The safety and sustainability of mining at diverse scales: Placing health and safety at the core of responsibility

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I certify that all material in this thesis which is not my own work has been identified and that any material that has previously been submitted and approved for the award of a degree by this or any other University has been acknowledged.

Abstract

Mining plays a major role in meeting global resource demands with Europe hosting extensive mineral potential. However, few of these prospects are feasible for conventional exploitation due to their small size & ore grade, proximity to dense populations and tenement constraints. Hence, a significant paradigm shift towards switch-on, switch off small-scale mining (SOSO SSM) is needed in order to increase the viability of small, complex, high-grade deposits. The IMP@CT project developed mobile, modularised solutions to facilitate rapid deployment and in-situ extraction & processing, which necessitates the translation and extension of best practice safety and sustainability from established national regulations and industry standards. Despite decades of accumulated safety regulation, knowledge and experience, workplace errors and violations still lead to fatal accidents, particularly if immature safety attitudes and behaviours pervade an organisation. The presence of a mature safety culture is vital for mitigating the occurrence of injuries and fatalities, through a collective commitment to safety improvement.

This study has aimed to consolidate safety and sustainability best practice that is tailored to SSM by identifying the critical safety considerations and applying safety culture maturity principles to the specific challenges associated with a semi-automated SOSO SSM system. Criteria-driven maturity modelling, informed by existing responsible mining initiatives and safety and socio-environmental culture perspectives from site personnel at all hierarchical levels, is developed to assess the environmental and social factors associated with small- to medium-scale regulated mining. The role of agile management for rapid adaptation and continuous improvement of safety and sustainability performance in SOSO SSM is discussed. This research has demonstrated that for SOSO SSM to effectively integrate a mature safety and socio-environmental culture within a flexible, containerised mining paradigm, managerial and technical agility, and human initiative must be encouraged to continuously drive progress in occupational health and safety and generate wider societal benefit.

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Statement of Research Impact due to Covid-19

This statement has been written to provide thesis examiners with specific contextual information relating to unforeseen disruptions to planned research activities due the Covid-19 pandemic. In this case, participatory site-based fieldwork in the UK, originally planned for March 2020 onwards, was significantly impeded by national lockdown and associated restrictions. Therefore, visitation to most small- to medium-scale mine sites around the UK for in-person research was not possible from March 2020 until December 2021. In addition, a number of essential academic-related commitments for my first supervisor directly induced by Covid-19 impacts inhibited the level of research project supervision received from July 2020 until January 2021.

This participatory fieldwork was necessary to obtain primary data for chapter 4, comprising of semi-formal interviews with mining personnel at all hierarchical levels to gather individual perspectives on safety and socio-environmental culture. Participatory group discussions for calibration and verification of environmental & social culture maturity models, as described in chapter 5 of this thesis, were facilitated during the same site visits as the semi-formal interviews. This research was undertaken with the intention of performing audit-style analysis to identify discrepancies between responses from participating groups and observed procedures & approaches. However, time restrictions only permitted an investigation of the environmental and social maturity models' applicability and practicality in a mining context, which did remain relevant to the primary aims and objectives of this research project.

Desk-based studies surrounding global trends in mining safety performance was conducted primarily as a replacement research activity, which is presented in chapter 2 of this thesis, because previously planned field visits were delayed significantly by nationwide restrictions. While this research was not originally planned prior to the Covid-19 pandemic, the content forming this initial chapter has provided a useful foundation from which the rest of this thesis is built upon.

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Abbreviations

ASM – Artisanal and small-scale mining

BOI – Bretby Operability Index

BoM – Bureau of Mines

BTA – Bowtie analysis

CAD – Computer-aided design

CapEx – Capital expenditure

CCM – Critical control management

CIRAS – Confidential incident reporting and analysis system

CM – Selective Mining Tool

CMM – Continuous mining machine

COSHH – Control of Substances Hazardous to Health

CRIRSCO – Committee for Mineral Reserves International Reporting Standards

CSR – Corporate social responsibility

DSEAR – Dangerous Substances and Explosive Atmospheres Regulations

E&S – Environmental and social

EASHW – European Agency for Safety and Health at Work

EBP – Effects-based planning

EBRD – European Bank for Reconstruction and Development

EC – European Commission

EI – Energy Institute

EIA – Environmental impact assessment

EITI – Extractive Industries Transparency Initiative

eLCA – Environmental life cycle assessment

EMESRT – Earth Moving Equipment Safety Round Table

ERM – Enterprise risk management

ESG – Environmental, Social and Governance

EU – European Union

FIFO – Fly-in, fly-out

FPIC – Free, prior and informed consent

GDP – Gross domestic product

GHG – Greenhouse gas

GMI – Global Mining Initiative

GRI – Global Reporting Initiative

H&S – Health and safety

HAZOP – Hazard and operability studies

HR – Human Resources

HRO – High reliability organisation

HRT – High Reliability Theory

HSE – Health and Safety Executive

HSO – Internal health and safety organisation

ICMM – International Council on Mining and Metals

IDC – International Data Corporation

IEA – International Energy Agency

IFC – International Finance Corporation

IMP@CT - Integrated Modular Plant and Containerised Tools

IOSH – Institution of Occupational Safety and Health

IP – Intervention point

IRMA – The Initiative for Responsible Mining Assurance

ISO – International Organisation for Standardization

LCA – Life cycle assessment

LHD – Load Haul Dump

LOS – Line of sight

LSM – Large-scale mining

LTI – Lost-time incident

MCDA – Multi-criteria decision analysis

MHRA – Major hazard risk assessment

MINER – Mine Improvement and New Emergency Response Act

MMP – Mobile Modularised Plant

MSD – Musculoskeletal disorder

MSHA – Mine Safety and Health Administration

NCB – National Coal Board

NDL – No days lost

NFDL – Non-fatal days lost

NGO – Non-governmental organization

OEM – Original equipment manufacturer

OSH – Occupational safety and health

OSHMS – Occupational safety and health management systems

PHA – Preliminary hazard analysis

PPE – Personal protective equipment

PSM – Process safety management

RoM – Run of Mine

SAMESG – South African guideline for the reporting of environmental, social and governance (ESG) parameters

SAMREC – The South African Code for the Reporting of Exploration Results, Mineral Resources and Mineral Reserves

SC – Surface comminution

SIA – Social impact assessment

SIMP – Social impact management plan

SLO – Social licence to operate

SME – Small and medium-sized enterprise

SMS – Safety management systems

SOS – Safety organising scale

SOSO – Switch-on, switch-off

SSM – Technologically advanced small-scale mining

SSP – Surface sorting & processing

SWA – Safe Work Australia

TSC – Total safety culture

TSF – Tailings storage facility

UK – United Kingdom

UN – United Nations

UNDP – United Nations Development Programme

UNEP – United Nations Environment Programme

USA/ US – United States of America/ United States

U/SM – Underground and/or surface mining

VDV – Vibration dose value

VR – Virtual reality

WBV – Whole body vibration

WRAC – Workplace risk assessment and control

XRF – X-ray fluorescence

1 Introduction

1.1 Background to safety in mining operations

Mining plays a major role in meeting the world's resource demands, with operations taking place across 6 continents, the largest of which being situated in countries such as China, Australia, South Africa, and so on. Europe has a wealth of proven mineral potential (BRGM, 2016), but very few of these prospects are feasible for large companies to exploit due to their small size & grade, close proximity to densely populated settlements, and land use & tenement constraints. Hence, a significant paradigm shift in mining is needed in order for small, high-grade deposits to be economically exploited using mobile, modularised mining solutions, necessitating the translation and extension of health & safety and sustainability best practice from well-established operations, national regulations, and industry standards.

Occupational safety and health (OSH) is defined as the physical reduction of risks as far as reasonably practicable under the circumstances that employees work, and is achieved through risk elimination, substitution for a less hazardous alternative, introduction of engineering and/or administrative controls, or PPE. Effective implementation of the hierarchy of controls is achieved through the use of integrated occupational safety and health management systems (OSHMS), which help to provide clear structure and alignment of the organisation toward a common goal or purpose (Haight et al., 2014; Iannacchione et al., 2008). OSH policy is developed by the organisation that is in line with their objectives, roles and responsibilities are set out, and plans are implemented to put the OSHMS into practice. Performance is measured against the minimum health & safety standards for the organisation, which is reviewed through a feedback loop using both internal and external audits and monitoring for the purpose of meeting key organisation-specific performance indicators and comparing against best practice standards (Health and Safety Executive, 2001, 1997). Within high risk industries such as mining, high-consequence low-likelihood material unwanted events are the most important to manage and so require specific tools and techniques to mitigate these, such as bowtie analysis for establishing preventative and mitigative control measures (Foster and Severn, 2013). Ergonomics and 'safety by design' also play an important role in maximising OSH from the outset, by developing solutions prior to manufacturing or during retrofitting that reduce exposure to musculoskeletal injury while maintaining productivity (Schutte and Smith, 2002; Torma-Krajewski et al., 2009, 2006).

Poor OSH performance has pervaded the industry despite gradual regulatory improvement, which might indicate more fundamental cultural issues that often manifest as human error. Immediate causes, such as a failure to adhere to procedures, tend to receive more attention during investigations, encouraging individual blame instead of establishing a complete sequence of event failures. The root causes are classified as either latent failures, the contributory factors that may lead to an unwanted event, or active failures which are the direct errors that cause an accident. The contributing factors often lie dormant until certain conditions arise that allow one or more failures to occur, especially if they are left unchecked for long periods of time. Deducing that the immediate causes are from operator error or technical failure of a component or piece of equipment doesn't fully identify the root cause(s), which could be cultural, organisational, or otherwise. An accident may be blamed on a failed component rather than incorrect use or lack of maintenance, which may arise from supply issues, product quality, poor management, or weak safety culture.

The working environment is significantly influenced by factors such as the commitment of management to safety (Zohar, 1980), described using the terms 'culture' and 'climate' which are distinguished by their scale in terms of safety. Culture refers to the attitudes and beliefs of the management and workforce within a particular organisation or industry, while climate describes the overriding safety standards and the level of compliance with those standards, thereby outlining a company's position on safety (Glendon and Stanton, 2000; Guldenmund, 2000). So, where climate is driven by the implementation of universal policies and standards, culture is developed through consistent management and supervision of individual and organisational safety. A positive, deeply embedded safety culture drives continuous improvement within organisations and enables management to track their strengths and weaknesses within the OSHMS. Ensuring that an effective safety management system is implemented with a high-level culture and organisational resilience can reduce the occurrence of major accidents and mitigate risks to an acceptable level of tolerance. There is widespread inconsistency in the delivery of safety, environmental and social performance as shown in the Responsible Mining Index report (RMF, 2018), which may be attributed to a lack of safety culture development guidance in responsible mining initiatives, as well as the inherent challenges associated with fully embedding a positive shift in culture.

The potential to diversify approaches to selective extraction and processing was tested within the EU Horizon 2020 *IMP@CT* Project (Integrated Modular Plant and Containerised Tools). The feasibility of small-scale, switch-on switch-off (SOSO) mining in Europe depends greatly on the quality of pre-operation planning from a safety, environmental and social perspective. The *IMP@CT* solutions aimed to reduce environmental impact, enhance community benefit and ownership opportunities, and reduce OSH risk, all whilst supplying sufficient raw materials for Europe's manufacturing and industrial sectors. Safety by design prior to manufacturing, the ergonomic suitability of equipment, and site-wide risk management are all key considerations for a safe and sustainable operation at this comparatively reduced scale. A resilient safety culture must be established from the outset in order to "hit the ground running" with regards to OSH, due to the novel mining and processing technologies, reduced workforce size and temporal duration. Techniques for assessment and improvement of safety culture maturity, and the applicability of maturity modelling for driving environmental, social & governance (ESG) performance will be explored.

The *IMP@CT* Project carried out hot commissioning and testing in Olovo, Bosnia and Veliki Majdan, Serbia in 2019-20, which provided an opportunity to directly compare safety conditions between the SOSO modularised system and traditional in-situ operations in Olovo through site risk assessments. The testwork localities presented unique social circumstances from which to explore the potential implications of small-scale mining (SSM) on communities in a region with important mining legacy. Obtaining social acceptance from surrounding populations is difficult to achieve when the risks associated with a mining operation appear to outweigh the benefits, opting for a 'NIMBY' attitude. Public perceptions can also be adversely affected by past accidents that have resulted in loss of life and capital, which creates further difficulties in securing a social licence to operate from community stakeholders. So, establishing trust and rapport between companies and local people, understanding their requirements, and frequently communicating relevant updates are essential for maintaining strong relationships between companies and nearby communities.

1.2 Project scope, research questions, and chosen approaches

Despite their existing dominance of the global base metal markets, the largest multi-national mining companies will need to move away from large-scale extraction from ‘world-class’ mineral deposits due to a declining number of economically, environmentally and socially viable prospects. Given the need for a sustainable supply of critical raw materials, the EU industry en bloc must support development of complex, high-grade deposits using small-scale mining (SSM) approaches. Traditional H&S design and management cannot be easily translated to smaller operations, so whole system solutions that are mobile, containerised and rapidly commissioned must be developed. This ensures that safety by design and ergonomics are incorporated prior to manufacturing to reduce the occurrence of injuries from the outset and minimise retrofitting.

Developments and trends in safety performance in small to medium scale mines globally since 2008 are analysed using past fatality and injury data to understand the key latent failure risks that should be prioritised for the purpose of optimising standards in SOSO SSM. This research focuses on modern, regulated mining operations from small- to medium-scale to deduce and align best practice from conventional extraction with that of SOSO SSM. Establishing a novel paradigm of SSM to diversify the extractives industry will be enhanced by optimising existing policy and procedures, with potentially wider application to conventional small to medium scale operations. Methods of safety culture maturity modelling have been developed and applied across several industries including mining, and this research will apply culture principles in this context to optimise safety management and performance in SOSO SSM. Established maturity modelling will be adapted to assess the ‘environmental and social culture’ of operations using criteria derived from safety, sustainability and responsible mining guidance. Guidance on safety culture and integration of cultural maturity principles in responsible mining frameworks is comparatively low, as these initiatives typically constitute a ‘tick box exercise’ for companies seeking accreditation. This guidance will be critically reviewed and selectively integrated into a maturity model for application as a facilitated self-assessment methodology for qualitative measurement of environmental and social culture maturity. From this defined scope, the overriding research questions that are addressed in this thesis are as follows:

1. How can safety performance be optimised in a switch-on, switch-off (SOSO) small-scale mining paradigm that is underpinned by rapid adaptation and flexibility, and what existing tools and techniques may be used to improve safety by design, ergonomics, and culture maturity?
2. How is safety and socio-environmental culture currently perceived by mining personnel in conventional in-situ operations at diverse scales, and how does this align with the principles of high reliability theory?
3. How can participatory maturity modelling of environmental and social performance in conventional in-situ operations drive increased awareness of internal culture and progress towards higher maturity?
4. What are the key considerations and approaches required to facilitate positive culture shift across diverse operational scales, and how can these lessons be applied to augment the switch-on switch-off mining paradigm based on its variable dependence on human and system control?

1.3 Research Aims

- To analyse the predominant latent failures affecting mining workforces and investigate the applicability of safety culture maturity as a tool for improving OSH standards across a diverse range of mining approaches and scales.
- To compare and contrast the occupational safety considerations for SOSO SSM and 'traditional' in-situ mining to inform best practice of the former.
- To determine the relationship between safety culture and ESG performance, through maturity modelling of environmental and social aspects of mining.
- To assess the means of integrating safety culture principles and techniques centrally into existing responsible mining frameworks.
- To evaluate the applicability of Agile management for continuous optimisation of safety and sustainability performance in SOSO SSM operations and across diverse scales of mining.

1.4 Research Objectives, Hypotheses & Thesis Structure

Chapter 2: To examine lagging indicator of safety (injury and fatality data) from small to medium scale mines to understand prevalent latent failures and forecast safety performance trends more accurately, to help inform necessary changes to prevent fatal and non-fatal incidents. Analysis of safety performance trends from Europe, the USA, and Western Australia between 2008-2017 are supplemented by data from US mining fatality reports published from 2010 until present, and placed in context of 4 decades of safety culture research.

- Hypothesis: Safety performance across specific regions has improved with time as OSH standards and systems are progressively updated to account for new knowledge and understanding of prevalent risks and hazards in mining, with some national-level variability due to local context and modifying factors.

Chapter 3: To investigate best practice health & safety for traditional in-situ mining and observe the innovative *IMP@CT* mining solutions during the design, commissioning, and testing phases in order to determine the most suitable OSH standards, procedures and design considerations for small-scale SOSO mining.

- Hypothesis: SOSO SSM operations will require fully integrated safety design, training, and management approaches to ensure that modular systems are fit for purpose from the outset, working standards are maintained at a high level from the start of operations through to closure, effective control measures are in place and verified at the start of operations, and effective knowledge transfer is facilitated between expert personnel.

Chapter 4: To holistically explore the prevailing attitudes and perceptions towards safety and socio-environmental sustainability from mining personnel at various hierarchical levels at small to medium scale mine sites in the UK, Bosnia and Herzegovina, and Serbia. Semi-formal interviews will be conducted with 54 participants and structured to examine variability in safety culture between frontline workers and general managers.

- Hypothesis: Cultural perceptions from interview respondents are anticipated to be negatively correlated with site duration as mines in their early stages of development and operation are less likely to have established a mature safety culture. Alignment of safety culture between management and employees is expected to differ between variably sized mines in relation to location, ownership and regulatory regime, comparative workforce sizes, and production rates.

Chapter 5: To conceptualise a 4-tier, criteria-driven ‘environmental and social culture maturity’ model based on safety culture maturity models and theory. This will be piloted at small- to medium-scale mine sites in the UK to establish a baseline level of environmental and social culture maturity, which will inform improvement measures based on those observations.

- Hypothesis: The success or failure of a mining project is primarily influenced by the level of trust between the organisation and the local communities & authorities. So, participating companies who maintain regular collaboration with local stakeholders in decision making, transparency in public dissemination, and responsible environmental stewardship are expected to perform well with regards to E&S maturity.

Chapter 6: To integrate research findings from preceding chapters in order to discuss (1) the role of automation and vernacular safety for reducing risk to SOSO workforces, (2) the optimal safety regulations and training approaches for the main unit processes to meet minimum compliance while alleviating safety clutter, (3) the implementation of environmental and social maturity across industries beyond mining to facilitate knowledge transfer and create wider societal benefit, and (4) the applicability of Agile for rapid adaptation and continuous improvement in safety and socio-environmental sustainability.

2 Trends in safety performance in modern regulated mining operations towards a scheme to address prevalent latent failures

2.1 Introduction & Scope

The root causes of incidents may be classified either as active or latent failures, depending on the nature of the incident itself. Latent failures are defined as the contributory factors that may lead to a material unwanted event, unlike active failures which are the direct errors that cause an incident. The contributing factors often lie dormant until conditions arise that allow one or more failure events to occur, especially if they are left unchecked. The immediate causes tend to receive more attention during investigations, encouraging individual blame rather than an understanding of the sequence of failures, which will require a greater commitment to developing safe systems as well as safe work. With this work we show that despite 4 decades of research, there are ongoing needs to tackle the causes of single-person fatal accidents (Dekker, 2014a; Jackson, 2023). We will examine the role of safety culture for improving OSH performance in high risk industries, with a focus on modern, regulated mining at various scales through an analysis of latent failure trends.

Conventional safety performance monitoring have been based predominantly on the assumption that less LTIs or NFDLs will result in fewer fatalities, a relationship first described in Heinrich's accident triangle (1931). Safety performance has focused on forms of 'measurable safety' such as LTIs, but recent incidents show that fatalities are independent of accident occurrence, notably in the Deepwater Horizon oil spill which killed 11 people (Casselman, 2010). Low-consequence, high-likelihood incidents should be used to provide insight for preventing high-consequence, low-likelihood accidents provided that they manifest with the same causal patterns (Bellamy, 2015; Dekker, 2018). The scope of this chapter is to address latent failures by conducting a literature review of safety culture development to establish the key cultural characteristics that are present in various industries, and perform an analysis of safety data.

Past fatality & incident statistics and fatality investigation data and reporting from several developed countries will be analysed to determine performance trends in modern, regulated mining. Then, the most common latent failures leading to individual fatal & non-fatal accidents in mining operations globally and regionally will be gleaned to reinforce interpretations from previous safety culture research and frame those within the context of small-scale, low-impact mining. The aim is to find a route to continued success and mitigate the plateau of safety performance by identifying the causal pathways to OSH failures within equivalent hazard types. This work will underpin the following chapters by providing overall context of mining industry safety performance and the linkage with safety culture as a key leading indicator. The importance of this research is in highlighting the opportunities that arise from understanding past failures and using those lessons to implement positive changes for prevention of future incidents and mitigation of harm both locally and industry-wide in mining.

2.2 Methods

A semi-chronological literature review of safety culture and performance-related research spans the last 4 decades at various operation scales. It describes the increased attention towards health and safety culture and standards in the mining industry, as a conceptual framework in which to discuss data analysis.

Statistics were compiled for fatalities, non-fatal days lost (NFDL) and no days lost (NDL) from 2008 to 2017 for mining in Europe, USA, and Western Australia in order to identify overall trends in safety performance by country and region. Data was compiled from the European Union’s ‘Eurostat’ database, the Mine Safety and Health Administration repositories for the USA, and online records from the Department of Mines, Industry Regulation and Safety in Western Australia. Lagging or trailing safety data, which was gathered from publicly accessible databases, were normalised per 100,000 workers to eliminate false trends caused by regional variation in mining activity, and to support analysis of variations in national safety culture. However, there is a limited scope for normalisation of publicly available safety data between important mining regions, a notable example being Western Australia (measured by ‘100,000 workers’) and Queensland (measured by ‘million hours worked’). In addition, public safety data repositories are limited or not present for other significant mining nations (e.g., South Africa, China, Brazil), so the conclusions drawn are not representative of the global industry, resulting in selection bias in favour of ‘first-world’ developed nations with modern, regulated mining industries in this

Figure 2.1: Methodology flowchart outlining process of data collection and literature review associated with chapter 2 study.

study. Furthermore, the consistency of primary statistical compilation between regions prevented a detailed account of the effects of seasonality, regulations, operational type, type of material extracted, and other external factors on trends in latent failures and overall safety performance. While normalisation of data ensured internal validity, a lack of comparative studies using primary data from mines in similar regions, with aligned regulatory systems, and/ or producing similar commodities limits the extent of external validity to this analysis.

Approximately 350 Mine Safety and Health Administration fatality reports dated from 2010 - 2021 were analysed to investigate the specific root causes of fatal and non-fatal accidents associated with various mining activities (haulage, operating equipment) and areas (underground, open pit, processing plant) in

US mines. The quality and accuracy of information gleaned from these reports is dependent primarily on the diligence of original incident investigators with regards to indirect factors which might have contributed to the fatality in question (e.g., rate of extraction, commodity type, seasonality, technological advancement). These factors can also be considered when investigating the validity of safety statistics in the three globally significant mining regions described above, as well as the precision of the data collection methodology. The applicability of the data obtained for this analysis is dependent on the extent to which occupational incidents leading to fatalities, injuries or lost time incidents are accurately recorded and tabulated. The choice to adopt a broad scope for this analysis, with regards to location, scale and type of mining operation, is owed to the perceived lack of correlation between safety culture performance and operational size. Taking a wider view of performance in modern, regulated operations enables a larger range of perspectives to be considered which can be examined and utilised for targeted development of best practice applicable to small-scale mining. Hence, this chapter will provide an accessible, evidence-based summary of key areas for safety improvement in mining at diverse scales, with emphasis on root causes and leading indicators. The full methodology is described in Figure 2.1.

2.3 Safety culture maturity as a concept

2.3.1 The origins of climate and culture as concepts in workplace safety

Early studies into safety organisation originated with the development of ‘climate’ as a concept to describe the perceptions of production employees towards OSH. The first methodology used for safety climate analysis was established by Zohar (1980), who used factor analysis of responses by Israeli factory workers to a questionnaire. The key indicators of safety climate were the perceived importance of safety training programs, management perceptions towards safety, and effects of safe conduct on promotion. Zohar’s methodology was utilised and adapted later by Brown & Holmes (1986), who assessed 425 production workers in the US and exercised caution when accepting the validity of results gathered from a safety climate measurement model. Their analysis indicated that persons who have experienced trauma tend to be less trustworthy of management’s concern towards occupational wellbeing. Research into

Zohar's approach continued to be refined, with work by Dedobbeleer & Béland (1991) who used a questionnaire-based survey of 384 construction workers across Baltimore, Maryland. They challenged Brown & Holmes' three-factor safety climate model, having a better fit to two-factor modelling through two linear structural relations procedures. The two factors were (1) management commitment, and (2) worker involvement in safety. Their apparent correlation does not prove that two-factor modelling is more accurate, as three or more factors can cover an increasingly wide range of safety climate scenarios.

Safety culture was first characterised in a report following the Chernobyl nuclear disaster in 1986, both in response to the nuclear accident itself and the ongoing discussions surrounding the safety culture concept within the health and safety research community at the time of publication (1991). It was defined as "*that assembly of characteristics and attitudes in organisations and individuals which establishes that, as an overriding priority, nuclear plant safety issues receive the attention warranted by their significance*". The report also included guidance on how organisations may self-assess and continuously improve safety from a cultural perspective. Niskanen (1994) found that road workers and supervisors in Finland felt that safety improves performance and production, is everyone's responsibility, and should be recognised when good practice is demonstrated. The study found several important dimensions for further investigation, including safety attitudes, safety vs. production and job/task variation and/or rotation.

Defining the terms 'safety culture' and 'safety climate' has confused OSH specialists, researchers and associated regulatory bodies due to the cross-duplication within the literature, leading to uncertainty regarding the validity of these concepts. Vu and De Cieri (2014) performed a literature review to provide clarity on the characteristic differences between each concept. A review of existing literature to identify original definitions of these terms revealed 51 for safety culture and 30 for safety climate, after excluding related constructs, unverifiable results, duplications and non-English results. The Health and Safety Commission published arguably the most cited original definition in 1993:

"Safety culture of an organisation is the product of individual and group values, attitudes, competencies, and patterns of behaviour that determine the commitment to, and the style and proficiency of, an organisation's safety management. Organisations with a positive safety culture are characterised by

communications founded on mutual trust, by shared perceptions of the importance of safety and by confidence in the efficacy of preventive measures."

(Health and Safety Commission, 1993)

Geller (1994) instead takes a pragmatic perspective of 'total safety culture':

"In a total safety culture (TSC), everyone feels responsible for safety… safe work practices are supported via rewarding feedback from peers and managers; people "actively care" on a continuous basis for safety. In a TSC, safety is not a priority that can be shifted depending on situational demands; rather, safety is a value linked with all other situational priorities."

(Geller, 1994)

A more succinct characterisation of safety culture is "the way we do things around here" (Confederation of British Industry, 1990). Investigations into major disasters such as Piper Alpha and the London Kings Cross Fire have cited safety culture as a contributing factor (Martyka and Lebecki, 2014). Mining accident investigations such as Westray (1992), Upper Big Branch (2010) and Pike River (2010) show that managers, employees and inspectors frequently refer to safety culture being linked to its accident record. However, the specific reasons for this poor safety culture are limited, preventing meaningful insight for implementing changes that pervade all levels of the organisational hierarchy.

Fundamentally, climate is defined by the prevailing perceptions of safety at a single point in time, while culture is expressed by the attitudes of individuals towards safety issues and how this collectively manifests within an organisation. Following the ongoing development of models and frameworks for measuring the relationships between organisation- and group-level safety climate (Zohar, 2008, 2002; Zohar and Luria, 2005), Zohar identified that much of the early work in this research area had focused on the measurement of safety climate while comparatively neglecting its conceptual basis. Hence, the themes that underpin safety climate constructs were clarified, providing a foundation for further analysis and augmentation with climate antecedents such as leadership & safety commitment by senior management, employee perceptions of safety management, risk perceptions and attitudes, and communication. Additionally, quantitative measurements of safety culture through maturity modelling enable comparisons of performance through time, between organisations or companies in similar industries, to quantify the relationship between safety culture and safety outcomes (Flin et al., 2000; Nævestad et al., 2021; Zohar, 2010). Recent work has comprehensively explored the breadth of safety culture literature from 1980 to 2021 using a bibliometric approach and identified the dominant topics and research development trends, which include safety culture, performance, behaviour, accidents, and model. Safety culture research has also shifted from concept and model development in earlier publications to the application of models to various industries and sectors (Yang et al., 2023).

2.3.2 Perception-based models of safety culture and organisational climate

Table 2.1: Reason's (1997) five inter-dependent safety sub-cultures.

Subculture	Characteristics
Informed culture	An effective and proactive safety information system which provide up-to-date information about the human, job, organisational and environmental factors that determine the safety of the system as a whole.
Learning culture	The organisation has the willingness and ability to understand and make changes based on the safety information that is provided through the system. Among the key elements of this subculture—"observing, reflecting, creating and acting"— acting is the most difficult element to carry out successfully.
Reporting culture	Workers are prepared to report errors, critical incidents and near misses, particularly their own, in a climate of trust and without fear of reprisals.
Just culture	An atmosphere of trust in which workers are encouraged to provide essential safety information and know the distinction between acceptable and unacceptable behaviours. Those who carry out unacceptable behaviours will be punished by way of disciplinary action.
Flexible culture	The organisation has an ability to reconfigure itself during high-risk operations or certain kinds of emergency. This flexibility enables the organisation to transfer control to "task experts in a crisis", regardless of the hierarchical nature of the organisation.

The critical components of safety culture have been expressed as multi-level models or sub-cultures to classify different approaches to measuring, classifying and altering organisational culture or climate. Reason (1997) developed 5 inter-dependent sub-cultures; Informed, Learning, Reporting, Just, and Flexible, described in Table 2.1.

Aspects of these 5 sub-cultures symbiotically interconnect since they depend on the successful implementation of one sub-culture for others to thrive. An *informed culture*, which requires an understanding of the technical, behavioural,

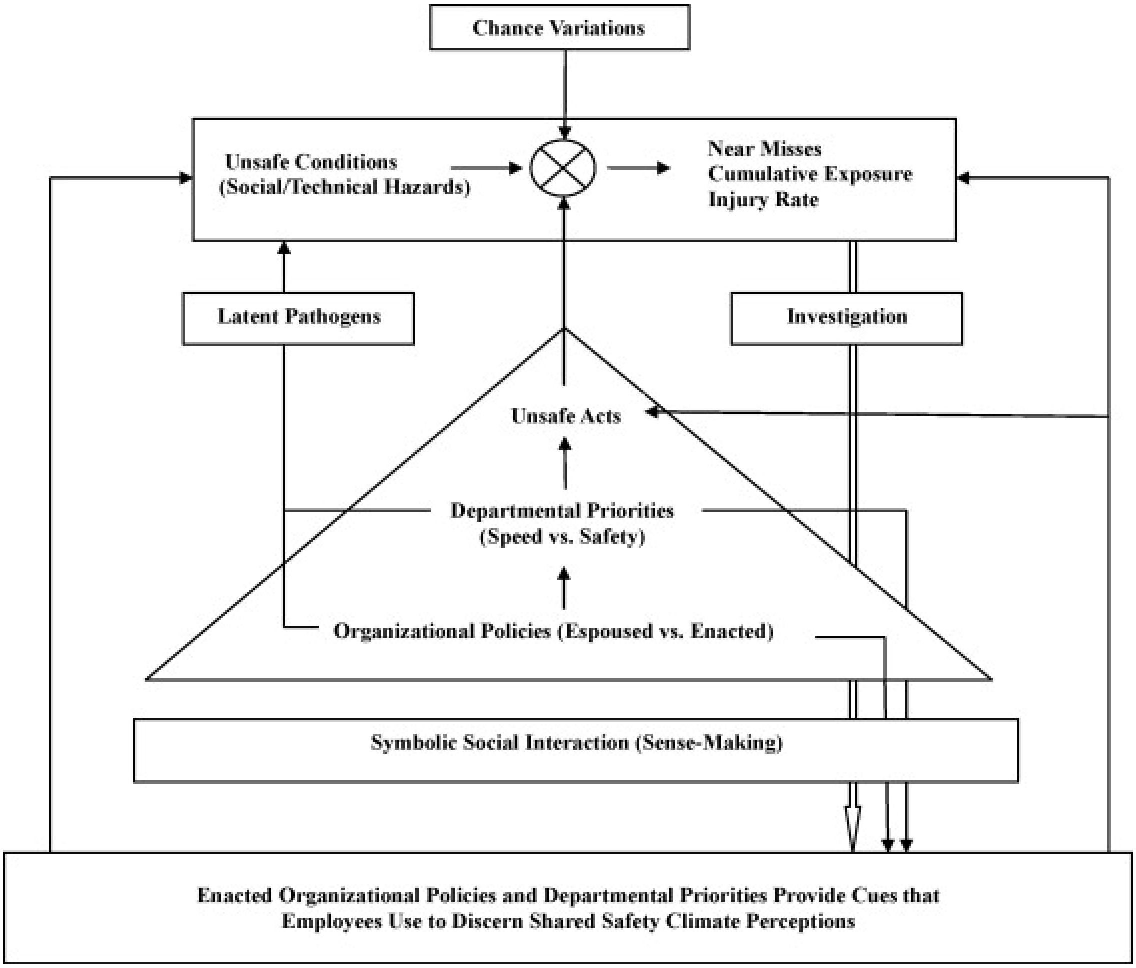


Figure 2.2: Multi-level integrated model combining Reason's Safety Pyramid model (1997) with Zohar's safety climate model (2010).

administrative, and environmental factors that influence the system, depends on the extent to which employees will report errors, violations and near-misses, generating a *reporting culture*. This links with the establishment of a *just culture*, where employees are entrusted with monitoring safety conditions and rewarded for providing important safety information. Both *learning* and *flexible culture* are essential for enabling fluid safety decisions through evolution of organisational safety attitudes (Reason, 1997). Reason’s Safety Pyramid (1997) integrated with Zohar’s safety climate model (2010) links OSH and organisational climate, forming a feedback loop of latent failures and leading indicators which inform culture development priorities (see Figure 2.2). This pyramid model can be mapped against the Old vs New View of safety described by Dekker (2014), from unsafe acts at the top which presume that human error is the primary cause of safety-related incidents, down to the wider organisational policies and priorities that define the parameters in which employees can work; hence, priority in investigations shift towards the organisational deficiencies that contributed to the incident instead of human error (New View).

Fleming and Lardner (1999) described three levels of safety culture: dependent (numerous accidents, negative safety attitude), independent (some accidents, indifferent attitude), and interdependent (few accidents, positive collective attitude to safety), which is reflective of the DuPont “Bradley Curve”. Westrum (2004) explored the means by which organisations process safety information, defined from Pathological (i.e. ignorant and irresponsible), Bureaucratic (i.e. respondent and inconsistent), to Generative (i.e. collaborative and sustainable). The importance of progressive attitudes towards safety from the workforces and management is emphasised in both studies. Fleming (2001) incorporated the Bradley Curve, with the updated model comprising 5 maturity levels (Emerging – Managing – Involving – Cooperating – Continually Improving). Hudson et al. (2000) reviewed the link between intrinsic motivation and safety culture through the ‘*Hearts and Minds’* project developed by Shell as a culture assessment toolkit. Their study addressed the need for organisations to take ownership of safety and gradually improve their culture using a similar 5 step process (Pathological – Reactive – Calculative – Proactive – Generative), with this 5-tier structure being adopted by multiple studies since *Hearts and Minds* (Filho and Waterson, 2018). The identification of an organisation’s prevailing cultural maturity can help to define suitable targets for progressing to higher culture

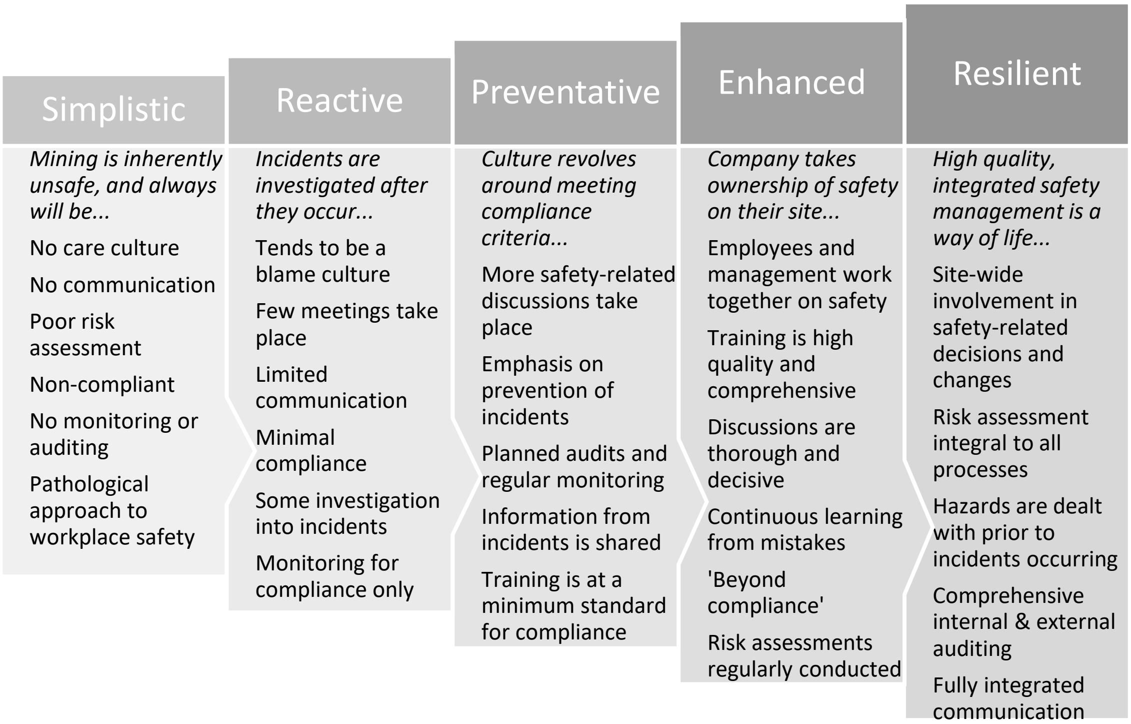


Figure 2.3: The safety culture maturity model applied to mining operations, comprising 5 stages of increasing maturity (Anglo American Plc, 2010; Foster & Hoult, 2011; 2013; IRM, 2011; The University of Queensland, 2008).

levels, and motivate workers to adapt their approach if the objectives are clear and attainable.

'*The Safety Way*' maturity model adapted the *Hearts and Minds* approach to suit the dimensions of UK Coal, producing a "Basic – Reactive – Planned – Proactive – Resilient" hierarchy. 'Basic' maturity refers to an organisation that accepts that accidents are part of the job, 'Planned' organisations are inclined to implement preventative measures, and 'Resilient' is defined by clear leadership which prioritises safety, with an integrated safety management system in place. *The Safety Way* model also divided culture into sub-categories tailored to UK Coal, which was tested at several mines in 2011, using a series of question sets relating to each sub-category. Management and operators were questioned on their views on organisational maturity which provided insight into internal culture and informed development of action plans (Foster and Hoult, 2011; 2013). A summary of the 5-level safety culture model with selective descriptions of each tier is presented in Figure 2.3.

While the Hearts and Minds model is a more comprehensive design which Hudson adapted to several high-risk industries such as aviation, petroleum and health care (Hudson, 2007, 2003), the Safety Way study has tailored the model to the specific needs of UK Coal. Therefore, when working to improve the safety culture of an organisation, there is no 'one size fits all' model; each site should be investigated on a case-by-case basis. Not all organisations will have the resources to make large steps towards high maturity, so areas for improvement should always be prioritised (Foster and Hoult, 2011; 2013).

2.3.3 Variability in safety culture across the industrial sector

The influence of culture on worker attitudes to risk was investigated by Nordlof et al. (2015) at a steel producing company in Sweden, through a series of group interviews that determined perceptions of safety. Workers articulated that; (a) you must accept the risk associated with your job, (b) most responsibility for safety lies with the worker, (c) attitudes to production vs. safety is not consistent within the workforce, and (d) communication is vital for high levels of safety (Nordlöf et al., 2015). The workforce acceptance of risk and lack of priority on safety over production indicates that management commitment to safety is more critical and can be independent of company and/or workforce size.

Bascompta et al. (2018) explored the current state of safety culture in South America to determine the effect of company size or number of employees on culture. The crucial factor in facilitating culture shift was the implementation of an effective safety management system, as shown by the improvements seen in smaller companies who adopt such systems (Bascompta et al., 2018).

Filho & Waterson (2018) produced a comprehensive literature review of safety culture with a focus on maturity models and their applicability in culture assessments. They showed that much of the experimental work involving maturity modelling within industry is not shared with academia, so they lack published evidence of success in generating cultural shift. Conceptualised models should be tested at similar sites or organisations at the same time to demonstrate repeatability and gain credibility (Filho and Waterson, 2018). Stemn et al. (2019) explored the link between safety culture and performance in the Ghana using a questionnaire at 4 large-scale mine sites. They recognised that, despite the negative correlation between culture and incidence rate, the levels of maturity often vary across different elements of a site's safety management system. Alshehri at el., (2023) adopted a structural equation modelling approach with survey data from 240 participants to examine the factors that are applicable to nuclear safety culture in Saudi Arabia, finding that personal safety commitment, personal error behaviours, and violation behaviour are affected most by the prevailing safety culture of a nuclear power operator.

The concept of High Reliability Theory (HRT) originated from the post-incident analysis of the Three Mile Island nuclear power station accident in 1979 which first identified the primary behavioural and cultural factors that promote safety in high-reliability organisations (HROs) (Hayes, 2006). Multidisciplinary research by Perrow (1984) and Roberts (1989) defined HROs by their ability to maintain extraordinarily consistent safety records despite the inherent major risks and hazards associated with normal operations.

"There is a class of organizations that can do catastrophic harm to themselves and a larger public. Within this larger set of potentially harmful organizations there is a subset which have operated extraordinarily reliably over long periods of time. Extraordinary attention is paid to operational reliability both because of the inherent dangers of the situation and because outcome reliability is

impossible to realize without operational reliability. Hence, we call these organizations "high reliability"."

(Roberts, 1989)

The five principles of "mindfulness" that underpin High Reliability Theory, first introduced by Weick & Sutcliffe (2001) and cited extensively since, are as follows (Hayes, 2006; Simpson et al., 2009; Weick and Sutcliffe, 2007).

- *Preoccupation with failure*, and detailed reporting and analysis of failure as essential for learning through knowledge transfer.
- *Reluctance to simplify interpretations*, seeking a diversity of views on complex, tightly connected organisational issues.
- *Sensitivity to operations*, by one or more individuals understanding the state of the operational system, and the organisation placing emphasis on integrated understanding of typical operations.
- *Commitment to resilience*, often by deference in depth, organisations are robust yet flexible, with the ability to recover from irregular variations and disruptions to prevent control being lost.
- *Deference to expertise*, especially for organisations flexible enough to allow responsibility for decision making in emergency situations to be passed to experts near the situation.

The first of these principles relating to *Preoccupation with failure* predominantly involves analysis of small local failures in order to understand failure pathways before more significant impacts occur. For high reliability organisations to mitigate the risk of major unwanted events, an understanding of past failures in the mining industry is required for learning and knowledge transfer among persons and departments. However, small local failures and incidents are often poorly documented, hence the need to utilise information from more severe incidents such as fatality and lost-time injury reports and statistics.

The key safety threats to mining workforces need to be placed in the context of similar operations, which can be gleaned from past health & safety records and statistics. A retrospective, computer-assisted qualitative analysis of OSH mining reports indicated the presence of 24 key terms relating directly to safety culture from 954 references and 6 themes, highlighting the role of both individuals and the overriding organisation in understanding and driving mature culture for workplace accident prevention (Tetzlaff et al., 2021). Students from the University of Wollongong developed an extensive fatality comparison between global regions to determine the most hazardous mining activities and occupations during and prior to 2008 (Noon and MacNeill, 2008). Individual countries, states, or jurisdictions often produce their own annual safety reviews, especially those with well-established industries such as the USA and Western Australia, which enable a normalised comparison for understanding trends in performance. This chapter will compile and analyse more recent fatality and injury data to understand the prevailing latent failures in mining operations.

2.4 Global trends in the regulated mining industry

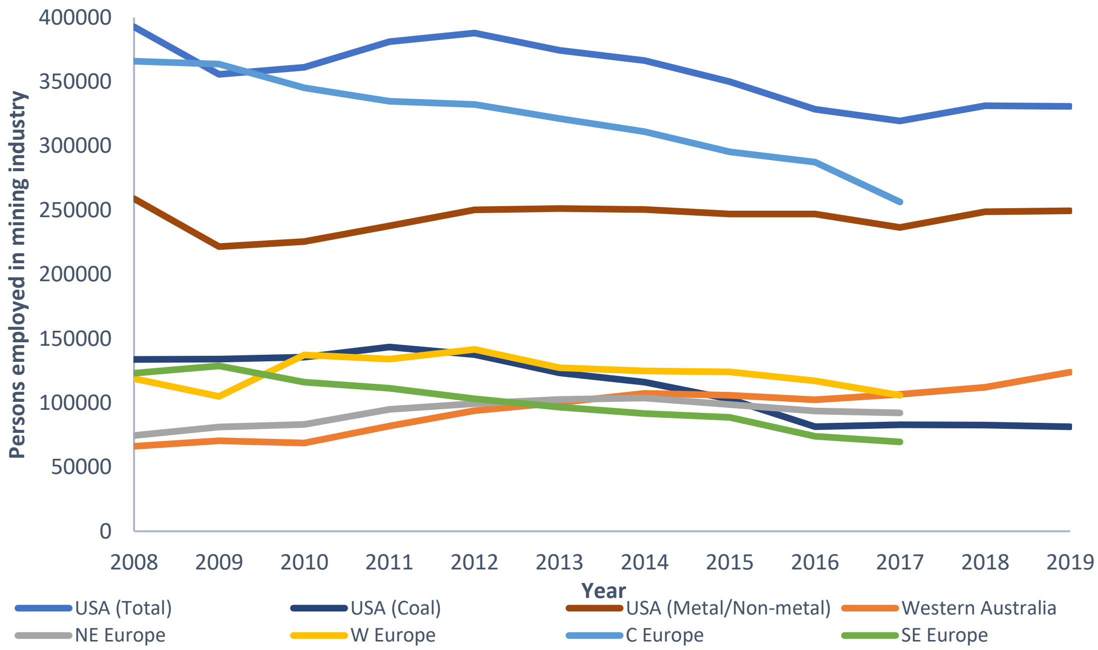


Figure 2.4: Persons employed in the mining industry by country/region (Department of Mines Industry Regulation and Safety, 2019; Eurostat, 2020; Mine Safety and Health Administration, 2019a, 2019b).

This analysis will focus on safety performance data from mining operations in European Union (EU) member states in Europe, the USA and Western Australia, which all have comprehensive fatality and injury statistics available from 2006, or earlier depending on the region, and can all be normalised by number of employees. Modern open-pit and underground mines at variable scales and commodities are the focus of this study, with artisanal small-scale mining not considered due to a lack of reliable, publicly accessible safety data.

US coal mine employees have decreased gradually since 2011 (Figure 2.4), which is attributed to the closure of less productive coal mines following less demand and stricter legislation supporting cleaner forms of energy (Hislop,

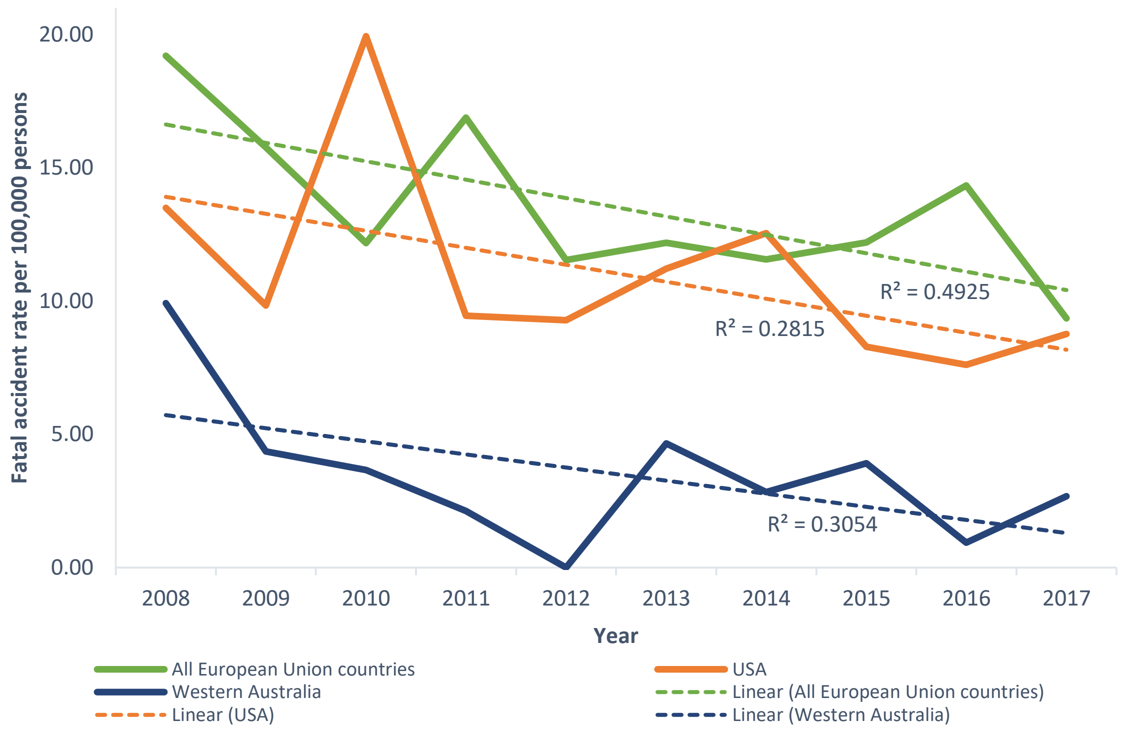


Figure 2.5: Fatal accident rates from 2008-2017 in European Union (average), USA and Western Australia (Department of Mines Industry Regulation and Safety, 2019; Eurostat, 2020; Mine Safety and Health Administration, 2019a, 2019b).

2018). The number of US metal & non-metal mining operations has stayed relatively constant since 2012 due to stable demand for industrial and base materials. Western Australia has increased in mining employees from 2008, in line with the expansion of existing operations and increasing extraction of Lithium and Vanadium for green technologies (Evans, 2019). For comparison between EU countries, the data is sub-divided into 4 major regions. North-eastern EU countries include Denmark, Estonia, Latvia, Lithuania, Finland, Sweden and Norway. Western EU countries include Belgium, Ireland, Spain, France, Luxembourg, Portugal and the United Kingdom. Central EU countries include Czechia, Germany, Italy, Hungary, Austria, Poland, Slovenia, Slovakia and Switzerland. South-eastern EU countries include Bulgaria, Greece, Croatia, Cyprus and Romania. Employment in central Europe has declined since 2008 due to the closure of major coal mines in Poland and Germany as green energy expands (DW, 2020; Republic of Mining, 2012), while western and north-eastern European employment has fluctuated with market shifts (Figure 2.4).

Figure 2.5 demonstrates that fatal accident rate can provide an indication of the effectiveness of regional approaches to safety, owing to downward trends in fatalities in Western Australia, the USA and Europe since 2006/08. Western Australia shows the lowest fatality rates since 2010, which may be attributed to

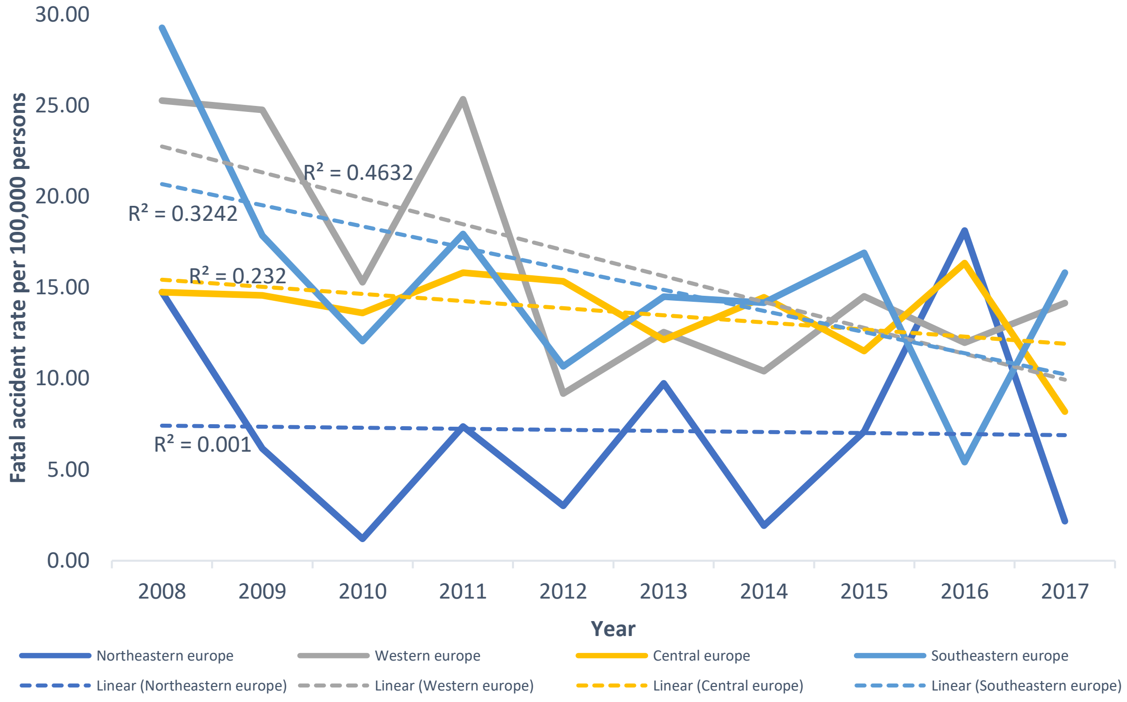


Figure 2.6: Fatal accidents from 2008-2017 in European regions, normalised to 100,000 persons (Department of Mines Industry Regulation and Safety, 2019; Eurostat, 2020; Mine Safety and Health Administration, 2019a, 2019b).

their recent advancement in safety regulations and automation. As of 2017, Western Australia experienced only 2.67 fatal accidents per 100,000 persons, while the USA and Europe had significantly more, with 9 and 9.35 fatal accidents respectively. The USA fatality data diverges most significantly from best fit due to the Upper Big Branch mine explosion in 2010 that killed 29 workers (McAteer et al., 2011). Western Australia has shown a declining fatality record since 2008, notably achieving zero fatalities in 2012. (Department of Mines Industry Regulation and Safety, 2019; Eurostat, 2020; Mine Safety and Health Administration, 2019a, 2019b).

North-eastern Europe shows the lowest fatal accident rate from 2008-2017 relative to the EU average, due to stringent regulations broadly implemented in Scandinavian operations. Over the 10-year period, both north-eastern and central Europe showed marginal improvement, decreasing by 0.058 and 0.3906 fatal accidents per 100,000 persons per year respectively. Western and south-eastern Europe have greater average annual reductions in fatal accidents of 1.4232 and 1.1607, respectively. Fewer fatalities shows that high-quality European safety regulations aligned safety performance between the main 4 regions by 2017, but with poor correlation due to variation in fatality rate within a small sample set, particularly in north-eastern and western Europe (Figure 2.6).

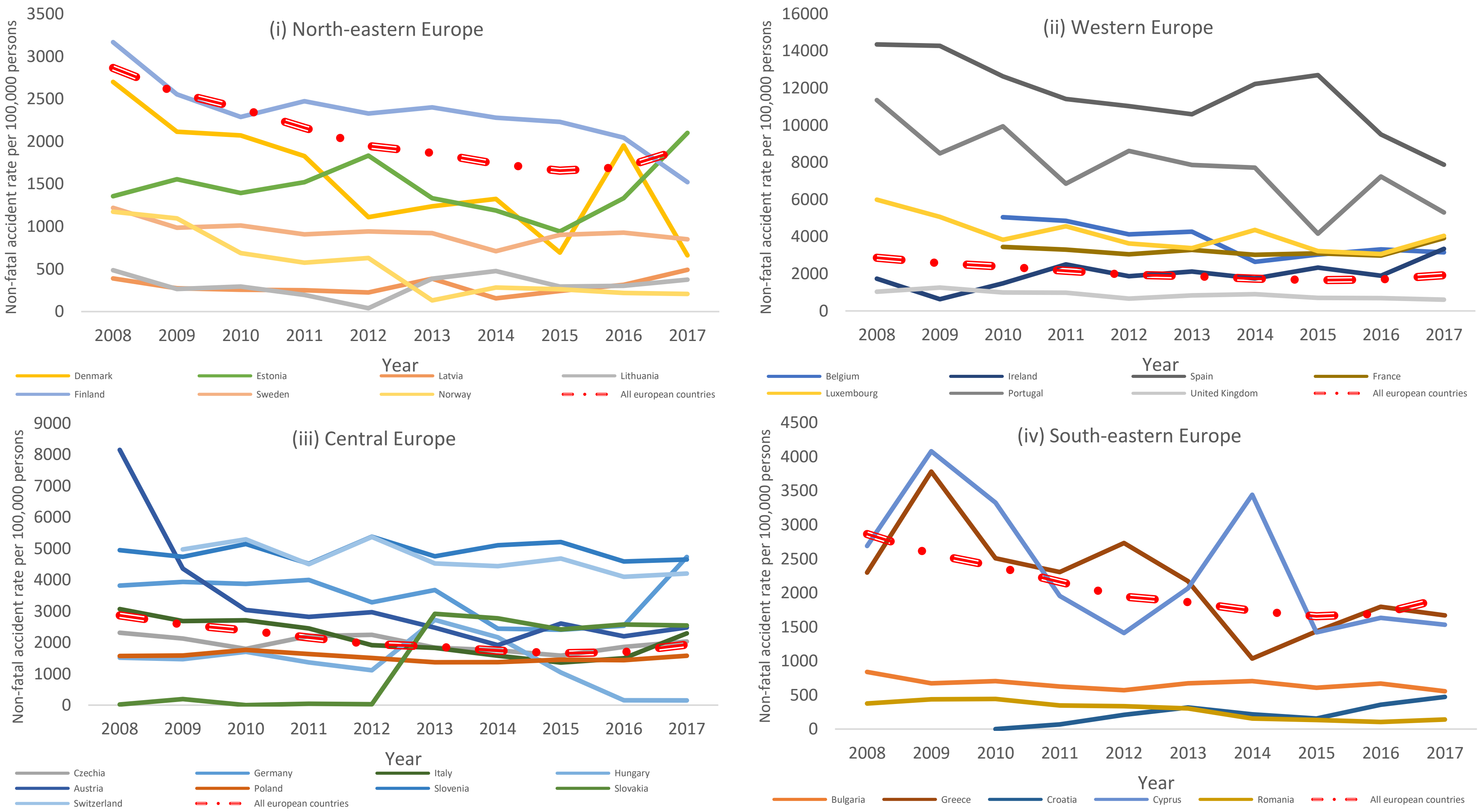


Figure 2.7: Non-fatal mine accident rates in (i) north-eastern, (ii) western, (iii) central, and (iv) south-eastern European countries (2008 – 2017) normalised per 100,000 persons (Eurostat, 2020).

Non-fatal accident rates in 28 EU countries divided by region from 2008-2017 are presented in Figures 2.7i-iv. In north-eastern Europe, all countries have non-fatal accidents rates that are equal to or below the continental average, with Norway, Lithuania and Latvia suffering the least. Accident rates in south-eastern Europe are at or below the EU average, with Romania, Croatia and Bulgaria having the least accidents. Most of western and central Europe have accident rates at or above the EU average, except for the United Kingdom and Poland. Spain, Portugal, Slovenia and Switzerland have the highest accident rates of the EU nations despite showing improved performance over 10 years. The number of non-fatal accidents per 100,000 persons reduced from over 14,000 in 2008 to less than 8000 in 2017 in Spain, and from over 11,000 in 2008 to ≈5300 in 2017 in Portugal. Other EU countries with a reduction in non-fatal accidents from 2008 to 2017 include Belgium, Luxembourg, United Kingdom, Norway, Finland, Sweden, Denmark, Austria, Hungary, Bulgaria, Romania, Cyprus and Greece. Overall, Europe, USA and Western Australia have recorded a steady decline in fatal accident rates between 2008 and 2017 (Figure 2.5), with alignment of performance across Europe within the same timeframe (Figure 2.6). Figure 2.7 shows regional variation in non-fatal accidents within the EU. Western Europe had the poorest safety performance of the 4 regions, while north-eastern Europe performed well by comparison. EU nations with above average accident rates recorded a sustained performance in safety, which contributed to the statistical alignment described in Figure 2.6.

2.5 Accidents by injury type in the mining industry

Recorded accidents by specific injury type in European mining operations fell rapidly across all of the EU nations surveyed from ≈18,000 in 2008 to ≈13,200 in 2012, while the number of employees was relatively stable at ≈680,000. After 2012, employee numbers began to fall by ≈30,000/year down to 532,641 in 2017. Accidents per year decreased and stabilised at ≈10,000 between 2015 and 2017, which may suggest that safety progress eased across Europe due to a recent lack of assurance on operations, or by inadequate reporting earlier in the period after implementation of more stringent reporting. The reported non-

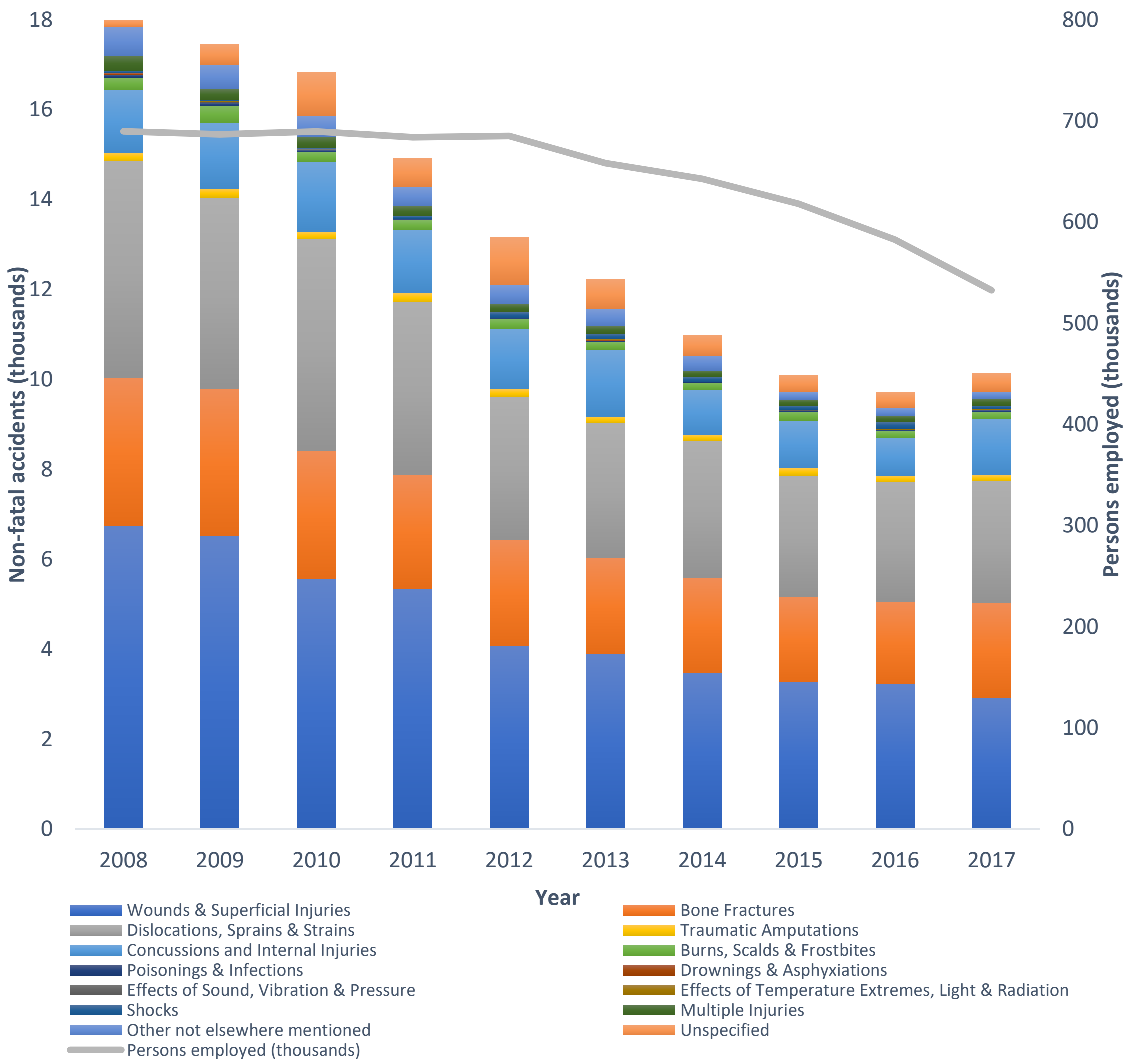


Figure 2.8: Non-fatal accidents by injury type (bars) & persons employed (line) from 2008-2017 in all measured EU countries (thousands) (Eurostat, 2020).

fatal accidents for most injury types reduce in number from 2008 to 2017: wounds and superficial injuries decreased by 56.5% on average over 10 years; bone fractures decreased by 36.4%; dislocations, sprains and strains decreased by 43.5%; and burns, scalds and frostbites decreased by 40.7%. Only occupational ergonomic factors such as sound, vibration and pressure effects, temperature extremes, light and radiation, and shocks increased (Figure 2.8). The relative proportion of these injury types is negligible, and changes to reporting standards may have impacted on how these injuries were disclosed compared to earlier in the analysis period (Eurostat, 2020).

