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RISK MANAGEMENT: ADAPTING RISKGATE FOR UNDERGROUND COAL MINES IN THE UNITED STATES

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ABSTRACT

The underground coal mining industry in the United States has recently seen the occurrences of several high profile, multi-fatality events. The explosions that occurred at the Sago Mine in 2006, the Darby Mine in 2006, and the Upper Big Branch Mine in 2010 have caused a ripple in an otherwise steadily improving safety record. These events transpired in the midst of an unprecedented level of government regulations and modern safety technologies. The recent increase in fatal events in conjunction with a minimal decline of both fatal and non-fatal injuries over the past decade may signify that current safety practices have reached a level of diminishing returns. Risk management, a safety approach that has been successfully applied in various industries including mining across the world, may provide a means to surpass the safety plateau in the U.S. RISKGATE is an Australian risk management program for mines that shows great potential for application in the U.S. However, fundamental differences between the coal mining industries in Australia and in the U.S. prevent direct implementation. This paper discusses aspects of the RISKGATE body of knowledge that require some adaptation before this program may be applied to the U.S. mining industry.

INTRODUCTION

The underground coal mining industry in the United States has recently seen the occurrences of several high profile, multi-fatality events. These events transpired in the midst of an unprecedented level of government regulations and modern safety technologies. The recent increase in fatal events in conjunction with a minimal decline of both fatal and non-fatal injuries over the past decade may signify that current safety practices have reach a level of diminishing returns. In order to combat this stagnation in performance, a modification to the manner in which the mining industry approaches worker safety may be warranted. The implementation of a risk management based approach presents a potential method for not only surmounting the current safety plateau but also for achieving the long desired objective of zero harm. RISKGATE a risk management body of knowledge designed for the Australian mining industry that shows great potential for application in the U.S. This paper discusses aspects of the RISKGATE body of knowledge that require adaptation before implementation in the U.S. mining industry. These adaptations are based on differences in operating practices and governmental regulations. This discussion will focus on the three major U.S. risk areas of explosion prevention, ground control, and moving equipment.

BACKGROUND

The U.S. underground coal mining industry has undergone vast safety improvements since the first federal statute governing mine safety was passed in 1891. Several high-profile events that followed that first legislation, such as the 1907 Fairmont Coal Company Mining Disaster in Monongah, West Virginia, prompted the creation of several significant laws. The most notable of these laws were the Federal Coal Mine Safety Acts of 1952, 1969 (Coal Act), and 1977 (Mine Act). These statues in conjunction with advances in mine safety technologies and cultural shifts in the industry toward achieving zero harm have resulted in a substantial decrease in mine events. Figure 1 displays the number of fatalities at U.S. coal mines from 1900 to 2013.

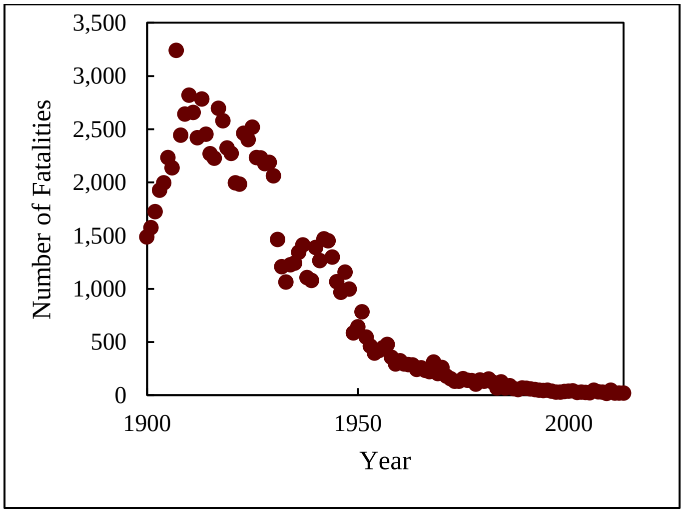

Figure 1. U.S. Coal Fatalities for 1900 through 2013 [1].

As can be seen in Figure 1, these measures have been effective overall in reducing the number of accidents. However, recent events have broken this trend and may justify a re-evaluation of current safety practices.

The explosions that occurred at the Sago Mine in 2006, the Darby Mine in 2006, and the Upper Big Branch Mine in 2010 have caused a ripple in an otherwise steadily improving safety record. Figure 2 displays the number of fatalities at U.S. coal mines from 1999 to 2013.

