Welcome to the Real-Time Mining project!

It is our pleasure to introduce you to the Real-Time Mining, a European H2020 funded, project. Different experts from across the Europe collaborate with one common goal, which is to develop a real-time framework to decrease environmental impact and increase resource efficiency in the European raw material extraction industry. In particular, the project will develop a real-time process-feedback control loop linking online data acquired during extraction at the mining. The data is used rapidly with a sequential up-dateable resource model associated with real-time optimisation of long-term planning, short-term sequencing and production control decisions.

Since the project started in Delft in April 2015 it has kicked off successfully and many interesting and interdisciplinary activities are ongoing in various fields of resource extraction. A first annual meeting was held in April in Lisbon, were a board of international experts evaluated the progress and the second year activities were aligned.

The intention of this newsletter is to inform you about ongoing activities, preliminary achieved results in these diverse fields and also provide some points of contact to you, if you are interested. In this issue of the newsletter you will find information about the consortium, the overall concept of Real-Time Mining and activities related to its building blocks, which are:

- Underground positioning,
- Automated material characterization,
- Machine performance,
- Data management and visualization,
- Rapid resource model updating and
- Production control optimization.

We hope you enjoy reading. Please feel free to get in touch with us for comments, questions or suggestions.

Project Coordination
Mike Buxton and
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The Real-Time Mining project has been awarded funding from the European Union’s Horizon 2020 Research and Innovation Programme under Grant Agreement No 641989
The project consortium comprises thirteen European partners from five countries and is led by the Resource Engineering Section of the Delft University of Technology assisted by an international External Expert Advisory Board. Besides Delft University of Technology, the partners involved include the Rheinisch-Westfälische Technische Hochschule Aachen; Imperial College of Science, Technology and Medicine; Associacao do Instituto Superior Tecnico para a Investigacao e Desenvolvimento (IST-ID); Nederlands Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek-TNO; Geovariances, Dassault Systems GEOVIA Ltd.; LSA-Laser Analytical Systems & Automation GmbH; XGraphic Ingenieurgesellschaft mbH, SonicSampDrill BV; Technische Universität Bergakademie Freiberg; Spectral Industries B.V. and Ingenieurpartnerschaft für Bergbau, Wasser und Depo-nietechnik (IBeWa).
With the depletion of known and established mineral reserves, the decrease in head grades and the continuing demand of mineral raw materials by the modern society, future exploitation will move towards extraction of deposits under geologically more complex conditions. Complex deposits are characterized by a low continuity in grade and high irregularity in the geometry of the ore boundaries. As a result, a profitable exploitation of the deposit becomes a lot more challenging. To be able to better utilize such unconventional mineral resources of the future, smart autonomous mining systems are needed, which integrate local exploration of spatially varying material characteristics in-situ and have the ability to follow and extract the pay zones in the ore body while optimizing the sustainable value of extraction (e.g. European Commission, 2010). The main barriers to overcome for the successful economic exploitation are:

- effective grade control which will maximize resource potential along the whole value chain,
- minimization of handling zero-value material introduced by dilution, thus,
- reducing unnecessary expenditure of energy and financial resources and
- management and control of the geological uncertainty due to limited information available, thus optimising resource utilisation.

The current state-of-the-art in mineral resource management is a discontinuous intermittent process along the mining value chain (Figure below upper part). It starts with collection of exploration data, e.g. drill holes, followed by the development of a 3D spatial resource model, generated using sophisticated geostatistical modelling techniques. The resource model is used to specify the extractable reserves. Due to data scarcity, it is associated with a significant level of uncertainty. Notwithstanding this uncertainty, mine planning decisions are made, expected performance is predicted and the plan is executed. A comparison between model based predictions and actual performance typically occurs at the end of the production process, when ore grades and tonnages are determined for materials shipped to the customers. At this stage, deviations from production targets are noted; however, the opportunity for corrective action is no longer available. From data gathering to the final reconciliation, often months or even years may have passed.

