Toward a Systems Framework Coupling Safety Culture, Risk Perception, and Hazard Recognition for the Mining Industry

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Introduction

- **Goal:** Reduce hazards and risks to worker health and safety
  - U.S. Mining Industry is a focus of study
  - Applicable to many others: Construction, manufacturing, oil & gas, transport, etc.

- Industry using increasingly robust health and safety management programs
  - Sophisticated procedures and processes
  - Sophisticated software systems (SMS)

- **Challenge:** *Reactive* approaches to safety
Leading Versus Lagging Indicators

Leading Indicators (Upstream Monitoring)

Learn

Predict

Lagging Indicators (Undesired Events)

Time

SMS Data

7000-1
Toward a Systems Framework

• Variables: Indicators are observable, but there are many latent (hidden) variables that interact to determine outcomes

• Studies have examined many of these factors in mining industry
  • Worker and manager risk attitudes and risk perception
  • Levels of work experience and health & safety training
  • Situational awareness and hazards recognition capability
  • Organizational safety culture and operating procedures

• A holistic understanding is needed: Key factors and interactions
  • For example, covariances and causal relationships (direct and indirect)
  • Motivation: These ideas have been explored in other heavy industries
# Study Goals and Deliverables

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<td>Aggregate findings across industries where safety is major concern</td>
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<td>Apply inductive processes to identify common factors and relationships</td>
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Literature Survey

• Survey metrics:
  • 44 articles considering 10 heavy industries
  • Over 80% of articles published since 2012

• Search terms:
  • “safety culture”, “risk perception”, and “hazard recognition”
  • “analysis”, “assessment”, “factors”, “risk”, “perception”, “root cause analysis”, and “safety”

Inclusion Criteria

• Peer-reviewed journal
• In specific topic areas
• Article had >40+ cites

Exclusion Criteria

• Articles <2 years old

Note: Three articles were included due to their relevance to this study, even though they did not meet the age / citation requirement.
Literature Survey Findings

• Identified candidate models and factors
  • 12 analytical models: SEM, Systems Thinking, Measurement Model, BBN
  • 70+ factor labels: Worker cognition and behavior, community, processes

• Requirements for consideration of model
  • Well-defined model with correlation relationships, ideally diagrammed
  • Evidence-based validation, versus speculative or purely conceptual
  • Covered at least 2 of safety culture, risk perception, and hazard recognition

• Observation: Similar constructs, relationships
Analytical Models

• Systems Thinking Approaches:
  • Explore **dynamics of a system** and interactions between components
  • Capture systemic processes, behaviors, and communications
  • Built using **loops** (e.g. reinforcing, balancing) and **delays**
  • Characterized via **archetypes** (e.g. shifting of burden, complacency, incentivizing/eroding safety, etc.)

(Shin et al. 2014)
Analytical Models

• Structural Equation Models (SEM):
  • Investigate causal relationships among factors (variables) in system
  • Broad leverage to determine what constructs are factors in system
  • Models both observable and latent factors in individual and community
  • May perform hypothesis testing using statistical methods (e.g. goodness of fit, confirm. factor analysis)

(You et al. 2013)
Model Consolidation

• A type of inductive analysis
  • Objective: Build **consensus meta-model** describing data
  • Used study models selected from our literature review
  • Grounded in *Contextual Design* (Beyer & Holtzblatt, 2017)

• Consolidation process:
  • **Open coding**: Identify relevant features (factors, paths)
  • **Axial coding**: Crosswalk, group, label similar features
  • **Selective coding**: Add features to final meta-model if they satisfy the **consensus threshold**

(Martinez-Jurado et al. 2014)
Model Consolidation Challenges

• **Consensus**: How to choose threshold?
  • Subjective: Should capture enough information into the meta-model
  • Draw motivation from common practices in analysis of factor consistency

• **Closure**: How many models are enough?
  • Grounded Theory motivation: When new models don’t provide any new findings
  • Reaching a closure state doesn’t require an exhaustive review

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<tr>
<th>Component</th>
<th>Threshold High</th>
<th>Threshold Low</th>
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<tbody>
<tr>
<td>Factors</td>
<td>75%</td>
<td>50%</td>
</tr>
<tr>
<td>Paths</td>
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<tr>
<th>Selected</th>
<th>Closure</th>
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<td>12</td>
<td>8</td>
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C-P-R Meta-Model

- **Safety Culture**
- **Perception of Risk**
- **Recognition Process**
C-P-R Meta-Model

• **Safety Culture**

• **Perception of Risk**

• **Recognition Process**

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[Diagram showing the relationship between Safety Culture, Perception of Risk, and Recognition Process, with internal and external factors, and thresholds indicated by solid and dotted lines.]
Discussion

• How can the **C-P-R Meta-Model** help us?
Discussion

• How can the C-P-R Meta-Model help us?

1. **Descriptive Analysis:** Understand the structure of the system and causal relationships among factors; Allow us to focus efforts on meaningful interventions.

   • Consider the impacts of external influences on workers’ thinking
   • Example: The impacts of experience and training on risk perception
   • Are there other interactions or factors not yet considered? Likely!
Discussion

• How can the C-P-R Meta-Model help us?

2. Evaluative Analysis: Validate and improve existing model; Deploy interventions and observe changes on outcomes based on model.

   • Use Confirmatory Factor Analysis (CFA) to refine the model’s pathways
   • Example: Implement new training technique to show consequences of hazards and run tests to evaluate impacts on system
   • Can mediating or indirect paths be utilized to improve H&S outcomes?
Discussion

• How can the **C-P-R Meta-Model** help us?

3. **Generative Analysis:** Develop computational models for resiliency testing; Explore hypothetical scenarios and simulate outcomes.

  • Develop a Systems Thinking model that captures the factors and pathways of our meta-model. (See Ma, Wu, & Chang, 2021)

  • Example: Use a worker survey to collect data on risk perception and use that data to predict possible negative outcomes, such as eroding safety conditions or unsafe behaviors.

  • Can such a model be used to reliably predict outcomes for mine operators?
Conclusions

• **Contribution**
  • Insight into key modeling methods for safety culture, risk perception, and hazard recognition
  • Potential factors (latent and observable) and their causal pathways
  • Consensus meta-model for further exploration in mining

• **Future work**
  • Validate of **C-P-R Meta-Model** with mining partners
  • Explore / translate to a Systems Thinking approach
  • Develop a system of **predictive analytics** for SMS
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