THE UNIVERSITY OF UTAH™

Center for Mining Safety & Health Excellence

‘Risk & Change Management in Mining’

Tom Hethmon
Associate Professor & Western Presidential Endowed Chair in Mine Safety
Director, Center for Mine Safety & Health Excellence
Department of Mining Engineering
University of Utah
135 South 1460 East
Salt Lake City, Utah, USA 84112
tom.hethmon@utah.edu

TOGETHER WE REACH

Risk Management

The heart of safety management in mining is risk management, i.e., identification of hazards, assessment of their risk, application of appropriate controls. Regardless of the nature of the hazard (e.g., geological or other energy sources, environmental, process, human error & behavioral, etc.), they should all be addressed through effective risk management.

This is the core work within CORESafety.

Everything else within COREsafety is there in support of risk management (leadership, culture, behavior, training, engineering, control measures, auditing, etc.).

MSHA vs. CORESafety Risk Management

MSHA: Hazards are addressed through standards. The MineAct doesn't address all hazards/risk.

- If your mine has any of the list of hazards in 30 CFR you need to implement the controls specified therein.
- Once you have completed that work, document it to establish that you are in compliance.
- You know you have done it correctly if you are inspected by MSHA and/or if you experience a reportable incident and receive and received no citations.
- If you receive citations, you must abate the identified the problem and pay the assessed fine.

CORESafety: All appropriate risk is addressed systematically and prioritized.

- Assess all of the hazards in your mine. There are many different techniques available to help you do this.
- Once the risk has been assessed, prioritize the risks and develop a strategy to optimize control of the risks.
- Implement the controls and maintained that level until there is a change to the underlying hazard and then reassess the risk to ensure controls are appropriate.
- You know if you've done it correctly if your level of risk allows you have the level of safety and health performance you seek.

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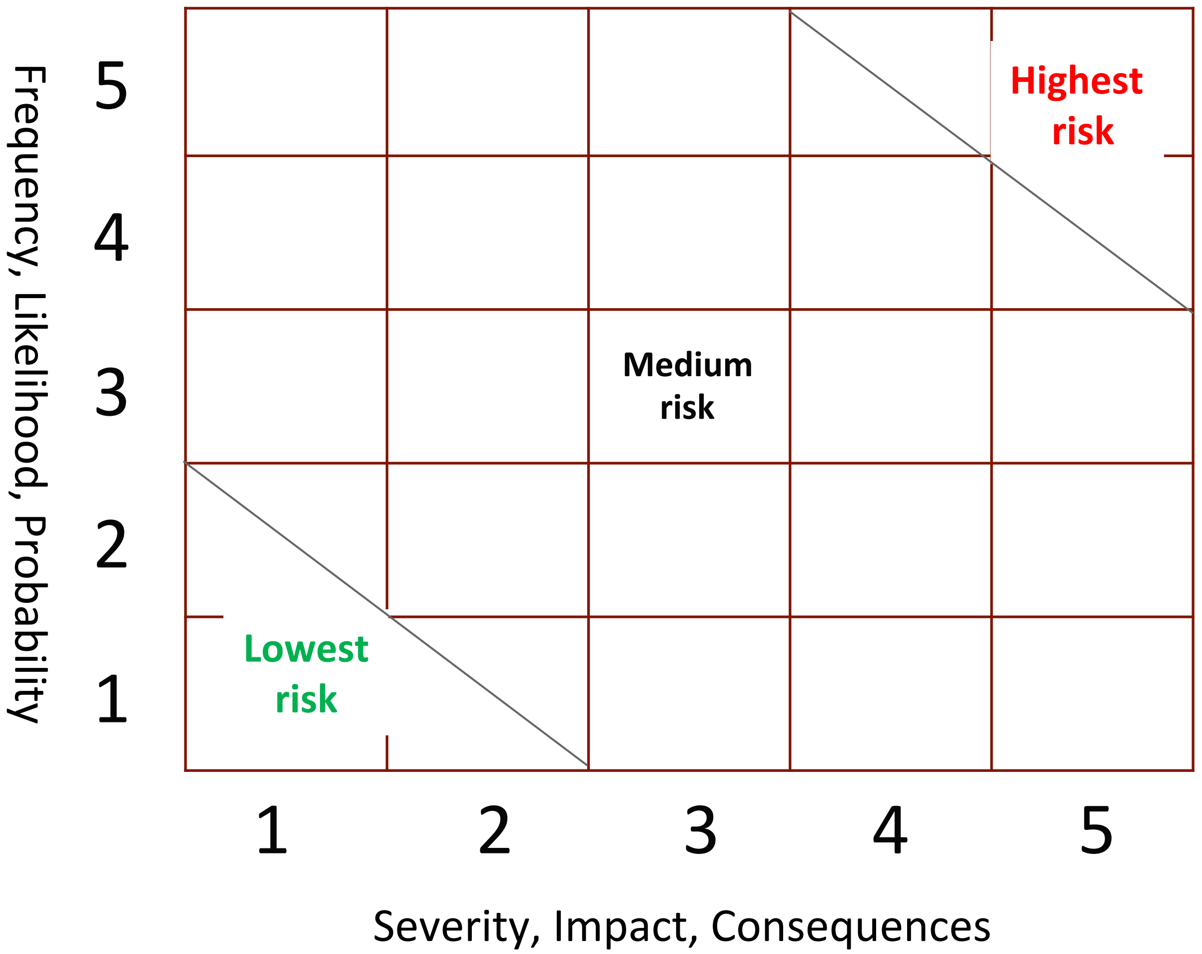
Risk

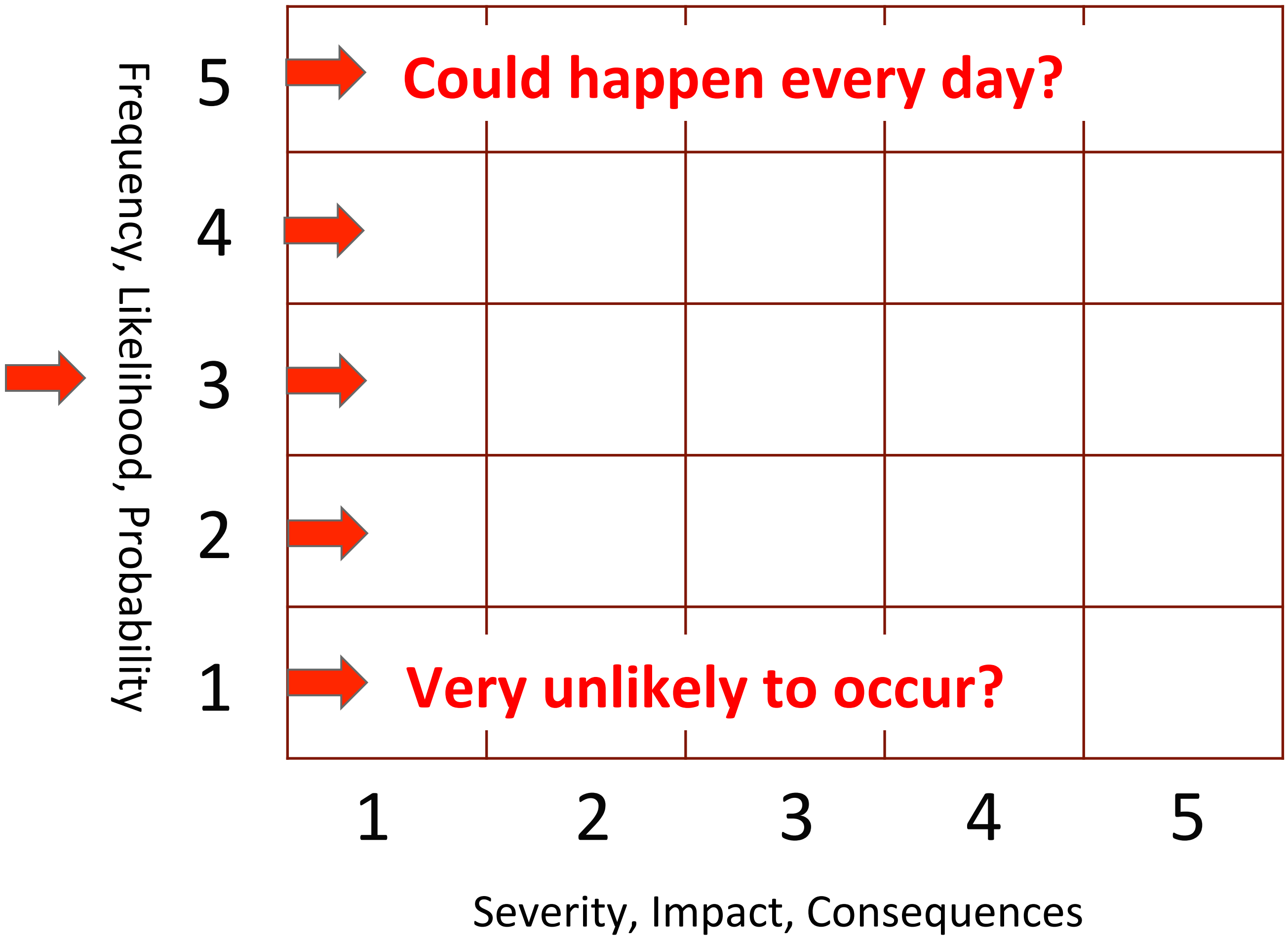
- Risk = Probability of occurrence X Consequence of outcome

