Lean Mining
A solution for sustainable Development

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What is Lean mining?
“LEAN MINING PRACTICES” brings effectiveness & efficiency in operation by eliminating uncertainty that often leads to wastage of resources:

“Toyota Production System - LEAN”

(JIT, TQM, TPM, & KAIZEN)
Those similarities bring an opportunity to successfully apply lean principle into mining industry.

In contrast to innovation approach which emphasize on a quick improvement/change, lean principle is a continuous improvement approach which emphasize on a small but constant improvements.

### Comparison of Mining and Automotive industry

<table>
<thead>
<tr>
<th><strong>Mining industry</strong></th>
<th><strong>Automotive industry</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Physically challenging environment</td>
<td>Ambient environment</td>
</tr>
<tr>
<td>Inherently variable environment</td>
<td>Stable work environment</td>
</tr>
<tr>
<td>Geographically spread output teams</td>
<td>Compact plants</td>
</tr>
<tr>
<td>Inherently variable raw materials</td>
<td>Controlled raw materials</td>
</tr>
<tr>
<td>Remote locations</td>
<td>Large centers</td>
</tr>
</tbody>
</table>
In contrast to innovation approach which emphasize on a quick improvements or STEP CHANGES, lean principle is a continuous improvement approach which emphasize on a small but constant improvements.
One approach to apply the lean principle in mining industry is to apply the concept of **Overall Production Effectiveness** to eliminate waste and increase the operational **reliability, production quality** and **performance** through engagement of all personnel.

**ELIMINATION OF UNCERTAINTY**
The following four subprojects are considered in our lean mining project:

1. Improvement of production availability and delivery assurance
2. Rock and machine interface
3. Remaining useful life of mining systems
4. Integration of mine work environment into production systems
Production assurance concept
1.1 WHAT IT IS?

- Production assurance models describe to what extent a system is capable of meeting demand for deliveries.
Introduction to concept
– Production assurance

WHY ???

• Uncertainty in operation is the main cause for delays, customer dissatisfaction and other waste of resources.
Models are being developed & Tested to make correct decision in order to meet customers’ requirements in term of volume and quality at short notices.
1.2 Production Assurance (PA)

The PA concept includes several other concepts such as reliability, maintainability, availability, supportability, capacity.
1.3 Production assurance: Empirical Model

PA can be described and calculated by combinations of capacity performance and system availability performance for period of \((t_1, t_2)\)

\[
PA = \frac{\text{Mean predicted operational availability} \int_{t_1}^{t_2} (\text{capacity performance}) \, dt}{\text{Planned operational availability}} \times \frac{1}{t_1 - t_2}
\]
Consider a simple numerical example of a transportation unit of an underground mine producing iron ore; it consists of three LHD which can be configured as a parallel system:
The failure of LHDs which consists of different and several components follows Poisson distribution.

In this case, the reliability of transportation system (LHD fleet) at time \( t \) is:

\[
R(t) = \exp(-\lambda t) \times \sum_{r=0}^{N} \frac{(\lambda t)^r}{r!}
\]

Where,

\( \lambda = \) Failure rate of LHD
\( t = \) Operation time of system
\( N = \) Total number of required LHD in period \( t \)
Each LHD is assumed to have a throughput capacity of either full \((c)\) or 0. Therefore, the possible capacity performance levels for transportation unit are thus \(3c, 2c, c,\) and 0.

The planned production rate for transportation unit is: 11250 ton/day.

The Markov diagram for three LHDs in parallel is:
Characteristics of LHDs

<table>
<thead>
<tr>
<th>System</th>
<th>Failure rate</th>
<th>Repair rate</th>
<th>System working capacity</th>
<th>System design capacity</th>
<th>Capacity performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHD</td>
<td>$3.75 \times 10^{-4}$</td>
<td>$4.96 \times 10^{-2}$</td>
<td>10000 ton/day</td>
<td>11250 ton/day</td>
<td>80%</td>
</tr>
</tbody>
</table>

Probability distribution of system capacity by Markov model

<table>
<thead>
<tr>
<th>System capacity level (%)</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>$3.843 \times 10^{-5}$</td>
</tr>
<tr>
<td>33</td>
<td>$3.651 \times 10^{-4}$</td>
</tr>
<tr>
<td>67</td>
<td>0.0104</td>
</tr>
<tr>
<td>100</td>
<td>0.9891</td>
</tr>
</tbody>
</table>
Challenges

CONTEXT DRIVEN PRODUCTION ASSURANCE MODELS
CONSIDERING LOCAL AND GLOBAL BUSINESS RISKS
Remaining Useful Life (RUL)

The remaining useful life (RUL) of the unit indicates its ability and length of surviving in operation in the future.

