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COMPARATIVE ANALYSIS OF COAL FATALITIES IN AUSTRALIA, SOUTH AFRICA, INDIA, CHINA AND USA, 2006-2010

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ABSTRACT: Coal mining (especially underground) is considered one of the most hazardous industries, and as a result considerable focus is applied to eliminating or mitigating hazards through careful mine planning, equipment selection and certification, and development of management systems and procedures. Regulatory agencies have developed in-house methods for reporting, classification and tracking of fatalities and other incidents according to the type of event, often including consideration of different hazard types. Unfortunately, direct comparison of mining safety statistics between countries is confounded by considerable differences in the way that individual countries classify specific fatalities or incidents.

This paper presents a comparative analysis of coal mining fatality data in Australia, South Africa, India, China and the United States from 2006 to 2010. Individual classification definitions are compared between the five countries, and methods presented to normalise each country's hazard definitions and reporting regimes around the RISKGATE framework of seventeen different priority unwanted events (or topics). Fatality data from individual countries is then re-classified according to the different RISKGATE topics, thereby enabling a comparative analysis between all five countries.

This paper demonstrates the utility and value of a standard classification approach, and submits the RISKGATE framework as a model for classification that could be applied globally in coal mining. RISKGATE is the largest health and safety project ever funded by the Australian coal industry (http://www.riskgate.org) to build an industry body of knowledge to assist in managing common industry hazards. A comprehensive knowledge base has been captured for risk management of tyres, collisions, fires, isolation, strata underground, ground control open cut, explosions, explosives, manual tasks and slips/trips/falls. This has been extended to outburst, coal burst and bumps, interface displays and controls, tailings dams and inrush.

INTRODUCTION

Globally, coal continues to be vitally important to energy production as well as manufacturing and construction. In 2012 it provided about 30% of the world's energy needs and was used in the production of about 70% of the world's steel (World Coal Association, 2013). It has driven the development of advanced countries and is now a leading contributor to the rapid economic growth of emerging countries such as China and India. Its pioneering role in the development of nations, has meant that coal mining is often embedded in the psyche of a country, its activities both influencing and being influenced by the peculiar historical, cultural, political, economic, labour, environmental and social factors of the location in which it operates. It was a key driver of the industrial revolution in Britain (Allan, 2006). Lahiri-Dutt (2014 in press) argues that coal is considered a symbolic icon of national pride in India, and is protected as a national asset. How this industry has and continues to manage worker safety is therefore no doubt influenced by broader and often hidden societal factors.

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Coal mining is inherently dangerous due to its combustible nature, the extraction process and the high level of mechanisation involved. Underground compared to open cut mining, is generally considered to be more hazardous due to the risk of explosions and strata failure. The enclosed nature of underground mining forces personnel to work in close proximity to risks and this compounds worker's potential for harm. For example, miners work near to the face and mechanical equipment and under a strata-roof and should there be a failure, they have restricted exit points. Also, the underground environment has low visibility and is often noisy. Open-cut mining hazards such as fall of ground and loss of control of explosives similarly have the potential for severe consequences.

While the risk associated with mining hazards, can now be managed to a tolerable or acceptable level, significant numbers of miners continue to die. In 2010, explosions in the Pike River Mine in New Zealand and the Upper Big Branch mine in West Virginia both killed 29 men and in 2007 underground strata failure caused the death of six miners (and three rescuers) in the Crandall Canyon Mine in Utah. Unfortunately, the number of fatalities in coal mines in developing countries is generally much higher. For example, between 2001 and 2008 strata failure and explosions caused over 14,000 workers' deaths in China (strata: 6,173 deaths from 4,653 accidents; explosions: 8,013 deaths from 1,027 accidents, Wang, *et al*., 2011). Wang *et al*. (2011) also reported that there were seven underground mine explosions in China between 2008 and 2011 and that each resulted in more than 100 deaths. Due to the underreporting of coal mine deaths in China, it is likely that many more miners lost their lives during this period (Jianjun, 2007).

