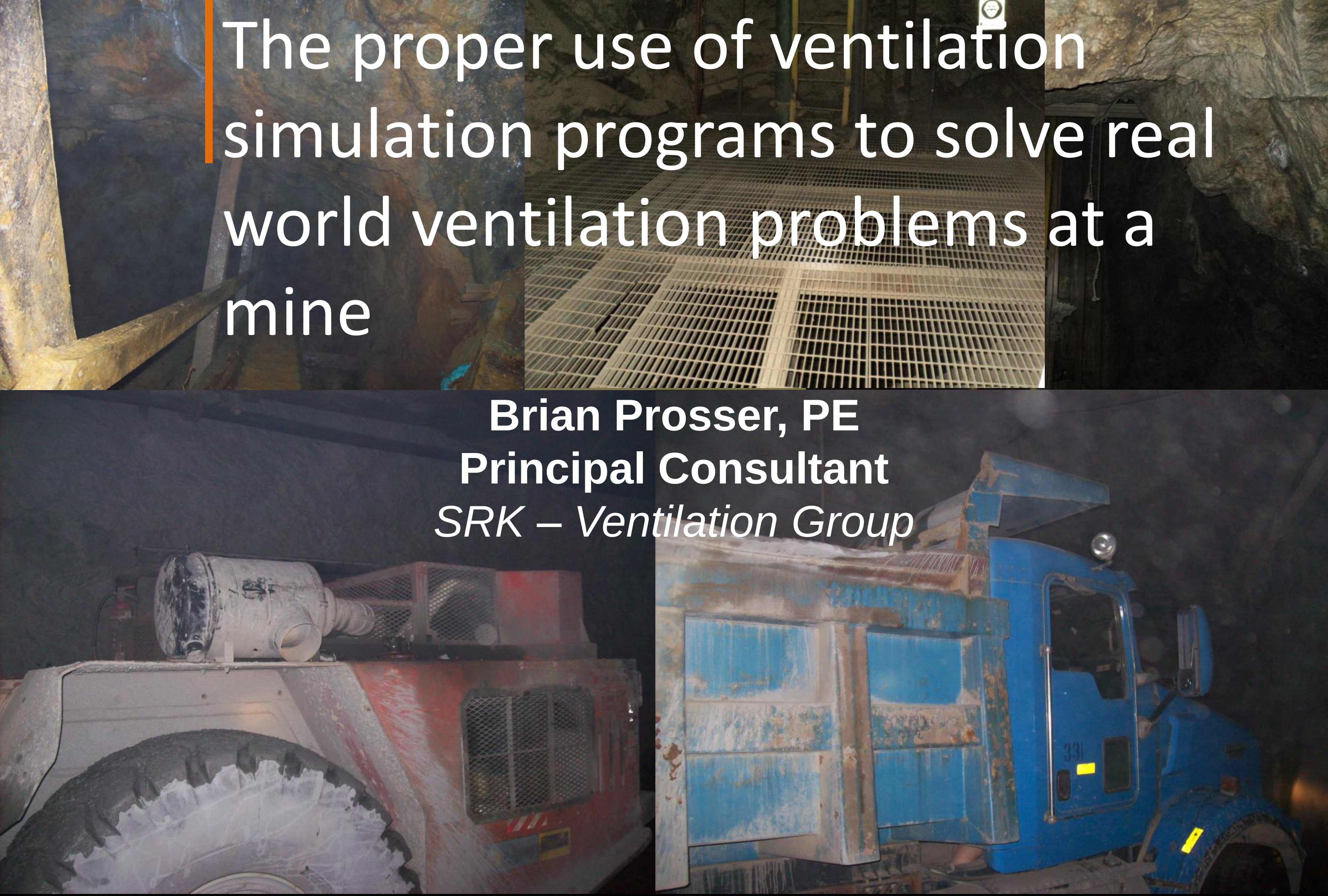

The proper use of ventilation simulation programs to solve real world ventilation problems at a mine