The Western Australian Department for Mine Safety recorded incidents by the direct cause rather than by specific injury as in the Eurostat database, and shows a 39.7% decrease from ≈3650 incidents per 100,000 employees in 2010

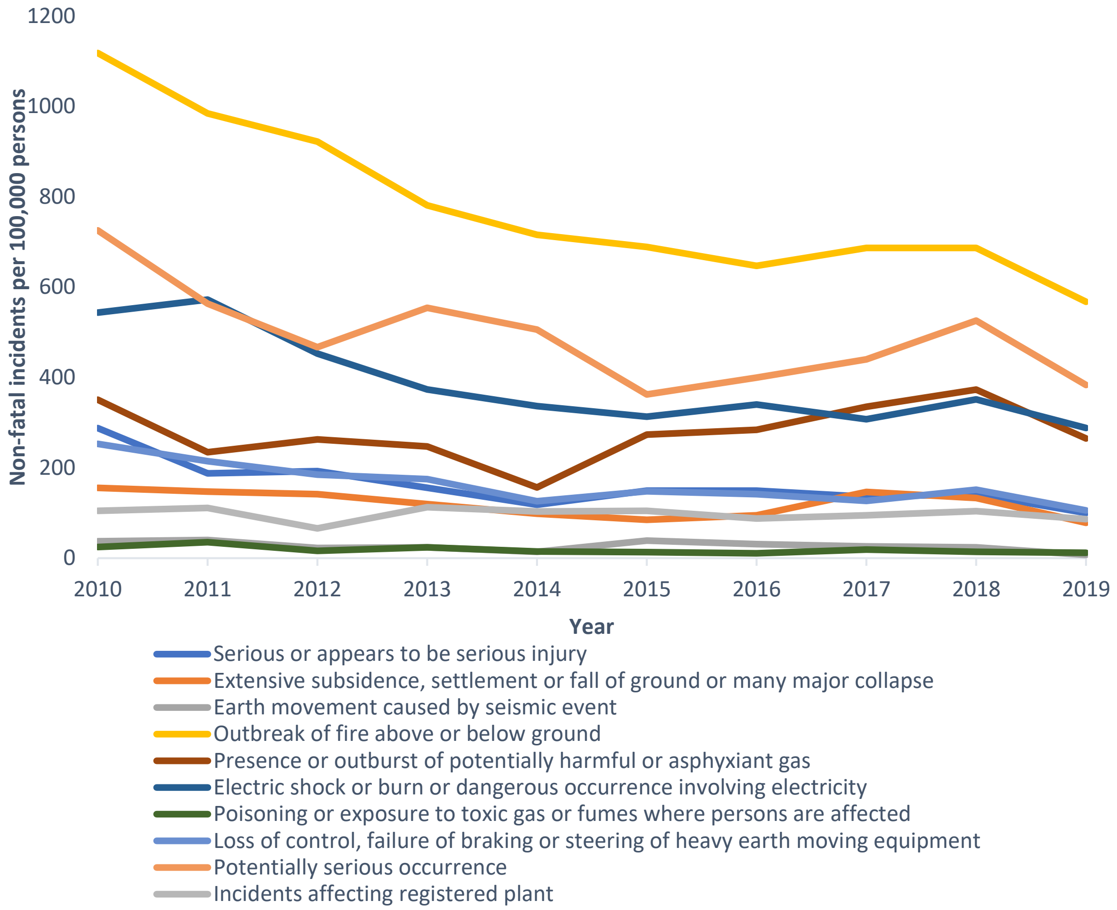


Figure 2.9: Non -fatal incident rates in Western Australian mining & exploration (2010 – 2019) normalised per 100,000 persons (Department of Mines Industry Regulation and Safety, 2019).

to ≈2200 in 2016. Incidents then increase to ≈2500 in 2018, before falling to a minimum of ≈1900 per 100,000 employees in 2019. These were mostly attributed to: (1) a fire outbreak at or below surface; (2) a potentially serious occurrence; (3) an electric shock or burn; (4) an outburst of potentially harmful or asphyxiant gas; (5) a serious injury; and (6) a loss of control of heavy earth moving machinery. The areas showing the greatest proportional improvement are: (1) earth movement due to seismic events (80.8%); (2) a (non-specific) serious injury (65.2%); (3) a loss of control of heavy earth moving machinery (58.2%); (4) poisoning or exposure to toxic gas (51.0%); and (5) subsidence or fall of ground (49.7%) (Figure 2.9). This may indicate a greater proportional improvement in safety measures for ground control, heavy mobile machinery, and site ventilation. Categories such as earth movement due to seismic events are a natural occurrence and cannot be systematically forecast. Years with a significant level of seismic activity will inevitably lead to more earth movement incidents, so mining operations can only mitigate the potential damage caused by earthquakes. (Department of Mines Industry Regulation and Safety, 2019).

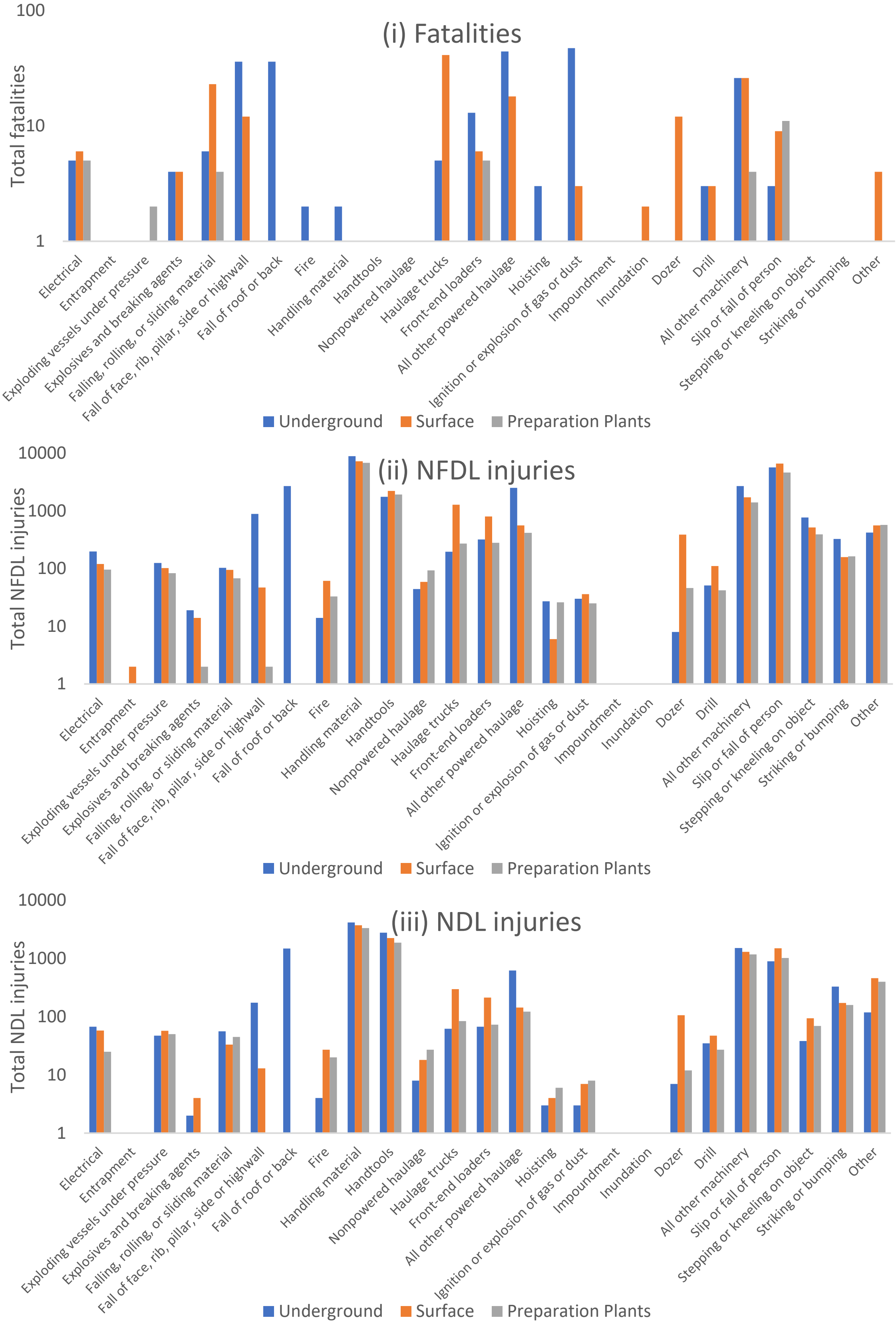


Figure 2.10: (i) Fatalities, (ii) non-fatal days lost (NFDL) injuries, & (iii) no days lost (NDL) injuries in US mines of all commodity types (2006-2019) (Mine Safety and Health Administration, 2020a).

Figure 2.10i-iii present the number of fatalities, non-fatal days lost (NFDL) & no days lost (NDL) injuries occurring in US mines categorised into one of 25 primary causes and organised by area of operation. The most common causes of fatalities occurring underground are a roof or back fall; face, rib, pillar, side or highwall fall; front-end loaders and other forms of powered haulage; and a gas or dust explosion. At surface, haulage trucks, dozers and other machinery cause most fatalities, though in preparation plants, slips & falls and electrical work are most lethal. NFDL and NDL injuries tend to follow similar patterns in terms of the number of injuries sustained and their site location. Slips & falls, handling materials, handtools and site machinery posed the highest risk of injury to mine workers, with these 4 causes comprising 76.9% of the total recorded NFDL injuries, and 81.6% of recorded NDL injuries (Mine Safety and Health Administration, 2020a).

While it is not possible to quantify the extent of data manipulation, or case management, across the regions investigated, some observed trends may be exaggerated due to individual companies or geographical areas adversely influencing safety targets. As Dekker (2018) describes, "the history of lost-time injuries (LTIs) mimics that of taxable windows in houses", referring to window taxes introduced in England in 1696 which resulted in newly constructed houses containing less windows in order to avoid tax at the cost of resident health and wellbeing. Hence, the true safety performance within and across these 3 major mining regions may diverge from the trends seen in the data from 2008 to 2017, as incentivised OSH targets drive behaviours that allow safety data to be selectively recorded to the detriment of worker health and safety.

2.6 Inappropriate practices for safety administration in high-risk industries

Heinrich and Bird pioneered the accident triangle under the common-cause hypothesis which demonstrated that by reducing the number of non-fatal accidents in a workplace, the number of fatalities proportionally decrease (Heinrich, 1931). The model has been scrutinised and evaluated by multiple industrial and academic sources (Bellamy, 2015; CSB, 2007; Dekker, 2018; Hopkins, 2001; Wright and Van Der Schaaf, 2004) due to proportional inconsistencies between the three consequence levels in the Heinrich/ Bird triangle (injuries and fatalities, damages, and near misses) and the actual measured proportions. Wright & van der Schaaf (2004) analysed accident data

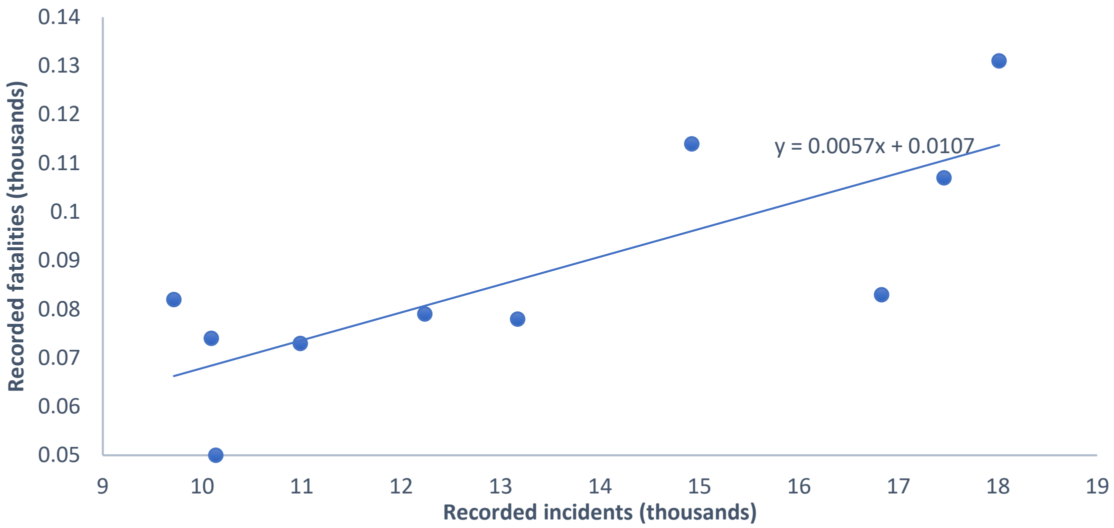


Figure 2.11: Linear regression of non-fatal incidents and fatalities in EU from 2008-2017 (Eurostat, 2020).

from the UK railways under the confidential incident reporting and analysis system (CIRAS) and its 21 cause taxonomy. The relative proportions between the three consequence levels outlined in Heinrich's triangle were calculated for each cause, with three of the 21 CIRAS causes displaying vastly different proportions in fatalities & injuries, damages, and near misses. Saloniemi & Oksanen (1998) focused on the direct relationship between fatalities and non-fatal incident frequency in the Finnish construction industry from 1977 to 1991, during a period with no significant changes to compensation procedures or data collection methods. Where a Heinrich/ Bird relationship is expected to be perfectly linear and positively correlated, the results of the Finland study showed a negative regression indicating that with less incidents in a given year, proportionally more fatalities would occur, which highlights "the specific nature

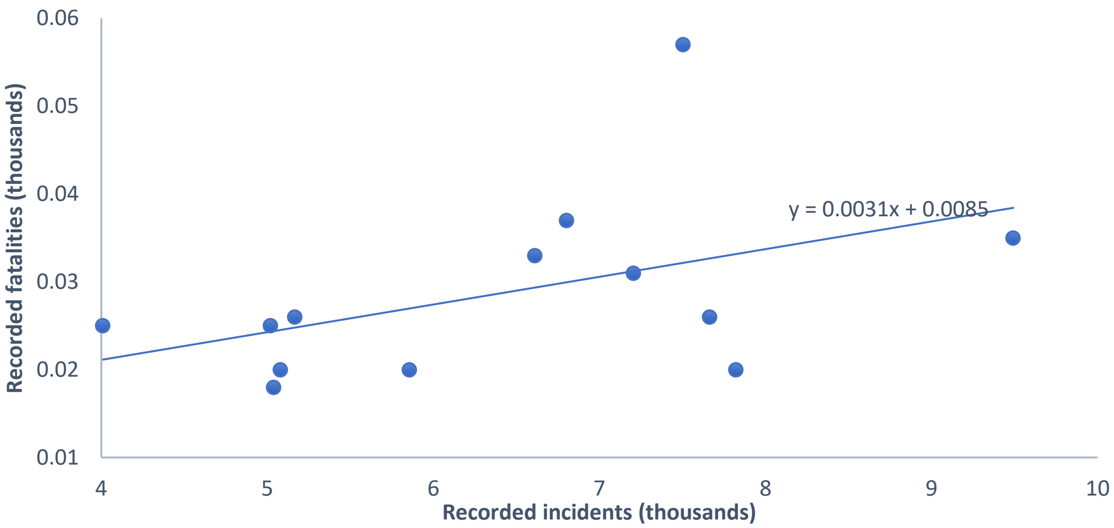


Figure 2.12: Linear regression of non-fatal injuries, including NFDL & NDL, and fatalities in the USA from 2008-2020 (Mine Safety and Health Administration, 2020a).

of fatal accidents, their own distinctive logic and their own causes" (Saloniemi and Oksanen, 1998).

Figures 2.11 and 2.12 describe the relationship between recorded incidents and fatalities using performance data from European Union nations and the USA. The analytical scope includes underground and surface mining environments, preparation and processing plants, as well as associated independent shops, yards and offices. They illustrate a relative lack of correlation between the two variables, despite an apparent positive trend in each chart (Eurostat, 2020; Mine Safety and Health Administration, 2020a). Due to uncertainty associated with secondary data from Eurostat and MSHA respectively, the accuracy of the statistics as a reflection of the collective safety performance of the EU nations and the USA cannot be verified. This interpretation is also not representative of the broader global perspective due to selection bias towards developed nations with established extractive industries which have the resource base to provide publicly accessible safety data.

Despite the Heinrich and Bird hypothesis that more numerous non-fatal incidents leads to more fatalities, the causal patterns observed are unclear due to the lack of available information linking common causes of incidents and fatalities in extractive occupations. By solely demonstrating an ability to administer performance through safety data measurements and records, the capacity to perform effective safety management of operational risks may be limited. Safety administration through measurement of failure types under the Heinrich & Bird model for performance maintains disproportionate emphasis on human influences and error as key contributing factors. Increasing attention is being paid to how system design and operability affects the ability for personnel to safely carry out their work. An approach that focuses on system resilience is process safety management, defined as a disciplined framework for protecting and maintaining the integrity of operating systems and processes through the control of unwanted energy manifesting from physical causal pathways (Aldrich et al., 2015; Stefana and Paltrinieri, 2020). By adopting a process safety approach, the means by which the system can let down the human operator can be understood and actioned, rather than how the human operator can let down the system as conventionally deliberated by occupational safety.

Table 2.2: Comparison of established responsible mining initiatives relevant to OSH from 2012-2020 (EBRD, 2014; Equator Principles Association, 2020; ICMM, 2018; IFC, 2012; IRMA, 2018; UNDP, 2014).

Name	Main Topics Covered
Key: PS- Performance Standard, PR- Performance Requirement, P- Principle, S- Standard.	
IFC Performance Standards (January 2012)	PS1: Assessment & Management of Environmental & Social Risks & Impacts; **PS2: Labour & Working Conditions**; PS3: Resource Efficiency & Pollution Prevention; **PS4: Community Health, Safety & Security**; PS5: Land Acquisition & Involuntary Resettlement; PS6: Biodiversity Conservation & Management of Living Natural Resources; PS7: Indigenous Peoples; PS8: Cultural Heritage.
UNDP Social & Environmental Standards (December 2014)	P1: Human Rights; P2: Gender Equality; P3: Environmental Sustainability; S1: Biodiversity Conservation & Sustainable Natural Resource Management; S2: Climate Change Mitigation & Adaptation; **S3: Community Health, Safety & Working Conditions**; S4: Cultural Heritage; S5: Displacement/ Resettlement; S6: Indigenous People; S7: Pollution Prevention & Resource Efficiency.
EBRD Performance Requirements (June 2017)	PR1: Assessment & Management of Environmental & Social Impacts; **PR2: Labour and Working Conditions**; PR3: Resource Efficiency, Pollution Prevention & Control; **PR4: Health and Safety**; PR5: Land Acquisition, Resettlement & Economic Displacement; PR6: Biodiversity Conservation & Sustainable Management of Living Natural Resources; PR7: Indigenous Peoples; PR8: Cultural Heritage; PR9: Financial Intermediaries; PR10: Information Disclosure & Stakeholder Engagement.
IRMA Standard for Responsible Mining (June 2018)	Social Requirements: 1) Fair Labour, **2) OSH**, **3) Community H&S**, 4) Mining & Conflict-Affected or High-Risk Areas, 5) Security Arrangements, 6) Artisanal & Small-Scale Mining, 7) Cultural Heritage. Environmental Requirements: 1) Waste and Materials Management, 2) Water Management, **3) Air Quality**, **4) Noise and Vibration**, 5) Greenhouse Gas Emissions, 6) Biodiversity, Ecosystem Services and Protected Areas, 7) Cyanide Management, 8) Mercury Management.
ICMM Performance Expectations (November 2018)	P1: Ethical business practice, corporate governance & transparency; P2: Sustainable corporate strategy & decision-making; P3: Human rights, cultures, customs & values of employees & communities; P4: Risk management strategies & stakeholder risk perceptions; **P5: Occupational health & safety performance**; P6: Environmental performance, energy & climate change; P7: Biodiversity & land-use planning; P8: Responsible design, use, re-use, recycling & disposal; P9: Social performance & community development; P10: Proactive engagement of key stakeholders, with effective reporting & verification.
The Equator Principles IV (June 2020)	P1: Review & Categorisation; P2: Environmental & Social Assessment; P3: Applicable Environmental & Social Standards; P4: Environmental & Social Management System & Equator Principles Action Plan; P5: Stakeholder Engagement; P6: Grievance Mechanism; P7: Independent Review; P8: Covenants; P9: Independent Monitoring & Reporting; P10: Reporting & Transparency.

Given the heightened sensitivity of communities towards mining, an increasing number of companies are seeking independent accreditation as a means of assurance when engaging with local stakeholders throughout a mining project. Several responsible mining initiatives with sufficient accreditation value highlight OSH as a key consideration for companies intending to be verified as ‘responsible’ (see Table 2.2), which have been developed by financial corporations, and international councils & associations comprising NGOs, mining companies, manufacturers and stakeholders. However, the emphasis placed on health & safety varies with each initiative depending on the scope and target audience, from general OSH (Equator Principles Association, 2020;

ICMM, 2018) to labour & working conditions (EBRD, 2014; IFC, 2012; UNDP, 2014), air quality, noise and vibration (IRMA, 2018).

While these initiatives provide comprehensive guidelines for companies aspiring for accreditation, they fundamentally remain a tick-box compliance tool that varies considerably in line with local laws & regulations. Given the extent of duplication and generalisation of OSH across various guidelines, safety procedures and activities that ostensibly demonstrate commitment to safety but do not truly contribute towards improving OSH may accumulate, referred to as safety clutter (Rae et al., 2018). For meaningful progress to be made in approaching zero harm, consideration of safety culture is vital. But, difficulties emerge due to its inherently qualitative and multi-faceted structure, hence the requirement for culture maturity modelling as a method of 'quantifying' organisational safety culture (Anglo American Plc, 2010; Foster & Hoult, 2011; 2013; IRM, 2011; The University of Queensland, 2008; Figure 2.3).

Dejoy (2005) compared behaviour change with cultural change in terms of their characteristics, and considered how they may be integrated to manage OSH more effectively. Behaviour-based safety was defined as a continuous data-driven process for modifying worker behaviours, resulting in victim-blaming by focusing only on immediate causes. Conversely, culture change is a self-sustaining intuitive approach which is subjective but also more participatory than behaviour-based safety. Cooper (2000) argues that current research has not fully considered the importance of establishing appropriate goals before attempting to make improvements in safety culture. Instead, safety culture should be placed in a goal-setting paradigm in order to provide more clarity regarding the progress of culture shift within an organisation. By setting out achievable objectives from the outset, the process of attaining high level culture can be accelerated. The objective of 'zero harm' must be driven by operational resilience with complex interactions and mutual coordination to improve working conditions and deter manipulatory behaviours (Dekker, 2014a).

2.7 Pathways to effective H&S management through latent failures

Administration of safety creates risk of incorrect interpretations of performance, despite the inherent preoccupation with failure that is required to make progress in OSH. Qualitative data from accident investigations illustrates the specific context that is absent from quantitative statistics, permitting consideration of the specific event chains that led to failure. Application of the Ten Pathways model to mining incidents in New South Wales, Australia resulting in fatalities and injuries indicated several recurring pattern failures, including engineering, inadequate risk assessments, OSHMS defects, overreliance on safety routines, and economic pressures. Regulatory incident investigations of single fatalities or injuries tend to bias towards individual behaviours than investigations of multiple fatality accidents, which don't adequately address the root causes. Pattern failures tend to interact with other causal factors, particularly economic drivers such as equipment acquisition, selection of high-level controls, and reward pressures, which influence high level decision-making (Jackson, 2023).

Table 2.3 summarises the active failures or immediate causes of fatal incidents subcategorised by primary activity when the incident occurred. Table 2.4 summarises the underlying latent failures contributing to the occurrence of each fatality subcategorised by the activity being conducted before the incident. Fatalities associated with vehicle operation and maintenance are linked to rule violations while driving, insufficient training, and inadequate policies & procedures regarding vehicle/ road maintenance. Fatalities during underground activity are mostly attributed to inadequate roof and ground support, pinning or striking accidents due to inadequate warnings, and inappropriate working practices for cutting, drilling & bolting. Root cause analysis by MSHA accident investigation teams determined the latent failures that directly or indirectly contributed to each fatality. The cultural and procedural factors that contributed most to single-person fatalities in US mining based on MSHA reports include inadequate unverified policies and procedures, poor task-specific training, lack of PPE, inadequate site safety procedures, and unfit safe working practices. From a study by Simpson (1997), behaviour-oriented solutions may be applied to address latent failures, including accurate and practical rules and procedures, effective training, adequate logistic support for workforces, and safe and operable working conditions.

Table 2.3: Activity carried out at time of fatality, with corresponding active failures and immediate causes from accident investigations from 2009-2020 (Mine Safety and Health Administration, 2020b).

Activity at time of fatality	Active failures/ Immediate causes
Pre-shift examinations and set-up	Loss of control of vehicle; Incorrect diagnosis; Seriously injured by exposed moving parts; Loco derailment.
Preparing to load or unload truck and/or trailer	Pinned between machinery; Failure of vehicle controls or components; Impeding devices not provided during dumping; Fall from height (no harness); Dust inhalation.
Driving haulage truck/ front-end loader/ maintenance vehicle	No seatbelt worn while in vehicle; No communication between driver and nearby workers; Loss of vehicle control on haul road or grade; Fall from height.
Continuous mining machine (CMM) operation/ service	Structural failure of roof and/or support ribs; Pinned or trapped by CMM during repositioning; Operational error during mining, tramming, or maintenance.
Section foreman/ Plant operator	Structural failure of roof, face, or side; Fall from height; Release of suspended load; Unsafe operation.
Driller/ Roof bolter/ Dozer operator	Structural failure; Roof or side collapse; Equipment failure during drill maintenance; Operator error during manoeuvring; Fall from height; Pinned during tramming.
Beltman	Trapped in conveyor belt mechanism; Electrocution by exposed wiring; Release of overhead suspended load.
General maintenance	Equipment/ machinery failure; Release of suspended load; Ignition of flammable surfaces; Fall from height.
Electrical maintenance	Electrocution by exposed wiring/ cables; Pinned by falling equipment or supports; Trapped by machinery.
Service mechanic	Trapped/ struck by unsecured mobile equipment; Fall from height; Loss of control of service vehicle; Burst hydraulics due to overpressure; Substandard visibility.
Miner/ Labourer	Struck or pinned by mobile equipment or vehicle; Loss of vehicle control; Injury while riding conveyor; Fall from height; Struck by concrete hose; Structural failure.

The immediate causes of fatal workplace accidents highlighted in Table 2.3 may be attributed to substandard behaviour, while the common latent failures shown in Table 2.4 are influenced primarily by “top-down” cultural shift. Management teams with pervasive culture deficiencies will encourage widespread negative behaviour, leading to violations and lapse errors as ergonomically inadequate workspaces are not rectified. Cultural maturity is a key influence on how and when latent failures manifest, leading to an injury or fatality. OSH strategies implemented at a national level are reviewed to examine their impact in improving safety performance within Europe and Australia respectively.

Table 2.4: Activity/occupation carried out at time of fatality, with corresponding latent failures and root causes gathered from accident investigations dated 2009-2020 (Mine Safety and Health Administration, 2020b).

	Activity at time of fatality (Hazard)									
Latent failures/ Root causes	Pre-shift examinations and set-up	Loading & unloading truck or trailer	Driving haulage truck/ front-end loader	Continuous mining machine operation/ service	Section foreman/ Plant operator	Driller/ Roof bolter/ Dozer operator	Beltman	General/ electrical maintenance	Service mechanic	Miner/ Labourer
Inadequate policies and procedures	✓	✓	✓		✓		✓	✓	✓	
Lack of task-specific training	✓		✓		✓	✓		✓	✓	✓
Ineffective/ poor PPE		✓			✓	✓	✓	✓	✓	✓
Violation of procedures by workers and/ or management	✓	✓	✓	✓	✓					✓
Safe working practices not fit for purpose			✓	✓		✓		✓	✓	✓
Ineffective safety guards/ barriers	✓	✓			✓		✓	✓		
Poor site communication		✓				✓		✓	✓	✓
Substandard equipment/ route maintenance	✓	✓	✓						✓	
Poor quality risk/ hazard assessment	✓					✓				✓
Ergonomically inappropriate equipment design		✓		✓		✓				
Inadequate structural support in high-risk workspaces				✓		✓				✓
Misidentification of geological conditions in high-risk areas of mine				✓		✓				✓
Ineffective visual/ audible warning systems				✓				✓		✓
Lack of effective site supervision						✓				

A lack of specificity in conclusions regarding mining accidents (e.g., violations of procedures, lack of effective supervision) influences the risk of misjudgement regarding the behaviour of frontline workers in hindsight based on observations from MSHA investigators. Elements of 'Old View' are observed in the analysed MSHA reports with frequent references to human error, where in truth the immediate and root causes are symptoms of deeper organisational issues. If action is taken with the 'New View' approach, then investigation outcomes can be more effective for resolving deeper issues that lead to 'human errors'. Some reports appear to place blame on organisational members who have breached rules and regulations while the potential root cause(s) are given inadequate attention. For example, an accident may be blamed on a failed component rather than incorrect use or lack of maintenance, which may arise from poor management or weak safety culture. This highlights the importance of a "New View" attitude for avoiding blame until the latent organisational failures have been detected. Similarly, "poor site communication" does not explain whether communication issues are due to incompetence which requires retraining, or whether communication systems are unfit for purpose requiring engineering or administrative solutions facilitated by the organisation.

The European Commission (EC) initiated a strategy to improve OSH regulations through "comprehensive legislation and policy actions implemented by the Union, Member States and stakeholders" (European Union Commission, 2014), which directly addresses 'inadequate policies and procedures' as a latent failure in mining. The 2007-2012 EC strategy framework for OSH achieved its primary objectives by reducing accident incidence rate (Figure 2.6) and implementing up-to-date OSH legislation. Small and medium-sized enterprises (SMEs) experienced difficulties in meeting regulatory requirements due to bureaucratic demand, and local impact on SMEs was unclear. Hence, methods of OSH management need to be appropriately scaled for SMEs to reduce fatal and non-fatal accident rates (European Union Commission, 2014). In line with the aim to reduce occupational diseases, the number of 'Poisonings & Infections' in EU operations decreased from 58 in 2008 to 22 in 2012, a 62% reduction over 5 years. The EC's key objectives from 2014 were to: (a) align national strategies and influence decision-making processes through policy co-ordination and funding; (b) ensure SMEs are compliant with EC legislation using suitable guidance; (c) simplify and enforce legislation within all member states through routine inspections; (d) support an ageing workforce and address their specific risks; and (e) enhance the Eurostat databases.

The European Agency for Safety and Health at Work (EASHW) examined how the EU strategic framework influenced the individual national strategies for the member states. They identified that updated national strategies comprised of realistic goals with specific monitoring and evaluation methods, and that the strategic direction was valuable to stakeholders as they guide collaborative OSH discussions and activities (Schmitz-Felten et al., 2018). Collaboration between EU member states on OSH strategy enables extensive knowledge sharing between countries with variable experience in mining development, to establish how regional objectives can be achieved most efficiently. Safety data repositories such as Eurostat can motivate continuous improvement of national mining safety practices through the publication of injury and fatality statistics by member state. The EC could also benefit from producing publicly accessible incident investigation reports, primarily to highlight latent failures alike to those identified by MSHA as directly or indirectly contributing to US incidents (see Table 2.3). From this, future national strategies can be developed that directly target the specific safety culture deficiencies within each member state and enable sharing of best practice for mining operations.

Safe Work Australia (SWA), a government statutory agency developing OSH policy, launched the Work Health and Safety Strategy 2012-2022 which set out 3 major national targets to be met by 2022: (a) 20% reduction in worker

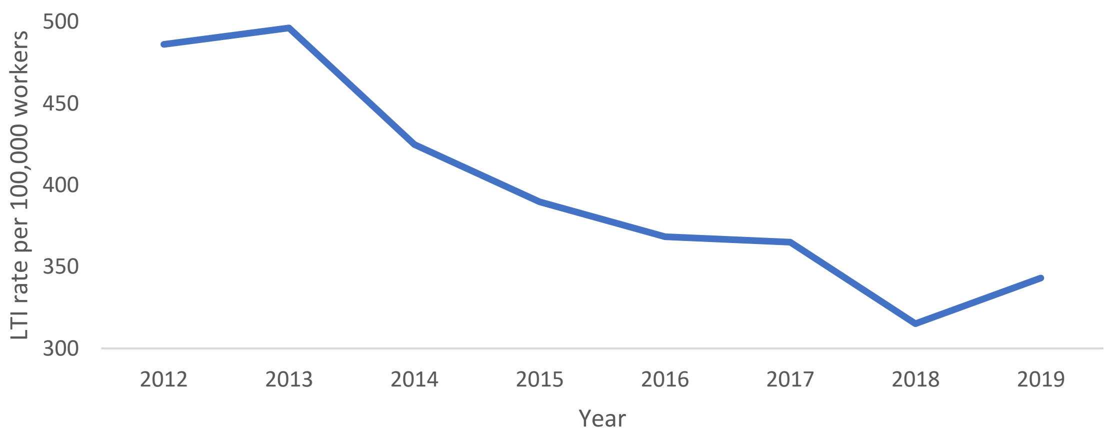


Figure 2.13: Lost time injury (LTI) rate per 100,000 workers in Western Australian mining operations (Department of Mines Industry Regulation and Safety, 2019).

fatalities; (b) 30% reduction in LTI rate; and (c) 30% reduction in LTI rate caused by musculoskeletal disorders. SWA also established the primary action areas that should be addressed at a national level: (1) healthy and safe by design, (2) supply chains and networks, (3) health and safety capabilities, (4) leadership and culture, (5) research and evaluation, (6) government, and (7) responsive & effective regulatory framework (Safe Work Australia, 2012).

'Healthy and safe by design', 'health and safety capabilities' and 'leadership and culture' are likely to have the most significant impact on LTI rates, as they have implications for the working environment and individual behaviours. Some categories presented in Figure 2.9, including electric shocks & burns, outbreak of fire and loss of control of heavy-duty equipment, appear to be linked to these action areas. Improved equipment design based on worker feedback as well as specialist training for equipment operators may reduce slip & lapse errors. Despite the strategic focus on agriculture, construction and transportation, the objectives and principles can be applied generally to OSH in mining. Reductions in fatality (Figure 2.5) and LTI rates (Figure 2.13) may be attributed to increased resources for safety development in line with expansion of Western Australian mining in the past 20 years. LTI rates decreased by 29.4% within the strategy period, indicating that the second objective in the context of Western Australian mining has almost been achieved with 3 years remaining at the time of writing.

Human error in its various forms (e.g., procedural violations, inadequate supervision) is not the root cause of incidents, but a symptom of systemic organisational problems that require more fundamental 'hard fixes' (Dekker, 2014a). Conclusions drawn from incidents investigations such as those from the MSHA, as well as the national safety strategies, should instead be used to locate deeper issues, or perhaps conceptual regularities in human behaviour, that have manifested these symptoms. Hence, thorough examination of fatality investigation reports shows some of the causal linkages between latent failures in mining occupations that most commonly cause harm. Further work is required to characterise organisational safety performance in order to facilitate direct comparison between safety culture and safety performance. Hammond et al. (2023) correlated 29 performance indicators with workforce safety culture perceptions for a US nuclear waste cleanup contractor, and found that while strategies for culture improvement can bolster organisational performance, they may contribute to degradation of safety if strategies are overutilised. Therefore, key performance indicators and metrics must be effective for measuring specific facets of safety performance and informing action (Hammond et al., 2023).

2.8 Concluding statement

Responsible mining initiatives lack specific guidance on safety culture for continuous improvement in OSH standards, through mitigation of latent failures and organisational collaboration in creating solutions. This work, which has adopted a preoccupation with past failures, shows that mining safety performance is influenced by the underlying cultural factors that originate from higher organisational levels and manifest either as technical failures or human errors. Placing these findings in context permits further advancement of health & safety standards, which can influence public perception of the extractives sector as demand for raw materials increases during the green transition. Public trust in mining is achieved most effectively by companies ‘doing what they do in the best way’, requiring a balance of regulatory intervention and practitioner-sourced human expertise that is specific to local context.

This chapter presented findings from analysis of safety performance data and fatality reports from EU nations, USA, and Western Australia to determine the latent failures that commonly contribute to individual fatalities and non-fatal injuries with similar causal patterns in the mining industry. The global trends in safety performance, which is dependent on the accuracy and reliability of recorded primary OSH data, indicate that while all show improvement on average from 2008 to 2017, Western Australia has set higher standards of safety than the EU and USA (Figure 2.5). Implementation of high-quality safety regulations aligned the performance of the 4 major EU regions (Figure 2.6), with specific injury types also decreasing since 2008 (Figure 2.8).

Preoccupation with failure emphasises the importance of failure analysis in high reliability organisations for organisational learning. Analysis of MSHA accident investigation reports indicate that most fatalities, regardless of activity or location, are influenced by inadequate policies & procedures, ineffective SWPs, poor quality risk assessments, inadequate maintenance, and limited training.

These can be linked to a company's safety culture, as it is the prevailing perceptions of safety that influence how hazards are managed and mitigated. While immediate causes of fatalities and LTIs may be attributed to substandard behaviour, latent failures contributing to fatalities are affected primarily by top-down cultural shift. The prevalence of procedural violations from both workers and management is an indication of the role that individual attitudes have on safety performance, as evidenced from analysis of MSHA reports. Further research is needed to clarify the extent to which individual behaviours contribute to safety culture in mining.

This study focused primarily on modern, regulated operations of both open-pit and underground type, due to the consistency of their safety reporting. In comparison, underregulated artisanal operations place the responsibility for failures primarily on frontline workers. Modern safety culture approaches evolved from the manufacturing and nuclear sectors, but the lessons learnt from mining can be used to further advance safety cultures across sectors. A strong safety culture can pervade an organisation's attitude towards safety, leading to action taken sooner on safety issues such as damaged electrical components or uncontrolled ignition sources in confined areas, which should involve practitioners and safety professionals. Building on the 'New View' of safety, that incidents occur due to organisational factors and conditions (Dekker, 2014a), uptake of a 'New View of Responsible Mining' theoretically allows organisations to self-reflect and resolve system deficiencies, instead of placing responsibility for failures on frontline workers as a result of hindsight bias.

3 Occupational safety considerations for optimising small-scale SOSO mining operations

3.1 Introduction & Approach

Current industry best practice is tailored to large-scale ‘conventional’ operations with substantial footprint and workforces, requiring supervision and training for efficient knowledge transfer. Legislative and regulatory improvements have contributed to reduced fatality and injury rates since the earliest disasters such as the Monongah explosion in 1907 (Britannica, 2020). However, despite a century of accrued regulation and experience, errors still occur with severe consequences. Development of a mature safety culture is vital for mitigating near misses, LTIs and fatalities, through a collective commitment to improving safety at all levels. The influence of latent failures on fatal and non-fatal incident occurrence is directly linked to prevailing safety culture. However, the study focused on ‘conventional’ regulated mines in the US, which differs from small-scale mining (SSM) by workforce size, production rate, and temporal duration (Sidorenko et al., 2020).

Traditional large-scale mining (LSM) operations require low-grade, high-tonnage mineral deposits for economic viability, depending on commodity type. While this scale suits base metals (i.e., Iron, Copper), it lacks agility to react to market shifts, is energy-intensive, and produces excessive waste with adverse ecological impacts. Modern technologies have enabled higher concentrate yields, but low concentration biproducts are often discarded due to processing constraints or low profit margins from secondary processing. Many high-grade, low-tonnage mineral deposits, particularly in Europe, are not exploited despite the presence of critical materials for the manufacturing of green technologies (BRGM, 2016). Demand for an expanding range of critical commodities will require innovative solutions with complex flowsheets and interconnected process risks. A new paradigm of SSM with containerised mining and processing solutions using a ‘switch-on, switch-off’ (SOSO) approach, is conceptualised and developed in the EU-funded Horizon 2020 IMP@CT Project. This approach aims to increase extraction and processing efficiency at low throughput, reduce environmental and social impacts relative to ‘in-situ’ mining, mitigate injuries and fatalities, and provide greater resource security in Europe. The aim of this chapter is to explore the characteristics of, and system processes that operate in, a SOSO SSM operation to deduce the important safety and training preparations before mining commences.

This chapter adopts a holistic approach from the functional outcomes of IMP@CT to investigate the critical safety considerations for SOSO SSM, using ‘conventional’ in-situ mining to inform best practice of the former. Conducting research within an EU-funded project provided an opportunity to think about, and implement, health and safety in a modern best practice context from the planning stage onwards for SOSO SSM. The safety by design, ergonomics and operability of the containerised equipment developed for IMP@CT were reviewed and advised upon prior to manufacturing. The health and safety risks in all unit processes, or ‘nodes’, of the pilot test site were analysed and evaluated in the context of existing health and safety tools. Best practice procedures and frameworks for optimising performance in SSM operations was placed in context of the three intervention points deduced from observations of the containerised system during pilot testwork in Olovo, Bosnia & Herzegovina.

3.2 Methods

Fatality and injury trends in the modern regulated mining industry, as described in Chapter 2, inform the focal areas for establishing safety best practice which are applied to an SSM context. A timeline of legislation in mining developed by the UK and US industries and their respective governments is constructed from the mid-19th century to the late 2010’s to determine the sequence of safety improvements introduced over the last 170 years in response to high fatality rates and major mining disasters.

After defining the characteristics of modern technological small-scale mining, a literature review of safety by design, ergonomics and operability in a conventional ‘in-situ’ mining context provides insight into the requirements of modular equipment prior to direct observations of pilot designs with OEMs during the planning phase. Field studies were conducted at the IMP@CT pilot testwork site in order to directly observe the safety by design, ergonomics, operability, and overall safety risk associated with the SOSO SSM system upon

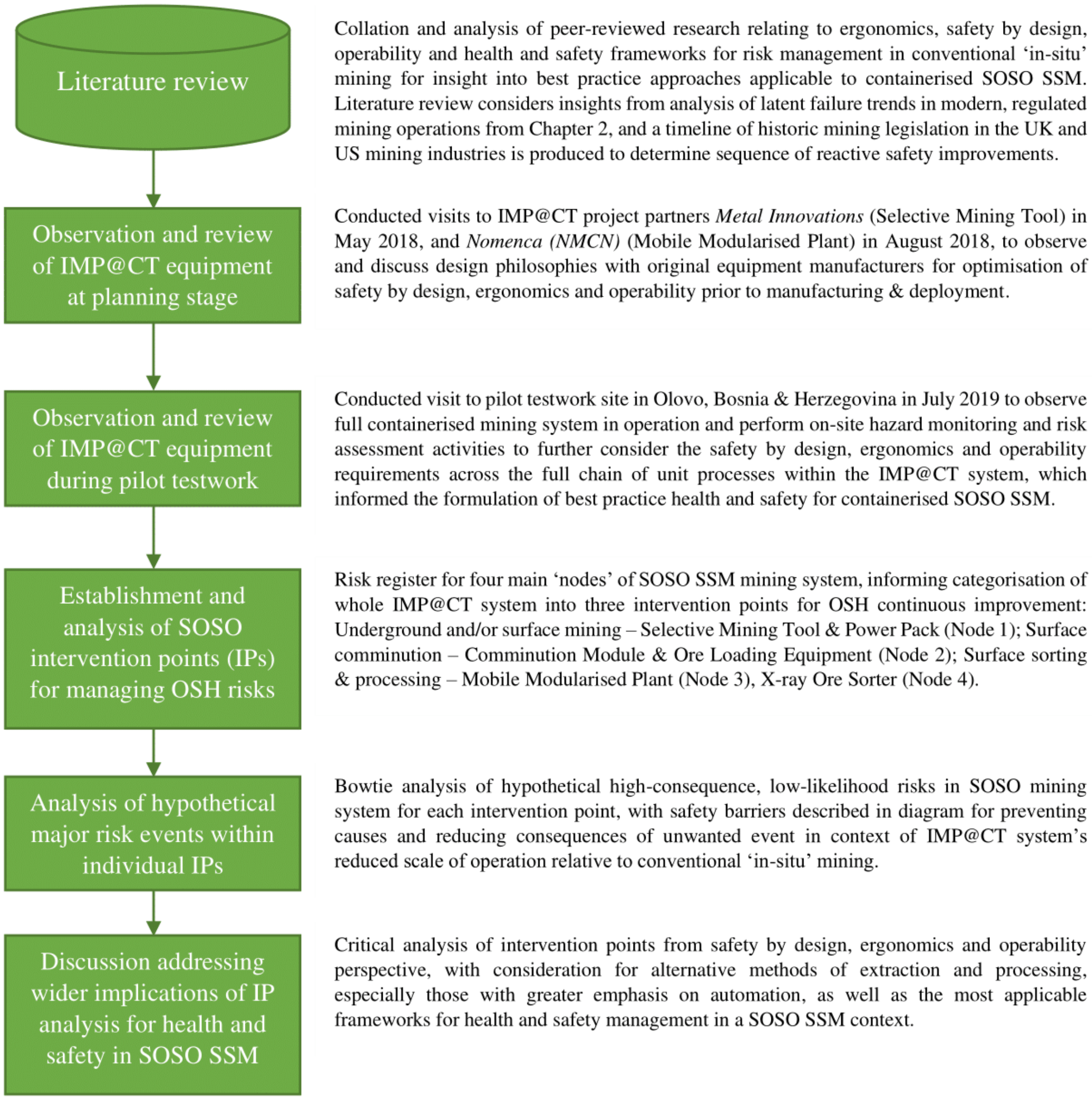


Figure 3.1: Methodology flowchart outlining process of data collection from fieldwork observations and literature review associated with chapter 3 study.

deployment, which facilitated the formulation of best practice health and safety approaches. A non-exhaustive risk register provided a foundation from which to evaluate SOSO mining safety as a series of intervention points, each of which represents an aspect of the complete pilot SSM system, formed of one or more 'nodes' which represent the system's primary unit processes.

As outlined in Figure 3.1, the intervention points were devised based on the level of automation adopted in order to reduce cross-duplication of health and safety procedures and ensure specialised training can be administered in only the specific areas where it is required (i.e., Underground and/or surface mining, surface comminution, and surface sorting & processing). Bowtie analysis using BowTieXP software is conducted for one hypothetical top event per intervention point in order to compare the safety requirements of the SOSO SSM mining paradigm with conventional approaches and develop best practice of the former. Critical analysis and evaluation of the three intervention points from the perspectives of safety by design, ergonomics and operability will be conducted, while addressing alternative approaches for SSM operations in terms of their level of automation. A discussion regarding the applicability of existing health and safety frameworks and techniques to SOSO SSM extraction will place emphasis on the critical approaches required for 'hitting the ground running' with regards to health and safety, due to the short lead time between deployment, commissioning and commencement of operations.

3.3 Defining a new mining paradigm

Moore et al. (2020) discussed the characteristics of a small mineral deposit and explored the relationships between SSM and manufacturing, investment, environment and society. Large-scale extraction targets low-grade disseminated bulk metal ores, with proportionally scaled processing and waste storage. At these vast economies of scale, extraction and concentration of high-grade metals and biproducts is unfeasible due to process flow variability for different commodities. The largest companies globally cannot readily adapt to feasibly extract small, high-grade, complex deposits. Despite their relatively higher grade than bulk commodities, technology metals (e.g., Cobalt, Tungsten, Rare Earth Elements) occupy a smaller market share with reduced turnover and high inherent criticality (Moore et al., 2020).

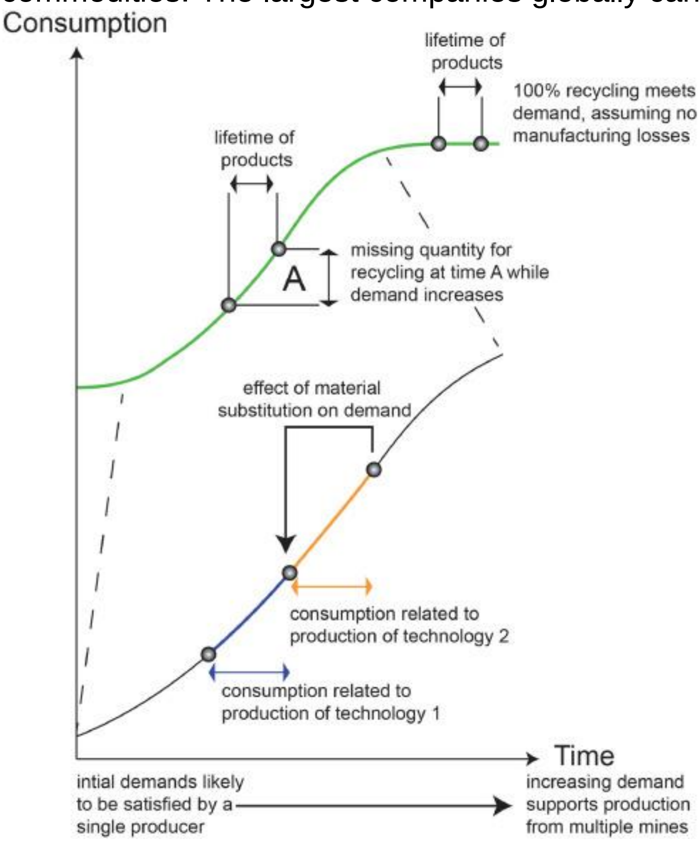


Figure 3.2: Adaptation of Steinbach & Wellmer's (2010) idealised growth curve (Moore et al., 2020).

An adaptation of Steinbach & Wellmer's growth curve (2010) illustrates that recycling and material substitution is not sufficient on its own to satisfy demand, as secondary material contribution is limited by demand growth rate and technological product lifetime (Figure 3.2). Reduced demand influences the number of suppliers of a given commodity, which increases criticality due to supply risk for sectors that are reliant on specific commodities (Moore et al., 2020). Satisfying demand through recycling is impacted by end-of-life recycling and recycled content rates of recoverable metals. End-of-life recycling rates can vary depending on where recycling takes place, and recycled content rates are lower than end-of-life due to reduced availability of scrap metal. Even with 100% end-of-life recycling, assuming demand continues to increase with the same end-of-life/recycled content ratio, primary production would still be necessary to meet demand. Some applications still require high elemental purity, such as Cobalt in Lithium-ion batteries, so primary sources are needed (Upadhyay et al., 2021).

Table 3.1: Features of 'IMP@CT-style' SSM when placed in the context of artisanal small-scale and large-scale mining (Sidorenko et al., 2020).

SSM Characteristic	**Description in relation to ASM and LSM**
Size of workforce as a function of unit area	Can be low compared to ASM and may be slightly higher than LSM, depending on the level of automation. Considered a better metric than company size because potential exists for majors to adopt small operations in certain contexts.
Sophistication of technologies	Higher than in ASM due to the capital start-up costs (CAPEX) for infrastructure, whether portable or otherwise, and the ongoing need for maintenance and fuel. Investment for CAPEX is more readily available to formal mining community.
Rate of production	Significantly higher than in ASM and significantly lower than in LSM. Throughput of an onsite processing plant at a small-scale mine may be between 5 and 50 tonnes per hour.
Small land use	Small-scale mine and adjoining processing facility will provide a greater opportunity to develop integrated land management that includes mining operations, and that facilitates reclamation.
Short temporal duration	Clustered small-scale mining projects are envisaged to be productive for between 2 and 10 years, with individual mine sites considered to operate for between 6 months and 3 years which may or may not be closed or placed into maintenance.
Limited socio-economic impacts	Such as the level of employment, local/regional tax revenues and royalties, will usually accompany small and short-term operations. Thus, the local economy and communities cannot expect large or long-term development contributions.
Occupational health & safety	Higher than in ASM due to formalised safety standards and regulations associated with modern mining & processing technologies, and potentially greater than LSM as a resilient safety culture can be established and maintained from the outset due to reduced workforce size provided that a top-down shift led by higher management is implemented.

Modern technologically advanced SSM was developed in a European mining policy context, in relation to the EC strategy for future mineral resource security. Poor alignment of existing small-scale mining definitions to current European policy constraints informed the development of a new classification for SSM. SOSO SSM is differentiated from artisanal small-scale mining (ASM) and large-scale mining (LSM) by Sidorenko et al. (2020), through consideration of the characteristics relating to these conventional mining paradigms (Table 3.1).

While taking the Eurocentric bias introduced by IMP@CT's focus on European nations and their interests into account, particularly from an EU perspective with the array of project consortium partners, the proposed definition of SSM is:

"Extraction from ore or mineral deposits using low-impact, potentially short-term, small-footprint, regulated mining operations and technologies that are usually not labour-intensive. The approach is suitable for, but not limited to, small ore deposits."

(Sidorenko et al., 2020)

Achieving economic viability with high safety standards in a unique SOSO SSM paradigm requires agility, so technological complexity must be adequately reduced to optimise deployment and commissioning efficiency. SOSO SSM mining was demonstrated within the *IMP@CT* project during an intensive pilot testwork phase in the Balkans between 2018-2020. The selective mining tool (node 1), comminution module (node 2), modular processing plant (node 3), and ore sorting equipment (node 4), as defined in Moore (2021), were operated from shipping containers to increase logistical flexibility and mitigate climatic exposure. To develop suitable OSH standards for SOSO SSM, these nodes will be reclassified into three 'intervention points', or key areas of the system with aligned OSH that can declutter procedures for targeted safety management.

- Underground and/or surface mining – Selective Mining Tool & Power Pack (Node 1).
    - Limited automation; predominantly human controlled.
- Surface comminution – Comminution Module & Ore Loading Equipment (Node 2).
    - Semi-automated; predominantly system controlled.

- Surface sorting/processing – Mobile Modularised Plant (Node 3) & X-ray Ore Sorter (Node 4).
    - Semi-automated; combination of human and system control.

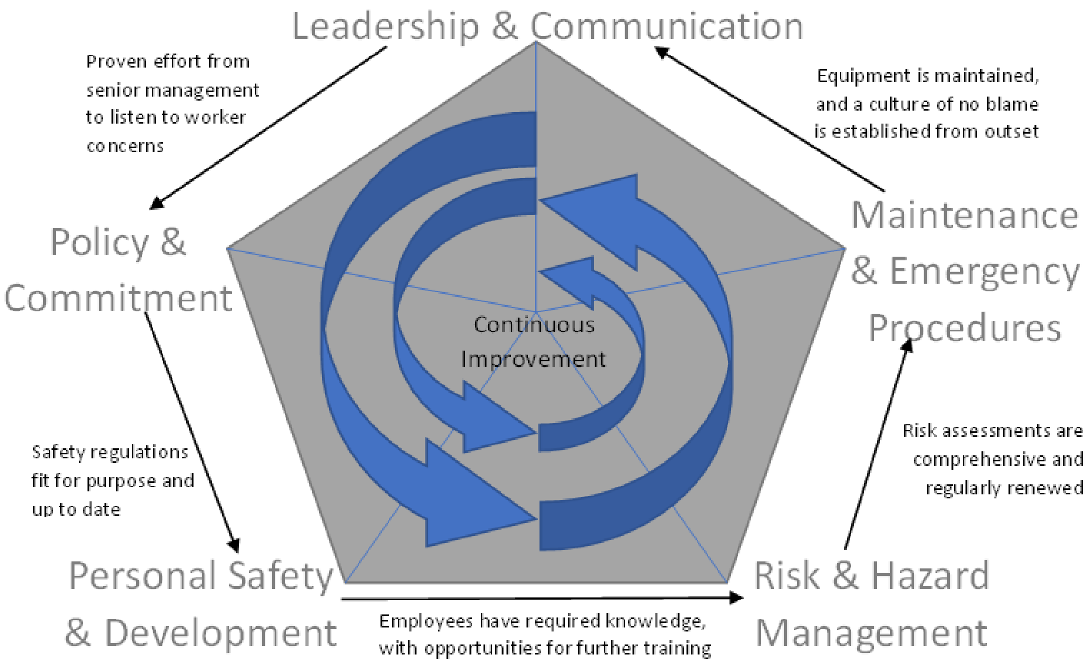


Figure 3.3: Conceptual model for continuous improvement of occupational health and safety standards.

The SOSO pilot testwork system was not labour-intensive, with semi-automated solutions developed to manage elements of the extraction, comminution, and processing units with partial human intervention. Research conducted during pilot testwork (now published in the co-authored manuscript Moore et al., 2021) showed that specialist operators are crucial for responding to sudden geological or operational variability. Implementing novel automation solutions in multiple nodes increases CapEx, with added costs if design retrofits are required. With greater human presence needed ‘at face’ to operate modular equipment, OSH is allocated a higher priority (Moore et al., 2021) with greater attention on safety by design, ergonomics, operability, risk management and training.

Figure 3.3 shows a continuous improvement process that is relevant to culture, including leadership and communication, policy and commitment, personal safety, risk and hazard management, and maintenance and emergency response. On-site observations of the pilot plant and operation directly informed the development of an IMP@CT-specific report: “Policy Statement, Standards and H&S Best Practice for Switch On-Switch Off (SOSO) Mining Operations”. This public deliverable specifically considered the safety by design prior to construction, ergonomic suitability during active operations, and integrated risk and hazard management across all site intervention points (Doyle, 2020).

3.4 Occupational safety regulation, design considerations and training in mining: implications for SOSO SSM

3.4.1 Mining industry safety and regulatory legacy

A large number of US fatalities investigated by the MSHA between 2010-2020 were caused by inadequate policies, task-specific training, unsuitable PPE, and unsafe working practices (see Table 2.3). Responsibility for incident prevention falls primarily on management, and is administered through comprehensive OSHMS (ISO, 2018a), but the resource base required to maintain an OSHMS is not suited to SSM. Latent failures can manifest during project planning and development due to substandard equipment, ergonomically inappropriate design, and ineffective warning systems. Adoption of design philosophies (EMESRT, 2018) during equipment conceptualisation can mitigate the risk of ergonomic and design flaws, and simplify procedural and training requirements (Simpson, 1993). But the clearest improvements in standards have come from administration of legislation and acts in nations with well-developed regulations.

The UK Coal industry saw rapid expansion in operations and employment in the early 19th century during the industrial revolution. The industry remained largely unregulated during this time which led to numerous fatal and non-fatal incidents, most of which were not officially recorded. The Royal Commission produced a report in 1842 highlighting poor working conditions and “human degradation” in coal mines across the UK and called for immediate reform (Royal Commission, 2021). The Mines and Collieries Act was approved by parliament later the same year, prohibiting employment of women and children in underground mines. Despite success in removing women and children from harmful environments, high-risk conditions remained for men who continued to work underground.

> *“Between 1866 and 1919 a miner was killed [on average] every six hours, seriously injured every two hours and injured badly enough to need a week off work every two or three minutes [in the UK Coal Industry].”*
>
> (Ridyard, 2004)

In response to unacceptably high fatality and injury rates in the UK during the late 19th to early 20th century, the government implemented increasingly stringent legislation which improved mining safety rules, increased worker age limits, updated mine inspection procedures, and developed new training and education materials. This illustrates decades of accumulated safety knowledge and progress, but also highlights how numerous reforms generate extensive cross-duplication of regulations and acts (Table 3.2).

Table 3.2: Summary of major legislation implemented in the UK Coal mining industry since 1842 (HSE, 2021; Mine Safety and Health Administration, 2013; UK Parliament, 2021).

Year	Act	Description of legislative amendments
1842	Mines and Collieries Act	Restrictions on the employment of women & children. Permission for appointment of a mine inspector.
1850	Coal Mines Inspection Act	More powers for inspectors in coal mines, with clear instructions regarding duties. Inspectors remained under supervision of Home Office. Amended in 185 with further definition of safety standards.
1860	Regulation and Inspection of Mines Act	Improved safety rules in coal mines. Increased minimum male worker age limit to 12 years old.
1872	Coal Mines Regulation Act	Pit managers required to obtain state certification of training. Miners granted right to appoint their own inspectors. Limits on working hours implemented. More safety rules established.
1881	Mines Regulation Act	Home Secretary permitted to hold inquiries into mine accidents.
1887-1908	Coal Mines Regulation Act	1872 & 1886 Acts consolidated and brought up to date. Cap lamps investigated. Further worker age restrictions. Prevention of underground explosions. Technical education for coal workers. Working hours limited to 8 hours per day.
1910	Mines Accidents (Rescue and Aid) Act	Maintenance of rescue equipment. Rescue team training.
1911-1937	Coal Mines Act	Replaces 'Coal Mines Regulation Act'. Established minimum wage. Further reduction of working hours permitted depending on economic conditions. Production and sales issues addressed. Age and time restrictions for employees working night shifts.
1947	Coal Industry Nationalisation Act	Nationalisation of UK Coal industry, and establishment of National Coal Board.
1954	Mines and Quarries Act	Revision of 1872-75 Metalliferous Mines Regulation Acts, 1894 Quarries Act, and 1911 Coal Mines Act to cover UK industry.
1969	Mines and Quarries (Tips) Act	Amendments to 1954 Act following devastating spoil heap collapse at Aberfan Colliery in 1966.
1974	Health and Safety at Work Act	Mine Inspectorate for coal mining restructured under Health and Safety Executive (HSE), a UK government agency.
1998	Provision and Use of Work Equipment Regulations	Code of Practice for those with responsibility for safe use of work equipment, including mine managers and shift supervisors.
1999	The Management of Health and Safety at Work Regulations	An update on the 1974 Health and Safety at Work Act, this is a legal document which states the minimum requirements of both employers and employees with regards to workplace health and safety, particularly in terms of performing risk assessments.
2002	Dangerous Substances and Explosive	DSEAR was developed to manage risks from explosions, fire and corrosive substances, and places responsibility on employers to protect their workforces from harm by these specific hazards.

	Atmospheres Regulations (DSEAR)	
	Control of Substances Hazardous to Health Regulations (COSHH)	COSHH by law requires employers in high-risk industries to control substances that are hazardous to worker health, through consideration for storage, ventilation and emergency procedures.
2014	Mines Regulations	Mines Regulations replaced pre-existing law and regulation by removing cross- duplication, and states clearly the need for proof of competence through an accredited qualification or certification.

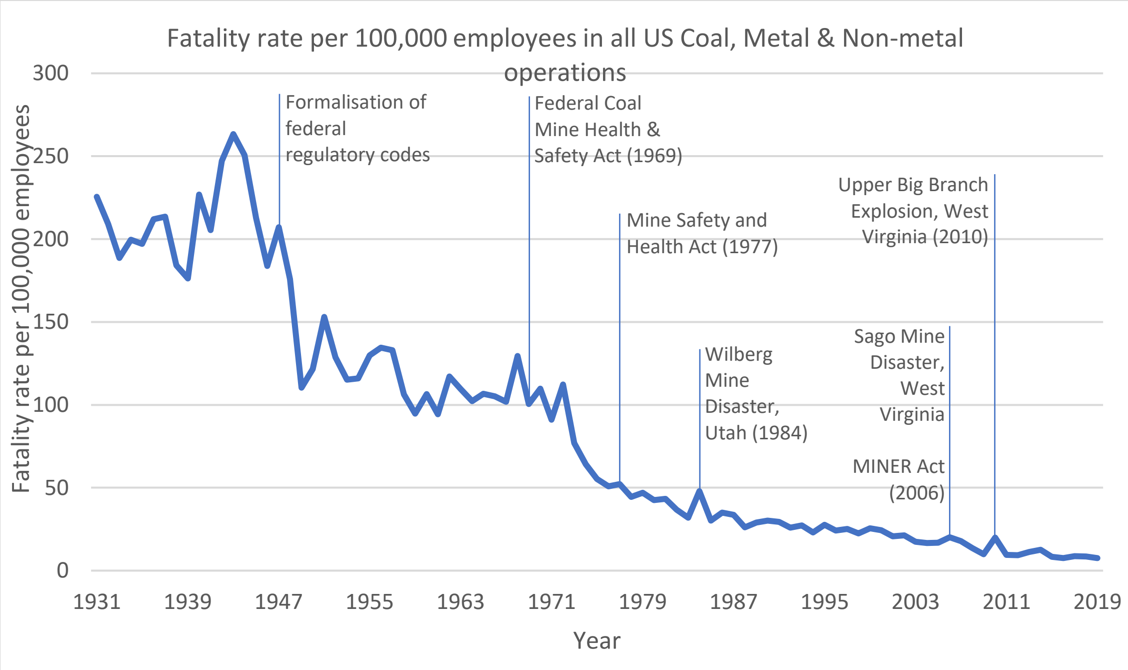


Figure 3.4: Fatality rate per 100,000 employees in all US Coal, Metal and Non-metal mining operations since 1931 annotated with notable US mining disasters and federal mining acts (Mine Safety and Health Administration, 2019a, 2019b).