Most research in the area of prevalence of mining fatalities has been limited to understanding direct causal factors at the operational site without reflection on the broad organisational, societal, economic, legislative or environmental conditions in which production takes place. It is proposed here that a comparative analysis of coal mining fatalities across different countries could provide a foundation of information for a more informed debate on safety management priorities for coal mining in both developed, and less developed countries that currently experience high rates of mining fatalities.

This paper describes preliminary research undertaken at the Minerals Industry Safety and Health Centre to develop a global framework for researching coal mining fatalities. It focuses on fatalities caused by underground explosions and strata fall and open cut ground fall and use of explosives in five major coal mining countries: Australia, China, India, South Africa and the United States. An important first stage has been to access different countries' fatality databases. Most coal mining countries have legislation requiring mining companies to report their accident, fatality and/or injury statistics, and sometimes their near misses or mishaps. This is because in high risk industries, a reporting culture is critical to identify prevalence and causation of incidents and sharing of lessons learnt (Reason, 1997, 2000). It engenders a safety culture at an individual organisational level and at a broader industry and regulatory level. At an organisational level an accident/incident database can trigger continuous improvement in site standards and controls, and training in accident prevention.

Benefits of industry-wide safety databases include continual improvement of standards and regulations, a more comprehensive understanding of safety risks – particularly infrequently occurring risks, better engagement of stakeholders, and design advances (Barach and Small, 2000). Regulatory bodies disseminate the information collected in these databases in various forms. Some provide detailed narratives of all fatalities (e.g. United States Mine Safety and Health Administration, MSHA) while others only disseminate higher-level analysis of statistics, such as annual fatality and injury frequency rates and/or safety alerts and bulletins. Safety bulletins typically alert the mining community to the circumstances of a fatality or dangerous event or report increased incidences of a particular risk or hazard, to encourage vigilance and provide information on better management of these unwanted events. Annual incident rates are generally categorised according to key mining hazards or risks, equipment type, environment (e.g. open cut, underground), and mining lifecycle (e.g. exploration, operations). The various categorisation methods used by regulatory bodies in different countries make it difficult to compare the causes of incidents at a broader global level.

It is vital to take into account the various contextual factors that influence coal mining activities and might drive variances in worker safety across countries. Table 1 provides general information about production and use of coal by the five countries that are the focus of this article. While this information provides some insight into potential explanations for between country disparities in safety performance, it does not tell the full story. It does however indicate why fatality rates need to be standardised across differences in workforce numbers and coal production rates. Also it may hint at differences in mechanisation, for example while Australia and India produce a relatively similar amount of coal, their numbers of workforces differ considerably, with India's workforce being ten times more than that of

Australia. This suggests a higher level of mechanisation in Australian mines and therefore it could be expected that this variance drive a between countries difference in the causes of fatalities. The numbers of underground and surface coal mines across countries may help to inform differences in the types of hazards that are more likely to be prevalent, although this must be tempered by information about the rates of production and numbers of employees across surface and underground contexts. For example, even though India has more underground mines, surface mines produced more coal (over 80%).

Table 1 - A comparison of coal production and consumption information for Australia, China, India, South Africa and the USA for 2011

	Number of coal mines			Coal production (per million tonnes)			Workforce	Coal exports (per million tonnes)			Coal imports (per million tonnes)			Coal consumption (per million
Country	Total	Surface	Underground	Total	Surface	Underground	(x1,000)	Steam	Coking	Total	Steam	Coking	Total	tonnes)
Australia	135	75%	25%	415.5	80%	20%	100	144	140	284			^	130.1
China	18,557	5%	95%	3,520			5,000			*	218	71	289	3471.7
India	572	36%	64%	588.5	84%	16%	1,000			*	123	37	160	654.5
South Africa		53%	47%	255.1	40%	60%	55	72	0	72			^	182.7
USA	1,325	62%	38%	993.7	68%	32%	91.6	34	63	97			^	972.3

Notes to Table 1: *China and India have negligible coal exports, with nearly all coal used domestically; ^Australia, South Africa and USA have negligible coal imports, as most coal is supplied domestically; Australian information sourced from Australian Bureau of Agricultural and Resource Economics and Sciences website, Australian Bureau of Statistics, Bureau of Resources and Energy Economics; Chinese information sourced from the World Coal Association website; Indian information sourced from Directorate General of Mines Safety and Indian Bureau of Mines websites; South African information sourced from South African Chamber of Mines website; US information sourced from the Mine Safety and Health Administration and US Energy Information Administration websites; General information taken from International Energy Agency: Coal Information 2012.