**Overall Concept**

Moving from discontinuous process to a real-time continuous closed-loop process.
In April 2015 the multi-partner and multi-national European Commission funded R&D project Real-Time Mining was launched. The key concept of Real-Time Mining research promotes the change in paradigm from discontinuous intermittent process monitoring and control to a continuous closed-loop process management system (Figure 1 lower part). The development of such an integrated framework in the context of mineral resource management is novel and involves significant scientific challenges as it has to integrate multiple distinct scientific disciplines into one coherent process monitoring and optimisation framework. Main building blocks of Real-Time Mining are:

- underground equipment positioning,
- sensor-based material characterization,
- sensor-based machine control monitoring,
- methods of spatial grade prediction using geostatistical approaches and rapid updating and
- optimization of short-term planning.

The main objective is to develop an innovative technical solution for resource-efficient and optimal high precision/selective mining in geologically complex settings. This will integrate the different components of autonomous positioning of mining equipment, spatially-referenced real-time sensor-based monitoring, extraction planning model updating together with decision and machine control optimization. The near autonomous system will enable access for exploration and exploitation in small deposits and difficult locations by selecting suitable equipment feasible in ruggedized and extreme conditions.

This contribution will introduce a closed loop framework for Real-Time Mining. First the concept and necessary building blocks are outlined followed by a review of the state-of-the-art. The focus in the review is on the identification of necessary progress in research and technology development to develop a so far conceptual framework (technology readiness level TRL 3-5) to an industrial proven concept (technology readiness level TRL 7-9). Over the next three years Real-Time Mining anticipates to close these gaps. An illustrative case study at the end highlights some selected aspects and demonstrates the potential value added.

The Real-Time Mining Concept and Building Blocks

Typical deposits in the context of geological complexity consist of some of the following attributes:

- geologically structurally irregular, e.g. dismembered, deformed, narrow veins, steep geometries (typical for tin or tungsten veins, lead-zinc, gold, chromite, rare earth deposits),
- high spatial variability of grades and presence of deleterious elements, e.g. arsenic, cadmium,
- highly diffuse grade boundaries (typical for rare earth deposits, massive sulphide hosted copper deposits),
- clusters of low tonnage deposits or occurrences (typical for tungsten deposits).

The extraction of these raw materials is generally done by surface mining and underground mining methods based on depth of occurrence of the ore. Common to both mining methods is the necessity to sequentially complete the following process steps:

- define and understand the ore body during exploration,
- estimate the resource potential (resource modelling),
- develop a long-term extraction plan (mine planning),
- develop a short-term sequence of extraction tasks (extraction sequencing),
- optimize operational control to produce material, including blending and dispatch decisions which accord with predefined specifications.

The amount of information available from traditional exploration is increasingly inadequate in more complex geological settings. The resolution of the data and the ability to interpolate in-between data is insufficient to generate the required knowledge about the deposit in order to provide real-time control of the extraction process within the limits set by principles of sustainable mining. In conventional mining applications this process is currently intermittent and discontinuous since it relies on physical sample collection and subsequent analysis in an external laboratory. The Real-Time Mining approach will progress towards an innovative self-learning extraction process. It will provide a real-time process feedback control loop linking online data acquired during extraction at the mining face and during material handling for rapidly updatable resource model associated with real-time optimization of long-term planning, short-term sequencing and production control decisions. Figure on the upper right hand side summarizes the integrated concept of the project and the interaction between necessary building blocks (BB). A similar approach to Real-Time Mining has been recently developed in the context of hydrocarbon extraction and demonstrated a reduced extraction cost and associated increase in resource efficiency of 6% - 9% (e.g. Jansen et al, 2009).

The Real-Time Mining concept follows the general closed-loop approach and can be applied to general mining settings, open pit and underground. It builds on a (near) real-time interaction between the mining machine and extraction process, resource and mine planning models and decisions to be made on a short-term scale. During the mining process, online production data will be obtained which can be geo-referenced based on localization and material tracking systems. Utilizing these data and relating them to material properties offers the ability to update resource/grade control models used for short-term decision making and production control. Decisions within the latter can be optimized using sophisticated optimization tools.
The building blocks are integrated in the RTM system are:

BB1: For a quantifiable impact assessment of the technologies and methodologies developed within RTM, a set of sustainability and industrial viability indicators is under development. These focus specifically on resource efficiency, techno-economic and environmental performance aspects. The indicators will use improved positioning equipment, sensor and machine performance parameters, as well as resource model quality and optimisation parameters to devise robust performance metrics for RTM implementation.