Frequent fatalities in US operations in the early 1900's prompted broad concern for the lack of mining safety regulation, encouraging many American people to lobby for stringent rules and regulations. In 1910, the US government formally established the US Bureau of Mines (BoM) which was responsible for mitigating accidents and conducting research and training on accident prevention, first aid, and mine rescue (Britannica, 2020). The BoM was not granted authority to carry out inspections until 1941, with the first authorised regulatory codes formulated in 1947. Figure 3.4 shows the long-term decline of fatalities in US mining after BoM formalisation from a peak of ~260 fatalities per 100,000 in 1943 to ~7.5 in 2019. The 'Federal Coal Mine Health & Safety Act' was enacted in 1969, amended to the 'Mine Safety and Health Act' in 1977 which consolidated existing legislation from mining operations, reducing cross-duplication of rules and regulations, and emphasised employee rights (Mine Safety and Health Administration, 2013).

17 major incidents causing 5 worker deaths have occurred since the Mining Safety and Health Act was introduced in November 1977. All but one of these disasters happened in underground coal mines, with two of the worst killing 27 and 29 workers at Wilberg Mine in Utah (1984) and Upper Big Branch Mine in West Virginia (2010) respectively (NIOSH, 2021). Two underground explosions in 2006 at Sago in West Virginia (12 fatalities) and Darby Mine in Kentucky (5 fatalities) generated significant concern, triggering the 'Mine Improvement and New Emergency Response' (MINER) Act in June 2006 (Enzi, 2006; NIOSH, 2021). The MINER Act enforced site emergency response, communication and rescue plans, and renewed criminal charges for violations (Mine Safety and Health Administration, 2021). As quoted from the 2006 Senate report:

"Improvements in safety come about because of a continued re-examination and revision of safety and regulatory practices in light of experience. These tragedies serve as a somber reminder that even that which has been done well can always be done better."

(Enzi, 2006)

Upper Big Branch highlighted the fatal consequences of not enforcing regulations and federal legislation, and ignorance of basic safety protocols and procedures. Management had ignored the risk of methane outbursts, coal dust overaccumulation, and substandard ventilation. Negligent culture and prioritised production resulted in unreported injuries, shortcutting of critical safety procedures, faulty or absent safety equipment, and deviant behaviours towards MSHA following the disaster (McAteer et al., 2011). Updates to legislation have been instrumental in improving safety standards throughout the UK and US industries, but notable accidents have indicated that safety culture remains a key consideration for preventing major incidents. Safety culture approaches developed and applied in other industries, informed by up-to-date regulations, have promoted a top-down culture shift towards safety maturity.

3.4.2 Ergonomics, safety by design & operability

Ergonomics is becoming a key design consideration in the modern mining technology. The pervasiveness of musculoskeletal disorders (MSDs) means that safety by design must be utilised early to mitigate health risks with designs should be based on established ergonomic principles.

Table 3.3: Selected definitions of ergonomics from ISO, IEA & Wilson (2000).

Source	Definition
"Ergonomics principles in the design of work systems" ISO/ CD6385, 1999	Ergonomics produces and integrates knowledge from the human sciences to match jobs, systems, products and environments to the physical and mental abilities and limitations of people, seeking to safeguard safety, health and wellbeing while improving efficiency.
IEA Executive working group, 2000.	Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other system elements, and the profession that applies theory, principles, data and methods to design to optimise wellbeing and overall system performance.
Wilson (2000)	Ergonomics is the theoretical and fundamental understanding of behaviour and performance in interacting socio-technical systems, and the application of that understanding to design of interactions in real settings.

Table 3.3 emphasises that common ergonomic principles are based on physical aspects, such as the human-machine interface or workplace design (EMESRT, 2018). Prior to the last century, machinery would be adjusted after deployment, incurring costs, a loss of productivity, and increased risk of injury. The Haddon Matrix was developed to evaluating each phase of an incident, demonstrating that significantly more factors influence safety incidents with the potential to cause harm prior to the event occurring (Horberry et al., 2011; Table 3.4).

Table 3.4: Haddon matrix for mining equipment (Horberry et al., 2011).

Phase	**Factors**			
	Host (mobile equipment operators and pedestrians)	**Vehicle (forklift or other mobile equipment)**	**Physical environment (mine site)**	**Social environment (company policies and rules)**
Pre-event	*Driver vision* *Pedestrian visibility* Alcohol use *Fatigue* *Equipment training* *Hearing and noise* Pedestrian paths Exclusion zones Obeying signage Safety inductions	*Brakes* *Tyres* *Load characteristics* *Speed of travel* *Turning radius* *Direction of travel* *Tyre position, tilt and angle* *Ease of control* *Visibility from cabin* *Warning devices*	Site design Visibility of hazards Surface friction Uneven ground Blind corners Intersection Crossings Doorways Signage and signals Exclusion zones Pedestrian walkways	Overall attitudes about safety Attitudes about alcohol Rostering Logistics planning *Maintenance scheduling* *Training* Speed limits and enforcement
Event (accident or incident)	*Safety belt use* *Use of PPE* Emergency manoeuvring skills	*Stability control* *Vehicle size* *Contact surfaces* *Load containment* *Rollover structures* *Seat belts and bars*	Guardrails Speed limits Characteristics of fixed structures	Attitude about seat belt use Attitude about PPE use

Post event	Operator age Physical condition	*Fuel cut-off* *Deadman's control*	*Emergency communication* Emergency medicine	First aid training Support for trauma and rehabilitation

Prioritisation of ergonomics during equipment conceptualisation and design can reduce costs through early development, in terms of machine tuning and injury compensation. This is even more critical for SOSO SSM operations due to rapid deployment and commissioning of novel mining and processing solutions. By allocating additional time and resources during the development of modularised SSM equipment, operating costs and injury rates can be reduced. Equipment and/or machinery that is already implemented on site should be evaluated for ergonomic suitability to advise on retrofitting or locating alternative equipment depending on relative cost-benefit (Mason, 1992; Simpson, 1993). Ergonomic work management systems (ISO, 2016), which closely align with OSHMS (ISO,

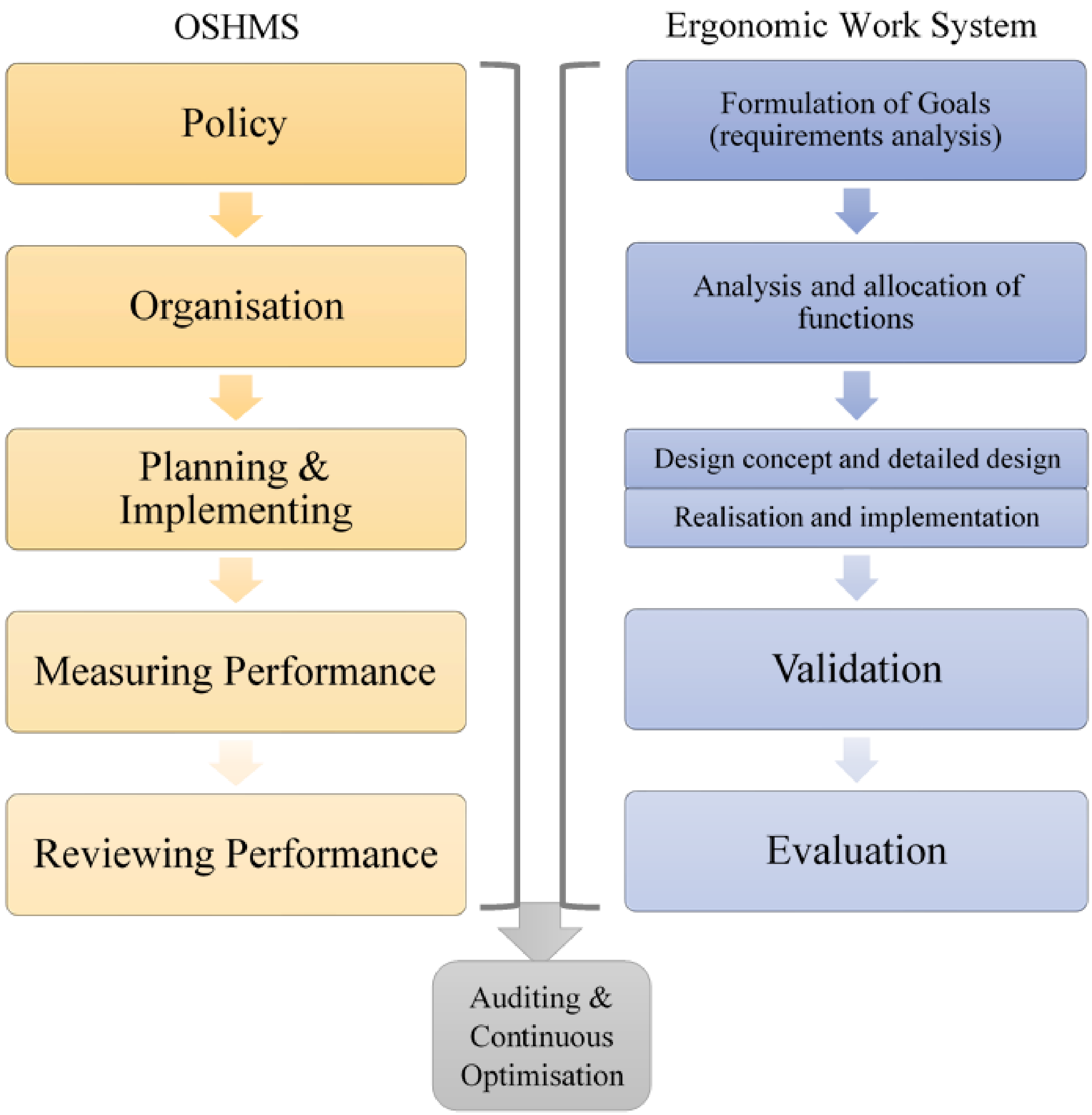


Figure 3.5: Comparison of the stages of an occupational health and safety management system (OSHMS) and an ergonomic work system as developed by ISO (2018a, 2016).

2018a), can help oversee improvements in equipment design and operability (Figure 3.5). Management of ergonomics through the same process as OSHMS can reduce safety cross-duplication which is essential in a SSM paradigm with reduced workforce size and administrative capability. The Bretby Operability Index (BOI) evaluates the ergonomic suitability of equipment by ranking the importance of sightlines, display and control arrangement, and seat protection. The BOI can compare pre- and post-retrofit ergonomics between machines under consideration to inform decision-making (Mason, 1992).

Optimising designs for ergonomic benefit is progressively becoming more commonplace with OSH regulations requiring a minimum level of worker protection (ICMM, 2016; McPhee, 2004). User-friendly human-machine interfaces must support personnel with handling extensive data to make decisions regarding potential hazards. Positioning of physical controls, ease of use and training alignment are all key factors in improving the human-machine interface (Flaspöler et al., 2009; Simpson, 1993). The SOSO SSM design approach enabled comminution, sorting and processing to be carried out semi-automatically using smart systems to control and manage throughput. By contrast, the selective mining tool required full human control from experienced operators due to the heterogeneity of in-situ material being extracted (Moore et al., 2021).

Table 3.5: Risk matrix covering the critical aspects of ergonomics; exertion, exposure, posture, and movement & repetition (Burgess-Limerick, 2007).

	Light (1)	Medium (2)	High (4)	Extreme (8)
Exertion	Minimal forces and work speed	Moderate forces or speed, but remains within capability of worker	High force or speed, but not close to maximal- “hard work”	Forces or speed are near the maximum the person is capable of
Exposure	Performed infrequently for short periods	Performed regularly, but with many breaks or changes of task	Performed often, with few breaks or task changes	Performed continuously for majority of shift
Posture	Comfortable postures, within normal range	Uncomfortable postures, but not those at the extreme of the range of motion	Postures at the extreme of the range of motion	
Movement & repetition	Dynamic and varied patterns of movement	Little or no movement, or repeated similar movements	Repeated identical movements	

Mitigating MSD risk requires an understanding of individual posture, workstation flexibility and overall exposure to harmful energies such as whole body vibration (WBV) during normal work. Whole body vibration (WBV) poses greater risk to mobile vehicles drivers, and is mitigated using in-seat shock absorbers and vehicle suspension (British Columbia, 2006). Poorly designed workstations and controls force operators to sit or stand awkwardly to reach critical controls, increasing stress on joints, muscles and ligaments. OSH regulations governing working hours and task rotation ensure that employees are not overworked by managing physical and psychological strain (ICMM, 2016; McPhee, 2004). Table 3.5 describes an ergonomics risk matrix that considers the exertion, exposure, posture, and movement & repetition of personnel (Burgess-Limerick, 2007). Work tasks should infrequently apply minimal force, allowing workers to maintain a neutral posture whilst permitting variable amounts of movement.

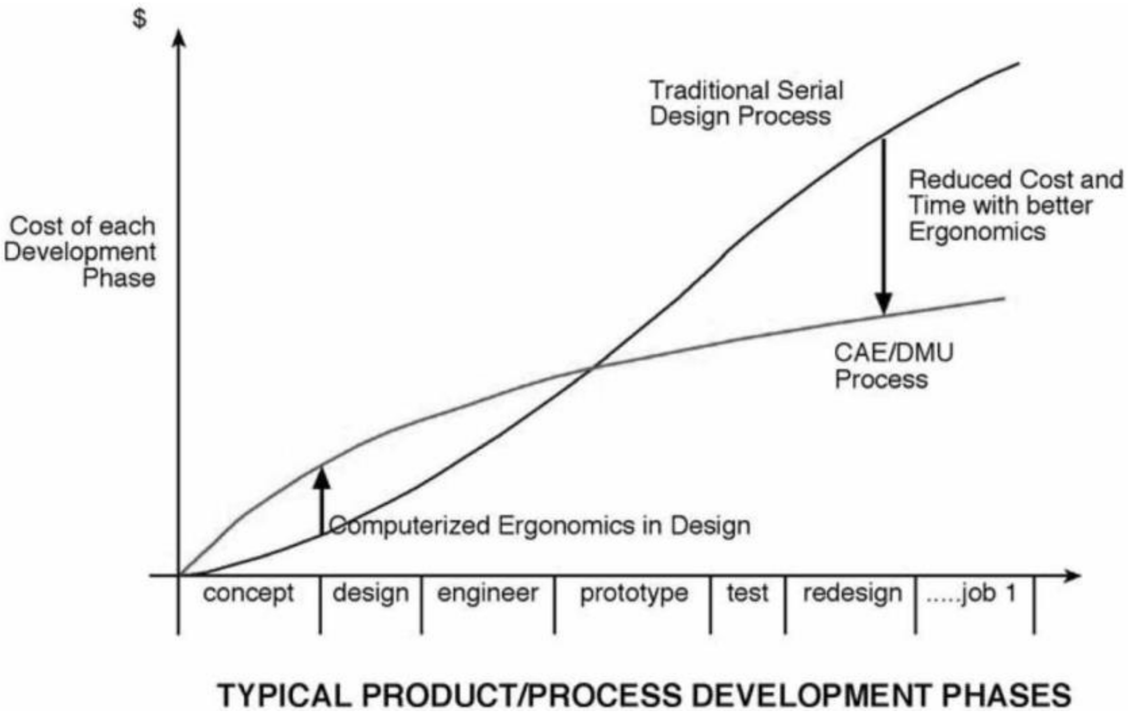


Figure 3.6: Cost-benefit analysis of ergonomics at design phase versus serial design process by Chaffin (2005).

Vehicle line of sight, or LOS, contributes significantly to trapping or pinning accidents due to a worker, vehicle or obstacle being located in blind spots. LOS modelling of multiple vehicle types can help optimise cab visibility and protection (Burgess-Limerick, 2007; Eger et al., 2004; West et al., 2007), or improve collision/proximity warning systems (Sammarco et al., 2012). Rearranging obstructing items or using rear and side view cameras can also improve overall visibility, as spotters providing visual assurance may be exposed to atmospheric hazards near the machine (Godwin and Eger, 2012; Simpson, 1993). Computer aided LHD modelling can be used prior to manufacturing, and virtual reality can support remote training, post-accident investigations, or ergonomic assessment of machinery, with applications in remote continuous mining and improving sight-lines (Foster and Burton, 2004; Godwin and Eger, 2012; West et al., 2007). However, this is expensive for operations with few resources, and maintenance of a consistent underground signal for remote operations is limited by subsurface heterogeneity.

While greater investment is required early relative to traditional methods of design and manufacturing, it eventually produces a large cost and time benefit through later product/process development phases (Figure 3.6), while also proactively improving ergonomics (Chaffin, 2005). MSD modelling can support OEMs with decisions regarding equipment selection, based on simulated ergonomic assessments. Forces exerted on critical areas when seated or optimising the design of a hand saw are some key use cases for this software (Rasmussen et al., 2003). While upfront costs during the design phase may be unfavourable, the long-term cost-benefit has positive safety implications. A balance between automation and manual control is evaluated by process complexity, occupational risk, resource base for technologically advanced solutions, and availability of skilled workers. Where automation is unfeasible or impractical, solutions must be designed with ergonomics and safety by design as a priority. The rapid deployment and short temporal duration of SOSO SSM further emphasises the need for ergonomic to be incorporated into equipment designs to prevent excess retrofitting, maintain productivity, and optimise safety.

3.4.3 Health & safety management and training requirements in SOSO mining

Training for SOSO mining workforces must ensure that all employees will be adequately prepared to conduct on-site work safely. The rapid deployment and commissioning of the SOSO SSM system necessitates that operations are initiated with suitable safety standards in a mature culture. Investigations of safety culture perspectives identified that: (a) Mature and experienced operators contribute the experience to rapidly start operations and impart knowledge to new employees, and (b) incomers that have not yet worked in an active mining environment are more likely to adopt best practice (Moore et al., 2021).

Figure 3.7: Human error likelihood influence framework outlining order of responsibility for traditional occupational safety management (Simpson et al., 2009).

All new workers must undergo general induction, COSHH and task-specific training as a minimum, with formal inductions and on-the-job training facilitated for persons joining established work teams. During testwork, training sessions were conducted by the H&S manager/lead officer, with contributions from the lead engineer for each specific node (i.e., selective miner, mobile processing, comminution, sorting) to ensure that procedures are understood. Supervisors then observed normal operations to ensure that workers put procedural knowledge into practice safely, and verified whether workers had read all relevant Risk Assessment and Method Statements specific to their task(s) (Moore et al., 2021). Establishing the procedural requirements ahead of operations is vital for enhancing operational efficiency without compromising safety, through greater autonomy among operators. Supervisory interventions should be limited to avoid bureaucratic overload from accountability processes by relying more on individual initiative.

Simpson et al. (2009) produced a framework illustrating the relative importance of factors influencing occupational safety, demonstrating that management systems developed in a mature culture enables determination of appropriate roles and responsibilities, which enhances the training measures, codes and procedures necessary for improving work environments and human-machine interfaces (Figure 3.7). Hence, suitable training approaches must be developed that enable efficient transfer of knowledge across hierarchical levels. OSH training applied to SOSO SSM must: (a) teach new and experienced employees the skills and mindset to identify hazards; (b) empower workers to voice issues to supervisors and managers; and (c) instil the confidence required to manage risks while underground or at surface (Haight et al., 2014). For the selective mining tool, workers must be trained on OSH ergonomic risks, and how to identify and report issues to supervisors for further investigation. Knowledge transfer from OEMs ensures that there is consistent instruction regarding best practice, to support reduced SSM workforces engaging in inspection and monitoring of safe practice in a controlled environment (Moore et al., 2021).

Testing and commissioning of the SOSO mining solution across two sites in Olovo, Bosnia and Veliki Majdan, Serbia demonstrated how OSH of operators is significantly improved compared with traditional mining. Skilled workers are typically expensive to recruit and retrain while on-site, but the modularised processing plant is fabricated, cold-commissioned and fully tested off-site in a safe, controlled environment. The acquired knowledge from training received at the commissioning stage can then be shared with semi-skilled workforces employed locally to operate the SOSO modularised mining system.

3.4.4 Risk, impact and critical control management for a SSM paradigm

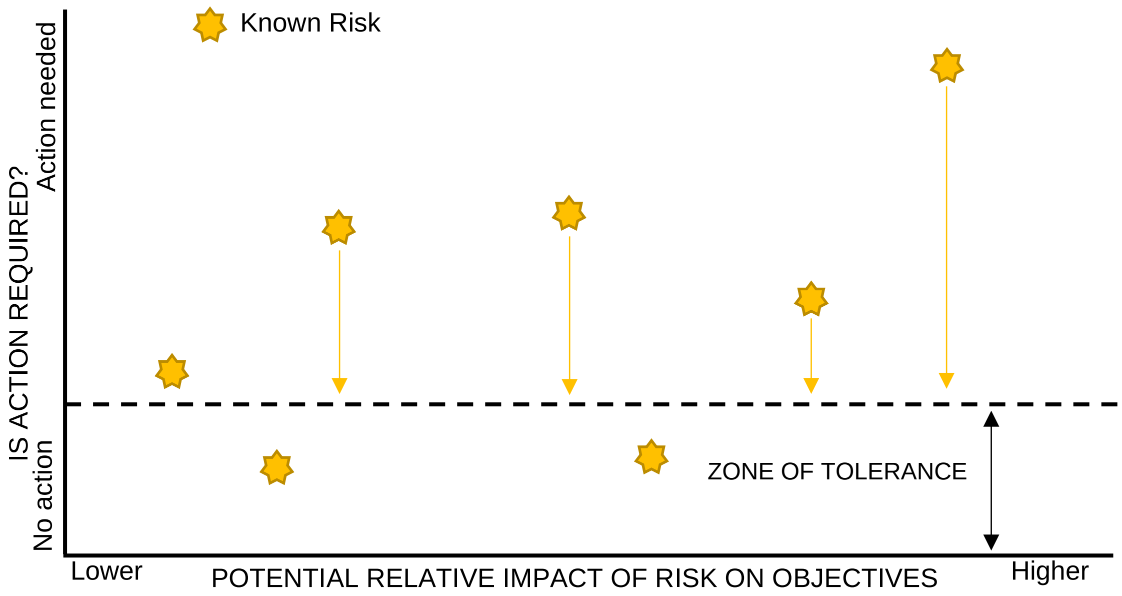


Figure 3.8: Risk Impact and Action Map (Satarla, 2021).

Risk assessments typically adopt a risk matrix methodology for comparing the likelihood of a risk manifesting against its severity. Injury severity can range from minor first aid to fatality, with moderate injuries resulting in more days lost in between, and financial risks can be very low impact (£10-100) to extremely high (over £1,000,000). This methodology tends to disregard opportunities by

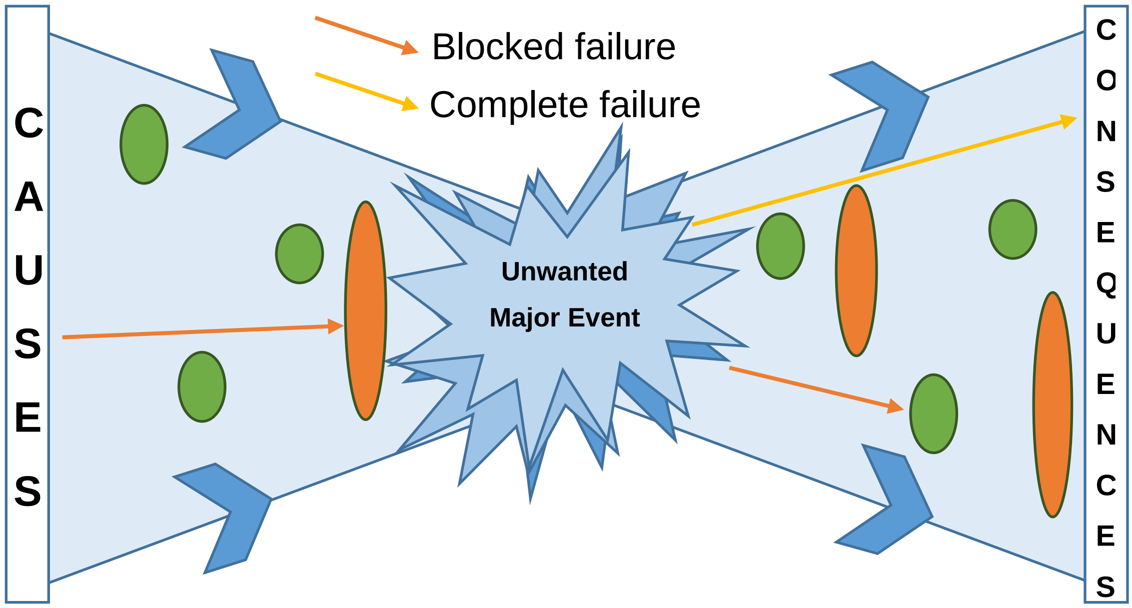


Figure 3.9: Bowtie analysis for critical control management (Modified from De Ruijter and Guldenmund, 2015; Foster and Severn, 2013).

placing overwhelming emphasis on negative impacts of a risk. According to the ISO 31000:2018 definition of risk, which is "The effect of uncertainty on objectives" (ISO, 2018b), risk management is mainly focused on establishing the level of action to reduce uncertainty by mitigating threats and enhancing opportunities. Figure 3.8 represents how known risks can be mapped by their potential impact on wider objectives by plotting them based on the amount of action required to reduce the risk to below a predetermined tolerance level. Risks with the largest impact are managed first and direct comparison of varying opinions on risk controls and mitigation strategies are permitted (Satarla, 2021). Clear knowledge of a system's inputs, processes and outputs ensures that action is correctly targeted to reduce the risk to a level that is as low as reasonably practicable.

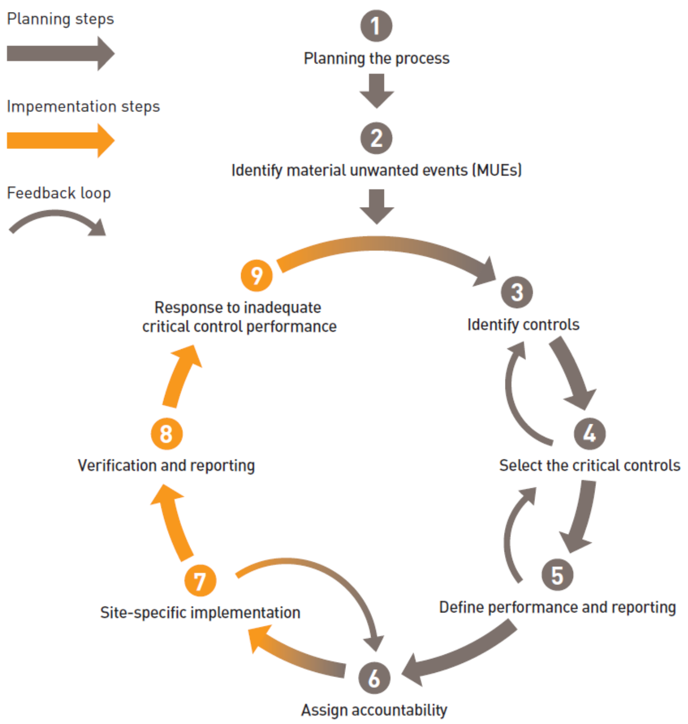


Figure 3.10: Critical Control Management Process (ICMM, 2015).

Unwanted major events are attributed to the presence of interconnected failure pathways with inadequate attention towards prevalent risks and hazards on site or within particular work areas, requiring engineering or administrative safety barriers to reduce the risk of harm. Critical controls are designed to intercept significant failure pathways and independently prevent unwanted events or mitigate the consequences (Figure 3.9). The critical control management (CCM) process described in Figure 3.10 begins by outlining the scope, persons involved and time available. The material unwanted event(s) that could cause harm are identified, critical controls that independently reduce risk are defined, and performance standards for each critical control are described. Roles and responsibilities are allocated to site management and workers to implement the CCM plan, and verify effectiveness against performance specifications (De Ruijter and Guldenmund, 2015; Foster and Severn, 2013; ICMM, 2015).

Table 3.6: Hierarchy of hazard control, outlining methods of risk reduction by their relative effectiveness and potential for human error (Iannacchione et al., 2008).

Control category based on hierarchy framework	**Major control issues**	**Potential for human error**	**Risk reduction**
Eliminate hazard	Economic/strategic	Doesn't exist	Complete
Minimise/Substitute hazard	Engineering	Human error plays a minor role	High
Physical barriers			
Warning devices	Assessing	Human error is possible	Medium
Procedures	Administrative and work processes	Human error can play an important role	Low
Personnel skills and training			

Major Hazard Risk Assessment (MHRA) is used for preventing severe hazards from impacting operations and workforces, such as explosions, outbursts, fire, and roof collapse. Engineering-focused MHRA utilises flowcharts for mapping processing flows and the associated hazards, while operational-focused MHRA analyses individual areas separately. Workplace risk assessment and control (WRAC) and preliminary hazard analysis (PHA) is used to prioritise risks that could cause a major event and determine how MHRA should be implemented. Identification of preventative and mitigative controls for known risks is carried out using Bowtie analysis. Control effectiveness is critical for the output phase of MHRA, so controls are classified according to the hierarchy framework (Table 3.6). Elimination is most effective as the risk is completely removed, with progressively less effectiveness from substitution, physical barriers, warning devices, procedures, and training measures (Iannacchione et al., 2008).

3.5 Fieldwork observations of SOSO SSM system for intervention points

Understanding the common hazards with potential to cause harm is essential before work begins to allow time to optimise equipment designs, operating procedures or PPE requirements. The anticipated severity of the consequences for these hazards differs from minor eye irritation up to a fatal injury due to a pinning accident or roof collapse. The action needed to mitigate hazards to an acceptable level will vary in proportion to the severity, and manifest as risk controls. Despite the focus on safety-related threats, positive observations were made during fieldwork. Operators were sheltered from intense weather which helped to prevent detrimental health impacts depending on climatic conditions. Modularised comminution allows containers to remain closed during crushing and milling, preventing exposure to excess dust. Ambient noise and whole body and hand-arm vibration generated by modularised equipment is reduced relative to in-situ operations (Moore et al., 2021).

Table 3.7: Occupational risks associated with Selective Mining Tool (CM) in underground environment at Olovo mine site.

Hazard Type	Those at risk	Means of Harm	Existing Controls
Dust inhalation	All workers underground	Inhalation of potentially toxic dust produced by cutting	Forced ventilation, hose water suppression, respirator masks
Crush injury	Operators near CM	Crushed between CM and mine wall (pinch point)	Alarm system when reversing, warnings to remain behind CM while in operation
Mild deafness	Operators near CM when cutting	Noise generated may cause mild deafness or hearing impairment	Ear defenders and plugs provided for personnel working near active face
Eye irritation	Operators near CM when cutting	Dust/rock fragments ejected towards eyes during cutting	Safety glasses provided for personnel working close to active face
Back/neck strain	Operator of CM	Leaning out of CM cab for improved visibility	Armrests on CM cab seat, shift rotation and regular breaks for CM operators
Broken beam/ head/picks	Operators near CM when cutting	Struck by beam or metal picks/ shards ejected from CM head	Restrictions on distance from active face, eye protection.
Roof collapse	All workers underground	Roof may partially collapse during cutting, releasing loose rock	Front deflector on CM cab, restrictions on access near active face

Table 3.8: Occupational risks associated with Containerised Comminution Module at surface of Olovo mine site.

Hazard Type	Those at risk	Means of Harm	Existing Controls

Trip & fall from height	Operators on container roof/ raised platform	Falling from top of container while loading material into mill	Harnesses provided for operators working at height
Strike injury from machinery	Operators near loading buckets/ crane	Struck by articulating crane arm and/or moving bucket	Radio communication between ground staff and crane operator
Spillage of material from loading bucket	Operators near bucket loading areas	Injury by crushed rock material falling on personnel	Radio communication between ground staff and crane operator
Fall of bucket from height	Operators near bucket loading areas	Serious injury from heavy bucket falling on operators	Radio communication between ground staff and crane operator
Falling from access ladder	Operator on top level of container	Fall from height while accessing/ egressing the container roof	Sturdy footwear, while maintaining 3 points of contact on ladder
Head injury from striking exposed parts	Operators and maintenance workers	Striking head on sharp edges and exposed parts inside container	Hard hats worn, minimise number of workers inside container at one time
Strain injury (back, arms, shoulders)	Operators on roof assisting with loading	Strain injury due to awkward positioning while moving buckets	Crane mostly positions bucket, so workers avoid stretching uncomfortably
Material blockage due to input error during loading	Operators near module during loading	Clogged milling equipment may be damaged causing harm	Training on loading procedure, workers keep distance while operating
Mild deafness	Operators near comminutor while operating	Excessive noise from crushing process may cause discomfort	Ear defenders and plugs for workers near module for extended time periods

Table 3.9: Occupational risks associated with Mobile Modularised Plant (MMP) at surface of Olovo mine site.

Hazard Type	Those at risk	Means of Harm	Existing Controls
Electrical shock	Operators within MMP	Electrical fault due to damaged/ exposed wiring, etc. may electrocute operators in contact	Electrical insulation on control panels & wiring, full coverage PPE to be worn
Falling objects	Operators within and outside MMP	Objects dropped from height to lower floor may strike workers below	Loose objects to be stored securely when not in use, hard hats to be worn in MMP
Slips, trips and falls	Operators within MMP	Protruding bars, pipes and other objects across walkways, or wet floor could present slip & trip hazard	Kickboards around open edges of floor, pipework arranged to avoid crossing walkways, regular cleaning
Whole body vibration	Operators within MMP	Vibrations from moving equipment (jigs, shaking tables) may cause discomfort to operators spending long time periods inside modules	Anti-fatigue mats will be placed where operators are stationed regularly to mitigate whole body vibration intensity
Noise	Operators within and outside MMP	Mobile MMP equipment generating noise may cause discomfort to operators	Ear plugs will be provided to all operators working within MMP
Fire	Operators within MMP and across mine site	Overheating of equipment may lead to ignition and spread by flammable materials	Temperature monitoring of equipment carried out, with automatic shutdown
Heat exhaustion	Operators within and outside MMP	Heat exhaustion related to climatic conditions during operating hours, and extent of air-conditioning	Ability to fully open container provides natural ventilation to operators, shift rotation to provide sufficient breaks

Sharp & protruding edges	Operators within and outside MMP	Collisions with edges & corners of steel supports and overheard bars could cause injury	Removal of sharp edges, and hard hats to be worn in and around MMP
Escape of fluids due to burst pipe	Operators within MMP	Impact from high pressure water caused by sudden burst in container pipework	Pressure gauges provided with warning alarms and emergency shutdown
Eye & Skin irritation	Operators within MMP	Spillage of slurry from IBC hopper, jigs, etc. may be ejected into face, causing eye & skin irritation	Safety glasses/goggles and gloves for operators handling ore slurry or cleaning spillages
Ingestion/ poisoning	Operators within and outside MMP	Spillage of process water/slurry into nearby operators, causing accidental ingestion of toxic fluid	Masks provided for operators cleaning spillages of ore-laden fluid

Consideration for threats and opportunities associated with mining activity is important for deciding whether risk is being adequately managed, but this study focused mainly on safety threats from containerised SSM equipment. Tables 3.7, 3.8, and 3.9 represent non-exhaustive risk registers for Olovo, Bosnia & Herzegovina testwork operations during field visits in 2019. They are subdivided by intervention point, and include hazard descriptions, persons observed to be at risk of harm, means by which persons might be harmed, and controls put in place to reduce the risk to a practicable level. An individual major hazard from each intervention point's risk register was selected for further Bowtie analysis.

3.6 Bowtie major event analysis of intervention points

Variation in safety approaches between conventional mining and SOSO SSM depends on the level of automation used in extraction and processing. The *IMP@CT* pilot system is categorised as mid-level automation due to the balance between automatic control and manual human operation. For the selective mining tool, operators must make rapid decisions based on changing conditions at face, with supporting inspections by specialists. Selective mining increases the risk of roof or wall collapse at face as systems are reliant on pre-programmed data to recognise compositional or structural nuances. While automation can maintain consistent loading rates, human operators are still required to manage Run of Mine and process throughputs (Moore et al., 2021). Human intervention with individual expertise is essential for managing flexible solutions and taking action to mitigate the risk of harm while acknowledging other competing goals. The *IMP@CT* technologies introduce uncertainty which cannot be easily eradicated via procedural bureaucracy, as overregulation and safety clutter inhibits worker autonomy (Dekker, 2018; Rae et al., 2018).

Table 3.10: Comparison of workforce safety aspects for traditional in-situ mining and small-scale SOSO mining across the three intervention points.

Intervention Point (IP)	Traditional in-situ workforces	'SOSO' mining workforces
Underground and/or surface mining (U/SM)	Traditional drilling and blasting methods are effective in removing relatively large volumes of material in bulk while ensuring workers are kept away from danger area during blasting, but this approach produces excessive quantities of waste.	Selective mining tool enables at-face extraction, reducing need for crushing of material, but places underground workers in most hazardous part of mine where stope ceiling & walls are weakest, requiring more frequent roof support installations.
Surface comminution (SC)	Large scale of crushers and mills presents greater risk for operators using and maintaining equipment, requiring more controls, PPE and training. Crushers and mills typical of traditional operations can generate large volumes of dust, which must be controlled to prevent inhalation.	Containerised comminution prevents the need for workers to be near crushing and milling equipment while operating, reducing the risk of harm. Modularised comminution units can be closed to contain most dust generated from crushing process, directly preventing inhalation.
Surface sorting & processing (SSP)	Depending on the commodity, larger processing plants may use greater quantities of chemicals and infrastructure and often generate more noise and vibration, creating inherently higher risk.	Modularised sorting and processing reduces need for vast infrastructure and volume of chemicals. Containerised processing units can reduce noise and vibration exposure for operators.

Table 3.10 outlines the site areas interpreted as intervention points (IP's), where updated standards & regulations, equipment design changes, or safety culture development can demonstrably improve OSH in mining, depending on the balance of automation and human control. They provide a baseline from which to compare and contrast the particular safety requirements between SSM nodes, using the *IMP@CT* mining system as a case study. 'Underground and/or surface mining' (U/SM) is predominantly human controlled and comprises all extraction activities that take place above and/or below ground, including operation of selective mining tool and front loader. 'Surface comminution' (SC) is predominantly system controlled and comprises all crushing and milling activities, specifically the containerised comminution module and other surface equipment for managing throughput. 'Surface sorting & processing' (SSP) is a combination of human and system control and comprises of modules involved in producing concentrate, including the x-ray ore sorter, mobile modularised plant and loading equipment (Table 3.10). Tables 3.7, 3.8 and 3.9 represent risk registers for the primary equipment involved in each IP; the selective mining tool for U/SM, the containerised comminution module for SC, and the modularised plant for SSP. Bowtie analysis is then used to qualitatively analyse a major top event, which informs the controls needed to prevent the causes and mitigate the consequences. The outcomes of bowtie analysis can inform appropriate updates to safety procedures or equipment designs for SOSO extraction.

3.6.1 Underground and/or surface mining

Figure 3.11: SOSO Selective Mining Tool developed by Metal Innovations. Left - Selective Miner, Dumper & Power Pack during Olovo testwork. Right - Selective Miner undergoing maintenance.

Underground mining activity in a SOSO paradigm requires selective extraction by using a semi-continuous mining tool designed, fabricated and operated by *Metal Innovations* (Figure 3.11). The selective approach relies on operator decisions and control 'at face', so the mining tool must be manually operated and supervised by at least one geologist to safely guide the operator along vein (Moore et al., 2021). Hot commissioning and testwork carried out in Bosnia & Herzegovina showed that additional personnel familiar with the mining tool and the power source would be preferable to regularly monitor the equipment condition. A minimum of 4 people will be present at the working face at any time

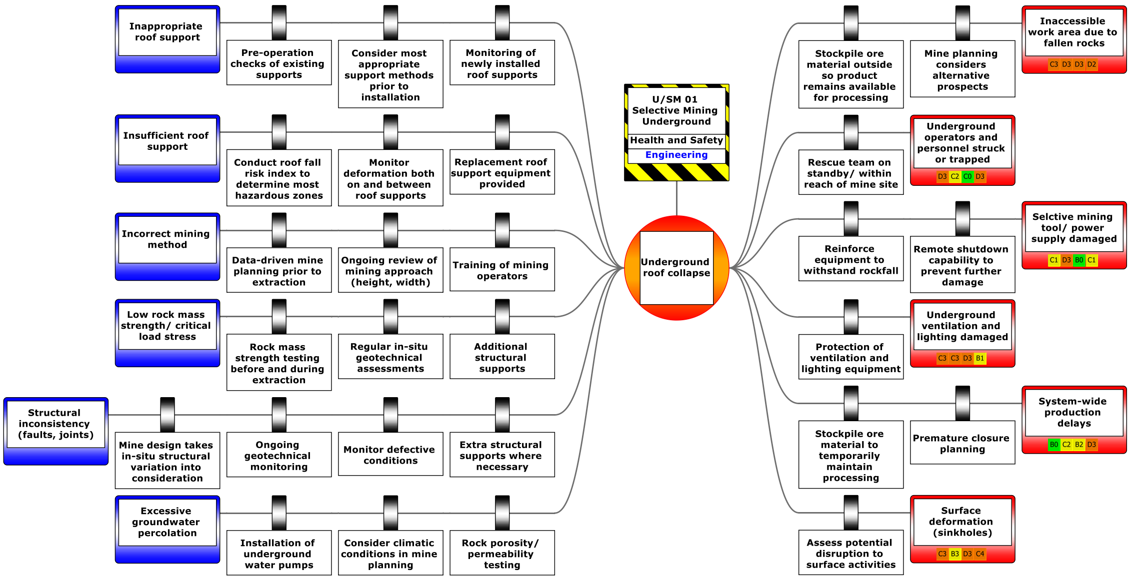


Figure 3.12: Bowtie analysis of a hypothetical underground roof collapse in SOSO small-scale mining.

during operations, resulting in a prevalent risk of serious injuries and fatalities from a roof collapse. Figure 3.12 shows the potential threats and consequences of a roof collapse in the context of a SOSO operation using Bowtie analysis. Continuous geological and geotechnical surveillance is needed for identifying compositional and structural inconsistencies in the exposed surfaces due to the increased human presence behind the selective miner. The host rock of the Cerussite (Lead ore) was composed of a calcitic and dolomitic groundmass with later clay infill in structural voids. The selective miner comprises several metal picks installed on a drum attached to a hydraulic arm, removing small flakes as the rotating picks engage with the rock. Dense fracturing and/or inconsistent geology negatively impacts on mining efficiency and safety as size distribution increases. The interplay between structural and geological processes increases the risk of collapse depending on the extraction method utilised. Semi-automated selective mining presents increased ground instability risk which must be mitigated with adequate roof supports in underground environments, with communication between operators, and designated stand-off distances.

3.6.2 Surface comminution

Figure 3.13: SOSO Comminution Module developed by Extracthive, set up for commissioning and testwork at Olovo.

The SOSO comminution circuit developed by *Extracthive* is comprised of a modularised gravity-based screening and milling process with material loaded via buckets placed on the container roof, and unloaded through the container base into an empty bucket below (see Figure 3.13). The module is semi-automated with doors kept closed during active processing, keeping operators at a safe distance from moving parts and

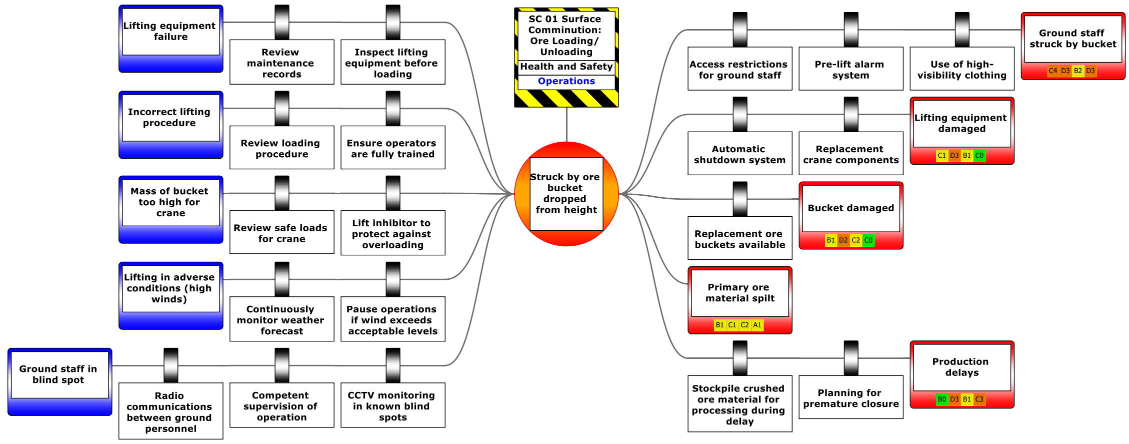


Figure 3.14: Bowtie analysis of a hypothetical ore loading/ unloading incident at surface in SOSO small-scale mining.

managing dust & noise exposure. Loading of ore material in buckets by crane presents particular risks from an ore bucket being dropped from height onto employees working below. This risk depends on the condition of the crane (e.g., arm hydraulics, hoist rope, etc.), loading procedure, adherence to mass restrictions for the bucket and/or crane, weather conditions, and positioning of ground personnel. Therefore, thorough pre-operation inspections and maintenance must be conducted, operators must account for any manual handling difficulties, be aware of the mass limits of the equipment, pause operations in adverse weather conditions, and ensure communication between the crane operator and ground engineers is maintained during loading (see Figure 3.14). Positioning the module on a vertical hillside or raised platform to supply material using dumpers may reduce this risk if gravity beneficiation is required. Ongoing communication remains essential as ground staff overseeing unloading would be hidden from dumper operators, even while wearing full, high-visibility PPE. The modularised comminution system places ground personnel at a heightened level of risk compared to conventional milling facilities, which must be mitigated using radio communication to provide advance warning before work commences.

3.6.3 Surface sorting & processing

The modularised processing plant (MMP), in combination with an X-ray fluorescence (XRF) ore sorter, enables in-situ sorting and processing at a lower throughput (~5 tonnes per hour) than traditional mineral processing facilities. The MMP is semi-automated, requiring monitoring by skilled to semi-skilled

Figure 3.15: SOSO Mobile Modularised Plant comprising of four containers, developed by the University of Exeter. Left - Start of gravity beneficiation circuit. Right - External view of MMP.

workers during active operation, and uses a wet process to concentrate Lead from Cerussite ore through several stages of jigs, shaking tables and spirals (Figure 3.15). Wet processing produces no dust which allows the system to be directly monitored from inside the MMP, which enables workers to directly observe, make decisions and adjust parameters more rapidly. But human presence inside the module creates additional risk of physical injury in the event of a sudden release of high-pressure process water from a seal leak or failed water pump. This may be caused by a hidden vulnerability in a section of pipework, an electrical fault in the control system causing a spike in water pressure, or a worker selecting the wrong input in response to a warning being displayed. Continued supervision by experienced senior engineers and periodic retraining will be critical to the safe operation of the MMP, which should ensure that operators retain sufficient knowledge about correct working procedures under normal and emergency conditions, and during maintenance. Toolbox

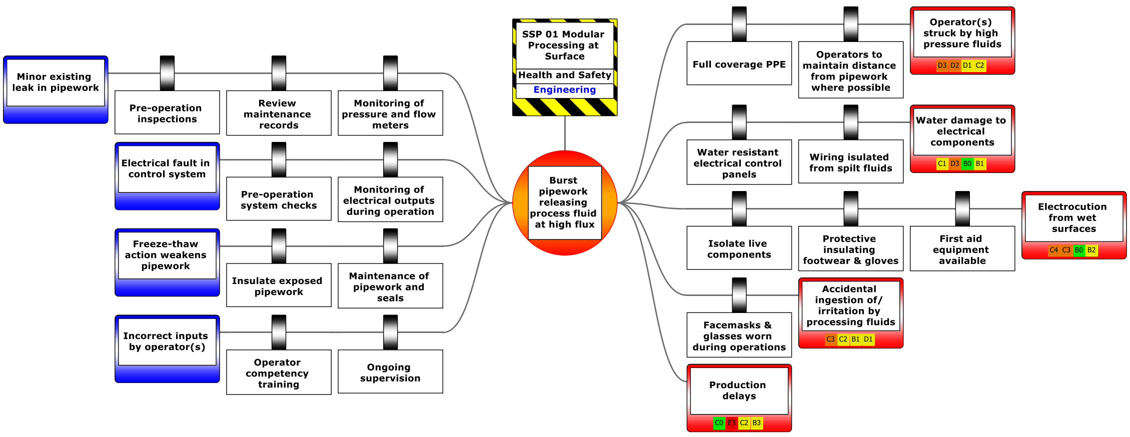


Figure 3.16: Bowtie analysis of a hypothetical burst pipe incident within the MMP in SOSO small-scale mining.

talks can maintain hazard awareness within the MMP team during operations, and empower individual operators to objectively assess their working environment from an occupational safety perspective (Figure 3.16).

3.7 Applying risk management to observed hazards in SOSO SSM context

Based on the Bowtie analysis performed using fieldwork data collected during pilot testwork, the observed risks and hazards can be represented in terms of their potential impact on objectives, which is to reduce the occurrence of minor and major failures to an acceptable level, and the action required to reach the risk tolerance threshold, using risk prioritisation techniques (Satarla, 2021).

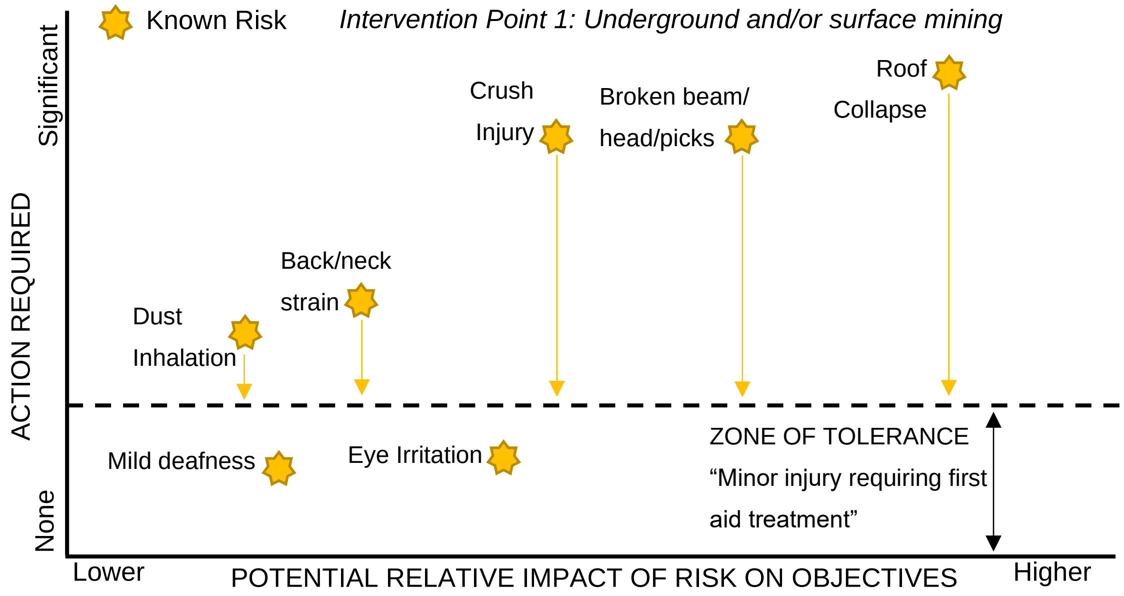


Figure 3.17: Hazards identified from fieldwork observations within Intervention Point 1 (Underground and/or surface mining).

Roof collapse inherently poses the highest risk due to the potential for multiple fatalities and/or serious injuries, and significant damage to assets such as the selective mining tool, the mine dumper truck, and the power pack. Mitigating roof collapse risk requires engineering solutions such as roof supports, bolting, rock mesh, shotcrete, etc., as well as in-situ monitoring to inform mine planning. Safety by design during the planning phase, thorough quality control during manufacturing, and frequent inspections ensure that defective components are not installed or utilised further. Operators of the selective mining tool receive training on how to safely manoeuvre the selective mining tool in narrow spaces to minimise risk of damage from collisions or high mechanical stress. Operators located in blind spots while the machine is active may be pinned or crushed by unexpected movement, which requires exclusion zones to be clearly marked both in front and alongside the machine while cutting is in progress (Figure 3.17).

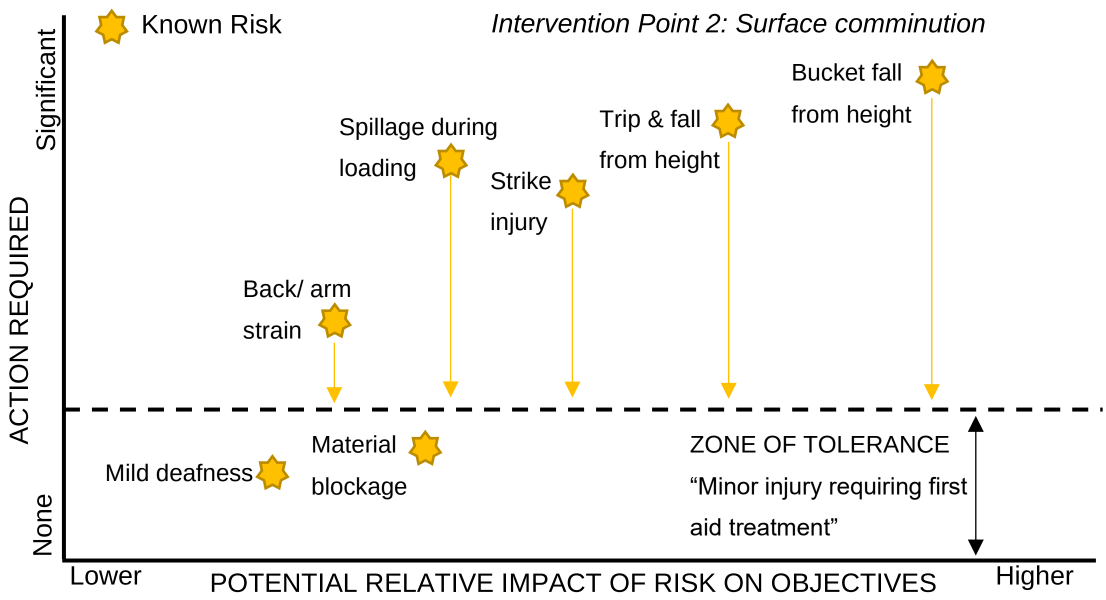


Figure 3.18: Hazards identified from fieldwork observations within Intervention Point 2 (Surface comminution).

Fall from height of either a raised ore loading bucket or an operator on the roof of the comminution module poses the most significant risk of harm to personnel on the pilot SOSO SSM site. Operators located on the modular container roof to position loading buckets are raised approximately 3.9m from the ground (Extracthive, 2018), so safety railing is installed around the top of the container and harnesses are worn by operators working at height to prevent a fall. Use of an external mobile crane means the maximum height reached by the buckets must exceed the combined height of the container and its foundations in order to clear the roof. Any ground operators in close proximity to raised loading buckets, particularly those that are fully laden, are at risk of serious injury if a bucket is dropped. Ground workers are expected to remain clear of the loading zone unless positive contact via radio is established and permission is given by the crane and front end loader operators prior to access (Figure 3.18).

The pilot mobile modularised gravity separation plant comprises 4 containers stacked in 2x2 formation to accommodate jigs, screens, shaking tables, hoppers and other gravity separation components. The flowsheet design complexity and semi-automated approach presents specific risks, the most serious of which includes rapid fluid escape from a breached high pressure pipe

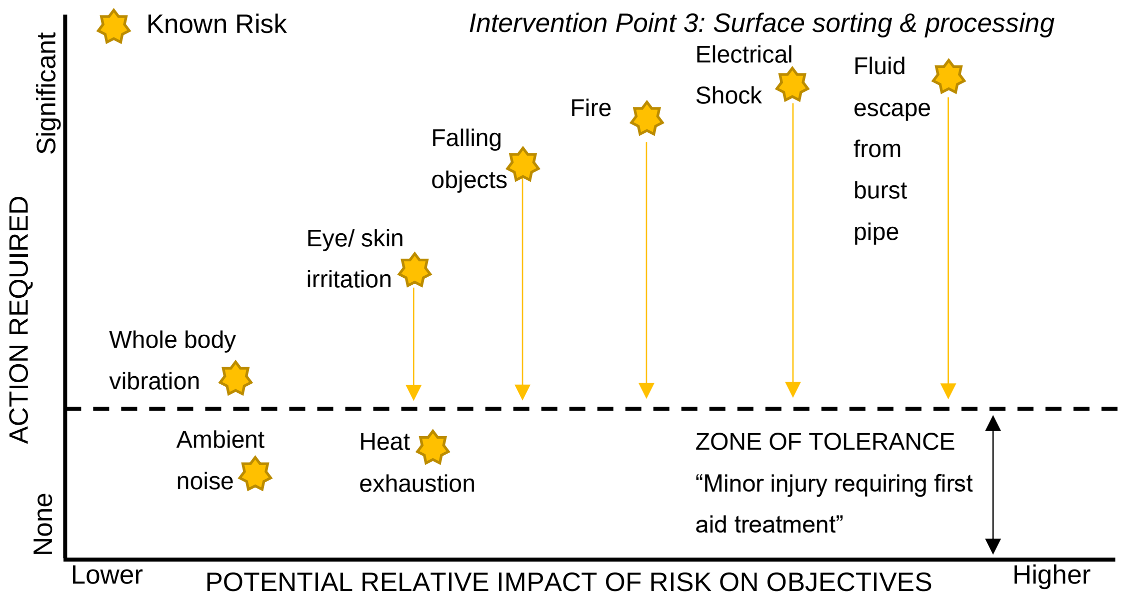


Figure 3.19: Hazards identified from fieldwork observations within Intervention Point 3 (Surface sorting & processing).

or seal, electrical shock, fire and falling objects. The high pressure burst was deemed higher risk than electrical shock and fire due to the potential impacts of rapid ejection processing fluids near live electrical equipment. Fluid pressures must be monitored with permanent gauges, automatic warning alarms and emergency shutdown capability to mitigate risk of pressure spikes escalating into failure. Electrical exposure can be fatal if components are used incorrectly or poorly maintained, especially where water infiltration through exposed circuits can endanger multiple operators. MMP electrical wiring and control panels must be insulated and tested during commissioning and pre-operation inspections to prevent water exposure. Temperature and pressure monitoring should inform shutdown systems to prevent equipment damage or injury (Figure 3.19).

3.8 Optimising safety in a small-scale SOSO paradigm

SOSO SSM varies from conventional in-situ mining by workforce size, level of automation, technological sophistication, production rate, and site footprint. Observations of equipment designs by their ergonomic suitability and operability precede considerations of the most applicable hazard management, safety culture and training requirements for maintaining high standards. Integration of ergonomics at the design and planning process can be complicated if several groups of actors are involved, producing uncertainty regarding responsibilities (Broberg, 1997). Design engineers may lack motivation to engage with ergonomics, logistical challenges can limit collaboration, and management may not prioritise ergonomics. Specifying ergonomics criteria in the design process can enable targets to be met earlier in the process than conventional designs, requiring clearly outlined roles and responsibilities (Broberg, 1997).

Figure 3.7 showed that, despite increased expenditure of computer-aided design compared with conventional serial design processes, design costs are recovered quickly during prototype development, testing and improvement due to reduced retrofitting. In SOSO SSM with reduced commissioning times and budgets, improving the safety and ergonomics of innovative equipment at the design phase using CAD is beneficial. MMP development in CAD allowed practitioners and manufacturers to visualise equipment and discuss appropriate changes to enhance safety ahead of manufacturing. Computerized design support systems were seen as low value by design and production engineers in the electro-mechanical industry, compared with training in the application of ergonomics and communication between actors (Broberg, 1997). Hence, CAD is not sufficient on its own for improving design ergonomics, despite the long-term reduction of capital expenditure relative to serial design processes.

Ergonomics principles applied during the operational phase using risk impact and control maps enable an understanding of the action required to manage prioritised risks. McPhee (2004) explored the role of risk management and participatory ergonomics for optimising mine task and workplace design when physical and cognitive capacity in aging workforces is considered. Participatory ergonomics considers worker perspectives when developing and implementing design changes, given that skilled frontline operators have sufficient expertise in their work area to find solutions. Frontline worker involvement depends on how decision-makers select and distribute participants, their expected contributions, areas of influence, and how changes are embedded (Burgess-Limerick, 2018). The smaller workforces in SOSO SSM may inhibit participatory ergonomics due to a comparatively limited range of perspectives available to discuss changes. Maximising the effectiveness of participatory ergonomics requires management commitment and presence of specialists, augmented by ergonomics and operability-focused training (Burgess-Limerick, 2018; Torma-Krajewski et al., 2009). Ergonomic risk matrices enable task evaluation based on exertion, exposure, posture, movement and repetition (Burgess-Limerick, 2007), but lacks regard for the physical and mental limits of older workers.

While a minimum level of regulatory compliance is mandatory, overregulation and procedural clutter may contribute significantly to incidents despite its intent to prevent harm (Rae et al., 2018). SOSO SSM operations may be at particular risk as regulations are added to accommodate updates to equipment design, flowsheet or mine planning without also removing irrelevant or out of date rules. Safety clutter inhibits worker ownership as more rules and regulations are written without worker consultation, impeding the transfer of feedback from site experts to management. Rigid rule-setting inhibits flexibility and adaptability among SOSO workers with the skillset to effectively problem-solve in dynamic situations without abundant rules (Rae et al., 2018). Medical professionals exhibit efficient problem-solving under high pressure during routine work, demonstrating that an ability to recollect rules does not increase the likelihood of success. Individuals are often unable to remember all rules and regulations, while many are regarded as irrelevant or redundant under ‘real’ conditions. Implemented rules should be regularly reviewed so they are fit for purpose to permit a minimum level of autonomy (Debono et al., 2013; Dekker, 2018).

Administering technical knowledge during induction and on-the-job training is necessary for instilling the required competencies to operate semi-automated SSM equipment safely. High individual skill and risk awareness relative to in-situ mining is needed to manage individual IPs as full automation is impractical. Both the technical and occupational safety knowledge must be cascaded down from the lead development engineers to the shift managers who pass that specialist knowledge to workers and operators via on-the-job training methods (Moore et al., 2021). As Karalis (2016) explains, the top-down cascade model for training is most useful when dealing with numerous workers, when there are time and/or budget deficiencies, and an overall lack of trainers available. This hierarchical cascade provides the required competencies to conduct normal duties as information flows from management to workforces, while cascade training involves sharing of best practice and corrective actions through multiple operational stations (Jacobs, 2002). The cascade approach suits SOSO SSM due to its time and budget constraints, as construction and commissioning turnaround is short, while lower CapEx reduces the budget for safety training. Hierarchical and process cascade training can efficiently transfer knowledge through all levels and between the three SOSO SSM IP's, provided that training remains relevant to existing processes. Moore et al. (2021) states that the development of a mature culture requires consideration of the technical and attitudinal elements during training, the positive examples of which should be cascaded and disseminated through the operational hierarchy.

In line with safety by design, ergonomic and operability considerations, establishing a mature culture is essential for attaining high safety standards from the start of operations. SOSO's comparatively short duration may impact on the cultural uptake due to insufficient time, resources or people to implement integrated OSHMS across a SOSO SSM site. The need to 'hit the ground running' with regards to safety, and adapt rapidly to variability within individual IP's requires a greater influence from vernacular safety. This is defined as the informal safety practices developed by individuals or teams from experience gathered over extended periods of interaction in safety-critical tasks. Skilled work naturally defines safe and productive methods for completing hazardous tasks through individual proficiency and experience, especially when workers are permitted freedom to share knowledge and take ownership of their own safety (Dekker, 2018). This approach can instil safety conscious mindsets among workers as they inherently accept responsibility for their safety, which can help to establish a new era of responsibility in mining with safety at its core.