Australian Fatality Injury Frequency Rates (FIFR) 10 year averages indicate that open cut mines have a rate less than 50 % of the USA and underground coal mines less than 16 %, yet the mining methods are the same (Minerals Council of Australia, 2007/2008). It appears that Australia's safety record outperforms that of the US, despite there being gross similarities between Australia and the US, including culture, language, education, Gross Domestic Product (GDP), and value of life. In regards to coal mining operations, both countries are highly invested in safety, have similar mining methods and levels of technology and mechanisation. Some of the more 'hidden' factors that may drive this difference in safety performance across countries are mine size, production rates, unionisation of workforce and key differences in the legislative environment and enforcement processes. For example, it has been shown that in Australia between 1991 and 2010 85 men lost their lives working in coal mines (Kirsch, *et al*., 2013b). Across this period there was a dramatic reduction in deaths, with 65 recorded fatalities between 1991 and 2000 and only 20 in the following decade (2001 to 2010). Such a reduction is even more significant when one considers it occurred during a period of rapid expansion in Australian resources (Connolly and Orsmond, 2011). Also, the relative proportion of deaths caused by non-principal hazards (i.e. incidents that are less likely to cause multiple deaths) compared to those from principal hazards has changed across decades. Whereas most deaths between 1991 and 2000 were caused by principal hazards (~52%), in the last decade, most deaths were actually caused by non-principal hazards (~68%). Therefore it could be said that workers in Australian coal mines are now no longer dying as a result of significant disasters that take the lives of many people, rather fatalities are occurring one-by-one, as a result of more innocuous hazards, such as collisions, slipping or falling from heights, loss of control of tyres, or uncontrolled release of hydraulic energy.

A potential explanation for this difference is the legislative change that occurred in the late 1990's and early 2000's regulating health and safety legislation for coal mines in Queensland and New South Wales. Part of a global shift in health and safety practice (Foster, *et al*., 1998), this change represented a move from a compliance-based to a risk management approach to safety (Cliff, 2012a, 2012b). Incorporated into this legislation was the concept of 'duty of care' that makes individuals legally responsible to take reasonable care so that others are unharmed. Another key element of these new legislations was the implementation of risk assessment based Mine Safety Management Plans for principal or major hazards. In response to these changes, it is perhaps significant that all major mining incidents in Australia since 1996 have been in metalliferous mines (at North Parkes, 1999; Bronzewing, 2000; and Beaconsfield, 2006).

As can be seen, coal mining safety performance is influenced not only by the immediate geographical or geotechnical environment in which mining activities take place, but also by broader political and social trends. The aim of this project was to develop and test a standardised incident classification framework that could be used to categorise fatalities according to key coal mining hazards across different countries. Different countries' fatality narratives (as available) would be categorised according to this incident classification framework. In this way we can begin to describe within and between country shifts in rates and distribution of fatalities by hazard. This would include the reporting of timelines of fatalities (by hazard) for countries, to identify shifts resulting in improving or declining safety performance. Ultimately this method will be used to attribute higher-level hidden factors to shifts in rates and distribution of fatalities by hazard within and between countries.

In this report, the preliminary stages of this project are described, including the gathering of narrative information of coal mining fatalities in Australia, China, India, South Africa and the United States and classification outcomes for four coal mining hazards.

Introduction to RISKGATE

RISKGATE is a web-based tool (www.riskgate.org) providing clear, up-to-date and practical checklists for controlling risks across 17 specific high priority unwanted events (hazards, called topics in the RISKGATE system) in Australian coal mining. A brief definition of each of these 17 RISKGATE topics is provided by Kirsch *et al*. (2014, this volume). Based on interactive Bow-Tie Analysis (BTA) to assist in the implementation of safer operations, each RISKGATE topic and each bow-tie is centred on a specific unwanted or initiating event. The funnelling of causal factors and consequences through this initiating event keeps the information concise, intuitive and targeted. Users can generate checklists that will deliver on-site managers and engineers quick and relevant access to broad industry-based current practice controls for consideration at their own site. These checklists are designed as prompts regarding current practice that could assist with risk assessment, auditing, accident investigation, and training.