Risk Matrix

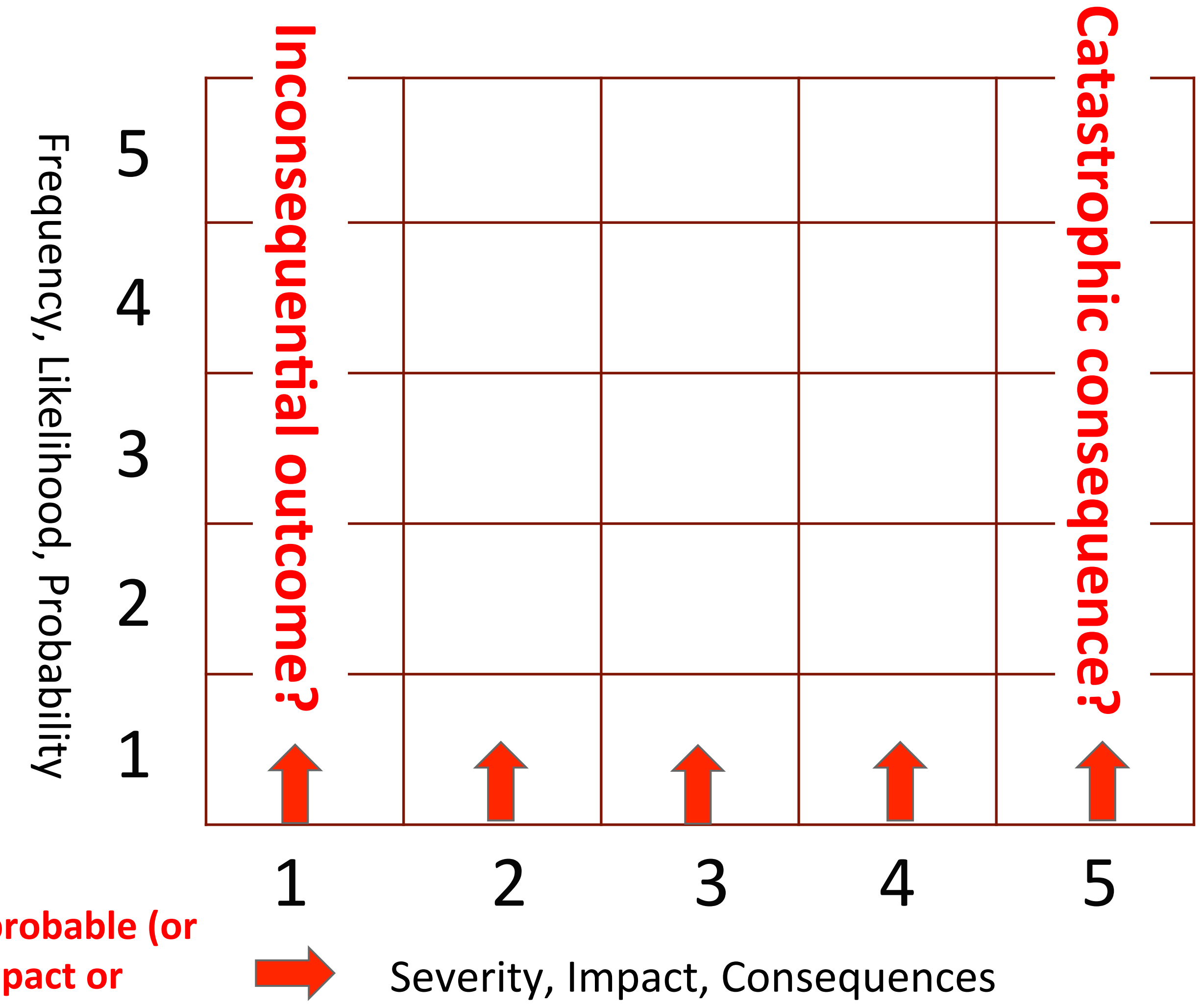

Frequency, Likelihood, Probability
5
4
3
2
1
Highest risk
Medium risk
Lowest risk
1
2
3
4
5
Severity, Impact, Consequences

Risk Matrix

What is the likelihood that a specific hazard will result in an expressed injury, fatality, or other outcome?



Risk Matrix

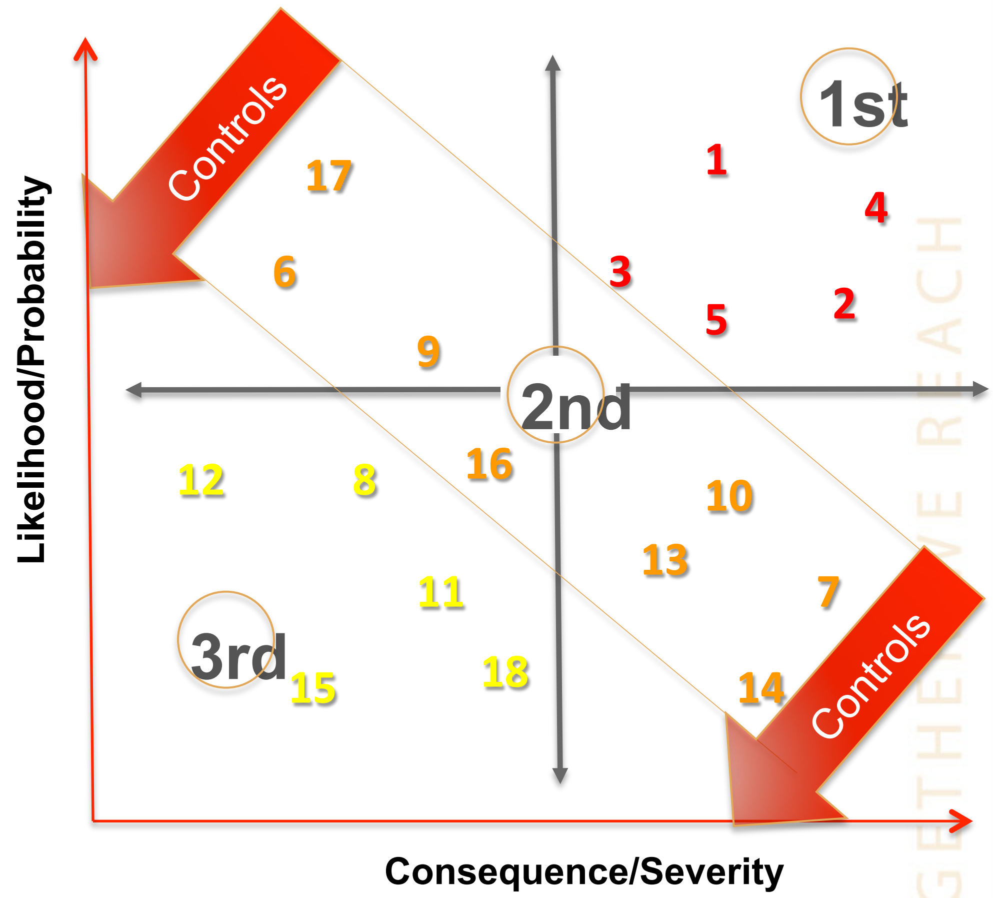


What is the most probable (or worst case) impact or consequence from the hazard?

