Integration of big data analytics in digital twinning of mineral deposits

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Digital twins – not just models & simulations

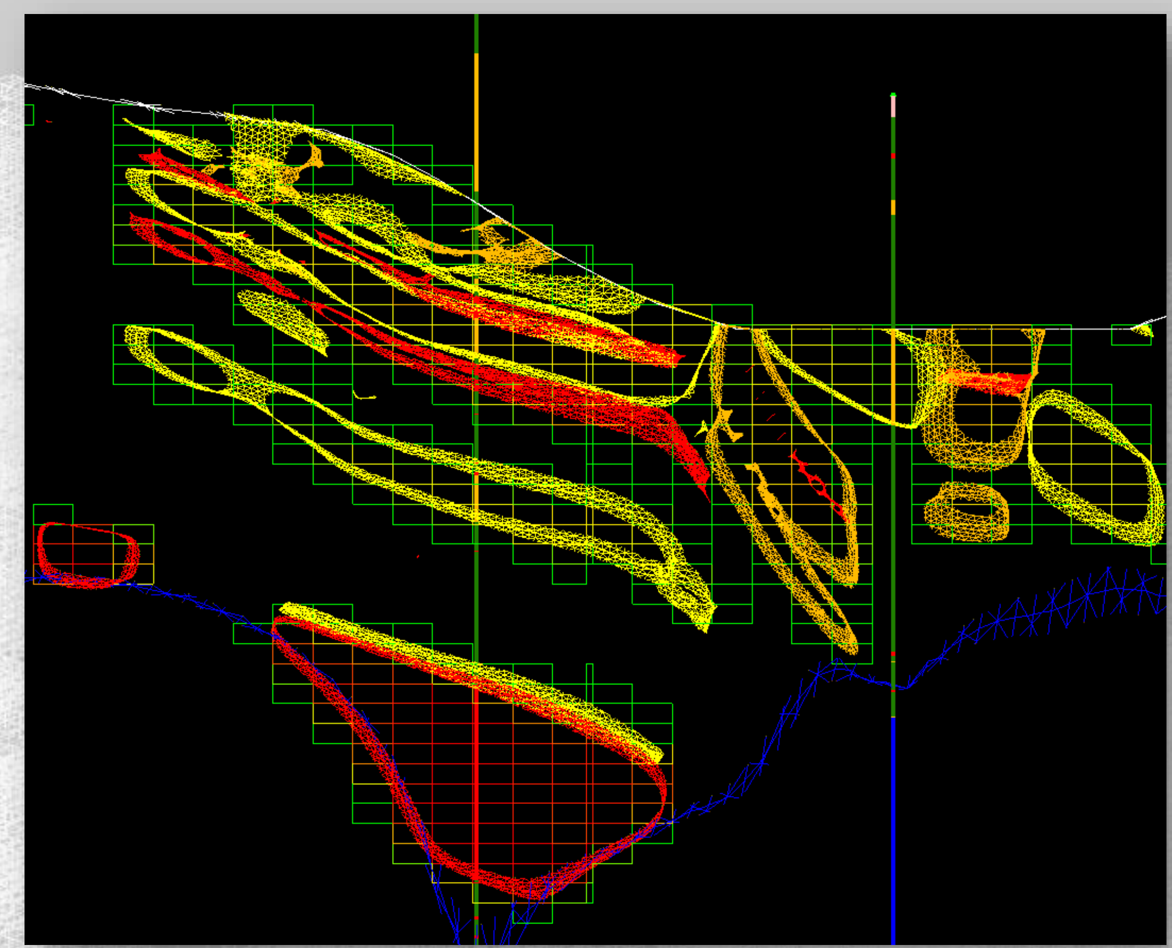
- At a minimum, a digital twin is a **synchronised, real-time pairing** of a virtual and a physical domain that **can predict its own behaviour** and **inform decision makers** with sufficient precision to ensure adequate productivity and safety **in real time**.
- It is clear from this and other definitions that a **model** of a physical system or a **simulation** of its operation and behaviour is **not a digital twin**.