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General Best Practices

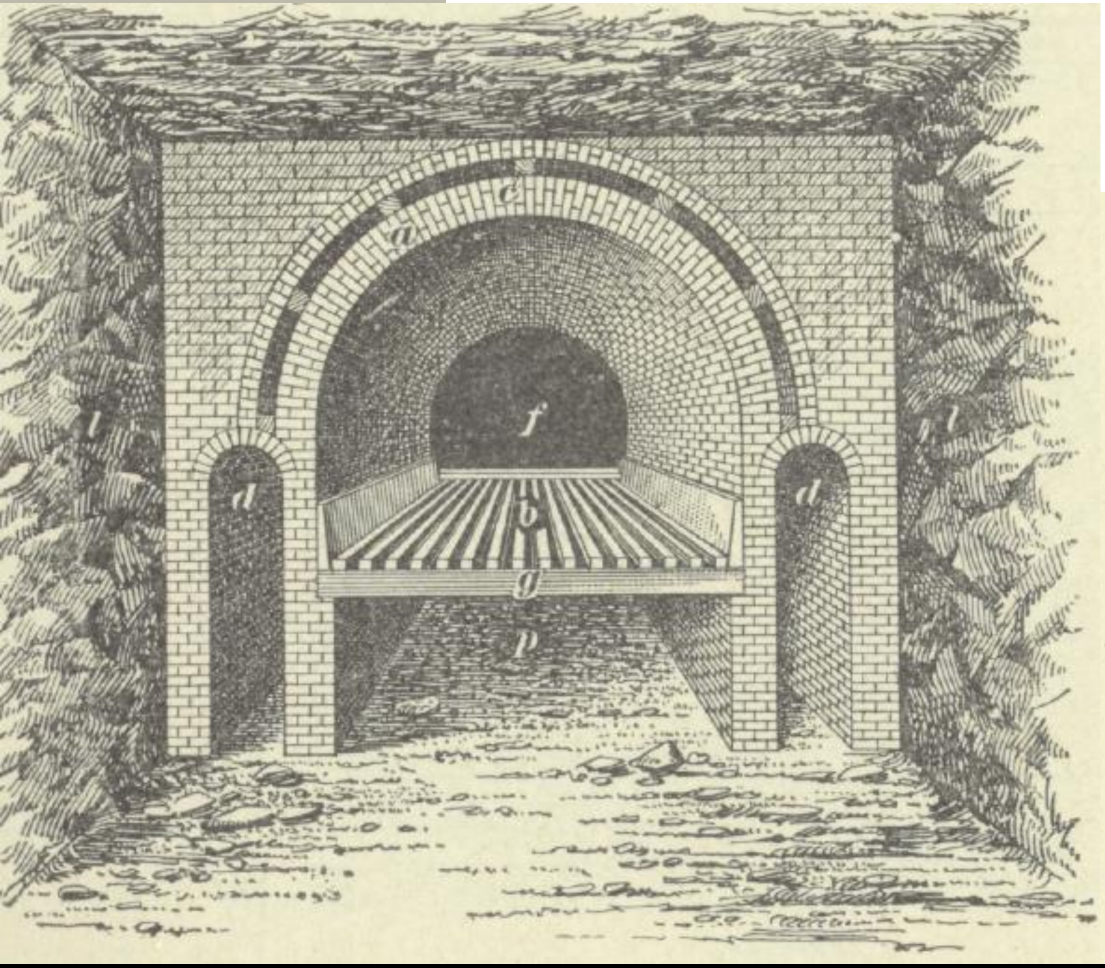
Why do we ventilate mines?

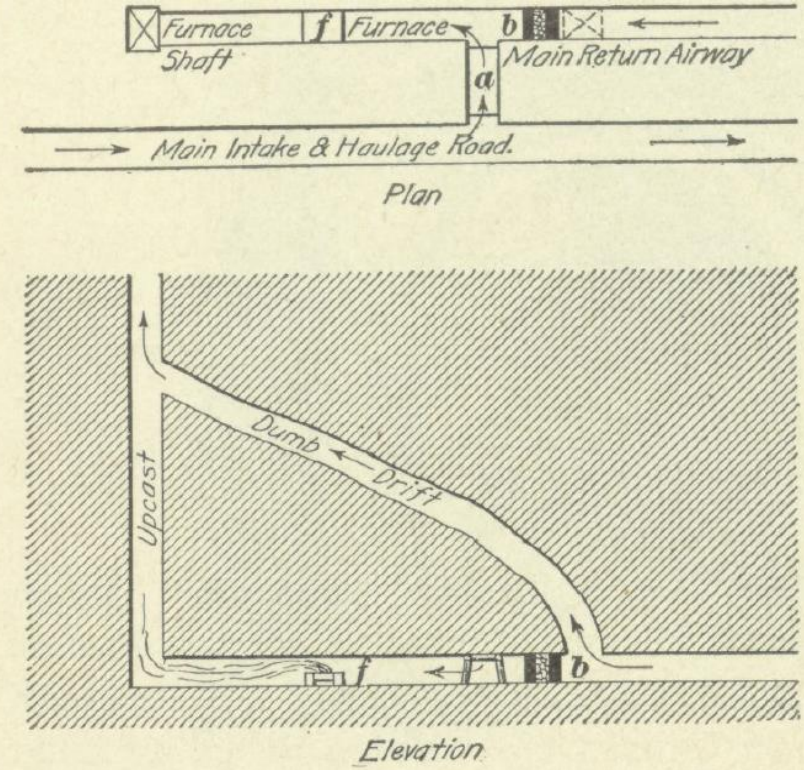
The objective of underground ventilation is to provide airflows in sufficient quantity and quality to dilute contaminants to safe concentrations in all parts of the facility where personnel are required to work or travel. (McPherson)

We design ventilation systems to ensure health and safety, not just to meet minimum legislative requirements.