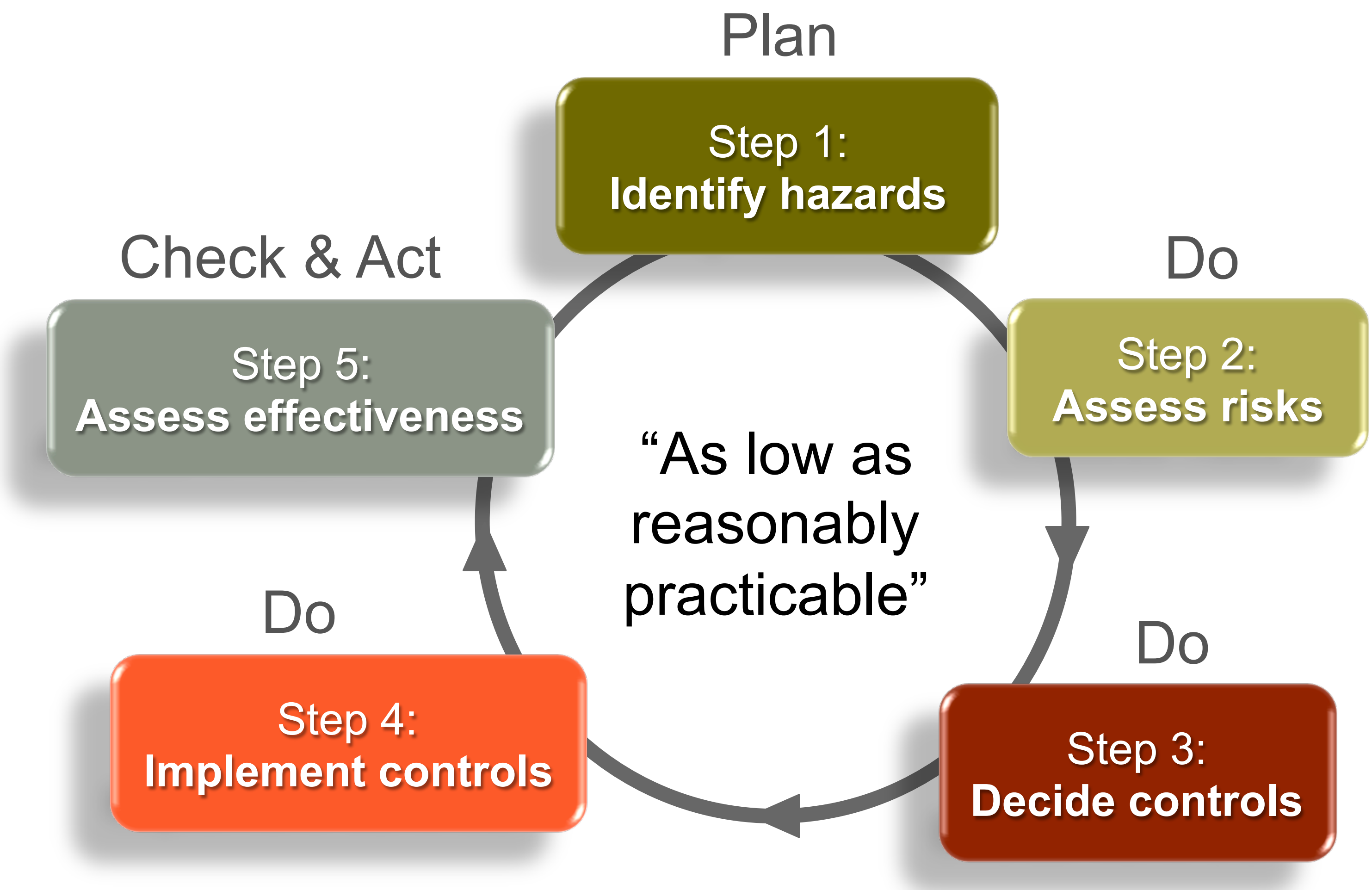
Mining Hazards

Example U/G coal risk ranking:

1. Gas/dust explosion
2. Ground fall
3. Proximity
4. Pinch points (proximity)
5. Hazard #5
6. Hazard #6
7. Hazard #7
8. Hazard #8
9. Hazard #9
10. Hazard #10
11. Hazard #11
12. Hazard #12
13. Hazard #13
14. Hazard #14
15. Hazard #15
16. Hazard #16



Risk Management



Risk Assessment Tools (Methods, Techniques)

- Job Hazard Analysis (JHA)
- Vulnerability Assessment
- Control Hazards Identification
- Structural Reliability Analysis
- Hierarchical Task Analysis (HTA)
- Maintenance & Operability Study (MOP)
- Failure Mode and Effect Analysis (FMEA)
- Predictive Human Error Analysis (PHEA)
- Structured Analysis & Design Techniques (SADT)
- Failure Modes, Effects, and Criticality Analysis (FMECA)
- Sneak Analysis
- DELPHI Method
- Bow Tie Analysis (BTA)
- Action Error Analysis (AEA)
- Human Reliability Analysis

Risk Assessment Tools (con't)

- Hazard & Operability Studies (HAZOP)
- Computer HAZOP (CHAZOP)
- Concept Hazard Analysis (CHA)
- Concept Safety Review
- Preliminary Hazard Analysis (PHA)
- Fault Tree Analysis (FTA)
- Cause Consequence Analysis (CCA)
- Goal-Oriented Failure Analysis (GOFA)
- Functional Integrated Hazard Identification (FIHI)
- Critical Examination of System Safety (CEX)
- Method Organized Systematic Analysis of Risk (MOSAR)
- Checklists
- 'What if?' Analysis
- 'What if-Checklist' Analysis
- Inherent Hazard Analysis
- Hardware Hazards Identification

Which RA* Techniques Should U.S. Mines Consider?

- Brainstorming
- What If/Checklist
- Bow Tie Analysis (BTA)
- Fault Tree Analysis (FTA)
- Event Tree Analysis (ETA)
- Hazard & Operability Study (HAZOP)
- Workplace Risk Assessment & Control (WRAC)
- Failure Mode, Effects & Criticality Analysis (FMEA)

*RA = Risk assessment

Risk Management

"It's not rocket science – it's more complicated"

- Coordinated activities to direct & control an organization with regard to risk.
- Systematic application of management policies, procedures & practices to the activities of communicating, consulting, establishing context, analyzing, evaluating, treating, monitoring and reviewing risk. (ISO 31000)

Standards of 'Acceptable' Risk in U.S. Mining

- Occupational Health & Hygiene: The OSHA PEL's XXXXX
- Environmental Management: Many EPA groundwater, soil and emissions standards (where chronic endpoints are the focus) are based on a 1:1,000,000 reference risk criteria.
- Safety: **Neither MSHA 30 CFR or accepted good practice in mine design are based on formal risk standards or criteria.**
- Each company must determine their level of acceptable risk.
- '0:50:0', 'Zero harm' & 'zero injuries' are aspirational goals and expectations, but do not reflect any specified level of risk.

Which Risk Are You Trying to Manage?

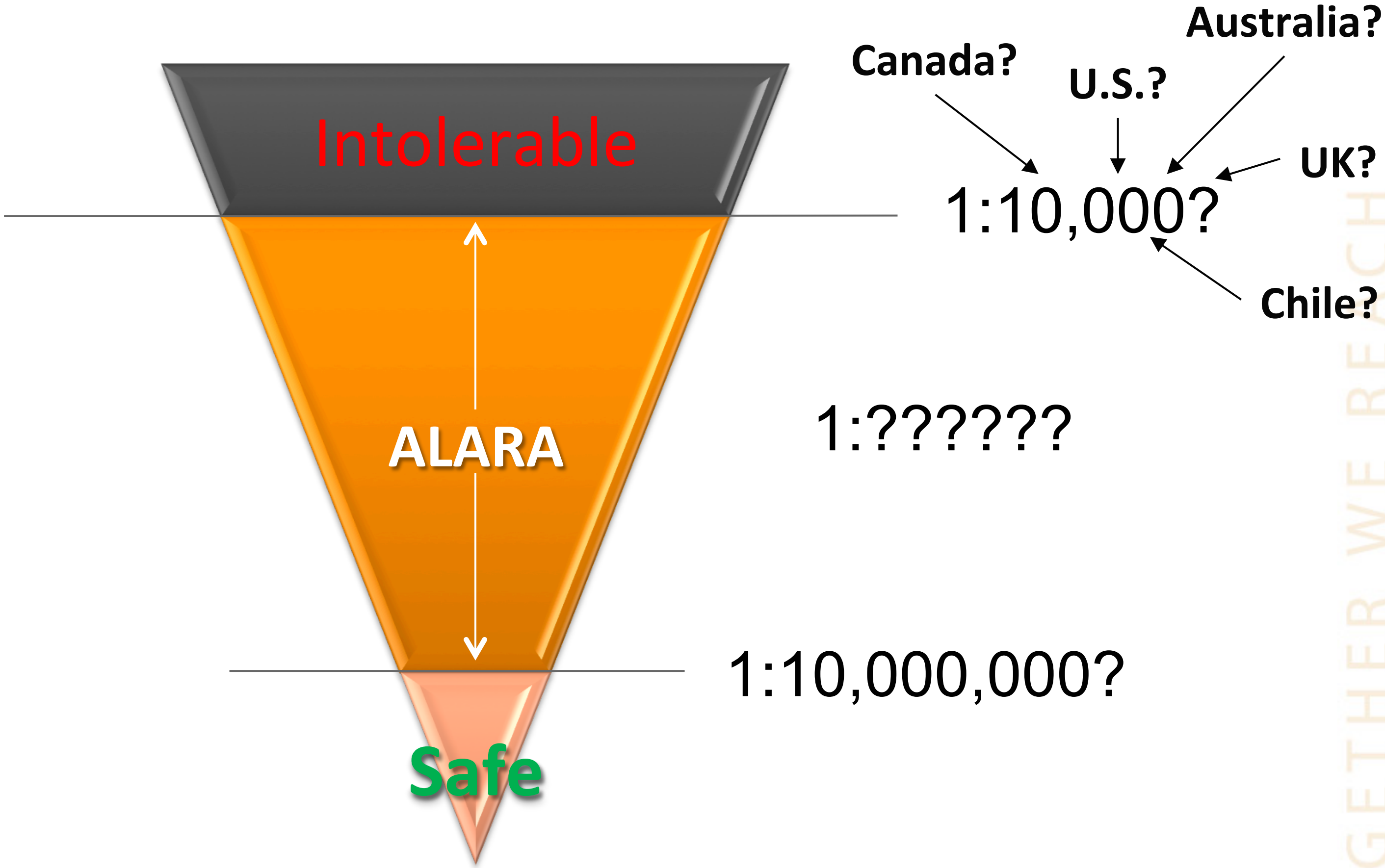
Total Risk − **Risk Controls** = **Residual Risk**

