Robotics in mining.

Henryk Karaś, Sherpa Group in EIP on RM, KGHM Polska Miedź; Provisional coordinator „Robotics in Mining” SPARC Topic Group

EUMICON 2015 „We design the future“; 5-6 May 2015; voestalpine Stahlwelt; Linz/Austria
Content of presentation.

1. Automation and robotics in current mining activities.
2. European and national programs in automation in mining.
3. Mining in H2020 innovation program.
4. SPARC program and safety first in mining operations.
5. Looking for minerals – options for robotics in other area.
6. Conclusions.
Why Robotics is important to Mining?

Probably robots will transform almost every industry and service sector, particularly in the area of extractive sector where safety is the first issue.

1. Robots provide the means to work in hazardous environments improving safety for operators and emergency service workers, in mining activities and in mine closure/decommissioning.

2. Their ability to map and monitor large spaces (underground, under water, and from the air) will provide a new and cost-effective means to gather valuable information important for mining and smelting operations (monitoring of environmental pollution).

Challenges for future metal mining operations.

**BASIC PRE-CONDITIONS FOR AUTOMATION**

- Rock Mass Characterisation
- Predictive Maintenance
- Condition Monitoring of ZEPA vehicle

**BASIC TECHNOLOGIES FOR AUTOMATION**

- Communication
- Localisation systems
- Road and Traffic Management

**REPLACING HUMANS IN ZERO ENTRY PRODUCTION AREAS**

- Human in Automated systems
- Augmented Reality
- Automated Inspection and Image Analysis
- Autonomous Patrolling Robots

**APPLICATIONS**

- Continuous mining
- Automated drilling
- Automation of Loading and Transportation
- Automation of Charging
- Automation of scaling and reinforcement
- Automation of Media Installation

After Prof. Håkan Schunnesson; Division of Mining and Geotechnical Engineering, LTU, Sweden
Examples of commercially available systems for LHD automation.

Underground loaders and trucks: there have been a number of steps towards automation for several years including vehicle monitoring systems, load weighing systems and several remote control systems. A tipically, remotedly steered LHD vehicle is equipped in 150 sensors.
Main Target – increased efficiency by mining activities during 24 hours.

- It is not unusual that the face utilization in underground mines is typical 25%. This usually due to reasons such as:
  - Blast ventilation, machine breakdowns, shift changes, lunch breaks and travel time within mine reduce face utilization
  - The complex sequencing of mine operation combined with a variable environment challenges optimization of production

- Mine Automation makes it possible to run an underground mine 24/7 and enhance the face utilization. Open pit mines and underground can optimize machine utilization

- Autonomous Machines enables huge improvements but requires huge investments and takes time to implement

- A Mining Operational Centre enables improvements both in short and long term
  - Easy and fast to implement
  - Requires an existing datacom infrastructure

Source: Hans Wahlquist; Director Business Development | Mobilaris AB; Sweden
„Intelligent Mine” implementation in Europe.

Helsinki University of Technology, Finland (1992-1997).

source: Prof. Pekka Särkkä, HUT, Finland
“The Intelligent Deep Mine“

- Intelligent
- Deep
- Mine
- Mining Methods
- Transport and Logistics
- Working Environment
- Ground Control / Rock Mechanics
- Near to face Processing
- Ore, Industrial Minerals, Coal
- Critical Raw Materials
- Green Mining
- Lean Mining

Intelligent Mass Flow Management
- Mine-wide Information Network
- Remote controlled and Autonomous Equipment
- New Sensor Technologies

ETP SMR Meeting, Aachen, 2009.12.16
Nordic Rock Tech Centre AB (RTC) established a consortium for the conceptual study to develop a common vision for future deep mining (2009-2012).

1. Taking the advantages of advance in automation and robotics based on IT and ES technologies, the deep mining will require the wide use of remote monitoring and controlling of all underground operations.

2. This is the vision for the „Smart Mine of the Future” which encompasses:

- removing people from hazardous environments;
- can give Europe the technological leadership in resource-efficient production of raw materials;
- design Next Generation machines to operate remotely and autonomously;
- introduce integrated and intelligent monitoring and control systems;
- create future perspectives for extractive industry with newly manufacturing technologies.

Source: Göran Bäckblom, LKAB, project leader-the VINNOVA „Mine of Future” project, Sweden (2009-2010)
KGHM - Boliden- LKAB; future vision as an inspiration for new solutions in future technological operations in mining (2010).