The Art of Ventilation Has Changed Over Time

- What was “state of the art” in the past will be superseded as new technology is developed.
- But as with any new technology it must be vetted before incorporation





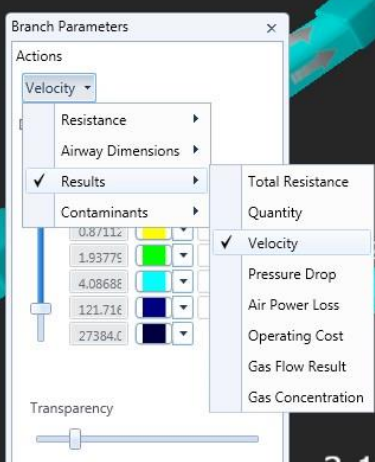
ICS Reference Library, Volume 145, 1907, Fig 15 & 16

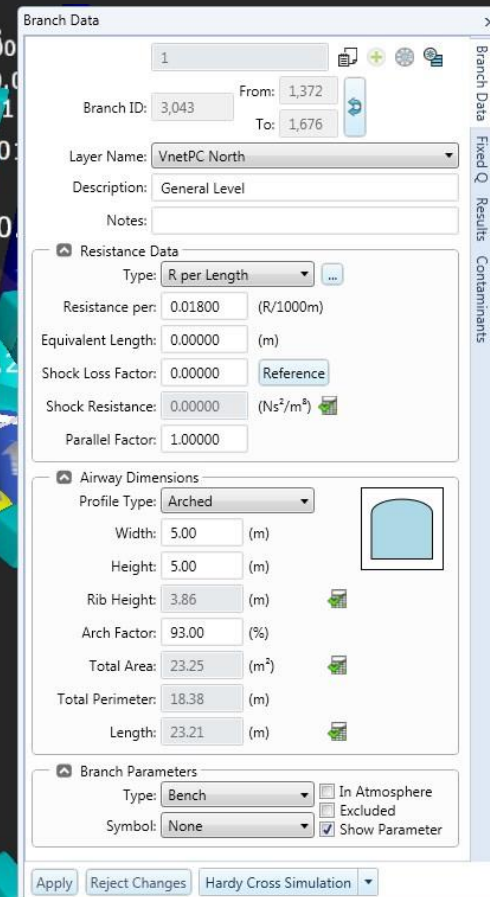
New Technology - Modeling

- Ventilation modeling represents the current state of the art for the design and planning of ventilation systems
- VentPC, VentSIM, VUMA, K-Mine, VentGraph, and Others
- But to be effective it must be used properly

Ventilation Modeling

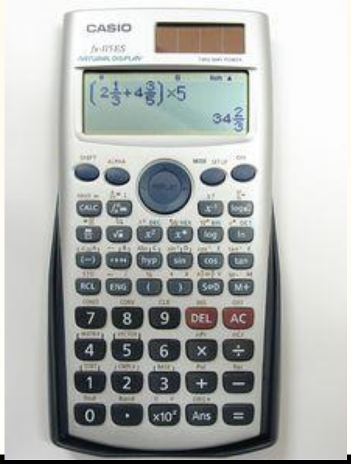
- With the software packages available today large changes in the ventilation systems should be modeled or previewed to identify potential pitfalls.
- New ventilation systems should be modeled
- Why take a chance on missing a resistance, miss calculating, or guessing.





Guiding Precept for Developing Ventilation Models

Key Concept - A network program is just a calculator you control the inputs, so you are responsible for the results. Always be familiar with the limits of the software you are using.



- A ventilation model needs to reflect what is actually going on in the mine.
- The ventilation model needs to reflect reality.
- Often there can be a disconnect between the ventilation engineer and operations, this gap needs to be closed in order increase the effectiveness of the modeling.
- The process generally starts with a ventilation survey, not just for the measurement of resistances, but to examine the basic ventilation methodology in use at the mine.
- Just looking at maps will not tell the full story.

Ventilation Network Analyses

Key Concept – The simulator is just a calculator, the results will depend directly upon what you put into it. If you want accurate results you need accurate resistance data.

WHY DO WE MODEL?

- A model is a predictive tool
- Predict future ventilation demands
- Model effects of vent controls

HOW DO WE KNOW THE MODEL IS ACCURATE?

