geoserver map layers.
<u>Uses:</u>
PostGIS extensions for PostGreSQL

Argus/Pegasys:

Very detailed 3D model which is polygon driven.
Could provide the basis for the new solution.
<u>Uses:</u>
TileDB custom database

Autonomous Haulage System (AHS):

Uses an (x,y) pixel grid for Northing and Easting.
Object locations and classes stored with (x,y) data
In-memory/database copies of Dispatch 6 location database
<u>Uses:</u>

Microsoft SQL Server (D6 server)
MySQL (Internal Database)

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<td>Project Objectives</td>
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This project aims to:

Establish a centralized repository of terrain and geology data, in industry standard modeling formats
Enforce consistent business logic and definitions, via a SEMANTIC layer that all applications will utilize
Provide common APIs and services for terrain access, surface models, and geologic layers
Enable real-time data streaming and access of terrain and geology updates (where needed)
Ensure consistency and traceability of geospatial data and interpretations
Enable cross-functional use of digital terrain and geology assets
Reduce manual handling of data and simplify data-driven applications

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<td>Timing</td>
<td>FY2025 - Q4: Develop Terrain and Geology Twins, OTP-364</td>
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Status	ON TRACK
Team	Cross-Functional Team Required (David Conrad and David Haukeness)

Requirements	The Terrain and Geology Digital Twin designs must provide the confidence that the required level of supervisory and operational decision making is supported. Clear distinction should be made between when applications will rely on Terrain and Geology and decisions documented to ensure that critical applications use the most accurate and up-to-date information. This should be done while considering the site network and machine capability constraints, among others.
	
	Loss of fidelity in terrain and geologic information can result in:
	• Inefficient Fleet Dispatch and Routing: fuel inefficiency, tire wear, higher cycle times
	• Poor Mine Planning and Design: Incorrect slopes, unsafe grades, survey vs reality misalignment
	• Grade Control and Ore Loss: Ore dilution, loss, incorrect blending
	• Safety Risks: Increased Risk of Accidents, rollovers, slope instability
	• Data Integrity Issues: Incorrect Forecasting and reconciliation with actuals
	• Rework and Cost Overruns
	• Regulatory Non-Compliance
	
	Functional Requirements
	
	• Centralize terrain models, geological block models, and spatial layers in a common database.
	• Support multi-format ingestion including point clouds, rasters, and CAD surfaces.
	• The solution must accept richer representations of the terrain and geology from 3rd parties and must be able to extend the model to include the new information.
	• **Accurate Modeling:** The terrain and geology twin models must accurately represent the physical site's state. **The team will need to determine what constitutes an acceptable "time to update" for each element of the Terrain and Geology Digital Twin, after discussions during the technical design phase.**
	• **MTS Applications Scope:**
	    ◦ The solution must address the needs of core MTS products, as well as our Autonomous Haulage needs.
	    ◦ Must be designed to support MST / Underground applications in the future.
	• Digital Twins at embedded and central should be synchronized/mirrored appropriately.

    - Ideally streaming changes, however geography is hard and sometimes its batched because a machine is offline.
    - Continuous and real-time data flow from the physical system to the digital twin, both at embedded and central. For example, from Provision as the shovel extracts ore.
- **Shared Interfaces:**
    - Provide APIs for consistent internal application access to all aspects of the Terrain and Geology Twins. Centralize business logic.
    - Interface with the terrain and geology service in a consistent way.
    - Implement consistent and reliable network transport.
- Enable coordinate system transformations and terrain meshing. This is important to ensure integration with legacy systems during the transition period.
- Integrate with GIS and 3D planning tools for real-time terrain views. (TBD)
- Historical Data Store: The solution **should** also:
    - Allow users to replay historical geographic state, for a point in time query.
    - Designed to efficiently store and retrieve large volumes of time-stamped data
    - Fast query capabilities for time-based analysis
    - Engineering Comments:
        - This is likely a HUGE body of work.
        - would require large, versioned, blocks of geographic information
        - Would probably be high-cost.
        - Need to determine if this actually lies in our MVP based on VoC.