3.9 Concluding statement

The IMP@CT report "Policy Statement, Standards and H&S Best Practice for Switch On-Switch Off (SOSO) Mining Operations" (Doyle, 2020) describes the on-the-ground work to consider OSH in a new paradigm of small-scale, low-impact selective mining (SSM). The aim of the IMP@CT approach is to maximise ore extraction, optimise processing, reduce E&S impact, mitigate the injury and fatality risk, and enhance resource security in Europe. A reduced workforce presence accompanies SSM innovations for agility, to enable rapid construction and commissioning, maintenance and decommissioning. This study has broadly examined the importance of safety by design, ergonomics and operability for optimising the occupational and operational safety of SOSO SSM.

Observations of virtual equipment designs prior to manufacturing allowed safety by design and ergonomics to be incorporated earlier in the process to optimise safety and reduce capital expenditure. Further observations of the pilot testwork facilities determined the minor and major hazards in SOSO SSM, requiring occupational safety management to control and mitigate risks and hazards to a reasonably practicable level. For suitable OSH standards, approaches and best practice for SOSO SSM, the whole mining system is reclassified into three ‘intervention points’. ‘Underground and/or surface mining’ (U/SM) is mostly human controlled and comprises all surface and sub-surface extraction activity. ‘Surface comminution’ (SC) is predominantly system controlled and comprises all crushing and milling activities. ‘Surface sorting & processing’ (SSP) is a combination of human and system control and comprises of all system modules involved in producing concentrate.

Bowtie analysis for mapping of causes and consequences of an unwanted top event manifesting from a known hazard within each IP informs the controls needed to block failure pathways. Despite significant attention paid to safety by design and ergonomic principles at the initial design phase, high-consequence events remain a major risk for personnel due to the human presence required in a semi-automated mining environment. Overregulation of safety and procedural clutter significantly contributes to the risk of harm, while skilled work naturally defines safe methods through individual proficiency and experience. ‘Hitting the ground running’ with regards to safety, with rapid adaptation to operating constraints within IP’s, requires greater influence from vernacular safety, defined as the informal safety practices developed by personnel or teams from experience gathered over extended periods of work, and individual initiative. In SOSO SSM, the informal practices adopted by frontline workforces can provide insight regarding safer and more efficient operational methods within each of the defined intervention points relative to the baseline procedures developed by permanent in-situ personnel and original equipment manufacturers.

4 Safety and socio-environmental culture perspectives in UK & Balkan mining operations

4.1 Introduction

There is potential for high consequence incidents in modern mining. The rarity of these incidents, despite work in hazardous environments, leads to the classification of organisations as having “high-reliability”, as defined by Roberts (1989). High Reliability Theory (HRT) outlines a series of “mindfulness” principles to guide high reliability organisations (HRO’s) towards maturity. *Preoccupation with failure* as described in Chapter 2 is important and can be applied using latent failures as lagging indicators of safety performance in HRT. In this chapter, safety culture perspectives are explored using deductive reasoning. This permits further investigation at UK and Balkan mine sites to address 3 HRT principles: (1) *Reluctance to simplify interpretations*, (2) *Sensitivity to operations*, and (3) *Commitment to resilience* (Hayes, 2006; Simpson et al., 2009; Vogus and Sutcliffe, 2007; Weick and Sutcliffe, 2007).

This study will holistically investigate attitudes and perceptions towards safety and socio-environmental impacts from mining personnel across the hierarchy on small- to medium-scale regulated sites in the United Kingdom (UK), Bosnia & Herzegovina, and Serbia. Ismail et al. (2021) explains that workplace cultures across the hierarchy informed themes such as management commitment, leadership, and worker ownership. We test the expectation that workers with extensive experience and education in the mining sector will be better placed than younger employees to manage safety in their occupations.

The aim of this chapter is to provide insight into the applicability of HRT’s mindfulness principles in a mining context, which has been previously applied in energy and other sectors. By considering the results obtained during semi-formal interviews from a HRT perspective, the prevailing safety culture in UK and Balkan mining operations can be contextualised towards the mindfulness principles. *Reluctance to simplify interpretations* is addressed by questions relating to the influence of worker reports and concerns on management decision-making and regularity of safety meetings and briefings, as they demonstrate an appetite for diverse views on issues. *Sensitivity to operations* is addressed through questions relating to management awareness of safety, environmental and social issues, reinforced by examples from interview participants, to demonstrate the extent to which individuals understand the operational system and associated impacts. *Commitment to resilience* is addressed by questions relating to management-worker and organisation-local community interactions when addressing known issues, and worker capability to recognise and react appropriately to workplace risks and hazards.

The additional concepts covered in Chapter 2 that provide a foundation to this study are perception-based models of safety culture and climate, and the development of a preoccupation with failure approach through analysis of safety performance. Relying on lagging indicators for monitoring safety can be overly bureaucratic and inefficient. Consideration of leading indicators can validate responses which ensures that the organisation is demonstrating safe working practices outlined in their policy commitments, accountability structures and training (Health and Safety Executive, 2001). The main assurance methods for typical organisational elements include leadership & accountability, training & competence, communication & consultation, and monitoring, auditing & reviews (Foster and Hoult, 2013, 2011). Contributory indicators drawn from each of these key leading indicators provide a means of proactive safety assurance (Bennett and Foster, 2005; Table 4.1).

Table 4.1: Leading indicators for assuring safety performance applied to mining operations from a cultural maturity perspective (Foster and Hoult, 2013, 2011).

Safety culture maturity elements	Leading indicators for assurance
Leadership & Accountability	Documentation outlining company/site hierarchy
Policy & Commitment	Policy statement, with proof of updates
Risk & Change Management	Records of risk assessment documentation
Legal Requirements	Internal records of legal compliance
Objectives, Targets & Performance	Records of agreed objectives & targets, with follow up meetings to assess progress against performance metrics
Training, Competence & Awareness	Training manuals, records of inductions, training workshops
Communication & Consultation	Stored records of safety meeting minutes
Control of Documents	Effective filing system for relevant safety documentation
Operational Controls	Operational manuals on hand for workers, engineers, etc.
Emergency Procedures	Emergency & rescue teams prepared; training carried out?
Incident Investigation	Incident reports and recommendations to reduce future risk
Monitoring, Auditing & Reviews	Internal and external safety reporting

4.2 Methods & Limitations

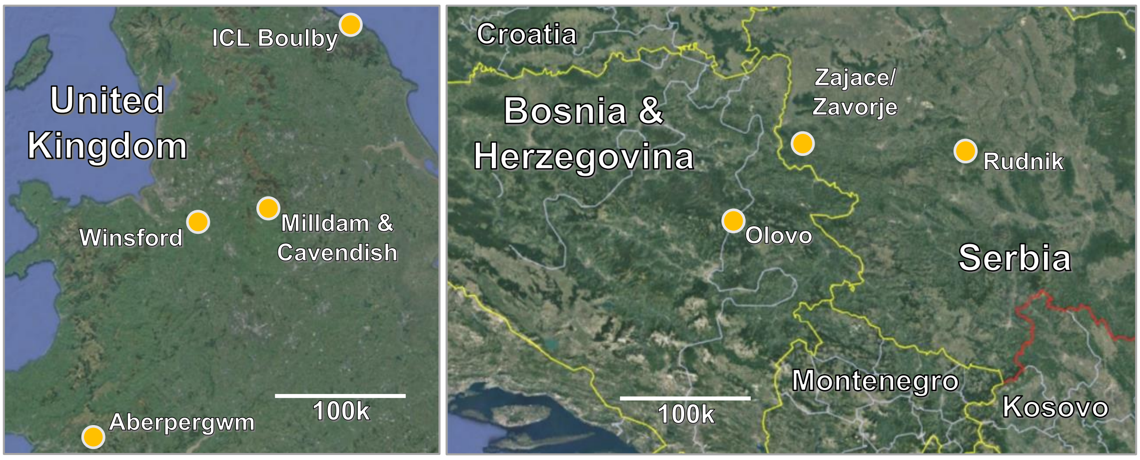


Figure 4.1: Regional maps with the locations of the 7 mine sites visited shown in yellow. Satellite images obtained from Google Earth (2022).

The initial literature review builds on safety culture research from chapter 2 by outlining the influences on cultural shift in high-risk industries and occupations, and by comparing established health and safety frameworks applicable to high-risk sectors. The historical context of UK and Balkan mining is described due to the influence of industry legacy on participant's cultural perceptions, in light of unique local sensitivities. This, along with published work on common safety culture influences, forms a key theoretical framework from which to analyse the prevailing perspectives of mining personnel using a participatory approach for a comprehensive view of culture trends in mining. High reliability theory provides an important analytical lens from which to frame interview responses within the principles of "mindfulness" and organisational culture. The 7 hard rock mining/ geo-exploration sites targeted for this study were located in the UK (Milldam/ Cavendish, ICL Boulby, Winsford, and Aberpergwm), Bosnia (Olovo) and Serbia (Zajace/ Zavorje, and Rudnik) (Figure 4.1), with 54 people interviewed. Interviews took place in the Balkans from 11th-13th November 2019, and in the UK between December 2021 and March 2022. The prolonged delay between fieldwork visits was caused by in-country and overseas travel restrictions enforced in 2020-21 during the Covid-19 global pandemic. Hence, time constraints permitted only a single day visit to each site, so the perspectives gathered from site personnel provided an indication of safety climate in each case, and inhibited a deeper safety-focused investigation of each mine site using the methods of assurance in Table 4.1. A combination of in-person and online interviews were conducted, from which participants in management or

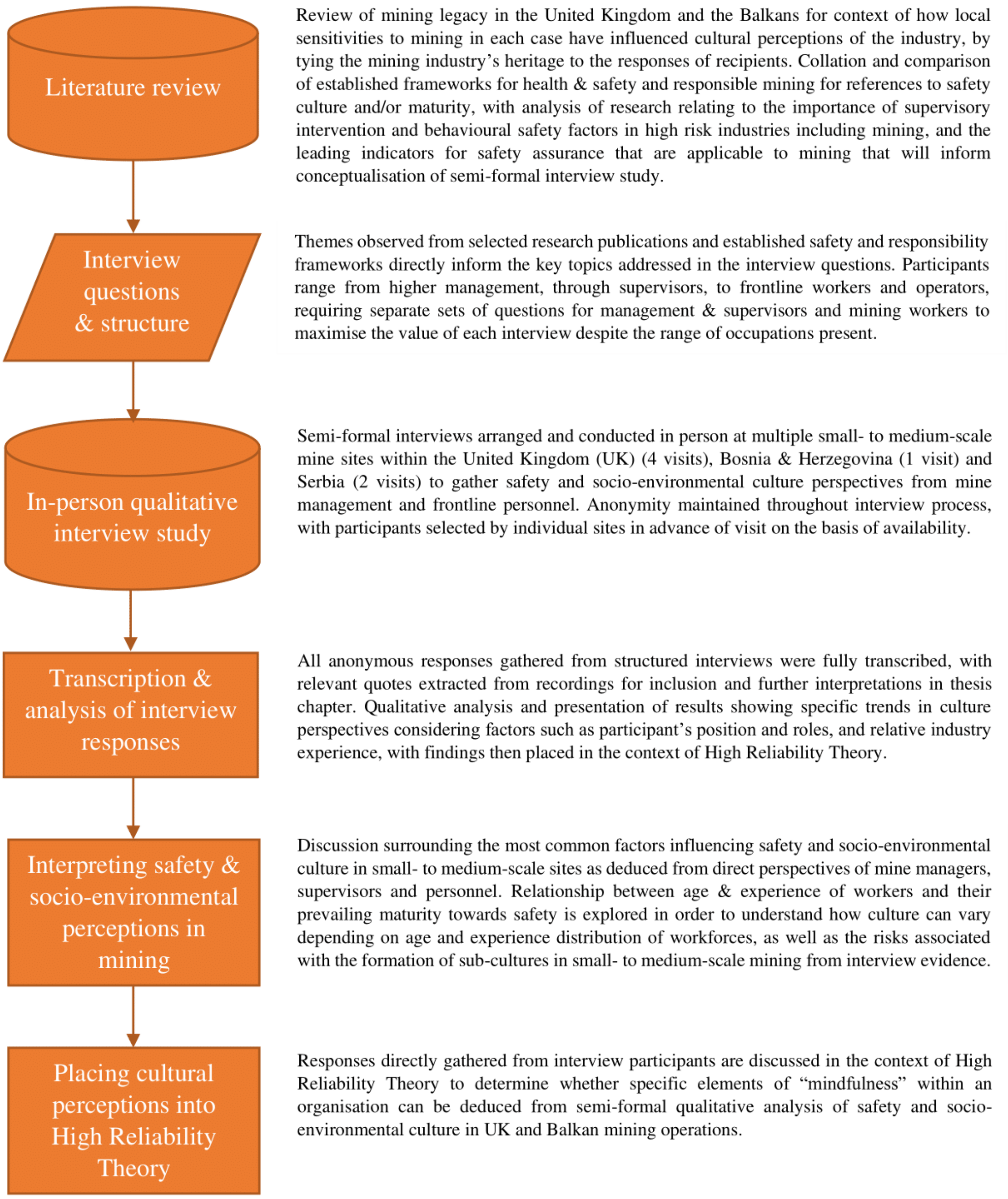


Figure 4.2: Methodology flowchart outlining process of data collection and literature review associated with chapter 4 study.

supervisory positions provided specific examples to support responses. Despite the suitability of questionnaires and surveys for rapid analysis of larger groups, Guldenmund (2007) describes them as a 'dirty' technique which may yield unreliable data due to an inability to control external influences and omit 'noise' from responses. Comparatively low numbers of available participants reinforces the suitability of semi-formal interviews for a qualitative study of safety culture. The use of semi-formal interviews is also advantageous as participants have capacity to convey much richer information and overall context within their responses, especially when dealing with technical and operational complexities.

Table 4.2: Basic statistics for all mine sites visited in interview study. Data is correct at time of writing.

Site name & commodities	Location	Workforce size	Production rate (tonnes per year)	Interview frequency	Supplementary sources
Olovo (Lead Cerussite)	Bosnia & Herzegovina	120 (as of 2019) 195-220 at present	120,000 (in 2019) 150,000 at present	6 (11.1%)	(Mineco, 2022a)
Zajace/Zavorje (Antimony)	Serbia	Currently under geo-exploration phase, mine reactivation is conditional.		5 (9.2%)	
Rudnik (Polymetallic: Copper, Lead & Zinc)	Serbia	450 (as of 2019) 470 at present	240,000 (in 2019) 295,000 at present	9 (16.7%)	(Mineco, 2022b)
Milldam/Cavendish (Fluorspar)	UK	65 at present	150,000 (in 2015) 120,000 at present	6 (11.1%)	(Robinson, 2015)
Boulby (Polyhalite, Potash plus, Salt)	UK	470 (as of 2018) 490 at present	450,000 (in 2018) 1,070,000 at present	14 (25.9%)	(BBC, 2018; Breen, 2018)
Winsford (Salt)	UK	112 at present	830,000 at present (10 year rolling average)	7 (13.0%)	
Aberpergwm (Anthracite Coal)	UIK	150 at present	250,000 at present (ROM tonnage)	7 (13.0%)	

Cultural alignment across hierarchies should differ between medium/ large-scale (i.e., Rudnik and Boulby) and small-scale (i.e., Olovo, Zajace/ Zavorje, Milldam/ Cavendish, Winsford and Aberpergwm) mines, from consideration of workforce sizes and production rate in Table 4.2. Comparing mine operational scales will be crucial for examining how cultural maturity can vary in practice.

Each interview contained between 11 and 15 set questions with opportunity for follow up questions based on responses given, and individual duration varying from 3 – 36 mins with an average length of 15 mins. The questions obtained responses and opinions from several specialist areas including general & technical managers, H&S officers, supervisors, technicians, and mining engineers (e.g., diggers, drill and blasting, mineral processing, environmental), which were fully transcribed and analysed. The full methodology is presented as a flowchart in Figure 4.2. All interviewees consented to their commentary being cited anonymously, and would submit written consent if they, or their company,

Table 4.3: Summary of participant roles across all interviews.

Interview	Site	Primary Role(s)
A1	Olovo, Bosnia and Herzegovina	Engineer, Environment
A2	Olovo, Bosnia and Herzegovina	Health & Safety Officer
A3	Olovo, Bosnia and Herzegovina	First Miner
A4	Olovo, Bosnia and Herzegovina	Explosives Engineer
A5	Olovo, Bosnia and Herzegovina	Assistant Digger
A6	Olovo, Bosnia and Herzegovina	Second Digger
B1 & B2	Zajace/Zavorje, Serbia	Technical Manager (B1); Safety Officer (B2)
B3	Zajace/Zavorje, Serbia	Assistant Miner
B4	Zajace/Zavorje, Serbia	Miner for Explosives
B5	Zajace/Zavorje, Serbia	Mine Supervisor
C1	Rudnik, Serbia	General Manager
C2	Rudnik, Serbia	Laboratory Manager
C3	Rudnik, Serbia	Flotation Plant Technical Co-ordinator
C4	Rudnik, Serbia	Supervisor, Crushing
C5	Rudnik, Serbia	Technical Maintenance
C6	Rudnik, Serbia	Miner
C7	Rudnik, Serbia	Drilling Miner
C8	Rudnik, Serbia	Miner
C9	Rudnik, Serbia	Technical Co-ordinator
D1	Milldam/Cavendish, UK	Senior Technical Services Manager
D2	Milldam/Cavendish, UK	Health & Safety, Mine Administration
D3	Milldam/Cavendish, UK	Training Officer; Explosives Co-ordinator
D4	Milldam/Cavendish, UK	Deputy Mine Manager
D5	Milldam/Cavendish, UK	Mine Manager
D6	Milldam/Cavendish, UK	Deputy Plant Manager
E1	Boulby, UK	Process Operator
E2	Boulby, UK	Senior Operator
E3	Boulby, UK	Mechanical Surface Supervisor
E4	Boulby, UK	Process Operator
E5	Boulby, UK	Production Manager, Infrastructure
E6	Boulby, UK	Operational Manager, Infrastructure
E7	Boulby, UK	Production Manager; Head of Operations
E8	Boulby, UK	Head of Operations, Mining and Infrastructure
E9 & E10	Boulby, UK	Infrastructure Supervisor; Assistant Infrastructure Supervisor
E11	Boulby, UK	Underground Face Overseer
E12	Boulby, UK	Production Miner; Safety Representative
E14	Boulby, UK	Head of Engineering
E15	Boulby, UK	Safety Manager
F1	Winsford, UK	Salt Operations Team Leader
F2	Winsford, UK	Despatch Controller
F3	Winsford, UK	Winder Man

F4	Winsford, UK	Process Operator
F5	Winsford, UK	Contractor Controller, SHEQ
F6	Winsford, UK	Technical Services Manager
F7	Winsford, UK	Assistant Mechanical Engineer
G1	Aberpergwm, UK	Health & Safety and Environmental Engineer
G2	Aberpergwm, UK	Assistant Health & Safety Manager; Training and HR Manager
G3	Aberpergwm, UK	Apprentice Electrician
G4	Aberpergwm, UK	Mine Manager; Company Director
G5	Aberpergwm, UK	Planning Manager
G6	Aberpergwm, UK	Miner (Bolting); Shuttle Car Driver
G7	Aberpergwm, UK	Electrician

wished to be acknowledged. Due to the risk of misinterpretation that predisposes respondents to certain answers, all interview questions were checked and approved by an ethics committee to ensure safeguarding against mission creep.

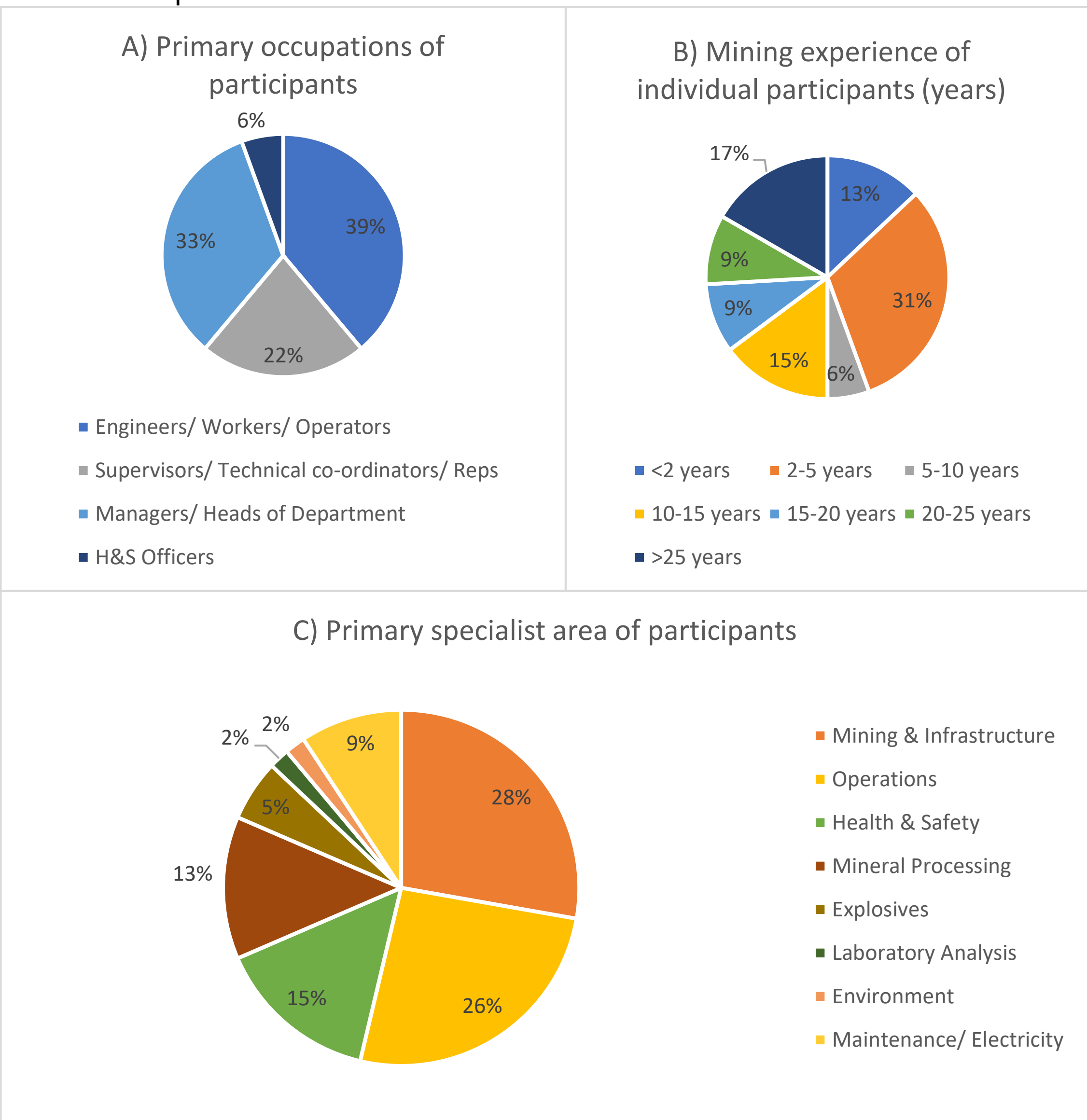


Figure 4.3: Circle charts summarising the distribution of interview participants by specific characteristic.

The topics addressed in the interviews included: (1) Characteristics of small-scale mines, and associated safety culture; (2) Worker age and experience as factors in how H&S is perceived; (3) How the scale of operations influences the severity of H&S, social and environmental issues; (4) Approaches to occupational H&S management in small to medium scale mining; and (5) Hazard identification and safety training methods for workforces. These were structured to examine culture variability between frontline workers and general managers, where the cultural gap is anticipated to be negatively correlated with site duration, as new operations are less likely to have a mature safety culture. It is anticipated that maturity is influenced predominantly by the management's overriding attitude towards safety, as cultural maturity is altered through top down shift. Summaries of individual mining and processing site statistics are shown in Table 4.2, interviewee roles outlined in Table 4.3, and participants' occupations, experience, and specialist areas on site are shown in Figure 4.3a-c. A balance of interviewees by hierarchical level (managers/ department heads vs workers/operators) mitigates risk of sample bias.

Qualitative analysis is preferred for obtaining detailed perspectives from participants, as safety culture is the product of individual and group values, attitudes and perceptions towards safety in an organisation (Health and Safety Commission, 1993). As shown in Figure 4.3a-c, the degree of skewness across all participants by factor (i.e., primary role and responsibility, experience in current role) is an important consideration when interpreting prevailing safety culture perceptions. A higher proportion of managers and officers relative to operators and employees within the interview pool may skew certain cultural perceptions as management may overestimate their safety, social and/or environmental standards due to reputational pressure.

4.3 Influences on safety culture shift in high-risk industries & occupations

The various pathways and approaches towards mature safety culture across several industries were discussed in Chapter 2, particularly for high reliability organisations where the outcomes of positive safety culture shift are most impactful. Safety culture is a shared mindset developed over extended periods of time, with maturity defining an organisation's response to cultural issues for continuous improvement. This differs from safety climate which is regarded as the prevailing perceptions of safety at a single point in time, which can be qualitatively or quantitatively reviewed to inform positive cultural changes (Guldenmund, 2000; 2007). Numerous studies, mostly or partly using semi-formal interview methods, have been conducted to qualitatively investigate safety culture and climate in transportation, manufacturing, energy, healthcare and mining (Ahadzi et al., 2021; Ben-Saed and Pilbeam, 2022; Bernard, 2021; Grinerud et al., 2021; Kalteh et al., 2020; Nævestad et al., 2020; Nordlöf et al., 2015; Tappin et al., 2015; van der Plank et al., 2016).

Emphasis on lagging indicators for safety management tends to promote a reactive culture that depends on accidents and near misses occurring to learn mistakes. 'Leading' indicators permit proactive OSH management through identification of risks and hazards to anticipate the system deficiencies before they contribute to a incident (Bennett and Foster, 2005).

"A leading indicator is a statistical time series that past experience has shown tends to reflect later changes and which thus can be used to forecast these changes because they precede the changes in a consistent manner and by a relatively constant time interval."

(Pass et al., 1995)

Numerous studies of safety culture for proactively reducing of fatalities, injuries and near miss incidents in regulated mining operations has indicated that the influencing factors on culture within mining remain poorly understood. Ismail et al. (2021) performed a systematic review of 33 peer-reviewed articles on safety culture from 12 countries, and developed 3 main themes (psychological, situational and behavioural) which were subdivided into several influencing factors. 'Psychological' refers to individual worker understanding and perceptions of safety, and is comprised of safety attitude, peer influence, safety knowledge, and perception of risk. 'Situational' refers to working conditions and site rules & regulations, and is the comprised of safety rules, accident & incident, reporting, working environment, and job satisfaction. 'Behavioural' refers to the collective attitudes expressed and actions taken by an organisation towards safety issues, and is comprised of management commitment, safety commitment, ownership of safety, safety training, safety communication, reward & recognition, safety investment, and worker's competencies. Systematic analysis indicated that 'behavioural' was most influencial in developing a mature culture, followed by 'situational' and 'psychological'. Therefore, demonstrating top-down organisational commitment to safety, permitting workers greater ownership, delivering quality training for high compentency, and investing in site improvements and recognition schemes are crucial for establishing a mature culture. Ensuring that good safety habits filter consistently through the hierarchy are are deeply embedded requires the prioritisation of safety over production.

From reviews of key elements and topics addressed in safety management frameworks, most attention has been paid to H&S compliance and bureaucracy, major hazard and risk management, employee competency and permitting, and working conditions (EBRD, 2014; EI Process Safety Committee, 2010; HSE, 2014; ICMM, 2018; IFC, 2012; IOSH, 2019; IRMA, 2018; ISO, 2018a).

Table 4.4: Comparison of regulations, frameworks and initiatives focusing on or including safety management between 2010-2021 (EBRD, 2014; EI Process Safety Committee, 2010; HSE, 2014; ICMM, 2018; IFC, 2012; IOSH, 2019; IRMA, 2018; ISO, 2018a).

Name	Main Health & Safety Topics Covered
Key: PS- Performance Standard, PR- Performance Requirement, P- Principle, R- Regulation.	
Energy Institute High Level Framework for Process Safety Management (PSM) (2010)	PSM Elements: 1) Leadership commitment & responsibility; 2) Identification & compliance with legislation & industry standards; 3) Employee selection, placement & competency, & health assurance; 4) Workforce involvement; 5) Communication with stakeholders; 6) Hazard identification & risk assessment; 7) Documentation, records & knowledge management; 8) Operating manuals & procedures; 9) Process & operational status monitoring, & handover; 10) Management of operational interfaces; 11) Standards & practices; 12) Management of change & project management; 13) Operational readiness & process start-up; 14) Emergency preparedness; 15) Inspection & maintenance; 16) Management of safety critical devices; 17) Work control, permit to work & task risk management; 18) Contractor & supplier, selection & management; 19) Incident reporting & investigation; 20) Audit, assurance, management review & intervention.
IFC Performance Standards (2012)	PS2) Labour & Working Conditions; PS4) Community Health, Safety & Security.
HSE Mining Regulations (2014)	R1) Health and safety management; R2) Control of major hazards; R3) Ventilation; R4) The mine environment; R5) Safe exit, escape and rescue; R6) Surveyors and plans; R7) Tips and tipping; R8) General (Records and mine plans); R9) Transitional provisions, repeals, revocations and modifications.
ISO H&S Standards (2015-2021)	ISO 9001:2015 – Quality management system. ISO 45001:2018 – Health and safety management standard (replaced OHSAS 18001). ISO 45003:2021 – Psychological health and safety at work.
EBRD Performance Requirements (2017)	PR2: Labour and Working Conditions; PR4: Health and Safety.

IRMA Standard for Responsible Mining (2018)	Social: 2) OSH, 3) Community H&S. Environmental: 3) Air Quality, 4) Noise and Vibration.
ICMM Performance Expectations (2018)	P5: Occupational health & safety performance.
IOSH Competency Framework (2019)	Technical competencies: 1) Health and safety law; 2) Risk management; 3) Incident management; 4) Culture; 5) Sustainability. Core competencies: 6) Strategy; 7) Planning; 8) Leadership and management. Behavioural competencies: 9) Stakeholder management; 10) Personal performance; 11) Communication; 12) Working with others.

The Energy Institute's process safety management framework comprises of 20 PSM elements which comprehesively outline minimum standards for process safety, where the energy industry's high-risk nature means that most elements have applicability to mining operations (EI Process Safety Committee, 2010). The ISO standards and regulations in Table 4.4 show relevance to mining, particularly with the introduction of the Mines Regulations which revised and aligned all pre-existing guidance on mine safety (HSE, 2014; ISO, 2018a). The 2019 IOSH framework aimed to optimise safety competencies among OSH professionals, and considers the cultural and strategic elements of safety management more than other standards and frameworks outlined. 'Culture' requires OSH professionals to apply themselves across organisations and strive for continuous improvement for the benefit of all stakeholders, particularly employee welfare and wellbeing (IOSH, 2019). These expectations link closely to the behavioural factors studied by Ismail et al. (2021) in terms of worker ownership, individual competencies, and reward & recognition. Enhanced self-confidence and morale among workers who consistently demonstrate safe working practices may encourage co-workers to exhibit similar behaviours.

Simard & Marchand (1994) explored supervisor behaviour in the manufacturing industry, concluding that their involvement in accident prevention positively contributes to occupational safety as key representatives for the workforce they are responsible for. Williamson et al. (1997) investigated the importance of workplace perceptions and attitudes to safety across a range of job types, revealing a consensus on some aspects of safety within the sampled workforce, which may provide more insight into how safety culture evolves over time. A site-based study investigated the factors influencing accidents from electrical equipment isolation (Mason, 1996) by looking at the attitudes and behaviours of craftsmen, supervisors and senior engineers in the UK coal industry. Significant criticism could be placed at the management's inability to communicate the importance of rules and procedures, as management exerted pressure to break rules and questioned the value of the Permit to Work system. The craftsmen's attitudes to rules, willingness to break them and overall commitment were linked to their perception that senior management paid inadequate attention to safety, even if those perceptions were false. Similar conclusions were found in a study of transport systems in South African mines (Simpson et al., 1996). But, the appropriateness of, and extent of cross-duplication in, rules and procedures for electrical maintenance is unclear. The impact of internal health and safety organisations (HSOs) on industry performance, through promotion of workforce-management interactions, was examined by Nielsen (2014). HSOs are effective for generating culture shift as indicated by improvements in safety performance, communication, and injury rate. Extensive academic-led research and industry-facilitated guidance has greatly advanced understanding of the key influences on safety culture for reducing incident occurrence in high-risk industries. Studies of safety culture perspectives described here will build on existing work by investigating overriding perceptions from the UK and Balkan mining sectors.

4.4 Fieldwork observations from semi-formal interviews in the UK and the Balkans

4.4.1 Historical context of participant responses

> "We used to come under the mines and quarries act of 1954… most of the regulations [were] written because somebody died… the HSE, who we're regulated by, in 2014 brought all of that together… to try and make it more of a modern regulation encompassing everything that could be there but still got a lot of the legacy British Coal regulations… the British Coal standard was top notch, [now] it's like we've gone across and changed direction, because it was ahead of its time… we train people here to that standard and bring in things like the national occupational standard so we're trying to meet that benchmark…" [G4].

The UK is renowned for its long history of coal production in the early 19th century with coal mining employment expanding to 216,000 in 1841, including men, women and children, which drew people away from agriculture and manufacturing (Bourdenet, 2003). Working conditions in coal mines was revealed publicly in Royal Commission reports from 1842, highlighting that children and young people worked excessively long hours while exposed to extremely hazardous conditions (Royal Commission, 2021). 69 fatal mining accidents were recorded in the UK coal industry between 1820-1839, the worst of which being a major underground explosion in 1835 at Wallsend Colliery in Northumberland (Winstanley, 2016). Increasing mining fatalities in combination with the Royal Commission's report placed pressure on the UK government to reform the industry by regulating employment and working conditions, leading to the Mines and Collieries Act in 1842 (Bourdenet, 2003; UK Parliament, 2021). Further legislative reforms through the mid-19th century further improved working standards across all UK operations (see Table 3.2).

Industry nationalisation in 1946 placed 800 coalmines under public ownership in order to improve wages and working conditions, and to invest in new equipment to reduce exertion from manual labour. The National Coal Board (NCB) was established to manage the industry and facilitate the post-war recovery of the coal industry (EconomicsOnline, 2020; WCML, 2022). However, the industry's decline began in the 1960's as railways were curtailed in favour of diesel and electric, leading to disputes and strikes over wages and premature closures in the 1970's and 80's (Macalister et al., 2015). Cheaper imports from Russia and Poland accelerated the closure of deep mines (The Guardian, 2015), while electricity privatisation exposed British Coal to greater competition by alternative energy supply sources (Robinson, 1989), leading to industry privatisation in 1994 and the demise of the NCB in 1997 (EconomicsOnline, 2020; Macalister et al., 2015). The deep mining expertise present at the height of coal extraction in the early 20th century diminished as the remaining UK mines were gradually shut down between 1997 and 2015 following commitments to transition away from coal power (The Guardian, 2015). The Health and Safety Executive produced the 2014 Mines Regulations compiling existing mining regulations, including legacy standards and procedures from British Coal, into a single document, omitting any outdated and cross-duplicated guidance (HSE, 2014). Past experience from the UK coal industry has been instrumental for developing OSH best practice standards and training appropriate for modern, regulated operations. Well-developed induction and refresher training programmes bolstered by committed leadership can instil mature safety attitudes among new workers, thereby generating a high level of safety culture from the outset.

> "Since privatisation… a large amount of money has been invested in H&S at work, we recently bought new safety equipment for all the workers in the company… but the money investing can't be dominant while planning, H&S depends on people and their training and the relations between them… right after the mine was privatised, a large amount of money has been invested, but the number of injuries didn't reduce… only after we realised that the problem is in the mind of people, and when the workers realised that [they] are responsible for their own H&S, the situation improved…" [C1].

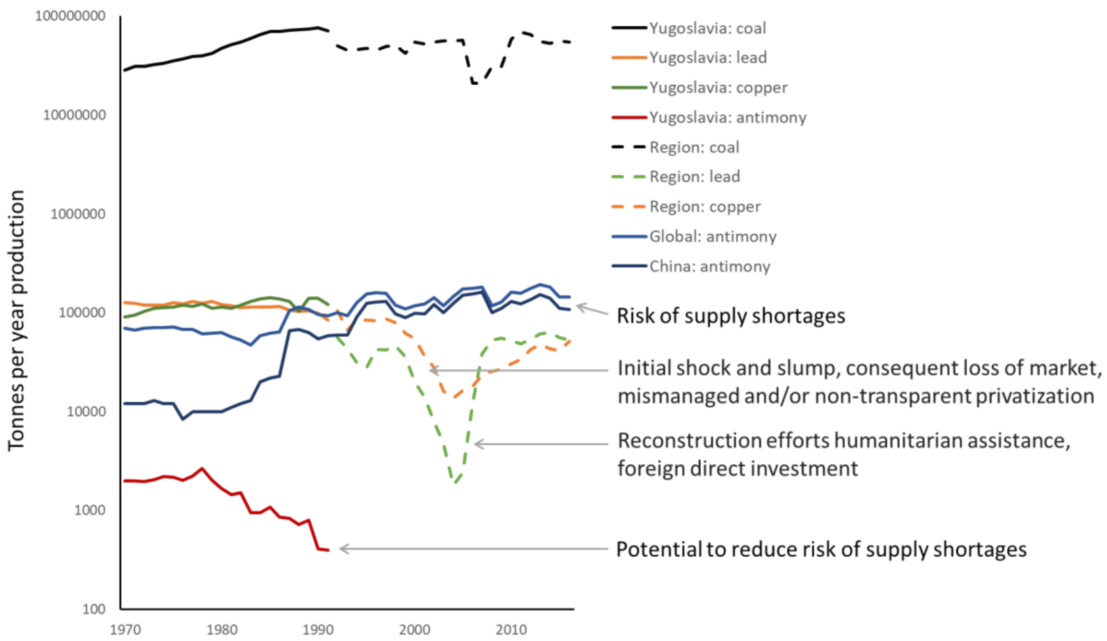


Figure 4.4: Raw materials production of selected commodities prior to, and following the onset of the Yugoslav Wars in 1991 (BGS, 2022).

Prior to Yugoslavia's dissolution, Bosnia and Herzegovina produced high quantities of steel, bauxite and aluminium, with minor lead, zinc, manganese extracted at Srebrenica, Olovo and Vares. Serbia comprises mainly of porphyry copper and massive sulphide deposits with extensive copper, lead, zinc and coal and minor gold, silver, bismuth and cadmium (Figure 4.4). Pollution from numerous legacy mines threaten the health of local rivers which impact local water supply (Egerer et al., 2010). This leads to detrimental effects on local reputation due to negative public perceptions, especially in Bosnia & Herzegovina which remains deprived of semi to highly skilled workers who emigrated during and after the 3 year war (Barnes and Oruc, 2012).

Although Bosnia was an industrialized region in Yugoslavia, many districts faced reindustrialization challenges related to the declining post-war economy, the complexities of Bosnia's political structure, and widespread unemployment. Between 2000-2010, many Yugoslavian mineral deposits were considered unprofitable due to increasing competition, metal price fluctuations, and limited economic opportunities (Calò and Parise, 2009). The resurgence of the Balkan mining industry has been slow due to few investment opportunities and the diaspora of skilled and educated citizens displaced by conflict in the 1990's. The lack of skilled and semi-skilled workers inhibited domestic economic development which impeded progress in the reform and harmonisation of national mining laws and regulations. Bosnia and Serbia have steadily declared interest in foreign direct investments, and while interest from foreign mining operators is still moderate, they've begun to form a partial mining sector in the Federation of Bosnia, Republika Srpska, and Western Serbia. Development of mines by private international companies can provide economic and societal benefits to the host country, and facilitate improved safety standards relative to other non-privatised operations and associated industries.

Mine development may lead to tensions between companies and communities accustomed to the traditional behaviour of state-owned mining enterprises, with the project feasibility being characterized by the special fragility of the local setting. Beyond managing the financial, logistical and technical problems associated with reopening a mine, special consideration must be given to the sensitive social circumstances in Bosnia & Herzegovina (Boege and Franks, 2012). Social deprivation present in the Balkans as a legacy of past conflict emphasises the need for secure employment in conflict-affected regions, with high quality training and education provided for new and existing employees, and local sourcing of materials. Privatisation encouraged greater investment to address these requirements and fund higher quality safety equipment for mining workers. Despite widespread safety improvements, lagging indicator data from one mine visited in this study revealed that injury rates didn't decrease, which resulted in site management paying greater attention towards behavioural factors and safety culture for reducing occupational injuries.

4.4.2 Safety culture perspectives

The purpose of this study was to establish safety culture perspectives, which required a basic scope of the interviewees' feelings regarding occupational health and safety. The managers and supervisors were first asked 'How would you describe safety culture in a mining context?' to understand their baseline attitude and understanding of safety culture in their occupation, with their responses summarised below in Table 4.5.

Table 4.5: Summary of key characteristics and factors associated with safety culture in mining using direct perspectives from interviews.

Primary factor	Supporting quote from semi-formal interviews
Widespread implementation of rules and regulations	*"Safety is paramount, it has to be paramount because you work in a high risk industry so therefore you have to be very stringent in your rules and regulations to make sure that that safety factor is, firstly, there, secondly, used, by all the workforce from top to bottom… all people have to work for the safety side of things" [E7].*
Worker education and training	*"Safety culture is developed mainly through education and different courses, and actual work at the mine itself, and application of the occupational safety measures… if miner is educated we can pass all sorts of law and byelaws, make some decisions, but they cannot be applied if they have no proper education of the miners… we have a positive legal framework defining environmental protection and safety measures, but if they do not have the proper trained and educated miners we cannot really put it in practice" [B1].*
Understanding major hazards	*"Clearly mining is a major hazard industry and one of the main thrusts of the current version of the mining regulations is around major hazards… which typically are ground control, inrush, fire, escape & rescue, electrical hazards, plant, maintenance of plant… So, as a safety culture we try to instil upon our workers the nature of the mining operation being a major hazard operation and everybody needs to be aware that everything that they do is a hazardous operation… we have to work towards, as a management team, providing the tools and procedures to mitigate those hazards… safety culture is about making sure everyone's working from the same playbook to generate a safe working environment" [D1].*
Investing in people	*"My philosophy is when you involve people that are doing the job, they become valued and you get a truer way that they're actually doing the job… hazards are identified rather than somebody just throwing the book at them and saying that's how you've got to do it and walking away, that's reactive not proactive to me, it's involving people on the job" [D3].*
Worker ownership of safety	*"Safety culture improves from year to year, because since we are approaching EU, we made our laws to be compared with their directives… since privatisation, a large amount of money has been invested in H&S at work, we recently bought new safety equipment for all the workers in the company, the best helmets, protectors, boots, but the number of injuries didn't reduce… only after we realised that the problem is in the mind of people, and when the workers realised that themselves are responsible for their own H&S, the situation improved… our main focus is that the injuries get to zero" [C1].*
Mine safety unions and representation	*"I've been working here for 25 years and the culture of H&S is growing a lot, also as a representative of the union I was involved in lots of international seminars and I can see an increase in H&S culture, also right now [participant] thinks that people need to be trained a lot, to give them books about first aid, fire protection, environmental impacts, so that they can educate… [participant] talks a lot with the employees here, and if they have any concerns or problems with the H&S, it's dealt with immediately with the H&S team at the mine" [C4].*
Prioritising safety over production	*"As we are now compared to 20 years ago the safety comes first, and the mindset of I would hope most of the workforce, they would stand up to the manager, the supervisor, and say 'look I'm not happy, can you come and have a look at this, I don't feel safe, it isn't safe in my opinion', and I would hope that [they] would come straight down and they would have a look at it and they wouldn't turn around and say 'well just get on and do it', they would stop*

	production whether that's surface, whether that's down the mine, whether that's Tees Dock, and that culture's changed over 20 years" [E1].

Development of a strong, mature safety culture from the perspective of mining personnel relies on the consistent application of rules and regulations for compliance, ensuring that workforces have a baseline expectation regarding occupational safety. In situations where the environment or job type carries a heightened level of risk, specialised education and training courses help ensure that workers operate safely within their occupation, which is especially important when new equipment or working procedures are introduced. In underground environments, the major risks and hazards dynamically evolve as ore extraction progresses which must be monitored to inform necessary action to manage the associated risk. Techniques such as 'Take 5', used by workers in hazardous environments to actively assess the safety of the work area, benefit this process by permitting workers autonomy to make decisions affecting their safety. This relates to the behavioural and attitudinal aspects that influence safety culture, by instilling the mindset that people carry responsibility for their own safety which encourages personnel to take ownership. While mining operations must be profitable, they cannot run efficiently if safety standards aren't maintained.

"When you do a job safely and you keep doing it safely, you become a lot more efficient so your production becomes easier" [D3].

4.4.3 Using worker reports to guide safety improvements

High-level safety culture depends on how management and employees interact and work together to solve safety issues. Despite workers generally reporting that most of the workplace safety norms are respected, and that management, supervisors and H&S officers are instrumental in implementing changes, some expressed concerns with regards to occupational safety. So, the question 'How much have worker reports and concerns influenced your decision-making from a H&S perspective?' was asked of the managers, officers and supervisors.

"In case of an injury, the worker is obliged to fill out a report stating everything that happened… they spend a lot of time asking the workers what they think could cause injury… to build a database of possible injuries that could occur… that's key information that they use to solve anything in regards to H&S" [A2].

“We take it very seriously and I take it to heart as well because I’m one of them… so if the instruction is coming from a shift supervisor and the workers come in and complain about it, it’s either the instruction might not have been safe or they’re not educated well enough to know how to do it safely” [D4].

“I think it’s about having clear communication, I do sit with safety reps on a monthly basis, so it’s about taking them seriously, hearing what they’ve got to say, obviously it’s about trying to influence them to [see] what they can do… from our standpoint I’ll take the other side of that coin maybe where I’ve got to speak with senior management to say what we can do” [E15].

The key themes observed from responses are constructive communication and collaboration on safety (i.e., PPE, major hazard awareness) between managers, supervisors and frontline workers, consistent reporting of near misses and injuries, and ensuring an understanding of shared responsibility for H&S across the company’s hierarchy. Participants A2 and E15 highlighted the importance of cooperation and instillation of increased worker autonomy and initiative. This does not nullify the responsibilities of senior safety personnel in developing the organisation’s H&S strategy and implementing changes to reduce accident to an acceptably low level. The effectiveness of solutions towards reported issues and concerns gives insight into management commitment to improving conditions, and worker perspectives of safety importance.

“Most of the injuries we had was when a piece of rock falls on the toes, so we transferred to boots that have metal support but they are heavy so it’s not really easy to walk that far, but on the other hand they know that those boots will protect them, so we made a compromise and found boots that are light but also protective… the workers know best, what the problems are that they encounter while working… we took some of the workers from every part of manufacturing and we gave them the equipment to test it to see if it works… after a month they gave a written report, what did they like about it and what not, then we intervened with the one who produces the equipment to [see] if they can change something to meet our needs, and now they are happy with it” [C1].

4.4.4 The importance of worker age & experience in mining

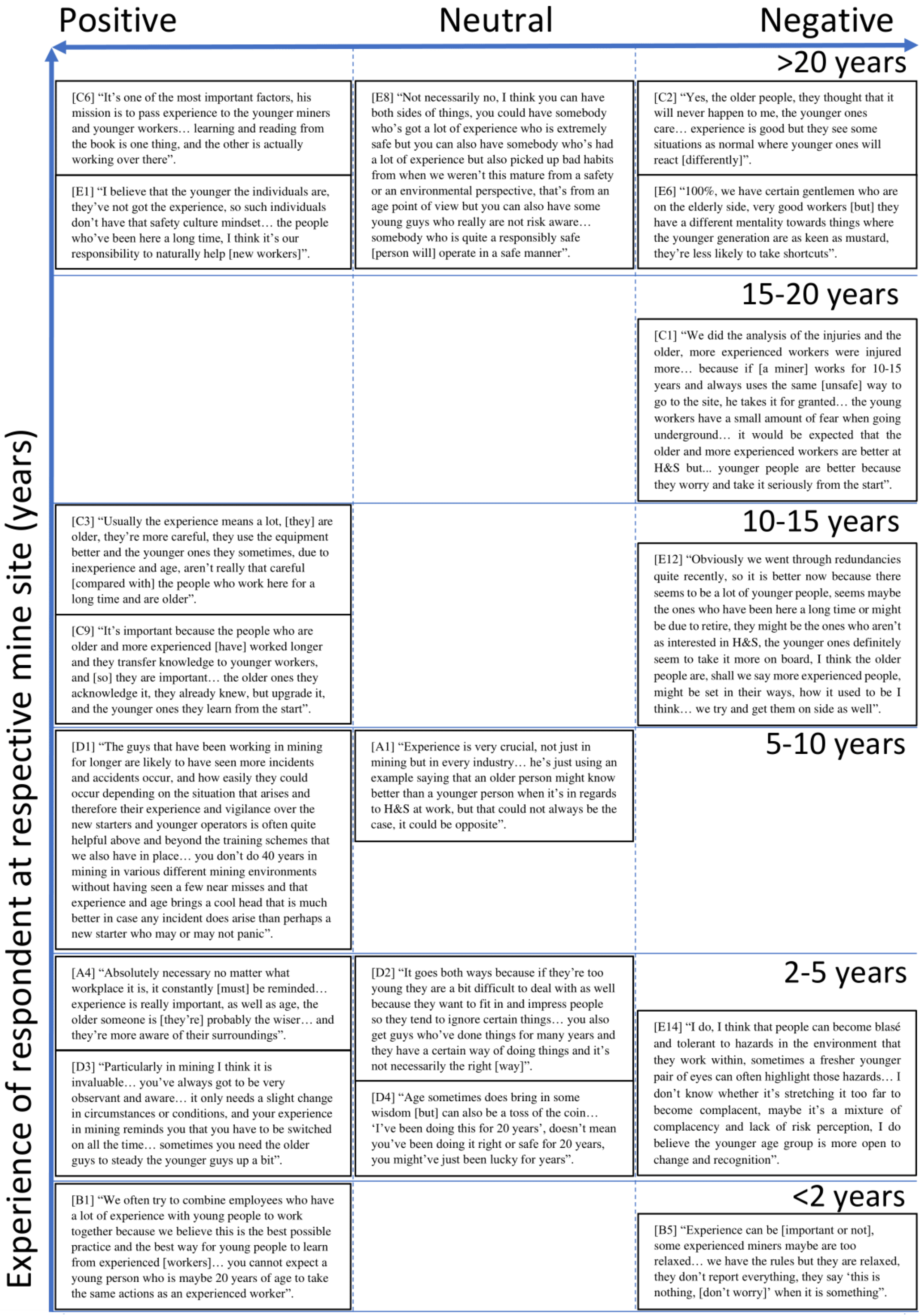


Figure 4.5: Relative perceptions of importance of greater age and experience arranged by experience of individual participant, with examples directly obtained from interviews.

The majority of interviewees, regardless of hierarchical position, were asked about their opinion regarding whether age and experience of employees are important factors in how H&S is perceived and the results varied considerably

(Figure 4.5). Participants from larger-scale sites tended to have greater experience within their respective occupation while those at smaller-scales comprised of personnel with less experience, but this did not consider previous experience each participant may have had due to inconsistent responses. The comparatively lower sample base for smaller operations in this study may cause skew depending on the participants selected relative to the larger-scale sites. Responses focused on the behavioural and attitudinal variation between older and younger workforces compared with other health-related factors such as cognitive function and recuperative ability (Margolis, 2010), likely due to the prevalent theme of safety culture throughout the interviews. Participants with a positive perspective of higher age and experience described older workers favourably in terms of their ability to mentor and impart good safety practices to younger, less experienced colleagues within their particular areas of work. On the other hand, participants with negative opinions described older workers as being complacent and 'blasé' with regards to personal safety, with the younger workers demonstrating greater enthusiasm and consideration for safety than older workers. Figure 4.5 also demonstrates that the range of perspectives gathered are widely distributed and consistent regardless of the experience held by each participant at their respective site at the time of study.

4.4.5 Managing social & environmental impacts and concerns

The managers, officers and supervisors across 3 mining and geo-exploration sites in the Balkans were also asked about examples of environmental and social issues that occurred as a result of their operations, and how they were dealt with. The key themes from this question are tailings management and effluent discharge into local environments and ecosystems, the organisation's responses to complaints, and reporting requirements to meet local compliance.

"In the nearby town, they had a meeting where they had a question about our work on the tailing pond, we asked the people from the government in town to visit us, they were most of the people who belong in that team including the people who asked… unfortunately their former knowledge was minimal and that's why they were wondering and asking about the [tailings pond]… they didn't know the details of our manufacturing but they really don't have to know

it, because all the reports about the state of water, air, dust go to governmental institutions who take care of it and control it".

"A few days a year when the water from the pond exits, when it's filtered and is released to the stream, sometimes it carries a little bit of Iron oxide, and where it exits, it can colour the pond in a reddish colour… and it causes a worry to the local community but it's not really a thing to be worried about because it stays right there, so it also happens 1 or 2 days a year when the level of water is extremely low… in the next year it should be part of our investment plan that we build a small filtration plant which could filtrate even those particles".

From interviews with participants from the 4 UK sites, some similar trends were observed regarding socio-environmental concerns and known impacts from their respective operations.

"As part of our legacy we have a number of open pit operations, they're predominantly restored now however there is one that is still in restoration and will be for some time and as our tailings dams are all now in restoration there's only TD4 which is used as a water monitoring facility so we just cycle water through it while the plant's running… the tailings are dewatered and used as a restoration material for our quarries… which will leave a small legacy feature that will contribute to the natural beauty of the national park… there's quite a lot of old mining that gradually nature reclaims and creates a beneficial landform".

"One of the ecological things that they usually look at is the amount of water you extract [and pump], and they want to know volumes, what is in the water, what is the acidic levels of it… we actually filter our water first through natural processes and if you have broken rock, pump your water behind broken rock so it can scrub it, so every time if we deal with the environmental agencies, we send off test results, and then we look at it and see what we need to change".

The main concerns that local communities in the both the UK and the Balkans have with regards to mining, as reported by the managers, officers and supervisors of all five mines visited, are:

- Overall health and wellbeing while living near the mine due to light, noise & dust pollution from surface activities conducted at night, trucks passing nearby villages and settlements, and mineral processing emissions.

- Overall environmental impact of the mine during active operations from tailings and/or processing effluent emissions, particularly on pastoral and arable land, as well as the potential for pollution of local water supplies.
- Structural integrity of the tailings facility post-closure, and potential for collapse and/or effluent leakage following shutdown and reclamation.
- Premature closure of the mine, leading to loss of direct local employment and community investment potential.

4.4.6 How scale affects implementation of standards & impact mitigation in mining

Mine managers and supervisors were asked whether the scale of a mining operation influences the ease with which H&S standards are established and maintained. A number of participants agreed that "with the increase of the mining operation, the number of people working increases, [hence] the more work that there is to do then there's more risk of injury… so it needs more effort [to manage]". Therefore, it is expected that more safety resources and training would be required in a large operation comprised of a larger workforce, in order to maintain a mature safety culture. Others decided that operational scale is irrelevant with regards to applying safety standards and meeting compliance.

"As soon as you start to mine, as soon as you start to process, as soon as you start to load a ship, whatever you do there's a standard you must follow no matter how much you do, no matter what you do, however big [or large], you've got to have your standards of health and safety and your H&S mindset" [E1].

Managing safety at different scales is influenced by the presence of applied engineering and management roles and responsibilities both underground and at surface. Small-scale mines tend to lack the resource base to hire personnel for these specialized positions, while comparatively larger mines have the financial capability to establish departments and sub-departments to deal with complex operational issues (e.g., geological and structural monitoring, mine design, ventilation, safety, and compliance). Smaller operations will typically comprise of sub-teams with fewer individuals compared with conventional large-scale mines, which simplifies the process of communicating safety messages and procedural changes when there are fewer people to inform and persuade.

"A small mine with 10 people working an old fashioned system… won't have a safety engineer and a training engineer and a ventilation engineer… supervisor numbers would be down as well… on the scale that we're working we've got all those in the management structure, bolting engineers, rock control engineers, safety engineers, training managers, all the way through the remit" [G5].

"The more people who are buying into something and the volume and size of something, it's sometimes a little bit more difficult to communicate… it's always easier to get your message across to three people and to supervise closely to a [small] room with three people in it… I'd say the bigger the operation, tactics need to be used differently" [F1].

The crucial factor with regards to scale affecting safety implementation appears to be the workforce's collective understanding of the major risks and hazards associated with their occupations and how knowledge is applied in practice. This impacts the prioritisation of safety over production as the inherent risk awareness and competency of workforces greatly influences attention towards reducing incidents, by assessing and interpreting local working conditions.

"If [any workers] tell me there's a problem then the job will stop… I'll go and have a look at it and I'll make a decision as to whether we do something to try and rectify it and make it safer, or whether the job stops completely" [E11].

"If anyone's got a safety issue, we raise it as a safety defect… any major serious incident will be done and dealt with the same day if we can, or the task will be stopped until we can do it, we don't take chances" [F7].

Furthermore, the local and regional working culture that exists off-site can be a key influence on an individual or team of workers' awareness of, and attitude towards, occupational safety matters observed on-site.

"H&S in the workplace is not that respected in this country, at the technical offices they have put the scaffolding up with no harnesses, that's just the working culture within this country, no-one pays much attention to it" [A2].

4.4.7 Recommendations for improvement

The final question asked was 'what one thing would you change or do differently to improve safety on your site?', and some participants were content with their situation and could not suggest anything new with regards to safety. However, several provided areas for improvement for the mining industries in the UK and the Balkans based on their own perspectives.

Table 4.6: Summary of safety improvement suggestions from responses given by interview participants arranged according to categorisation in Table 4.4.

Primary factor	Suggestions for changes or approaches to improve safety standards
Widespread implementation of rules and regulations	○ Updated national mining laws & regulations, and greater harmonisation with company/site standards. ○ Introduction of act enforcing regular completion of risk assessments at work. ○ Continual improvement and evaluation of existing safety systems using best practices from elsewhere within the mining industry.
Worker education and training	○ More strict and relevant introductory training measures for new miners entering underground operations (e.g., 1 year as non-qualified worker before promotion to qualified miner). ○ Reinforcement of safety and hazard awareness within the workforce itself, through relevant refresher training and daily reminders from supervisors regarding PPE requirements and safe working practices such as 'Take 5'.
Understanding major hazards	○ Identification and control of major hazards associated with the mining environment from operations commencing and throughout the life of mine. ○ Use of real-life examples of mining accidents to deliver message regarding the importance of mining safety with greater impact than with training alone.
Investing in people	○ Greater focus on cultural and behavioural change through engagement in safety and risk perception from the working teams. ○ Avoiding a blame culture by instilling trust within the workforce that the primary purpose of investigating incidents is to learn from mistakes. ○ Higher awareness in local communities through education and open days. ○ Increased employment to support existing workforces unless more automated mining/ processing solutions are adopted.
Worker ownership of safety	○ Using culture maturity to educate workforces on how they can demonstrate initiative in safety matters such as major hazard and risk awareness. ○ Investment in smart technology and connectivity underground to encourage greater autonomy within the workforce in terms of reporting safety concerns.
Mine safety unions and representation	None of the feedback from participants directly related to safety unions, but there may be crossover with worker ownership as employees who raise concerns via representatives will typically be more invested in personal and workplace safety.
Prioritising safety over production	○ Use of safer alternative types of equipment on site (i.e., metal support structures to replace timber, safer explosives, less aggressive laboratory chemicals). ○ More time, resources and dedicated personnel to support commitments to the continuous improvement of workplace safety.

Many of these suggestions can be closely related to the majority of the key factors associated with safety culture in a mining context, except for mine safety representation and unions which may interconnect with worker ownership of safety (Table 4.6). Due to the high quantity of cross-duplication in responses, the suggestions are populated as summary bullet points for brevity. Participants in management roles tended to make suggestions relating to mining laws, acts, regulations and standards, owing to their operational knowledge of local, regional and national context. Participants in frontline roles (i.e., miners, process operators, drivers) provided feedback regarding worker education and training in hazard awareness, use of safer alternative equipment, and greater provision of resources. Suggestions relating to the organisation’s investment in people and worker ownership of safety on site were not specific to a particular hierarchical level or occupation.

4.5 Discussion

4.5.1 Effect of age, experience and site scale on cultural perceptions in mining

The impact of worker age and experience on occupational safety is varied, with the majority of responses were in favour of the benefits of experience, especially when they can effectively transfer knowledge onto younger, less experienced employees. Studies by Kao et al. (2008), Gyekye & Salminen (2009), and Ahadzi et al. (2021) are in agreement, stating that older workers are typically more positive, enthusiastic and constructive about safety culture than younger workers, and are better placed to inform cultural development. A few participants stated that experienced workers tend to be more complacent towards occupational hazards, by prioritising production over safety and cutting corners to complete tasks quicker. Participants who held a positive, or optimistic, viewpoint regarding age and experience described older workers as role models with the capability to mentor younger workers and transfer best practice knowledge. Experienced workers can exhibit more risk awareness and caution in high risk situations which is instilled through years of exposure to previous incidents and near misses. Participants with more hazardous primary responsibilities may inherently demonstrate greater safety maturity through advanced risk and hazard awareness, especially if they have prolonged experience in industry. Hence, it would be reasonable to infer that older, experienced workers are demonstrating cautiousness and humility, which in this context refers to individuals acknowledging that, despite their experience working in high-risk environments, they are not immune to a serious injury or fatality in the future. On the other hand, some participants were more negative

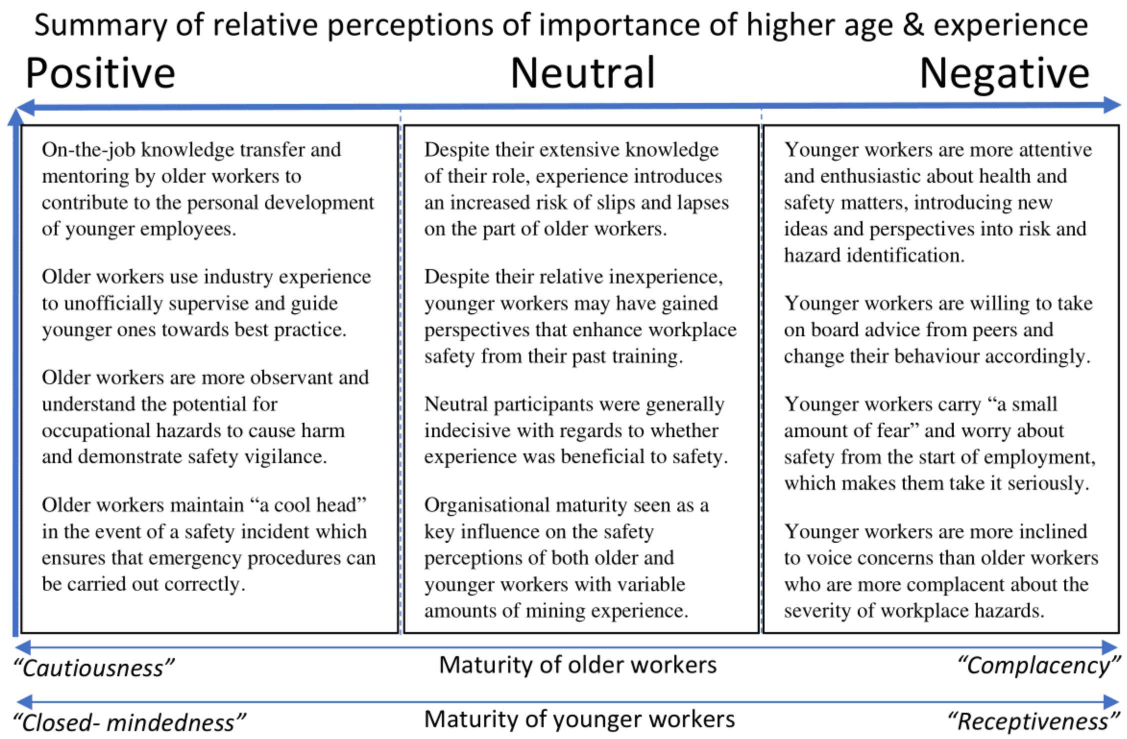


Figure 4.6: Summary of Figure 4.5 outlining key themes in perceptions of the relative importance of higher age and experience for improving safety deduced directly from participant's responses.

and pessimistic about how experience affects uptake of safety maturity, describing older workers as narrow-minded, 'blasé', and 'set in their ways'. Experienced workers may demonstrate a relative lack of risk awareness and perception due to an underlying complacency which stems from their extensive exposure to major hazards throughout their careers. Therefore, they can be at risk of underestimating the severity of occupational hazards leaving themselves more vulnerable to harm, particularly in active underground environments.

