REAL - TIME MINING

PROJECT OVERVIEW

FONTAINEBLEAU, SEPTEMBER 2015
J BENNDORF

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 641989
WHO WE ARE: RESOURCE ENGINEERING AT TU DELFT

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1 Associate Professor
2 Assistant Professors
1 Lecturer
1 Post-Doc
7 PhD’s

EAB Member
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Potential of critical raw materials in Europe classified by deposit sizes (PROMINE)

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BACKGROUND

• Complex deposits, characterized by a low continuity in grade and high irregularity in the geometry of the ore boundaries

• The profitable exploitation of the deposit becomes a lot more challenging resulting in an underutilization of valuable sources of raw materials

The main barriers to overcome for the successful economic exploitation are

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

thus optimising resource utilisation.

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MOTIVATION

THE TRADITIONAL APPROACH

SILO 1
Exploration and Data Collection

SILO 2
Resource Modelling

SILO 3
Mine Design Equipment Selection Reserve Estimation

SILO 4
Production Scheduling and Operation

SILO 5
Processing and Sale

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THE REAL-TIME MINING APPROACH

Integration of distinct scientific disciplines into one coherent process optimization framework:

- underground equipment positioning and material tracking,
- 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 REAL-TIME MINING
PROJECT OBJECTIVES

Overall objective:

*Develop an innovative technical solution for resource-efficient and optimal high precision/selective mining in geologically complex settings.*
THE REAL-TIME MINING
PROJECT OBJECTIVES

PO2: Develop a system of representative sustainable performance indicators (SPI) for high precision selective mining focusing on resource efficiency

PO3: Development and integration of sensor technology for online raw material characterization at the mining face, in drill holes and of bulk materials at high throughput.

PO4: Develop a key enabling methodology for real-time reconciliation by feedback of online sensor data into the numerical model

PO5: Optimization of short-term production system control decisions in a real-time fashion

PO6: Integration and visualization of all REAL-TIME-MINING components in a central control and monitoring cockpit.

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THE REAL-TIME MINING
REAL-TIME DATA

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THE REAL-TIME MINING PROJECT OBJECTIVES

WP 1: Sustainability and Industrial Viability Indicators
- Evaluation towards resource efficiency and environmental impact
- Development of measures accounting for sustainability and industrial viability

WP 2: Underground Positioning
- Positioning and inertial Navigation
- Infrastructure

WP 3: Sensors for Material Characterization
- Sensor combinations
- Link to ore properties (geochem, texture, mineralogical physical)
- Representative sampling strategies

WP 4: Sensors for Machine Performance
- Sensors for rock cutting applications
- Sensors for sonic drilling applications

WP 5: Data Integration, Management and Visualisation
- Central Process Control Cockpit

Mine Modelling and Mine Planning

WP 6: Rapid Resource Model Update – Real Time
- Geo-Metallurgical Uncertainty Models
- Real-Time Updating integrating exploration data and sensor information (material + machine performance sensors)

WP 7: Integrated Long- and Short-Term Optimization
- Long-term planning optimization of innovative mining technology incl. option pre-sorting
- Real-time optimization of short-term sequencing and production control

Demonstration activities in a near operational environment are compiled in WP8 and not included in this diagram.
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TEST CASES

Mining Equipment considered:

- A1) Underground Drilling (Results used in grade control)
- A2) Sonic Drilling Innovative application: grade control
- B) Rock Cutting No grade control

Test Sites
- Experimental Lab Settings
- “Reiche Zeche” mine of TU BAF
- Neves Corvo mine (SOMINCOR)
- Further to be defined throughout this meeting

All tasks performed during the project are intended as research and innovation activities. For proof of concept a series of limited but closely connected demonstration activities will be undertaken in a near to operational environment.
**TEST CASES**

The **Neves-Corvo** massive sulphide deposit is part of the Iberian Pyrite Belt (IPB) and discovered in 1977. It is one of the largest deposits in the IPB, with approximately 300 Mt of sulphide-rich rock. Neves-Corvo is currently mined for Copper, Tin and Zinc.