- *Correlation:* compute the error between the measured and predicted airflow distributions

Model Accuracy

Key Concept – Identify the model accuracy through the "correlation error" – keep it less than 10%

$$\frac{\sum|Q_{measured} - Q_{predicted}|}{\sum Q_{measured}}$$

- How accurate is your model?
- What basis is used to compare the model accuracies?
- What are the issues with the this approach to determine model accuracy?
  - Honesty of calculation is key
  - Avoid "manufactured precision"

Accurate Representation – Ensuring the Model is indicative of the Actual Mine

- Do not overestimate leakage path resistances (typical error is using a very high per bulkhead resistance)
- Do not underestimate friction factors and airway resistances (shock losses)
- For existing mines, start the model development with a ventilation survey
  - A full ventilation model is preferable
  - If the ventilation system exists then representative values of resistance can be measured
  - Resistance values are very site specific

Future Ventilation Planning

To modify the basic ventilation model to represent future mine development use the following:

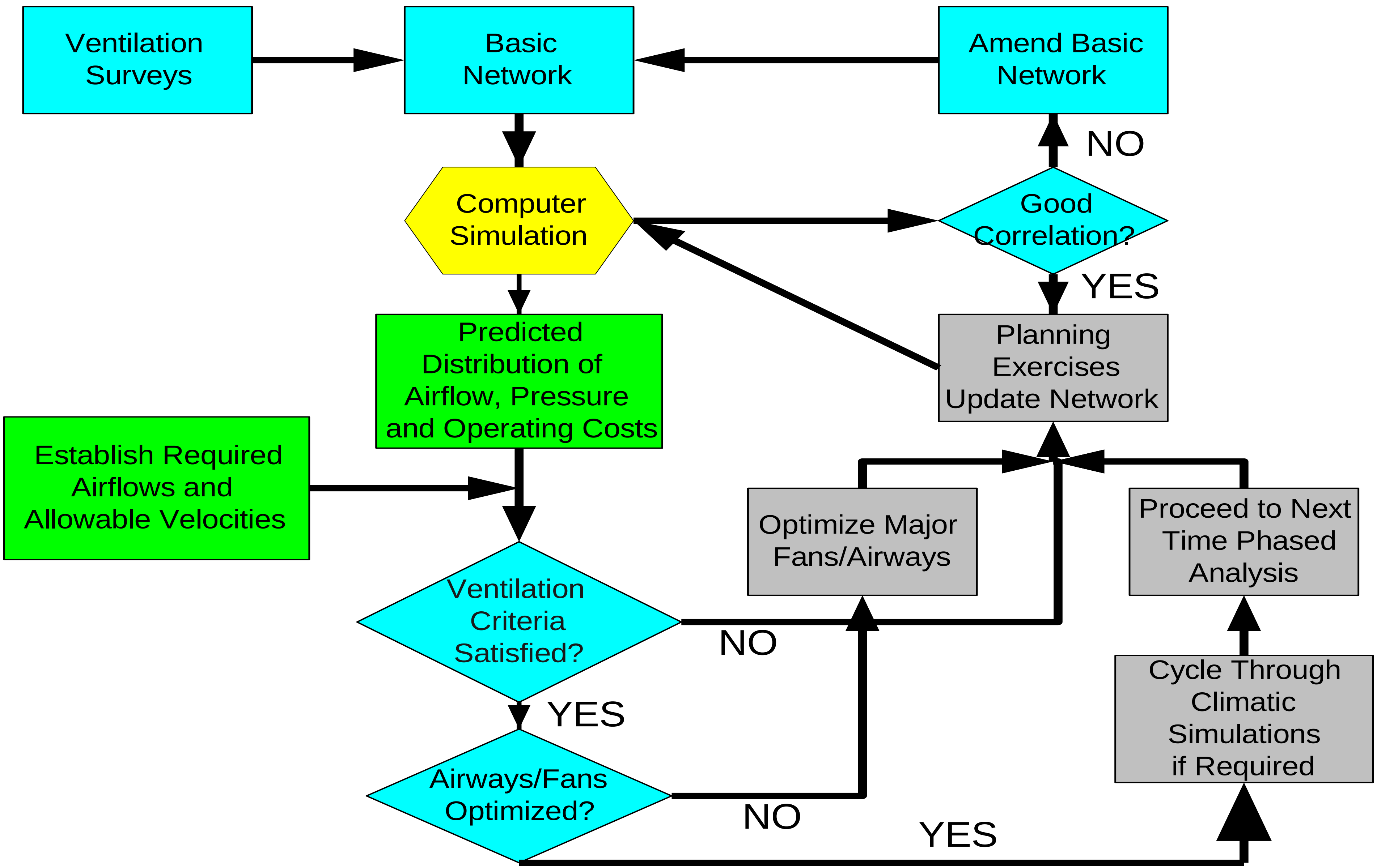
- Measured friction factors and airway geometry
- Measured resistance per length and airway length
- Typical measured resistances for ventilation controls

Add shock losses for major bends, junctions and changes in area

Put fans on their respective curves and check that they are functioning correctly

- Fan curves may not match expected operating setting – remember the translation from survey measurements

Workflow


Ventilation Surveys
Basic Network
Amend Basic Network
NO
Computer Simulation
Good Correlation?
YES
Predicted Distribution of Airflow, Pressure and Operating Costs
Planning Exercises Update Network
Establish Required Airflows and Allowable Velocities
Optimize Major Fans/Airways
Proceed to Next Time Phased Analysis
Ventilation Criteria Satisfied?
NO
YES
Cycle Through Climatic Simulations if Required
Airways/Fans Optimized?
NO
YES

Developing Models with a Single Friction Factor

- If developing a ventilation model from empirical values, select values based upon the conditions expected to be encountered in the mine.
- Shafts, raises, overcasts, travel ways will all have different resistance characteristics and should be modeled accordingly.
- Use shock loss factors for high airflow branches.
- Friction factors are a function of air density.