RISKGATE is funded by the Australian Coal Association Research Program (ACARP); managed and implemented by the University of Queensland; and each of the thousands of specific controls loaded into the RISKGATE system have been instigated and assessed by industry experts from Australia's leading mining companies. RISKGATE is built on a foundation of industry expert knowledge gathered through topic specific action research workshops (Kirsch, *et al*., 2012, 2013a, 2013 b, Worden, *et al*., 2013). Topics which have been completed to date include: fires (Harris, *et al*., 2012), underground strata control (Kirsch, *et al*., 2013c), open cut ground control, collisions, tyres, isolation, explosions (Kirsch, *et al*., 2013c), explosives (Harris, *et al*., 2013), manual tasks, and slips trips and falls (Lynas, *et al*., 2014, in press). The intent of RISKGATE is not to specifically assess risk for any unique site, but instead provide a decision support tool, resources and outputs, such as tailored checklists, that can assist users in their site-specific risk assessment and risk management.

METHOD

The narratives of coal mining fatalities occurring between 2006 and 2010 were obtained for five countries (Australia, India, South Africa and the United States). Data from the United States was accessed via the Mining Safety and Health Administration website (MSHA; http://msha.gov). Indian and South African data was sourced with permission from private communication with personnel in those country's coal mining regulatory bodies. We accessed Australian fatality data from a University of Queensland, Minerals Industry Safety and Health Centre (MISHC) database. Each country's narratives differed in detail as shown in the fall of Strata examples below[1]:

- While drilling into roof to do the brushing, a slab of rock, the size of the intersection came off the roof and fell on the workers drilling.
- At approximately *time* on *date*, *age*-year-old *name* and *age*-year-old *name*, mobile roof support (MRS) machine operators, were fatally injured when a portion of the mine roof collapsed, pinning both individuals. They had x years and x years of mining experience respectively. They were repositioning MRS machines after the completion of the third lift in the #3 entry while performing retreat mining on the North Section. The slicken-sided portion of the mine roof that collapsed measured approximately 8 feet in width by 9 feet in length and was up to 18 inches thick.
- Crushed when roof collapsed while inspecting conditions in pillar extraction area.
- Fall of roof

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[1] *Note, Personal details have been removed from these narratives; while these narratives only refer to underground fall of strata all narratives for all of the different accident causes were collected.*

Data from China was most difficult to obtain as their mining regulatory bodies do not provide public access to coal mining fatality databases. As a result, data was obtained from the United States Mine Rescue Association (USMRA, http://www.usmra.com/chinatable.htm) website. The moderators of this website collate media reports of accidents and resulting fatalities in mines in China. Therefore, only major incidents with multiple fatalities are reported - single fatalities are not reported. Also, the reports only give the number of deaths at the time of reporting, they do not give the final number of fatalities; including those who later died as a result of their injuries. Therefore, the number of Chinese fatalities reported in our study are conservative, and do not represent all coal mining deaths in China. The reliability of the information also rest on the accuracy of the media reports. However, the reports are quite detailed which enabled it to be classified for each incident according to the hazard taxonomy. An example of an incident report is:

- *Location*, *Date* - Nine workers were killed and 11 others injured after a tunnel collapsed on Thursday afternoon in a coal mine in China's *Location* Province. The incident happened at *time* p.m. when a 80-meter section of a tunnel suddenly collapsed in the *Name* Coal Mine, which belongs to *Name* in *Location*, said a spokesman of the group on Friday. The injured were hospitalised. An investigation into the cause of the incident has begun.

Once data was obtained, each incident for each year and country was then categorised according to 11 key coal mining hazards; see Kirsch *et al*. (2014) for brief hazard definitions). While the RISKGATE system now covers and provides definition for 17 coal mining hazards, this classification study was initiated when only the first 11 hazards were completed (Kirsch, *et al.*, 2012). The RISKGATE categories of mining hazards were identified as priority unwanted events in coal mining by ACARP members and comprehensively defined through the action research workshop process, thereby providing a framework for standardised and accurate re-classification of the five country's fatality narratives.