From the perspective of younger workers, the perceptual relationship between is primarily inverse meaning that complacency within older workers tends to highlight receptiveness to change among younger employees, while cautious older workers can accentuate the closed-mindedness of younger individuals. Receptive younger workers tend to display an appetite to learn and develop as professionals, understanding early that safety is a key priority in high-risk occupations. Conversely, closed-minded younger workers may assume that they have sufficient background knowledge about the major hazards associated with their role and in turn not fully appreciate the dynamic nature of occupational risks in mining, increasing the risk of lapses and errors in judgement (Figure 4.6). A key consideration is whether the perspectives gathered are to be taken

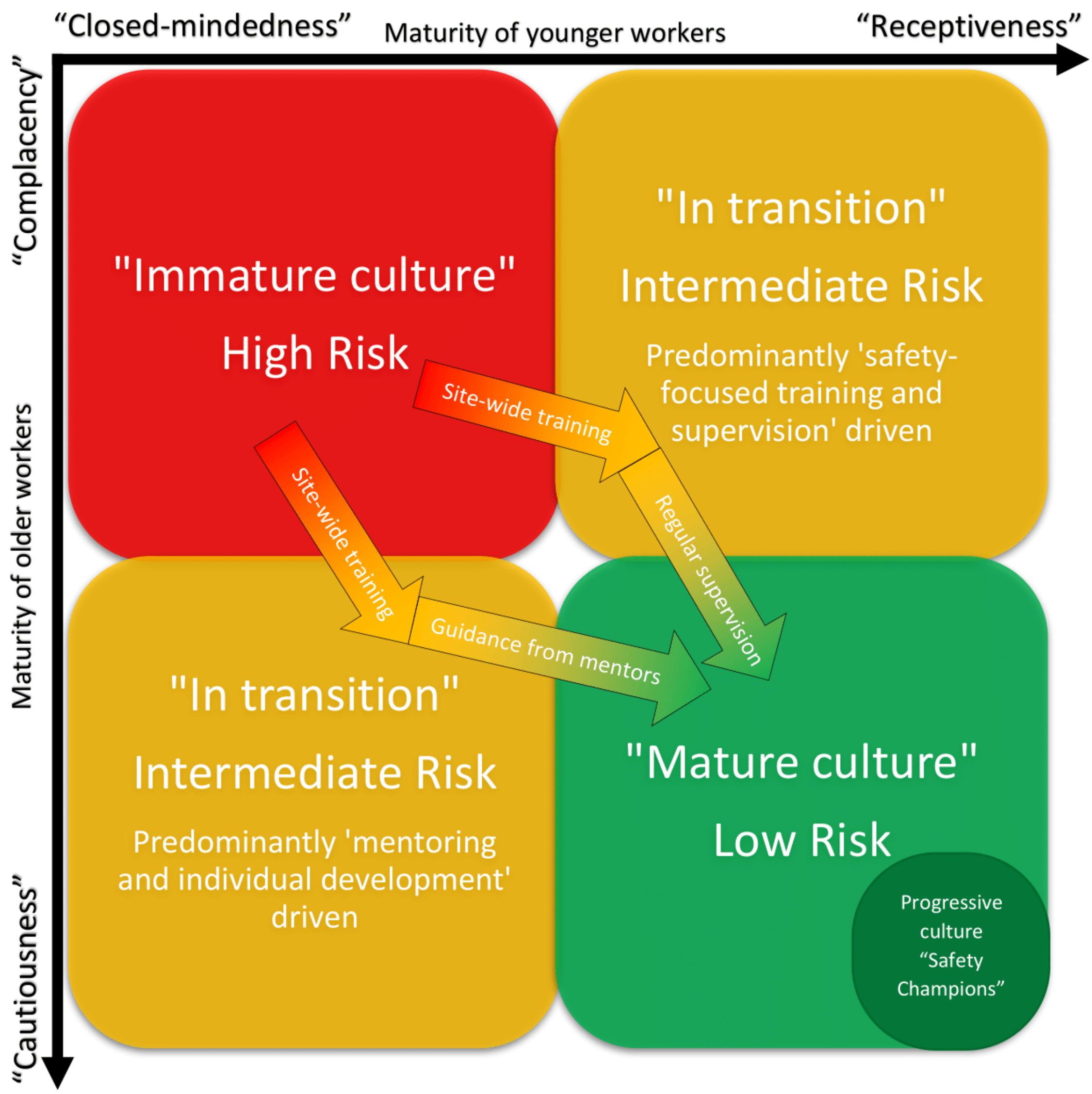


Figure 4.7: Safety maturity matrix illustrating relative cultural variability and improvement pathways in response to varying attitudes towards safety from younger and older workers at their respective sites.

at face value, or whether the age and experience of the respondents creates a skewed impression of their younger co-workers. Due to respective attitudes towards safety, it is possible that older workers who are more conscientious and careful may bias towards observing unsafe behaviours among younger employees, while complacent workers may place younger workers more highly in their estimations.

Figure 4.7 illustrates the relationship between the safety maturity of older and younger workers in terms of how organisational culture varies due to their overriding behaviours, using individual qualitative perspectives gathered from interviews as a proxy variable for this analysis. Based on the range and responses of participants involved in the study, it is proposed that younger workers are those individuals with less than 5 years of experience within their

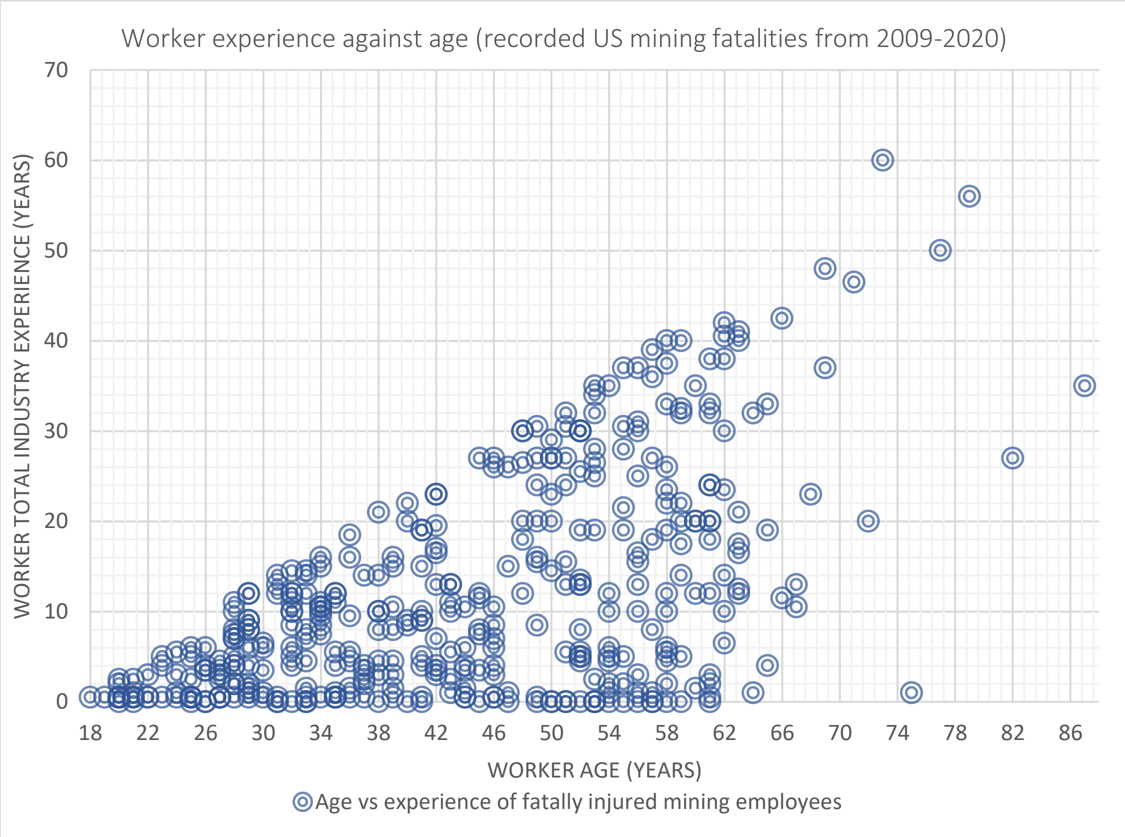


Figure 4.8: Total industry experience plotted against age of workers suffering fatal accidents in US mines from 2009-2020 recorded in Mine Safety and Health Administration database (2020b).

present role, while older workers are those with 5 or more years of experience. "Immature" safety cultures are dominated by complacent older workers and closed-minded younger workers, due to the comparative lack of caution towards safety issues across all levels within the workforce. Site-wide safety training is interpreted to be a crucial pre-requisite for moving away from immaturity by encouraging and fostering more cautious behaviours among older workers and more receptive attitudes among young workers. Cultures that are "in transition" are comprised of either receptive younger workers or cautious older workers, which requires safety-focused training & supervision, and mentoring & individual development respectively for the workforce to advance towards greater safety maturity. Progressive, "forward-thinking" cultures are possible with an inferred critical mass of highly receptive younger workers and cautious older workers who may represent either an individual team, the department or the organisation as "safety champions". The variation in opinions regarding the influence of worker age and experience on injury or fatality likelihood is reflected in data obtained from past MSHA fatality reports (Figure 4.8) (Mine Safety and Health Administration, 2020b). The darker circles relate to denser clustering of data, indicating that most individuals suffering fatalities are between 20-35 years old with 10 years of experience or less. Fatalities remain common in persons aged 60 or less, particularly those with limited experience, with some anomalous post-retirement fatalities. Figure 4.8 reinforces the importance of worker experience in reducing incidents because some older workers suffering fatal injuries lacked experience being new entrants into the mining sector.

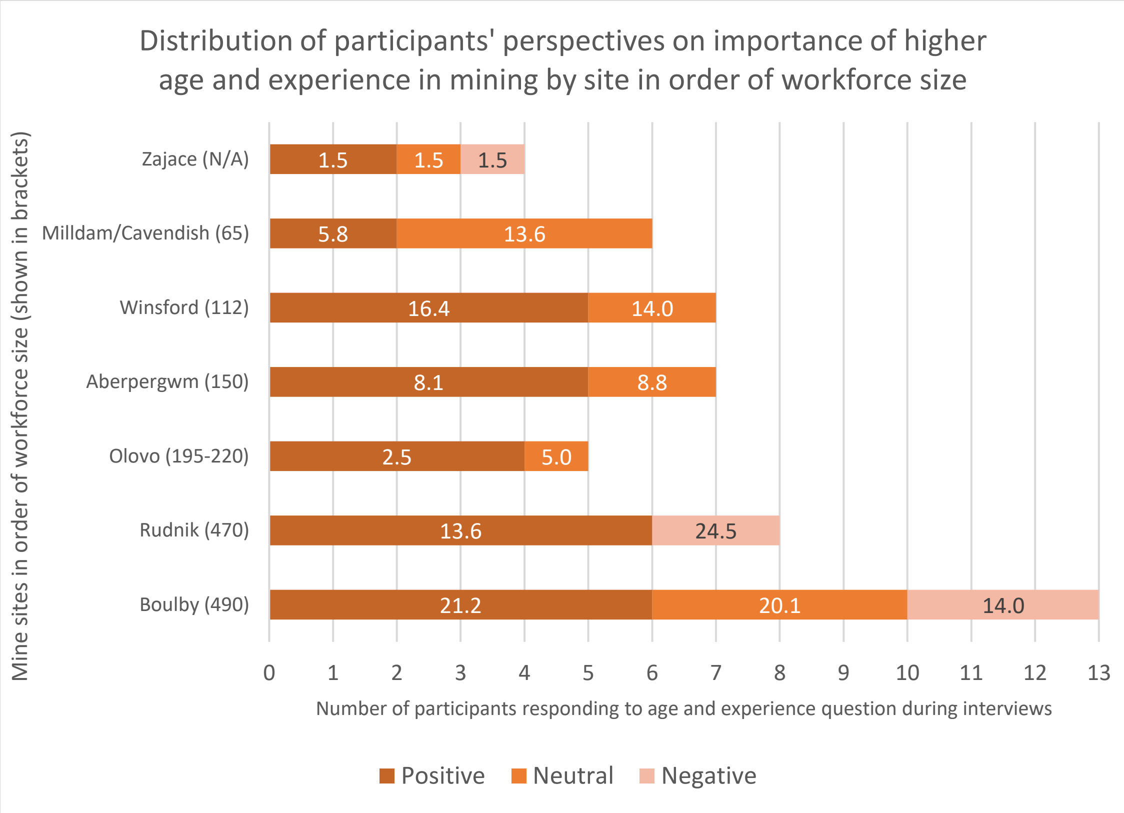


Figure 4.9: Distribution of individual perspectives regarding the importance of higher age and experience from participants by site, with average years in post of individuals providing opinion towards higher age and experience.

The apparent distribution of safety attitudes and perceptions among workers may also support the existence of 'sub-cultures' within high-risk organisations, which occurs as small groups of workers, usually forming around existing subdivisions, develop unique attitudes that don't align with wider organisational perspectives (Chandler, 2010). Sub-cultures tend to manifest and grow most rapidly in larger organisations with complex bureaucratic structures and numerous departmental branches with various levels of independence, as they include a wide range of functions and technologies (Trice and Beyer, 1993). Some sub-cultures may underestimate the importance of safety and respond negatively to and perhaps resist attempts to improve organisational culture (Nævestad et al., 2021). Conversely, other sub-cultures may develop mature perceptions towards safety than the wider organisation which permits greater initiative and ownership of their own safety relative to higher management. The presence and quantity of sub-cultures is likely to be proportional to operational scale due to larger workforces which introduces a wider range of personalities on site, some of which may carry unique opinions and perspectives.

Figure 4.9 shows that participants at larger sites, irrespective of location, show a broader range of opinions on the importance of older and more experienced workers on site relative to smaller operations, but there is a lack of correlation between the chosen opinion and the average time participants were employed. As sub-cultures are expected to develop within departmental sub-teams rather than within groups of workers with similar time in post, more data is required to verify whether these opinions would correlate better across specific occupations and departments. Further studies should focus on the variation of perceptions at diverse operational scales and workforce sizes using a larger sample size to investigate the consistency of the relationship between age & experience and their attitudes and perceptions of safety.

The scale at which a company operates is an important consideration since comparatively smaller plants or operations may have insufficient budget or personnel available for driving improvements in safety standards. Bureaucratic approaches used by HSOs for example, has implications for the long-term success of these specialist departments in protecting worker safety, especially in smaller organisations with fewer resources. Organisational scale appears to affect the level of management intervention required to inform workers on safety and achieve a collective ‘buy-in’ from workforces. Scale may be less important from the perspective of management commitment as smaller-scale operations develop their cultural maturity more readily due to reduced workforce numbers and ‘team spirit’ among frontline colleagues. Conversely, the impact of scale on mitigation of socio-environmental issues caused by mining should be more significant as sites with higher production rates and footprint have the potential to cause incidents with more extensive impacts depending on the extracted commodities and processing methods used.

Variation between the management team’s stated approach towards safety and the action observed by workers was also identified from interviews. Participants from one mine reported issues with support structures, emergency access/ egress routes and worker fatigue, which were not mentioned by management when they were anonymously questioned about any recent concerns affecting their workers. Participants from a larger mine gave multiple examples of how safety and socio-environmental concerns were addressed and solved, including unsuitable work boots, excessive spacing between ladder steps, visual contamination of local streams, and dust pollution. Small-scale operations are interpreted as being more prone to poor culture due to smaller workforce sizes and management team available to enforce high standards on site. This may be driven in part by the "silo mentality", described as an unconscious behaviour in which individual departments cannot or choose not to share information with others, which impacts production efficiency and overall team morale (Gleeson, 2013). These silos exist across vertical specialisation areas (e.g., production, marketing, quality control) and horizontal segments (e.g., higher management, senior leadership and frontline employees), and can have detrimental effects on team identity (Cilliers and Greyvenstein, 2012). Distribution of worker age and experience, leadership quality and commitment, mining phase (exploration vs active operation), and geographical and societal factors may also play a role.

The factors affecting how safety culture is developed or impacted are complex and multi-faceted, requiring a certain level of maturity from management to consider all these factors carefully and strategically overcome them before poor safety culture can pervade. The importance of education and training was widely emphasised in terms of ensuring that workforces can (1) understand the regulations and standards being implemented, (2) safely operate complex, high-risk equipment and machinery, and (3) identify minor and major hazards in their work areas. Higher levels of education also allows more freedom when updating and steering policy, as workers will better understand any changes made and why they have occurred. Proper education and safety training also provides workers with skills to think critically about the work environment, which benefits management as they receive more detailed safety reports, as well as their younger, less experienced colleagues through on-the-job knowledge transfer. The quality of training programmes is fundamentally arranged and delivered by the operating company, which can be independent from the prevailing national laws and regulations that must be updated to ensure they are relevant and fit-for-purpose. Due to the lack of regulatory reform in developing nations, mining companies with private ownership often set their own standards which may inform new laws and byelaws, producing a mutually beneficial relationship between companies and local governments for sharing of best practice safety.

4.5.2 Evidence of HRT principles in safety culture perspectives

High reliability organisations (HRO's) are structurally complex with overlapping interdepartmental responsibilities and interconnected risks with varying levels of severity towards individuals within the organisation, yet safety performance is maintained to a high standard. Hence, "high reliability" refers to the ability for organisations to prevent unwanted safety events by establishing a culture of continuous learning from previous incidents and near misses, which contributes to the overall "mindfulness" of those team members (Beyea, 2005). The HRT principles outline how organisations construct and maintain a comprehensive and accurate understanding of safety across their operations, through an inherent preoccupation with failure, a reluctance to simplify interpretations of safety, a sensitivity to the state of the operational system, a demonstrable commitment to safety resilience and an ability to grant responsibility for decision-making to expert individuals on the frontline (Hayes, 2006; Simpson et al., 2009; Vogus and Sutcliffe, 2007; Weick and Sutcliffe, 2007, 2001).

Table 4.7: Selected HRT principles and definitions from Weick & Sutcliffe (2001) with factors relevant to each principle deduced from interviews. Modified from Vogus and Sutcliffe (2007).

HRT Principle	Definition	Relevant factors from interviews
Reluctance to simplify interpretations	Taking deliberate steps to question assumptions and wisdom for a complete and nuanced picture of ongoing operations	Questions relating to the influence of worker reports and concerns on management decision-making and the regularity of safety meetings and briefings, as they demonstrate a need to seek diverse views on site issues.
Sensitivity to operations	Ongoing interaction and information-sharing about the human and organizational factors that determine the safety of a system as a whole	Questions relating to management awareness of safety, environmental and social issues affecting the operation, reinforced by examples given by participants during the interviews, to demonstrate extent to which individuals understand the operational system and its wider impacts.
Commitment to resilience	Developing capabilities to detect, contain, and bounce back from errors that have already occurred, but before they worsen and cause more serious harm	Questions relating to the organisation's ability to prevent incidents with safety, environmental and social risks through management-worker and organisation-local community interactions, and the capability of workers to recognise and deal with minor and major workplace risks and hazards.

The HRT principles were published as part of Weick & Sutcliffe's Mindfulness Audit (2001), which have since informed the Safety Organising Scale (SOS), a quantitative methodology developed by Vogus & Sutcliffe (2007) which was later modified and applied by Teske & Adjekum (2022) to investigate HRT and safety management systems. Studies of "mindfulness" and SOS contributed a greater understanding of the key factors needed to instil mindful behaviours among personnel in order to establish a mature safety culture in HRO's. Haslam et al. (2022) investigated and modelled the shared social identity that informs the collective psychology of a HRO, interpreted as organisational culture, and highlighted the importance of top-down identity leadership. High-reliability cultures are maintained most effectively through implementation of integrated SMS in order to manage prevalent safety risks and ensure that verified controls are effective (Teske and Adjekum, 2022; Vogus and Sutcliffe, 2007). While the SOS methodology has been used for analysis of culture and mindfulness in HRO's in the healthcare and aerospace sectors, consideration of three of the five high reliability principles in a mining context is possible using qualitative data from the semi-formal interview study. Table 4.7 is modified from Vogus & Sutcliffe (2007) and summarises the three selected principles, as well as how the responses obtained from specific questions relate to each principle.

Demonstrating a *reluctance to simplify interpretations* within an organisation requires management, specialists and representatives to actively encourage workers to voice concerns, and respond appropriately when concerns are raised. An understanding of working conditions "at face" is established through open dialogue between frontline workers, management and supervisory teams to accelerate the process of finding solutions. If reported issues are too serious to continue work, then management should pause operations to allow adequate time to rectify problems, unless workers are empowered to act independently. Openness to accept criticism also enables management teams to identify and maintain records of patterns in the types of safety concerns reported, which can influence system or procedural changes conveyed through safety meetings and briefings. Representatives are especially useful in larger organisations for helping to convey concerns of individuals facing difficulties in speaking with higher management due to pressure from other personnel or lack of confidence. Representatives are responsible for disseminating relevant information to workers after safety meetings, meaning that updates to rules and procedures aren't cascaded as often as broader organisational changes which can inhibit worker involvement in safety updates. Through dialogue and transparency in knowledge sharing, safety and socio-environmental deficiencies are prioritised, with continuous learning from past incidents to inform development of rules and regulations while appreciating the complexities associated with daily work.

Discussions relating to *reluctance to simplify interpretations* links closely with the organisation's *sensitivity to operations*, which is deduced from interactions and interdepartmental knowledge-sharing, which should be integrated and transparent. Workplace design and accessibility greatly influences individual behaviours and attitudes, especially if production pressures shift attention away from safety, as workers will be compelled to use shorter but less safe routes to complete tasks. Initiatives such as "Take 5" can permit workers autonomy to independently assess risks and hazards in their own workspaces and discuss concerns with peers and supervisors. Regular feedback provides a clear picture of working conditions at face which maximises the applicability of site updates and action plans. Operations are often very resource- and energy-intensive depending on scale and processing techniques, where organisations are responsible for managing consumption and preventing the effluent release into local environments.

Organisations that regularly monitor and report site inputs, processes and outputs are well placed to manage socio-environmental risk through awareness of operational issues that might detrimentally impact local communities and ecosystems.

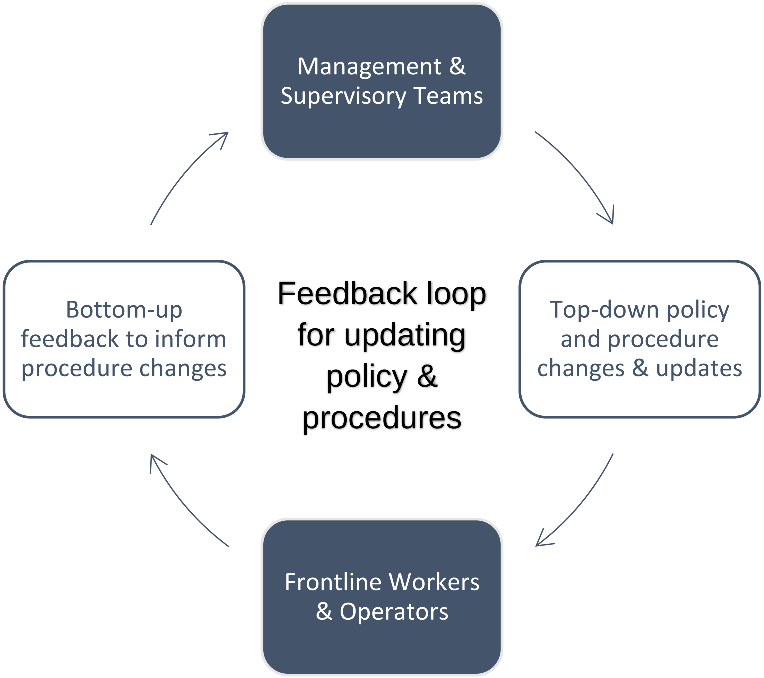


Figure 4.10: Basic feedback loop between management & supervisory teams and frontline workers & operators.

Features of a high reliability organisation's *sensitivity to operations* are also linked to their *commitment to resilience* because those organisations that actively develop and implement initiatives and strategies to mitigate safety and socio-environmental risk are better prepared to respond if a similar incident occurs later. Resilience is bolstered by a collective understanding of both the minor and major risks that manifest through normal operations, which is instilled during initial and refresher training. Site-wide meetings provide an interface between workers, supervisors and managers to relay top-down updates and bottom-up feedback, which informs further top-down updates (Figure 4.10).

Maintaining trust is built upon clear reciprocal communication and transparency regarding known and probable risks facing communities as obtained from reporting and complaints. Internal meetings consolidate understanding of local issues and instigate discussions regarding possible solutions for preventing socio-environmental harm and maintaining strong relationships with stakeholders. These societal factors all have important implications for public reputation and SLO status which is essential if operations are to prevent local conflict fuelled by distrust (Costanza, 2016; Hurst et al., 2020; ICMM, 2014; Thomson and Boutilier, 2011). The SLO is embedded in perceptions held by local people, and evolves with the requests of communities, authorities and other stakeholders, requiring ongoing dialogue and collaboration (Gunningham et al., 2004; Thomson and Boutilier, 2011). Sensitivity of mining organisations towards socio-environmental risks is crucial for instilling collective attitudes that allow the organisation to promote best practice in stakeholder engagement and environmental management. The selected HRT principles show applicability to modern, regulated mining as observed from this qualitative interview-based field study. Future work should use established tools for analysing HROs to reinforce understanding of the characteristics of mining organisations with a mature safety and E&S culture (Cantu et al., 2021).

4.6 Concluding statement

This study was carried out to holistically explore safety and socio-environmental culture perspectives from managers, officers, supervisors and workers at seven small- to medium-scale mines in the UK, Bosnia & Herzegovina, and Serbia.

The interviews addressed the characteristics of small-scale mines and their associated culture, worker age and experience as factors in how H&S is perceived, how scale influences the prevalence of H&S, social and environmental issues, approaches to occupational H&S management in small- to medium-scale mining, and hazard identification & safety training methods for workforces. Qualitative examples of how safety, social or environmental issues have occurred and how they were resolved provide insight into best practice that has been implemented in small- to medium-scale mining operations.

Participants from all hierarchical levels were questioned on their understanding of safety culture in mining. Continuous scrutiny and vigilance regarding lagging and leading indicators were determined as essential for a mature culture, informed by regular, integrated communication. Implementation of new standards and regulations frequently is important for instilling confidence and trust in workforces, so that they know their H&S is being prioritised, even if national regulations are unfit for purpose. Identifying workplace risks and hazards by miners is also vital if mature culture is to be maintained, through training, communication and encouragement to report safety concerns.

The quality of grassroots education and training courses is key as it allows the organisation to pass new laws and byelaws which employees can understand and act upon to make their job safer. This also provides workers with the skills to think critically about their work areas for more detailed safety reporting. Collectively, these aspects of individual attitudes towards safe jobs and work areas describe how employees take ownership of their safety culture. Opinions on whether experience was beneficial in mining were varied, with most participants stating that experienced workers are valuable for instilling best practice onto younger employees. Others said that older, experienced workers can take situations for granted, putting themselves at greater risk by not fully appreciating prevalent risks by taking shorter but less safe routes for example.

Recommendations for developing safety and socio-environmental culture in mining include (1) Updated national mining laws & regulations, (2) Introduction of new acts for risk assessment, (3) Use of safer alternative types of equipment, (4) Employment of miners to support existing workforces, (5) Local awareness of mining through open days, and (6) Increased awareness of safety through refresher training. The safety climate trends observed across all 7 sites have implications for prevailing culture by individual locality and within the industry.

High-reliability “mindfulness” principles published by Weick & Sutcliffe (2001) were applied in a modern, regulated mining context using data from semi-formal interviews to determine the HRT characteristics of mining organisations. In relation to *Reluctance to simplify interpretations*, management, specialists and representatives must actively encourage workers to voice concerns, and respond appropriately when reports are raised. Workers’ behaviours and attitudes to safety are influenced greatly by the design of their workplace and production pressures, as workers may be compelled to use shorter routes to finish the job quicker at the expense of personal safety. In relation to *Sensitivity to operations*, permitting autonomy to independently assess risks and hazards through training and “Take 5” initiatives enables feedback to be relayed to colleagues, supervisors and higher management, further promoting a mature culture. In relation to *Commitment to resilience*, Organisations that utilise worker and community feedback to develop or optimise safety initiatives and strategies to mitigate risk are best prepared to respond if similar incidents occur in future.

While top-down decision-making is fundamental to setting the groundwork for safety culture in HRO’s, cultural maturity is maintained through communication between frontline workers, supervisors and management to encourage learning and improvement. While major regulatory advances facilitated safety progress as the mining industry modernised, recent improvements have focused on culture and collective “mindfulness” towards operational risks and impacts.

5 The application of safety culture maturity & sustainability principles for assessing environmental and social performance in mining

5.1 Introduction

Organisational and operational risks are being increasingly evaluated by their potential socio-environmental impacts, which are informed by environmental, social and governance (ESG) ratings that enable investors to measure a company's prevailing attention towards ESG risks. Measured ESG performance drives investor decision-making through support for projects that are prepared to manage the expected environmental and social impacts of their operations. The ESG guiding principles are designed to encourage greater sustainability and responsibility from operating companies with regards to their business practices and strategies for socio-environmental stewardship (Maybee et al., 2023).

Conventional ESG and responsible mining frameworks allow companies to transparently report their performance against standards to demonstrate accountability (EBRD, 2014; GRI, 2021; ICMM and GRI, 2010; IRMA, 2018). As discussed in chapter 3, regulatory interventions from a health and safety perspective significantly reduced the occurrence of harmful incidents, with further progress made through the implementation of organisational culture maturity. This study transfers the principles of existing health & safety culture initiatives and frameworks to manage E&S aspects, forming a novel approach to E&S culture maturity that is applicable to modern, regulated mining, with emphasis on self-assessment and reflection built into the methodology. The scope is limited to natural capital and social capital, with particular focus on the evolution of socio-environmental regulations and their role in facilitating improved E&S performance in modern, regulated mining.

The aim is to encourage greater environmental and social responsibility in mining by providing organisations with the means to self-scrutinise their current performance and increase awareness of existing attitudes towards impacts that have direct and indirect implications for local communities, authorities and ecosystems. This will be achieved by using criteria-driven, facilitated maturity models that address prevalent E&S risks associated with mining operations from the perspective of all impacted stakeholder groups. The E&S models each comprise 4 levels that progressively increase in maturity, with the goal being to move up the culture ladder by implementing the suggested criteria for each stage, including factors such as community involvement, employment opportunities, energy use, and air quality. The focal stakeholders are those who experience the most considerable socio-environmental impact from operations, such as local communities and vulnerable minorities, local governments & related authorities, and on-site personnel.

The case studies chosen for the application of these models are located at 4 small- to medium-scale mining operations across the UK: Milldam/Cavendish, ICL Boulby, Winsford and Aberpergwm. A broad range of industrial mineral commodities are extracted including fluorspar, polyhalite, rock salt, and anthracite coal, each creating unique challenges from an environmental and social perspective. It is inferred that the status of a mining project is primarily influenced by the level of trust between the company, local communities and authorities. The applicability of maturity modelling for understanding baseline socio-environmental culture for informing and encouraging continuous improvement towards ESG issues in modern, regulated mining will be explored.

5.2 Methods & Limitations

The conceptualisation of criteria-driven maturity models is underpinned by empirically tested culture models and informed by recognised sustainability initiatives and frameworks to provide a robust foundation from which to examine the environmental and social culture of participating sites. The practical collaborative approach chosen for this research provides a comprehensive overview of culture from each study group through open dialogue that mitigates any predispositions towards comparatively biased views and perspectives.

Semi-formal discussion groups were facilitated with senior and frontline team members who reviewed the criteria within in each category and formed a consensus on an appropriate score for each, except in cases where individuals were interviewed alone. The 4-tier culture maturity models enable traditionally qualitative information to be classified quantitatively through scores awarded based on the response that aligns closest the present situation for each criteria sub-category. Scores will be presented as radar plots to enable direct comparisons between sites, and to interpret how environmental and social culture maturity differs across various small- and medium-scale mines. The participants included management, H&S managers, HR representatives, and environmental and/or social specialists due to their extended knowledge and understanding of E&S matters associated with their operation. Recording equipment was used for transcription purposes but no identifying details of participants was obtained, unless written permission was provided during or following each visit. This E&S maturity study is placed in the context of leading

Figure 5.1: Methodology flowchart outlining process of data collection and literature review associated with chapter 5 study.

indicators for E&S performance from group discussions with mine personnel. The full study methodology is presented as a process flowchart in Figure 5.1, outlining the steps taken to conceptualise the maturity models, conduct on-site participatory studies, and perform analysis to understand the E&S performance trends observed across the four sites.

Table 5.1: Basic statistics for all mine sites in E&S maturity study. Data is correct at time of writing.

Site name & commodities	Location	Workforce size	Production rate (tonnes per year)	Participants involved in discussions	Supplementary sources
Milldam/Cavendish (Fluorspar)	UK	65 at present	150,000 (in 2015) 120,000 at present	3 individual persons	(Robinson, 2015)
Boulby (Polyhalite, Potash plus, Salt)	UK	470 (as of 2018) 490 at present	450,000 (in 2018) 1,070,000 at present	2 groups of 4 persons each	(BBC, 2018; Breen, 2018)
Winsford (Rock Salt)	UK	112 at present	830,000 at present (10 year rolling average)	1 group of 4 persons	
Aberpergwm (Anthracite Coal)	UK	150 at present	250,000 at present (ROM tonnage)	1 group of 3 persons	

Table 5.1 outlines the workforce, production, and discussion participant statistics for the sites involved. Time constraints prevented investigation of the study's reliability and validity through follow-up visits which would've enabled a dynamic account of each site's E&S culture over a set period of time. The depth and flexibility of criteria content for addressing various mining contexts led to some categories being omitted, such as in tailings management or free, prior and informed consent (FPIC). The conditions of this participatory study necessitated ethics approval in advance of visitation, which required information to be issued ahead of the interviews and discussions taking place. This advance notice may allow management to carry out preparation which might obscure certain cultural characteristics of the site in question. Hence, the ethical permissions required for this study means it is unfeasible to attend without prior notice, which will influence the responses gleaned. Despite this, valuable insights into E&S culture maturity can be gathered from these semi-formal discussions.

Table 5.2: Main factors informing environmental & social maturity criteria for culture maturity models.

Environmental	Social
1: Management & assessment of environmental impacts & risks i. Environmental policy, regulatory compliance & disclosure ii. Pre-operation environmental considerations iii. Appropriateness of environmental impact assessment for risk management iv. Post-closure environmental planning	**1: Management & assessment of social impacts & risks** i. Social policy, regulatory compliance & disclosure ii. Pre-operation social considerations iii. Appropriateness of social impact assessment for risk management iv. Post-closure societal planning
2: Natural/ occupational hazard monitoring & mitigation i. Airborne pollutants ii. Occupational noise & vibration iii. Effluent monitoring & control iv. Biodiversity & ecosystem protection	**2: Corporate social responsibility (CSR) & human rights** i. Corporate social responsibility ii. Human rights impacts iii. Free, prior and informed consent (FPIC) iv. Worker rights & fair labour
3: Emergency measures and Response & Incident Investigation (RII) planning i. Site-wide emergency preparedness & planning ii. Senior response & incident investigation (RII) procedures and training iii. Assignment of roles & responsibilities iv. Off-site collaborations with authorities & communities	**3: Community engagement & conflict resolution** i. Community dialogue & decision-making ii. Stakeholder engagement process iii. Conflict management
4: On-site energy & resource management for CO^2 reduction i. Greenhouse gas (GHG) emissions and monitoring ii. Assessment & management of site water consumption iii. Environmental life cycle assessment (eLCA) approach & review process	**4: Local community benefits & opportunities** i. Local employment opportunities ii. Outreach & education schemes iii. Infrastructural investment
5: Site-generated waste management & tailings storage i. Low to moderate risk: Domestic waste ii. Moderate to high risk: Laboratory, medical & waste iii. Moderate to high risk: solid & liquid mine waste (TSF management)	**5: Occupational & community health and safety** i. Health & safety management systems (HSMS) ii. Health & safety communication and engagement iii. Health & safety risk assessment and management iv. Epidemiological considerations

The categories and associated criteria that form the framework for the E&S maturity models (see Table 5.2) which informs data analysis and discussion surrounding site performance in individual criteria sub-categories and within overall categories. They are largely aligned with established E&S guidance and requirements to maximise relevance for the participants engaging with the models (EBRD, 2014; Equator Principles Association, 2020; ICMM, 2018; IFC, 2012; IRMA, 2018; UNDP, 2014). However, these are not designed to replace established regulatory processes in the mining industry, such as external audits by accredited bodies managing responsible mining initiatives. Instead, they are intended to supplement these existing initiatives, regulatory procedures and standards to encourage greater responsibility through organisational culture shift. The economic- and governance-related factors that comprise a significant part of ESG strategy are outside the scope of consideration for this study.

5.3 ESG dimensions in the mining industry

5.3.1 Regulatory approaches for sustainable development in mining

Sustainable development, as defined by Brundtland in the UN 'Our Common Future' report (1987), is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Hence, extraction of raw metal and mineral resources through mining and processing is crucial for meeting the needs of today's society, while ensuring that sufficient resources remain for 'tomorrow's society' to thrive. Due to the finite nature of mineral and industrial resources, achieving sustainability within the mining sector is technically impossible. However, through development of a global circular economy, it is feasible to meet the needs of present and future generations if the industry operates with greater responsibility for environment and society.

Mining operations are economically driven ventures focused on maximizing profits through rapid exploitation of a known mineral reserve. Mining is becoming increasingly efficient with the development of modern technologies and innovations that enable higher ore production and primary recovery rates. But viable mineral deposits are reducing in grade which requires more overburden removal,

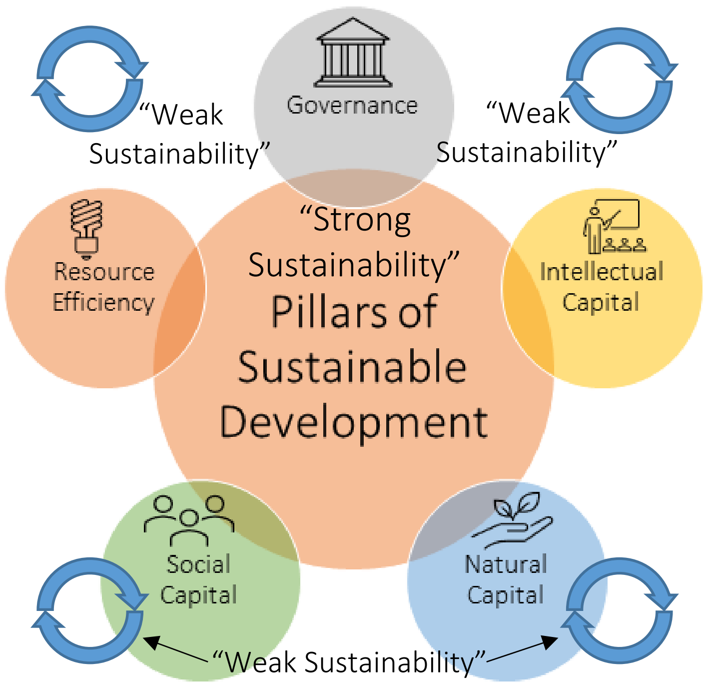


Figure 5.2: The 5 'Pillars' of sustainable development incorporating strong and weak sustainability (modified from Segura-Salazar and Tavares, 2018; Solability, 2021).

increasing operating costs and waste generation (Spitz and Trudinger, 2009). Balancing wealth generation with sustainable development is becoming more challenging with increasing scrutiny from stakeholders with competing goals relating to economic or ‘resource’ rents, defined as the variance between commodity price and production costs (The World Bank, 2022), emissions targets, and community benefits. The 5 ‘pillars’ of sustainable development provide a foundation for addressing common stakeholder demands and societal expectations for which mining companies are responsible, and are outlined in detail below (Segura-Salazar and Tavares, 2018; Solability, 2021; Figure 5.2):

- **Governance-** Infrastructure, market state, employment structure, and a framework for sustainable wealth generation driven by political and corporate leadership.
- **Intellectual Capital/Technological Innovation-** Capability to generate wealth and employment through innovations, artificial environments, industries, and people that add value to the company or operation.
- **Natural Capital/Natural Environment-** The resource availability within the ecosphere, the supply & depletion of said resource, and the impacts felt by the geosphere and biosphere.
- **Social Capital/Society-** Quality of life of an affected country/ community, measured by health, security, freedom, and equality for local communities, workers, NGOs, public authorities.
- **Resource Efficiency/Economy-** The way that available resources are used to remain competitive on the market and sustainable.

Two key perspectives have been characterised in response to the varied scope of sustainable development by definition. “Weak sustainability” refers to the prioritisation of business and economic systems with a secondary intervention to control and manage environmental impacts of the organisation and its activities. “Strong sustainability” instead describes a system in which business and economic decisions are fully dependent on potential environmental and social impacts, embracing stewardship and responsibility for natural and social capital (Roome, 2012; Segura-Salazar and Tavares, 2018). The lack of discrimination between these concepts inhibits progress towards sustainability targets, requiring organisations to address strong sustainability to a greater extent by addressing all five sustainable development pillars. Achieving strong sustainability requires a “systems thinking” approach that encourages managers to be more open-minded and conducive to alternative ideas and contributions from other sources beyond the conventional business actions and decisions (Bondy and Matten, 2012; Roome, 2012).

Laurence (2011) conducted a literature review to identify the reasons mines have been unsuccessful, and outline the focal areas for improving sustainability. Nearly half (44%) of all mine closures between 1981-2009 were a result of economic issues, 34% on mine efficiency, 11% caused by community intervention, 6% due to environmental damage, with the final 5% closed due to safety related concerns. Hence, a successful yet sustainable mining operation should; (1) be able to react to market changes and operate with low capex, (2) reduce the waste/ore ratio with effective planning, (3) have a collaborative relationship with local people and government, (4) provide support in continuous remediation of local environments, and (5) maintain resilient attitudes to safety from all site operators and managers (Laurence, 2011). Horsely et al. (2015) outlined 5 important sources of capital; financial, human, natural, social and physical, which can be affected positively or negatively depending on the company’s commitment to sustainability. Companies working near vulnerable communities have a greater responsibility to uphold their moral obligations, as the impacts of a lack of ownership can be highly detrimental on local people and the environment they depend on (Horsley et al., 2015).

Early management of ‘natural capital’ in mining took a similar approach to health and safety, comprising of a ‘Command and Control’ system involving enforcement of environmental standards bolstered by penalties for regulatory breaches, and later supplemented by tax incentives or tradable permits. In practice, these systems created uncooperative relationships between government regulators and industries, leading to forms of co-regulation being conceptualised to encourage compliance through stakeholder consultation. The Environmental Impact Assessment (EIA) was devised to mitigate project risks by formulating best practices for environmental protection within parameters agreed upon between the company and key stakeholders prior to operations commencing. The EIA documents and quantifies expected environmental impacts such as solid & liquid waste pollution, airborne emissions, and energy & water usage in order to prioritise and develop strategies to manage potential impacts and maximise project value (Spitz and Trudinger, 2009).

Recent methods of self-regulation (e.g., codes of practice, self-assessment and auditing) have shown variable effectiveness in improving standards, generating extensive debate over the positive and negative aspects of voluntary initiatives. Self-regulation has the potential to increase speed and efficiency of audits, flexibility across the organisation, and sensitivity to market shifts (Gunningham, 2011). Organisations that engage with these initiatives tend to already exhibit strong performance, while those falling short of expectations experience few consequences and sanctions due to the absence or ineffectiveness of enforcement measures (Brereton, 2002; Gunningham, 2011). From a health and safety perspective, shifting towards management of individual behaviours over the organisation as a whole enables employers and authorities to show the benefits of internal regulation. However, this approach may cause management to deprioritise the development of long-term strategic solutions in favour of short-term fixes. Business cases should be bolstered by proactive legislation that receives intellectual contributions from workers (Hart, 2010). Self-regulation can permit involvement of all hierarchical levels in developing rules, procedures and standards to instil a sense of ownership and responsibility.

5.3.2 Public reporting and disclosure of environmental and social performance

The four regulatory control approaches of command and control, economic instruments, and co- & self-regulation are adapted depending on local context, such as the national government’s resource base for regulatory enforcement. For self-regulatory approaches to be successfully implemented across the modern industry, collective agreement on objectives among a consortium of corporate and industry members is required. The ICMM was formed for the purpose of advancing the industry’s commitment to ‘sustainable development’, which paradoxically outlines an ambition that cannot be met by an industry which extracts finite resources. Hence, the preferred term ‘responsible mining’ is coined (ICMM, 2022a; Jarvie-Eggart, 2015). Of ICMM’s 10 sustainable development principles, 6 align with aspects addressed in the E&S maturity models: P3: H*uman rights and respect for cultures, customs, and values;* P5: *Continual improvement of safety performance;* P6: *Continual improvement of environmental performance;* P7: *Biodiversity conservation and land-use planning;* P9: S*ocial, (economic), and institutional development;* P10: *Stakeholder engagement, communication, and verified reporting requirements with our stakeholders* (ICMM, 2022b; Jarvie-Eggart, 2015).

Table 5.3: Summary of the Global Reporting Initiative's disclosure categories with number of indicators shown in brackets (GRI, 2021, 2010; ICMM and GRI, 2010).

GRI Category	**Reporting Indicators/ Disclosures**	**Total**
Economic	201 Economic Performance (4); 202 Market Presence (2); 203 Indirect Economic Impacts (2); 204 Procurement Practices (1); 205 Anti-corruption (3); 206 Anti-competitive Behaviour (1); 207 Tax (4).	17
Environmental	301 Materials (3); 302 Energy (5); 303 Water and Effluents (5); 304 Biodiversity (4); 305 Emissions (7); 306 Effluents and Waste (5); 306 Waste (5); 308 Supplier Environmental Assessment (2).	36
Social	401 Employment (3); 403 Occupational Health and Safety (10); 404 Training and Education (3); 405 Diversity and Equal Opportunity (2); 406 Non-discrimination (1); 407 Freedom of Association and Collective Bargaining (1); 408 Child Labor (1); 409 Forced or Compulsory Labor (1); 410 Security Practices (1); 411 Rights of Indigenous Peoples (1); 413 Local Communities (2); 414 Supplier Social Assessment (2); 415 Public Policy (1); 416 Customer Health and Safety (2); 417 Marketing and Labeling (3); 418 Customer Privacy (1).	35
Mining	12 Coal Sector (22); Mining & Metals Sector Supplement (~22).	~44

The ICMM's members comprise of globally recognised mining organisations with adequate resource base to perform effective self-regulation by ensuring a comprehensive assessment of mining activities and the resulting impacts across material and process flows. Third-party assurance in accordance with the GRI were implemented from 2008 to independently verify sustainability reports with clear standards of conduct within member companies (Jarvie-Eggart, 2015; Sethi, 2005). GRI sustainability reporting guidelines are internationally recognised across a range of industries, and include numerous indicators that address a range of economic, social and environmental factors (GRI, 2021; Jarvie-Eggart, 2015) (Table 5.3). The *Mining and Metals Sector Supplement* was developed with the ICMM to produce standardised reporting specifically for the mining industry, comprising of approximately 22 additional indicators for land use & control, socio-economic development, stakeholder engagement. labour rights, environmental management, and artisanal & small-scale mining relationships (GRI, 2010; ICMM and GRI, 2010).

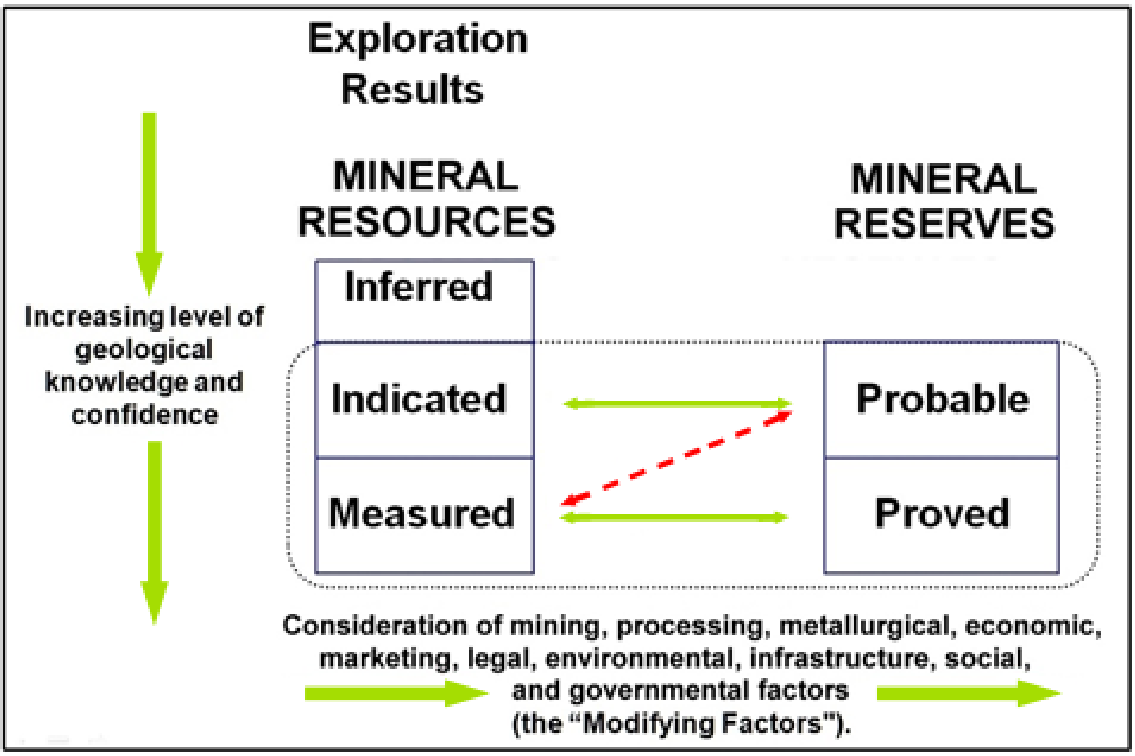


Figure 5.3: Relationship between the results of mineral exploration based on geological knowledge of mineral resources & reserves and consideration of 'modifying factors' (CRIRSCO, 2021).

Increasing attention is being paid to ESG reporting within the mining industry that is aligned with CRIRSCO reporting codes, from which respective members develop their own codes based on the CRIRSCO template to publicly report on exploration targets and results, and mineral resources and reserves (CRIRSCO, 2019). Increasing geological knowledge from exploration converts indicated mineral resources into probable reserves, which can be measured and proven as confidence increases (Figure 5.3). For a mineral resource to be viable, the 'modifying factors' such as extraction and processing requirements, economic implications, and ESG impacts must be understood (CRIRSCO, 2021).

Code 13.1 of the CRIRSCO guidelines states that "Public Reports should discuss environmental, social, and health and safety impacts that are expected during development, operation and after closure. These impacts will affect employees, contractors, neighbouring communities, and customers". Despite the claim that health and safety is the key consideration as it quantifies performance using lagging indicators, the guidance does not explore the safety leading indicators necessary for incident prevention (CRIRSCO, 2019).

The South African Code for the Reporting of Exploration Results, Mineral Resources and Mineral Reserves, or SAMREC, adopts the CRIRSCO standard with broad incorporation of sustainability considerations into the 'Technical Studies' section, which includes project scoping, pre-feasibility and feasibility planning (SSC, 2016). The South African guideline for the solid minerals and oil & gas industries (SAMESG) was prepared to promote reporting of ESG issues in mineral and oil & gas projects, which are aligned with the SAMREC codes. Existing sustainability principles and frameworks developed by the International Organisation for Standardization (ISO), the World Bank Group and the IFC have informed the specific technical standards outlined in SAMESG to further align with current best practice in ESG reporting (SAMESG Committee, 2017). As investors place increasing emphasis on ESG in project valuations, companies must show greater transparency and disclosure regarding E&S planning.

5.3.3 Socio-environmental responsibility and impact management

Figure 5.4: The corporate social responsibility hierarchy integrated with the four levels of SLO pyramid. Edited from Carroll, 1991 and Thomson and Boutilier, 2011.

While emphasis was initially placed by corporate figures on economic development, it led to discussions about the stakeholders that hold leverage on mining projects. This evolved into CSR (Figure 5.4), an illustration of the various levels of responsibility that should be demonstrated based on existing attitudes and commitment to socio-environmental sustainability (Carroll, 1991; Thomson and Boutilier, 2011). With sufficient effort devoted to maintaining the SLO, ‘Psychological Identification’ with stakeholders can be achieved (Thomson and Boutilier, 2011). The SLO concept in a European context, and the development of the Scalar SLO Model within the H2020 MIREU project, is defined by the division between community and societal drivers which may indicate differing values (Lesser et al., 2021). Community-company relationship is considered the more predominant conceptualisation of the term relative to the society-industry relationship, and further studies explored how scale of SLO is key for clarifying the concept. Quantitative analysis found that site level factors are important for local communities, such as how mining activity and company behaviour are perceived by communities, while societal benefits are more significant at the societal level (Lesser et al., 2023). Going beyond compliance, providing support for projects, and maintaining community relations are typical characteristics of companies demonstrating high CSR in pursuit of the SLO (Carroll, 1991; Gunningham et al., 2004). Companies increasingly engage with initiatives either on a mandatory or voluntary basis to increase collaboration with local communities and minorities (Jarvie-Eggart, 2015).

Kemp (2009) pointed out that mining companies are generally well resourced to meet community requirements, but progress is hindered by corporate decision-making that is positioned towards production, so responsibility is enhanced when time and funding is diverted more to community support and engagement (Kemp, 2010). Kemp considered 3 main dimensions for responsible mining: (1) ensuring the company understands community concerns; (2) developing a mutual understanding to bridge gaps between company and community; and (3) changing company practices to improve social performance. Internal changes aimed at disseminating information and containing relationship issues tend to prioritise corporate reputation. However, ‘emergent’ methods aim to empower local communities through participatory collaboration activities (Kemp, 2009).

The social impact assessment (SIA) is a complex multidisciplinary area of study which is often carried out with the EIA, and there is no single methodology or approach for completing an SIA due to the broad range of social, cultural and geopolitical contexts (Suopajärvi, 2013). The unpredictability of social impact management was addressed by Everingham (2012) who defined them as ‘wicked problems’, or social issues with no consistent origin or solution.

Everingham's study proposed a tool that requires companies to submit a Social Impact Management Plan (SIMP), which outlines the responsibilities of all persons involved in the project, and addresses plans for housing, healthcare, infrastructure, and utilities (Everingham, 2012). Social sustainability in context with environmental conservation has become a key consideration in feasibility planning, which has influenced the development of the combined Environmental & Social Impact Assessment (Dendena and Corsi, 2015; Grubert, 2018).

Hodge (2014) identified that the accelerating development of global communication channels are giving local communities greater autonomy to voice mining-related social issues. Establishing strong relationships with communities and local governments, and demonstrating transparency through public disclosure, can increase mutual trust and understanding (Gunningham et al., 2004; Hodge, 2014). A community development strategy incorporating multi-criteria decision analysis (MCDA) during mine planning was presented by Sinan Erzurumlu and Erzurumlu (2015). MCDA compares scenarios based on set criteria, where mine target suitability is assessed by grade, location and natural disaster susceptibility. Application to a small operation in Central America found that "early community involvement and rigorous impact assessment on a regular basis" enhances trust (Sinan Erzurumlu and Erzurumlu, 2015).

Van der Plank et al. (2016) identified that poor local perceptions of mining can originate from first impressions of the operating company, especially if trust is not established ahead of work commencing. Walsh et al. (2017) determined that perceptions are negatively affected by inconsistent two-way communication. By empowering communities and authorities through more regular consultations, the risk of disagreements or protests can be minimised (Grubert, 2018; Walsh et al., 2017). However, depending on the level of control gained by stakeholder groups, conflicts can arise that are only resolved by negotiations, so due care must be taken to track company-community interactions (Grubert, 2018; O'Faircheallaigh, 2010). Mancini and Sala (2018) determined three common societal effects of mining, which include land use and territory issues, environmental health impacts, and human rights violations, using the UN's Sustainable Development Goals, the Global Reporting Initiative, EU policy, and social life cycle assessment as indicators. The disorganisation of local- to macro-scale perspectives produced gaps in social impact research, particularly in land use conflicts and demographic influences (Mancini and Sala, 2018).

Embedding sustainable development into conventional mining via the five key pillars must consider strong and weak sustainability to address the challenges associated with substitution of finite resources. Public reporting and disclosure initiatives have promoted sustainable practices and transparency in ESG, but debates regarding the effectiveness of self-assessment compared to third-party regulation and auditing are ongoing. Internationally recognised frameworks have begun to promote greater ESG transparency and accountability, where the criteria delineate minimum expected standards for the industry. ESG reporting standards and CSR principles for responsible mining are considered together to inform the development of tiered criteria-driven E&S culture maturity models.

5.4 Past failings in mining affecting the environment and society

Recent discussion surrounding E&S impacts from mining has scrutinised how companies manage their tailings, after two catastrophic tailings dam failures at Vale-owned mines in Brazil. The Samarco dam collapsed in November 2015, releasing over 50 million m^3 of iron ore tailings into the Rio Doce river, killing 19 people and destroying hundreds of homes. The toxic metal contaminants also spoilt the water supply of over 250,000 people, at an estimated expense of US$54 billion for restoration and compensation (Burritt and Christ, 2018; Gomes et al., 2017; Hanson Pastran and Mallett, 2020; Queiroz et al., 2018). Less than 4 years later, the Brumadinho dam disaster occurred in similar circumstances, causing 259 fatalities as of January 2020 (Hanson Pastran and Mallett, 2020). The decision to place important mining infrastructure directly below the tailings facility placed workers at an unacceptably high level of risk. Dam construction adopted a cheaper upstream approach that indicated prioritisation of costs over safety from the onset of operations (Silva Rotta et al., 2020). Vale conducted minimal action to resolve known issues associated with tailings facility maintenance, local communication, and emergency response & preparedness (Milanez et al., 2021). This demonstrated an immature culture that was present within Vale with regards to waste management and environmental & community protection before and leading up to the tailings dam

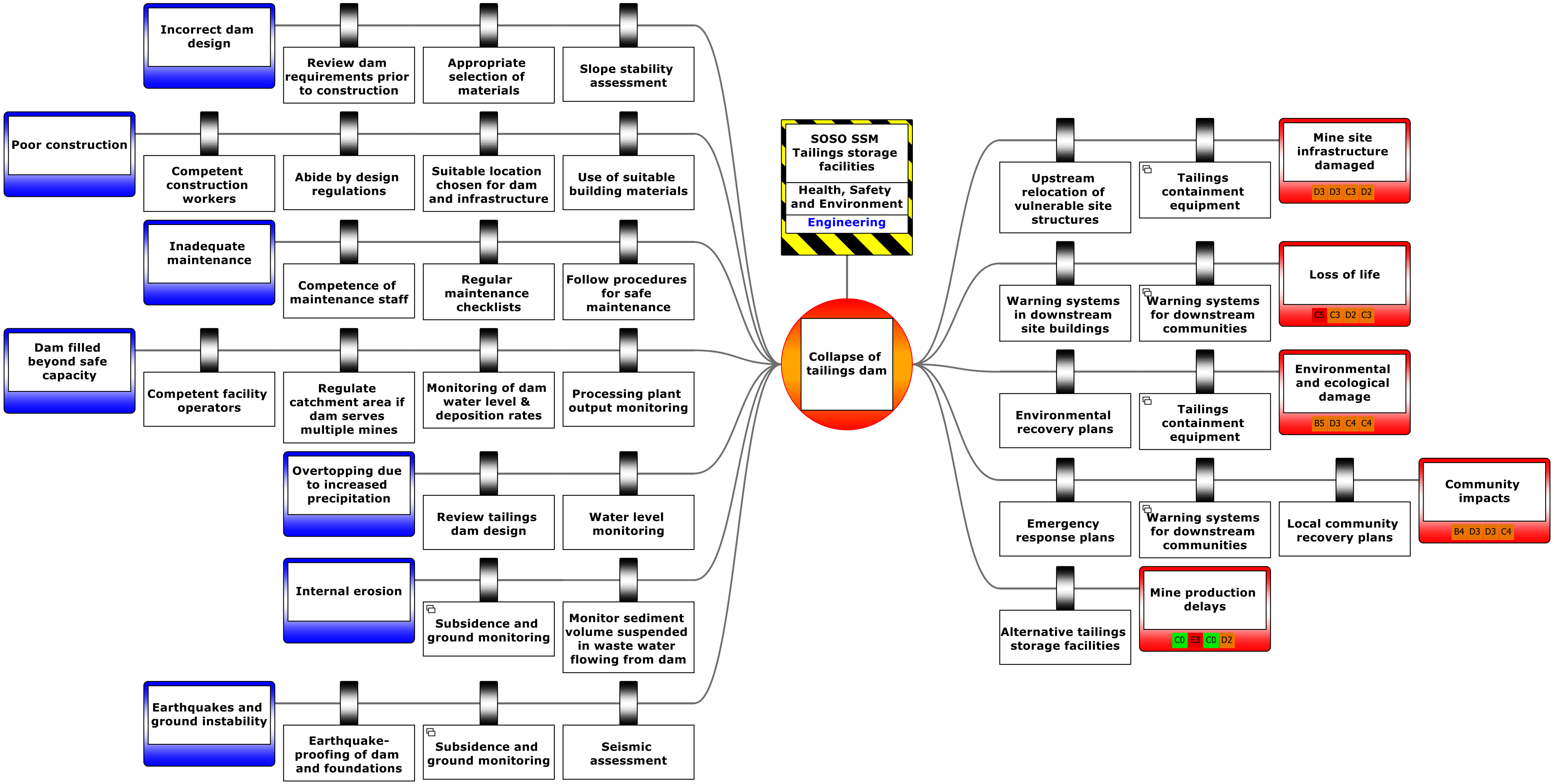


Figure 5.5: Bowtie analysis of a hypothetical tailings dam collapse in the context of SOSO small-scale mining operations.

collapses, as the company did not act on critical safety issues by implementing barriers to prevent structural failures or mitigate the consequence severity.

Bowker and Chambers (2015) identified that, despite tailings dam incidents decreasing between 1910-2010, the occurrence of “serious and very serious” accidents, defined as having caused multiple deaths (20 or more), released over 10^6 m^3 of material and travelled over 20km from source, has risen since 1960. Favourable mineral economics for lower ore grades, made possible by modern technology, has reduced the cost to economically mine a ton of ore which increases waste as production accelerates (Bowker and Chambers, 2015). According to Armstrong et al. (2019), the occurrence of severe tailings dam failures globally has approximately doubled since 1999, and their analysis of 4 recent tailings dam disasters determined that a lack of experienced mining workers, accelerating production and cost cutting were key contributing factors.

To mitigate the incidence of severe environmental disasters, mineral processing should be adapted to reduce water consumption, extraction methods should be optimised to generate less waste, and more severe penalties should be imposed for damages (Armstrong et al., 2019). Figure 5.5 illustrates the threats and consequences of a tailings dam collapse for a small-scale SOSO mining using Bowtie analysis. The reduced tonnage and throughput of SOSO SSM compared with traditional mining will likely decrease the threat of widespread environmental damage from a spillage for the same commodity, provided waste management takes place locally. However, if a single large-scale tailings storage facility serves multiple ‘clustered’ SOSO mines, then the risk of serious failure increases proportionally with the number of sites supplying tailings waste. This will require more careful mine waste management depending on the cumulative production rate of all mines in catchment area, the size distribution of tailings, and volume of processing water consumption.

Greater emphasis must be placed on encouraging and incentivising good safety practices as opposed to rewarding increased production, in order to mitigate at-risk behaviours that may lead to incidents with impacts felt beyond the site. Where the various definitions of safety culture outlined in chapter 2 share common ground in terms of the collective attitudes of an organisation towards safety as a core value, it is feasible to adapt this to address the specific environmental and social challenges of mining.

Socio-environmental culture is defined by the prevailing attitudes and perceptions of management and employees towards occupational risks that have direct and indirect implications for local & regional communities, authorities and ecosystems.

Achieving a culture shift requires mutual trust, commitment from all levels, and clear structured guidance through the life of mine. The E&S maturity models described in the next section, adopting a similar structure as the safety culture equivalent (Foster and Hoult, 2013, 2011; see Figure 2.3), comprise of four tiers of increasing maturity to prevent respondents who are undecided from 'taking the middle ground' with regards to their E&S maturity. The aim is to address the main factors associated with E&S culture maturity (Table 5.2) and outline the typical maturity traits for each level, thereby informing measures for achieving best practice management which can then permeate all levels of the company. In a SOSO SSM context, this is vital due to the rapid turnaround for deployment and commissioning of the containerised system, so companies must hit the ground running with regards to their E&S culture. If organisational attitudes towards mitigating E&S impacts are aligned and reflect the severity of known risks, then contributory at-risk behaviours may be gradually eliminated.