> *"…digital twin means an integrated multiphysics, multiscale, probabilistic simulation of a complex product, which functions to mirror the life of its corresponding twin".*
>
> (Glaessgen and Stargel, 2012)

> *"A set of virtual information constructs that fully describes a potential or actual physical manufactured product from the micro atomic level to the macro geometrical level. At its optimum, any information that could be obtained from inspecting a physical manufactured product can be obtained from its Digital Twin."*
>
> (Grieves and Vickers, 2017)

Mineral deposits and mineral resource models

- A mineral deposit is a concentration of solid material of economic interest in or on the Earth's crust with reasonable prospects for eventual economic extraction.
- Most of the rock mass of a mineral deposit cannot be seen prior to its excavation and statistical methods and expert judgements are typically used to provide an estimate of its properties and behaviour.
- Mineral deposits are commonly approached as simplified mineral resource models on the basis of mineable units (blocks).
- These resource models are built using all necessary/available information and are regularly updated during the life of a mine.

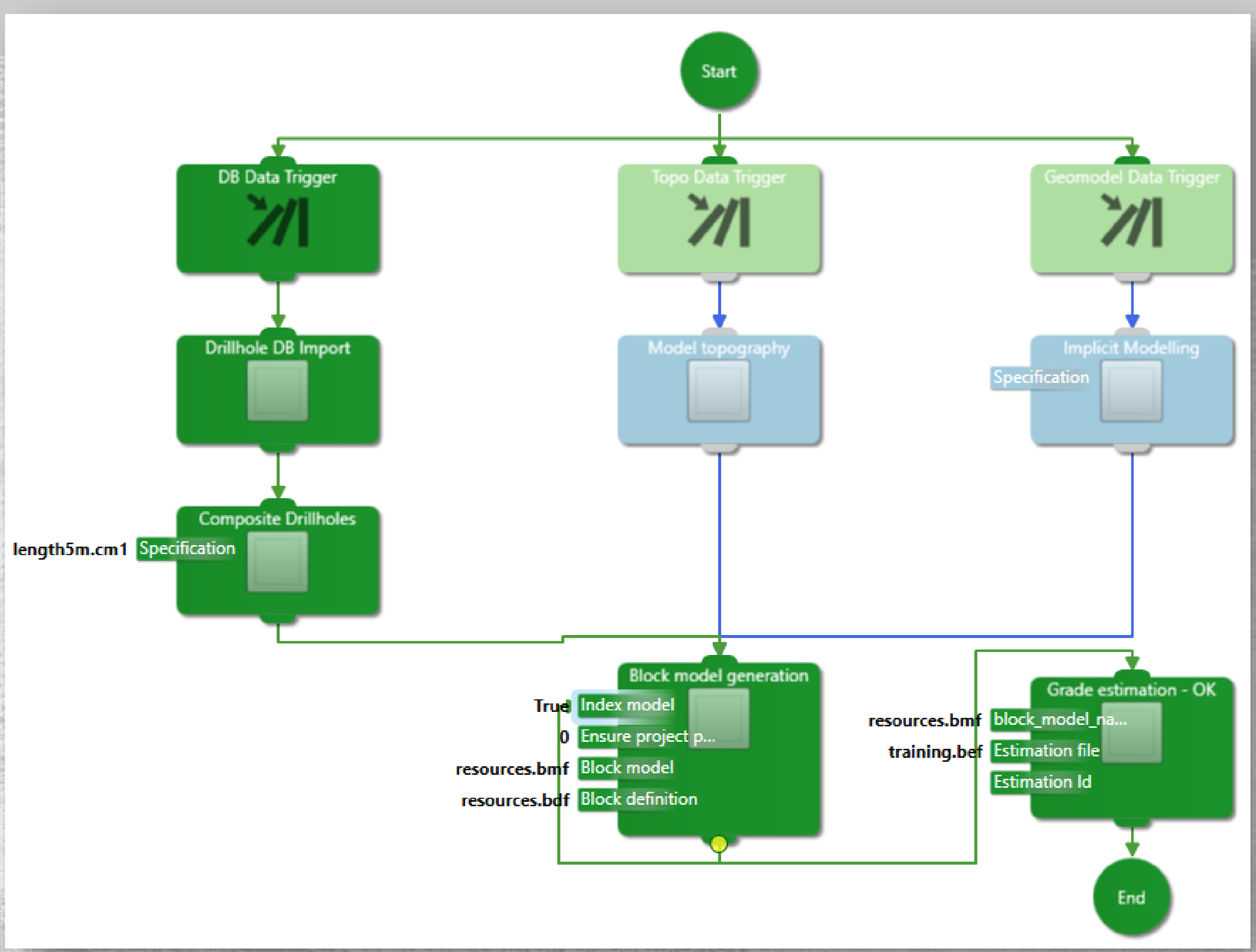


Digital twinning of mineral deposits – dynamically linking data to models

- Mineral deposits and the contained mineral resources are not dynamic systems or entities.
- However, our **perception** of them is **dynamic** and changes through time during various stages of mineral exploration and later during mining with the inflow of new information and data from various sources.
- **Current approaches** to building models of mineral deposits are **work-intensive**, **repetitive**, **time consuming** and lead to a **static representation**, consisting of **multiple disconnected components** that require human intervention to update with new data and information.