- One control room;
- Zero entry mine;
- Mine – attractive and safe place to work;
- Continuous mining;
- Pre-concentration;
- **On line monitoring** of mining and mineral processing operations.

source: Report „Setting the Scene: „ Smart Mine of the Future” (SMIFU) – stage I, .
I2Mine – FP7 UE funded project:


1. I²Mine project will develop some innovative projects to execute the vision of Intelligent Mine.

2. EU expects innovative methods, technologies and machines enabling efficient and safe extraction of minerals from deep laying deposits.

I²Mine workpackages

- WP1: Mine wide information and control systems, logistic and mass flow management
- WP2: Novel mining and underground processing methods
- WP3: Rock Mechanics and Ground Control
- WP4: Innovative machinery for deep underground mine
- WP5: Application, Demonstration, Validation
- WP6: Health and safety and environmental aspects in future deep mining
- WP7: Communication, dissemination and societal issues
- WP8: Coordination and management

European Initiatives – I²Mine

I² Mine is the biggest EU RTD project in extractive sector funded by EU FP7 grant (23 mln Euro budget).
World RTD centers in automation and robotics in mining.

source: Prof. Håkan Schunnesson, LTU, Sweden, Mine Automation Key Research and Development Partners: Universities, Research Institutes and Companies
The “Robolution” in mining – Canadian example.

During a couple of last decades the quick process of mechanisation in mining sector has been followed by implementation of embedded systems, board computers and establishing IT network for mining operations.

The first phase has been accomplished, the others have lagged.
New knowledge and mobilization of existing competence should contribute to:

• Safer mines through remote control and automation
  • No Human Exposure to Production Faces (Short term goal)
  • No Humans in the Mine (Long term goal)
  • No Accidents

• Maximize the production efficiency in existing and new processes; (example of Swedish underground mines).

• Optimize the complete production chain from mine to mill to customer through integrated process control systems.
New standards in mining legislation when implementing automation and robotics in mining.

Introduction of autonomous mobile mining systems into their operations to achieve a safe and successful outcome needs a:

- comprehensive mine site risk assessment prior to making the decision to introduce autonomous mining;
- a well-documented change management process, including roles and responsibilities of system builders and operators;
- development of strategies which integrates autonomy into mine design and planning as early as possible;
- putting in place project management plan (PMP) requirements having proper incident reporting.

Source: IM October 2014, Western Australia, Department of Mines and Petroleum,
Real and sustainable productivity improvements may require significant adjustments including changes to mine plans, reassessment of mining methods, changes to equipment fleet and configuration, and increasing automation.

Place for Robotics in the EU Horizon 2020 innovation programs.

HORIZON 2020 WORK PROGRAMME
5. Leadership in enabling and industrial technologies
   i. Information and Communication Technologies (ICT - SPARC)

HORIZON 2020 WORK PROGRAMME
5. Leadership in enabling and industrial technologies
   ii. Nanotechnologies, Advanced Materials, Biotechnology and Advanced
       Manufacturing and Processing (Factory of the Future - FoF)

HORIZON 2020 WORK PROGRAMME
12. Climate action, environment, resource efficiency and raw materials
    EIP on Raw Materials (SIP).
euRobotics was founded on 17 Sep 2012 by 35 organisations. By May 2014, euRobotics represented 182 companies, universities and research institutions, ranging from traditional industrial robotics manufacturers to producers of agricultural machinery and innovative hospitals.

With €700M in funding from the EC for 2014 – 2020, and triple that amount from European industry (€2100M) SPARC is the largest civilian-funded robotics innovation programme in the world.
The Public Private Partnership in SPARC program.
SPARC - Operating Environment.

the creation of SPARC program will provide the all EU robotics community an opportunity to develop solutions which can give Europe the technological leadership in resource-efficient production of raw materials and create future perspectives for extractive industry with newly manufacturing technologies

There are six primary operating environments for robots in SPARC;

• on the ground, (m)
• in the air,
• underground (m)
• underwater (m),
• in space (m)
• inside the human body.

1. Robotics technology has the potential to impact on a number of social challenges both directly and indirectly.

2. It is also recognised that robotic mining may be the only way of extracting the significant mineral resources that lie deep in the earth and under the oceans.

The robotic market domains – high level categories.