The Sago Mine and the Darby Mine directly prompted the establishment of the Mine Improvement and New Emergency Response Act (MINER Act), which is the most substantial legislation enacted since the Mine Act of 1977. The MINER Act most notably required mine-specific emergency response plans in underground coal mines, added new regulations regarding mine rescue teams, added new requirement for sealing abandoned areas, and heightened civil penalties. The explosion at the Upper Big Branch mine in 2010 subsequently occurred while the MINER act was already in place.

As can be seen by these aforementioned examples, the historical response to mine accidents has been to enact broad sweeping legislation. Although this technique had been very effective during the earlier years, the addition of more laws seems to have reached a point of diminishing returns in the modern day. This stagnation in safety performance improvement can be seen with plateauing accident reduction rates and continuing occurrences of multi-fatality events.

Based on this trend, the established ideology of prescriptive regulation may no longer be able to cope with the modern mining environment.

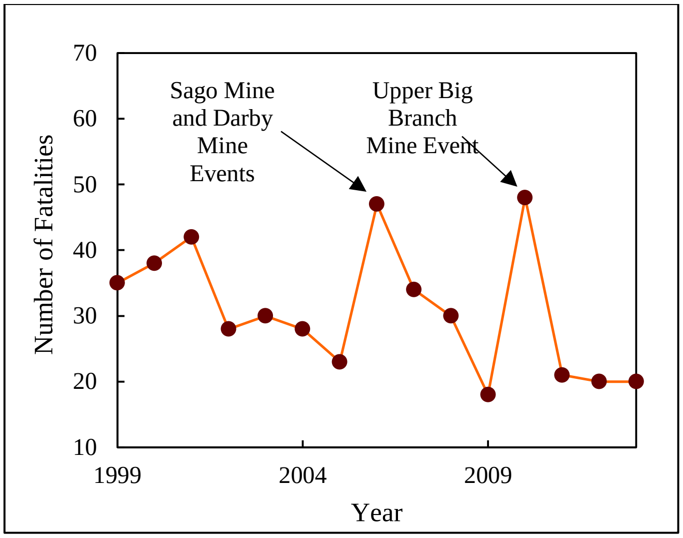

Figure 2. U.S. Coal Fatalities for 1999 through 2013 [1].

Underground coal mines have always been subject to site specific conditions resulting from the inherent nature of geologic formations. Some generalities could be defined, such as the presence of methane, the need for ground control, etc. However, these issues have already been addressed in the present form of coal mining legislation. Requirements designed for broad spectrum deployment are not able to adapt to some of the highly varying intricacies in underground coal mines. A possible tool to overcome these challenges is presented by the risk management approach.

RISK MANAGEMENT

U.S. mine safety initiatives such as improved training programs, the utilization of more reliable equipment, and the adoption of better technology have helped enhance worker safety. However, these efforts have thus far only produced a limited effect. These techniques are still based on the prescriptive approach. As a result, they neither address the site specific nature of mines nor the underlying causes of major accidents. The risk management approach, which has already been successfully implemented in other U.S. heavy industries, has the potential to reinforce these weaknesses.

The goal of the risk management approach is the prevention of occupational risks. Although the complete elimination of such risks are not possible, they can be reduced and controlled. Successful risk management is achieved through the development of operating standards based on site-specific assessments of work environment hazards. From these assessments, hazards can then be evaluated and prioritized so that a proportional allocation of resources can be allotted to address high risk areas [2]. The tailored nature of the resulting safety measures can effectively improve the overall health and safety of the workplace by addressing high priority issues, which can differ from location to location. Although risk management is a relatively new concept to the U.S. mining industry, it has already been successfully adopted by many other countries. Australia is one of the more prolific countries to apply the risk management approach to underground coal mines.

The Australian coal mining industry began examining the prospect of implementing a duty-of-care risk-based safety structure in the 1990s. This system would not only replace the prescriptive legislative practices already in place but simultaneously place the legal duty of worker safety in the care of each mining company. After final revisions were made to this law following the Moura Mine explosion in 1994 and the Gretley Mine flood in 1996, the duty-of-care risk based approach for coal mine safety was enacted in 2002. Coincident with the adoption of this new safety system, the Australian underground coal industry experienced a significant reduction in incidents [2, 3]. This correlative increase in safety performance suggests that a risk management system may improve coal mine safety in the U.S.