- Digital twinning of mineral deposits can be the answer to these issues and provide a more holistic approach for mine planning purposes.

Mineral resource digital twin framework

- Developing a digital twin of a mineral resource requires formulation and automation of various analytical and modelling steps that lead to the generation of the necessary model components such as geological and topographical boundaries, structural surfaces, and grade estimates.
- For the purposes of our research, a graphical environment called **Workflow Editor** is used to develop automated procedures that access a wide range of existing geological modelling, and grade estimation tools, and additional data processing and modelling components written in Python.
- Some of the additional components use machine learning algorithms to speed-up the digital twin operation and reduce the requirements for human intervention.

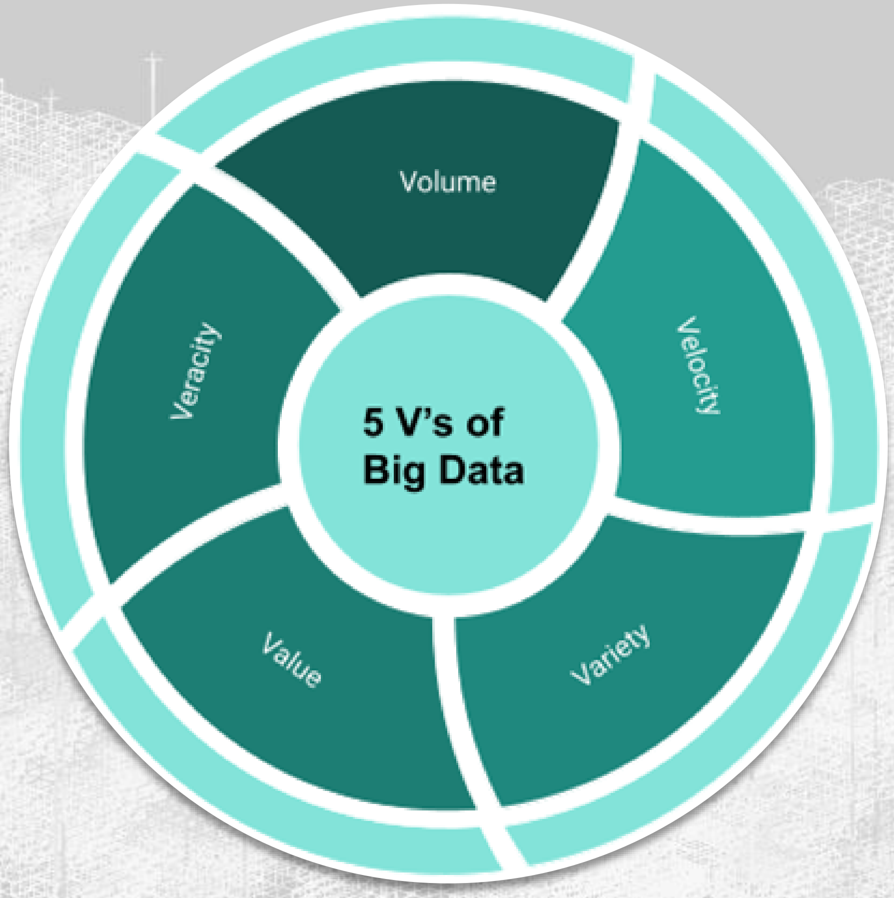


Digital twins of mineral deposits – the challenges

- While engineered systems can be digitally twinned, natural systems containing **inherent uncertainties** , such as mineral deposits, present challenges, especially where **human-intensive procedures** are required.
- Each mineral deposit differs as to one or more aspects, requiring different combinations of analytical and modelling processes.
- Traditional mineral resource modelling methods tend to require **repetition of the entire procedure** to account for changes in the available data and information, even when the scope of these changes is spatially limited.
- These methods also tend to be less suitable for automation, making them more difficult to integrate in a digital twin of a mineral deposit.