All the risk in your mining operation

Everything you do to manage risk in your mining operation

The risk that is *not* controlled, i.e., the potential for your people to be hurt or other assets damaged

Acceptable (Residual) Risk



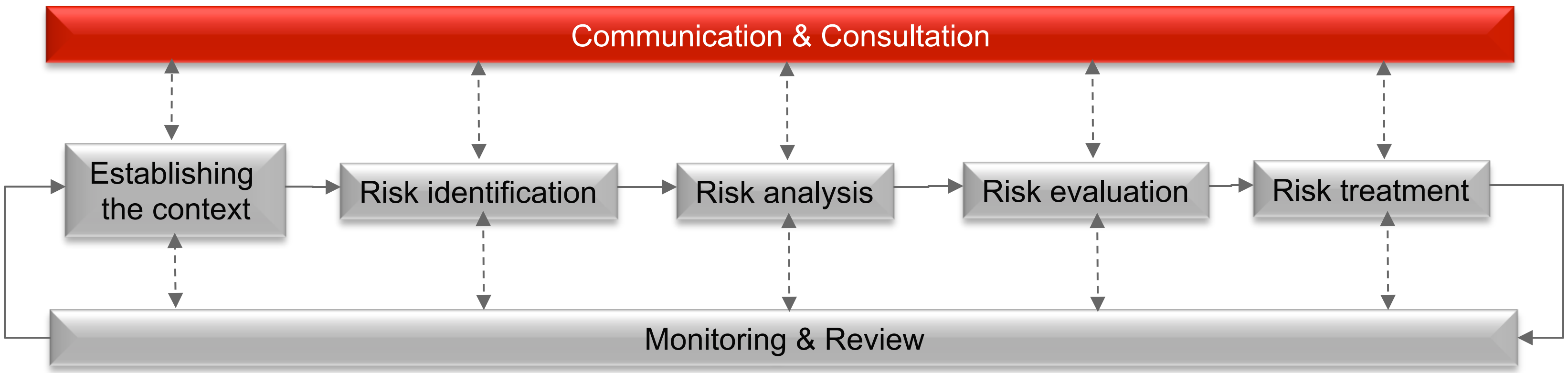
ALARA: As Low As Reasonably Achievable

Generic Risk Registry

RISK REGISTER

Risk ID #	Risk Statement (Description)	Probability of Occurrence	Impact	Score (Probability x Impact)	Risk Trigger	Risk Owner	Planned Response(s) (Description)

The Risk Management Process (ISO 31000)



- Who are the internal & external stakeholders?
- Which stakeholders are essential to RM decision-making?
- How often does consultation need to occur?
- To whom does RM report: financial RM vs operational RM?
- Can you communicate too much re: RM?

Is mining risk acceptable when…

1. it falls below an arbitrary defined probability?
2. it falls below some level that is already tolerated?
3. the cost of reducing the risk would exceed the costs saved?
4. the cost of reducing the risk would exceed the costs saved when the "costs of suffering" are also factored in?
5. public health (or safety) professionals say it is acceptable?
6. the general public say it is acceptable (or more likely, do not say it is not)?
7. politicians say it is acceptable?

ALARA (As Low As Reasonably Achievable)

- Refers to the *residual risk* needing to be as low as reasonably practicable.
- A risk is ALARA when it's possible to demonstrate that the cost involved in reducing the risk further would be grossly disproportionate to the benefit gained.
- It should not be understood as simply a quantitative measure of benefit versus harm.

Scoping (the risk assessment)

- Defines objective, scope & breadth of the risk assessment.
- Must be completed in advance of the risk assessment exercise.
- Typical contents:
  - Risk assessment objective;
  - Boundaries of the equipment, system, process being assessed;
  - Hazards to be included;
  - Risk assessment technique(s) to be utilized;
  - External influences to be considered;
  - Consequences of interest;
  - Core assumptions;
  - Facilitator & team composition;
  - Date, time & location of risk assessment exercise;
  - Data, deliverables & documentation requirements.

Risk Assessment Facilitator

- Design the RA exercise based on the scoping (document).
- Introduce the RA team to the scope & RA technique(s).
- Keep the RA process on track throughout the exercise.
- Promote creative thinking in identifying appropriate controls.
- Guide the RA team through the exercise.
- Resolve any conflicts within the RA team.
- Help reach consensus, where required.
- Ensure the objectives are achieved within specified time.

Risk Assessment Team Composition

Potential members depending on issue & location:

- Facilitator (internal vs external)
- Recorder/Secretary
- Operations management and/or miners/operators
- S&H professional
- Engineer:
  - Mining, geology, engineer/project design, process.
- Maintenance management and/or personnel
- Other subject matter experts (SME)

Is There a Best Practice?

- The most common risk assessment strategy adopted by international mining companies today is 'layered risk assessment' or a variation on this approach.
- The approach grew from a benchmarking trip by a U.S. mining company in Australia.
- It advocates that companies take a (initial) broad view of risk

Layered Risk Management Model

1
- Major hazard, full site, baseline

2
- Project, selective risk assessment

3
- Work processes & procedures

4
- Personal/crew risk assessment

Layered Risk Management Model

1 • Major hazard, full site, baseline

- Used to assess major, principal or catastrophic risks.
- Consider life cycle of mine/facility:
  - Start with exploration, end with remediation.
- Include major incidents for existing & prospective sites.
- Look at the nature, magnitude, potential impacts & uncertainties of hazards encountered.
- Link major risks with selective layers 2 - 4.

Layered Risk Management Model

2

- Project, selective risk assessment

- Used to assess projects, changes & serious incidents:
  - Issues not covered in layer 1.
- Need to define triggers for risk assessment:
  - What kind of change, projects and incidents undergo RA?
- Define RA tools to be used for types of change:
  - Equipment, process, work practices.
- Track all outcomes in a risk registry.

Layered Risk Management Model

3

- Work processes & procedures

- Used for routine & unique work processes & procedures:
  - Issues not covered in Layer 2.
- Define RA tools to be used for types of change:
  - SOP & work guidelines or plans.
- Outcome: documentation, training, competence, auditing.
- Include change management process for documentation.

Layered Risk Management Model

4

- Personal/crew risk assessment

- Used for pre-task risk assessment:
  - Stop & think before starting a task.
- Critical for non-routine tasks w/out Layer 3 assessment.
- Ensure individuals know what safe is before proceeding.
- Elevate excessive risk to supervisor and/or Layer 3.
- Discuss outcomes with other doing the same work.