Many different approaches can be taken in the implementation of risk management system. A successful risk management system can incorporate a number of tools to develop a risk management plan. Despite the adopted methodology, all tools are designed to assist in one or more of the following areas: identification of work place hazards and those at risk, evaluation and prioritization of the identified risks, and determination of preventive actions or policies. One such tool in widespread use in Australia is RISKGATE.

RISKGATE

RISKGATE is an online body of knowledge that generates checklists for controlling risks across high priority events pertinent to the Australian coal mining industry. RISKGATE is funded by the Australian Coal Association Research Program (ACARP) and managed by the University of Queensland. This web-based software is designed to be a decision support tool that assists mine operators in the development of a site-specific management plan. RISKGATE, given the nature of the body of knowledge used to generate its checklists, is not intended to specifically address unique risks for a single site but to rather provide guidelines based on industry-wide priority hazards. As a result, Australian mine operators can reference a single database detailing various safety technologies and practices instead of relying on scattered and inconsistent sources. RISKGATE provides its risk assessment and evaluation guidelines through bow-tie analysis [4, 5].

Bow-tie analysis is a method used to generate event-specific controls based around initiating events, such as a roof collapse. For each initiating event, a list of causes and consequences are provided with their associated preventative and mitigating controls respectively. The purpose of bowtie analysis is to not only customize a means of preventing the initiating event but also of minimizing the impact of that event if the preventative controls fail. This analysis technique focuses operators on the relationship of cause and event as well as event and consequence instead of just cause and consequence. The final checklist provides guidelines for improving safety based around high risk initiating events so that a risk management plan may be customized for the mine site. Figure 3 graphically represents the bowtie analysis structure.

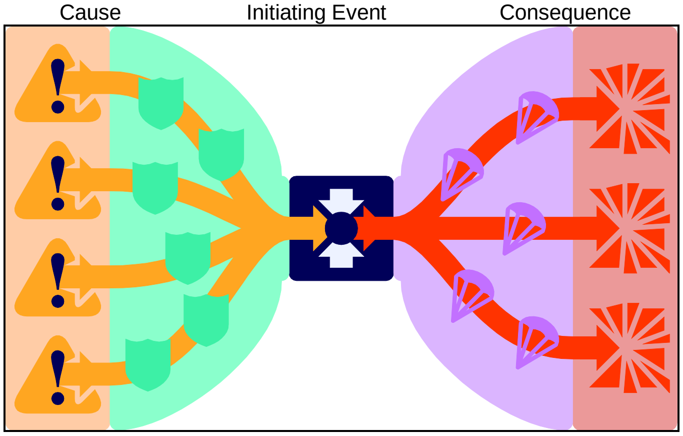

Figure 3. Bowtie analysis diagram presenting the cause, event, and consequence structure.

The proven application of RISKGATE in Australia suggests that this tool can be effectively applied to the U.S. underground coal mining industry. Furthermore, the online nature of RISKGATE can potentially facilitate widespread distribution with minimal logistical cost. The primary challenge of implementing RISKGATE in the U.S. is presented by the inherent differences in the risk areas of explosion prevention, ground control, and moving equipment between the U.S. and Australia. These differences result fundamentally from the manner in which mines are developed as well as from regulatory differences between the U.S. and Australia.

THE U.S. AND AUSTRALIAN UNDERGROUND COAL MINING INDUSTRIES

The RISKGATE topic areas and associated content were developed based on industry knowledge and research by academic entities specifically for application in Australia. As such, many of the recommendations produced by RISKGATE either cannot be directly applied to the U.S. or lack certain topics pertinent to U.S. coal mines. The manner in which U.S. coal mines are managed and operated fundamentally differ from Australian coal mines in certain aspects. As a result, certain priority risks within each topic area, such as pinch points around moving equipment, are missing from RISGATE. The differences in the regulatory environments present the most significant variability between the U.S. and Australia.

As previously stated, U.S. coal mines are heavily regulated under one standard collection of prescriptive constraints. In contrast, Australia migrated to a duty-of-care risk system in 2002. Under this system, Australian mine operators are directly responsible for the development of safety standards based on the specific conditions at the mine site and are accountable for any lapses. The ability to tailor safety standards is restricted in the U.S. Under certain circumstances, customizations may be allowed in such areas as roof bolting if the modifications exceed established safety standards. The following sections provide an overview of differences in mining practices and regulation that RIKSGATE must adopt for effective implementation in the U.S.