5.5 Environmental & social maturity models for establishing baseline culture in mining

The origins and concept of maturity modelling was discussed in chapter 2, particularly relating to its application across a wide range of industries including construction (Dedobbeleer and Béland, 1991), nuclear energy (International Atomic Energy Agency, 1991), manufacturing (Nordlöf et al., 2015), aviation (Gordon et al., 2007), health care (Hudson, 2007, 2003; Westrum, 2004), petroleum (Filho et al., 2010; Hudson, 2001; Hudson et al., 2000; Parker et al., 2006) and mining (Anglo American Plc, 2010; Bascompta et al., 2018; Foster and Hoult, 2013, 2011; Stemn et al., 2019). These models were developed and applied as 5-tier self-assessment tools for companies and organisations in their respective industries to determine their current level of maturity. Filho and

Waterson (2018) deduced that most of the safety maturity publications selected for their study focused on model development (>80%), with less than 10% addressing model application, and validation and reliability only appearing in 5% of those studies. Hence, safety culture research to date has prioritised maturity model development, with less attention on applicability, validity and reliability.

Early iterations of maturity models stem from Crosby's Quality Management Maturity Grid describing 5 phases of quality management (Crosby, 1979), and was first applied to environmental management following the Brundtland report (1987) to facilitate positive change in organisational attitudes towards environmental impacts. Roome (1992) conceptualised a 5-level 'Strategic Options Model' for charting pathways towards sustainability for businesses, starting with compliance which progresses into 'commercial and environmental excellence', and 'leading edge'. Maturity models applied to environmental factors within manufacturing and production have examined the pattern of organisational attitudes and behaviours towards sustainability issues, which move from "reactive" to "proactive" maturity (Azzone and Noci, 1998; Klassen and Whybark, 1999; Roberts and Gehrke, 1996; Vastag and Rondinelli, 1996).

The breadth of maturity models expanded with consideration for policy commitment, management support in addressing public concerns, GHG reduction & energy efficiency, and legal compliance in supporting pathways to environmental sustainability, which links with some social aspects (Jabbour et al., 2014; Jeswani et al., 2008; Potrich et al., 2019; Winn and Angell, 2000). Work by Ormazabal et al. (2016, 2013) produced evolutionary maturity models for environmental management that considered the appropriateness of employee education and training, process efficiency of activities, and quality of consistent communication on environmental matters. Shukla and Adil (2021) reviewed the evolution of maturity modelling in a "green manufacturing" context to develop a four stage maturity model (1: Compliance driven, 2: Eco-opportunist, 3: Green innovator, and 4: Green manufacturing evangelist), which was applied at 2 paint manufacturing plants in India, and showed clear improvement in maturity. Recent research has progressed maturity model development that is relevant to specific E&S factors in higher education, hospitality, maritime, manufacturing, production, and freight transport industries

(Ahmed et al., 2021; Espadinha-Cruz et al., 2023; Housni et al., 2022; Kijewska et al., 2021; Pizzutilo and Venezia, 2021; Spaltini et al., 2022; Vasquez et al., 2021). Of these 7 publications cited, 5 have studied the model's application while the others focused solely on development. None of these publications directly addressed E&S maturity in mining. Hence, the environmental and social maturity models developed and applied to UK operations in this study is a novel application in this specific research area.

Community relations can be managed more effectively when the company is aware of the characteristics that comprise a high level of E&S culture. So, the intended outcome of these models is to guide mining companies towards improved E&S performance by outlining how they can go beyond compliance with regards to operational E&S factors. Early iterations of the E&S maturity models developed for this study were presented at a UK-based conference and

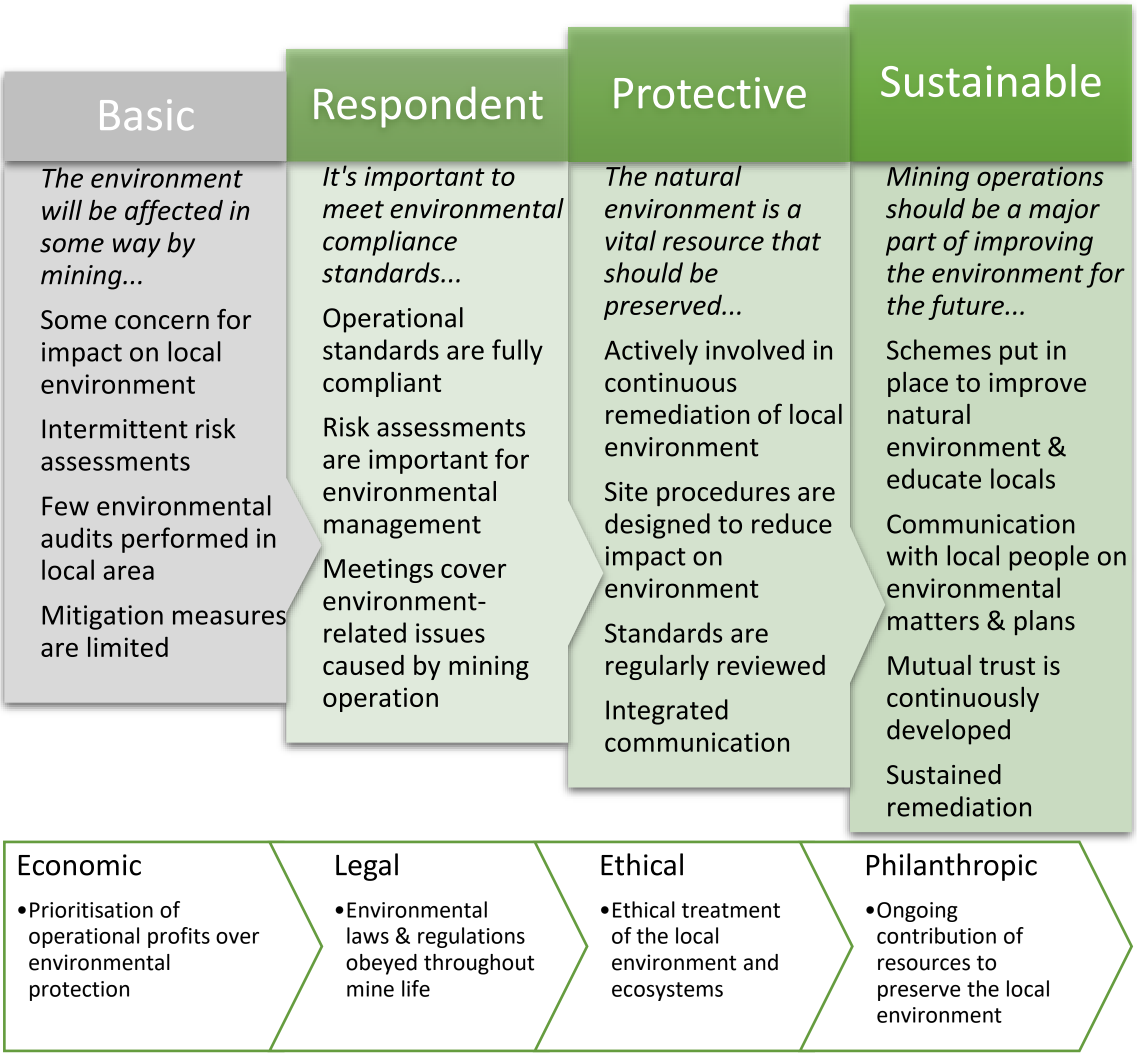


Figure 5.6: The environmental culture maturity model integrated with the corporate social responsibility hierarchy applied in an environmental context.

published as a contribution to the proceedings (Doyle and Sidorenko, 2019). The risk arising from the conventional 5 tier structure is participants choosing the middle ground if they are uncertain about which direction to judge performance, so the latest model iterations are designed with 4 maturity levels. The target audience is site management, frontline personnel and environmental or social specialists in companies currently (i) at the feasibility and planning stage looking to understand their prevailing maturity, and (ii) in active operation looking to evaluate their current E&S maturity performance and prioritise areas for improvement. The factors influencing maturity from a socio-environmental perspective are outlined in Table 5.2, and each model includes criteria relevant to each factor which outline expected characteristics at each tier.

The proposed environmental culture maturity model (Figure 5.6) describes the expected environmental management characteristics of a company at each of

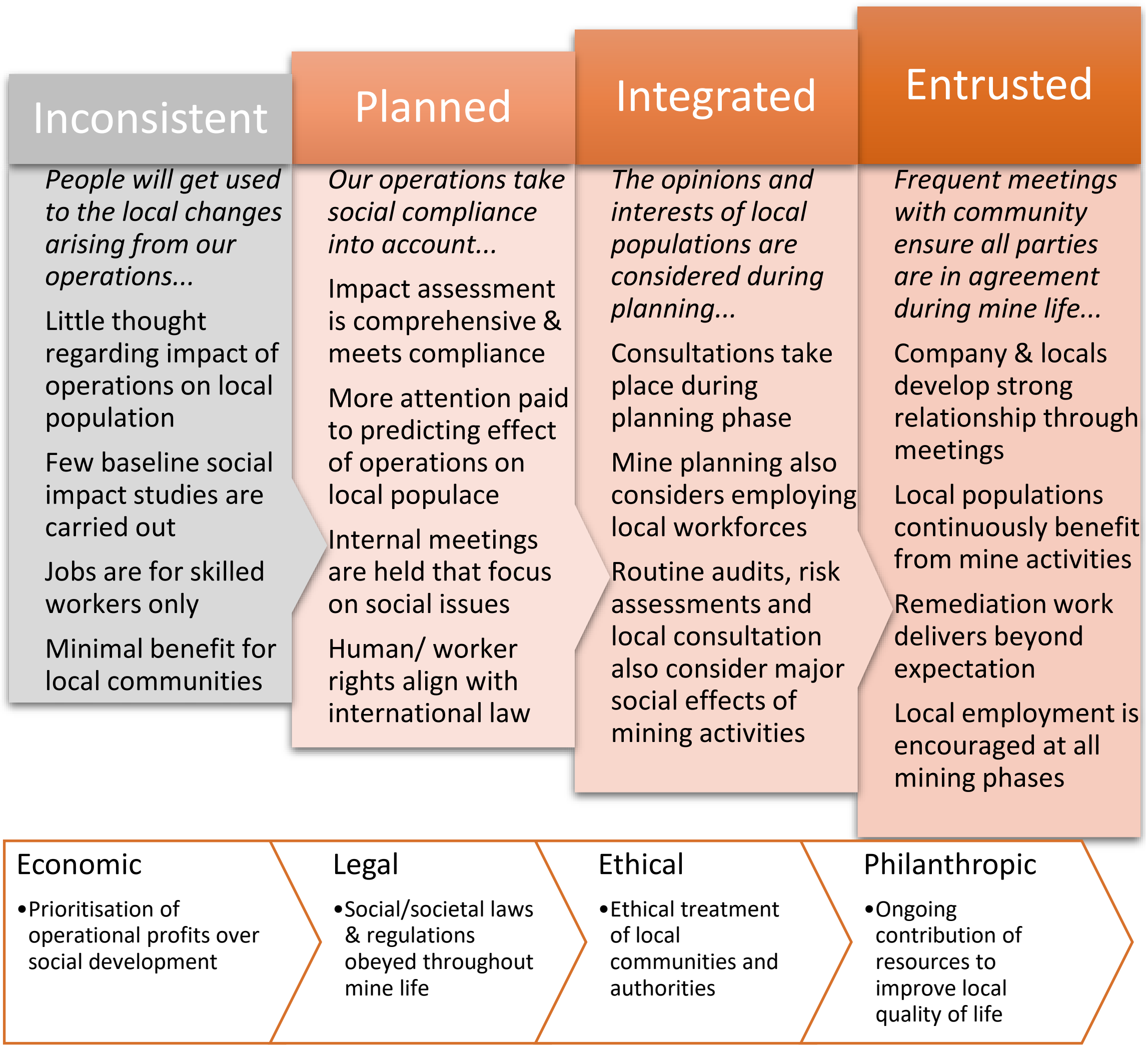


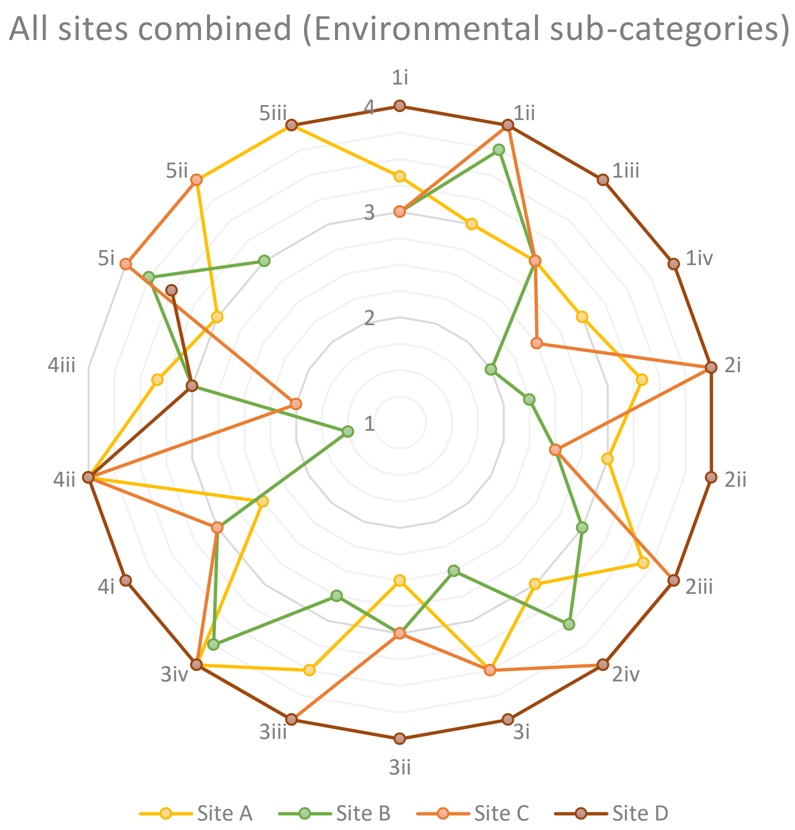
Figure 5.7: The social culture maturity model integrated with the corporate social responsibility hierarchy applied in a societal context.

the four tiers. ‘Basic’ describes a culture that lacks meaningful communication regarding environmental matters, little to no compliance with environmental standards, and limited emphasis on environmental protection. Moderate to high maturity organisations (‘Respondent’ to ‘Protective’) demonstrate consideration for the potential environmental impact of operations, carry out environmental risk assessments and monitoring, and meetings regularly discuss environmental concerns. ‘Sustainable’ companies prioritise environmental protection by implementing most community requests, committing to remediation through the mine lifecycle, and supporting outreach and education programmes. Companies that continuously improve their environmental practices are more likely to save on rejuvenation costs while maintaining their reputation as a considerate organisation, which cultivates a positive relationship with communities. For example, ‘negligent’ operations will conduct limited post-closure remediation. By contrast, ‘sustainable’ operations emphasise the importance of environmental protection, encouraging a concerted effort to mitigate ecological impacts by demonstrating a ‘beyond compliance’ approach when undertaking remediation.

The social culture maturity model is similar in structure (see Figure 5.7), and considers the typical features of a company’s social management system at each of the four maturity stages. ‘Inconsistent’ refers to a culture comprising ineffective communication, a passive approach to dealing with local opposition and inadequate compliance. ‘Planned’ and ‘Integrated’ organisations consider social risks in more depth during feasibility studies, conduct internal meetings dedicated to resolving social issues, and regularly interact with community representatives. An ‘Entrusted’ approach goes beyond compliance, seeking to positively contribute to affected communities by offering employment options, helping to develop personal skills whilst boosting local and regional economic growth. Strong relationships managed throughout the life of mine can mitigate conflict escalation, with any disagreements resolved swiftly through regular consultation. The social model can inform companies of best practice for interacting with local people, and how collaborative management can accelerate the process of earning an SLO. The criteria developed for these models are aligned with internationally recognised responsible mining initiatives and guidelines such as the Initiative for Responsible Mining Assurance (IRMA), addressing factors relating to E&S impact management, hazard monitoring, mine waste management, community engagement, and local community benefits (Table 5.2).

5.6 Fieldwork observations from semi-formal facilitated discussions using E&S culture maturity models

5.6.1 General environmental & social culture maturity trends



1: Management & assessment of environmental impacts & risks
- i. Environmental policy, regulatory compliance & disclosure
- ii. Pre-operation environmental considerations
- iii. Appropriateness of environmental impact assessment for risk management
- iv. Post-closure environmental planning

2: Natural/ occupational hazard monitoring & mitigation
- i. Airborne pollutants
- ii. Occupational noise & vibration
- iii. Effluent monitoring & control
- iv. Biodiversity & ecosystem protection

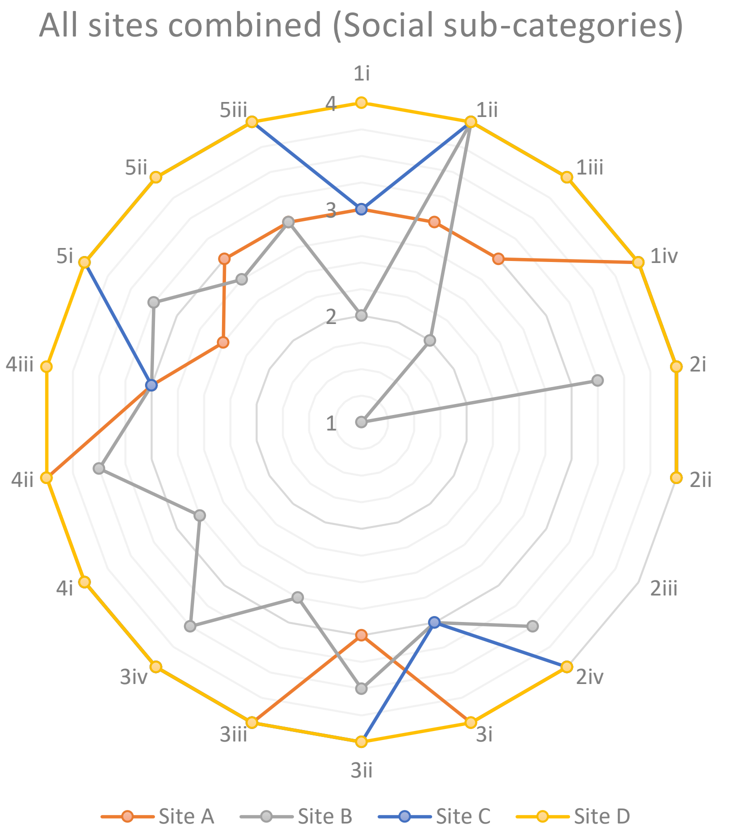
3: Emergency measures and Response & Incident Investigation (RII) planning
- i. Site-wide emergency preparedness & planning
- ii. Senior response & incident investigation (RII) procedures and training
- iii. Assignment of roles & responsibilities
- iv. Off-site collaborations with authorities & communities

4: On-site energy & resource management for CO^{2} reduction
- i. Greenhouse gas (GHG) emissions and monitoring
- ii. Assessment & management of site water consumption
- iii. Environmental life cycle assessment (eLCA) approach & review process

5: Site-generated waste management & tailings storage
- i. Low to moderate risk: Domestic waste
- ii. Moderate to high risk: Laboratory, medical & waste
- iii. Moderate to high risk: solid & liquid mine waste (TSF management)

Figure 5.8: Radar plot of environmental maturity scores by sub-category for all sites, with radial axis labels referring to: 1 – Basic; 2 – Respondent; 3 – Protective; 4 – Sustainable.

The environmental maturity model scores from 1 to 4 per sub-category, which, assuming all categories receive a response, results in a minimum overall score



1: Management & assessment of social impacts & risks i. Social policy, regulatory compliance & disclosure ii. Pre-operation social considerations iii. Appropriateness of social impact assessment for risk management iv. Post-closure societal planning **2: Corporate social responsibility (CSR) & human rights** i. Corporate social responsibility ii. Human rights impacts iii. Free, prior and informed consent (FPIC) iv. Worker rights & fair labour **3: Community engagement & conflict resolution**	i. Community dialogue & decision-making ii. Stakeholder engagement process iii. Conflict management **4: Local community benefits & opportunities** i. Local employment opportunities ii. Outreach & education schemes iii. Infrastructural investment **5: Occupational & community health and safety** i. Health & safety management systems (HSMS) ii. Health & safety communication and engagement iii. Health & safety risk assessment and management iv. Epidemiological considerations

Figure 5.9: Radar plot of social maturity scores by sub-category for all sites, with radial axis labels referring to: 1 – Inconsistent; 2 – Planned; 3 – Integrated; 4 – Entrusted.

of 18 and a maximum of 72. As a percentage of the highest possible score when unanswered categories are omitted, the scores of all four sites ranged from 72.4% to 97.8% with a standard deviation of 10.4%. Environmental culture maturity scores by sub-category range from 2.83 (‘Respondent’-‘Protective’) to 4.00 (‘Sustainable’) on average across all sites, collectively performing best in tailings management (5iii), off-site collaborations with authorities & communities in emergency planning (3iv), pre-operation environmental considerations (1ii), effluent monitoring & control (2iii), and laboratory & medical waste management (5ii). Sites generally performed worst in environmental life cycle assessment approach & review process (4iii), post-closure environmental planning (1iv), occupational noise & vibration (2ii), and senior response & incident investigation procedures and training (3ii). Observed weaknesses in environmental maturity relate primarily to the bureaucratic requirements of mining operations with regards to environmental site planning and life cycle assessment, and the key documentation for post mine closure, emergency preparedness and occupational hazard management. The active management of mine waste & effluent, the protection of ecosystems, and the cultivation of local relationships with communities and authorities are clear strengths observed in this study. Calculating the standard deviation of all site scores for each sub-category shows that sites performed consistently with respect to eachother in tailings management (5iii), and off-site collaborations with authorities & communities in emergency planning (3iv), while sites were relatively more inconsistent with respect to one another in assessment & management of site water consumption (4ii), post-closure environmental planning (1iv), and airborne pollutants (2i) (Figure 5.8).

The social maturity model scores from 1 to 4 per sub-category, which, assuming all categories receive a response, results in a minimum overall score of 18 and a maximum of 72. As a percentage of the highest possible score when unanswered categories are omitted, the scores of all four sites ranged from 73.0% to 100% with a standard deviation of 11.8%. Social culture maturity scores by sub-category range from 3.00 ('Integrated') to 4.00 ('Entrusted') on average across all sites, generally performing best in human rights impacts (2ii), worker rights & fair labour (2iv), local employment opportunities (4i), infrastructural investment (4iii), and corporate social responsibility (2i). Sites generally performed worst in social policy, regulatory compliance & disclosure (1i), appropriateness of social impact assessment for risk management (1iii), post-closure societal planning (1iv), and health & safety management systems (HSMS) (5i). Weaknesses in social maturity are similar to the environmental model in terms of the bureaucratic obligations for demonstrating minimum action taken towards management of social impacts both syn- and post-mining. Observed strengths relate primarily to the protection of human and worker rights as well as the level of support given to local populations through job creation, provision of essential amenities and corporate social responsibility. As in environmental, the standard deviation of site scores for each sub-category shows that sites performed very consistently with respect to eachother in

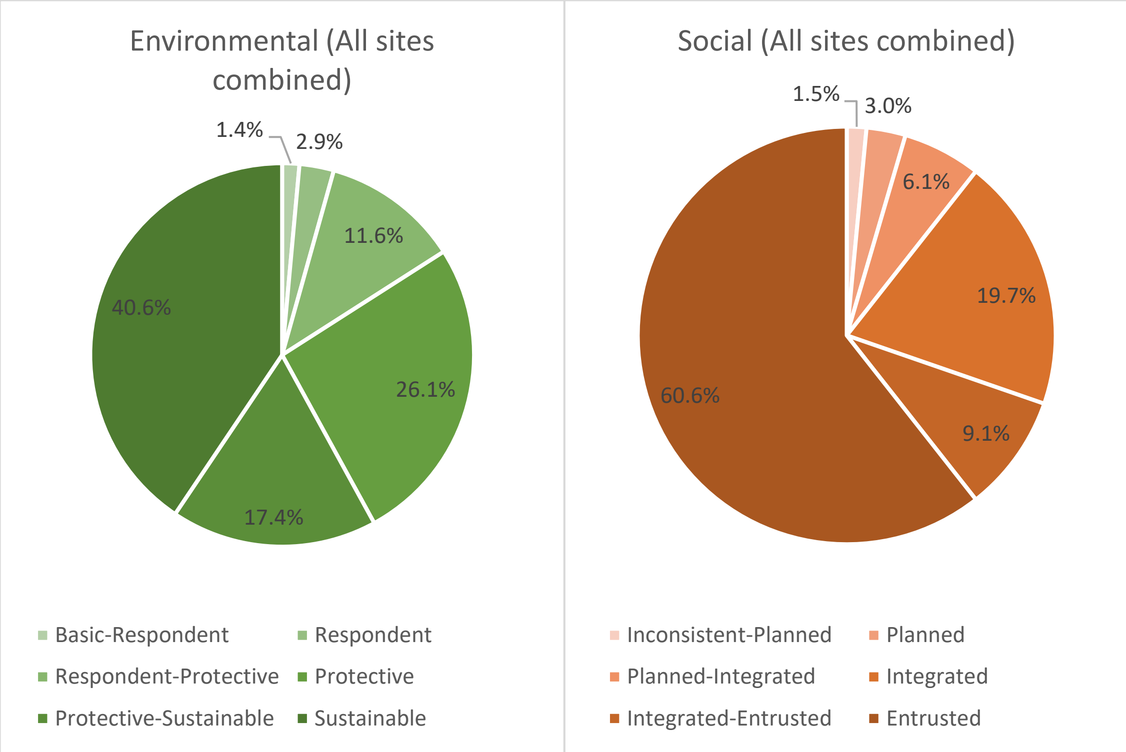


Figure 5.10: Circle charts representing proportions of each score range for E&S maturity across all sites and sub-categories.

human rights impacts (2ii), worker rights & fair labour (2iv), local employment opportunities (4i), and infrastructural investment (4iii), while sites were relatively more inconsistent with respect to eachother in post-closure societal planning (1iv), appropriateness of social impact assessment for risk management (1iii), and social policy, regulatory compliance & disclosure (1i) (Figure 5.9).

The circle charts in Figure 5.10 show that 84.1% of scores in the environmental maturity model were 'Protective' to 'Sustainable', with 89.4% of scores in the social maturity model between 'Integrated' and 'Entrusted'. Hence, the specific self-assessments applied to regulated UK mining operations are of high quality and suitably justified with evidence provided during participatory discussions, with overall social maturity across the four mines generally outperforming environmental maturity in the higher levels of each model.

5.6.2 Environmental & social maturity trends by primary factor

Table 5.4: Summary of E&S model's primary factors with number of sub-categories in associated factor.

Environmental Factors	Sub-categories	Social Factors	Sub-categories
E1: Management & assessment of environmental impacts & risks	4	S1: Management & assessment of social impacts & risks	4

E2: Natural/ occupational hazard monitoring & mitigation	4	S2: Corporate social responsibility (CSR) & human rights	4
E3: Emergency measures and response & incident investigation planning	4	S3: Community engagement & conflict resolution	3
E4: On-site energy & resource management for CO2 reduction	3	S4: Local community benefits & opportunities	3
E5: Site-generated waste management & tailings storage	3	S5: Occupational & community health and safety	4

The participatory approach enabled individuals to contribute personal insights to each of the model's sub-categories which provided context to each site's E&S culture at the time of visitation. In both models, there are 5 primary factors with associated sub-categories that contain the criteria needed to determine an appropriate maturity level. Table 5.4 summarises the 5 factors for each model and the number of sub-categories per factor, with a more detailed overview of the full structure of sub-categories presented earlier in Table 5.2. The average scores and standard deviation of each primary factor are shown in Table 5.5, with these results illustrated graphically as radar plots, representing the environmental and social maturity models respectively, to compare scores and identify positive and negative trends in E&S performance.

Table 5.5: Summary of primary factor scores by site and overall, ranked by highest to lowest average score and by standard deviation.

Factor	Average scores per factor out of 4.00				Factor rank	All sites average out of 4.00	Factor rank	Standard deviation of factor scores
	Site A	Site B	Site C	Site D				
E1	3.08	2.94	3.13	4.00	4th	3.29	3rd	0.48
E2	3.25	2.81	3.63	4.00	3rd	3.42	5th	0.51
E3	3.38	3.00	3.63	4.00	2nd	3.50	2nd	0.42
E4	3.28	2.50	3.00	3.67	5th	3.11	4th	0.49
E5	3.67	3.38	4.00	3.75	1st	3.70	1st	0.26
S1	3.25	2.25	3.75	4.00	5th	3.31	5th	0.77
S2	4.00	3.38	4.00	4.00	1st	3.84	1st	0.31
S3	3.67	3.08	3.67	4.00	3rd	3.60	3rd	0.38
S4	4.00	3.25	4.00	4.00	2nd	3.81	2nd	0.38
S5	2.88	3.00	3.75	4.00	4th	3.41	4th	0.55

While analysis of the environmental model indicates high maturity across all sites, they generally performed best in *site-generated waste management and tailings storage*, with Site C scoring highest overall out of four studied and Site B lowest in this specific factor. *On-site energy & resource management* scored lowest on average of the five primary factors, with Site D scoring highest of the

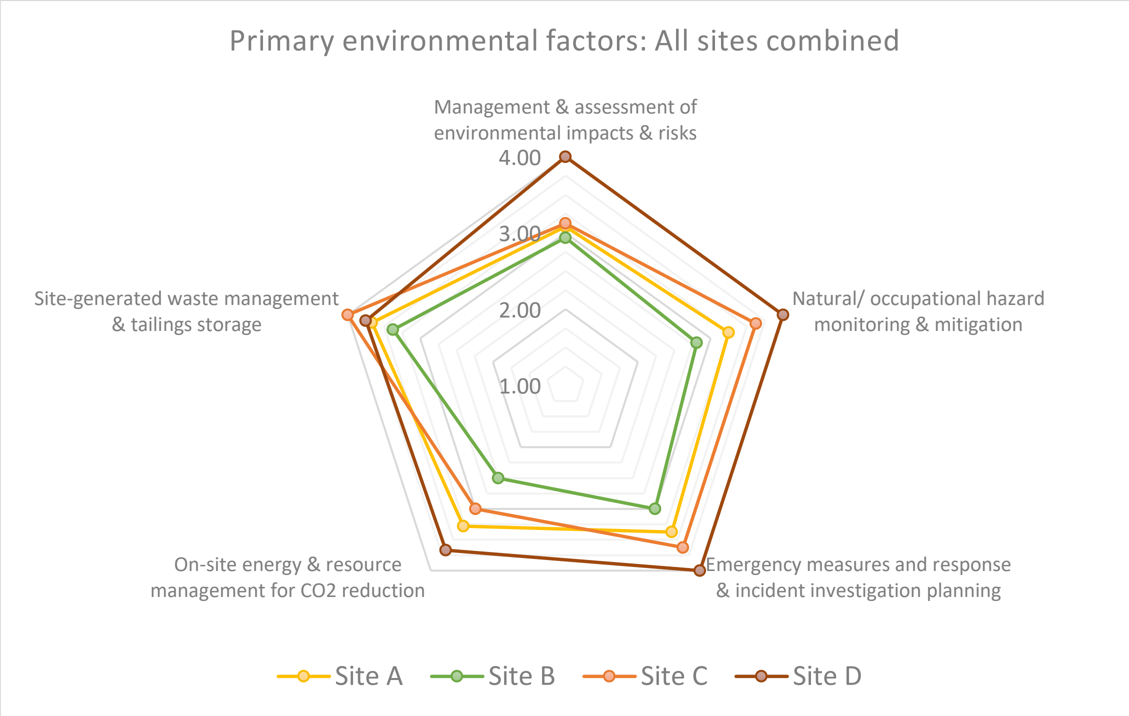


Figure 5.11: Radar plot of average site scores per primary environmental factor from study depicting broader maturity trends across all sites

four sites visited and Site B lowest. Comparative performance between the sites was also relatively consistent, particularly in categories 2 & 3 relating to *hazard monitoring & mitigation* and *emergency measures & planning*. All sites demonstrated high social maturity by scoring between Integrated and Entrusted, generally performing best in *corporate social responsibility & human rights*, with Sites A, C, and D all scoring a maximum of 4.00 and Site B lowest (Figure 5.11). Participating sites amply justified their self-assessment of community support and investment with several case examples, including:

- Hiring personnel from area immediately surrounding the operation.
    - *80% of workforce employed within a radius of 15 miles (Site B).*
- Ongoing dialogue and collaboration with academic institutions.
    - *Worked with a company helping children with photography project, and student conducted photography on site for studies (Site D).*
- Investing in local projects to improve accessibility for residents & tourists.
    - *£18 million into tourism and infrastructure investment, road widening and tree planting to reduce line of sight (Site B).*
    - *Community fund contributions cover costs of local projects, people bid for funding through external voting to allocate funds (Site D).*

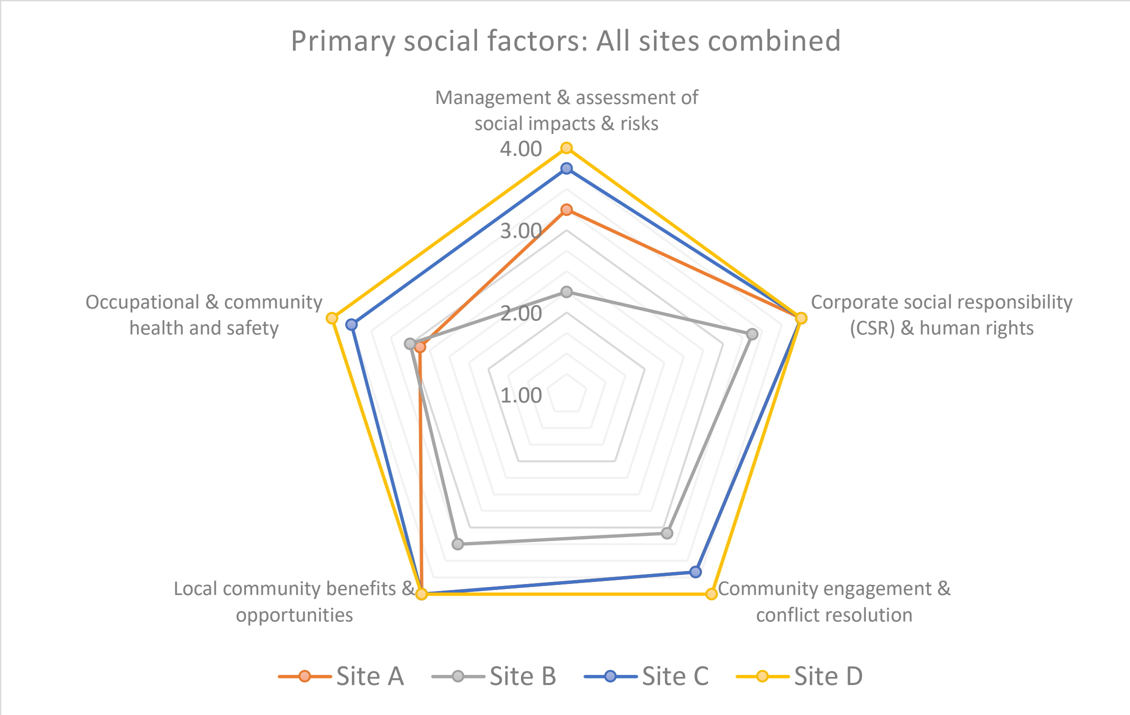


Figure 5.12: Radar plot of average site scores per primary social factor from study, depicting broader maturity trends across all sites.

Management & assessment of social impacts & risks scored lowest on average of the five primary factors, with Site D scoring highest and Site B lowest. Comparative performance is less consistent than in environmental but the order of classification by average performance for the four sites remains similar. The distribution of scores also indicates a characteristic level of maturity at each site, showing that the criteria has captured E&S maturity variation between operations. The range of scores shows that operations in the same country can progress through multiple stages from Respondent/ Protective to Sustainable, and Planned/ Integrated up to Entrusted respectively. None of the sites scored at the lowest levels in each factor, but some did score at the 'Basic-Respondent' and 'Inconsistent-Planned' levels in model sub-categories (Figure 5.12).

5.7 Discussion

5.7.1 Interpreting key trends from E&S maturity study

The site-based studies of UK mining operations aimed to establish the key areas of relatively good and poor performance from an E&S perspective, using criteria-driven models to facilitate collaborative discussions. The environmental maturity results indicate high performance in waste and tailings management, which is expected given the increased attention on tailings storage facility management after several notable dam failures (see chapter 5.4). The requirements for mine waste and tailings storage vary depending on commodity type and subsequent processing methods used. Operations producing industrial minerals need comparatively less complex waste management infrastructure than those extracting polymetallic ore minerals with multistage processing. Scores in tailings and waste management may be strongly influenced by processing complexity and the potential ecotoxicological impact of by-products, as well as the overriding attention paid to safe mine waste storage. Sites scored lowest overall in energy & resource management, which highlights deficiencies in greenhouse gas emission and water consumption monitoring, and the presence and quality of environmental life cycle assessments (LCAs). Mining companies that integrate data driven LCA into their environmental management strategy obtain a more detailed understanding of how system inputs (e.g., consumption of electricity, fossil fuels, water, chemicals, etc.) influence the local and regional environmental impacts. LCAs highlight alternative methods and technologies for ore extraction and processing to optimise energy efficiency while maintaining product quality. The findings from this study indicate that environmental performance can be improved with monitoring of energy and resource consumption, with data fed directly into environmental LCAs to inform decision-making on site strategy.

Social maturity across all sites indicate the strongest performance in CSR and human & worker rights, demonstrating the importance of protecting workers and contractors, as well as local people who are vulnerable to adverse impacts. Sites performed well in local community benefits & opportunities, judged predominantly by the company’s investment in local employment, education schemes and projects, and financial support for local infrastructure. By contrast, bureaucratic components such as social policy, regulatory compliance and disclosure, and post-closure social considerations scored lowest of the 5 primary categories. The companies involved demonstrated good practical CSR through actions and commitments, but lacked the administrative foundations for regular monitoring and review. The complexity and context-specificity of social impact assessments prevents a single approach to completion due to variable social, cultural and geopolitical situations that interplay through the life of mine (Everingham, 2012; Suopajärvi, 2013). Some participants demonstrated with evidence that they actively support local community development, even in the absence of well-developed policy, impact assessments and closure planning.

5.7.2 Benefits and shortcomings of E&S maturity models

The E&S maturity study enabled perceptions to be gathered that supported and supplemented the scores agreed upon by individuals or groups of participants at each site. Some variation in engagement was observed between participants who completed the exercise on their own or in groups of three or more persons. Individuals were typically more decisive as they worked through the criteria, which is attributed to the lack of opportunity for further discussion with others before selecting an appropriate score. Participant groups typically spent more time deliberating before reaching a consensus as individuals introduced their own perspectives and justifications. Some group discussions progressed more efficiently in cases where one participant, often the most senior group member, informally led each conversation and pressed for a final decision. Collaboration between diverse participants led by senior staff can maximise the effectiveness of the exercise for identifying and addressing E&S culture maturity trends.

The study shows the potential for facilitating interdepartmental discussions regarding the safety, environmental and social impacts of small- to medium-scale operations involving participants that aren’t limited to higher management and departmental leadership. The model’s applicability for assessing large-scale operations requires further study as the elevated workforce size increases the risk of sub-cultures that may inhibit the process of identifying culture trends. The maturity models allow qualitative data to be represented quantitatively to understand the strengths and weaknesses in E&S impact management, and to incentivise progress towards higher maturity. Direct comparisons between sites with similar operation scale, company structure, commodity type, or workforce size introduces increased risk of data manipulation and behavioural adjustment for meeting targets (Dekker, 2018). The primary outcome without delays to research would have been to supply feedback on a case-by-case basis that considers local variability, custom and context for appropriate points of action.

E&S maturity modelling in a mining context could contribute to the just transition so that raw material extraction is conducted responsibly. While the transition towards low-carbon technologies can reduce greenhouse gas emissions and enhance local economies surrounding green technology development hubs, there is significant risk of community disruption if injustices are overlooked. A just transition should endeavour to develop environmentally friendly solutions while maintaining equality within minority groups and communities situated near projects supporting the green transition in a circular economy (Sovacool et al., 2019; Wang and Lo, 2021). The models are designed to guide companies towards responsible practices that protect local environments and communities, which can positively contribute towards a just transition. For ESG principles to be effectively incorporated, natural and social capital must be measured and assessed at various stages in a mine's lifecycle, which can be facilitated by modelling of E&S maturity at individual sites.

Statutory environmental regulations are stringent legal requirements for mining companies to ensure that they are adequately protecting the local environment, allowing them to proceed with operations. A participant from Site A described the environmental model's 'Basic' tier as predominantly illegal and non-compliant based on the most up-to-date UK environmental regulations. The lowest sub-category score achieved was between Basic and Respondent, so despite the scope for improvement, none are at risk of illegality on any specific E&S aspects. Sites which must adhere to the strictest regulatory compliance, depending on location and commodity type, tend to produce the best overall maturity scores. However, this doesn't nullify the importance of clear leadership and an overriding organisational commitment to socio-environmental protection for establishing a mature E&S culture.

Despite only being applied at UK operations, the models are designed for small- to medium-scale regulated mines regardless of location through their alignment with internationally recognised responsible mining frameworks (EBRD, 2014; Equator Principles Association, 2020; ICMM, 2018; IFC, 2012; IRMA, 2018; UNDP, 2014). Several sub-categories of the E&S models closely interlink with economic and governance factors such as worker distribution, pay equity, local procurement, and board decision-making. Future work should integrate economic and governance maturity to further align with established ESG and socio-economic reporting (Barnes and Oruc, 2012; EITI, 2019; ICMM, 2022c;

ICMM and GRI, 2010; IRMA, 2018; SAMESG Committee, 2017), as they are beyond the scope of this research.

5.7.3 Applicability of E&S maturity modelling in a SOSO SSM system

SOSO SSM requires a ‘hit the ground running’ attitude to safety from all persons involved on site, from higher management through to frontline workers. The collective attitudes and perceptions of safety across an organisation defines its cultural maturity which depends on management commitment, resource allocation, training quality, and communication. Criteria-driven maturity modelling enables a baseline understanding of organisational culture to be obtained at a point in time, regarded as its climate, which can then inform changes to gradually increase maturity. The E&S models are designed to investigate socio-environmental culture in conventional small- to medium-scale mines with the capacity to engage with and provide benefit to local stakeholders and progress towards strong ESG performance. The applicability of maturity modelling for improving E&S standards in small- to medium-scale mining has implications for establishing best practice in managing E&S impacts in SOSO SSM operations as conceptualised and pilot tested in the IMP@CT project.

Implementing socio-environmental impact management should be underpinned by organisational strategies and action planning that requires a minimum level of expertise (Spitz and Trudinger, 2009). Site specialists in socio-environmental management are often present in traditional in-situ mining operations, but the reduced scale of SOSO SSM limits the capacity for specialists to be present on site. The company’s ability to develop constructive relationships and trust with local people may be inhibited if those responsible for facilitating stakeholder engagement are only available on a temporary basis. Roles and responsibilities must be set out for SOSO SSM prior to operations commencing to ensure that local stakeholders have a clear point of contact regarding E&S concerns. The capacity of the IMP@CT SOSO pilot system was insufficient to feasibly address local employment, education, and infrastructural investment due to the lack of generated revenues and royalties (Sidorenko et al., 2020). A scaled-up system configuration with multiple units for increased throughput may provide sufficient funding for local development projects and schemes. The E&S maturity models may hold relevance to establishing the baseline maturity of SOSO SSM as well as conventional in-situ operations when calibrated by relative economic scale.

SOSO small- to medium-scale mining operations will play a vital role in diversifying the portfolio of modern mining by adopting innovative technologies to access complex, high-grade ore deposits (Moore et al., 2020). Appropriate regulatory and investment structures must support the expansion of small- to medium-scale mining within a mature culture so responsible attitudes pervade the organisation. Maturity modelling can enable greater socio-environmental performance by establishing the baseline E&S culture and providing guidance to move to higher maturity. It is noted that inherent limits to progress will be present in companies striving for improved E&S performance due to limited availability of resources and specialists, particularly in SOSO SSM operations.

5.8 Concluding statement

As socio-environmental impacts of mining are increasingly considered, an understanding of prevailing E&S culture is vital for establishing whether the maturity of a company is sufficient for protecting local people and environments. While international reporting structures such as CRIRSCO have been essential for defining exploration targets, resources and reserves, ESG factors are not explicitly addressed. SAMESG, along with other internationally recognised ESG frameworks developed by the GRI, ICMM, and IRMA, promote transparency and accountability. Incorporating E&S maturity principles into reporting codes and guidance can provide the foundations from which to prevent at-risk behaviours that contribute to negative E&S impacts. Companies that establish and permeate a mature E&S culture can achieve psychological identification with communities and minorities more rapidly, assuming they have accurately identified their prevailing maturity. This study has broadened the scope of accountability by applying maturity principles to directly address E&S impacts.

The E&S culture maturity study specifically targets small- to medium-scale mining operations, which differentiates this approach from published research into E&S maturity specifically focused on higher education, hospitality, maritime, manufacturing, and logistics. Facilitated self-assessment studies took place at 4 UK mines to test the models' practicality, and obtain data to analyse each site's

E&S culture maturity and understand the benefits and shortcomings of a maturity model approach for improving socio-environmental performance.

Results of the participatory study showed that despite consistent variability in both models between individual sites by primary factor, most maturity scores were located in the two upper tiers. Trends in the environmental model revealed that sites generally performed best in active management of waste, local ecosystem health and stakeholder relationships, but fell short on bureaucratic elements of their operations including life cycle assessment, closure planning, and emergency preparedness, as well as in energy and resource management. The social maturity model demonstrated that sites show good performance in human and worker rights, and support for local development projects that encourage job creation, education and provision of utilities and amenities, but lacked maturity in social policy, impact management, and post-closure planning.

While some of the ‘Basic’ environmental criteria would be considered illegal under UK environmental compliance regulations, the models are designed to be applicable to any small- to medium-scale operation independent of jurisdiction. These findings have implications for how conventional small- to medium-scale mining operations can broaden awareness of their own socio-environmental performance, which informs the applicability of this approach for ‘hitting the ground running’ in E&S impact management of SOSO SSM operations. The reduced capacity of the IMP@CT SOSO pilot system introduces limitations for actively supporting local stakeholders and communities through project revenue, but scaled-up configurations may provide adequate funding for local development projects and schemes. E&S maturity modelling can establish the baseline maturity of SOSO mining and guide operations towards improved socio-environmental responsibility once calibrated by scale. Future work should consider the model’s applicability to operations at various economies of scale, and integrate economic and governance factors in order to align more closely with globally recognised ESG and socio-economic reporting frameworks.

6 The drivers of progress in health & safety and sustainable development for regulated SOSO small-scale mining operations

6.1 Introduction

Achieving resilience and optimising responsiveness in mining operations requires process flexibility and adaptability to ensure in-situ targets can be exploited while maintaining high health & safety and socio-environmental standards. Chapter 2 highlighted the role of safety culture for instilling a positive attitude towards organisational and occupational safety that is built upon a balance of human expertise, interdepartmental collaboration, and regulatory intervention. Chapter 3 emphasised the importance of mining legislation for improving safety standards within the industry, and the safety requirements and considerations for a SOSO SSM system. The reclassification of SOSO mining operations, based on findings from the IMP@CT pilot test site, into three intervention points was proposed to optimise safety management by reducing clutter and cross-duplication, in order to hit the ground running with regards to site safety. Chapter 4 explored safety and socio-environmental culture perspectives from mining personnel at all hierarchical levels to understand how the industry perceives safety, environmental and social matters. Results were placed in the context of High Reliability Theory to understand how mining organisations currently prioritise and commit to safety & socio-environmental development. Chapter 5 investigated the E&S culture maturity trends of four UK sites to determine the areas of relatively good and poor socio-environmental performance, and validate the role that maturity modelling can play in influencing positive culture shift across small- to medium-scale mines.

The resulting web of complexities requires further analysis and consolidation by considering the role of human traits and attitudes in progressing safety and sustainability, such as shared internal safety perceptions, worker behaviours and safety maturity. The political, organisational and socio-economic drivers, including integrated risk management, technological modernisation, company-community relations, and environmental protection, is discussed in the context of SOSO SSM. This chapter will address the key influences and factors affecting safety and sustainability performance, and consider the management techniques necessary to instigate and maintain standards, for regulated SOSO SSM via the following subsections.

- The human traits influencing positive shifts in safety & sustainability, including human expertise and initiative over bureaucratic safety clutter, modern approaches to human error & culpability, and the silo mentality in safety behaviours. Underpinned by research from:
    - Chapter 2 investigating safety performance trends in modern, regulated mines, and the link to safety culture maturity for improving standards.
    - Chapter 3 exploring the role of health & safety regulation and legislation for improving safety standards and decreasing the occurrence of fatalities and injuries through elimination and reduction of latent failures.
    - Chapter 4 investigating safety culture perspectives in small- to medium-scale mining operations to understand how workers, supervisors and managers view the importance of human factors, safety ownership and training measures.
- The organisational, socio-economic and political drivers of safety in a mining context, including the management of integrated enterprise risks in SSM, and the role of mining in shared socio-economic pathways and the associated theoretical scenarios. Underpinned by research from:
    - Chapter 3 into integrated risks associated with the SOSO SSM paradigm, with potential solutions presented for mitigating threats and enhancing opportunities through risk impact and control.
    - Chapter 4 investigating socio-environmental culture perspectives in small- to medium-scale mining operations to understand how E&S impacts are prioritised and managed in practice.
    - Chapter 5 capturing socio-environmental culture trends from participatory maturity modelling to identify areas of good and poor performance in small- to medium-scale mines.
- The application of agile management for maximising productivity while maintaining high safety and socio-environmental standards, through consideration of its core values, principles and frameworks for rapid

adaptation and continuous improvement, and integration of Scrum pathways into culture shock and change management. Underpinned by research from:

  - Chapter 3 outlining the key occupational and organisational safety considerations in SOSO SSM across three intervention points; Underground and/or surface mining (U/SM), Surface comminution (SC), and Surface sorting & processing (SSP).
  - Chapter 4 investigating safety and socio-environmental culture perspectives which highlights potential deficiencies in management of these key factors, informing the relevance of an agile approach to SOSO small-scale mine management.
- The consolidation of best practice safety and sustainability in SOSO SSM operations using insights from previous chapters to discuss the balance of human intervention and automation by their safety and socio-economic impacts, and the management techniques to ensure agility and versatility in SOSO operations. Underpinned by research from:
  - Chapter 3 exploring key considerations for mine safety in a SOSO context by intervention point, determined by the extent of human vs automated process control across the SOSO pilot system.
  - Chapter 4 identifying the overriding perceptions of safety and socio-environmental culture, highlighting the importance of worker age and experience and the presence of sub-cultures for understanding how to enhance awareness and performance.
  - Chapter 5 identifying trends in safety and socio-environmental maturity to determine where small- to medium-scale mining operations demonstrate either strong, acceptable or substandard performance, and interpret the key drivers of these trends.

6.2 Defining human traits and attitudes for positive shifts in mining safety and sustainability

6.2.1 Embracing human expertise and initiative over bureaucratic safety clutter

Frontline workers engaged in active extraction and/or processing face highly dangerous and rapidly evolving conditions, particularly in underground workings with complex geological variability. Safe working practices and procedures have a crucial role to play in managing worker safety, even those with advanced expertise and experience to act upon safety issues in their work environment. Complex system risks have traditionally been managed with stringent regulations and standards to shore up failure pathways so harm to workers can be avoided or mitigated. Promoting cultural alignment across the organisation is important for risk mitigation as “the collective culture of an organisation is an aggregate of what is common to all of its group and individual mindsets” (Lawson and Price, 2003). Companies must ensure that higher management are fully committed to changes, employees understand and agree with any changes, recognition systems encourage employees to engage, and employees are equipped with appropriate resources and training (Lawson and Price, 2003). Top level management must permeate positive cultural attitudes to the lower levels of the hierarchy, reinforcing the importance of a top-down approach for improving safety culture (see chapters 2.7 and 2.8).

Chapter 4 reinforced the importance of safety standardisation for instilling confidence and trust among workers that safety is prioritised. While regulatory compliance permits adherence to OSH law and legislation, excessive regulation from centralised control sources can be detrimental to safety progress due to cross-duplication and cluttering. This removes the intrinsic motivation that naturally manifests in people who are permitted broader autonomy and the freedom to self-organise and solve problems in their work areas. Chapter 3.4.1 highlighted the importance of updated legislation for improving safety, but the effectiveness of regulations have reduced as fatality and injury rates approach zero, due to immature prevailing culture and cross-duplication of regulations.

The development of intervention points for the SOSO mining system in chapter 3 mitigates the risk of cross-duplication and safety clutter for targeted safety management, training and culture development in these operational areas. The Woolworths experiment demonstrated how bureaucratic decluttering and control decentralisation could improve OSH standards, by removing all ‘unnecessary’ rules and placing more responsibility on frontline store workers to actively engage with workplace safety (Oberg, 2016). Out of 30 stores, 10 ‘control’ stores maintained centralised safety control, another 10 removed all safety rules and procedures to develop ‘grass-roots safety’ organically, and the final 10 had all rules removed with retraining using Dekker’s *Safety Differently* principles (Dekker, 2018, 2014b; Oberg, 2016). The experiment showed demonstrable success in the stores with unnecessary rules and procedures removed, with even greater improvements in those who received training in *Safety Differently* as workers were given greater autonomy and ownership of their own safety. This technique has potential for maximising safety within other organisations, but the high risk nature of mining compared with retail means a similar experiment would be highly problematic even in modern, regulated operations.

Centralised standardisation of safe working practices and procedures for a SOSO SSM system would be suitable for achieving compliance, which would enable a ‘Woolworths-style’ experiment to be conducted across a cluster of modular mine sites. Inefficiencies of safety management in SOSO mining driven predominantly by cross-duplication and overregulation may be detrimental to safety progress, hence the need for greater safety ownership by skilled workers. Considerable safety and ethical concerns remain due to the novel, innovative nature of the containerised SSM solutions. The SSM system’s adaptability will likely limit standardisation of safety regulations to individual components due to the versatility of containerised processing flows, hence the need for intervention points. High safety performance in modularised SSM requires implementation of comprehensive and appropriate regulations with minor reforms and retrofits, while encouraging increased worker autonomy and initiative.

Establishing a culture of knowledge sharing and collaboration for continuous improvement requires an understanding of the workforce distribution in terms of age and experience. Analysis of interview responses in chapter 4 indicated that some older workers demonstrate strong safety consciousness and mentorship for the benefit of younger and/or less experienced colleagues. Other older workers exhibit complacency towards safety issues due to their extensive industry experience and expertise, leading to overconfidence and a comparative disregard for safety standards. By contrast, younger workers either have a keen interest in enhancing their knowledge through senior employees, or display closed-mindedness towards safety due to inexperience and complacency imparted by like-minded older workers. These are key considerations for how training is administered, and how work team distribution and circulation are arranged to optimise the mutual benefits of youth and experience. Distribution of sub-cultures can sometimes inhibit safety progress as communication is impeded. However, independent opinions developed within sub-cultures may enable unconventional solutions to be deduced that would not have been discovered in a fully cohesive organisation. Facilitating sub-cultures for establishing innovative safety solutions requires careful management to mitigate the risk of fractious attitudes developing across teams over time. In SOSO SSM, sub-cultures should theoretically be less prevalent due to the smaller workforce size relative to conventional in-situ mining as communication remains localised and perceptions are more aligned across the organisation.

Bottom-up feedback from site experts is valuable for improving safety, but often hindered by bureaucratic clutter, and intensive implementation of safety management systems. The forward thinking nature of younger workers can promote a modern view on safety that relies less on bureaucratic intervention, which contrasts the nature of complacent older workers who tend to be more set in their ways. By contrast, some individuals or groups will be more conducive to updated standards without increasing safety clutter. Relying solely on 'bottom-up experts' may not be wise due to narrow perspectives and organisational context to effectively manage integrated risks, including political, financial, legal, and reputational. Consideration of an appropriate risk appetite within the broader 'universe' of risk is necessary to determine the balance between autonomy & bureaucracy depending on local context. The operation and interface for complex mining equipment such as the selective mining tool is described in procedures and instructions from the manufacturer. However, contingencies for managing the variability in conditions while working at face cannot be bureaucratically managed without generating extensive safety clutter and cross-duplication. Placing trust in expert operators, engineers and geologists to make logical decisions based on an aligned risk appetite, in the presence of a mature safety culture, can supply the motivation to show initiative and autonomy. Moving from excess bureaucracy towards embracing expertise and instilling self-belief in workers is referred to as Anarchism, defined as "a set of ideals and ideas… [that value] horizontal coordination rather than hierarchical top-down authority" (Dekker, 2018). Adopting anarchism principles for greater autonomy and intrinsic motivation to manage complex systems encourages greater freedom of interaction between skilled practitioners. From insights by Dekker (2018), Hollnagel (2014), Deming (2000) and Rasmussen (1997), governing safety in complex systems is practicable where: (1) safety is cross-coordinated and self-organised; (2) local interactions and connections are fostered and maintained; (3) financially incentivised safety goals are eliminated; and (4) a culture is instilled that supports intrinsic motivation and worker pride.

6.2.2 A modern perspective on 'human error' and accountability

From analysis in chapter 2.7, there is overwhelming emphasis on human error as a root cause of fatalities, which is solved by more rules, procedures and training. Post-incident investigations reach conclusions without acknowledging the full event chain, and the reasons for decisions made by workers at critical junctures in the lead up to failure. This is defined as the "Old View" of 'human error, where the priority is to control and change behaviours to reduce incident occurrence, and assumes that people come to work to deliberately cause problems (Dekker, 2014a).

The reduced scale of SOSO operations requires rapid decision-making to reduce the risk of delays that result in wider impacts for employment prospects and SLO status. The innovative modularised SOSO equipment and reduced workforce size introduce additional threats in a safety incident where in-depth investigations are needed to understand the failure pathways and root causes. The semi-automated extraction and processing system's complexity heightens the risk of slip and lapse errors if safety, ergonomics and operability aren't considered sufficiently at the design phase (see chapters 2.8 and 3.4.2). Taking a "New View" on human error looks beyond behaviour as the main cause of failures at work by paying closer attention to working conditions at the time of the accident, and how workers involved interacted with work environment. Human error is regarded as merely a symptom of more deeply rooted problems within the working area in question.

Organisations with an "Old View" of human error tend to strive for 'zero harm' in the belief that less reported incidents is due to improved safety standards. The interactions operators have with the work environment increases available data,

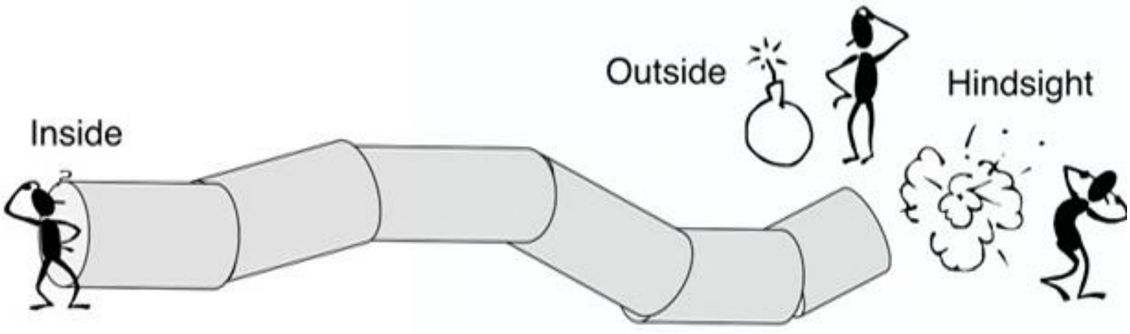


Figure 6.1: The 'tunnel' model of hindsight bias in safety incident analysis from Dekker (2014a).

which influences the decisions made by workers with consequential safety implications. Dekker's 'tunnel' model shows how the perspective of post-incident investigators can be skewed by hindsight bias, as they can trace back the event chain, accordingly criticise and place blame (Dekker, 2014a; Figure 6.1). Those directly involved are unable to foresee the potential routes to failure while inside the tunnel, so they must act on their own expertise and intuition.

Those who were closest to the incident at the 'sharp end' (e.g., vehicle cab, module/container operator) typically receive the most scrutiny from investigators with regards to their decision-making. By primarily considering the 'proximal' factors that influence incident occurrence and severity at the sharp end, the 'distal' factors at the blunt end (e.g., targets, provisions, equipment, training) are ignored. The proximal nature of SOSO SSM operations, owing to its smaller physical footprint and workforce size, means that sufficient provisions must be available to allow safe work, while ensuring that broader objectives do not compromise safety. Performance assessments that prioritise the sharp end demonstrate hindsight bias by comparing data from the event to known procedures (i.e., micro-matching, cherry-picking). This does not fully explain why frontline workers chose a particular course of action which violated the technical procedures provided by the organisation. As a dangerous situation unfolds, workers receiving cues from the system and the environment will use data to make appropriate decisions, some of which won't be specified in safe working practices. The "New View" discourages the belief that occupational accidents occur because of worker incompetence or violations; understanding the complete organisational context is crucial for establishing the reasons for workplace failures (Dekker, 2014a). The challenge for SOSO SSM is in developing systems with sufficient agility and diligence to encourage New View thinking and impart greater responsibility across all levels of the hierarchy.

Table 6.1: Old and New View interpretations of procedural adaptations from Dekker (2014a).

"Old View"	**"New View"**	**Application to SOSO SSM**
Procedures are the best thought-out, safest way to carry out a task	Procedures are resources for action (next to other resources)	Workers should be empowered to use procedures appropriately and adapt depending on the situation arising.
Procedure-following is IF-THEN, rule-based behaviour	Applying procedures successfully is a substantive, skilful cognitive activity	Individual worker skill and knowledge should be used with procedural guidance to optimise safety.
Safety results from people following procedures	Procedures cannot guarantee safety. Safety comes from people being skilful at judging when and how they apply	Workers should think outside the box with regards to safety and engage in collaborative problem solving to optimise overall performance.
Safety improvements come from organisations telling people to follow procedures and enforcing this	Safety progress comes from organisations monitoring and understanding the gap between procedures and true practice	Management should always engage with workforces to understand how procedures are applied in practice to reduce clutter and cross-duplication.

As shown in Table 6.1, rules and procedures should be treated as a guide for experienced and skilled operators to work with, not as strict limits providing little to no capacity for adaptation and improvisation (Dekker, 2014a), except when those rules are legally enforced for compliance. The complexity of the SOSO SSM mining tool, comminution, and processing units requires operational flexibility to adapt to rapidly changing conditions (e.g., geological & structural variability, process flow rates, fluid-concentrate balance in processing circuit).

Assuming high geological confidence, the reduced economy of scale and increased adaptability of the SOSO modularised system can deprioritise the financial risk relative to traditional operations due to its short temporal duration and rapid turnaround time. Safety margins need not be exploited excessively for incremental economic benefit because the SOSO system comprises relatively lower CAPEX and OPEX costs than traditional large-scale mining projects. There are also implications for the availability of provisions, training and equipment at the blunt end of culpability, potentially placing greater pressure on skilled human operators to maintain standards and minimise slips and lapses. Risks associated with SOSO SSM comminution and ore processing flowsheets must be continuously evaluated to ensure that 'normal' day-to-day procedures remain viable against the organisation's competing goals (e.g., production, efficiency, safety). This ensures that personnel are less likely to develop habits that cause them to deviate significantly from the norm, referred to as 'Drift'.