Risk Assessment Tools

1. Full site review — PHA, FTA, WRAC, BTA
2. Selective risk assessment — FMEA, HAZOP, FTA
3. Work processes & procedures — JSA, WRAC
4. Personal/crew risk assessment — Take 5, SLAM

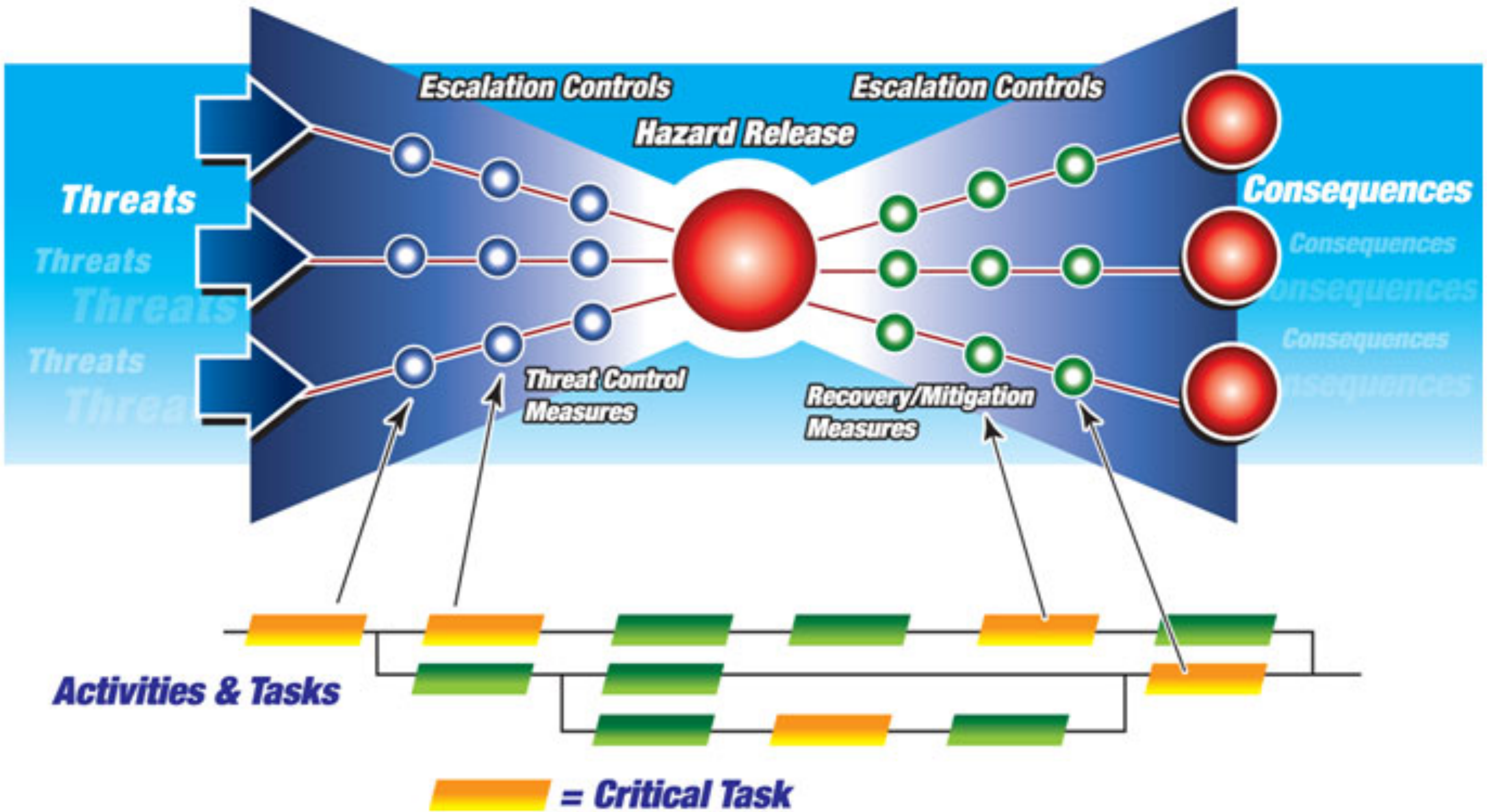
Bow Tie Analysis (BTA)

- Powerful technique in risk and control measures assessment.
- Structured approach for risk assessment of 'events' where quantification is not possible or desirable.
- Combines causes and consequence analysis into one diagram. The diagram when plotted resembles a bowtie.
- The theory behind BTA is found in the Swiss Cheese model of Reason and concepts of layer of protection.
- Earliest mention of concept by ICI in 1979 and Royal Dutch/ Shell Group was the first company fully integrate the method into business practices.

Bow Tie Analysis (BTA)

- Understanding of existing risk decision-making process.
- Decision framework based on stakeholder & operational needs should be developed to maximize the strength of each tool.
- Develop criteria for evaluating barrier effectiveness & importance.
- The bow-tie model is not intended for use in quantification of risks, however, it supports frequency & consequence analysis & allow detailed quantified risk analysis to be developed.

Bow Tie Analysis (BTA)



Source: THESIS Software

Bow Tie Analysis Terminology

- **Hazard**: Any situation that has a potential to cause harm.
- **Top event**: The 'release' of the hazard.
- **Threat** : Any possible cause that will potentially release a hazard and result in a undesirable top event.
- **Preventive barrier**: A protective measure to prevent threat(s) from releasing a hazard.
- **Recovery measure**: A preparedness measure to recover or reduce risks if the top event occurs or measure to limit the severity of the outcome.
- **Consequence**: Condition or event(s) that result from the release of hazard / top event.

Bow Tie Analysis (BTA)

- By linking hazards and consequences through a series of event lines it is possible to develop a diagram illustrating the routes to accidents.
- On the diagram, preventive and recovery controls are illustrated to show the fundamental components of the safety management system.
- Further understanding is gained by examining the routes by which the controls can fail and identifying the critical components of the system that prevent these failures.

BTA: The Process

- Develop bow-tie to show the problem (hazard & top event)
- Identify the threats that can cause the problem
- Display the barriers to prevent the problem occurring
- Describe the potential consequences
- Identify the recovery measures required if the problem occurs
- Identify escalation factor and escalation factors control
- Identify tasks and responsibilities
- Link the controls to safety management system

Building the Bow-Tie Questions

- **Top Event** (hazard):
  - What is the potential to cause harm?
  - What happens when the hazard is released?
  - What happens when control is lost?
- **Threat**:
  - What causes the hazard to be released?
  - How can we keep control?
- **Consequence**:
  - How can the event develop?
  - What are the potential outcomes?

Building the Bow-Tie Questions (Con't)

- **Threat Barrier**:
  - How do we prevent the hazard from being released?
  - How do we keep control?
- **Recovery Preparedness**:
  - How do we limit the severity of the event?
  - How do we minimize the effects?
- **Escalation Factor**:
  - How might controls fail?
  - How could their effectiveness be undermined?
- **Escalation Factor Control**:
  - How do we make sure controls do not fail?

Building the Bow-Tie Questions (Con't)

- **Tasks:**
  - What tasks do we do to make sure the control continues to work? Include design, operations, maintenance & management.
  - How do we verify that the tasks have been done?
  - Who does the task?
  - How do they know when to do the task?
  - How do they know what to do?
  - Is there a procedure, checklist, instruction?

BTA: Advantages & Disadvantages

- **Advantages:**
  - The Bow Tie graph can give a clear picture of complex safety management systems;
  - Clear links between management systems & risks are shown.
- **Disadvantages:**
  - Requires a high level of knowledge regarding a system & the components of the system that relate to its safety;
  - It is difficult to link to quantitative techniques.

Hazard & Operability Studies (HAZOP)