Coal Mine Development in the U.S. and Australia

One of the main differences between U.S. and Australian coal mines are the techniques utilized for mine development. Longwall mining is the predominant method used in Australia for extracting coal. The use of bord and pillar (room and pillar) has declined in favor of longwalls because of their production and economic advantages. In general, because of the limited use of bord and pillar in Australia, RISKGATE does not provide recommendations for hazards that are more prevalent in room and pillar mines, which is a technique that remains heavily used in the U.S. The economy of scale advantage for Australian longwalls is supported by the thicknesses of the typical Australian coal deposit, which are much greater in general than coal thicknesses in the U.S. [6, 7]. Many of the operational differences are a function of these geologic characteristics. Techniques used for gateroad development, ventilation, and ground control also differ in some aspects because of historically adopted practices, mining conditions inherent with thicker deposits, and mining regulations. Given the prevalence of longwall mining in Australia, the comparisons in this discussion will be focused on this particular mining method as they relate to explosions, ground control, and moving equipment.

Explosions

Explosions have been responsible for over 80% of the fatalities in U.S. underground coal mines since 1900 [8]. Recent incidents in Kentucky and West Virginia were no exceptions. The frequency of these events classifies explosions as one of the primary hazards in underground coal mines. Coal mine explosions primarily result from the ignition of dangerous concentrations and distributions of methane, coal dust, or a combination of the two. These ignitions can occur in various areas of a mine including on the active face, in the gob, and behind the seals. The most effective preventative measures for preventing methane and coal dust explosions are ventilation and rock dust application, respectively.

Rock dusting is a standard practice in both the U.S. and Australia. Although the required percentage of incombustible material may differ, the overall implementation and maintenance processes for rock dust application remain largely the same. As a result, rock dusting policies and procedures do not present enough significant differences to be highlighted in this discussion. The remaining explosion control is underground ventilation. The manner in which many Australian longwall mines are ventilated differ substantially from U.S. longwall mines. Certain Australian coal deposits have a high propensity for spontaneous combustion. Spontaneous combustion prone mines in Australia encompass a much greater proportion of underground mines than in the U.S. Mines that are at risk for spontaneous combustion utilize a bleederless ventilation system [9].

Bleederless systems are designed to prevent the introduction of oxygen into the gob, or goaf, to prevent spontaneous combustion. This isolation is achieved by only ventilating the open sections of the headgate and the tailgate as well as the open face. The airways, or bleeders, located at the rear of the panel that are normally found in U.S. longwall mines to remove methane from the gob are removed in a bleederless system. The majority of U.S. longwall mines utilize a T-split ventilation design with a supporting bleeder system. This system requires the use of secondary supports, such as cans and pumpable cribs, to maintain an open airway from the active face to the bleeders through the tailgate. The bleeder airways are exhausted using auxiliary centrifugal fans. The conventional T-split ventilation scheme is designed to maintain a nominal airflow within the gob that theoretically prevents the accumulation of methane in hazardous concentrations. The lack of a true bleeder infrastructure makes the Australian system simpler both to maintain and to develop in terms of physical infrastructure. As a result, RISKGATE does not provide thorough guidelines that addresses risks associated with developing and maintaining a bleeder system.

Another significant difference between U.S. and Australian mine ventilation is the ability to use booster fans in both bleederless and true bleeder ventilation layouts. Australian regulations permit the use of booster fans in both underground longwall and room and pillar coal mines [9, 10]. The use of such fans is strictly prohibited in the U.S. because of recirculation and ignition concerns. RISKGATE sometimes highlights the implementation of a booster fans for certain explosion risk scenarios. These booster fan recommendations are sometimes used to substitute for more common auxiliary ventilation techniques practiced in the U.S. In order to comply with U.S. mining regulations, all booster fan recommendations would need to be removed and replaced with the more common auxiliary ventilation techniques practiced in the U.S.

Ground Control

The characteristics of the average Australian coal deposit greatly differ from U.S. coal deposits in terms of size. Coal reserves in Australia are generally much thicker averaging 2 m to 4 m (6 ft to 10 ft) at the working face with many seams exceeding 15 m (50 ft) in thickness across numerous regions [11, 12]. As previously discussed, the size of these deposits promote a greater utilization of longwall mining with average mining heights greater than the typical U.S. longwall mine. In order to extract these deposits, the use of appropriately designed mining equipment is required. One of the main concerns with mining heights of these magnitudes is the stability of the roof, the ribs, and the active face.