Select the Correct Friction Factor

Know your sources: McElroy – 1935 – Engineering Factors in the Ventilation of Metal Mines This source has been used by Hartman, SME, McPherson, and Vutukuri. Are your airways similar to those described by McElroy's (1935) work acceptable to use, or should you select more recent values? The values reported in the 1935 study were based largely on work from 1924 to 1925 in Butte, Montana in openings varying from 20 ft^2 (1.8 m^2) to 60 ft^2 (5.6 m^2) with entries mined with jack legs.

Is this still representative for operations today?

Size Effect – Von Kármán Equation

$$f = \frac{k}{0.6} = \frac{1}{4[2\log_{10}(d/e) + 1.14]^2}$$

- The size of the airway with respect to the height of the asperities has a direct effect on the friction factor.
- Different size drifts with similar asperities may have different friction factors.
- (note: above equation is dimensionless)

Friction Factor Measurements

	Level Drift	Ramp	Alimak Raise	Bored Raise	Beltway	TBM Drift
Average Value	0.00879 (47.4)	0.01158 (62.4)	0.01126 (60.7)	0.00466 (25.1)	0.01399 (75.4)	0.00440 (23.7)
Maximum Value	0.01284 (69.2)	0.01739 (93.7)	0.01579 (85.1)	0.00698 (37.6)	0.01664 (89.7)	0.00560 (30.2)
Minimum Value	0.00468 (25.5)	0.00698 (37.6)	0.00874 (47.1)	0.00230 (12.4)	0.01228 (66.2)	0.00341 (18.4)
Std. Deviation	0.00239 (12.9)	0.00310 (16.7)	0.00330 (17.8)	0.00152 (8.2)	0.00184 (9.9)	0.00111 (6.0)
# of Measurements	40	20	5	10	5	3

Metal Mine Measurements

	Intake Drift	Return Drift	Belt Drift	Cribbed Drift
Average Value	0.00753 (40.6)	0.00872 (47.0)	0.01058 (57.0)	0.06781 (365.5)
Maximum Value	0.01148 (61.9)	0.01133 (61.1)	0.01757 (94.7)	0.14409 (776.6)
Minimum Value	0.00482 (26.0)	0.00566 (30.5)	0.00459 (24.3)	0.04522 (243.7)
Std. Deviation	0.00219 (11.8)	0.00176 (9.5)	0.00636 (34.3)	0.02516 (135.6)
# of Measurements	23	15	5	7

Coal Mine (Bedded Deposits) Measurements

Friction Factor Comparisons

Airway Type	Mean MVS Measured Data	Suggested MVS Value	McPherson (1993)	Hartman et. al. (1997)
Rectangular Airway – Clean Airway (coal or soft rock with rock bolts limited mesh)	0.0075 (41)	0.0075 (41)	0.009 (49)	0.0080 (43)
Rectangular Airway – Some Irregularities (coal or soft rock with rock bolts limited mesh)	0.0087 (47)	0.0087 (47)	0.009 (49)	0.0091 (49)
Metal Mine Drift (arched and bolted with limited mesh)	0.0088 (47)	0.010 (60)	0.0120 (65)	**0.0269 (145)**
Metal Mine Ramp (arched and bolted with limited mesh)	0.0116 (62)	0.013 (71)	-n/a-	**0.0297 (160)**
Metal Mine Beltway (large area, rock bolted with mesh)	0.0140 (75)	0.015 (80)	-n/a-	-n/a-
Bored Circular Raise (contains entry/exit loss)	0.0047 (25)	0.0050 (27)	0.004 (22)	0.0028 (15)
Rectangular Alimak Raise (un-timbered with rock bolt and mesh)	0.01126 (61)	0.0129 (70)	0.014 (75)	-n/a-
TBM Drift (rock bolts with mesh)	0.0044 (24)	0.0050 (26)	0.0055 (30)	0.0037 (20)

Note: Atkinson's Friction Factor in kg/m^3 ($lbf min^2/ft^4 \times 10^{-10}$). Bold indicates large discrepancy with MVS measured values.

Back Calculating Representative Friction Factors for all Airways in a Model and Adjusting for Reasonableness

- If a model is developed based upon the resistances measured during a ventilation survey, then leave the resistances in the model as measured (exception to this rule is if there is a physical change to the airway)
- By back calculating friction factors “after the fact” may not be evaluating the correct “as-built” airway dimensions.
- Shock loss factors generally cannot be removed from measured survey data, thus limiting the comparison of friction factors.