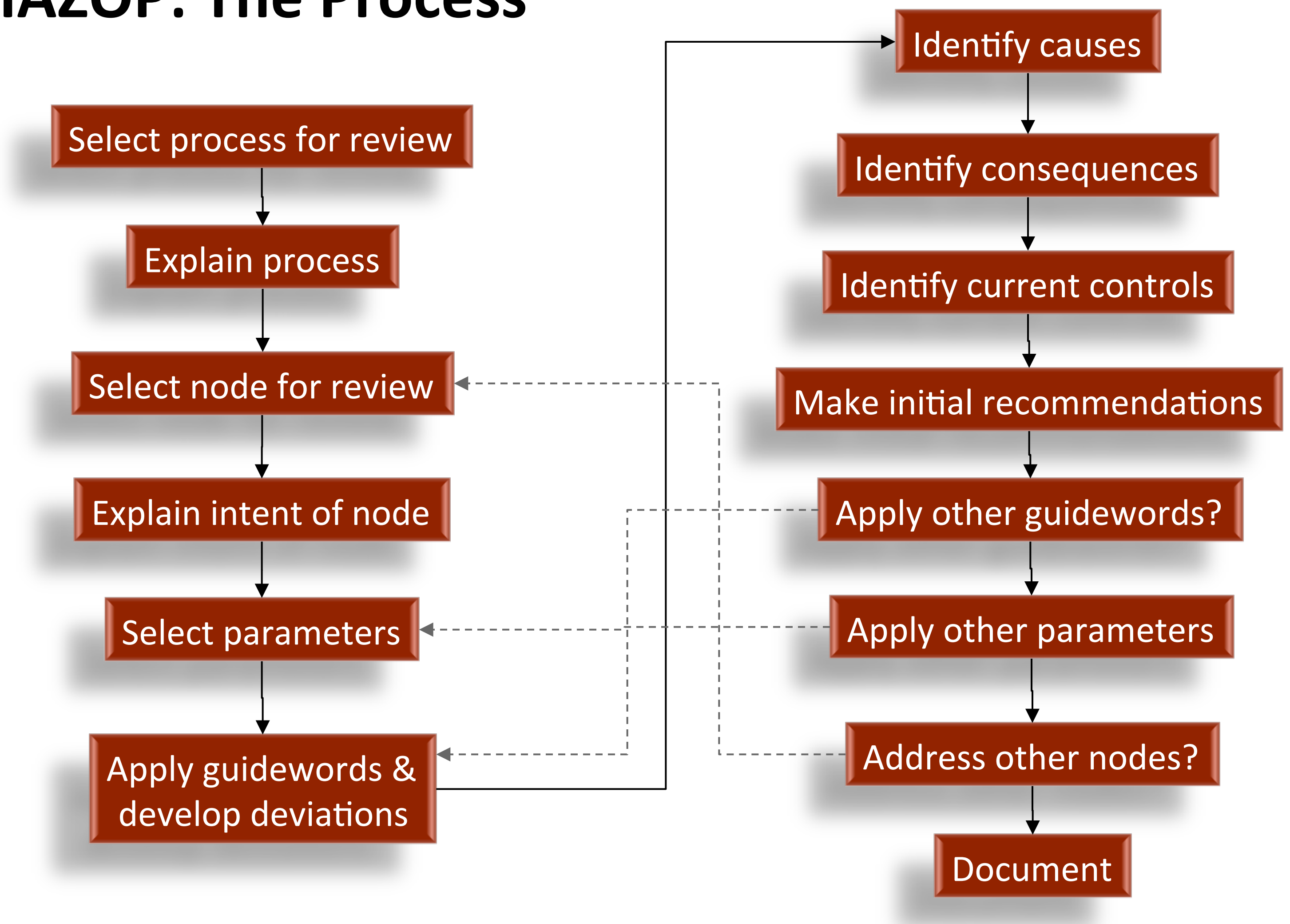
- Used extensively in the chemical industry.
- Used to assess deviations from normal procedure.
- Assumption: normal is safe.
- Conducted at any stage of a project.
- Optimal: latter stages of project design.
- Typically lacks a risk calculation.

Guide → Deviation → Consequence → Causes → Suggested Action

HAZOP

- Structured critical examinations of plant or processes, either batch or continuous.
- Undertaken by an experienced team to identify all possible deviations from an intended design, along with the consequent undesirable effects concerning safety, operability and the environment.
- The possible deviations are generated by rigorous questioning, prompted by a series of standard ‘guidewords’ applied to the intended design.

HAZOP: The Process

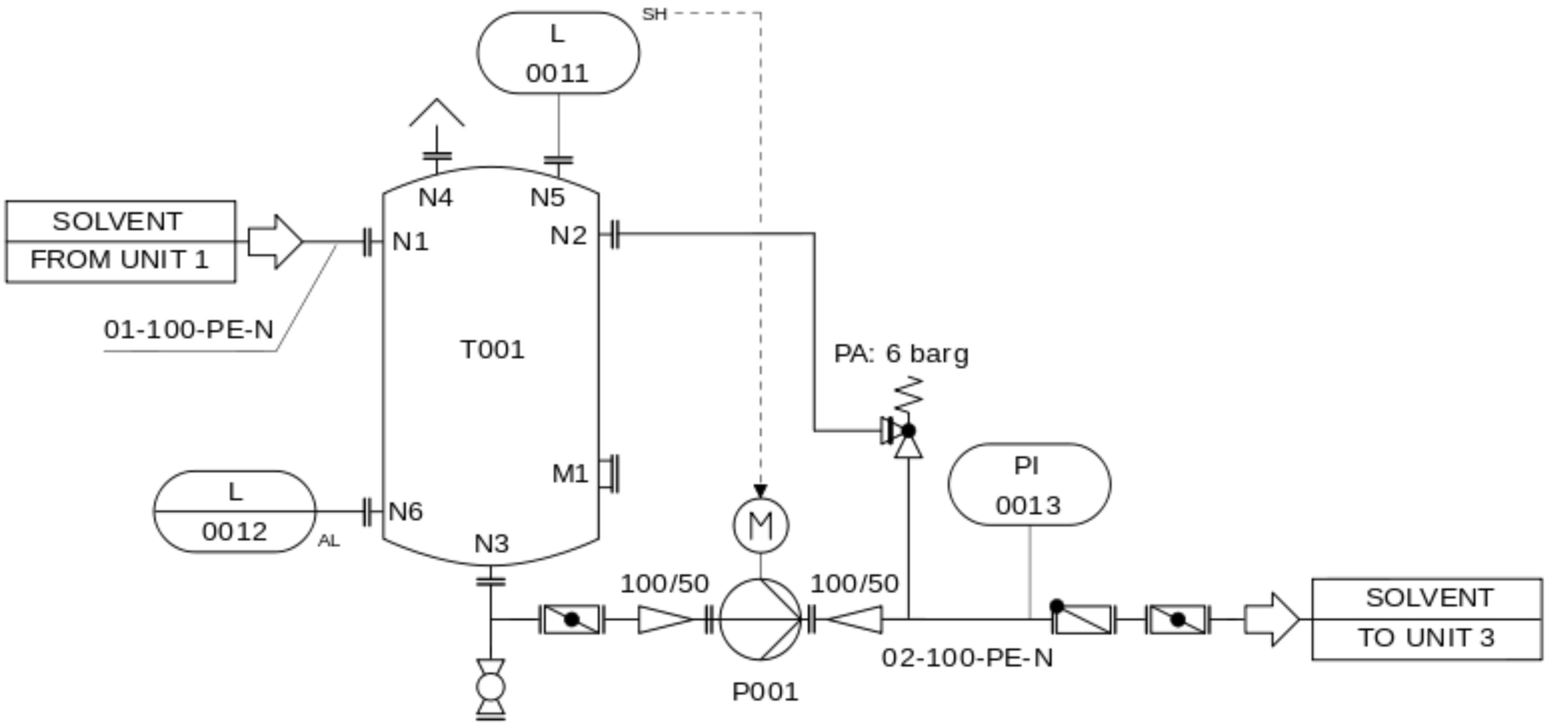


HAZOP Guidewords & Meaning

Guideword	Meaning
No (not, none)	None of the design intent is achieved
More (more of, higher)	Quantitative increase in a parameter
Less (less of, lower)	Quantitative decrease in a parameter
As well as (more than)	An additional activity occurs
Part of	Only some of the design intention is achieved
Reverse	Logical opposite of the design intention occurs
Other than (other)	Complete substitution. Another activity takes place

PI&D (Piping & Instrumentation Diagram)

	T001	P001
SERVICE	STORAGE TANK	FEED PUMP
DATA	DIAMETER: 1000 mm HEIGHT: 3000 mm CAPACITY: 2.4 m3	FLOW RATE: 5 m3/h DIFF. PRESSURE: 2.5 bar
DESIGN PRESSURE	10 barg	10 barg
DESIGN TEMP.	50 °C	50 °C



Typical HAZOP Worksheet

DEVIATION	CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION

HAZOP: Advantages & Disadvantages

- **Advantages:**
  - Group/team activity;
  - Effective for making sense f highly complex process flows;
  - Can be used at any stage of system or process development. Works for batch & continuous processes.
- **Disadvantages:**
  - Design must be somewhat mature to effectively use HAZOP;
  - Can be very complex and time-consuming analysis.

Failure Mode & Effects Analysis (FMEA)