Many Australian are also located at depths exceeding 300 m (1,000 ft), a characteristic that amplifies these concerns [12]. As the height of the mine roof increases, the ability of smaller debris to cause significant injuries also increases. In order to prevent such injuries, roof bolting patterns are generally more densely spaced in Australian coal mines relative to U.S. coal mines. Roof mesh use is also much more prevalent to protect workers from small, loose material detaching from the roof. The larger mining heights also increase the risk of injury from shallow failures of the outer pillar surfaces, or rib rolls.

In order to prevent injury from rib rolls, mine walls are also bolted and meshed. This practice of rib bolting and meshing is not as common in the U.S. Although rib bolting and mesh is applied in certain circumstances in the U.S., these controls are only applied on an as-needed basis. The risks associated with thicker coal seams also extend to the active face. The taller mining height at the face increases the risk and severity of injuries caused by face collapses. Since direct stabilization of the face through the installation of support infrastructure can be exceptionally challenging, the longwall shields used in Australia are designed with additional features to increase the stability of the face and to prevent collapses onto walkways. An example of a U.S. longwall shield and an Australian longwall shield are presented in Figures 4 and 5, respectively.

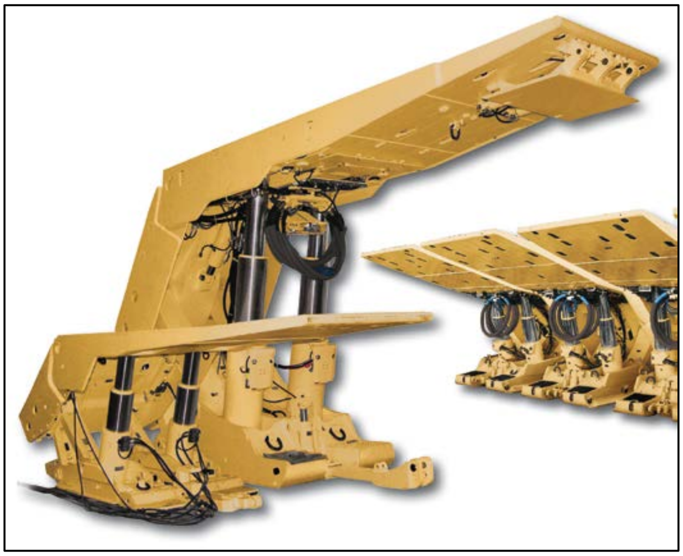

Figure 4. Picture of a typical longwall shield used in U.S. longwall mines (Reprinted Courtesy of Caterpillar Inc.).

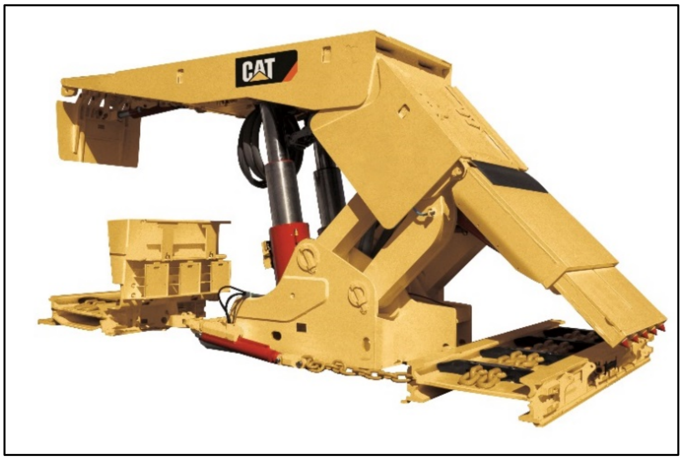

Figure 5. Picture of a typical longwall shield with face supports used in Australian longwall mines (Reprinted Courtesy of Caterpillar Inc.).

These longwall shield components, such as flippers, are not common in the U.S. The risk of coal outbursts is also a larger problem in Australia, which is reflected by the presence of a single, dedicated topic area in RISKGATE for outbursts. The increased outburst risks result from a combination of depth and larger amounts of in-situ coal formation gases. These concerns are also not as serious in U.S. coal mines.

