EMPIRICAL METHODS IN MINING ENGINEERING PRACTICE
Topics

1. Background
2. History
3. Inside Workings
4. Pitfalls
5. The Future
EMPIRICAL

Webster’s Definition: “Relying or based on experiments or experience”

Mining Definition: Methods that are derived from knowledge gained during full scale “testing” of mine designs (case histories).
Empirical Methods are Models

- Modeling is fundamental to all engineering design
- Models are simplified versions of reality that replicate all the important aspects of the prototype.
Design of Engineering Structures
Rock engineering problems are often data-limited.
In mining, case histories are a rich potential source of data. Each pillar that is developed, or stope that is mined, is a full-scale test under real conditions.
Many other fields that deal with highly complex, poorly-understood systems rely on statistical analyses of real world data.
EMPIRICAL METHODS

1. Focus on the *outcome* (the success or failure of the design)
2. Require *relative* input values, not absolute ones
3. Are well-suited for *risk-based* mine design.
With enough input data, perhaps a numerical model could explain why this intersection collapsed.....
But then how do we explain why the 100 neighboring intersections are stable?
History of Empirical Methods
Bunting's (1911) anthracite coal pillar strength formula

\[ p = 1,750 + 750 \frac{W}{h} \]

\[ p = 778 + 222 \frac{W}{h} \]

\[ p = 700 + 300 \frac{W}{h} \]
Following the Coalbrook mine disaster, Salamon (1967) developed his South African coal pillar strength formula.
“The empirical method is are a very powerful, and to an engineer, very satisfying technique to solve strata control problems….The main advantage of this approach is its firm links to actual experience. Thus, if it is judiciously applied, it can hardly result in a totally wrong answer.”

“An empirical method must start with a reasonably clear understanding of the physical phenomenon in question. This is a feature which distinguishes it from ordinary regression used in statistics.”
Rock mass classification systems developed in the early 1970’s to guide support design for tunnels.
Barton’s (1974) Q-System for Tunnel Support
Rock mass classifications have been successful because they:

- Provide a methodology for characterizing rock mass strength using simple measurements;
- Allow geologic information to be converted into quantitative engineering data;
- Enable better communication between geologists and engineers, and;
- Make it possible to compare ground control experiences between sites, even when the geologic conditions are very different.
Empirical design techniques developed for underground hard rock mining.
Stability Graph Method for stope design
NIOSH Coal Pillar Design Software

Analysis of Longwall Pillar Stability (ALPS)

Analysis of Retreat Mining Pillar Stability (ARMPS)

Analysis of Multiple Seam Stability (AMSS)
Coal Mine Roof Rating (CMRR)
Other empirical techniques from US coal mining

Analysis of Roof Bolt Systems (ARBS)

Design of pre-driven longwall recovery rooms

Evaluation of the feasibility of extended cuts
Empirical Methods in Australian Coal Mining

Analysis of Longwall Tailgate Serviceability (ALTS)

Analysis and Design of Rib Support (ADRS)

Design of Longwall Set-Up Rooms

Many mine-specific roof support selection guidelines
Steps in the Development of Empirical Design Technique

1. Identify the problem

2. Develop a conceptual rock mechanics model

3. Identify measures for each of the key parameters, and develop new measures (such as rating scales) where necessary

4. Collect case history data

5. Statistical analysis

6. Package the final product
ANALYSIS OF MULTIPLE SEAM STABILITY (AMSS)
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Failure mechanisms: Types of multiple seam interactions
Overburden

Upper Seam (Earlier Mining)

Interburden

Lower Seam (Current mining)
Ultraclose multiple seam mining: Development mining only, no full extraction.
Dynamic multiple seam interactions are the most destructive.
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Sizing of chain pillars for longwall mining was initially treated as a *pillar* design problem.
TAILGATE ENTRY STABILITY

PILAR DESIGN

ENTRY SUPPORT ↔ ROOF ROCK QUALITY

Diagram showing the layout of tailgate entry systems and the interaction between pillar design, entry support, and roof rock quality.
Elements of tunnel/entry/stope stability analysis

- Rock mass quality
- Applied stress
- Orientation of discontinuities relative to the mine opening
- Size and shape of the opening
- Characteristics of installed support
- Outcome variable defining success or failure of the design
Multiple Seam: Parameters in the initial model

- Over/Under Mining
- Development/Retreat
- Overburden thickness
- Interburden thickness
- Seam heights
- CMRR
- Total pillar stress
- Multiple seam stress
- LAM2D convergence

- Nature of interburden
- Extra support
- Pillar SF
- Nature of abandoned seam structure
- Settling time
- OB/IB ratio
- IB/lower coal thickness ratio
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Measures for Stress Level

In some cases, just the depth of cover is adequate.
MEASURED STRESS (MPa)

DEPTH OF COVER (m)

KEY
- US-East
- QLD
- NSW
- South Africa

Vertical Stress
The “abutment angle” concept has been used to estimate abutment loads due to full extraction.
AMSS uses LAM2D, a simplified version of LaModel, to estimate multiple seam loads.
Simple 2-D elastic stress analysis used to estimate maximum principal stresses around a stope for the Stability Graph Method.
Multiple Seam Mining:

Many types of remnant structures may be encountered in the real world.
For AMSS, these were simplified into two types:
- Gob-solid boundaries
- Isolated remnant pillars
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The heart of any empirical method is the case history data base.
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Bivariate Statistics

Number of Cases

Failure
Success

Depth of Cover (m)
Stability Number N'
Hydraulic Radius S (m)

MEASURED STRESS (MPa)

KEY
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- South Africa

Vertical Stress
Multivariate Statistics: LOGISTIC REGRESSION

Statistical technique used when there are two possible outcomes.