Typical Resistance Values for Ventilation Controls

- Doors: 5-50 P.U (Typical = Ns^2/m^8)
- Seals: 1000-10,000 (Typical = 2,500 Ns^2/m^8)
- Curtains or Brattices:
  1-5 P.U (Typical = 2.5 Ns^2/m^8)
- Bulkheads or Stoppings:
  50-5,000 P.U (Typical (metal mine = 500 Ns^2/m^8)

When using “generic” values to simulate future mining conditions stay away from values that are on the extreme ends of the spectrum, choose values that represent “average” conditions (particularly if measured).

Definition of Shock Loss

Whenever air encounters a bend, junction, change in cross section, obstruction, regulator, or at the entry and exit points to the system, additional vortices will be initiated. The propagation of these eddies consumes mechanical energy, and the resistance of the airway may increase significantly. This increase in resistance is known as shock loss.

Example Shock Losses

Example Shock Losses

Constriction

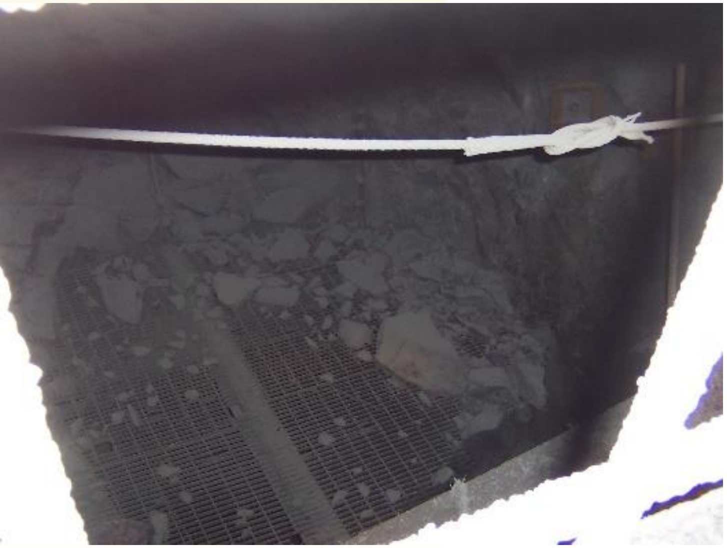
Added Resistance due to Shock Losses

Individual loss values can be found in various texts/books

$$R_{sh} = b\frac{\rho\,X}{A^2}$$

- R_{sh} = Resistance (P.U. or Ns^2/m^8)
- X = Shock Loss Factor (dimensionless - see notes)
- A = Area (ft^2 or m^2)
- b = 829.5 for imperial units and 0.5 for SI
- Evaluate at measured air density (lb/ft^3 or kg/m^3)

Raise/Shaft Resistance

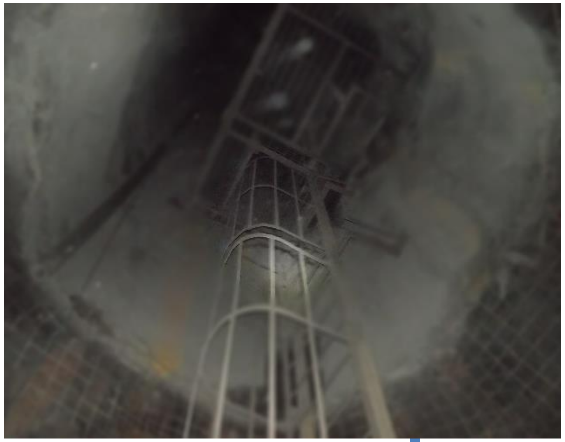


- Not all shafts and raises are "smooth lined" with a low friction factor
- Need to make sure that the shaft/raise resistance equates to what is actually going to be constructed
- Landings, buntons, ground control, utilities need to be accounted for

What do your shafts look like?

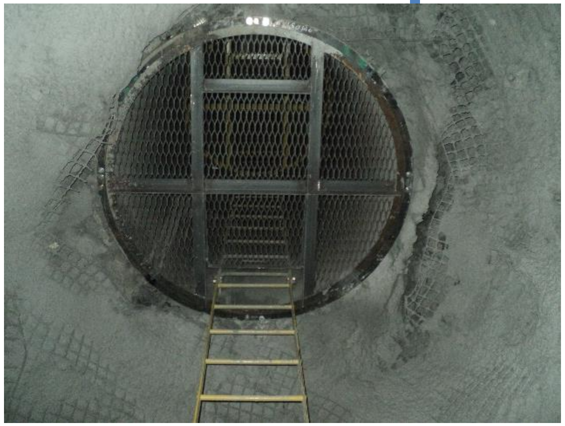
“Smooth Shaft”