Moving Equipment

The development of gateroad infrastructure for Australian longwall panels is notably different from the U.S. system. Gateroads in the U.S. are driven in three entry wide developments to allow for an additional fresh air intake branch. This additional branch serves as an auxiliary escape passage as required by the Federal Mine Safety and Health Act of 1977 (i.e. the Mine Act). U.S. gateroad entries are developed using the change-place method with one continuous miner paired with shuttle cars or ram cars in addition to a roof bolter. Development sections can also include two continuous miners working in tandem with additional shuttle cars, ram cars, and roof bolters added to increase productivity. In contrast, Australian gateroads are driven in two entry sections using a continuous miner-roof bolter hybridized system [13-15]. An example of a U.S. continuous miner is displayed in Figure 6.

The hybridized miner-bolter travels as a single unit and does not undergo constant entry changes. Instead, the miner-bolter excavates and secures mine entries simultaneously. In order to develop gateroads and travelways in this manner, the cutting head of the continuous miner is sized to excavate the entire width of the entry at once. During the excavation process, the miner-bolter is extended into the solid coal. As this occurs, the roof bolters at the rear of the continuous miner secure the newly exposed mine roof and ribs. Once the excavating and bolting is complete, the units then advance as a whole to repeat the process in the next section of the gateroad. The major differences between the U.S. change place method and the Australian integrated miner-bolter method are personnel positioning and equipment tramming. An example of a miner-bolter is displayed in Figure 7.

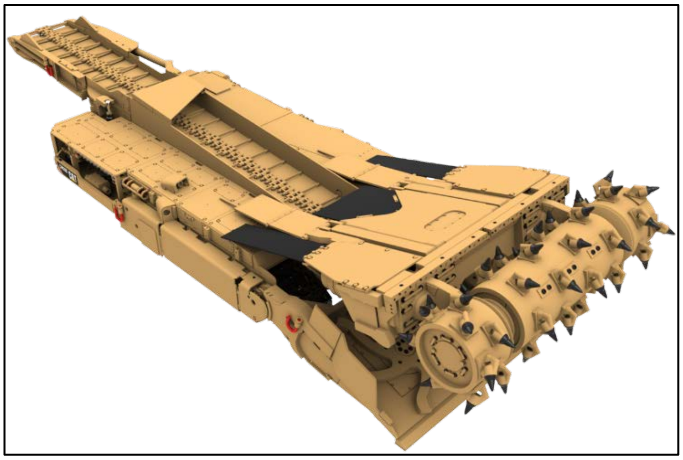

Figure 6. Example of a continuous miner used for gateroad development in the U.S. (Reprinted Courtesy of Caterpillar Inc.).

Figure 7. Example of a miner-bolter used for gateroad development (Reprinted Courtesy of Caterpillar Inc.).

Using the change-place method, the continuous miner operator controls the miner using a remote control. The operator is usually located in the vicinity of the continuous miner in order to provide line-of-sight to the working face. Depending on the roof bolter being used, the bolter operators may also be located beside the equipment. In contrast, both miner and bolter operators travel on the equipment in the Australian method. As a result, they are not exposed to certain hazards associated from being located around a piece of equipment. Additionally, the ability to develop entries with limited place changes reduces hazards associated with equipment tramming. The U.S. change-place method requires the continual movement of mining equipment. The continuous miner and the roof bolters regularly pass back and forth along the active face, which increases the exposure of mine workers to moving equipment hazards.

The advance of the Australian miner-bolter significantly reduces overall equipment movement. The nature of miner-bolter operation and increased ground control support requirements also cause the advance rate of this technique to be much slower than the advance rate of the U.S. change-place technique. The decrease in speed is caused by denser roof bolt installation patterns, greater use of rib bolts, heavier use of roof and rib meshes, as well as larger coal seam thicknesses. The reduced development rate of Australian gateroad entries combined with limited equipment tramming greatly decreases the risk of hazards associated with the change-place method. Certain safety technologies such as proximity detection systems and remote cameras are implemented in the U.S. because of complexity of the change-place method. These technologies are not utilized as heavily in Australia and are thus not addressed in RISKGATE.

U.S. Regulatory Environment for Underground Coal Mines

Title 30 Code of Federal Regulations (CFR) Part 75 (30 CFR 75) governs the primary safety requirements for underground coal mines in the U.S. The majority of these requirements have limited flexibility in terms of customizations based on site conditions. This aspect of U.S. underground coal mines reflects the primary contrast between the U.S. and Australia. The duty-of-care system adopted by the Australian coal mining industry affords substantially more flexibility than the prescriptive regulatory system currently practiced in the U.S. This fundamental difference can be reflected in RISKGATE to further improve the adoption of this body of knowledge.