Non Functional Requirements

- **Handling Complexity and Uncertainty:** Real-world systems are complex, asynchronous, and can be unpredictable. Digital twin synchronization methods need to account for these factors, and be uniform in their implementation and interfaces to maximize deployability, supportability, and compatibility.
- **Data Latency and Bandwidth:** The solution must be designed to ensure timely data transfer between the physical and virtual worlds even in challenging network environments.
- **Scalable and Available:**

- This solution must support terrain models up to 10 km^2 and block models with (TBD) of cells.
    - Based on one of the largest mines, Kennecott copper, where the pit measures about 7 square kilometers.
- This solution must support critical mine operations at sites that operate 24/7, with large fleets that could exceed 350 trucks and 50 shovels.
- Scheduled maintenance must be limited to predefined maintenance windows and communicated in advance.
- Downtime, and Untimely/Missing/Inaccurate data could:
    - Seriously disrupt or limit the use/benefit of supervisory systems for Fleet Management and Autonomous Haulage, health monitoring services, and maintenance scheduling systems.
    - Result in serious financial losses to the mine operator, <u>which could be passed on to MTS as a punitive measure for not meeting obligations</u>.
        - For example, Freeport-McMoRan, can lose $1 - $2 million per day if a major asset like the Morenci site goes offline.
        - This is about $100K per hour if extraction operations are halted.
        - A similar scale applies to other Tier 1 mines across Chile, Peru, the U.S., or Australia.
- The Terrain and Geology Digital Twin data and processes must
    - Fulfil customer communicated SLAs (response time, uptime, error rate) for availability, uptime, and performance.
    - Implement Failover mechanisms and redundant infrastructure to meet SLA.
- **The engineering team will define the Service Level Objectives/Indicators/Agreement (SLA, SLO, SLA), along with identifying the Key Leading Indicators of failure and document an FMEA to proactively address those issues.**

- **Security and Privacy:**
    - Protect sensitive data and ensure the security of the system.
    - Implement robust encryption and security measures for data at rest and in transit.
    - Adhere to industry-standard security protocols and best practices
    - Comply with relevant data protection regulations (e.g., GDPR, CCPA)
    - Implement strong authentication and access control mechanisms

- **Governance and Continuity:** Comply with the established *MTS Governance Framework for Domain Services* with regards to:
  - Ownership & Accountability - Every domain must have a named owner and data steward. Clear RACI assignments for domain services, data, and lifecycle events.
  - Domain Registration, Stewardship, & Metadata Management
  - Standards & Policies
  - Tools and Enablers
  - Data Quality and SLAs
  - Access Management & Security
  - Change Management
  - Lifecycle Management
  - Interoperability and Integration
  - Monitoring & Reporting
  - KPIs for Governance Effectiveness
- **Data Retention:** Establish appropriate data retention policies, after considering storage available, entity sizes, and desired reporting capabilities.
- **Data Quality:**
  - Proactively validate data completeness and accuracy. Escalate errors that could lead to data loss or misrepresentation.
  - Provide detailed audit logs for all data transmission activities.
  - Ensure data integrity throughout the transmission process (Store and Forward where comms are lost).
  - Ensure compliance with SOC2 and ISO standards.
- **Data Labeling:** Data should be labeled appropriately, at the time of generation, including the:
  - Source of the data
  - Classification of the data
  - Owner of the data (Komatsu vs Customer)
  - Sensitivity of the data (PII, Location, etc..)
- **Monitoring and Error Handling:** The solution must be fault-tolerant and ensure real-time monitoring, logging, and alerting in case of performance issues or errors. Proactive remediation of potential issues must be implemented.

	• **Develop Documentation for development teams** on how to utilize the Terrain and Geology data and services.
Investment required	Investment procured as part of the Mine Platform Expansion Project (SGP)
Constraints and Considerations	• Integration with legacy CAD or GIS tools • Large file sizes may impact data performance without proper optimization • Compliance requirements may vary by jurisdiction and change over time • Shared interfaces should be developed with consideration to ease of transition for non-platform applications