BB2: The spatial context of all data acquired has to be determined in order to fully exploit the value of sensor data gathered during production. BB2 will provide and integrate demonstrated technologies for underground positioning (UP). These technologies have to be applicable to the physical conditions expected in small scale mining applications, including case specific required level of precision.

BB3: Understanding relevant geological material parameter to monitor and classify, BB3 will provide ruggedized and modular combinations of sensor technologies applicable for real-time material characterization in small scale mining environments. The intention is to characterize grades and geo-metallurgical attributes such as textures, mineralogy and hardness. This application requires the development of a multi-variate statistical interpretation rule to relate combination of sensor signal with raw material properties and an appropriate sampling strategy to account for the sampling medium, material variability and required levels of precision. The sensor data will be spatially constrained using the data from BB2 and integrated into a consistent data base.

BB4: Sensor concepts acquiring real-time machine performance data provide additional information related to material characteristics, such as specific energy usage, pull up or pull down pressure. Depending on the rock strength and rock hardness RTM considers two scenarios of extraction: A) Extraction by drilling and blasting with subsequent loading/hauling and B) Extraction by rock cutting coupled with continuous hauling. Examples of machines considered are shown below.

A1) Underground Drilling (Results used in grade control)  
A2) Sonic Drilling  
B) Rock Cutting  

Innovative application: grade control  
No grade control

Examples of mining machines considered within Real-Time Mining (RTM).
BB5: Computational efficient methods for integrating enormous data sets have to be advanced for integrating sensor information with different formats into a single consistent spatial database. Visualization tools will be developed for supporting real-time operation control and decision making, resulting in a virtual operation control cockpit. This will also integrate results from the updated resource model (BB6) and optimized mine plan (BB7).

BB6: provides a geostatistical framework allowing for a rapid and sequential update of the short-term resource/reserve model utilizing highly dense sensor based data generated from online material characterization (BB3) and machine performance (BB4). To predict the performance along the whole value chain, attributes of the spatial model to be updated including economic, extractability and processing relevant attributes of the raw material as well as attributes affecting safety and environment as defined in BB1. Results will be used as input for optimizing the extraction process in BB7.

BB7: provides rapid and real-time optimization methods in the context of long-term mine development, short-term sequencing, production control and auxiliary processes.

Utilizing real-time updated models about the spatial distribution of ore from BB6, it is expected to lift a huge potential in improving efficiency-related to selective extraction and resource recovery, eliminating waste in an early stage of the process chain, more effective dispatch decisions, blasting design or local rock support strategies. To close the loop, BB7 will feed back information to BB5 as virtual operation control cockpit.

Figure below illustrates the concept for a general underground mining setting. Based on a prior resource model the extraction sequence at different loading points is planned and a model based prediction can be performed for monitoring/sensor stations. Sensors will measure the actual properties of the raw material within a certain precision. The difference between model based prediction and sensor based measurements will be fed back into the resource model resulting in an updated or posterior resource model. Based on the new information available mine planning decisions and production control strategies can be revised and adjusted to most current information.

Schematic example of RTM applied to an underground mining operation.
Within the RTM project framework, BB2 aims to provide a set of intrinsic indicators that impact on sustainable performance and industrial viability assessment during primary extraction of raw materials, specifically tailored to small and geologically complex deposits. At the end of the project, all results from demonstration activities will be reconciled against the predicted project impact using the established SPIs. In the context of the BB2, there are five tasks. The first two of these have already been completed:

- The first task compiled a generic process map of real-time-mining, including a preliminary definition of key performance indicators (KPIs), controlling factors influencing the KPIs and geological and technical machine or system parameters that need to be measured for effective extraction process control. This task also proposed a state-of-the-art advanced mine control, operation and safety system for small scale mines under standard operation, to be extended further with the additional input from the REAL-TIME-MINING data acquisition and processing systems.