RISKGATE is designed with the underlying assumption that safety practices may be customized according to the hazards present at the site in question. The tone of flexibility present in RISKGATE can be adapted to express U.S. mining regulations while concurrently providing suggestions for improving safety. This modification does not require a full revision of RISKGATE but rather the incorporation of 30 CFR 75 as requirements instead of suggestions. The addition of Part 75 is also needed to address the utilization of mandated technologies such as wireless tracking and wireless communication technologies, which are not common in Australia. Simultaneously, all inapplicable Australian-specific regulations, such as the allowance of booster fans, can also be removed. This translation of Part 75 can be accomplished by separating each topic area into requirements and enhancements sections instead of a single checklist.

The new requirements section would still remain centered around the initiating events but would first ensure that U.S. State and Federal regulations are in compliance before presenting further suggestions. Part 75 naturally allows integration into the RISKGATE bowtie system because the majority of the regulations can be categorized as either a preventative or mitigating control. An example of how this conversion may appear is presented in the following tables. Tables 1 through 3 (see APPENDIX) outline an example RISKGATE bowtie for moving equipment. This bowtie represents the following initiating event: the collision between a mine vehicle and a person in which the fault is attributed to the person. Table 1 display the cause, event, and consequence for this bowtie. Table 2 presents how applicable regulation topics from Part 75 can be organized by cause. Table 3 presents how applicable regulation topics from Part 75 can be organized by consequence.

This example conversion represents a simplified version of the final product given the amount of individual regulations that exist within each of the Part 75 topic areas. Along these lines, one of the primary challenges will be classifying each requirement with causes and consequences across initiating events. This difficulty is reflected by the simple moving equipment bowtie presented in Tables 1 through 3. Each topic area, such as §75.1403-6 Criteria—Self-propelled personnel carriers, are populated with numerous individual requirements, which are not shown in the tables. The requirements for §75.1403-6 are listed below:

(a) Each self-propelled personnel carrier should:
    (1) Be provided with an audible warning device;
    (2) Be provided with a sealed-beam headlight, or its equivalent, on each end;
    (3) Be provided with reflectors on both ends and sides.

(b) In addition, each track-mounted self-propelled personnel carrier should:
    (1) Be provided with a suitable lifting jack and bar, which shall be secured or carried in a tool compartment;
    (2) Be equipped with 2 separate and independent braking systems properly installed and well maintained;
    (3) Be equipped with properly installed and well-maintained sanding devices, except that personnel carriers (jitneys), which transport not more than 5 men, need not be equipped with such sanding device;
    (4) If an open type, be equipped with guards of sufficient strength and height to prevent personnel from being thrown from such carriers.

As can be seen by this one topic, many of the requirements are not applicable to the initiating event outlined in Tables 1 through 3. In fact, many of the regulations can be attributed to not only multiple causes but also to multiple initiating events. This multi-applicability issue is present in the majority of Part 75 topic areas. Given the complexity and the length of Part 75, the extraction and classification of each requirement will require a significant effort. Another challenge is the organization and presentation of Part 75 through RISKGATE.

RIKSGATE is designed to present its body of knowledge based on the significant risks for a particular operation. However, all applicable Part 75 stipulations are required as long as a subject area, such as a mine seal, exits regardless of the level of risk for each individual cause or event. As a result, a U.S. version of RISKGATE must present these requirements in a manner that allows the effective presentation of both mandated policies according to the subject area and applicable enhancements corresponding to the high risk items. Using this format, additional suggestions based on site-specific risk assessments would be given only when operators acknowledge that primary requirements have been met.

Once an effective 30 CFR 75 conversion is completed, this new U.S. version of RISKGATE would provide a comprehensive database of both mandated and available safety technologies and protocols. One of the main contributions of a U.S. RIKSGATE body of knowledge would be the compilation of state-of-the-art safety technologies and practices in a single database accessible to all U.S. underground coal operators, which currently does not exist. Although the U.S. mining industry does not have much flexibility for customizing base safety regulations, practices that exceed State and Federal standards may be allowed.

These additional controls can be implemented once all underlying regulations have been satisfied and if approval is gained from applicable entities. Although 30 CFR 75 already addresses many underground safety practices, the requirements are at times phrased in a general manner and are not as extensive as the body of knowledge contained in RISKGATE. For example, RISKGATE suggests that firefighting plans should be tailored to mitigate specific types of initiating explosion events, which may vary from mine to mine. Part 75 does not require the development of such plans in Subpart L. The ability to enhance safety through the addition of directed practices would be a novel addition to the prescriptive system of the U.S.