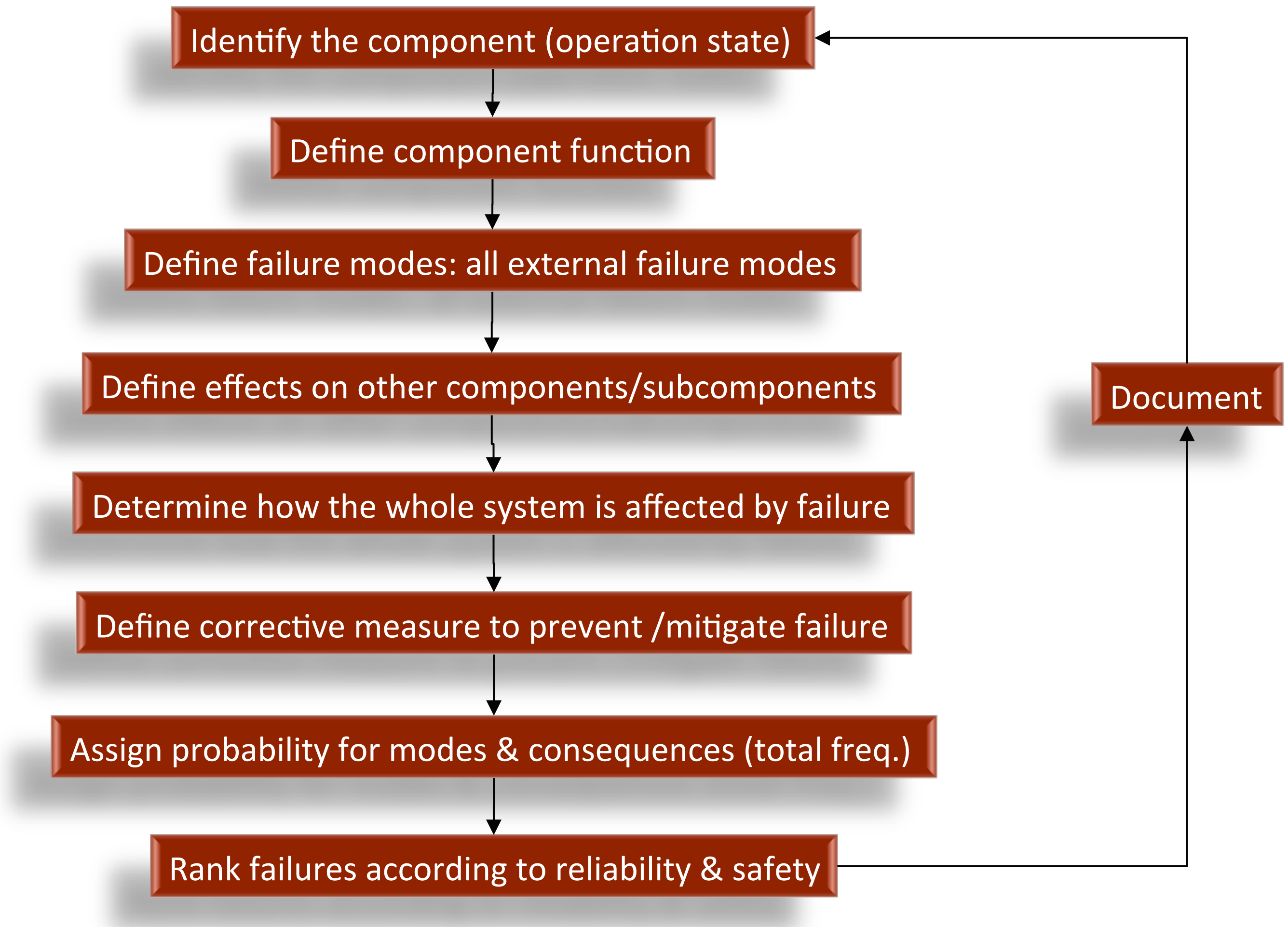
- Risk analysis technique used to assess failure of mechanical/hardware/system components, i.e., how does a component or sub-component failure affect the whole system?
- Team-based.
- Requires technical & engineering expertise of system in question.
- Determine the mode of failure and assess the probability & consequence of those failures.
- Qualitative, inductive technique, but requires quantitative failure probabilities.

Fault Versus Failure

- Failures are basic abnormal occurrences in a system or system component.
- Faults are "higher order" or more general events.
- Fault are initiated by other events or conditions.
- All failures are faults, but not all faults are failures.
- A fault requires the specification of not only what the undesirable component state is but also when it occurs.
- A fault may be repairable or not, depending on the nature of the system. Under conditions of no repair, a fault that occurs will continue to exist.

1. Identify the component (operations state).
2. Define component function.
3. Define failure modes: all external failures modes.
4. Define effects on other components/subcomponents.
5. Determine how the whole system is affected by failure.
6. Define corrective measure: to prevent or mitigate failure.
7. Assign probability for modes & consequences (total freq.)
8. Rank failures according to reliability and safety.
9. Document.

FMEA/FMECA: The Process



FMEA

List of Example Failure Modes		
Corrosion	Ingress	Delamination
Fracture	Vibrations	Erosion
Material Yield	Whirl	Thermal shock
Electrical Short	Sagging	Thermal relaxation
Open Circuit	Cracking	Bonding failure
Buckling	Stall	Starved for lubrication
Resonance	Creep	Staining
Fatigue	Thermal expansion	Inefficient
Deflections or deformations	Oxidation	Fretting
Seizure	UV deterioration	Thermal fatigue
Burning	Acoustic noise	Sticking
Misalignment	Scratching and hardness	Intermittent system operation
Stripping	Unstable	Egress
Wear	Loose fittings	Surge
Binding	Unbalanced	
Overshooting (Control)	Embrittlement	
Ringing	Loosening	
Loose	Scoring	
Leaking	Radiation damage	

FMEA/FMECA: Advantages & Disadvantages

- **Advantages:**
  - Very systematic approach for evaluating systems or procedures;
  - Broad range of applications.
- **Disadvantages:**
  - Need to know what failure is and what success is in advance of applying FMEA/FMECA;
  - Requires a strong technical understanding of the system, process, system, subsystem, design, software, being evaluated.

Job Hazard Analysis/Job Safety Analysis

- A simple risk assessment technique that focuses on job or work tasks as a way to identify hazards and control their risks.
- It focuses on the relationship between the worker, the task, the tools, and the work environment.
- It normally results in a written document that is used to standardize the job or work task, e.g., SOP which addresses multiple issues associated with the task/job, e.g., process, specification(s), materials, timing, quality, cost, etc.
- Best if JHA/JSA is conducted by the people who will conduct the work. The JHA/JSA can form the basis of task training, e.g., the workers.

When to Apply JHA/JSA

- Jobs (tasks) with the highest injury or illness rates.
- Jobs with the potential to cause severe or disabling injuries or illness, even if there is no history of previous incidents.
- Jobs in which one simple human error could lead to a severe incident or injury.
- Jobs that are new or have undergone changes in processes and procedures.
- Jobs complex enough to require written instructions:
  - Routine job tasks;
  - Non-routine job tasks.

Job Hazard Analysis: The Process

Select job task to be analysed
↓
Check any relevant documentation
↓
Identify the step or stages involved in doing the job and write them down
↓
Identify all the hazards in each step of the job
↓
Find ways to eliminate or reduce exposures to the hazards
↓
Incorporate the JHA results into the new procedure to ensure critical hazards within the job task are addressed
↓
Update and maintain records and revisions

JHA/JSA: Advantages & Disadvantages

- **Advantages:**
  - Easy to use;
  - Can increase involvement of workers in risk assessment;
  - Can use used as an auditable training guide;
  - Clear links between management systems & risks are shown.
- **Disadvantages:**
  - Subjective (garbage in, garbage out);
  - Tendency to miss steps & minimize complexity even if that means missing hazard/risk.
  - It is difficult to link to quantitative techniques.

Personal Risk Assessment

- Simple extemporaneous risk assessment.
- Informal in nature. Personal brainstorming.
- Normally conducted just before the actual work task.
- Can use used individually or in small groups.
- Applied during a task when the work/conditions change.
- Good to use for both routine & non-routine work.
- If the task risk can not be confidently assessed using personal risk assessment, pause and go back to JHA/JSA.
- Can be used off-the-job as well.

Personal Risk Assessment

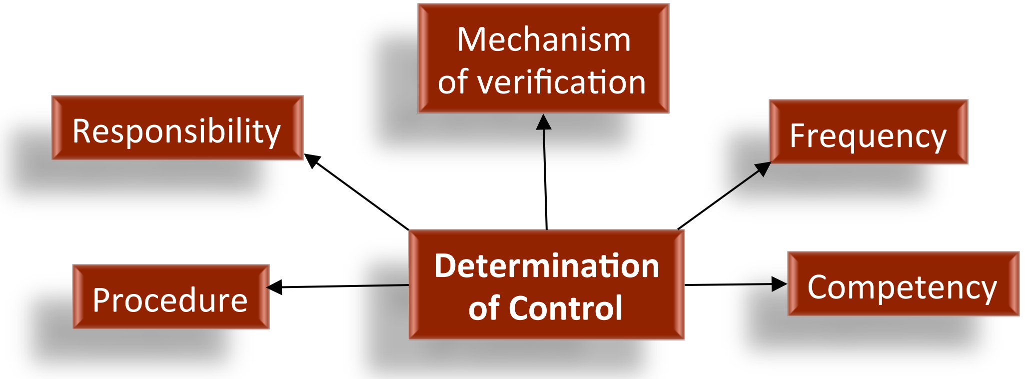
Five steps to personal risk assessment:

- Identify the hazard(s)
- Decide who might be hurt and how (what if)
- Evaluate the risks and decide on controls
- Record findings for future reference
- Review your assessment and update if necessary.

- Examples: Take 5, Take Time, Take Charge, SLAM, PLAN, Hudson's Rule of Three, Stepback 5X5, Positive Attitude Safety System (PASS), Take 2, etc.