- The second task provided a thorough review of the existing sets of standards, regulatory frameworks and policies, quality management and environment management systems, best practices and benchmarks relevant for the mining of small and complex mineral deposits and identified the gaps and opportunities for further indicator development and standardisation.

Current work is focusing on the third task looking to develop the detailed Sustainable Performance Indicators (SPIs) of the process, allowing for a measurable quantification of impacts of RTM. The aim is to articulate the required sensor performance that is needed to quantify the SPIs and define the critical levels of precision and accuracy for each SPI in order to ensure that reproducible and factual sustainable performance can be measured in small-scale raw materials extraction.

The validation and update of the preliminary KPIs will be carried out as the fourth task, which will also define definitive interfaces to BB3, BB4, BB6 and BB7.

The final task is the integration of project demonstration activities and reconciliation of results with respect to the predicted project impact.

Special points of interest:

**From task 1:** The KPIs need to refer to the value of the sensor technologies with regards to the extraction process and the real time update and re-alignment of mining processes as:

- sensor effectiveness: which needs to be defined in different terms for each sensor technology
- sensor cost: including capital cost, operational cost (maintenance, and personnel costs in order to implement the monitoring method.

In this respect, the performance of given equipment and the extraction process is to be measured and compared against the standard benchmarks using the following KPIs, which are also referred to as metrics:

- Extraction technology (machine) performance and effectiveness metrics
- Metrics assessing the value of the real time monitoring data and updated models
- Sustainability and industrial viability metrics.

The requirements for a state-of-the-art advanced mine control, operation and safety system for small scale mines under standard operation, suitable to be extended with the additional input from the RTM data acquisition and processing systems, have also been outlined. A system that fulfils the demands of a small to medium scale mine while still remaining affordable, is a considered a challenging task.

**From task 2:** Small scale mining operations are treated no different than larger operations as far as legislation, directives, and policies are concerned in the individual EU member states.

In terms of gaps towards the establishment of SPIs relevant for small scale mining, these have been identified and relate to legislation, effects of climate change, assessment of impacts, as well as integrated geological databases, the use of renewable energy in operations, utilisation of mining waste products and the effects of early waste separation by automated sensor systems and their integration in the mining production cycle.

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Generic process map for small scale and complex underground mining systems

(room and pillar, cut and fill, sub-level stoping, open stoping, bench stoping, drift and fill).
Building block 2 (BB2) of the Real-Time-Mining project is focused on the development of a real-time robust, modular precise positioning system suitable for mobile equipment used in underground mining applications. For that purpose sensor information of different sensors such as ultra-wideband radio (UWB), inertial measurement units (IMU), and geometrical systems like, e.g. a laser scanner are merged. If all three sensor systems are providing information it is expected to obtain a precise and robust position information for a machine in an underground environment at an accuracy of at least 0.5 m (within a 90% confidence interval).

To employ the sensor most efficiently and suitably, two use cases for the positioning were defined:

- **Use Case 1 (UC1):** the high accuracy positioning, e.g. the real time positioning of a drill rig before and during the drilling process.
- **Use Case 2 (UC2):** the positioning of fast moving machines, which need a high update rate of the position information (e.g. shuttle cars)

In both use cases the UWB system will act as an absolute system for obtaining the position information. The method employed is the time of flight measurement between UWB-modules at fixed positions, also called anchors, and one or more mobile tag on a machine. The position can then be derived using methods like multilateration.

However, this also means that an extensive infrastructure with UWB anchors has to be deployed in the respective mine. In future practical realisations this might lead to economic issues. At the same time a line of sight between the tag on the machine and at least three anchors may not be ensured all over the whole mine at all times. Because of this Use Case 2 (UC2) was defined. In UC2 the information of the other sensor systems, which are independent of an infrastructure, will be used as backup information for the calculation of the position.

To prove the concept and induce further developments on each of the sensors a first test measurement was undertaken at the Freiberg test mine “Reiche Zeche”. In this underground mine two areas were chosen for testing of the two use cases. A long linear stretch for UC2 and a bended track for UC1. Both tracks are outfitted with rail tracks. This made it practical to obtain further reference position information. At the same time it was easy to strap the different sensor systems onto a rail cart (Fig. 1) as well as a separate laserscanner system, to reconstruct the track in hindsight.