CONCLUSIONS

As previously introduced, the primary challenge of applying RISKGATE to the U.S. lies within specific differences between underground coal mines in the U.S. and Australia. In terms of explosion prevention, ground control, and moving equipment, these dissimilarities are present in ground control designs, ventilation requirements, coal deposit characteristics, mine development techniques, and governmental regulations. As a result, some of the risk areas and knowledge proposed in RISKGATE must either be removed or modified to align with U.S. policies and practices. Some of the more prevalent areas that would need adaptions were previously presented in this paper.

Although, a number of revisions are needed, especially to include 30 CFR Part 75, these adjustments can be efficiently accomplished with two separate initiatives. One initiative would be to classify and re-categorize 30 CFR Part 75 for input into RISKGATE as preventative and mitigating controls. The second initiative would be to revise the RISKGATE body of knowledge so that U.S. risk areas and mining practices are adequately represented. Although this process may be challenging, the application of risk management to U.S. underground coal through RIKSGATE has the potential to overcome the current plateau in safety improvement. The similarities between major aspects of mining, such as mining techniques, types of equipment, and safety technologies suggest that the successful adoption of RISKGATE in Australia may translate to the U.S. given a proper adaption.

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APPENDIX

Table 1. Cause, event, and consequence bowtie for a moving equipment collision.

Causes	Initiating Event	Consequence
• Remotely operated equipment within operator's line of sight places personnel in hazardous positions (operators or others) • Vehicle infrastructure design creates undue interaction between people and vehicles • Restricted or reduced visibility travelways due to design constraints and conditions • Restricted or reduced visibility of pedestrians • Personnel enter red zones or restricted areas • Personnel incorrectly enter an area with vehicle infrastructure (e.g. trailing cables) • Breach or bypass of safe work procedures, protocols or devices • Pedestrian distraction in proximity to mobile equipment • Unplanned or unexpected movement by unmanned equipment	Collision with person or personnel located in unexpected location (the fault of the incident is attributed to the person and not to the vehicle)	Injury or fatality of person or personnel in proximity to moving equipment

Table 2. Preventative controls extracted from 30 CFR 75 and organzied by cause for the moving equipment collision bowtie.

Cause	Preventative Controls
Remotely operated equipment within operator's line of sight places personnel in hazardous positions (operators or others)	§ 75.1719-4 Mining machines, cap lamps; requirements § 75.834 Training § 75.1725 Machinery and equipment; operation and maintenance
Vehicle infrastructure design creates undue interaction between people and vehicles	§ 75.834 Training § 75.1403-6 Criteria—Self-propelled personnel carriers § 75.1403-7 Criteria—Mantrips § 75.1403-8 Criteria—Track haulage roads § 75.1403-9 Criteria—Shelter holes § 75.1404 Automatic brakes; speed reduction gear § 75.1405 Automatic couplers
Restricted or reduced visibility in travelways due to design constraints and conditions	§ 75.1403-6 Criteria—Self-propelled personnel carriers § 75.1403-7 Criteria—Mantrips § 75.1403-8 Criteria—Track haulage roads § 75.1403-9 Criteria—Shelter holes § 75.1404 Automatic brakes; speed reduction gear
Restricted or reduced visibility of pedestrians	§ 75.834 Training § 75.1719 Illumination § 75.1719-4 Mining machines, cap lamps; requirements
Personnel enter red zones or restricted areas	§ 75.834 Training § 75.1719–4 Mining machines, cap lamps; requirements § 75.1725 Machinery and equipment; operation and maintenance
Personnel incorrectly enter an area with vehicle infrastructure (e.g. trailing cables)	§ 75.833 Handling high-voltage trailing cables § 75.834 Training
Breach or bypass of safe work procedures, protocols or devices	§ 75.834 Training
Unplanned or unexpected movement by autonomous/unmanned equipment	§ 75.832 Frequency of examinations; recordkeeping § 75.1404 Automatic brakes; speed reduction gear § 75.1725 Machinery and equipment; operation and maintenance

Table 3. Mitigating controls extracted from 30 CFR 75 and organzied by consequence for the personnel collision bowtie.

Mitigating Controls	Consequence
§ 75.523 Electric face equipment; deenergization § 75.834 Training § 75.1713 Emergency medical assistance (includes requirements for emergency communication systems); first-aid	Injury or fatality of person or personnel in proximity to moving equipment