Material Transport Technology Scan – Surface Mining Project ‘Preview”

June 4, 2019
Phase 1: Project scope

- **Identify** existing and developing material movement solutions – worldwide.
- All participants will **share** existing knowledge on current state to avoid duplication.
- **Assess** current technology readiness level (TRL).
- **Establish the evaluation framework** to objectively compare the different technologies.
- **Develop a roadmap** to accelerate the evaluation, adoption and value realization of improved material movement solutions.
Hauling system innovations will be viewed through different technology lenses.
Technology does not change uniformly or independently. Evaluation will consider rate of technology changes.
1. Identify existing and developing solutions and assess TRL

Use a structured framework to categorize solutions

<table>
<thead>
<tr>
<th>Control elements</th>
<th>Technology Readiness Level</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Manual, Remote, Autonomous</strong></td>
<td><strong>9</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mechanical elements</th>
<th>Energy Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rubber tire vehicles, conveyor-based, rail-based, cable-based, pipe-based</td>
<td>Diesel, Bio- and renewable diesel, NG, CNG, HDCNG, LNG, Hydrogen, Electricity</td>
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<table>
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<tr>
<th>Characteristics</th>
<th>Energy storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gradient, material size, capacity, batch/continuous, transfer mechanism, size, weight</td>
<td>Gas, liquid, solid (batteries)</td>
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</table>

<table>
<thead>
<tr>
<th>Infrastructure requirements</th>
<th>Energy conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reciprocating ICE, Turbine ICE, Electric motors (incl LSM)</td>
<td></td>
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</tbody>
</table>
2. Establish objective evaluation framework

Develop a comprehensive measurement framework

- **Society Value**
- **Economic Value**
- **Environmental Value**

**Economic Profitability**
\[
\text{EM} \% = \frac{\text{EM}}{\text{Gross Assets}}
\]

**Levelized Cost of Energy**
\[
\text{LCOE} = \frac{\text{$/kWh}}{\text{$/GJ}}
\]

**Energy Intensity**
\[
\text{kWh/t}
\]

**Levelized Cost of Material Movement**
\[
\text{LCOM} = \frac{\text{$/t}}{\text{$/t.km}}
\]

**Cash Cost of GHGs**
\[
\text{CCOG} = \frac{\text{$/t}}{}
\]

**CO₂**, **NOₓ**, **SOₓ**, **PM10**

**Parts Inventories**
- Energy infrastructure
- Maintenance infrastructure

**Utilization**
- Operator training
- Technician training
- Road infrastructure

**Equipment costs**

**Road infrastructure**
Consider complex trade-offs in the context of mine operations

Members will help develop evaluation criteria

- Spatial VS Capacity Flexibility VS Energy efficiency
- Economics VS Flexibility VS Operability
- Society VS Environment VS Economic value
- Existing VS Brown field VS Green field
- Mine adoption readiness VS Technology readiness
- Others
3. Develop a roadmap to accelerate the evaluation, adoption and value realization

Faster, better, and cheaper with lower risk

- Determine what analyses, modelling and simulations approaches to use
- Determine what operations to apply simulations to
- Establish evaluation process
- How to achieve maximum value from collaboration, while allowing for customized evaluations
Modelling and simulation focus piloting efforts - Examples

**Dynamic Operation**
- Simulates operation of the haulage system
- Deals with dynamic complexity
- Each component in the system behaves independently
- Test rules that control interactions between the system components
- Highlight bottlenecks and feedback loops
- Accumulate output continuously
- Output as graphs, 2D and 3D dynamic visualizations

**Site/process Integration**
- Simulates operation of the mine-to-mill integrated process
- Simulate material and energy flows dynamically
- Highlight site constraints
- Output as graphs and 2D or 3D dynamic visualizations

**Haulage Economics**
- Simulates operation of the haulage system
- Deals with dynamic complexity
- Each component in the system behaves independently
- Test rules that control interactions between the system components
- Highlight bottlenecks and feedback loops
- Accumulate output continuously
- Output as graphs, 2D and 3D dynamic visualizations

**Technical**
- 3D component design
- Animation
- Finite Element Analysis
- Test component strengths
- Prove design works
- Reliability simulation

**Site LOM Economics**
- Aggregation of multiple models to represent a multi-year plan
- Estimate capital, maintenance and operating expenses per year
- Consolidation model
- Output as data and graphs

**Site**

**System**

**Sub-system**

**Component**

**Physical Simulation**
- Solidworks
- CAD/FEA

**Dynamic Simulation**
- ANYLOGIC
- MineRP

**Performance modelling**
- Excel
- Monte Carlo

**Plans & Budgets**
- Excel
- MineRP