Big data analytics

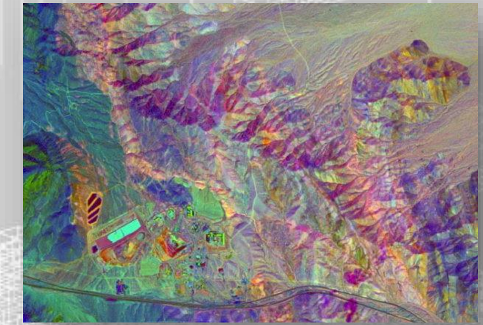
- Big data refers to large volumes of structured and unstructured data produced by and related to a process on a day-to-day basis.
- It encompasses data from a variety of sources, at the planning and operation stage of an industrial or other process.
- Big data analytics can significantly enhance mineral resource modeling by enabling the integration, analysis, and interpretation of large and complex datasets from diverse sources.

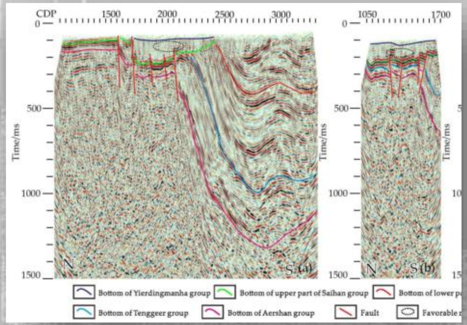


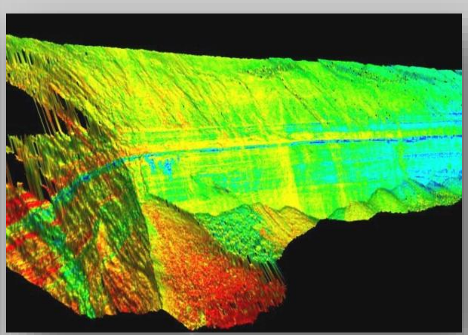
Mineral deposits – sources of big data

Common characteristics of big data	Data from mineral deposits
Volume: The amount of data generated periodically. Includes both structured data (e.g., databases) and unstructured data (e.g., social media posts, emails).	Large volumes of data can be generated at various stages of mineral exploration and mining, including actual measurements and expert views and interpretations.
Velocity: The speed at which data is generated and collected. With the advent of real-time data streaming and internet-connected devices, data can be generated at an unprecedented pace.	The flow of data and information is mostly regular during mineral exploration stages, but quite irregular in between and once mining commences. Digitalisation of exploration and mining gradually reduces the associated time delays.
Variety: The different types of data available. Big data can come in various forms, including text, images, videos, sensor data, and more.	Data can come in different formats such as spreadsheets, 3D point clouds, survey lines, images, text, and more.

Major sources of data for mineral deposits (1)