RUL is estimated based on the physics of the failure and statistical analysis.
Remaining Useful Life

\[ X_1, X_2, X_3: \text{Remaining useful life of system based on different degradation (P1, P2, P3) rate} \]
Challenges

Remaining useful Life of a Component

Remaining useful Life at a System level

Remaining Useful Life at an Asset Level

System of System level
Remaining Useful Life (RUL)

Performance

Expected Performance

Acceptable Limit

Time

\(P_1\)

\(P_2\)
Degradation Behaviour of COMPONENTS IN A SYSTEM

- Wear depth (mm)
- Safety Limit
- Maintenance Threshold limit
- ASME B31.3

MGT/ Age (Years)
Data Segregation

- Components with no degradation
- Suspensions
- Maintenance limit
- Safety limit
- Failures
- ASME B31.3

- MGT/Age (Years)
- Thickness (mm)

\[ T_{NOM} \]
EQUIPMENT
Design & Dev phase

Function & Performance
Application Environment
RAMS, LCC & Risk analysis
Maintenance & Service program
Safety, Environment, Sustainability, ROI

Integrated LEAN Solutions
Cost Effective Product Development & Life Cycle Management

LIFE CYCLE MANAGEMENT
OPERATING ENVIRONMENT BASED MODELS

\[ \lambda(t, z) = \lambda_0(t) \exp(z \alpha) = \lambda_0(t) \exp\left(\sum_{i=1}^{n} \alpha_i z_i\right) \]

\[ R(t) = R_0(t) \]

\[ \lambda(t, z) = \frac{\beta}{\eta} \]

\[ MTTF = \eta \]
Remaining Useful Life concept is subjective....
Probability of failure

Time (lifespam)

Average life

Population that require maintenance

Population survive longer than average
Most of the items fail around average life with few living longer or needing early repairment.
Operation phase

WHAT?

Describing System state & behavior

WHY?

Explaining

When?

Predicting

Prognosis

Controlling

How?

Effective Asset & Production Management

Integrated LEAN Solutions

Safety, Environment, Sustainability, ROI

Research

Condition Monitoring

WHY?

Diagnosis

WHEN?
Challenge

FUSION OF QUALITATIVE DATA WITH QUANTITATIVE & EXPERIENCE DATA
What is Remaining Useful Life (RUL)?

$T = 0$ to $T_2$
## RUL – Case study

<table>
<thead>
<tr>
<th>Variable</th>
<th>p - Value</th>
<th>Final Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Step0</td>
<td>Step1</td>
</tr>
<tr>
<td><strong>OPSK</strong></td>
<td>0.480</td>
<td>0.077</td>
</tr>
<tr>
<td><strong>DUST</strong></td>
<td>0.461</td>
<td>0.031</td>
</tr>
<tr>
<td><strong>TEMP</strong></td>
<td>0.078</td>
<td>0.082</td>
</tr>
<tr>
<td><strong>HOILQ</strong></td>
<td>0.109</td>
<td>0.179</td>
</tr>
<tr>
<td><strong>MCSK</strong></td>
<td>0.968</td>
<td></td>
</tr>
</tbody>
</table>

- The effect of three covariates (OPSK, DUST, and TEMP) is significant at 10% p-value.
Actual Hazard Model

\[ \lambda(t, z) = \lambda_0(t) \exp(-1.201\text{OPSK} - 1.425\text{DUST} - 0.748\text{TEMP}) \]

\[
\lambda(t) = \frac{\beta}{\eta} \left( \frac{t}{\eta} \right)^{\beta-1} \exp(\sum_{j=1}^{n} \alpha_j z_j)
= \frac{\beta}{\eta} \left( \frac{t}{\eta} \right)^{\beta-1} \times \exp(-1.201\text{OPSK} - 1.425\text{DUST} - 0.748\text{TEMP})
\]