Some skilled SOSO operators must remain with the equipment through each deployment cycle, and while other skilled to semi-skilled workers will reside

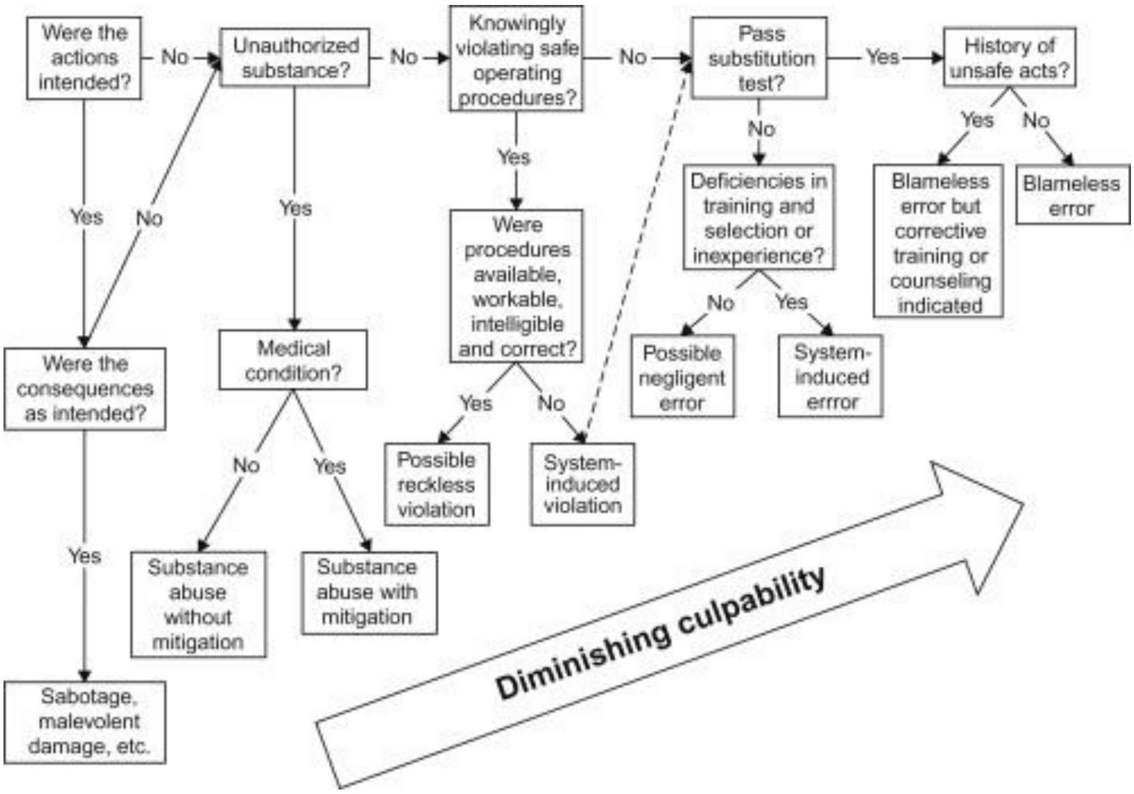


Figure 6.2: Reason's culpability decision tree, obtained from Moriarty (2015).

near the deployment location. This presents particular risk of drift deviation as new workers will require training that must account for local cultural and societal variation. This deviation may lead to more frequent near misses that will be considered as a ‘success’, despite the potential for some of these to escalate into harmful incidents later (Dekker, 2014a; Turner et al., 1997). Incremental narrowing of safety margins by organisations over time in order to meet other objectives may be misinterpreted as ‘good performance’, because it encourages at-risk behaviours for the sake of maintaining financial performance. Reason's culpability scale (Figure 6.2) and Dekker's ‘Just Culture’ principles for substantive, procedural and restorative justice have been considered to locate the point at which individual blame becomes appropriate in light of accident investigations. Reason considers the interactions between the individual’s intent to cause harm, their prevailing medical conditions, the adequacy of working procedures and practices, the quality of training, and the individual’s history of unsafe acts (Reason, 1997).

Dekker & Breakey (2016) explored ‘just culture’, an approach which aims to balance the eradication of individual blame on one hand, and the consistent reporting of safety issues by individuals on the other. Optimising safety in a SSM paradigm must take a no-blame approach to maximise depth and pace of feedback sharing from workers who make mistakes or experience near misses. A ‘just culture’ paradigm can strike a consistent balance between individual and system accountability, requiring open dialogue at all levels of a SOSO SSM hierarchy to accelerate the process of constructive culpability and broader organisational learning. A prevalent trait among skilled workers in hazardous industries relates to their confidence in their ability to complete complex tasks such as electrical maintenance, which may inhibit transparency when mistakes and near misses occur (Mason, 1996). This could be problematic in SOSO SSM as workers may be uncomfortable with openly admitting that they lacked the required knowledge to carry out their job safely and without error, reinforcing the need for a ‘just culture’ for effective feedback sharing. Organisations demonstrating a mature culture should also incorporate a just culture approach that is built on open, interdepartmental dialogue to accelerate the process of learning and continuous improvement.

6.2.3 The silo mentality and conformity in safety behaviours

Early investigations into conformity conducted by Asch (1951) discovered that when individuals are placed in situations where their opinions diverge significantly from most persons in a group, “a substantial minority yielded [to the collective view], modifying their judgements in accordance with the majority”. The fear of rejection strongly contributes to people’s decision to accept what they know to be wrong, owing to the desire to align with the social norm, which is prevalent in inexperienced workers who lack the competence to make correct decisions, and so are more compelled to ‘follow the crowd’. (Ragain, 2015; Tata et al., 1996).

Since industry experience is key for establishing cores of influence within work teams, management must ensure that influential senior members demonstrate positive safety attitudes to encourage younger, less experienced workers to conform to desirable safety behaviours. Using safety champions (see Figure 4.7) as influential people to help drive groups of workers towards better safety performance may discourage detrimental conformity, as positive messages and habits gradually filter through the organisation (Bunning, 2021). Work team distribution by relative age and experience will be a key consideration for management attempting to optimise maturity by promoting conformity towards positive safety attitudes and behaviours.

SOSO SSM intervention points for safety management may generate isolated thinking when devising solutions for safety issues. The prevalence of "silo mentality" is a key consideration with regards to interdepartmental knowledge sharing, as the modular design and reduced workforce size affects the extent of adaptability required to effectively operate safely while processing sufficient high-quality product. Frontline workers carry greater responsibility for decisions that are critical for balancing site safety and productivity relative to conventional in-situ mining, so site teams must always remain connected to ensure regular collaboration. Greenberg and Baron (2011) describes the highest position in an organisation as carrying predominant responsibility for overall performance, as well as the final say in decision-making. Decision-making and authority progressively fades in the lower levels of the hierarchy, leaving frontline employees with limited authority (Cilliers and Greyvenstein, 2012; Hirschhorn, 1997). This increases the risk of sub-cultures and siloing as communication through the vertical and horizontal specialisations disintegrates, leading to rebellious attitudes from isolated groups and a deterioration of team identity (Chandler, 2010; Cilliers and Greyvenstein, 2012; Nævestad et al., 2021). Poor equipment design, ineffective communication, and immature culture perceptions should not be addressed in isolation. Organisations should integrate employee views from multiple departments and sub-sectors to ensure that good relations are maintained between teams to promote constructive communication.

Immature safety cultures comprise of complacent older workers and younger workers being closed-minded. Transitioning towards increasing maturity, site-wide training, supervision, and mentoring is required to develop and maintain high safety and risk awareness. Organisational sub-cultures and the silo mentality may indicate a desire to conform, especially if younger, less experienced workers, even those receptive towards safety, are placed with predominantly comprised of older, more experienced workers. Overcoming the danger of conformity within workforces, and sub-cultures within those, must be a key consideration for higher management and supervisors.

6.3 Defining the organisational, socio-economic and political drivers of safety in a mining context

6.3.1 Managing integrated enterprise risks in small-scale operations

Despite the complexity of the modularised solution, the reduced workforce size and short lifespan, SOSO SSM operations will be crucial for supporting the green energy transition through resource targeting that cannot be economically mined using conventional methods. Managing system complexity requires an understanding of the organisation's integrated risks with positive and negative implications for the project's goals, in the context of SOSO extraction. This inherent complexity requires an integrated approach that utilises continuous improvement of policy, communication, training, and risk & critical control management outlined in chapter 3.4. Traditional risk management tends to be siloed which creates problems when risks are managed by department or business unit leaders without consideration for the implications of decisions on other areas of the organisation (Frigo and Anderson, 2011).

Enterprise risk management (ERM) enables organisations to identify, analyse, interpret and respond to risks using a continuous cross-departmental process of measuring, monitoring and action planning (Cormican, 2014). Risk is the "effect of uncertainty on objectives", which is the variability of both the negative and positive impacts of a project's activities to support decision-making at all organisational levels (ISO, 2018b). Risk exposure, which is normally monitored and mitigated using integrated risk management (chapter 6.3.1) and risk impact & control maps (chapter 3.7), evolves continuously throughout a project's lifecycle depending on the influence of internal and external factors. Small organisations may struggle to implement integrated ERM to manage risk exposure, due to insufficient financial capability, weak management structures, and limited commitment to long-term ERM strategy (Beasley et al., 2005; Brustbauer, 2016; Cormican, 2014). Therefore, the organisation must be physically and culturally empowered at all levels to engage in adaptive problem solving to increase efficiency in integrated risk management.

As organisational scale increases, the scope for threatening events varies which influences the criticality of a thorough risk management structure for reducing threats, requiring adequate financial capacity to integrate ERM (Beasley et al., 2005; Brustbauer, 2016). Qualitative studies by Cormican (2014) on 134 advanced technology manufacturing companies explored the challenges and factors associated with ERM in small-scale organisations. The inductive qualitative approach collects numerous opinions and perspectives from participants to reveal dimensions from complex issues within the study. The key themes revealed by Cormican's study were: (1) ensuring *Awareness* of ERM; (2) defining ERM *Policies* and strategies; (3) establishing *Processes* for risk identification and analysis; (4) implementing effective ERM *Management*; (5) building an ERM *Culture*; and (6) measuring the *Benefits* of ERM practices (Cormican, 2014). SOSO SSM can implement ERM provided that the necessary structures, policies and processes are fully integrated, with an embedded culture that prioritises the importance of utilising ERM for breaking down organisational silos.

Table 6.2: Threats and opportunities of SSM relative to large-scale mining (LSM) from an ERM perspective, addressing social, environmental, safety, financial, political, reputational and legal risks.

Threats to SSM relative to LSM	**Opportunities from SSM relative to LSM**
• Reduced employment opportunities • Strategic outcast in government planning due to small operation scale • Lack of co-operative working • Not large enough to attract traditional funding schemes • Reputational damage to higher level company responsible for SSM operations that have an incident causing disruption • Limited response time in mine rescues • Education & knowledge gap in mining • Waste management – Tailings (toxicity) • Post-mining legacy (environmental) • Taking responsibility for legacy mines • Permitting/ licencing restrictions • Land ownership complexities • 'Brain drain' in developing regions • Adhering to environmental regulations • Sterilisation of future potential deposits • Leverage against LSM paradigm	• Cash flow coming in sooner due to lower CAPEX for equipment, infrastructure, commissioning, etc. • Logistics & transport of SOSO equipment across Europe; more cost effective for companies. • Localised impacts of SOSO mining can be an advantage in 'crowded' Europe. • Interdisciplinary knowledge transfer through co-operation of SSM-specialised companies, institutions and OEM's • EU lobbying to promote SSM paradigm • Post-mining legacy (useful infrastructure such as mobile renewable solutions) • Local contracting and indirect employment • Legacy credits (i.e., waste dump reprocessing), thereby avoiding excess comminution • Focused mining activities producing less waste, leading to improved margins and reduced environmental & social impacts • Mobile equipment to improve SSM performance may have applications in Peru and Chile
Threat mitigation	**Opportunity enhancement**
• New funding schemes to encourage uptake of SSM operations • Dedicated rescue teams for site 'clusters' • Representative bodies to lobby & inform government, to support SSM companies	• Database of risk prioritisation for SSM • Mining alliances & co-operatives dedicated to SSM management, solutions and outreach • Early (pre-feasibility) planning of post-closure reclamation strategy and proposed activities

• Streamlining of permitting requirements • Universal standardisation of SSM • Training of local workforces provide transferable skills for post-mining legacy • Underground backfilling with tailings paste • Transparency & accountability (of environment protocols, cashflow, etc.)	• Increased research into rapid deployment and commissioning methods • Modern strategies for clustered mineral deposit exploitation within Europe • Detection & investment in 'stable' legacy deposits • International outreach activities led by EU to promote SOSO mobile solutions

By adopting the ERM approach, the threats and opportunities associated with the core activities of regulated, small-scale mining projects can be identified, measured and managed. Table 6.2 presents a comprehensive overview of the anticipated threats and opportunities of SOSO SSM relative to conventional large-scale mining in a European context, which was populated during breakout discussions with *IMP@CT* project consortium partners in March 2020. The consortium group worked to collate the positive and negative impacts of the *IMP@CT* SSM system by project risk, which was supplemented with strategies and suggestions for mitigating threats and enhancing opportunities.

Socio-economic development of local populace requires sufficient financial scope within the project to direct funds and support for projects and schemes in the local area while also covering operational costs. This will likely be achieved in SOSO SSM through employment and upskilling of local workforces through specialised training, and financial support for local businesses and suppliers. Moore et al. (2021) investigated the potential reduction in unemployment of three operations at two pilot test deployment sites in the municipalities of Olovo in Bosnia & Herzegovina and Ljubovija in Serbia. For an IMP@CT workforce operating continuously over a 24 hour period, it was inferred that unemployment in the two municipalities would be reduced by 8.8% and 5.2 % respectively, based on census data accurate at the time of publication. Upscaling and 'clustering' of modularised systems to target deposits with higher reserves that remain classified as 'small-scale' may have positive implications for local development, employment prospects, and closing the sector knowledge gap, requiring an ERM approach to strike a balance between probable risk factors.

Increasing automation, or the intelligent management of mining and processing systems with minimal human intervention (Lynas and Horberry, 2011), serves an incremental reduction in unit cost at large 'world-class' mines, driven by an ambition to remove workers from hazardous environments. The shift from large, skilled teams to small, high- to semi-skilled workers, due to implementation of mid-level system automation, can have detrimental implications for employment opportunities. Mid to full automation lacks adaptability and introduces high capital expenditure, while manual operation facilitates in-situ decision-making as the equipment is under human control. Safety requirements are also reduced and viable deposits situated in sparsely populated regions are more accessible assuming that sufficient capital is available. Low level automation involves variable workforce sizes that rely on manual operation, which can maintain social acceptance, but requires more consideration of OSH risks and hazards. The scope of deposit targets is limited by higher capital expenditure demands, which can often only be covered by revenue generated from world-class mines. Societal perceptions and employment opportunities are also detrimentally impacted by increased dependence on automation. Management-level decisions regarding how automation solutions are implemented within SSM can benefit from an ERM approach to ensure all risk categories are considered.

6.3.2 Shared socio-economic pathways and the role of SOSO mining in theoretical scenarios

Since the Anthropocene, the global population has driven extensive growth and exploitation of natural resources such as minerals and metals, at the expense of the world's ecosystems, with legacy impacts for global food chains (Dold, 2020). The raw materials sector's ability to address sustainability issues is limited by the finite nature of mineral extraction. For mining to contribute to sustainable development, companies must optimise waste streams along the value chain through efficient extraction and processing, and smart waste management to maximise production and minimise the volume of disposed material. The E&S maturity study in chapter 5 showed that companies operating small- to medium-scale mines tend to perform best in tailings and mine waste management, local ecosystem health, and investment in local development projects. This indicates emphasis on active impact management through regular monitoring & control and local collaborations that enhance social sustainability. Responsible mining is principally underpinned by the SLO, which depends on company-community relations established early in the life of mine, commitment towards socio-economic development, and environmental protection.

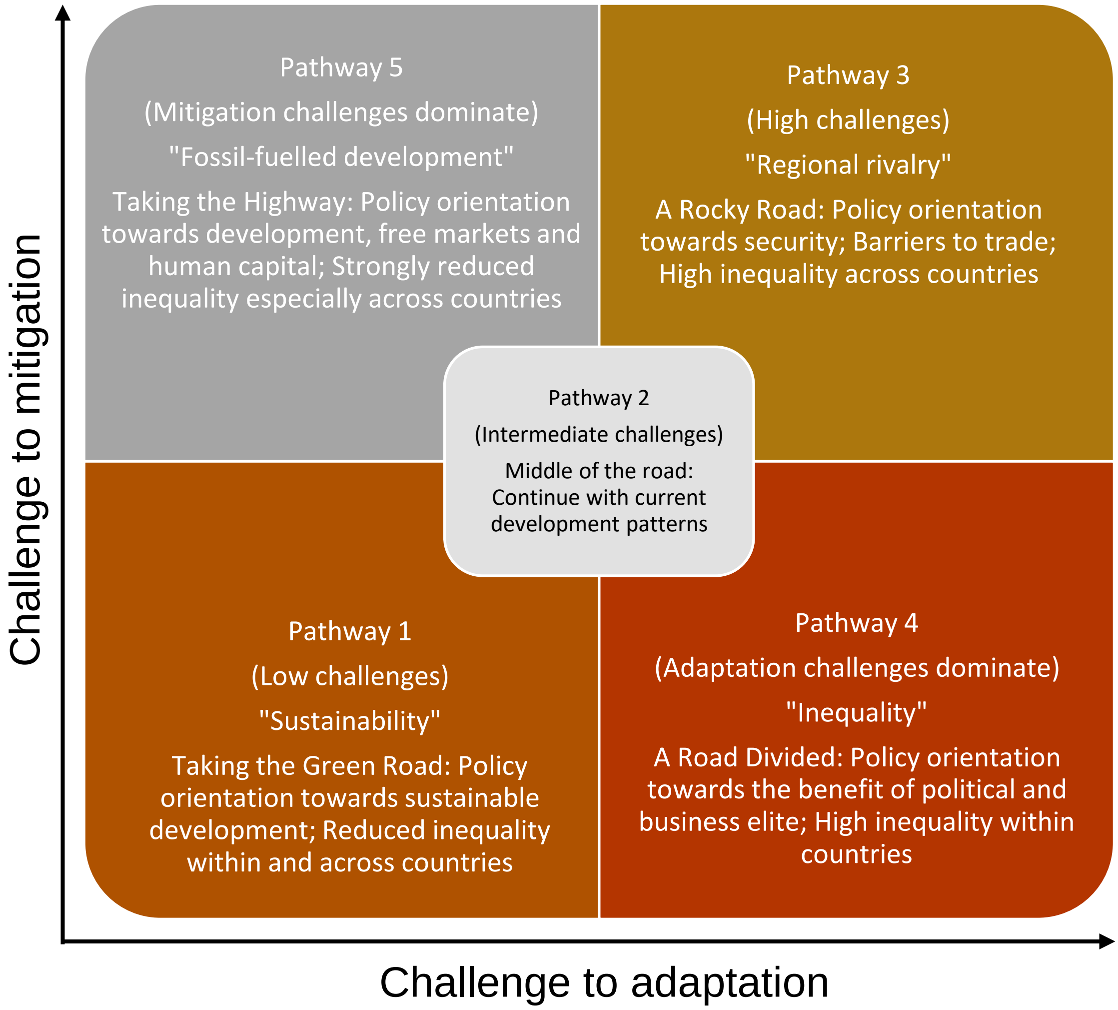


Figure 6.3: The shared socioeconomic pathways in the context of climate change research (O'Neill et al., 2017, 2014; Riahi et al., 2017; UNEP, 2021).

The characteristics of responsible mining broadly correlate with how long-term global climate scenarios and their resulting impacts on society, economic markets, trade, security and the environment are mapped to forecast the likely challenges faced under each scenario. Figure 6.3 represents a theoretical framework for climate change research integrating future global warming trends with pathways of socioeconomic development defined by their mitigation and adaptation challenges (UNEP, 2021). The development pathways define socio-economic scenarios through the next century characterised by the effects of mitigating climate change or adapting to changes associated with predicted global warming trends. Increased reliance on adaptation produces relatively high inequality within and across global nations as individual countries prioritise economic preservation and technological development, through building connections with sources of proven economic value. This reduces the capacity for authorities and governments to provide financial support for minority groups, producing complex social and ethical challenges that increase inequality. Increased reliance on mitigation is driven by high reference greenhouse gas emissions due to high population and/or growth rates, intensive land use, and high energy and resource consumption. This drives rapid economic growth through policy commitment towards free global trade, national security and societal development, with variable technological advancement and inequality.

Pathways 1 & 5 (low adaptation, variable mitigation) produce the lowest global population and the highest GDP of the five scenarios, but energy consumption is highest in pathway 5 owing to its emphasis on fossil-fuel development. SOSO SSM operations can help to reduce the mining industry's dependence on fossil fuels through the use of modular, rapidly deployable renewable energy systems to provide sufficient power for containerised mining systems in off-grid locations (Paneri et al., 2021). Pathway 1 shows the lowest predicted consumption due to the importance placed on sustainable development and reduced inequality. Long-term employment opportunities are necessary for decreasing local inequality, but this reduces the scope for automation solutions as operations will predominantly offer low-skill, manual jobs. SOSO SSM's semi-automated design paradigm may inhibit local employment and equality, as processing systems must be operated and monitored by skilled to semi-skilled workers.

At face value, SOSO SSM appears to align closest with pathways 1 & 5 for optimisation of global economic and sustainable development, which will increase consumption for development of new energy-efficient, environmentally friendly technologies, which relates to pathways 3 & 4. Beylot et al. (2021) conducted life cycle analysis of the SOSO modular mining system to assess environmental performance, concluding that impact reduction should prioritise electricity demand, originating in the ore preparation and gravity separation elements, through installation of mobile modular renewable energy solutions. To reduce the environmental impact of SOSO mining, fossil fuel dependence must be mitigated through utilisation of renewable technologies to offset emissions, requiring variable base and critical metals which must be recycled or mined.

The flexibility of modular SSM can enable a governance model that is underpinned by community ownership according to Andy Reynolds, further stating that "a flexible mindset supported by model-based design tools" are necessary to tailor small-scale modular mines to the specific needs of communities (Leonida, 2021). Pathways that reduce both mitigation and adaptation challenges must prioritise sustainable development and social equality through the provision of technologies that mitigate environmental impacts with community involvement. Sustainable energy and agriculture must remain capable of satisfying demand from a relatively lower global population than the high adaptation scenarios. Modular SSM operations must increase efficiency and versatility to reduce energy & resource consumption, requiring new funding, alliances and co-operatives to facilitate investment and knowledge exchange. Local employment and implementation of governance models for community ownership can enhance human capital and facilitate reinvestment into local economies for sustainable growth. Transferable skills developed through training administered by SOSO SSM can also enhance local prospects through upskilling, contributing to the rebalance of regional inequality.

6.4 Applying agile management for maximising productivity while maintaining high safety and socio-environmental standards

6.4.1 Core values and principles of agile

The balance between human control and automation in SOSO SSM equipment design and normal operations has implications for knowledge transfer facilitated by cascade training. The flexibility of deployment options for a SOSO operation, or cluster of sites, requires a minimum number of skilled workers who move with the site to ensure there is a core team with the capability to administer training to newly appointed workers at each deployment (Moore et al., 2021). The applicability of Agile for rapidly adaptable and efficient mine management in a paradigm that depends on versatile logistics, workforce training and in-situ extraction & processing, and for maintaining community relations, is discussed.

Agile was first discussed by William Royce to improve the management of large software development projects, by highlighting the deficiencies of the ‘waterfall’ methodology for achieving objectives on time and within budget (Royce, 1970). Traditional ‘waterfall’ project management considers the immediate costs of the project and plans for factors such as price, scope and time. Agile management focuses on teamwork, customer collaboration and flexibility through a cyclical

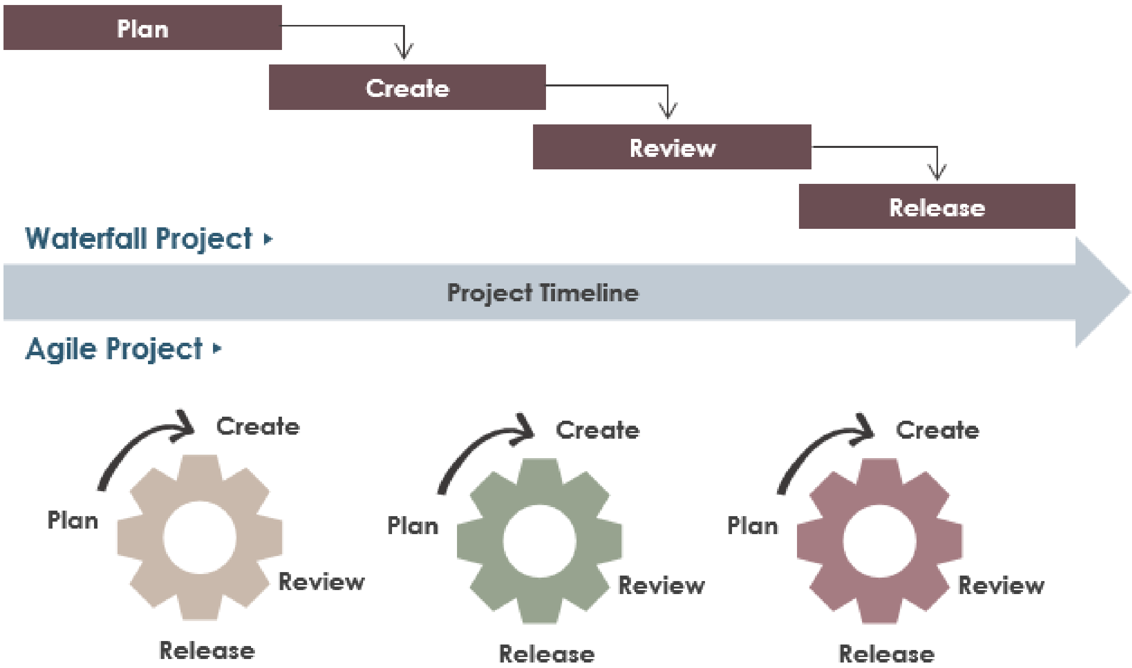


Figure 6.4: Conceptual comparison between waterfall and agile project management. Obtained from Visual Paradigm (2022).

process (Figure 6.4). The traditional system is regarded as “cumbersome, restrictive and unsuitable for the new era of speed”, because planning takes place at the start, leaving minimal opportunity for review and improvement (Visual Paradigm, 2022). Agile management is built around the assumption that change is inevitable and a natural part of building a product or deliverable, which aligns with the inherent flexibility of the modularised SOSO SSM system. Frequent interventions in the concept development and design stages can significantly benefit the quality of the final product, as excess costs aren’t spent on retrofitting & redesigning after completion. According to the 2011 CHAOS Manifesto from the Standish Group, Agile projects are three times more successful than Waterfall projects (Visual Paradigm, 2022). Successful implementation of Agile in non-software sectors, such as manufacturing, varies depending on the teams or managers involved, as observed in partial attempts at Agile informed by best practice from completed projects (Stare, 2014).

Agile management is underpinned by 4 core values; human interaction through every development phase, regular customer collaboration, flexibility to changes, and a tangible outcome in the form of a working product (Bennett, 2019). Management teams should prioritise individuals and team interactions over processes and tools, as it is preferable to have competent workers collaborating effectively. The SOSO containerised mining system is inherently agile, due to its adaptability to different commodities, flexibility to market shifts, and rapidity of deployment, commissioning, operation, and redeployment. Site management and workforces must have the ability to rapidly respond to environmental and circumstantial change. The production of a tangible mineral ore concentrate is key for demonstrating the success of agile management to stakeholders and investors. Although individual project teams or workforces may be ready for agile development, other departments may not be, which becomes a prevalent issue when sub-cultures are established.

Stantec (2019) cited increased productivity, reduced environmental footprint and rapid uptake of technological solutions after introducing agile into their operations, stating that commitment, cautious optimism and collaboration were key to its success. Agile is best used when deploying innovative technologies by removing the silo mentality and encouraging interdepartmental collaboration to rapidly iterate improvements and improve decision-making (Fraser, 2022). A cascade training scheme developed by Moore et al. (2021) for facilitating knowledge transfer between equipment manufacturers and site operators, and for introducing design and procedural amendments, may assist the uptake of Agile management in SOSO SSM. Permanent workers with knowledge of Agile processes can administer training and collaborate with operators during each deployment, especially where availability of skilled trainers is limited. Strategic and cultural alignment is imperative as projects can create benefits for some but consequently cause detriment to others in the organisation. Recurring cycles of Agile described in Figure 6.4 may place focus mainly on completing sprints quickly with inadequate care and attention towards product quality, with knock-on effects for other organisational areas as well as the overriding socio-environmental culture perceptions throughout the hierarchy (see chapter 4).

6.4.2 Agile management frameworks for rapid adaptation and continuous improvement

Scrum and Lean describe the iterative process of Agile management that concentrate on people & task-based approaches and engineering & production-focused practices to deliver quality products efficiently. The two frameworks are directly compared by their definition, leadership and management structure, scalability, adaptability and process basis. The key difference is that Scrum facilitates adaptive, collaborative development of complex products through 'Sprint' cycles, while Lean is built around organisational engagement and alignment of resources for solving problems and improving performance.

Table 6.3: Comparison between the Scrum and Lean agile management frameworks (Lean Enterprise Institute, 2008; Sutherland, 2019; Sutherland and Schwaber, 2016).

Category	**Scrum *(Theoretical)***	**Lean *(Practical)***
Definition	A framework within which people can address complex adaptive problems, while productively and creatively delivering viable products of the highest possible value. Built on repeating process of Transparency, Inspection and Adaptation. **"Team-led Rapid Adaptation"**	A series of practices that enables people to understand and own problems, aligning resources to achieve goals. Lean management engages everyone in design processes to solve problems and improve performance, while using the fewest possible resources. **"Widespread Continuous Involvement"**
Leader	Scrum master – Responsible for ensuring Scrum is understood and enacted, and do this by ensuring that the Scrum (Development) Team adheres to the Scrum theory, practices & results.	Change agent – Leader of a lean conversion, often external, with the drive to initiate fundamental change. Group leader – Frontline supervisors involved in planning production, reporting & auditing.
Manager	Product Owner – Responsible for maximising the value of the product and the work of the Development Team. They are the sole person responsible for managing the Product Backlog, the point of contact for the Development Team, and accountable for its results.	Chief Engineer – Responsible for product development and manages a dedicated team that creates product concept, develops business case, leads technical design, manages development process, coordinates with production engineering and marketing, and initiates production.
Scalability	Scrum@Scale – Based on a scale-free architecture that allows organic growth, it is a framework for effectively coordinating networks of multiple Scrum teams, addressing problems of greater complexity than single teams.	Capital linearity – Philosophy for designing and buying production machinery so small amounts of capacity can be adjusted as demand changes. From this, the capital needed per unit produced can be very nearly level (linear).
Adaptability/ Quality Control	All aspects of process must be visible to all persons that are responsible for the outcome (Scrum Team), they must be reviewed in order to detect undesirable variances, and adjusted where necessary.	"Jidoka" – Providing machines and operators with the ability to detect when an abnormal condition has occurred and stop work, building quality in at every process stage to highlight root causes.
Process basis	Transparency, Inspection & Adaptation – The main steps taken by the Scrum management process, to ensure tasks are completed effectively and on time, and that inefficiencies are addressed and improved for future cycles (Sprints). This	Fulfilment stream - A supply chain that embodies Lean and flows collaboratively, rather than operating as a group of connected links. The 'FS' eliminates all nonvalue-creating activities among suppliers and producers. The goal is to

	is to ensure that the final deliverable is optimised to customer requirements.	deliver the highest value to the customer at the lowest total cost to stakeholders.
Approach	*People- & task-focused framework*	*Engineering- & production-focused practices*

Scrum is more theoretical in nature with applications across multiple disciplines besides software development (e.g., media, industry), while Lean focuses on production through process optimisation (Table 6.3). Leading members of each approach have similar roles, responsibilities, and duties (Lean Enterprise Institute, 2008; Sutherland and Schwaber, 2016; Womack and Jones, 2003).

The applicability of Agile in SOSO SSM requires an understanding of how tasks and processes are deconstructed, such as in a hazard and operability study (HAZOP) which is used for systematically reviewing a system to understand how individual parts may present a hazard (Shooks et al., 2014). Through this approach, risk exposure would incrementally increase with each task phase during operations and closure, but in consistent manageable steps. Each step, or sprint, would form a feedback loop to understand how to optimise the next sprint. The same process has applications in managing exposure benefit as interactions with local stakeholders are frequently conducted and reviewed to ensure socio-environmental risk exposure is carefully managed. Scrum can help to assess the response to the SOSO mining system prior to redeployment if each cycle is regarded as an individual sprint, for the purpose of identifying system deficiencies to improve productivity & standards in future deployments.

Strategic implementation of positive changes to an operation may be facilitated from the top-down using effects-based planning (EBP), a military term first coined by the United States Joint Forces Command (Deptula, 2001). EBP focuses on desired strategic effects, then plans backwards to the tactical level actions required using a minimum amount of force to improve efficiency with as few casualties as possible. It focuses on decision superiority and requires an ability to adapt rules and assumptions to reality (Batschelet, 2002; Davis, 2001; Deptula, 2001). The underlying principle is to work backwards from a common goal or objective to establish how to move forward in an efficient manner. In an OSH context, an understanding of prevalent latent failures is key to mitigating losses from incidents (see Chapter 2), the outcomes of which may be incorporated into tactical level actions for achieving project goals.

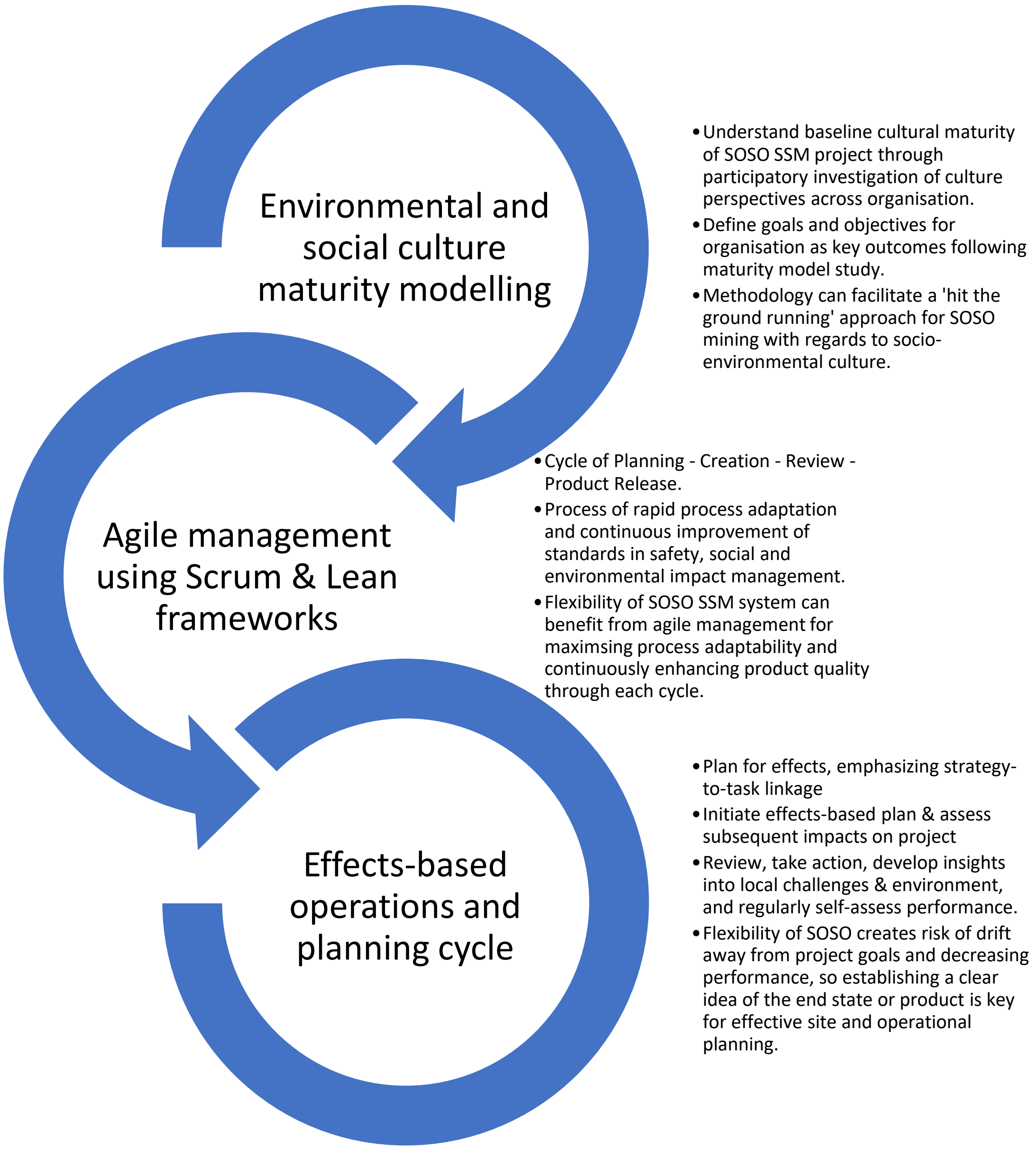


Figure 6.5: Conceptual process of continuous improvement and rapid adaptation using the E&S maturity model approach developed and tested in chapter 5, agile management, and effects-based planning.

The E&S maturity models developed and tested in Chapter 5 define the baseline culture of four mining companies which can inform improvement measures to reach higher levels of maturity. The maturity tier being targeted for each model category may be regarded as the defined common objective. The criteria are necessary for guiding improvement measures based on the requirements of the next tier, where Scrum and Lean management processes and EBP can enable continuous improvement of culture maturity through rapid, incremental changes (Figure 6.5). By conducting a thorough process of review and action through each cycle, standards and performance can be improved incrementally in these specific areas. This cyclical process is more reflective of the Plan-Do-Check-Act process for continuous risk management & mitigation, which has implications for how users interpret the importance of the review and action phase (Doyle, 2020; Haight et al., 2014). Scrum & EBP can form an effective methodology to culturally align pathways towards best practice safety and sustainability as each cycle presents opportunity to self-criticise and take necessary action.

6.4.3 Integrating Scrum pathways into culture shock and change management

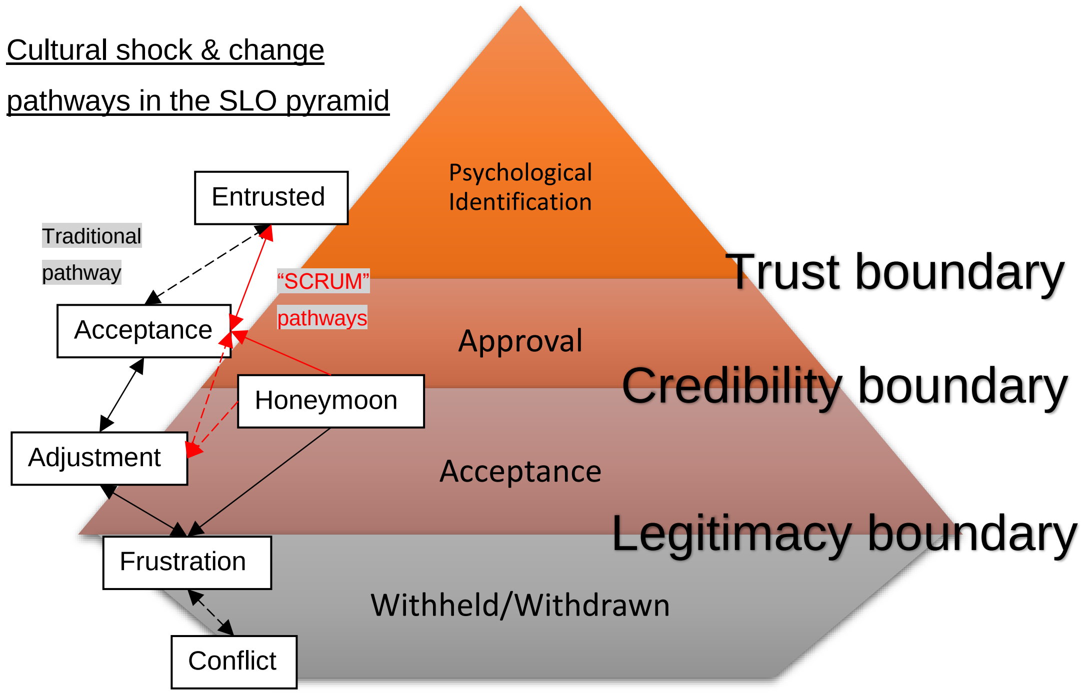


Figure 6.6: SLO pyramid integrated with traditional pathways of culture shock & change management and hypothesised Scrum pathways. Modified from Participate Learning, 2016 and Thomson and Boutilier, 2011.

SOSO SSM represents a paradigm shift that requires significant culture shift to accommodate modularised, adaptable mining systems for exploitation of small, complex, high-grade mineral deposits. With that shift comes a need for outward-facing SLO of the industry to be redirected inwards to manage the positive and negative E&S impacts of SOSO mining that affect local stakeholders. The short temporal duration of operations and prioritisation of automation over manual labour will inherently reduce opportunities for stable employment and localised development, so solutions must be embedded through regular collaboration. These interactions can help to establish a baseline level of legitimacy, credibility or trust between the operation and affected communities, which links to the processes of E&S maturity modelling for establishing baseline maturity towards known issues (see chapter 5). Communities located in regions with specific cultural sensitivities and fragility towards mining due to the behaviours of previous state-owned enterprises will experience greater tension towards companies attempting to initiate projects. Local populations with particular sensitivities may be more susceptible to culture shock as uncertainty and apprehension surrounding planned mining activities are heightened. This aligns with the work by Lesser et al. (2023, 2021) which articulated that community-company relationship is the more predominant conceptualisation of SLO, and that site level factors are important for local communities, such as perceptions of mining activity and operating company behaviour by local communities.

Culture shock and change, or the way that people respond to vast unfamiliar cultural deviations, are important considerations for companies entering culturally sensitive regions to intitiate operations. Those experiencing culture shock go through 4 phases; Honeymoon, Frustration, Adjustment, and Acceptance (Participate Learning, 2016). By combining the culture shock and change pathways with the SLO pyramid (Figure 6.6), the relationship between public perception and the SLO status can be explored. The culture shock and change model illustrates the potential for companies to misinterpret the SLO status. If overall acceptance is observed at the feasibility phase, they might expect a trajectory towards entrusted. However, they may be experiencing 'honeymoon' traits, meaning that complacent attitudes and behaviours will lead to frustration and conflict. Deployment and commissioning speed in a SOSO SSM operation may cause some community members or groups to quickly feel disenfranchised from the project, especially if the SLO condition is severely misinterpreted. The resulting frustration and conflict risk may present significant exposure to SOSO projects with inherently reduced employment and socio-economic prospects. SOSO SSM must build resilience in line with HRT, through application of impact assessments, regular communication, development of community initiatives, and establishment of a mature culture (see chapter 4.5.2).

Mining projects are typically expected to be long-term, bringing abundant job opportunities and socio-economic growth, which is not characteristic of SSM. This accentuates the risk of outward migration, requiring consideration of the broader perceptions of social impacts in relation to scale (Sydd et al., 2022).

Chapter 4.5.1 outlines that E&S mitigation should be more consequential as sites with higher production and footprint can cause comparatively larger incidents with more widespread impacts. SOSO SSM would be expected to hold relatively lower socio-environmental risk provided that a mature culture is present with sufficient capacity to conduct impact management. The lack of socio-economic potential in SOSO may drive communities into withdrawal, while reduced socio-environmental risk can encourage acceptance through social credibility and transparency. Establishing strong connections with local populace requires involvement of minorities and interest groups through promotion of a shared vision of socio-economic enhancement (Thomson and Boutilier, 2011). Local communities with a positive latent relationship prior to operations commencing will be more likely to approve of the project proposals. Projects that move from acceptance to withheld causing frustration and conflict, due to poor management of social capital, can potentially recover the SLO and achieve psychological identification.

Employment and socio-economic development prospects play a key role in building social capital, which is limited by the small resource potential per annum in SOSO SSM compared with conventional in-situ operations. Ongoing communication and collaboration is crucial as companies engage with Agile for incremental change, in order to give communities the freedom to adjust and reach acceptance of the company's presence. Small iterations in a feedback loop, informed by Scrum, can ensure that the SLO is obtained and managed for the mutual benefit of the company, local communities and other stakeholders.

6.5 Consolidating best practice safety and sustainability in SOSO SSM

Chapter 6 has integrated findings from the previous four chapters by discussing the human, political, socio-economic and organisational drivers of safety and sustainability in a regulated, small-scale mining context. Encouraging worker initiative over bureaucratic intervention, taking a new view on human error and culpability to optimise organisational improvement, removing the silo mentality, and striving for conformity towards mature culture attitudes are considered. The management of integrated enterprise risks, the role of mining in the UN's shared socio-economic pathways, and the potential of Agile for accelerating operational & technological adaptation, in line with strategic frameworks such as EBP, are also examined. Managerial agility, operational flexibility and strong safety and E&S culture must be maintained in SOSO SSM to drive progress in ESG across all five pillars of sustainable development (see chapter 5.3.1).

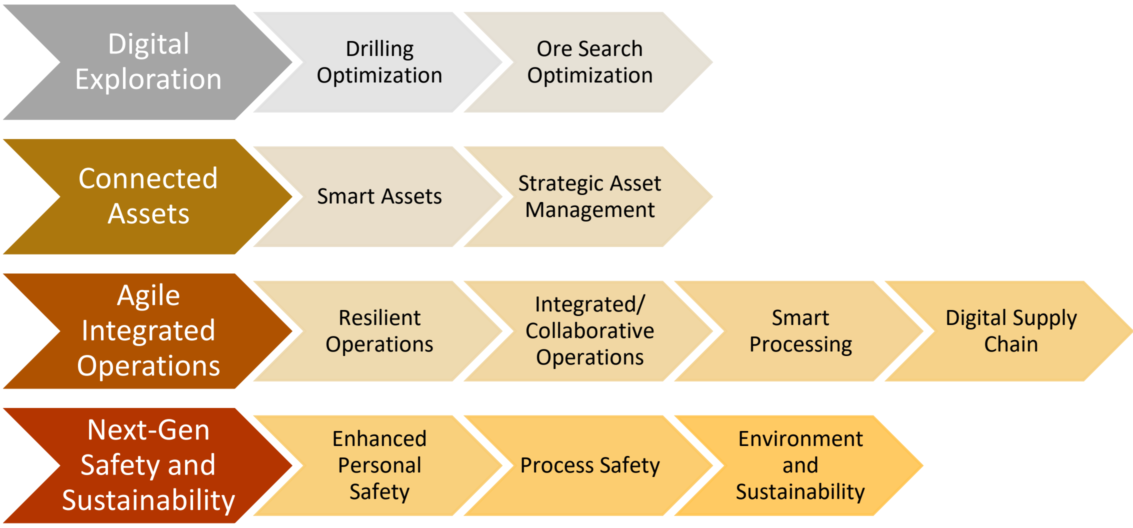


Figure 6.7: The IDC Energy Insights' strategic priorities and associated programs for agile mining operations (IDC, 2019).

SOSO SSM's operational flexibility requires resilience to ensure consistent throughput of processed ore via gravity separation in the case of IMP@CT's pilot system. Specifically, the selective mining tool utilises semi-continuous extraction that "follows the vein", reducing comminution and sorting demand. Extensive geological and structural variability observed at-face as the mining tool progresses requires adaptability and responsiveness to change. Site-based pilot testing work confirmed that full automation lacks practicality due to in-situ variability, requiring expert geologists and engineers to monitor the active face during cutting. The agility of intuition and decision-making, and appropriateness of operating procedures are key for maintaining a constant run of mine through each circuit for a steady flow of consistently high-quality ore concentrate (see chapter 3.6). Agile operations will bring together smart mining techniques, digital solutions, process automation, and the integration of these elements to enable the efficient data flow between the organisation and operators (Figure 6.7). Companies who establish Agile systems, and create visibility and control in and between operational processes will likely outperform the broader industry (Ditton and IDC, 2017; IDC, 2019). Collaborative, autonomous operations with grade optimization, resource management and integrated recovery are needed (IDC, 2019), which reflects the IMP@CT pilot system's characteristics.

Process safety, through condition monitoring and self-inspection (IDC, 2019), ensures that operators can observe semi-automated equipment and actively prevent faults. Embedded digital systems for equipment monitoring and control require complex infrastructure for data capture and transmission which may be unavailable in remote locations and impractical for SSM (Lynas and Horberry, 2011). Complex variability in mining and processing environments will also present specific challenges for implementing affordable, integrated digital monitoring systems for improving safety and process efficiency (Wang et al., 2020). Small-scale operations with limited scope for automated extraction & processing must supplement their OSH interventions by using individual initiative and expertise. Safety must be cross-coordinated through local interactions, conventional safety targets should be eliminated to prevent data manipulation, and an embedded culture should encourage intrinsic motivation (Dekker, 2018; Deming, 2000; Hollnagel, 2014).

Sustainable energy management and rehabilitation are key use cases under the 'Environment and Sustainability' program for Agile mining, which relates closely with the anticipated benefits of SOSO SSM over in-situ mining. Energy supply for SSM in remote locations often depends on diesel generators owing to their increased mobility and modularity. Paneri et al. (2021) found that modularised renewable energy systems can provide adequate supply to SOSO SSM operations in Europe with moderate CapEx while reducing greenhouse gas (GHG) emissions. The socio-environmental implications of adopting renewable energy systems remain poorly understood, particularly in terms of perceptions regarding ownership of legacy infrastructure (Paneri et al., 2021). Participatory E&S maturity modelling found relatively lower performance in energy and resource management, which highlighted deficiencies in GHG and water use monitoring, and quality of environmental life cycle assessments (eLCAs). Mine waste and tailings management and post-closure planning showed variable performance, with the highest average scores in waste management & tailings storage, and lower scores in closure planning. Most sites were deficient in the bureaucratic operational facets elements including eLCAs, closure planning and emergency preparedness. Modern, regulated mines tend to perform well in operational areas requiring monitoring and risk control, but lack similar attention on long-term planning such as post-closure and impact management. Individual sites that must adhere to strict compliance regulations often produce higher quality best practice while placing emphasis on maximising project value. SOSO SSM operations must strive for continuous improvement to adapt to market shifts and socio-economic conditions, address sustainability goals, and maximise value for stakeholders within a flexible, modularised mining paradigm.

6.6 Concluding statement

This chapter has consolidated the industry-wide and site-specific safety and socio-environmental trends observed in modern, regulated mining operations through desk-based research, semi-formal interviews and participatory studies. Instilling positive culture and attitudes towards organisational and occupational safety issues in high-risk industries requires a balance of human expertise, interdepartmental collaboration, and regulatory intervention. This chapter has organised the web of complexities described in this thesis by integrating human, political, socio-economic and organisational drivers of safety and sustainable development in a regulated, modularised SSM context. The importance of initiative and expertise over excessive bureaucratic intervention permits workforces greater autonomy in decision-making and a greater sense of ownership in safety. The new view on human error to promote continuous learning and improvement while breaking down silos and striving for conformity towards more positive safety attitudes and behaviours is key in a paradigm that relies on rapid adaptation and flexibility. SOSO SSM's limited scope for fully automated, digitally embedded extraction & processing must supplement safety interventions described in chapter 3 by drawing on initiative, experience and expertise. Local interactions should be maintained, safety performance targets must be eliminated, all fortified by an embedded organisational culture that encourages intrinsic motivation through diverse expertise and experience.

Encouraging greater worker initiative and instilling positive safety perceptions throughout operations can support the implementation of Agile to rapidly iterate improvements through interdepartmental collaboration and integrated ERM.

Evaluating the trade-off between manual operation and automation in terms of expected safety and social impacts can benefit from ERM in order to mitigate the silo mentality due to isolated decision-making. Shared socio-economic pathways that map climate mitigation and adaptation scenarios reinforces the importance of mining for developing technologies that reduce energy consumption and emissions, increase local employment, and enhance local economies to generate growth in underdeveloped regions.

Agile's cyclical process involves human interaction through every development phase, regular collaboration with customers, flexibility to environmental and circumstantial changes, and a tangible outcome in the form of a product. Applying Agile frameworks, such as Scrum and Lean, in mining highlights the role it can play in deploying novel technologies, eliminating silos, and building collaborations that permit rapid decision-making and iterative development. Scrum agile management forms a reactive feedback loop to decompose risk exposure into consistent, manageable steps, which can facilitate rectification of technical and operational deficiencies in SOSO SSM for future redeployments. Managing exposure benefit, or the positive impacts of decision-making related to SLO, through local interactions and relationships with stakeholders can be enhanced iteratively through Agile, as socio-environmental risk is continuously observed and reviewed. The health of the social licence is linked to the concept of culture shock and change, as strong relations with local communities are a necessary precursor for mitigating frustration or subsequent conflict within local populations prior to operations commencing. The Scrum process has potential to facilitate incremental development towards positive public perceptions that accelerates the SLO into acceptance, which is crucial in a paradigm that carries comparatively less socio-economic potential than conventional in-situ mining. Managerial and technical agility, operational flexibility and strong safety & socio-environmental culture must be established and maintained in SOSO SSM to continuously drive performance across all five sustainable development pillars.

7 Conclusions and contributions to science

The five studies divided by chapter in this thesis have contributed to a deeper understanding of the role of safety culture in modern, regulated mining and how this informs socio-environmental culture, through insights from UK and Balkan operations. This research is underpinned by theoretical frameworks relating to culture maturity modelling, high reliability theory, safety by design and ergonomics principles, agile management, and safety anarchism for a New View approach to responsible mining. The following sections describe how this research has informed the research questions outlined in Chapter 1.

> *Research Question 1: How can safety performance be optimised in a switch-on, switch-off (SOSO) small-scale mining paradigm that is underpinned by rapid adaptation and flexibility, and what existing tools and techniques may be used to improve safety by design, ergonomics, and culture maturity?*

Actively engaging with a preoccupation with failure through analysis of safety performance in the European, US and Western Australian mining sectors in Chapter 2 provided a baseline from which to discuss the latent failures that contribute to safety incidents in modern, regulated operations. This has implications for how safety improvements are prioritised and actioned from evidence of past failures, which informed best practice design and operation of the *IMP@CT* pilot plant and mining system. Safety by design principles, site procedures, and equipment operating standards were described in an *IMP@CT* report “Policy Statement, Standards and H&S Best Practice for Switch On-Switch Off (SOSO) Mining Operations” (Doyle, 2020). This public deliverable was developed by the candidate within their role as a H&S researcher for the IMP@CT project, and explored safety by design before construction, ergonomic suitability and integrated risk management during operations as defined in Chapter 3. Site-based risk assessment observations informed the baseline social life cycle assessment indicators identified from the pilot operation in published work by Muller et al. (2021).

This research study has examined the safety implications of extracting and processing complex, high-grade ores from narrow vein-type deposits in the Balkan region using a mobile, containerised system with reduced workforce capacity. Delineation of intervention points highlighted the nuances of, and alignment between, operational nodes which informs targeted development of appropriate safety best practice across the SOSO SSM system. This work directly contributed to a published article by Moore et al. (2021) through incorporation of safety culture maturity principles into cascade training for SOSO mining personnel and effective dissemination of site safety practices.

> *Research Question 2: How is safety and socio-environmental culture currently perceived by mining personnel in conventional in-situ operations at diverse scales, and how does this align with the principles of high reliability theory?*

Exploration of the role of safety culture for optimising performance and reducing incident occurrence in mining, and understanding the OSH characteristics of SOSO SSM, provided the foundations for which to investigate safety and E&S culture across organisational hierarchies in Chapter 4. A holistic study captured culture perspectives from managers, officers, supervisors and workers at seven small- to medium-scale mines in the UK and the Balkans. Semi-formal interviews addressed SSM characteristics, the importance of worker age and experience, the influence of operational scale on safety, social and environmental issues, and OSH management approaches. This research produced recommendations from participants relating to updated laws and regulations, new risk assessment acts, safer alternative equipment, optimised training, boosted employment, and industry awareness. Participants articulated that experienced workers have the expertise to instil best practice in younger employees, but others may remain complacent towards site risks. Communication between hierarchical levels encourages continuous scrutiny and improvement, with recent focus on culture and “mindfulness” towards operational risks and impacts. Translation and alignment of interviews with HRT revealed linkage between culture perspectives in mining and a *reluctance to simplify interpretations*, *sensitivity to operations* among individuals and teams, and an overriding *commitment to resilience*.

> *Research Question 3: How can participatory maturity modelling of environmental and social performance in conventional in-situ operations*

drive increased awareness of internal culture and progress towards higher maturity?

Application of safety culture maturity modelling to expected environmental and social impacts of mining was studied using participatory discussions with senior and frontline personnel across 4 UK operations in Chapter 5. Conceptualisation of the E&S maturity models produced two 4-tier models with guiding questions and criteria to inform the facilitated self-assessment process. Early iterations of the E&S models were orally presented at a UK-based conference and published as a contribution to proceedings (Doyle and Sidorenko, 2019). The environmental maturity model revealed that sites performed best in active waste management, local ecosystem health and stakeholder relationships, but fell short on life cycle assessment, closure planning, emergency preparedness, and site resource management. The social maturity model indicated good performance in human and worker rights, support for local development projects that encourage job creation, education and provision of utilities and amenities, but lacked maturity in policy, impact management, and post-closure planning. This has implications for how conventional small- to medium-scale mining can broaden awareness of their socio-environmental performance, which informs the applicability of maturity self-assessment and modelling for ‘hitting the ground running’ in E&S impact management of SOSO SSM operations.

Research Question 4: What are the key considerations and approaches required to facilitate positive culture shift across diverse operational scales, and how can these lessons be applied to augment the switch-on switch-off mining paradigm based on its variable dependence on human and system control?

This research project has organised a web of complexities between facets of OSH, cultural maturity, and socio-environmental sustainability by integrating the human, socio-economic and organisational drivers of safety and responsibility in mining in Chapter 6. The process by which a mature safety culture can be fostered and embedded in SSM, across diverse operations and workforces, and in ESG through its novel application to E&S factors, has been developed and practically tested. The importance of initiative and expertise over excessive bureaucratic intervention for permitting workforces greater autonomy in decision-making and sense of ownership is emphasised. SOSO SSM’s limited scope for fully automated, digitally embedded extraction & processing must supplement SOSO safety interventions by drawing on individual initiative and experience that is carefully balanced for optimised knowledge exchange across hierarchical levels. Application of Agile in a mining context permits rapid decision-making and iterative development when deploying new technology, eliminating silos, and building interdepartmental collaborations. Scrum agile management can form a reactive feedback loop for decomposing risk exposure into consistent steps and facilitating the rectification of technical and operational deficiencies in SOSO SSM. Managerial and technical agility, operational flexibility and strong safety and socio-environmental culture maturity are the primary characteristics that SOSO SSM must establish and maintain to continuously drive progress OSH and ESG performance across all five pillars of sustainable development.

8 Appendices

8.1 Safety culture interview information and questions

Rationale

The principles of safety culture maturity have been developed as a basis for achieving and maintaining high level standards in occupational health & safety management, by directing the existing organisational attitudes and perceptions of safety towards best practice. These principles have also influenced the development of a new culture maturity concept aimed at improving environmental and social sustainability. The uptake of environmental, social, safety and health (ESSH) culture maturity in small-scale, low-impact extraction may allow higher ESSH standards to be achieved much sooner in the life of mine, which is important due to the short-term nature of these operations. The methodology will integrate findings from thematic interviews with mining management and workforces with literature review on:

1. The development of ESSH culture maturity in the mining industry.
2. The prevailing attitudes and perceptions of safety & socio-environmental sustainability within the industry at various hierarchical levels.

The results of this study will inform a best practice approach to health and safety as well as environmental & social sustainability in small-scale, low-impact mining, which may be taken up by future operations of this type.

Stakeholder groups

- Mining managers and supervisors (present and retired)
- Mining engineers (main workforce)

Guidelines for ethical conduct:

1. Safeguarding against mission creep (framing questions in such a way that predisposes interviewees to a particular response)

a. Questions will be worded carefully to avoid leading interviewees to particular answers and to make sure that focused questions are clearly articulated…

b. Participants in the survey will be asked to describe their perceptions of small scale mining before being provided with the terms of reference delineated within the project

c. The responses of participants will be anonymously placed in the context of prior interaction with the project

2. Protection of personal data and informed consent procedures

    a. Thematic interviews will be conducted in person, by video- or tele-conference *by prior arrangement*

    b. A prepared statement will be used to describe consent procedures as follows: 'By conducting this interview, you consent to your commentary being cited anonymously in a wider analysis of the mining industry. We would be happy to acknowledge your, or your organisations, participation in the study at the end of any documentation or publication arising but we will require your written consent to do so.'

    c. Questionnaires will be stored using a reference number only and will be completely anonymised. Personal data and identifying factors will be kept in a separate and password-protected repository while data is processed. At the end of the project all the research data in all formats will be destroyed, and will not be used for another purpose, nor passed to any third party.

<u>Thematic interviews with mining managers and supervisors (present and retired)</u>

1. What is your current role at this mine, and how long have you worked here?

2. What do you understand to be a small scale mine?

In our project we have defined a technological small scale mine (SSM) as having: smaller total workforce, footprint, and socio-economic impact than either ASM or LSM mining (typical of a small to medium enterprise); intermediate CAPEX and throughput/employee ratio between that of ASM and LSM; reduced environmental impact per mine, though the cumulative impact has yet to be established; higher grade in ore deposit which can potentially offset reduced recovery rates.

3. How does this compare to the mine you currently operate?
4. How would you describe safety culture in a mining context?
5. To what extent do you prioritise H&S in your operation(s), relative to production?
6. Have you experienced any environmental and/or social issues as a result of your operations, and if so how have you dealt with these?
7. What is your approach to dealing with concerns and requests from local communities?
8. How much have worker reports and concerns influenced your decision-making from a H&S perspective?
9. Do you think employee age and experience are important factors in how H&S is perceived by workforces?
10. Does the scale of mining operations influence the ease with which H&S standards are established and maintained?
11. Does the scale of operations affect how you have to manage socio-environmental risk, and the associated public perceptions?
12. What management strategies have you adopted to improve your H&S standards on site?
13. What one thing would you change or do differently to improve safety on your site?

<u>Thematic interviews with mining workforces/employees</u>

1. What is your current role at the mine, and how long have you worked here?
2. To what extent do you prioritise H&S in your occupation?
3. How much training have you received since starting your job, and has it helped you identify risks and hazards in your workplace?
4. How much of a say do you have in decision-making related to H&S?
5. Are you able to freely voice safety concerns to your managers & supervisors?
6. Do you feel that management value your opinion about H&S matters on site?
7. Are you regularly informed of changes to safety policy and procedures, through H&S-focused meetings and briefings, and do you find these helpful?
8. Do you think employee age and experience are important factors in how H&S is perceived by workforces?
9. What one thing would you do differently to improve safety in your job?