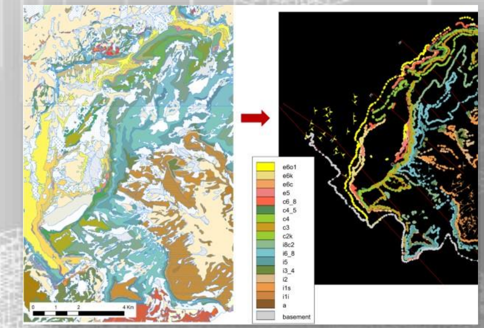




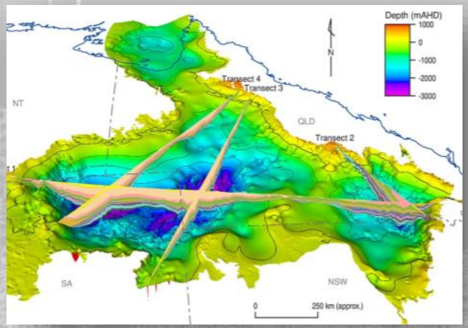
	Satellite images	Geophysical surveys	Drilling	Laser scanning
Stage	Mineral exploration	Mineral exploration	Mineral exploration and production	Mineral exploration and production
Volume	Gigabytes per image	Gigabytes to terabytes per survey	Megabytes	Megabytes to gigabytes
Velocity	Depends on the time resolution of the satellite system	Can be high during the survey	Low as drilling is a non continuous processes	Can be high during the survey
Variety	Low as most images produced are of standard formats	Low as most surveys are recorded in standard file formats	Medium as drillhole data is commonly recorded in spreadsheet format but columns/variables will vary from one deposit to the other.	Low as most scan files produced are of standard formats
Scope	Identify rock types, geological structures, and alteration zones, detect surface minerals	Geological modelling including rock types and structures	Geological modelling including domaining, structural modelling, and grade estimation	Geological modelling, topographical modelling, geotechnical analysis
Automated analysis and interpretation	Possible using supervised and unsupervised methods of image processing, feature extraction, classification, etc.	Possible using supervised and unsupervised methods of analysis and interpretation	Requires statistics and geostatistics that can be automated to some extent - possible use of machine learning methods	Possible using supervised and unsupervised methods of analysis and interpretation

Major sources of data for mineral deposits (2)

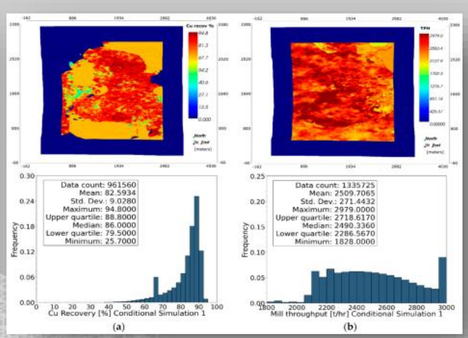
Geological maps



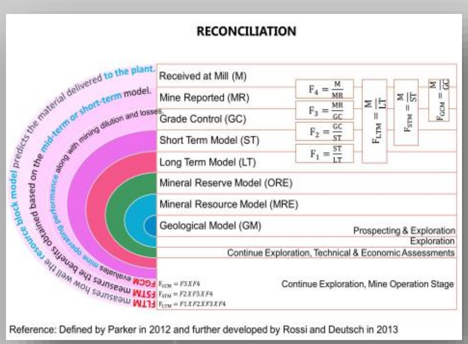
Hydrogeological measurements



Geometallurgical data



Operational data



	Geological maps	Hydrogeological measurements	Geometallurgical data	Operational data
Stage	Mineral exploration	Mineral exploration and production	Mineral exploration and production	Production
Volume	Megabytes up to gigabytes depending on scan resolution	Megabytes	Megabytes	Megabytes
Velocity	Low	Low	Medium	Low
Variety	Low as most images produced are of standard formats	Medium - piezometer readings, ground penetrating radar, water table data	Low	High as the data can differ depending on the mining method, equipment, life of mine, and even ESG factors.
Scope	Geological modelling	Geological modelling	Assessment of ore recovery, cutoff grades, processing costs, etc.	Resource model orientation and resolution (size of mining units), mining and processing recovery, dilution, operational costs
Automated analysis and interpretation	Possible using supervised and unsupervised methods of image processing, feature extraction, classification, etc.	Requires statistics and geostatistics that can be automated to some extent - possible use of machine learning methods	Principal component analysis (PCA), cluster analysis, and geostatistical methods	Not possible for now – human input is required

Big data analytics – applications in mineral resource digital twin development and operation (1)