1. Manufacturing,
2. Healthcare,
3. Agriculture.

4. Consumer Robots,
5. Civil Robots,
6. Commercial Robots,
7. Logistics & Transportation
8. Military Robots.

It is highly likely that improved equipment and better mining techniques will enable extraction of minerals at greater depth and under the sea.”

**SPARC** topics groups which could be important for developing autonomous mining operations.

<table>
<thead>
<tr>
<th>Total number of SPARC Topic Group (33)</th>
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<tbody>
<tr>
<td>Autonomous Navigation</td>
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<tr>
<td>Benchmarking and Competitions</td>
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<tr>
<td>Artificial Intelligence (AI) and Cognition in Robotics</td>
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<td>Industrial Robotics</td>
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<td>Maintenance and Inspection</td>
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<td><strong>Marine Robotics</strong></td>
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<td>Mechatronics</td>
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<td>Miniaturised Robots</td>
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<tr>
<td>Perception</td>
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<tr>
<td>Physical Human Robot Interaction</td>
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<tr>
<td>Software &amp; Systems Engineering, System Integr.,</td>
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<tr>
<td>Telerobotics and Teleoperation</td>
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**Robotics in Mining – established in March 2015**
An example of robot primary functions to implement in some mining operations.

**Surface Process:** The function of applying a process to a flat surface or the surface of an object. This could be spraying, scraping, drilling holes.

**Interaction:** The function of interacting with either a human or another machine or robot.

**Exploration:** The function of exploring an unknown or partially known space with the goal of mapping that space or the specific goal of, for example, finding a person, resource or location.

**Transporting:** Transporting involves orienting and moving objects or people between known start and end locations, movements may be over short or long distances.

**Inspection:** Mapping and scanning the space to monitor specific parameters or mapping for specific purposes, for example monitoring pollution.

**Grasping:** The function of holding and orienting an object, tool or person. Includes firstly identifying and then working out how to hold the object.

**Manipulation:** The function of utilising the characteristics of a grasped object to achieve a task. For example: charging explosives in drilled holes.

European Institute of Technology (EIT) has identified Raw Materials as one of the 3 areas with establishment of a new Knowledge and Innovation Community (KIC) – Dec. 2014.

2. The future KIC shall have strong links with implementation of the EIP on Raw Materials.

KIC „RawMat” head office: Berlin

Priority activities” of KIC „RawMat” by 2018:

• support and development of 40 new technologies; and 16 start-ups;
• education of 1000 MSc and PhD graduates,
• by 2022 r. commercialisation of 70 patents.
• Space for „Robotics in Mining”

Planned budget of KIC „RawMat” in the second stage of development - 120 mln euro.
c) [2015] Deep mining on continent and/or in sea-bed.

Proposals should develop new highly-automated technological sustainable solutions for deep mining on the continent and/or in the sea bed combined with *in-situ* processing of minerals, particularly addressing the challenge of industrial viability, the exposure of workers underground and the impact on the continental and marine environment and reducing the amount of waste rock to be transported. Related raw materials, marine and maritime policies are to be taken into account.
Call for commitments in EIP on RM program- 2015.

1. Continuous underground mining of hard rock minerals. This project addresses SIP actions; Automated mining. Coordinator: **Atlas Copco Rock Drills AB**; Sweden


4. Flexible haulage system: **Sandvik Mining & Constr. Materials Handling GmbH & Co Austria**

5. Alternative Blue Advanced Technologies for Research On Seafloor Sulfides” : securing long term raw material supply to Europe by developing and testing deep-sea technologies for exploration and evaluation: Coordinator **ERAMET SA**; France.


KGHM is going to develop mining activity program both in Poland and world-wide.

**Canada, Ontario**
- Victoria (Cu, Ni, Pt, Pd, Au)
- Sudbury region exploration

**Canada, B.C.**
- Ajax (Cu, Au)

**USA, Nevada**
- Robinson (Cu, Au, Mo)

**Chile**
- Franke-Pelusa (Cu)
- Sierra Gorda (Cu, Mo, Au)
- Atacama region exploration

**Greenland**
- Malmbjerg (Mo)

Source: KGHM
Underground mining operations on the level of 1400m need new approach in and became more challenging for future activities of KGHM.