Control of Hazards

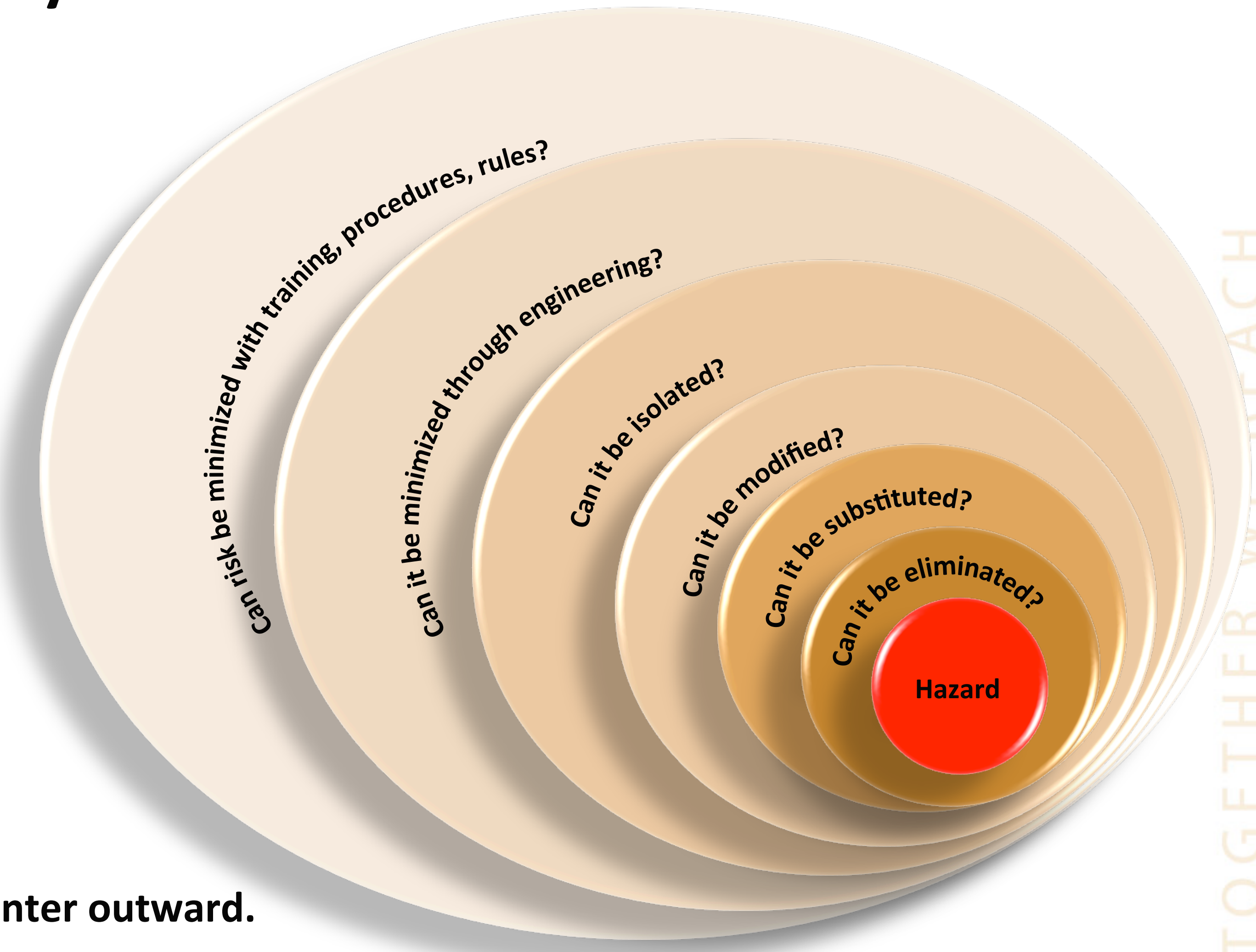
- Must integrate MSHA compliance.
- Apply the hierarchy of control – institutionalize?
- Always consider human factors implications:
  - Will human factors be a consideration regarding maintaining controls?
- For critical risks, ensure control verification is systematic:



Risk Control & Treatment

1. Identify treatment options:
   - Use risk rank order & consequence rank to prioritize.
2. Evaluate & select treatment options.
3. Prepare & implement treatment options:
   - Design, engineer & build.
   - Training & new procedures required?
   - Change management implications?
4. Monitor control efficacy:
   - Internal & external audits.
5. Make modifications as necessary (based on step 4).

The Hierarchy of Control



Work from the center outward.

Effectiveness of Controls

Control Category	Major Control Issue	Potential for Human Error	Risk Reduction Effectiveness
Eliminate	Economic & strategic	None	Complete
Minimize/Substitute	Engineering	Minor	High
Physical barrier	Engineering	Minor	High
Warning device	Assessing	Possible	Medium
Procedures & rules	Administrative	Important!	Low
Personal skills & training			

Change Management

- Define ‘change’ requiring management review.
- Communicate this process to all affected employees, contractors & other stakeholders.
- Develop a change management procedure that defines the ‘who, what, when and how’ for the reviews.
- Define who is authorized to approve change actions.
- Ensure that the procedure includes provisions to verify that change management actions have been completed and that they do not significantly result in new, negative risk.

Change Management

- Integrate change management actions into the S&H communication system to ensure all affected parties are aware of the new reality. Check for understanding.
- Document change management decisions for tracking and verification purposes, and for future reference.
- Pre-start up safety reviews should be conducted on all new mines, mine expansions, processing facilities, major mobile and fixed equipment and control systems.
- Ensure that change management is fully integrated with risk management.

Change Management

What to Include in Change Management Assessment:

- The technical basis for the proposed change.
- Impact of change on safety and health.
- Modifications to operating procedures.
- Necessary time period for the change.
- Authorization requirements for the proposed change.
- Update of existing RA information & operating procedures.

CORESafety SHMS

Benefits of Effective Risk Management

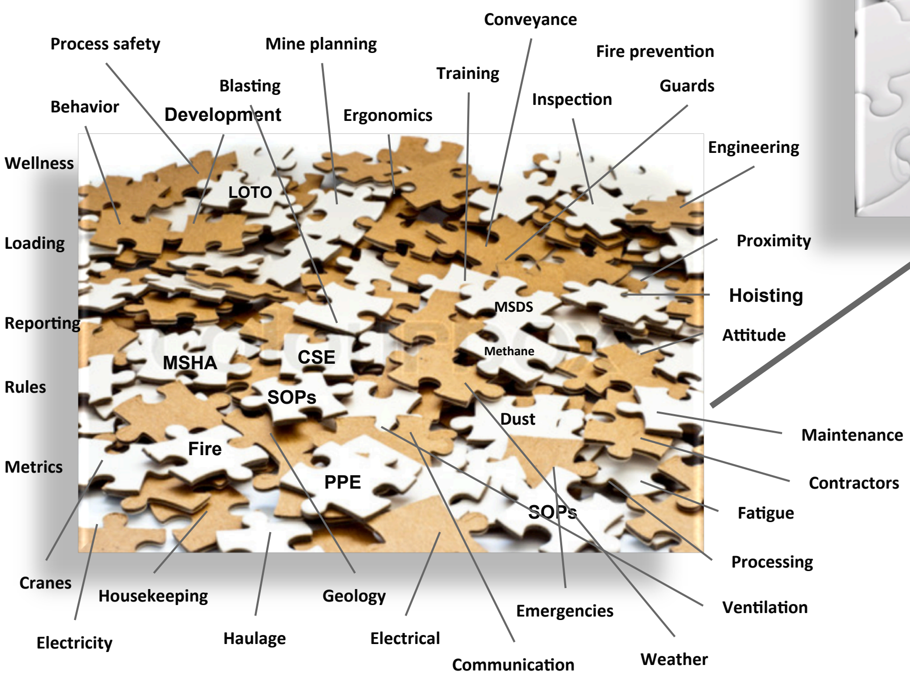
- Reduce mining incidents and associated costs;
- Identify threats and opportunities to the business;
- Improve decision-making and planning;
- Improve allocation and utilization of resources;
- Emphasize proactive versus reactive management;
- Improve stakeholder confidence and trust;
- Improve compliance with relevant legislation;
- Improve corporate governance.

Integrated systems (sprint)

Effective system (run)

Basic system (walk)

Programs (crawl)



As with other operational systems (e.g., production, maintenance, procurement, HR, IT, etc) it takes time to develop an effective SHMS and it requires responsibility, accountability and a high degree of integration.

Thank You For Your Attention

Tom Hethmon
Associate Professor
Department of Mining Engineering
Director, Center for Mining Safety and Health Excellence
University of Utah
801.581.7521
tom.hethmon@utah.edu

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