Partial Landing



Ladder With No Landing

Full Landings

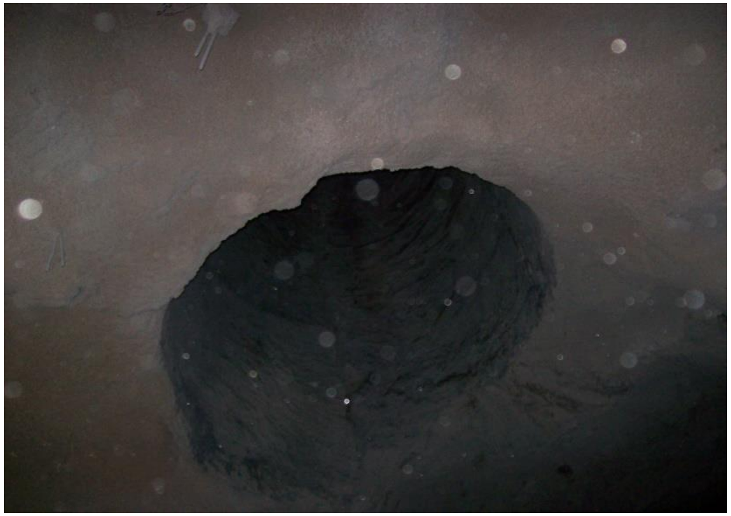


Calculation

	SI (Ns^2/m^8)	Imperial (P.U.)
Shaft Walls	$\frac{kL\ per}{A^3}$	$\frac{kL\ per}{52\ A^3}$
Buntons	$1.2\ \frac{L}{S}\ C_D\ \frac{A_b}{2A^3}\left[0.0035\ \frac{S}{W} + 0.44\right]$	$62.2\ \frac{L}{S}\ C_D\ \frac{A_b}{A^3}\left[0.0035\ \frac{S}{W} + 0.44\right]$
Conveyances (maximum)	Stationary: $\frac{0.6\ X_{conv}}{A^2}$ Maximum: $\frac{0.6\ X_c}{A^2}\left[1 + \frac{U_c^2}{U_a^2}\right]$ X_c from figure 2	Stationary: $\frac{62.2\ X_c}{A^2}$ Maximum: $\frac{62.2\ Xc}{A^2}\left[1 + \frac{U_c^2}{U_a^2}\right]$ X_c from figure 2
Entry and Exit	$\frac{0.6\ X}{A^2}$ (See App.A-3 in Hartman, 1982)	$\frac{62.2\ X}{A^2}$ (See App.A-3 in Hartman, 1982)
Parameters (w/units)	k = friction factor (kg/m^3) L = length (meters) per= perimeter (m) A = area (m^2) S = bunton spacing (m) W = bunton width (m) U_c = cage velocity (m/s) U_a = freestream velocity (m/s) C_D = coefficient of drag A_b = area of buntons (m^2)	k = friction factor $\left[\frac{lbf\ min^2}{ft^4} \times 10^{10}\right]$ L = length (ft) per = perimeter (ft) A = area (ft^2) S = bunton spacing (ft) W = bunton width (ft) U_c = cage velocity (ft/min) U_a = freestream velocity (ft/min) C_D = coefficient of drag A_b = area of buntons (ft^2)

Resistance Calculation

Basic wall resistance (lining type)
Conveyance (speed and cross-section)
Entry and exit losses (shock losses)
Buntons and landings (shock losses)

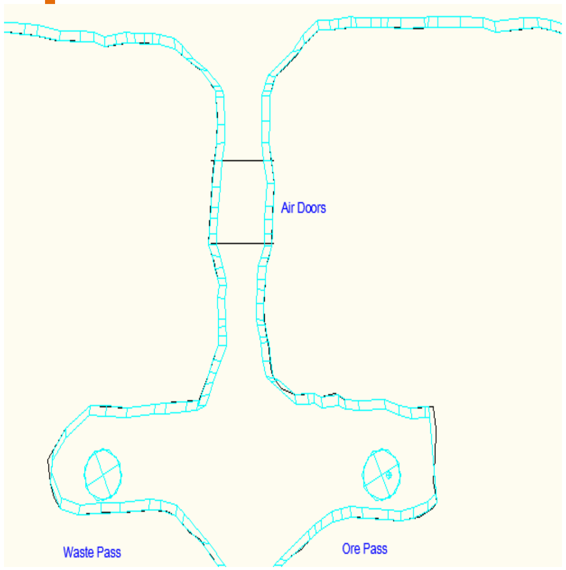


Ore Pass Issues

- Ore passes are frequently used in multi-level metal mines.
- Much of the time the ore passes are modeled with either a high resistance or are omitted from the model.
- Is this really the case?
- What happens when an ore pass is opened?
- Short circuiting of air from one level to the next.
- Injection of dusty air onto the level.
- Uncontrolled disruption in the ventilation system.
- Improper location of Ore Pass accesses

Ore Pass Regulation Options

Air Doors



Automatic Lifters

Conveyor Belt Flaps

LHD Plugs/Covers

General Comments

- Although with enough design and engineering almost anything can be justified.
- What happens if “engineered” solutions fail?
- How can the ventilation systems be designed to promote success?
- What basic design parameters can be adjusted to provide a basic level of coverage?
- These would be considered “best practices”.