The tests were conducted successfully, also thanks to the great help of the TU Bergakademie Freiberg team. By now the participants of BB2 are engaged in the data evaluation and processing of the measurement results. Further test measurements are planned and will be carried out based on the experiences and the developments that resulted from the first test measurement.
Sensors for Materials Characterization

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Within the framework of real-time mining project, BB3 “Sensors for Material characterization” aims to define, develop and test potential sensor combination concepts for raw material characterization to provide relevant data for real-time online process control and optimization in small scale mining applications.

In the context of the BB3, there are four tasks. The first task of the project aims to identify suitable technologies and define potential sensor combinations for different commodity styles and the considered case study mines. The second task of the project aims at definition of sensor combination concept based on definition of sensor specifications for raw material characterization. The third task aims at laboratory scale test work and validation of sensor specifications and the fourth task aims to develop a statistical inference rule linking KPIs with sensor measurements. The first two tasks (Task 1 and Task 2) are completed. Task 3 and task 4 are the subsequent tasks. A field campaign was undertaken in order to define, image and map the mine face and to collect fully representative samples over a 2 week period. To ensure the coverage of spatial variability along 22m exposure of mine face, channel sampling method which is advantageous to sample from each lithotype and ore type independently was deployed. A total of 23 channels were cut and about 102 samples were collected at different intervals of each channel. The subsequent task is to undertake laboratory scale test measurements using the collected samples and the different sensor technologies defined in Task 4.2.

Special points of interest:
- Suitable sensor technologies for polymetallic sulphide mineral characterization
- Sensor parameter specification for material characterization
- Sensors combination for material characterization
- Validation of sensor specification
- Statistical inference rule linking KPIs with sensor measurements

Sensor Technologies

Applicability of sensor technology for raw material characterization is rapidly growing, and innovative advancement of the technologies is observed. However, due to economically marginal deposits, deeper mine and complex geology, there is still a need to define and develop improved technology which can address the current and future mining challenges. One of the approaches to address these challenges is to define and develop a sensor combination concept for raw material characterization and this is the main focus of this project.
The old miners’ proverb ‘It’s always dark ahead of the pick’ also applies for cutting and drilling processes. This expression reveals the uncertainty about evaluating the rock and its geology. It is impossible to predict what the machine will cut or drill through. Questions arise like: What kind of material are we cutting or drilling through and how will it change in a few meters? Will it get harder? Will it get softer? How will the material break? How can the optimal machine performance be reached?

Hence, in terms of safety, energy consumption and the performance of the whole machine it would be beneficial to monitor the process in real-time. Part of building block 4 (BB4) is to answer at least some of those questions by using sensor information.

By breaking down a drilling or a cutting process into tools in contact with rock the process is directly dependent on their interaction meanwhile the interaction is dependent on the tool condition and the critical rock properties (e.g. rock strength, abrasiveness, natural jointing). Thereby, through the interaction behaviour several information like forces, vibrations, tool temperatures are generated which can be measured by sensors and link them to the rock properties and the energy consumption of the process. Hence, these information can be used to monitor machine performance. Possibly, in the future it also can be used to adapt process parameters like advance rates to the given rock.

Different sensor combinations are currently tested. Questionable is, which sensor or sensor combination can deliver the necessary information on the cutting or drilling process. Therefore, different sensors or sensor combinations like strain gauges, an infrared camera, PT1000, acceleration sensors and acoustic emission sensors are tested and evaluated.

Laboratory tests with different sensor technologies replicating cutting processes on relevant cutting machinery at the new RWTH RockCutting Center (RCC) are conducted. The most important scenarios of cutting sequences are tested with different rock types. Parallel drill tests with a monitoring while drilling system are conducted on a drill rig.