Estimates the probability of an outcome given values for all the significant parameters.
**STATISTICAL ANALYSIS: LOGISTIC REGRESSION**

Logistic regression table for final model

<table>
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<th>Variable</th>
<th>Coef.</th>
<th>Std. err.</th>
<th>z</th>
<th>P &gt; z</th>
<th>95% confidence interval</th>
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<td>–3.58</td>
<td>0.117</td>
<td>–10.0055 –2.92914</td>
</tr>
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</table>
Logistic Equation

\[ P(x) = -0.81 \times \text{Total vertical stress} \\
+ 1.79 \times \text{Undermining} \\
+ 0.0233 \times \text{Interburden thickness} \\
+ 2.02 \times \text{Extra support} \\
- 1.80 \times \text{Remnant pillar} \\
+ 1.95 \times \ln(\text{CMRR}-20) \\
- 6.47 \]
Selecting Design Probability

![Graph showing Sensitivity vs. Specificity](image)

- **Sensitivity** (gray line)
- **Specificity** (black line)

*Axes:*
- **Y-axis:** Sensitivity/Specificity
- **X-axis:** Probability cutoff

The graph illustrates the trade-off between Sensitivity and Specificity at different probability cutoffs.
Multiple Seam Design Equation

\[ \text{INT}_{\text{crit}} (\text{ft}) = 35 \times \text{Total Vertical Stress} - 77 \times \text{Undermining} - 87 \times \text{Extra Support} + 77 \times \text{Remnant Pillar} - 83 \times \ln(\text{CMRR}-20) + 359 \]
Critical Interburden (No Extra Support)

Critical Interburden (With Extra Support)

Eagle seam previously mined out
97% of cases (with proper pillar SF) are successful

93% of cases with extra support are successful

Only 52% of cases are successful
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Pitfalls of Empirical Methods
Generic guidelines vs. local site calibration
CRANDALL CANYON MINE DISASTER
Historical pillar recovery case histories at the Crandall Canyon mine.
Failed pillar design at the Crandall Canyon mine.
“These pillars have been standing for 20 years. Why not use this success to guide design for this mine?”
Massive collapse of approximately 40 pillars. The airblast severely injured 3 miners on the surface.
Federal officials aware of problem, but miners live with the danger

By Jennifer S. Brown

Despite the awareness, the dangers of pillar mining continue to pose a significant risk to miners. The practice involves leaving sections of the mine pillar intact to support the roof. However, this leaves miners exposed to the risk of cave-ins and other hazardous conditions.

The pillar mining method is commonly used in coal mining, where the pillars are left to support the overlying strata. The process is not without its risks, as evidenced by the recent deaths of miners.

Room-and-pillar mining

This method involves mining in a series of rooms, leaving pillars of coal to support the roof. However, the pillars can also be weakened over time, leading to the risk of collapse.

Coal pillar failures

A recent study by the National Institute for Occupational Safety and Health (NIOSH) found that pillar failures account for a significant number of mining accidents. The study highlights the need for improved safety measures to protect miners from these dangers.

Miners continue to face challenges in a dangerous industry, but improvements in safety protocols and technology offer hope for a safer future.
Case histories were used to identify three key changes to retreat mining technology and methods.

- **Leave the final stump**
- **Use extra roof bolt support**
- **Mobile Roof Supports**
Risk perception: “We have never had any trouble at our mine. Why should we change?”
The Future of Empirical Methods
First International Congress on Mine Design
Using Empirical Methods
2014 Lima Peru
New technology is making it possible to collect more data than ever before. The challenge will be *interpretation*. 
Longwall shield pressure data is sent daily to the mine’s geotechnical engineer.
Roof Performance Data

Extensometer data compared to mapped faults

Zones of red TARP triggers
In-situ stress related

Abnormal

Normal
Geophysical logs can be used to estimate rock properties.
Seismic monitoring is another opportunity for statistical analysis and empirical design.
Development of mine-specific rock mass classification and roof support selection guidelines.

Steps involved in analysis:
1. Identify roof units on the basis of sonic, gamma logs
2. Choose representative sonic transit times
3. Convert to UCS
4. Prepare roof sections & plans – ½ m, 2 m and 12 m
A critical challenge: Integrating empirical and numerical methods together into mine design.