An example of a RISKGATE hazard (termed Topic in RISKGATE) definition is displayed in Box 1, which highlights the depth of information that was used to guide our incident classification (detailed definitions can also be accessed at www.riskgate.org). Further, RISKGATE provides more specific second level definitions for each hazards' 'initiating events' (or points at which control is lost according to bow-tie analysis; Detailed explanation of the application of bow-tie analysis within the RISKGATE program can be found in Kirsch *et al*. (2012; 2013a, 2013b) and Worden *et al*., 2013). So for the Explosives open cut topic, there was not only the general topic definition (Box 1) but also definitions for each of the five initiating events listed in this definition. Shown in Table 2 are examples of definitions that regulatory bodies use to categorise fatality narratives as being caused by explosives. These are included here to highlight their brevity in comparison to the RISKGATE definition.

Procedure

Individual student researchers, all studying engineering (and mostly mining engineering) worked on classifying fatality narratives for each country. Prior to commencing this process, each was thoroughly trained on using the RISKGATE topics to classify fatality narratives. Any narratives that researchers found difficult to classify were identified, and then discussed and finally classified during regular team meetings. Outside expertise was sought to classify narratives that the group was unable to categorise. Narratives that did not fit any of the 11 RISKGATE categories were classified 'Other'[1].

RESULTS

In this article only preliminary fatality statistics for four hazards: explosions, fall of strata – underground, fall of ground – open cut, and explosives – open cut are presented. Table 2 reveals that nearly half of the fatalities in coal mines in the United States are caused by explosions and strata failure. Further, these hazards cause two out of three fatalities in China and nearly four out of ten fatalities in India. Strata failure alone results in about 20 to 25 % of all coal fatalities in India and South Africa. Explosions are quite infrequent in South Africa, with only three recorded deaths (or 3.5% of the total), probably due to the low gas content in coal in that region. This table also shows that the two underground hazards are much more dangerous (in terms of fatalities) than the two open cut hazards. It appears that for these countries, the likelihood of fatalities due to explosives and surface ground fall is low compared to that of the underground hazards of explosions and strata fall.