The **Freiberg area** is the oldest mining district in the eastern part of Erzgebirge. It was mined for Ag and for Cu, Pb, As (from 1168 to 1915) and later mainly for Zn and pyrite. Due to economic factors in 1969, the mine was closed. Starting from 1976, Reiche Zeche and Alte Elisabeth shafts were reconstructed as a research and teaching mine.
MINING METHODS
CASE FREIBERG

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MINING METHODS
CASE NEVES CORVO

Drift&Fill Mining in Stockwork Zone

Mini Bench & Fill Mining in Compact Ore

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Step 2: Ore Handling

Core Sample

Drill Hole

Ore zone

Muck-pile

LHD

Selective Loading Scheduling

Ore-pass

Ore Transfer

BIN

Crusher

Dispatching

A

B

C

Control decision points

Sensors for material characterization

Sensors for machine performance

Sensors for geo-referencing (positioning and material tracking)
DEFINING RESOURCE EFFICIENCY

According to the Horizon 2020 call, the central high level KPI is RESOURCE EFFICIENCY

KPIs related to resource efficiency

Most complex/optimal use of a natural resource:
- extraction recovery,
- process recovery
- Minimization of deleterious elements

Most efficient use or resources needed for extraction
- process efficiency (cost or resource usage/t of produced metal)
- OHS

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### DEFINING RESOURCE EFFICIENCY

<table>
<thead>
<tr>
<th>Resource Efficiency Dimension</th>
<th>KPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resource Efficiency</td>
<td>Extraction Recovery</td>
</tr>
<tr>
<td></td>
<td>Processing Recovery</td>
</tr>
<tr>
<td></td>
<td>(Ore/Waste ratio (Amount of Dilution))</td>
</tr>
<tr>
<td></td>
<td>...</td>
</tr>
<tr>
<td>Process Efficiency</td>
<td>Costs per ton of ore/metal</td>
</tr>
<tr>
<td></td>
<td>Specific energy usage per ton of ore extracted</td>
</tr>
<tr>
<td></td>
<td>Uptime of extraction equipment</td>
</tr>
<tr>
<td></td>
<td>Utilization of extraction equipment</td>
</tr>
<tr>
<td></td>
<td>Production per shift/day</td>
</tr>
<tr>
<td></td>
<td>Effective capacity of equipment</td>
</tr>
<tr>
<td></td>
<td>Compliance to long-term plan</td>
</tr>
<tr>
<td></td>
<td>...</td>
</tr>
</tbody>
</table>
CONTROLLABILITY
WHAT CAN BE CONTROLLED?

How can KPI’s be positively influenced by short-term planning and production control (Decisions to be optimized in WP8)?

Decisions prior extraction (short-term planning)
- Delineation of geometry to be extracted
- Classification of SMU’s to be extracted (ore/waste selection and classification in different products)
- Extraction sequencing
- Blast design
- …

Decisions post extraction (production control)
- Pre-upgrading: sorting, separation of material streams
- Mining logistics and blending: Dispatching decisions
SENSORS FOR RESOURCE PROPERTIES

At which locations and to which point in time related to extraction can sensors improve understanding of the orebody to support previously mentioned decisions?