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Data Integration, Management and Visualization

The purpose of building block 5 (BB5) "Data Integration, Management and Visualization" is the development of an integrated data management system and a 3D visualization cockpit to collect, exchange and visualize all the accumulated data in the project. The integrated data management system forms a centralized data base integrating all data collected via sensors (BB2, BB3 and BB4). This data base provides the corresponding access for the real-time resource model update (BB6). The central visualization cockpit is a high performance module that includes the visualization of deposit-model, 3D extraction planning, integrated data of the positioning-system as well as the visualization of sensor and machine performance data. The developed control cockpit will be technically integrated into a wider central control and monitoring station of the whole mine and will facilitate the demonstration action in the real industrial environment test cases (BB8).

A key topic in BB5 is the definition of the interfaces between the different WPs: The successful integration of the Central Data Exchange System depends on the file formats used and the implementation of an easy conversion methodology for different data types. As a first result, an analysis of the detailed requirements and available state-of-the-art standardized data formats has been compiled. Based on existing software solutions from Dassault Systemes for information exchange for mine planning and monitoring and for gathering and alignment of data, the specific requirements for the central data exchange framework have been defined. Current work includes the implementation of specific interfaces and testing of cross-partner data communication.

The visualization cockpit is planned as fully interactive 3D application. Different screens for mine layout overviews and the visualization of active operating points with details about mineral content, tonnage, schedule information and the local grade control model will be available. Key component will be a so-called "Face View" with an interactive optimization of the blast block planning based on real-time sensor and available 3D data. For the implementation of the 3D visualization cockpit, available toolkits and various 3D engine solutions have been evaluated. Current work includes the implementation of data import libraries and the definition of the graphical user interface for the different screens.

Flow chart and Building Blocks (BB) of Real-Time Mining (RTM).
Sequential Resource Model Updating

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One of the cornerstones of the Real-Time Mining concept is the ability to rapidly integrate different sensor data gathered during extraction, such as face images, material characterization data on conveyor belts or energy usage records of the mill, and feed it back into decision making models. These typically are the resource model for long-term planning activities and the grade control model for short-term planning and production control. Below figure illustrates the process and information flow for a generalized process and links the decisions to be taken within the different steps of a mining process with the underlying models, modelled properties and available data.

Results of BB6 will provide a geostatistical framework allowing for a rapid and sequential update of the short-term grade control model utilizing highly dense sensor based data generated from online material characterization (BB3) and machine performance (BB4). To predict the performance along the whole value chain, attributes of the spatial model to be updated including economic, extractability and processing relevant attributes of the raw material as well as attributes affecting safety and environment. Results will be used as input for optimizing the extraction process in BB7. Under the lead of Delft University of Technology a dedicated group of experienced partners from industry and academia currently investigates alternative methodological approaches.

**Planned Conference Presentations related to BB6:**

Partners will present intermediate results amongst others at following conferences:

- Geokinematicer Tag in Freiberg, Germany – May 2017
- SME Annual Meeting in Denver, USA – February 2017
- IAMG conference in Perth, Australia – September 2017

**Virtual Asset Models as Playground for Research and Development**

In a first project phase, 3D Virtual Asset (VA) models were created for typical deposit types considered in the project, including a complex sulphide base metal deposit, a polymetallic hydrothermal ore deposit and a vein hosted gold deposit. These VA models will provide a synthetic full scale 3D exhaustively known environment, which captures main features to be expected in typical application cases of the Real-Time Mining concept. Further, these models serve to derive different sampling scenarios, including deriving expected sensor responses, and serve as benchmark for performance investigation of different methods and parametrizations. Figures on the next page show examples of VA models for a hydrothermal vein consisting multiple minerals and a sulphide stockwork orebody.

![Generalized process and information flow in underground mining.](image)
Simulated geometry and mineralogy for a vein in a polymetallic hydrothermal deposit (TU Delft in collaboration with Dassault Systems and Geovariances)

Updating Concepts Considered

At this moment, in particular academic partners investigate theoretical approaches for fast updating models. Initial investigations have shown that amongst other techniques data assimilation techniques offer a potential solution. These methods originate from weather forecasting and have been successfully applied in updating numerical models in different fields such as, such as hydrogeology or petroleum engineering. These methods will be adapted to the particular scope of Real-Time Mining.