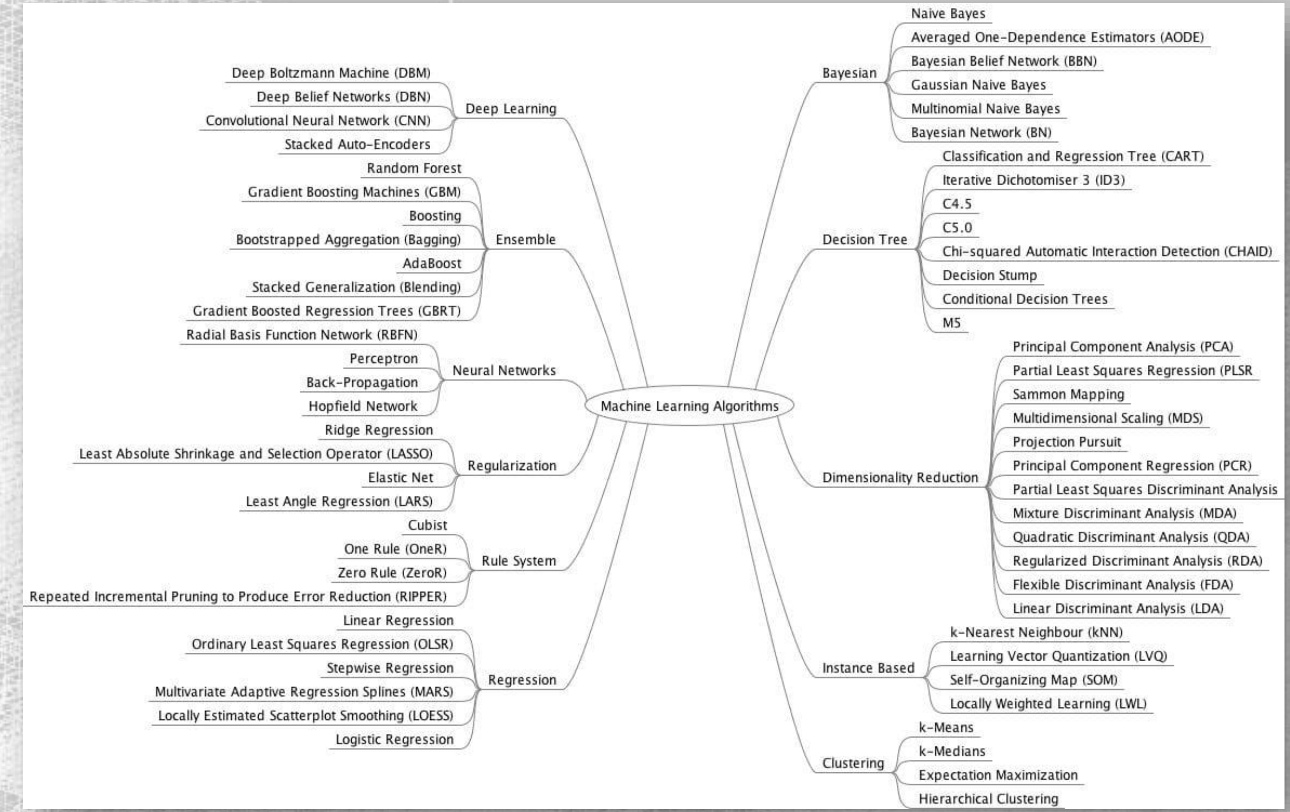
1. **Data Integration**: facilitate the integration of heterogeneous datasets, including geological, geochemical, geophysical, drilling, metallurgical, and operational data.
2. **Data Preprocessing**: automate the preprocessing of raw data, including data cleaning, normalization, transformation, and quality control.
3. **Feature Extraction**: enable the extraction of relevant features from large datasets, such as mineralogical signatures, geochemical anomalies, geological structures, and spatial patterns.
4. **Predictive Modeling**: support the development of predictive models that estimate mineral resources and reserves based on geological, geochemical, and geophysical data.

Big data analytics – applications in mineral resource digital twin development and operation (2)

5. **Spatial Analysis**: enable spatial analysis of geological and geospatial data to identify spatial trends, patterns, and correlations within the exploration area.
6. **Uncertainty Analysis**: facilitate uncertainty analysis and risk assessment in mineral resource modeling by quantifying uncertainties associated with data inputs, model parameters, and resource estimates.
7. **Real-time Monitoring**: enable real-time monitoring and analysis of exploration and mining operations, providing timely insights into ore grade, production performance, and process efficiency.
8. **Data Visualization and Reporting**: support data visualization and reporting tools that communicate modeling results, insights, and trends to stakeholders effectively.

Big data analytics – methods and techniques in mineral resource digital twin development and operation

- Regression analysis
- Principal component analysis
- Clustering methods
- Neural networks
- Random forests
- Support vector machines
- Deep learning



Conclusions

- Having access to in-depth data is necessary for the mining industry to support accurate decision-making, as well as meet a growing list of sustainability and compliance requirements.
- Digital twin technology is rapidly gaining ground in this data-driven industry to supply this crucial data.
- The application of big data analytical procedures is crucial in digital twinning of mineral deposits and opens the door to a **new age of mineral resource modelling and mine planning tools**.
- By leveraging big data analytics, mining companies can improve the accuracy, efficiency, and effectiveness of mineral resource modeling, leading to better-informed decisions, optimized resource utilization, and enhanced operational performance.

Thank you for your attention!