Pre extraction:
- MWD (Monitoring while drilling blast holes) – WP5 SSD
- Drill hole logs - WP4
- Grade control data (Chip- and Channel Sampling) – WP4
- Face mapping data (imaging and feature extraction) – WP4
  …

During extraction:
- Specific energy usage cutting (only applicable for cutting) – WP5
- Location and Material Tracking- WP3
  …

Post extraction:
- Pre crusher (size distribution, textures, mineralogy, geochemistry)-WP4
- Post crusher (textures, mineralogy, geochemistry)- WP4
  …
**TIMELINE**

<table>
<thead>
<tr>
<th>Phase</th>
<th>Start</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Start</td>
<td>01.04.2015</td>
<td></td>
</tr>
<tr>
<td>Project Duration</td>
<td></td>
<td>48 Months</td>
</tr>
<tr>
<td>Project Set Up Phase</td>
<td>WP1</td>
<td>Month 1 to 24</td>
</tr>
<tr>
<td>Development</td>
<td>WP2-WP7</td>
<td>Month 6 to 36</td>
</tr>
<tr>
<td>Demonstration Phase</td>
<td>WP8</td>
<td>to Month 48</td>
</tr>
</tbody>
</table>

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WORK PACKAGE 7 – OVERVIEW

RESOURCE MODEL UPDATING

KICK-OFF MEETING
TU DELFT, APRIL 2015

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THE TEAM

TU Delft

Geovariances

Imperial College London

Dassault Systemes

TÉCNICO LISBOA

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1. Definition of a detailed problem specification and a conceptual model of an updating feedback loop
   • M6
2. Development of a theoretical mathematical-statistical framework for rapid updating of 3D resource/reserve models
   • M24
3. Implementation of the updating feedback method and testing plausibility of results
   • M36
EXAMPLE: DATA ASSIMILATION OF SENSOR MEASUREMENTS TO IMPROVE PRODUCTION FORECASTS IN RESOURCE EXTRACTION

Tom Wambeke, Jörg Benndorf
Resource Engineering, Delft University of Technology
CONTENT

Problem
Challenges
Approach
Case Study
Takeaways
PROBLEM

Predict / Proact

Estimated WIo (GeoMet model)
Set P & R
Predict $P_{80}$
Proact - adjust R if $P_{80} \neq$ target

Measure / React

Measure P & R, $P_{80}$
Calculate WIo
React - adjust R if $P_{80} \neq$ target

\[
\frac{P}{R} = WIo \times \left( \frac{10}{\sqrt{P_{80}}} - \frac{10}{\sqrt{F_{80}}} \right)
\]

$P_{80}/F_{80}$ - 80% passing size of product/feed [\(\mu m\)]
P - Power draw [kW]
R - throughput [t/h]
WIo - Work Index [kWh/t]
PROBLEM

Grade Control (GC) Model
1. Reconcile – Extracted Blocks
2. Update – Scheduled Blocks

Ball Mill Performance
1. Improve production forecasts
2. Optimize throughput (proact)
CHALLENGES

1. Difficult to link observations to the GC model.
2. Observations are made on blended material streams.
**APPRAOCH**

**Calculation Steps**

1. Geostat. Simulation $z^i_0$
2. Forward Prediction $\mathcal{A}_t(z^i_{t-1}(x))$
3. Measurement $d_t + e^i_t$
4. Update

\[
z_t^i(x) = z^i_{t-1}(x) + W_t dz_t^i
\]

\[
dz_t^i = (3) - (2)
\]
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CASE STUDY

Blended Material

A : 80 truckloads

B : 40 truckloads

40 h update interval
2 h averages
20 measurements

= 1620 t @ 2 h

4 truckloads from A
2 truckloads from B
±

= Blend (2h average)

20 truckloads

4 truckloads from A
2 truckloads from B
CASE STUDY

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CASE STUDY

120 SMU’s

± 40 h production

40h average

20 Blocks A + 20 Blocks B

2 h averages (6 SMU’s)

40 h
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SMU scale

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THREE TAKEAWAYS

1. Assimilation of production data into the grade control model can significantly improve production forecasts.

2. Simulation based approach allows a fast and flexible integration of indirect measurements on blended material of different support.

3. The forward prediction model linking the GC model to the observations can be general, e.g. mine and plant process simulator.
THANK YOU FOR YOUR ATTENTION!
QUESTIONS?

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j.benndorf@tudelft.nl