Other fields of currently ongoing research include:

- filter algorithms dealing with the data density of sensor data
- supervised learning for identifying the relation of sensor data and raw material characteristics
- methods for generation of initial prior grade control models
- sequential updating algorithms for structural geological attributed
- sequential updating algorithms for geometallurgical properties
- scenario reduction algorithms as input for optimization in BB6
- Conditional bias correction to integrate a) fast and abundant XRF, b) chip samples and c) much less abundant bore-hole data

For the latter one the CERENA group of the Technical University of Lisbon has recently conducted a sampling program in a sulphide mine and currently investigates method for integration of soft XRF data into updating of local reserve estimations.

Simulated Zn grade realization in a stockwork zone serving as VA model (Geovariances in collaboration with TU Delft)

Concept of integrating soft sensor data in local reserve models
The overall aim of BB7 is to analyse and evaluate the total potentials of integrating real-time data generated by BB1 to BB4 into the mine planning procedures and production control. Thus deviation between the origin prediction and the real resource can be easier considered in future plans.

The overall objective during last month’s work is to show potentials of using real time data by integrating the expected uncertainty in the resource model. Therefore mine planning software was analysed regarding functionality of integrating uncertainty. Besides having a look at the available software packages the general procedures for underground long-term mine planning optimization were investigated and evaluated. To exploit full potential of integrating real-time data in mine planning procedures possible uncertainties that could be reduced by real-time data were identified. An overview of a common mine planning procedure and potential uncertainties are shown in Figure “Uncertainties in mine planning procedure”.

Steps in BB7

- Select cut-off grade
- Select mining method
- Design stopes, mine infrastructure
- Schedule mining operation and development
- Analyze cost & economics (Result: NPV)

For fulfilling the long-to mid-term related objectives, the further research is set on:

- Developing a tool optimizing mining sections and stope geometries as well as mining sequence under uncertainty
- Investigating the use of smart tags for bulk material tracking
Demonstration Activities

Demonstration activities cover all partners of the Real-Time-Mining consortium. Led by TU Bergakademie Freiberg, the underground research and education mine “Reiche Zeche” serves in this project as a test and sampling facility, as well as demonstration site of the Real-Time-Mining’s achievements. In addition, two technologies are developed in form of a mine control system and wireless through the earth (TTE) data transmission.

The mine control system developed by the team of TU Bergakademie Freiberg, Chair of Underground Mining Methods, aims for applicability at small to medium mining operations. For this, conditions differ to large scale settings in respect to financial capability and surveillance manpower to control operations. In order to assess the current situation the best possible, a targeted analysis on system integrations was performed at multiple mining sites. Discussions with providers and applicants of mine control systems allowed evaluating the challenges in respect to technical realization and usability. Based on these experiences, TU Bergakademie Freiberg decides to focus on pushing the standardization of data provision among mining machinery and control systems. The unified integration of machine and sensor data is actually considered the key parameter for an economical provision of control systems at small to medium scale operations. Consequently, TU Bergakademie Freiberg became part of the International Rock Excavation Data Exchange Standard (IREDES) Consortium in June 2016, sharing a matching comprehension with this initiative. Like this, the mine control system will be developed to allow easy implementability on site, while containing the Real-Time-Mining’s control cockpit developed by the consortium.

The mine “Reiche Zeche”, operated by TU Bergakademie Freiberg, is unique in its form within Europe. Representing a former silver ore mine under production until 1969, it is characterized by small drifts and narrow ore veins within the deposit. Nowadays it is used for research and educational purposes by TUBAF and numerous partners from academia and industry. For Real-Time-Mining the complex and small deposit represents an excellent test case to meet the project’s objectives. The partners of Real-Time-Mining visiting the mine are able to perform data acquisition by sampling and imaging in an expressive environment. Moreover, new technological concepts are tested and optimized to gain experimental knowledge within an underground ore mine. TU Bergakademie Freiberg is glad to arrange and organize this acquisition and test sessions, having been performed by RWTH Aachen, TU Delft, TNO and IBeWa in the meanwhile.

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In July 2016 an extensive sampling program was conducted at the mine “Reiche Zeche”, Freiberg. Data will be used for calibration of different sensor technologies and for the development of resource updating models.
List of selected publications


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