Covariates Existence Situation

(OPSK, DUST, TEMP)

<table>
<thead>
<tr>
<th>State</th>
<th>Value</th>
<th>State</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>(1,1,1)</td>
<td>S5</td>
<td>(-1,1,1)</td>
</tr>
<tr>
<td>S2</td>
<td>(1,1,-1)</td>
<td>S6</td>
<td>(-1,1,-1)</td>
</tr>
<tr>
<td>S3</td>
<td>(1,-1,1)</td>
<td>S7</td>
<td>(-1,-1,1)</td>
</tr>
<tr>
<td>S4</td>
<td>(1,-1,-1)</td>
<td>S8</td>
<td>(-1,-1,-1)</td>
</tr>
</tbody>
</table>
Actual Reliability Function

R(t) at different stages of existing covariates and times

<table>
<thead>
<tr>
<th>Age (t)</th>
<th>13000</th>
<th>14000</th>
<th>15000</th>
<th>16000</th>
<th>17000</th>
<th>18000</th>
<th>19000</th>
<th>20000</th>
<th>21000</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>0.44</td>
<td>0.02</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>S2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Reliability vs. Age (hr)
Remaining Expected Useful Life

![Graph showing remaining useful life over time and state of covariates.](image-url)
Wear and remaining useful life prediction of grinding mill liners
To optimize:

- Mill profitability
- Wear measurement
- Replacement and maintenance scheduling

by means of estimation of the remaining useful life of mill liners
# Grinding mill liners

## Wear Profile

**Boliden G1A C1 - Mill: 5.7x5.5m, File no: 12181**

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Install date</td>
<td>2011-04-10</td>
</tr>
<tr>
<td>Parts list</td>
<td>31 -944838</td>
</tr>
<tr>
<td>Lifter bar</td>
<td>OF 210-400</td>
</tr>
<tr>
<td>Plate thickness</td>
<td>130</td>
</tr>
<tr>
<td>Rubbercloth thickness</td>
<td>0</td>
</tr>
<tr>
<td>Op.Hours</td>
<td>0</td>
</tr>
<tr>
<td>KWH</td>
<td>0</td>
</tr>
<tr>
<td>Tons</td>
<td>0</td>
</tr>
<tr>
<td>*/Remaining plate thickness</td>
<td>93 mm</td>
</tr>
<tr>
<td>Lifter height</td>
<td>268</td>
</tr>
<tr>
<td>Measuring date</td>
<td>2011-12-15</td>
</tr>
</tbody>
</table>

![Diagram of grinding mill liners](image)

### Diagram Notes:
- **270°**: Shoulder
- **180°**: Shoulder angle
- **90°**: Shoulder angle
- **0°**: Shoulder angle
- **270°**: Shoulder angle
- **180°**: Shoulder angle
- **90°**: Shoulder angle
- **0°**: Shoulder angle
Data collection from Metso Mineral

Condition monitoring data (height and life)
2 Cycle condition monitoring data
Prediction of ANN

Height Curve

- 2008-March-15
- 2009-Sep-23

Remain life Curve

- 2009-Dec-22
- 2011-March-10
Real condition monitoring data vs. ANN prediction
Results of the ANN

• High degree of correlation between the input and output variables

• The proposed model is able to approximate the input-output function accurately

• Neural network found to be very effective in defining a function which was capable of establishing good correlation between the input and output variables.
CONCLUDING REMARKS

LEAN MINING R & I CHALLENGES

- Generic Production and Delivery Assurance Model
- Context Driven Production Assurance Model
- Understanding of Rock Mass and Machine interface
LEAN MINING R & I CHALLENGES

- Eatimation of RUL at System and Asset Level
- Context Driven RUL for Operation
- Decision based on disparate data
- Planned obsolescence vs Sustainability goals (Equipment/System Suppliers)
THANK YOU