- Minimising ore dilution and copper ore losses in low seam copper ore deposits;

- Elimination of human exposure in deep underground conditions (hot rock temperature, humidity, gas and diesel fuel emissions, dust, noise, rock burst hazards)

- When going deeper, most of of underground mining operations should be run from remote places. It calls for new methods of extraction and implementing automated communication and data transfer systems in mining operations.
KGHM participates in numerous R&D projects focused on innovative technologies in mining.

- Innovative systems to access and explore deposits – automated technologies, biometallurgy and hydrometallurgy (BioMore) that will allow previously unmined deposits to be reached.
- Minimizing human presence in hazardous areas (I2Mine)
- Automation of production processes. Usage of artificial intelligence and Big Data (Robotics in Mining)
- Online mineralogical and chemical analysis in production processes (NCBJ/KGHM)

Roadheader MH 620 (SANDVIK) in Lubin Mine and Polkowice-Sieroszowice mine at KGHM

Testing the longwall complex (ACT Caterpillar, USA) with continuous mining at a copper ore mine, KGHM; 2014

Source: KGHM
Overview of calls in H2020/ICT-24 Robotics in 2015

<table>
<thead>
<tr>
<th>Roadmap-based R&amp;I in Robotics</th>
<th>ACTION TYPE</th>
<th>Funding %</th>
<th>Size</th>
<th>Amount</th>
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<tbody>
<tr>
<td>Deadline: 14 April 2015</td>
<td></td>
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<td>€83m</td>
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<tr>
<td>ICT24.a – Research &amp; Innovation Actions</td>
<td>RIA</td>
<td>100%</td>
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<td>Priority market domains: healthcare, consumer, transport</td>
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<td>Advance key technologies for priority domains</td>
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<tr>
<td>ICT24.b - Technology transfer</td>
<td>IA 70%</td>
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<td>Large</td>
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<td>Industry-academia cross-fertilisation</td>
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<tr>
<td>ICT24.c - Technology transfer</td>
<td>IA 70%</td>
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<td>Small/Large</td>
<td>€12m</td>
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<td>Robotics use cases</td>
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<tr>
<td>ICT24.d - Pre-commercial procurement in robotics: especially healthcare</td>
<td>PcP 70%</td>
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<td>Large</td>
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<tr>
<td>ICT24.e - Community building and robotics competitions</td>
<td>CSA</td>
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<td>€4m</td>
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The first step to establish topic group (TG) - Robotics in Mining in EU SPARC program is setting up international consortium to apply for EU-funding in H2020/ICT 24e Coordination and Support Action (CSA) - Community building and Robotic competitions.

Source: Conference Robotics Horizon 2020 ICT Call 2 – Brussels, 9 December 2014
Supporting the European robotics community;

Networking, education, outreach, public awareness, technology watch, standardisation, and industry-academia collaboration, links to national programmes and initiatives.

Ethical, legal, societal and economical aspects

International cooperation (intra or extra-EU) impact to be demonstrated, matching resources expected

Coordinating work on the next generation of cognitive systems and robotics.

Source: Juha Heikkilä, PhD; Head of Unit Robotics DG for Communication Networks, Content and Technology Second Horizon 2020 Call Robotics – ICT24
International consortium which applies for EU fund in ICT CSA 2015 call: „Challenges for Robotics in Mining”

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<thead>
<tr>
<th>Participant No</th>
<th>Participant organisation name</th>
<th>Country</th>
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<tr>
<td>1 (Coordinator)</td>
<td>AGH University of Science and Technology</td>
<td>Poland</td>
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<td>2</td>
<td>GIG Central Mining Institute</td>
<td>Poland</td>
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<td>3</td>
<td>RWTH Aachen</td>
<td>Germany</td>
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<td>4</td>
<td>LTU Lulea Technical University</td>
<td>Sweden</td>
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<td>5</td>
<td>KGHM CUPRUM Research and Development Centre</td>
<td>Poland</td>
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<td>6</td>
<td>OULU University</td>
<td>Finland</td>
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<td>7</td>
<td>KGHM Polska Miedź SA</td>
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<td>8</td>
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<td>10</td>
<td>Atlas Copco</td>
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<td>11</td>
<td>Mobilaris (SME)</td>
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<td>STAM</td>
<td>Italy</td>
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<td>13</td>
<td>EMAG – Institute of Innovative Technologies</td>
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<td>14</td>
<td>LCM – Linz Centre of Mechatronics GMBH</td>
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<td>15</td>
<td>FAMUR SA (LE)</td>
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<td>16</td>
<td>PWr – Wroclaw University of Technology</td>
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<td>17</td>
<td>WAT – Military University of Technology</td>
<td>Poland</td>
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<td>18</td>
<td>Institute of Mechanised Construction &amp; Rock Mining</td>
<td>Poland</td>
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„Challenges for Robotics in Mining“ - „RoboMine“ project