Relationship Between Mining Area Values and Total Mine Airflow

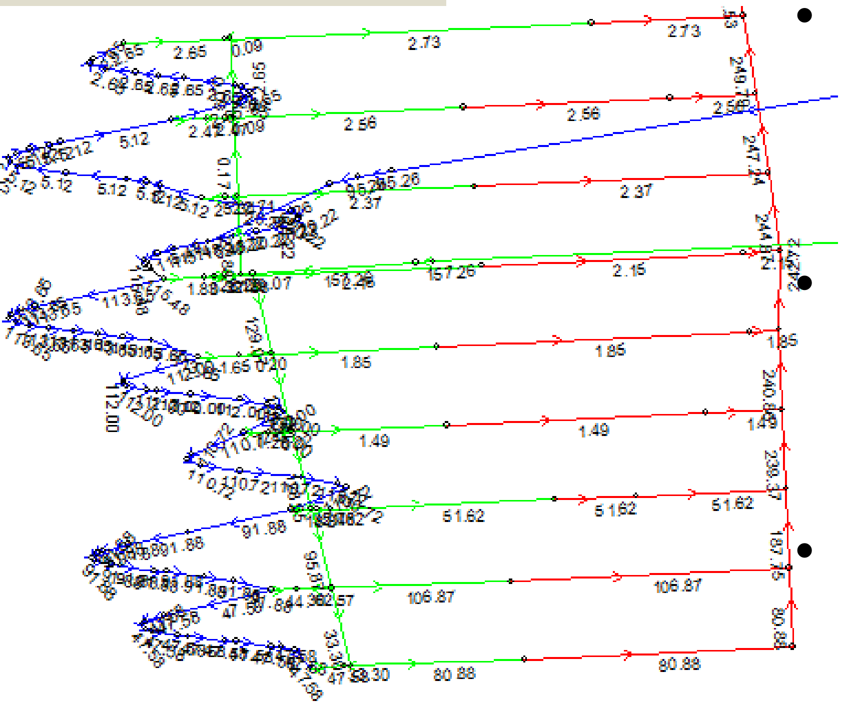
The mining area airflow requirement does not directly translate to the overall mine airflow requirement.

- Leakage rates must be accounted for.
- Leakage rates may vary from 25% to 90% depending upon many site-specific factors:
    1. Number of Bulkheads
    2. Type of Construction for Bulkheads
    3. Age of Infrastructure
    4. Doors
    5. Intake/Exhaust Connections
    6. Fan Placement
    7. Ventilation of Dedicated Areas (Ramps, etc.)

Relationship Between Mining Area Values and Total Mine Airflow

How is the total mine airflow determined?

- Applying generic system efficiency values – least accurate



- Developing a ventilation model based on empirically derived values (friction factors, resistance estimates) – moderately successful
- Developing a ventilation model based on site measured data and measured infrastructure values – greatest success
- More information on this will be discussed this afternoon

Ventilation Modeling Process

Thank you for your attention

Feel free to ask questions here or contact me later at:

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Literature

This is a starting point, not an exhaustive list

Its always good to start with what other people have already done;

- Ventilation Symposium
- Published/Peer Reviewed Papers and Designs
- Well Ventilated Operating Mines (Similar Designs)
- NIOSH
  - *Chekan*
- Mine Design Wiki
  - *Hardcastle and Kocsis*
- Mine Ventilation Australia
  - *Brake*
- Mine Ventilation Services/SRK
  - *Prosser & Wallace*
- HSE Occupational Health in Mines Committee
  - *Gilmour et al.*
- Pittsburgh Safety and Health Technology Center
  - *Schultz*
- Minerals, Metals and Materials Technology Centre
  - *Kurnia and Mujumdar*

Selected References

Fytas, K. and Gagnon, C., 2008. A Database of Ventilation Friction Factors for Quebec Underground Mines, *Proceedings of the 12th US/North American Mine Ventilation Symposium*. Pp 615-622 (University of Nevada, Reno).

Duckworth I.J, Loomis I, Prosser B. 2012. Fifteen Years of Resistance Data Collected at Freeport Indonesia, *Proceedings of the 14th US/North American Mine Ventilation Symposium*, pp 161-166 (University of Utah)

Prosser, B.S., Wallace, K.G., 1999. Practical Values of Friction Factors, *Proceedings of the 8th US Mine Ventilation Symposium*, pp 691-696 (University of Missouri-Rolla Press)

McPherson, M.J., 2009. *Subsurface Ventilation and Environmental Engineering*, (Mine Ventilation Services, Inc. California USA) ISBN: 978-0-692-00024-3

Vutukuri V.S., Lama R.D., 1986. *Environmental Engineering in Mines*, Cambridge University Press, London, ISBN: 0-521-24605-9