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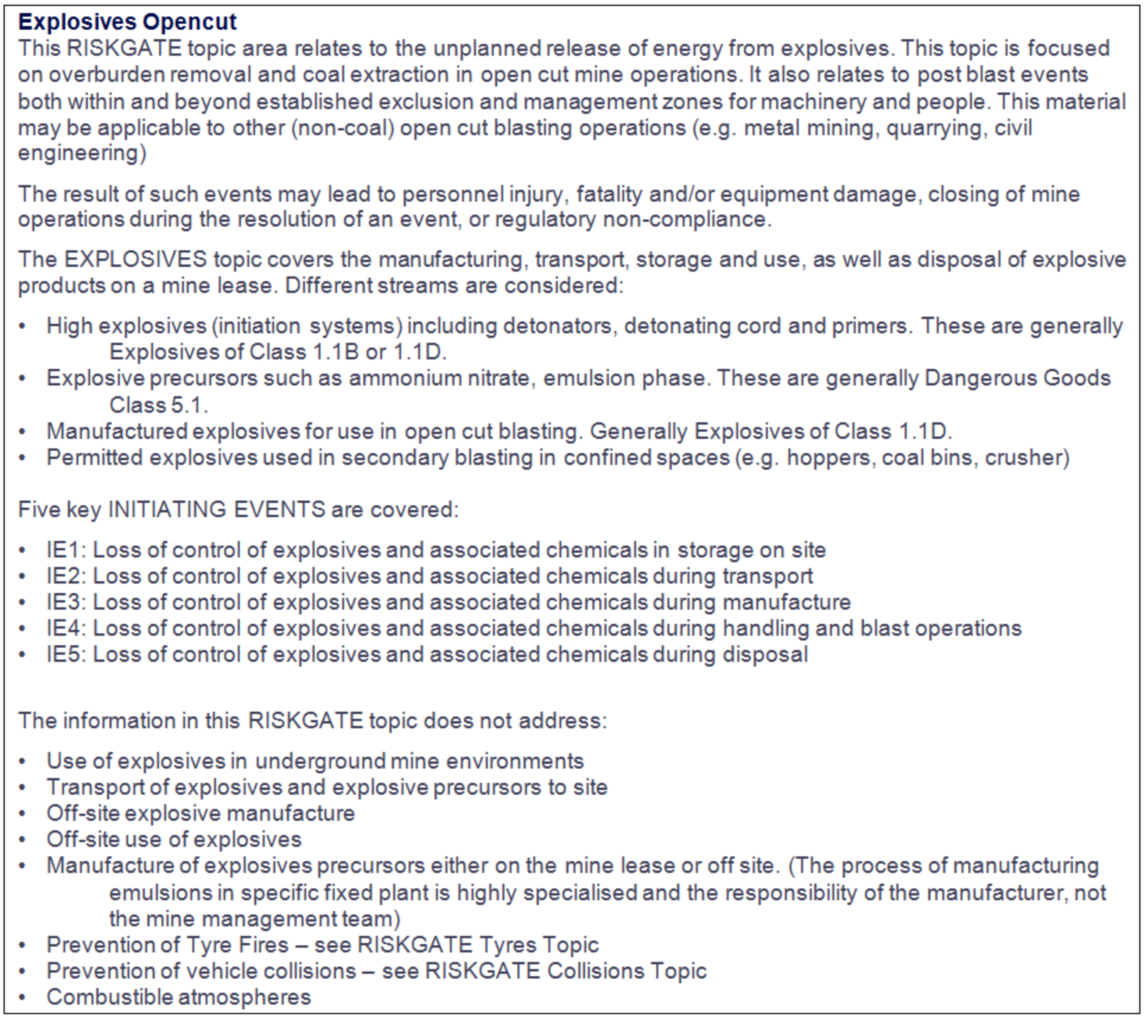
[1] *Note, since the time of this study RISKGATE has now added more hazards to its body of knowledge including outbursts, coal bumps and bursts, interface, inrush, tailings dams, occupational hygiene*

There are a number of possible explanations as to why explosives cause fewer incidents in surface coal mines. One is that drilling and blasting is now a relatively automated process. For example, computers are used to drill and monitor blast holes and assist in the delivery of explosives (e.g., ANFO, heavy ANFO and pumped emulsion blends) to blast holes. Automation improves the reliability and accuracy of these tasks as well as reduces the number of personnel required for potentially hazardous jobs. It is now not uncommon for loading of blast holes to be completed by one person, sitting in an explosive loading vehicle with an additional shot firer ensuring the collar length is achieved on the bench. Further, the development of remote firing systems allows operators to fire the blast from safe distances. Mine-site personnel who do supervise blasting operations are required to hold shot firing licenses and associated mandatory competencies. These risk treatments are common to blasting operations around the world, including developing countries. In Australia the handling and use of explosives must also be done in accordance with national standards that further drive safe practice.

Box 1 - Example of a RISKGATE hazard definition (Explosives Open Cut topic)



Explosives Opencut

This RISKGATE topic area relates to the unplanned release of energy from explosives. This topic is focused on overburden removal and coal extraction in open cut mine operations. It also relates to post blast events both within and beyond established exclusion and management zones for machinery and people. This material may be applicable to other (non-coal) open cut blasting operations (e.g. metal mining, quarrying, civil engineering)

The result of such events may lead to personnel injury, fatality and/or equipment damage, closing of mine operations during the resolution of an event, or regulatory non-compliance.

The EXPLOSIVES topic covers the manufacturing, transport, storage and use, as well as disposal of explosive products on a mine lease. Different streams are considered:

- High explosives (initiation systems) including detonators, detonating cord and primers. These are generally Explosives of Class 1.1B or 1.1D.
- Explosive precursors such as ammonium nitrate, emulsion phase. These are generally Dangerous Goods Class 5.1.
- Manufactured explosives for use in open cut blasting. Generally Explosives of Class 1.1D.
- Permitted explosives used in secondary blasting in confined spaces (e.g. hoppers, coal bins, crusher)

Five key INITIATING EVENTS are covered:

- IE1: Loss of control of explosives and associated chemicals in storage on site
- IE2: Loss of control of explosives and associated chemicals during transport
- IE3: Loss of control of explosives and associated chemicals during manufacture
- IE4: Loss of control of explosives and associated chemicals during handling and blast operations
- IE5: Loss of control of explosives and associated chemicals during disposal

The information in this RISKGATE topic does not address:

- Use of explosives in underground mine environments
- Transport of explosives and explosive precursors to site
- Off-site explosive manufacture
- Off-site use of explosives
- Manufacture of explosives precursors either on the mine lease or off site. (The process of manufacturing emulsions in specific fixed plant is highly specialised and the responsibility of the manufacturer, not the mine management team)
- Prevention of Tyre Fires – see RISKGATE Tyres Topic
- Prevention of vehicle collisions – see RISKGATE Collisions Topic
- Combustible atmospheres

Table 2 - Examples of national hazard definitions (Explosives)

Country	Definition
India	Accident in the course of using explosives
South Africa	Any un-authorised or accidental ignition or detonation of explosives
United States	Accidents involving the detonation of manufactured explosives, Airdox, or Cardox, that can cause flying debris, concussive forces, or fumes

Notes to Table 2: Indian definition taken from Mandel and Sengupta, 1999; RSA Department of Mineral Resources, 2012; US definition taken from MSHA website

Table 3 - Coal mining fatalities caused by explosions, fall of strata, open cut explosives, fall of ground and all fatalities (including other causes) in Australia, China, India, South Africa and the United States between 2006 and 2010

	underground hazards			open cut hazards			
Country	Explosions	Strata fall	Explosions and Strata	Explosives	Ground fall	Explosives and Ground	All coal mining fatalities
Australia	0	0	0	0	0	0	8
China	2145 (60.7%)	188 (5.3%)	2333 (66.1%)	17 (.5%)	35 (1%)	52 (1.5%)	3532
India	74 (14.3%)	114 (22%)	188 (36.2%)	0	5 (1%)	5 (1%)	519
South Africa	3 (3.5%)	21 (24.7%)	24 (28.2%)	0	0	0	85
USA	49 (27.7%)	26 (14.7%)	75 (42.4%)	0	4 (2.3%)	4 (2.3%)	177

Note: percentages represent the number of fatalities caused by that hazard relative to the total number of fatalities in that country

Within China, it was found that the top five hazards, accounting for 94% of reported coal mining deaths, were all associated with underground mining. These were explosions (60.7% of all fatalities for China), inrush (16%), fire (primarily all underground, 6.5%), explosives underground (5.5%) and fall of strata (5.3%). These outcomes are as expected considering 95% of coal mines in China are underground, also coal seams have a relatively high gas content.

DISCUSSION

In this article we have the importance of considering how higher-level hidden factors might impact shifts in rates and distribution of coal mining fatalities by hazard within and between countries has been described. Also a hazard taxonomy that has now been used to successfully categorise fatality narratives was presented across Australia, China, India, South Africa and the United States. This is an important first step in having a standardised method of categorising fatality narratives across different countries. This study describes this taxonomy and the method we used to gather fatality databases and then carefully categorise these. The next steps involve beginning to describe within and between country shifts in rates and distribution of fatalities by hazard for these countries. It is the aim to then evaluate these trends in terms of broader organisational, societal, economic, legislative and environmental conditions in which production takes place. It is believed that this will provide for a more informed debate on global safety management priorities for coal mining.

Future work will extend the study to include the fatality data from other mining countries (e.g. Colombia, and Mozambique) as well as investigate methods to better normalise results across countries so that safety indicators account for variations in number of mining employees, hours worked and production of coal.

Finally, this project has proven utility in engaging high level undergraduate engineering and/or science students in direct research activity. Over two cohorts of students, a research program (structure and process) that is successfully building towards a comprehensive global database of coal mining fatality and injury outcomes normalised using RISKGATE definitions has been developed. Students gain first hand knowledge of risks and human costs in coal mining, and the opportunity to manage these risks through application of the RISKGATE body of knowledge. Over time, and with adequate resources, this exercise will be expanded to include as many coal mining countries as possible, and then further expanded with the addition of metalliferous mining outcomes.

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