Scope of Works: WPs:

WP 1: Project management;
WP 2: Robot Minable resources in the EU countries;
WP 3: Analysis and outreach to robotic technology key performers; experts and state of the art of robotics in mining;
WP 4: Research and Technological Gap Identification and Overall Impact. Assessment the feasibility and benefits of introducing robotics in mining;
WP 5: Actions and strategies for robotics in mining;
WP 6: Dissemination and communication activities.

LCM - Linz Center of Mechatronics GmbH is partner for research and development of new as well as for enhancement of existing technical products, system and processes. LCM specializes in different fields of Mechatronics. Based on its know-how promotes new smart systems for industry.

In the RoboMine project LCM is a participant in WPs 4 and WP 5.
TG Robotics in Mining – opportunities to apply for EU funds in H2020/ICT-2016 and further.

### Time Line for ICT-2016 ICT-2017

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Commercial Domain - Extraction of Minerals.

1. There is a long standing use of robots and remote guided vehicles in the oil and gas sectors and more recently in mining.

2. Many of the Mining and Mineral industries operate within hazardous environments and the extraction of earth resources is often limited by the level of risk associated with human working conditions.

3. There is a significant opportunity to utilise robots for extraction in order to reach more inaccessible mineral resources. In particular there are considerable mineral resources on the deep ocean bed where robots could provide the solution to long term and viable extraction.

Seabed mining – an example of solution.

High technology, high quality products, less waste, low pollution of environment.

Production support vessel

Seafloor production machine.

Source: New Frontiers - Ocean Minerals Exploration and Development; Jonathan Lowe V.P. Strategic Development and Exploration; Brussels; 14 June, 2014
Metals are abundant in space
Prospecting and Exploration

Platinum group metals are some of the most rare and useful elements on Earth. They exist in such high concentrations on asteroids that a single 500-meter platinum-rich asteroid can contain more platinum group metals than have ever been mined in human history.

Asteroids contain more common metallic elements such as iron, nickel, and cobalt, sometimes in incredible quantities and often in their pure, non-oxidized metal form. These base metals, silicates and other asteroid resources can support entirely new space ventures, from deep space habitats to space-based solar power arrays.

Source: http://www.planetaryresources.com/asteriods/#market-for-h20
Planetary subsurface exploration, space mining

Institutions

1. NASA (National Aeronautics and Astronautics Agency) – USA
2. ESA (European Space Agency)
3. In-situ Resource Utilization (ISRU)
4. In many EU member states: national space agencies

Three major directions of technology development

1. Surface construction
   - Site characterization
   - Earthwork and ground improvement
   - Foundations and lateral support
   - Building with regolith

2. Surface and subsurface robots development
   - Rovers, hoppers, locomotion problems
   - Drills, penetrometers, „bigger” devices

3. Mining
   - Mineral Resource Classification
   - Generic resource extraction
   - Resource assessment
   - Resource acquisition
   - Resource Beneficiation
   - Mine site management

Source: Karol Seweryn, Centrum Badań Kosmicznych PAN 2015
From Mars to Underground Robotics.

Mars Science Laboratory Mission's Curiosity Rover

Future ESA mission - Mars

Three missions are considered in the frame of Mars Robotic Exploration Program (ESA):

1. Inspire – a network mission on Mars
2. Phootprint – mission to Phobos
3. Mars Precision Lander

source: Karol Seweryn, Centrum Badań Kosmicznych PAN 2015
Conclusions.

1. One of the biggest challenges the mining industry faces today is the ability to manage the complete the entire value chain as one operation.

2. Automation and robotics may become a reality at a number of key underground mines and may bring many opportunities to improve safety and efficiency of mining operations.

3. Robotics and automation in mining operations does not eliminate jobs, it shifts the nature of jobs.

4. Solving the problems of deep underground metal mining can give Europe technological leadership in the resource-efficient production of raw materials.
Thank you.

Europe’s first competition of Mars rovers was held in Poland in September 2014.


Henryk Karaś, Adviser to Management Board of KGHM Polska Miedź, member of Sherpa Group in EIP on RM.

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