8.2 Environmental & social maturity model criteria tables

Environmental

Basic	Respondent	Protective	Sustainable
1i: Environmental policy, regulatory compliance & disclosure			
Little to no evidence of environmental policy statement or relevant working practices, resulting in limited regulatory compliance. Compliance records are not maintained or disclosed	Some aspects of environmental policy prioritise impact planning, with appropriate working practices and procedures in place, which are stored and readily disclosed	Environmental policy statement comprehensively covers potential site impacts. Periodic reviews of working practices to ensure compliance is met at local level, and non-compliance issues are always disclosed	Environmental policy, working practices and procedures are fully integrated, and are regularly updated with input from all levels of company to ensure compliance is maintained. Public disclosure deemed crucial for building mutual trust.
1ii: Pre-operation environmental considerations			
Company understands little of the potential impacts of their operations on the environment prior to mine opening	Company sets out clearly the expected positive & negative impacts associated with their operation which influences the operating practices from outset	Environmental impact assessment forms an integral part of overall mine management system, which guides best practice and procedures on site	Development of EIA involves significant work with local people and authorities prior to start-up of mine to understand the initial requirements and vulnerabilities in local area
1iii: Appropriateness of environmental impact assessment for risk management			
Poor understanding of environmental impacts results in lack of attention paid to mitigation and monitoring plans during operation	Company addresses most of the risks outlined in the impact assessment, which begins to guide best practice environmental management	Company addresses all risks outlined in the impact assessment, which continuously informs & influences the agreed site working practices and procedures	Updates to EIA involve work with local populations and authorities throughout life of the mine to ensure company has clarity on how environmental issues may evolve and have impact
1iv: Post-closure environmental planning			
Company has paid minimal attention to the potential direct & indirect impacts of their operations on the environment after mining operations cease	Most of the identified environmental impacts facing the site post-closure are addressed and resolved before mine closure takes place	All known risks following closure of site are dealt with in collaboration with communities and related authorities surrounding the mining operation, with mitigation measures widely agreed upon	Updates to impact assessment focus on establishing a clear, feasible reclamation strategy, which requires ongoing dialogue with local populations & their authorities to reach mutually beneficial agreement on post-closure plans
2i: Airborne pollutants			
Plant-generated dust pollution is not monitored	Excessive dust pollution levels are addressed	High levels of dust are prevented from outset by	Procedures and equipment are regularly

on-site, and the health & environmental risks are not considered	and dealt with promptly by management, using engineering or procedural solutions	ventilation and water suppression, to minimise worker exposure and prevent transport off-site	changed to minimise dust generation from outset, with additional safety barriers in place on site to prevent dust transport
2ii: Occupational noise & vibration			
Excess site-generated noise and vibration is not monitored on-site, and the associated safety risks are not considered	Increased levels of noise and/or vibration in working areas are monitored incrementally and dealt with quickly with suitable PPE or procedural changes	Excessive noise pollution and vibration is mitigated from outset using natural and/or artificial noise barriers and vibration absorbing flooring respectively	More regular shift rotation and procedural changes are adopted to minimise risk to workers who are exposed to significant levels of noise and/or vibration
2iii: Effluent monitoring & control			
Effluent generated from processing and heap leach runoff is not controlled effectively, leading to pollution caused by escape of fluids into local streams and groundwater	Increased levels of effluent generation is monitored only when required, particularly during high flux, and is only managed after issues first arise	Levels of effluent are regularly monitored on site, with overflow storage ponds used to prevent escape during periods of high precipitation and/or flux	Processing techniques are adjusted to minimise use of water where possible, reducing the potential volume of released effluent in the event of a spill
2iv: Biodiversity & ecosystem protection			
Condition and health of local ecosystem surrounding operation is not considered, with biodiversity of said ecosystem impacted by runoff of toxic effluent	Visible ecosystem impacts observed by site teams or reported by local communities are dealt with promptly, with samples taken where required	Site management arranges regular sampling of local streams to ensure water supplies are unpolluted and biodiversity remains at an acceptable level	Site management engages regularly with local community to ensure local ecosystem health is maintained, with efforts to help enhance biodiversity during active operations and post-closure
3i: Site-wide emergency preparedness & planning			
No procedures are in place for dealing with on-site emergencies related to environmental hazards, and workers & communities aren't sufficiently consulted	Emergency plans consider the potential risks and planned response procedures in greater depth, with occasional drills for staff and managers	Employees are trained for particular hazards and scenarios, and everyone is clear on their responsibilities in emergency management	The emergency plans are fully integrated into site management system, with continuous reviews to ensure plans remain fit for purpose. Training drills are routinely carried out.
3ii: Senior response & incident investigation (RII) procedures and training			
No plans are in place for responding to and investigating both on- or off-site environmental incidents	RII plans consider to limited extent the potential risks and response procedures in greater detail, with periodic updates applied	Senior level site members receive specialist training on RII procedures that is relevant to their area of operation and workforce size	RII planning is integrated into the site management system with all senior members of operation involved in development and reviews of RII procedures
3iii: Assignment of roles & responsibilities			
No clear roles and responsibilities have	Some roles have been assigned to handle	All primary roles are allocated to manage site emergencies	All primary and secondary roles and their

been delegated to relevant site members to deal with environmental emergencies and incidents	emergency preparedness and post-incident investigations but lack clarity on responsibilities	and investigations, but communication channels are not fully utilised to optimise RII procedures	responsibilities are clearly stated from outset and reviewed regularly for effectiveness
3iv: Off-site collaborations with authorities & communities			
No off-site communication or collaboration with local authorities or communities about management of off-site environmental impacts	Representatives of local authorities are consulted periodically by site management only in response to complaints regarding local environmental issues	Both local community and authority representatives are consulted regularly on environmental matters relating to mining operations, often following an incident with impacts off-site	Local communities and authorities are involved in decision-making processes from start of mining operation, with representatives of each collaborating with management on suitable strategies for protecting the local environment
4i: Greenhouse gas (GHG) emissions & monitoring			
No monitoring and evaluation of GHG emissions is carried out on site	Monitoring of GHG emissions only takes place in energy intensive areas, and results rarely inform reviews of equipment and/or transport options	GHG emissions are measured regularly in line with local regulations, and viable engineering solutions for reducing emissions are evaluated	GHG emissions are monitored across whole operation continuously, and data from this is integrated into long term strategy for mining operation
4ii: Assessment & management of site water consumption			
No monitoring of water consumption on site, nor any evaluation of off-site impacts is carried out	Monitoring of water consumption only takes place in resource intensive areas such as processing, and results rarely inform changes to equipment	Water consumption is measured regularly in line with local regulations, and viable engineering solutions for limiting consumption are evaluated periodically	Water consumption is monitored across entire operation continuously, and data gathered is integrated into long- term operational strategy
4iii: Environmental life cycle assessment (eLCA) approach & review process			
eLCA is not utilised to evaluate crucial environmental factors in operation	Outcomes of eLCA are considered based on their level of urgency, and potential solutions remain internal to operation	eLCA is regularly reviewed to ensure that environmental impacts of operation both internally and externally is known	eLCA is fully data driven, continuously evaluated and widely integrated to inform both short and long term decision-making
5i: Low to moderate risk: Domestic waste			
Domestic waste accumulates with limited consideration for how and where it should be safely disposed	Overaccumulation of domestic waste is dealt with only in response to external audit recommendations or complaints	Dedicated domestic waste storage areas are provided on site that are safe from ignition sources, until waste is transported to local landfill site	Recyclable waste is separated prior to collection, and organic waste is used for compost or biofuel to reduce quantity of landfill waste
5ii: Moderate to high risk: Laboratory & medical waste			
Medical/ laboratory waste accumulates with limited consideration for	Overaccumulation of medical and/or laboratory waste is dealt	Dedicated medical/ laboratory waste storage areas are allocated in order to minimise	Laboratorial and medical systems are constantly reviewed & improved to

how and where it should be safely disposed	with only in response to external audit recommendations or complaints	the risk of accidents involving mishandling of toxic materials, following COSHH regulations	reduce waste generation from outset, as many biological & chemical products cannot be reused safely
5iii: Moderate to high risk: solid & liquid mine waste (TSF management)			
Minimal consideration is paid to (i) managing mine tailing toxicity, (ii) the suitability of the TSF design, & (iii) maintenance of TSF in response to changes in processing rate & meteorological factors	TSF structural deficiencies and operational errors & violations are only addressed and rectified in direct response to warnings from external audits and specialist engineers	TSF is constructed and consistently maintained to high standard in order to minimise risk of total or partial collapse and leakage, with most hazardous elements of tailings thoroughly screened prior to disposal	Majority of the potentially toxic bi-products are removed at mineral processing stage to eliminate ecotoxicological risk of mine tailings before being disposed in TSF, while also generating secondary revenue from useful bi-products

Social

Inconsistent	Planned	Integrated	Entrusted
1i: Social policy, regulatory compliance & disclosure			
Little to no evidence of social policy statement or relevant working practices, with limited regulatory compliance and disclosure of associated records	Some aspects of social policy prioritise impact planning, with appropriate working practices and procedures in place, which are stored and readily disclosed	Social policy statement comprehensively covers potential site impacts. Periodic reviews of working practices ensure compliance is met at local level, and that non-compliance issues are disclosed	Social policy, working practices and procedures are fully integrated, and are regularly updated with input from all levels of company to ensure compliance is maintained. Public disclosure deemed crucial for building and maintaining stakeholder trust.
1ii: Pre-operation social considerations			
Company understands little of the potential social impacts of their operations on local populations prior to opening of mine	Company identifies some of the expected positive & negative impacts associated with their operation, which partially influences decision-making on social matters	Social impact assessment forms an integral part of overall mine management system, which guides best practice and procedures on site	Development of SIA involves significant work with local people and authorities prior to start-up of mine to understand the initial requirements and vulnerabilities in local area
1iii: Appropriateness of social impact assessment for risk management			
Poor understanding of social impacts results in lack of attention paid to mitigation and monitoring plans during operation	Company addresses most of the risks outlined in the impact assessment, which begins to guide best practice in social & community management	Company addresses all risks outlined in social impact assessment, which continuously informs & influences the approaches taken to manage social risks	Updates to SIA involve significant work with local people & authorities throughout life of the mine to ensure company is clear on how environmental issues may evolve and cause impact

1iv: Post-closure societal planning			
Company has paid minimal attention to the potential impacts of their operations on local populations after mining operations cease	Most of the identified short-and long-term social impacts facing the site post-closure are addressed and resolved before mine closure takes place	All known short- and long-term risks following closure of site are dealt with in collaboration with communities and authorities surrounding the mining operation.	Updates to SIA are focused on feasible reclamation strategies which involve extensive dialogue with local populations and their authorities after operations have ended
2i: Corporate social responsibility			
Only some potential impacts on communities are addressed, but there is little consideration for how to effectively mitigate them	Company expects social impacts to occur as a result of their operations, which ensures they are better prepared for community-related issues arising	Company is seen to demonstrate corporate responsibility occasionally, with fair distribution of funding for local projects, and careful resource management	Ensuring that responsible operating practices are carried out consistently (i.e., philanthropy, ethical treatment of local people & employees, etc.) to help to build mutual trust between company and local community
2ii: Human rights impacts			
Company pays little attention to ongoing human rights impacts associated with their operation, and lacks a long-term policy commitment to respect human rights	Human rights context in operating area is considered in risk planning, though rights impacts are only acted upon in response to local problems arising	Company values the importance of human rights and integrates this into monitoring and management strategies in collaboration with internal & external stakeholders	Human rights is highly prioritised within risk management processes, with local consultation and research into human rights impacts near site carried out during both feasibility and active operations
2iii: Free, prior and informed consent (FPIC)			
Rights of indigenous people towards land, property, culture and religion is not fully considered, with limited constructive engagement between operating company & local populations, and FPIC subsequently not being granted	Free, prior and informed consent is assumed to be granted following early negotiation & positive dialogue with indigenous people, but some rights remain infringed during operation	Company works closely with tribal/ indigenous people throughout life of mine in order to understand how operations may impact on local customs & cultures, with most of this feedback informing proposed activities	Free, prior & informed consent is valued as an integral part of the social licence to operate with local indigenous communities, and demonstrates a clear commitment to upholding promises regarding protection of their rights, culture & livelihoods
2iv: Worker rights & fair labour			
Workers' rights are not prioritised by company, increasing the risk of problems arising related to unpaid wages, working conditions, discrimination, etc.	Company respects the internationally recognised rights of workers which is built into business strategy, ensuring workers feel valued and are equipped to carry out their job	Worker wellbeing is considered with upmost importance by management, which informs the necessary measures to protect their rights and express grievances related to their work	Workers receive fair & equal opportunity and labour rights are upheld as outlined in international law, site facilities are fit for purpose, & company regularly discusses employee experience with

			representatives of the workforce
3i: Community dialogue & decision-making			
Limited attention is paid to the needs and desires of local communities and authorities at any stage of project, by focusing heavily on self-interests	Company listens to and acts on most of the concerns raised, and integrates these into the mine project proposal prior to commencement of operations	The opinions of the local community, including vulnerable and indigenous populations, are valued & addressed constantly through ongoing public consultations.	Company establishes high level of trust with communities, reflected in the nature and regularity of discussions that take place between both parties, and the actions that company takes in response.
3ii: Stakeholder engagement process			
Stakeholder groups receive minimal relevant updates & feedback, with predominantly one-way communication from company to stakeholders	Important updates are periodically relayed to project stakeholders on request, but remain peripheral with regards to decision-making	All stakeholder parties, including minority groups, are represented in important decision-making processes on request of the company	Inclusive, two-way stakeholder dialogue is an ongoing process which feeds directly into the wider project strategy to provide mutual benefit for all parties involved during life of mine
3iii: Conflict management			
Company takes little notice of local conflict against or surrounding mining operation, with few steps taken to reduce tension by prioritising internal damage limitation	Company attempts to identify community requirements in response to their direct complaints and implement relevant changes to actively reduce risk of conflict starting or continuing	Decisions involve all stakeholder groups and communities to reduce the risk of disputes regarding the impact of operation on local area as all opinions are heard & acted on before situation can escalate	Company devotes considerable time interacting with local populations to gather cultural and societal insight, which is used to collaboratively develop a project strategy which suits all stakeholders and helps facilitate long-term relationships
4i: Local employment opportunities			
Mine operation makes some effort to improve work opportunities, but results of this are not monitored regularly	Strategies for uptake of employment in local communities are developed prior to operations starting, to improve short- & long-term prospects for local populations	Company encourages employment of skilled workers for local operations, in turn providing secondary work in local settlements	Company primarily employs a local workforce to operate their mines, with sufficient training provided to all employees where necessary
4ii: Outreach & education schemes			
Limited funding is provided to initiate programmes within local community, and progress is not monitored to ensure their success	Company suggests potential community projects & schemes during earliest stages of engagement with local populations, and helps to leave a legacy of high-	Majority of planned projects & schemes are supported, with regular input from both parties on approach and broad impact of schemes, ensuring that young people	Company & local communities co-operate continuously, with emphasis placed on effective planning, implementation and review of outreach & education

	quality educational resources for local people	& minority groups benefit most	schemes throughout mine life & during post-closure
4iii: Infrastructural investment			
Limited funding is allocated to new developments, but the impact of this infrastructure is not addressed	Extent and nature of investment in new developments is established during early planning phase & closely monitored	The developments carried out are mainly influenced by the requests of the community, ensuring overall approval by locals	All infrastructural developments are subject to local consultations to determine whether they will sufficiently benefit residents and authorities
5i: Health & safety management systems (HSMS)			
Lack of evidence for a HSMS in place on site for ensuring workplaces are safe and risk of injury to local communities & workers are reduced	A basic HSMS exists which is periodically utilised to help improve safety standards during operations for the benefit of both local communities and workers	Health & safety is a key consideration in senior management decision-making from a business perspective, with resources allocated to maintain HSMS	People are considered highest priority from a health & safety standpoint so top-level leadership implements an effective HSMS which involves participation from community & company representatives
5ii: Health & safety communication and engagement			
Communication between company and local people/ employees is not productive & leads to unacceptable safety risk	Health & safety is discussed between management and representatives only in response to a safety-related concern or incident caused by sitework	Communication begins at feasibility stages to build trust & understand local concerns prior to making important decisions on mining & processing techniques	Communities and their representatives are invited to visit operation in order to educate local people about how company is dealing with health & safety risks and demonstrate willingness to be open & transparent
5iii: Health & safety risk assessment and management			
Risk assessments are inadequate for identifying the type, likelihood and severity of critical health & safety impacts on local people & workers	Mine site impacts are understood at a basic level and they periodically inform procedural changes, specifically with regards to critical risks and hazards	Site risk assessment is regularly updated & heavily integrated into management system, which informs the site risk register and helps prioritise actions	Mature safety culture prioritises risk & impact management at all stages of operation with the aim of reducing risk to a reasonably practicable level in collaboration with local people and workers
5iv: Epidemiological considerations			
Impacts associated with transmission of airborne and/or waterborne disease due to mining work aren't understood or considered	Company makes verbal commitment to managing epidemiological risk to communities in close proximity to mine, but evidence of action is lacking	Company shows transparency by acknowledging and closely monitoring the epidemiological risk of operations & the resulting impact on local people and their provisions	Communities receive access to free testing & treatment from company for diseases introduced or worsened by mining operation, as well as providing education for local people on best practice prevention

9 References

Ahadzi, D.F., Afitiri, A.R., Ahadzi, E., 2021. Organizational safety culture perceptions of healthcare workers in Ghana: A cross-sectional interview study. Int. J. Nurs. Stud. Adv. 3, 100020. https://doi.org/10.1016/j.ijnsa.2021.100020

Ahmed, M., Guo, Q., Asif, M., Ali, S., Akram, K., Salam, J., 2021. International Journal of Hospitality Management Do green HR practices enhance green motivation and proactive environmental management maturity in hotel industry? Int. J. Hosp. Manag. 94, 102852. https://doi.org/10.1016/j.ijhm.2020.102852

Aldrich, M., Ramsden, M., Steer, R., Hamilton, I., 2015. Golden rules to improve process safety behaviour, in: SPE Annual Caspian Technical Conference & Exhibition. Baku, Azerbaijan.

Alshehri, S.M., Alzahrani, S.M., Alwafi, A.M., 2023. Modeling and assessment of human and organization factors of nuclear safety culture in Saudi Arabia. Nucl. Eng. Des. 404. https://doi.org/https://doi.org/10.1016/j.nucengdes.2023.112176

Anglo American Plc, 2010. Detailed Journey Workbook, in A3 Safety Risk Management Process Training Material. London.

Armstrong, M., Petter, R., Petter, C., 2019. Why have so many tailings dams failed in recent years? Resour. Policy 63, 101412. https://doi.org/10.1016/j.resourpol.2019.101412

Asch, S.E., 1951. Effects of Group Pressure Upon the Modification and Distortion of Judgments, in: Social Psychology. Prentice-Hall, New York, pp. 222–236. https://doi.org/10.1525/9780520313514-017

Azzone, G., Noci, G., 1998. Identifying effective PMSs for the deployment of “ green ” manufacturing strategies. Int. J. Oper. Prod. Manag. 18, 308–335.

Barnes, S., Oruc, N., 2012. Reversing the Bosnian “Brain Drain”: Opportunities and Challenges, in: Arandarenko, M., Bartlett, W. (Eds.), Labour Market and Skills in the Western Balkans. FREN- Foundation for the Advancement of Economics, Belgrade, pp. 177–198.

Bascompta, M., Sanmiquel, L., Vintro, C., Rossell, J.M., Costa, M., 2018. Safety culture maturity assessment for mining activities in South America. Work 61, 125–133. https://doi.org/10.3233/WOR-182781

Batschelet, A.W., 2002. Effects-based Operations: A new Operational Model?

BBC, 2018. Theresa May promises “help” to axed Boulby potash mine workers. BBC News 1.

Beasley, M.S., Clune, R., Hermanson, D.R., 2005. Enterprise risk management: An empirical analysis of factors associated with the extent of implementation. J. Account. Public Policy 24, 521–531. https://doi.org/10.1016/j.jaccpubpol.2005.10.001

Bellamy, L.J., 2015. Exploring the relationship between major hazard, fatal and non-fatal accidents through outcomes and causes. Saf. Sci. 71, 93–103. https://doi.org/10.1016/j.ssci.2014.02.009

Ben-Saed, M., Pilbeam, C., 2022. The effect of an embargo, sanctions and culture on safety climate: A qualitative view from aviation maintenance in the MENA region. J. Safety Res. https://doi.org/10.1016/j.jsr.2022.03.003

Bennett, J., Foster, P., 2005. Predicting progress: The use of leading indicators in occupational safety and health. Policy Pract. Heal. Saf. 3, 77–90. https://doi.org/10.1080/14774003.2005.11667663

Bennett, L., 2019. The 12 Principles Behind the Agile Manifesto. iLounge 1.

Bernard, B., 2021. Regulating nuclear safety through safety culture. J. Saf. Sci. Resil. 2, 172–178. https://doi.org/10.1016/j.jnlssr.2021.08.001

Beyea, S.C., 2005. High reliability theory and highly reliable organisations. Patient Saf. First 81, 3.

Beylot, A., Muller, S., Segura-Salazar, J., Brito-Parada, P., Paneri, A., Yan, X., Lai, F., Roethe, R., Thomas, G., Goettmann, F., Braun, M., Moradi, S., Fitzpatrick, R., Moore, K., Bodin, J., 2021. Switch on-switch off small-scale mining: Environmental performance in a life cycle perspective. J. Clean. Prod. 312. https://doi.org/10.1016/j.jclepro.2021.127647

BGS, 2022. UK and world mineral statistics datasets [WWW Document]. UK Res. Innov. URL https://www.bgs.ac.uk/datasets/uk-and-world-mineral-statistics-datasets/ (accessed 5.25.22).

Boege, V., Franks, D.M., 2012. Reopening and developing mines in post-conflict settings: The challenge of company-community relations, in: Lujala, P., Rustad, S.A. (Eds.), High-Value Natural Resources and Peacebuilding. Routledge, pp. 87–120.

Bondy, K., Matten, D., 2012. The Relevance of the Natural Environment for Corporate Social Responsibility Research, in: The Oxford Handbook of Business and the Natural Environment. Oxford University Press, pp. 519–536. https://doi.org/10.1093/oxfordhb/9780199584451.003.0028

Bourdenet, N., 2003. The Mines Act, 1842 [WWW Document]. Univ. Paris Ouest. URL https://web.archive.org/web/20110721022926/http://anglais.u-paris10.fr/spip.php?article88 (accessed 4.19.22).

Bowker, L.N., Chambers, D.M., 2015. The risk, public liability & economics of tailings storage facility failures.

Breen, J., 2018. Jobs secure as Boulby mine stops potash production after 45 years. North. Echo 1.

Brereton, D., 2002. The Role of Self-Regulation in Improving Corporate Social Performance: The Case of the Mining Industry, in: Currrent Issues in Regulation: Enforcement and Compliance Conference. Australian Institute of Criminology, Brisbane, pp. 1–23.

BRGM, 2016. Minerals4EU [WWW Document]. URL http://minerals4eu.brgm-rec.fr/minerals4EU/ (accessed 2.15.19).

Britannica, T.E. of E., 2020. Monongah mining disaster of 1907 [WWW Document]. Encycl. Br. URL https://www.britannica.com/event/Monongah-mining-disaster-of-1907 (accessed 4.26.21).

British Columbia, 2006. Work Related Musculoskeletal Disorder Prevention Guide for Mining Training Manual.

Broberg, O., 1997. Integrating ergonomics into the product development process. Int. J. Ind. Ergon. 19, 317–327. https://doi.org/10.1016/S0169-8141(96)00041-8

Brown, R.L., Holmes, H., 1986. The use of a factor-analytic procedure for assessing the validity of an employee safety climate model. Accid. Anal. Prev. 18, 455–470. https://doi.org/10.1016/0001-4575(86)90019-9

Brundtland, G.H., 1987. Our common future - Call for action, World Commission on Environment and Development. New York City. https://doi.org/10.1017/s0376892900016805

Brustbauer, J., 2016. Enterprise risk management in SMEs: Towards a structural model. Int. Small Bus. J. Res. Entrep. 34, 70–85. https://doi.org/10.1177/0266242614542853

Bunning, B., 2021. Using nudge techniques to influence health and safety behaviour.

Burgess-Limerick, R., 2018. Participatory ergonomics: Evidence and implementation lessons. Appl. Ergon. 68, 289–293. https://doi.org/10.1016/j.apergo.2017.12.009

Burgess-Limerick, R., 2007. Reducing injury risks associated with underground coal mining equipment.

Burritt, R.L., Christ, K.L., 2018. Water risk in mining: Analysis of the Samarco dam failure. J. Clean. Prod. 178, 196–205. https://doi.org/10.1016/j.jclepro.2018.01.042

Calò, F., Parise, M., 2009. Waste management and problems of groundwater pollution in karst environments in the context of a post-conflict scenario: The case of Mostar (Bosnia Herzegovina). Habitat Int. 33, 63–72. https://doi.org/10.1016/j.habitatint.2008.05.001

Cantu, J., Gharehyakheh, A., Fritts, S., Tolk, J., 2021. Assessing the HRO: Tools and techniques to determine the high-reliability state of an organization. Saf. Sci. 134, 105082. https://doi.org/10.1016/j.ssci.2020.105082

Carroll, A.B., 1991. The pyramid of corporate social responsibility: Toward the moral management of organizational stakeholders. Bus. Horiz. 34, 39–48. https://doi.org/10.1177/0312896211432941

Casselman, B., 2010. Rig Owner Had Rising Tally of Accidents. Wall Str. J. 1.

Chaffin, D.B., 2005. Improving digital human modelling for proactive ergonomics in design. Ergonomics 48, 478–491. https://doi.org/10.1080/00140130400029191

Chandler, N., 2010. Subcultures: The implications for Organisations, in: Association of Hungarian PhD and DLA Students, Spring Wind (Tavaszi Szél) Conference. p. 8.

Cilliers, F., Greyvenstein, H., 2012. The impact of silo mentality on team identity: An organisational case study. SA J. Ind. Psychol. 38. https://doi.org/10.4102/sajip.v38i2.993

Confederation of British Industry, 1990. Developing a safety culture: Business for Safety. Confederation of British Industry, London.

Cooper, M.D., 2000. Towards a model of safety culture. Saf. Sci. 36, 111–136.

Cormican, K., 2014. Integrated Enterprise Risk Management: From Process to Best Practice. Mod. Econ. 05, 401–413. https://doi.org/10.4236/me.2014.54039

Costanza, J.N., 2016. Mining Conflict and the Politics of Obtaining a Social License: Insight from Guatemala. World Dev. 79, 97–113. https://doi.org/10.1016/j.worlddev.2015.10.021

CRIRSCO, 2021. About CRIRSCO [WWW Document]. Comm. Miner. Reserv. Int. Report. Stand. URL http://crirsco.com/background.asp (accessed 8.16.21).

CRIRSCO, 2019. International Reporting Template for the public reporting of exploration targets, exploration results, mineral resources and mineral reserves.

Crosby, P.B., 1979. Quality is free: The art of making quality certain, 17a ed. New York : McGraw-Hill, New York.

CSB, 2007. Investigation Report for BP Texas City Refinery Explosion.

Davis, P.K., 2001. Effects-Based Operations: A Grand Challenge for the Analytical Community.

De Ruijter, A., Guldenmund, F., 2015. The bowtie method: A review. Saf. Sci. 88, 211–218. https://doi.org/10.1016/j.ssci.2016.03.001

Debono, D.S., Greenfield, D., Travaglia, J.F., Long, J.C., Black, D., Johnson, J., Braithwaite, J., 2013. Nurses' workarounds in acute healthcare settings: A scoping review. BMC Health Serv. Res. 13. https://doi.org/10.1186/1472-6963-13-175

Dedobbeleer, N., Béland, F., 1991. A safety climate measure for construction sites. J. Safety Res. 22, 97–103. https://doi.org/10.1016/0022-4375(91)90017-P

Dejoy, D.M., 2005. Behavior change versus culture change: Divergent approaches to managing workplace safety. Saf. Sci. 43, 105–129. https://doi.org/10.1016/j.ssci.2005.02.001

Dekker, S., 2018. The safety anarchist : relying on human expertise and innovation, reducing bureaucracy and compliance, First. ed. Routledge, New York.

Dekker, S., 2014a. The Field Guide to Understanding "Human Error," Third. ed. CRC Press.

Dekker, S., 2014b. Safety Differently: Human Factors for a New Era, Second Edi. ed. Routledge.

Dekker, S.W.A., Breakey, H., 2016. ' Just culture :' Improving safety by achieving substantive , procedural and restorative justice. Saf. Sci. 85, 187–193. https://doi.org/10.1016/j.ssci.2016.01.018

Deming, W.E., 2000. Out of the Crisis, Second Edi. ed. The MIT Press.

Dendena, B., Corsi, S., 2015. The Environmental and Social Impact Assessment: A further step towards an integrated assessment process. J. Clean. Prod. 108, 965–977. https://doi.org/10.1016/j.jclepro.2015.07.110

Department of Mines Industry Regulation and Safety, 2019. Minerals safety statistics [WWW Document]. Gov. West. Aust. URL http://www.dmp.wa.gov.au/Safety/Safety-statistics-16198.aspx (accessed 7.15.20).

Deptula, D.A., 2001. Effects-Based Operations: Changes in the Nature of Warfare.

Ditton, E., IDC, 2017. IDC FutureScape: Worldwide Mining 2017 Predictions.

Dold, B., 2020. Sourcing of critical elements and industrial minerals from mine waste – The final evolutionary step back to sustainability of humankind? J. Geochemical Explor. 219, 106638. https://doi.org/10.1016/j.gexplo.2020.106638

Doyle, K., 2020. Deliverable 5.5: Policy Statement, Standards and H&S Best Practice for Switch On-Switch Off (SOSO) Mining Operations. IMP@CT Public Report.

Doyle, K., Sidorenko, O., 2019. Environmental & social maturity as a new concept for self-assessment of best practice in a mining context, in: Society for Geology Applied to Mineral Deposits (Ed.), 15th Biennial SGA Meeting, Proceedings Volume 4. University of Glasgow Publicity Services, Glasgow, pp. 1619–1622.

DW, 2020. The end of an era: hard coal in Germany [WWW Document]. URL https://www.dw.com/en/the-end-of-an-era-hard-coal-in-germany/a-43545024 (accessed 5.29.20).

EBRD, 2014. Environmental and Social Policy Framework.

EconomicsOnline, 2020. Nationalisation. Econ. Online 1.

Eger, T., Salmoni, A., Whissell, R., 2004. Factors influencing load-haul-dump operator line of sight in underground mining. Appl. Ergon. 35, 93–103. https://doi.org/10.1016/j.apergo.2003.12.002

Egerer, H., Peck, P., Sandei, P.C., Simonett, O., Williams, S., Stuhlberger, C., 2010. Mining and environment in the Western Balkans, 1st ed. UNDP, UNEP, OSCE, NATO, UNECE and REC.

EI Process Safety Committee, 2010. High level framework for process safety management.

EITI, 2019. The EITI Standard.

EMESRT, 2018. Design Philosophies [WWW Document]. Earth Mov. Equip. Saf. Round Table. URL https://emesrt.org/design-philosophies/ (accessed 6.18.18).

Enzi, M., 2006. Mine Improvement and the New Emergency Response Act of 2006 or the "MINER Act."

Equator Principles Association, 2020. The Equator Principles IV.

Espadinha-Cruz, P., Neves, A., Matos, F., Godina, R., 2023. Development of a maturity model for additive manufacturing: A conceptual model proposal. Heliyon 9, e16099. https://doi.org/10.1016/j.heliyon.2023.e16099

European Union Commission, 2014. EU Strategic Framework on Health and Safety at Work 2014-2020, European Commission.

Eurostat, 2020. Accidents at work statistics [WWW Document]. Eur. Comm. URL https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Accidents_at_work_statistics#Analysis_by_activity (accessed 7.15.20).

Evans, S., 2019. West is best: profiling Western Australia's mining boom [WWW Document]. Min. Technol. URL https://www.mining-technology.com/features/western-australias-mining-boom/ (accessed 5.29.20).

Everingham, J.-A., 2012. Towards Social Sustainability of Mining., Greener Management International.

Extracthive, 2018. Mobile Equipment for Mineral processing of Ore from small scale deposits.

Filho, A.P.G., Andrade, J.C.S., Marinho, M.M.D.O., 2010. A safety culture maturity model for petrochemical companies in Brazil. Saf. Sci. 48, 615–624. https://doi.org/10.1016/j.ssci.2010.01.012

Filho, A.P.G., Waterson, P., 2018. Maturity models and safety culture: A critical review. Saf. Sci. 105, 192–211. https://doi.org/10.1016/j.ssci.2018.02.017

Flaspöler, E., Hauke, A., Pappachan, P., Reinert, D., Bleyer, T., Henke, N., Kaluza, S., Schieder, A., Windel, A., Karwowski, W., Salminen, S., Blaise, J.-C., Claudon, L., Ciccotelli, J., Eeckelaert, L., Verjans, M., Muylaert, K., Beeck, R. Op De, 2009. The human machine interface as an emerging risk. https://doi.org/10.2802/21813

Fleming, M., 2001. Safety culture maturity model. Edinburgh. https://doi.org/ISBN 0 7176 1919 2

Fleming, M., Lardner, R., 1999. Safety culture – the way forward. Chem. Eng. 16–18.

Flin, R., Mearns, K., Connor, P.O., Bryden, R., 2000. Measuring safety climate: identifying the common features. Saf. Sci. 34, 177–192.

Foster, P., Burton, A., 2004. Virtual reality in improving mining ergonomics. J. South African Inst. Min. Metall. 104, 129–134.

Foster, P., Hoult, S., 2013. The Safety Journey: Using a Safety Maturity Model for Safety Planning and Assurance in the UK Coal Mining Industry. Minerals 3, 59–72. https://doi.org/10.3390/min3010059

Foster, P., Hoult, S., 2011. Development and Use of a Safety Maturity Model as a Safety Assurance Tool in UK Coal Operations, in: ICSMRI. pp. 447–458.

Foster, P., Severn, R., 2013. Roof Fall Major Hazard Analysis with Bowtie Diagrams, in: 35th International Conference of Safety in Mines Research Institutes, London. p. 10.

Fraser, M., 2022. Can Agile management principles help metals and mining companies embrace innovation? [WWW Document]. Axora. URL https://www.axora.com/insights/agile-management-principles-help-metals-mining-embrace-innovation/ (accessed 8.26.22).

Frigo, M.L., Anderson, R.J., 2011. Strategic Risk Management: A Foundation for Improving Enterprise Risk Management and Governance. Wiley Period. Inc. March/Apri, 81–88. https://doi.org/10.1002/jcaf.20677

Geller, E.S., 1994. Ten principles for achieving a total safety culture. Prof. Saf. 39, 18.

Gleeson, B., 2013. The Silo Mentality: How To Break Down The Barriers. Forbes 1.

Glendon, A.I., Stanton, N.A., 2000. Perspectives on safety culture. Saf. Sci. 34, 193–214.

Godwin, A., Eger, T., 2012. Evaluating Underground Mining Equipment Line-of-sight and Augmented Vision.

Gomes, L.E. de O., Correa, L.B., Sá, F., Neto, R.R., Bernardino, A.F., 2017. The impacts of the Samarco mine tailing spill on the Rio Doce estuary, Eastern Brazil. Mar. Pollut. Bull. 120, 28–36. https://doi.org/10.1016/j.marpolbul.2017.04.056

Gordon, R., Kirwan, B., Perrin, E., 2007. Measuring safety culture in a research and development centre : A comparison of two methods in the Air Traffic Management domain. Saf. Sci. 45, 669–695. https://doi.org/10.1016/j.ssci.2007.04.004

Greenberg, J., Baron, R.A., 2011. Behavior in organizations : understanding and managing the human side of work, 10th ed. Pearson Education Limited.

GRI, 2021. Consolidated Set of the GRI Standards Consolidated Set of the GRI Standards 2021.

GRI, 2010. Sustainability Reporting Guidelines & Mining and Metals Sector Supplement.

Grinerud, K., Aarseth, W.K., Robertsen, R., 2021. Leadership strategies, management decisions and safety culture in road transport organizations. Res. Transp. Bus. Manag. 41, 100670. https://doi.org/10.1016/j.rtbm.2021.100670

Grubert, E., 2018. Relational values in environmental assessment: the social context of environmental impact. Curr. Opin. Environ. Sustain. 35, 100–107. https://doi.org/10.1016/j.cosust.2018.10.020

Guldenmund, F.W., 2007. The use of questionnaires in safety culture research – an evaluation. Saf. Sci. 45, 723–743. https://doi.org/10.1016/j.ssci.2007.04.006

Guldenmund, F.W., 2000. The nature of safety culture: a review of theory and research. Saf. Sci. 34, 215–257.

Gunningham, N., 2011. Investigation of Industry Self-Regulation in Workplace Health and Safety in New Zealand. J. Safety Res. 31, 120–143.

Gunningham, N., Kagan, R.A., Thornton, D., 2004. Social License and Environmental Protection: Why Businesses Go Beyond Compliance. Berkeley Law Scholarsh. Repos. 29, 307–342. https://doi.org/10.1111/j.1747-4469.2004.tb00338.x

Gyekye, S., Salminen, S., 2009. Age and workers' perceptions of workplace safety: A comparative study. Int. J. Aging Hum. Dev. 68, 171–184. https://doi.org/10.2190/AG.68.2.d

Haight, J., Yorio, P., Rost, K., Willmer, D., 2014. Safety Management Systems: Comparing Content & Impact. Prof. Saf. 59, 44–51.

Hammond, D.M., King, A.L., Joe, M., Miller, J.R., 2023. Understanding the relationship between safety culture and safety performance indicators in U . S . nuclear waste cleanup operations. Saf. Sci. 166, 106241. https://doi.org/10.1016/j.ssci.2023.106241

Hanson Pastran, S., Mallett, A., 2020. Unearthing power: A decolonial analysis of the Samarco mine disaster and the Brazilian mining industry. Extr. Ind. Soc. 7, 704–715. https://doi.org/10.1016/j.exis.2020.03.007

Hart, S.M., 2010. Self-regulation, corporate social responsibility, and the business case: Do they work in achieving workplace equality and safety? J. Bus. Ethics 92, 585–600. https://doi.org/10.1007/s10551-009-0174-1

Haslam, S.A., Jetten, J., Maskor, M., McMillan, B., Bentley, S. V, Steffens, N.K., Johnston, S., 2022. Developing high-reliability organisations: A social identity model. Saf. Sci. 153, 105814. https://doi.org/10.1016/j.ssci.2022.105814

Hayes, J., 2006. Safety decision making in high hazard organisations at the production / maintenance interface – A literature review.

Health and Safety Commission, 1993. ACSNI Study Group on Human Factors. Third Report: Organising for safety.

Health and Safety Executive, 2001. A Guide To Measuring Health & Safety.

Health and Safety Executive, 1997. Successful health and safety management, Health and Safety Executive. https://doi.org/10.1177/026765919701200402

Heinrich, H.W., 1931. Industrial Accident Prevention. A Sceintific Approach, Second Edi. ed. New York & London : McGraw-Hill Book Company, Inc., New York.

Hirschhorn, L., 1997. Reworking authority: Leading and following in the post-modern organisation, Revised. ed. The MIT Press, London.

Hislop, J., 2018. US coal mine closures, falling production leads to productivity increases – EIA [WWW Document]. EnergiMedia. URL https://energi.media/usa/coal-mining-productivity-increases-production-falls/ (accessed 5.28.20).

Hodge, R.A., 2014. Mining company performance and community conflict: moving beyond a seeming paradox. J. Clean. Prod. 84, 27–33. https://doi.org/10.1016/j.jclepro.2014.09.007

Hollnagel, E., 2014. Safety-I and Safety-II: The Past and Future of Safety Management, First Edit. ed. Routledge.

Hopkins, A., 2001. Lessons from Esso's gas plant explosion at Longford. Australian National University, Canberra.

Horberry, T., Burgess-Limerick, R., Steiner, L., 2011. Human Factors for the Design, Operation, and Maintenance of Mining Equipment. CRC Press.

Horsley, J., Prout, S., Tonts, M., Ali, S.H., 2015. Sustainable livelihoods and indicators for regional development in mining economies. Extr. Ind. Soc. 2, 368–380. https://doi.org/10.1016/j.exis.2014.12.001

Housni, F., Boumane, A., Dalby, B., Reda, M., Barnes, P., Abdelfettah, S., Maurady, A., 2022. Environmental sustainability maturity system : An integrated system scale to assist maritime port managers in addressing environmental sustainability goals. Environ. Challenges 7, 100481. https://doi.org/10.1016/j.envc.2022.100481

HSE, 2021. Legislation [WWW Document]. Heal. Saf. Exec. URL https://www.hse.gov.uk/mining/legislatlist.htm (accessed 4.29.21).

HSE, 2014. The Mines Regulations 2014.

Hudson, P., 2007. Implementing a safety culture in a major multi-national. Saf. Sci. 45, 697–722. https://doi.org/10.1016/j.ssci.2007.04.005

Hudson, P., 2003. Applying the lessons of high risk industries to health care. Qual. Saf. Heal. Care 12, 7–12. https://doi.org/10.1136/qhc.12.suppl_1.i7

Hudson, P., 2001. Safety management and safety culture the long, hard and winding road. Occup. Heal. Saf. Manag. Syst. Proc. First Natl. Conf. 3.

Hudson, P., Parker, D., Lawton, R., Verschuur, W.L.G., Van der Graaf, G.C., Kalff, J., 2000. The Hearts and Minds Project: Creating Intrinsic Motivation for HSE, in: SPE International Conference on Health, Safety and the Environment. p. 8.

Hurst, B., Johnston, K.A., Lane, A.B., 2020. Engaging for a social licence to operate (SLO). Public Relat. Rev. 46, 101931. https://doi.org/10.1016/j.pubrev.2020.101931

Iannacchione, A., Varley, F., Brady, T., 2008. The Application of Major Hazard Risk Assessment (MHRA) to Eliminate Multiple Fatality Occurrences in the Minerals Industry, NIOSH.

ICMM, 2022a. Our history [WWW Document]. Int. Counc. Min. Met. URL https://www.icmm.com/en-gb/about-us/our-history (accessed 1.17.22).

ICMM, 2022b. Mining Principles [WWW Document]. Int. Counc. Min. Met. URL https://www.icmm.com/en-gb/about-us/member-requirements/mining-principles (accessed 1.17.22).

ICMM, 2022c. Social and economic reporting: Framework and guidance. London. https://doi.org/10.1016/B978-0-323-03104-2.50020-X

ICMM, 2018. Performance Expectations.

ICMM, 2016. Good Practice Guidance on Occupational Health Risk Assessment.

ICMM, 2015. Critical Control Management Implementation Guide. International Council on Mining and Metals, London.

ICMM, 2014. Understanding company-community Relations: IFC Toolkit.

ICMM, GRI, 2010. GRI Mining and Metals Sector Supplement [WWW Document]. Int. Counc. Min. Met. URL https://icmm.uat.byng.uk.net/en-gb/publications/commitments/gri-mining-and-metals-sector-supplement (accessed 4.18.22).

IDC, 2019. IDC Energy Insights: Agile Mining Operations.

IFC, 2012. Performance Standards on Environmental and Social Sustainability. IFC.

International Atomic Energy Agency, 1991. Safety Culture: A report by the International Nuclear Safety Advisory Group.

IOSH, 2019. Competency framework: Professional standards for safety and health at work.

IRM, 2011. Risk Appetite and Tolerance guidance paper, Life Insurance Risk Management Essentials.

IRMA, 2018. IRMA Standard for Responsible Mining V.1.0.

Ismail, S.N., Ramli, A., Aziz, H.A., 2021. Influencing factors on safety culture in mining industry: A systematic literature review approach. Resour. Policy 74, 102250. https://doi.org/10.1016/j.resourpol.2021.102250

ISO, 2018a. Occupational health and safety management systems - Requirements with guidance for use. BSI Standards Limited.

ISO, 2018b. ISO 31000:2018 - Risk Management - Guidelines. Organ. Int. Norm.

ISO, 2016. ISO 6385:2016 Ergonomic principles in the design of work systems.

Jabbour, A.B., Jabbour, C., Govindan, K., Kannan, D., Arantes, A.F., 2014. Mixed methodology to analyze the relationship between maturity of environmental management and the adoption of green supply chain management in Brazil. Resour. Conserv. Recycl. 92, 255–267. https://doi.org/10.1016/j.resconrec.2014.02.004

Jackson, H., 2023. Pathways to single fatality and serious injury incidents in coal and metalliferous mining in NSW , Australia : Can we learn from multiple fatality incidents to prevent serious injury ? Saf. Sci. 165, 106194. https://doi.org/10.1016/j.ssci.2023.106194

Jacobs, R.L., 2002. Institutionalizing organizational change through cascade training. J. Eur. Ind. Train. 26, 177–182. https://doi.org/10.1108/03090590210422058

Jarvie-Eggart, M.E., 2015. Responsible Mining: Case Studies in Managing Social & Environmental Risks in the Developed World, First Edit. ed. Society for Mining, Metallurgy, and Exploration, Englewood.

Jeswani, H.K., Wehrmeyer, W., Mulugetta, Y., 2008. How Warm Is the Corporate Response to Climate Change? Evidence from Pakistan and the UK. Bus. Strateg. Environ. 17, 46–60. https://doi.org/https://doi.org/10.1002/bse.569

Kalteh, H.O., Salesi, M., Cousins, R., Mokarami, H., 2020. Assessing safety culture in a gas refinery complex: Development of a tool using a sociotechnical work systems and macroergonomics approach. Saf. Sci. 132, 104969. https://doi.org/10.1016/j.ssci.2020.104969

Kao, C.-S., Lai, W.H., Chuang, T.F., Lee, J.-C., 2008. Safety culture factors, group differences, and risk perception in five petrochemical plants. Process Saf. Prog. 27, 145–152. https://doi.org/https://doi.org/10.1002/prs.10246

Karalis, T., 2016. Cascade approach to training: theoretical issues and practical applications in non - formal education. J. Educ. Soc. Policy 3, 104–108.

Kemp, D., 2010. Mining and community development: Problems and possibilities of local-level practice. Community Dev. J. 45, 198–218. https://doi.org/10.1093/cdj/bsp006

Kemp, D., 2009. Community relations in the global mining industry: exploring the internal dimensions of externally orientated work. Corp. Soc. Responsib. Environ. Manag. 17, 1–14.

Kijewska, K., Oliveira, L.K. de, Santos, O.R. dos, Bertoncini, B.V., Iwan, S., Eidhammer, O., 2021. Proposing a tool for assessing the level of maturity for the engagement of urban freight transport stakeholders : A comparison between Brazil, Norway, and Poland. Sustain. Cities Soc. 72, 103047. https://doi.org/10.1016/j.scs.2021.103047

Klassen, R.D., Whybark, D.C., 1999. Environmental Management in Operations: The Selection of Environmental Technologies. Decis. Sci. 30, 601–631.

Laurence, D., 2011. Establishing a sustainable mining operation: An overview. J. Clean. Prod. 19, 278–284. https://doi.org/10.1016/j.jclepro.2010.08.019

Lawson, E., Price, C., 2003. The psychology of change management. McKinsey Co. 1.

Lean Enterprise Institute, 2008. Lean Lexicon: a graphical glossary for Lean Thinkers, Fourth. ed. The Lean Enterprise Institute, Cambridge, MA.

Leonida, C., 2021. Creating scalable, adaptable, future-fit mines. Intell. Min. 1.

Lesser, P., Gugerell, K., Poelzer, G., Hitch, M., Tost, M., 2021. European mining and the social license to operate. Extr. Ind. Soc. 8, 100787. https://doi.org/10.1016/j.exis.2020.07.021

Lesser, P., Poelzer, G., Gugerell, K., Tost, M., Franks, D., 2023. Exploring scale in social licence to operate: European perspectives. J. Clean. Prod. 384, 135552. https://doi.org/10.1016/j.jclepro.2022.135552

Lynas, D., Horberry, T., 2011. Human Factor Issues with Automated Mining Equipment. Ergon. Open J. 4, 74–80. https://doi.org/10.2174/1875934301104010074

Macalister, T., Duncan, P., Levett, C., Sheehy, F., Scruton, P., Swann, G., 2015. The demise of UK deep coal mining: decades of decline. Guard. 1.

Mancini, L., Sala, S., 2018. Social impact assessment in the mining sector:

Review and comparison of indicators frameworks. Resour. Policy In Press. https://doi.org/10.1016/j.resourpol.2018.02.002

Margolis, K.A., 2010. Underground coal mining injury: A look at how age and experience relate to days lost from work following an injury. Saf. Sci. 48, 417–421. https://doi.org/10.1016/j.ssci.2009.12.015

Martyka, J., Lebecki, K., 2014. Safety culture in high-risk industries. Int. J. Occup. Saf. Ergon. 20, 561–572. https://doi.org/10.1080/10803548.2014.11077076

Mason, S., 1996. Measuring Attitudes to Improve Electrician's Safety. Min. Technol. 78, 166–170.

Mason, S., 1992. Improving the Ergonomics of British-Coals Mining Machinery. Appl. Ergon. 23, 233–242. https://doi.org/10.1016/0003-6870(92)90151-K

Maybee, B., Lilford, E., Hitch, M., 2023. Environmental, Social and Governance (ESG) risk, uncertainty, and the mining life cycle. Extr. Ind. Soc. 14. https://doi.org/https://doi.org/10.1016/j.exis.2023.101244

McAteer, J.D., Beall, K., Beck Jr, J.A., McGinley, P.C., Monforton, C., Roberts, D.C., Spence, B., Weise, S., 2011. Upper Big Branch Explosion: Report to the Governor, Governor's Independent Investigation Panel.

McPhee, B., 2004. Ergonomics in mining. Occup. Med. (Chic. Ill). 54, 297–303. https://doi.org/10.1093/occmed/kqh071

Milanez, B., Ali, S.H., Puppim de Oliveira, J.A., 2021. Mapping industrial disaster recovery: Lessons from mining dam failures in Brazil. Extr. Ind. Soc. 8, 100900. https://doi.org/10.1016/j.exis.2021.100900

Mine Safety and Health Administration, 2021. MINER Act [WWW Document]. URL https://www.msha.gov/miner-act (accessed 7.15.21).

Mine Safety and Health Administration, 2020a. Mining Industry Accident, Injuries, Employment, and Production Statistics and Reports [WWW Document]. United States Dep. Labor. URL https://arlweb.msha.gov/ACCINJ/accinj.htm (accessed 7.15.20).

Mine Safety and Health Administration, 2020b. Fatality Reports [WWW

Document]. United States Dep. Labor. URL https://www.msha.gov/data-reports/fatality-reports/search (accessed 7.15.20).

Mine Safety and Health Administration, 2019a. Coal Fatalities for 1900 through 2019 [WWW Document]. United States Dep. Labor. URL https://arlweb.msha.gov/stats/centurystats/coalstats.asp (accessed 7.15.20).

Mine Safety and Health Administration, 2019b. Metal/Nonmetal Fatalities for 1900 through 2019 [WWW Document]. United States Dep. Labor. URL https://arlweb.msha.gov/stats/centurystats/mnmstats.asp (accessed 7.15.20).

Mine Safety and Health Administration, 2013. History of Mine Safety and Health Legislation [WWW Document]. MSHA. URL https://web.archive.org/web/20130218074218/http://www.msha.gov/mshainfo/mshainf2.htm (accessed 4.26.21).

Mineco, 2022a. Olovo Mine [WWW Document]. Mineco Gr. URL https://www.minecogroup.com/olovo (accessed 1.24.22).

Mineco, 2022b. Rudnik Mine [WWW Document]. Mineco Gr. URL https://www.minecogroup.com/rudnik (accessed 1.24.22).

Moore, K.R., Moradi, S., Doyle, K., Sydd, O., Amaral, V., Bodin, J., Brito-Parada, P.R., Dudley, F., Fitzpatrick, R., Foster, P., Goettmann, F., Roberts, D., Roethe, R., Sairinen, R., Sambrook, T., Segura-Salazar, J., Thomas, G., 2021. Sustainability of switch on-switch off (SOSO) mining: Human resource development tailored to technological solutions. Resour. Policy 73. https://doi.org/10.1016/j.resourpol.2021.102167

Moore, K.R., Whyte, N., Roberts, D., Allwood, J., Leal-Ayala, D.R., Bertrand, G., Bloodworth, A.J., 2020. The re-direction of small deposit mining: Technological solutions for raw materials supply security in a whole systems context. Resour. Conserv. Recycl. X 7, 100040. https://doi.org/10.1016/j.rcrx.2020.100040

Moriarty, D., 2015. 4 - Error management and standard operating procedures for organizations, in: Practical Human Factors for Pilots. Academic Press, pp. 119–132. https://doi.org/https://doi.org/10.1016/C2013-0-13582-9

Muller, S., Beylot, A., Sydd, O., Doyle, K., Bodin, J., Villeneuve, J., 2021. Applying social life cycle assessment in the early stages of a project development — an example from the mining sector. Int. J. Life Cycle Assess. 26, 2436–2456. https://doi.org/10.1007/s11367-021-01995-x

Nævestad, T.O., Blom, J., Phillips, R.O., 2020. Safety culture, safety management and accident risk in trucking companies. Transp. Res. Part F Traffic Psychol. Behav. 73, 325–347. https://doi.org/10.1016/j.trf.2020.07.001

Nævestad, T.O., Storesund Hesjevoll, I., Elvik, R., 2021. How can regulatory authorities improve safety in organizations by influencing safety culture? A conceptual model of the relationships and a discussion of implications. Accid. Anal. Prev. 159, 106228. https://doi.org/10.1016/j.aap.2021.106228

Nielsen, K.J., 2014. Improving safety culture through the health and safety organization: A case study. J. Safety Res. 48, 7–17. https://doi.org/10.1016/j.jsr.2013.10.003

NIOSH, 2021. Historical Mine Disasters [WWW Document]. Centers Dis. Control Prev. URL https://wwwn.cdc.gov/NIOSH-Mining/MMWC/MineDisasters/Table (accessed 4.26.21).

Niskanen, T., 1994. Safety climate in the road administration. Saf. Sci. 17, 237–255. https://doi.org/10.1016/0925-7535(94)90026-4

Noon, R., MacNeill, P., 2008. International Mining Fatality Database Project Report.

Nordlöf, H., Wiitavaara, B., Winblad, U., Wijk, K., Westerling, R., 2015. Safety culture and reasons for risk-taking at a large steel-manufacturing company: Investigating the worker perspective. Saf. Sci. 73, 126–135. https://doi.org/10.1016/j.ssci.2014.11.020

O'Faircheallaigh, C., 2010. Public participation and environmental impact assessment: Purposes, implications, and lessons for public policy making. Environ. Impact Assess. Rev. 30, 19–27. https://doi.org/10.1016/j.eiar.2009.05.001

O'Neill, B.C., Kriegler, E., Ebi, K.L., Kemp-Benedict, E., Riahi, K., Rothman, D.S., van Ruijven, B.J., van Vuuren, D.P., Birkmann, J., Kok, K., Levy, M., Solecki, W., 2017. The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. Glob. Environ. Chang. 42, 169–180. https://doi.org/10.1016/j.gloenvcha.2015.01.004

O'Neill, B.C., Kriegler, E., Riahi, K., Ebi, K.L., Hallegatte, S., Carter, T.R., Mathur, R., van Vuuren, D.P., 2014. A new scenario framework for climate change research: The concept of shared socioeconomic pathways. Clim. Change 122, 387–400. https://doi.org/10.1007/s10584-013-0905-2

Oberg, M., 2016. The Woolworths Project: Organisational Report. Brisbane.

Ormazabal, M., Sarriegi, J.M., Barkemeyer, R., Viles, E., McAnulla, F., 2013. Evolutionary Pathways of Environmental Management in UK Companies. Corp. Soc. Responsib. Environ. Manag. 22, 169–181. https://doi.org/10.1002/csr.1341

Ormazabal, M., Sarriegi, J.M., Viles, E., 2016. Environmental management maturity model for industrial companies. Manag. Environ. Qual. An Int. J. 28, 632–650. https://doi.org/10.1108/MEQ-01-2016-0004

Paneri, A., Moore, K., Beylot, A., Muller, S., Braun, M., Yan, X., 2021. Renewable energy can make small-scale mining in Europe more feasible. Resour. Conserv. Recycl. 172. https://doi.org/10.1016/j.resconrec.2021.105674

Parker, D., Lawrie, M., Hudson, P., 2006. A framework for understanding the development of organisational safety culture. Saf. Sci. 44, 551–562. https://doi.org/10.1016/j.ssci.2005.10.004

Participate Learning, 2016. The 4 Stages of Culture Shock [WWW Document]. Medium. URL https://medium.com/global-perspectives/the-4-stages-of-culture-shock-a79957726164 (accessed 8.29.22).

Pass, C.L., Lowes, B., Pendleton, A., Chadwick, L., 1995. Collins Dictionary of Business, Second Edi. ed. Collins, Glasgow.

Perrow, C., 1984. Normal Accidents: Living with High-Risk Technologies, First. ed. BasicBooks.

Pizzutilo, F., Venezia, E., 2021. On the maturity of social responsibility and sustainability integration in higher education institutions : Descriptive criteria and conceptual framework. Int. J. Manag. Educ. 19, 100515. https://doi.org/10.1016/j.ijme.2021.100515

Potrich, L., Nogueira, M., Fleith, J., Medeiros, D., 2019. A systematic literature review on firm-level proactive environmental management. J. Environ. Manage. 243, 273–286. https://doi.org/10.1016/j.jenvman.2019.04.110

Queiroz, H.M., Nóbrega, G.N., Ferreira, T.O., Almeida, L.S., Romero, T.B., Santaella, S.T., Bernardino, A.F., Otero, X.L., 2018. The Samarco mine tailing disaster: A possible time-bomb for heavy metals contamination? Sci. Total Environ. 637–638, 498–506. https://doi.org/10.1016/j.scitotenv.2018.04.370

Rae, A.J., Provan, D.J., Weber, D.E., Dekker, S.W.A., 2018. Safety clutter: the accumulation and persistence of ‘safety’ work that does not contribute to operational safety. Policy Pract. Heal. Saf. 16, 194–211. https://doi.org/10.1080/14773996.2018.1491147

Ragain, R., 2015. Peer Pressure, Conformity and Your Safety Culture. RAD Gr. 1.

Rasmussen, J., 1997. Risk management in a dynamic society: A modelling problem. Saf. Sci. 27, 183–213. https://doi.org/https://doi.org/10.1016/S0925-7535(97)00052-0

Rasmussen, J., Dahlquist, J., Damsgaard, M., de Zee, M., Christensen, S.T., 2003. Musculoskeletal modeling as an ergonomic design method. Int. Ergon. Assoc. XVth Trienn. Conf. 24–29.

Reason, J., 1997. Managing the Risks of Organizational Accidents, 1st ed. Ashgate Publishing Ltd.

Republic of Mining, 2012. Mining in Poland: History and Current Production (Poland’s Natural Resources) [WWW Document]. URL https://republicofmining.com/2012/02/20/mining-in-poland-history-and-current-production-polands-natural-resources/ (accessed 5.29.20).

Riahi, K., van Vuuren, D.P., Kriegler, E., Edmonds, J., O’Neill, B.C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O., Lutz, W., Popp, A., Cuaresma, J.C., KC, S., Leimbach, M., Jiang, L., Kram, T., Rao, S., Emmerling, J., Ebi, K., Hasegawa, T., Havlik, P., Humpenöder, F., Da Silva, L.A., Smith, S., Stehfest, E., Bosetti, V., Eom, J., Gernaat, D., Masui, T., Rogelj, J., Strefler, J., Drouet, L., Krey, V., Luderer, G., Harmsen, M., Takahashi, K., Baumstark, L., Doelman, J.C., Kainuma, M., Klimont, Z., Marangoni, G., Lotze-Campen, H., Obersteiner, M., Tabeau, A., Tavoni, M., 2017. The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. Glob. Environ. Chang. 42, 153–168. https://doi.org/10.1016/j.gloenvcha.2016.05.009

Ridyard, R., 2004. Mining Days in Abram, 1st ed. Leigh Local History.

RMF, 2018. Responsible Mining Index.

Roberts, K.H., 1989. New challenges in organizational research: high reliability organizations. Ind. Cris. Q. 3, 111–125.

Roberts, L., Gehrke, T., 1996. Linkages between best practice in business and good environmental performance by companies. J. Clean. Prod. 4, 189–202.

Robinson, C., 1989. Electricity privatization- What future now for British Coal? Energy Policy 17, 22–26. https://doi.org/10.4324/9781315272290-8

Robinson, P., 2015. Underground Fluorspar Mining in the Peak District Milldam Mine.

Roome, N., 2012. Looking Back, Thinking Forward: Distinguishing Between Weak and Strong Sustainability, in: The Oxford Handbook of Business and the Natural Environment. Oxford University Press, pp. 620–629. https://doi.org/10.1093/oxfordhb/9780199584451.003.0034

Roome, N., 1992. Developing environmental management strategies. Bus. Strateg. Environ. 1, 11–24. https://doi.org/https://doi.org/10.1002/bse.3280010104

Royal Commission, 2021. 1842 Royal Commission Reports [WWW Document]. Coalmining Hist. Resour. Cent. URL http://www.cmhrc.co.uk/site/literature/royalcommissionreports/ (accessed

4.19.22).

Royce, W.W., 1970. Managing the development of large software systems, in: IEEE WESCON. The Institute of Electrical and Electronics Engineers, pp. 1–9.

Safe Work Australia, 2012. Australian Work Health and Safety Strategy 2012 – 2022, Safe Work Australia. Canberra.

Saloniemi, A., Oksanen, H., 1998. Accidents and Fatal Accidents- Some Paradoxes. Saf. Sci. 29, 59–66.

SAMESG Committee, 2017. The South African Guideline for the Reporting of Environmental, Social and Governance Parameters within the Solid Minerals and Oil and Gas Industries. Johannesburg.

Sammarco, J., Gallagher, S., Mayton, A., Srednicki, J., 2012. A visual warning system to reduce struck-by or pinning accidents involving mobile mining equipment. Appl. Ergon. 43, 1058–1065. https://doi.org/10.1016/j.apergo.2012.03.006

Satarla, 2021. How to build & use a Risk Impact versus Action Map.

Schmitz-Felten, E., Lieck, L., Seifert, M., 2018. National Strategies in the field of Occupational Safety and Health in the EU.

Schutte, P.C., Smith, J.R., 2002. Practical ergonomics in mechanized mining. J. South African Inst. Min. Metall. 102, 145–149.

Segura-Salazar, J., Tavares, L.M., 2018. Sustainability in the minerals industry: Seeking a consensus on its meaning. Sustainability 10, 1429. https://doi.org/10.3390/su10051429

Sethi, S.P., 2005. The effectiveness of industry-based codes in serving public interest: The case of the International Council on Mining and Metals. Transnatl. Corp. 14, 55–100.

Shooks, M., Johansson, B., Andersson, E., Lööw, J., 2014. Safety and health in European Mining.

Shukla, G.P., Adil, G.K., 2021. A four-stage maturity model of green manufacturing orientation with an illustrative case study. Sustain. Prod. Consum. 26, 971–987. https://doi.org/10.1016/j.spc.2021.01.009

Sidorenko, O., Sairinen, R., Moore, K., 2020. Rethinking the concept of small-scale mining for technologically advanced raw materials production. Resour. Policy 68, 101712. https://doi.org/10.1016/j.resourpol.2020.101712

Silva Rotta, L.H., Alcântara, E., Park, E., Negri, R.G., Lin, Y.N., Bernardo, N., Mendes, T.S.G., Souza Filho, C.R., 2020. The 2019 Brumadinho tailings dam collapse: Possible cause and impacts of the worst human and environmental disaster in Brazil. Int. J. Appl. Earth Obs. Geoinf. 90, 102119. https://doi.org/10.1016/j.jag.2020.102119

Simard, M., Marchand, A., 1994. The behaviour of first-line supervisors in accident prevention and effectiveness in occupational safety. Saf. Sci. 17, 169–185.

Simpson, G.C., 1997. Behavioural Safety - An External Viewpoint.

Simpson, G.C., 1993. Applying Ergonomics in the Mining Workplace.

Simpson, G.C., Horberry, T., Joy, J., 2009. Understanding Human Error in Mine Safety. Ashgate Publishing Ltd.

Simpson, G.C., Rushworth, A.M., von Glehn, F.H., Lomas, R.M., 1996. Causes of transport and tramming accidents on mines other than Coal, Gold and Platinum. Final Report on Safety in Mines Research Advisory Committee Project OTH 202.

Sinan Erzurumlu, S., Erzurumlu, Y.O., 2015. Sustainable mining development with community using design thinking and multi-criteria decision analysis. Resour. Policy 46, 6–14. https://doi.org/10.1016/j.resourpol.2014.10.001

Solability, 2021. The Global Sustainable Competitiveness Index [WWW Document]. URL https://solability.com/solability/the-global-sustainable-competitiveness-index/the-index (accessed 11.16.21).

Sovacool, B.K., Martiskainen, M., Hook, A., Baker, L., 2019. Decarbonization and its discontents: a critical energy justice perspective on four low-carbon transitions, Climatic Change. https://doi.org/10.1007/s10584-019-02521-7

Spaltini, M., Acerbi, F., Gusmeroli, S., Taisch, M., Acerbi, F., Pinzone, M., Gusmeroli, S., Taisch, M., Stief, P., Dantan, J., Etienne, A., Siadat, A., 2022. Defining the Roadmap towards Industry 4.0: The 6Ps Maturity Model for Manufacturing SMEs. Procedia CIRP 105, 631–636. https://doi.org/10.1016/j.procir.2022.02.105

Spitz, K., Trudinger, J., 2009. Mining and the environment: from ore to metal, First Edit. ed. CRC Press, London.

SSC, 2016. The South African Code for the Reporting of Exploration Results, Mineral Resources and Mineral Reserves. Johannesburg.

Stantec, 2019. Agile mining leads to breakthrough results [WWW Document]. URL https://www.stantec.com/en/ideas/topic/energy-resources/agile-mining-leads-to-breakthrough-results (accessed 8.26.22).

Stare, A., 2014. Agile Project Management in Product Development Projects, in: Procedia - Social and Behavioral Sciences. Procedia - Social and Behavioural Sciences, pp. 295–304. https://doi.org/10.1016/j.sbspro.2014.03.034

Stefana, E., Paltrinieri, N., 2020. Integration between occupational and process safety: Existing approaches and challenges for an enhanced framework. Chem. Eng. Trans. 82, 31–36. https://doi.org/10.3303/CET2082006

Steinbach, V., Wellmer, F.-W., 2010. Consumption and Use of Non-Renewable Mineral and Energy Raw Materials from an Economic Geology Point of View. Sustainability 2, 1408–1430. https://doi.org/https://doi.org/10.3390/su2051408

Stemn, E., Bofinger, C., Cliff, D., Hassall, M.E., 2019. Examining the relationship between safety culture maturity and safety performance of the mining industry. Saf. Sci. 113, 345–355. https://doi.org/10.1016/j.ssci.2018.12.008

Suopajärvi, L., 2013. Social impact assessment in mining projects in Northern Finland: Comparing practice to theory. Environ. Impact Assess. Rev. 42, 25–30. https://doi.org/10.1016/j.eiar.2013.04.003

Sutherland, J., 2019. The Scrum@Scale Guide.

Sutherland, J., Schwaber, K., 2016. The Scrum Guide.

Sydd, O., Sairinen, R., Orenius, O., Tiainen, H., 2022. Social Impacts of Modern Small-scale Mining: Case Studies from Serbia and Bosnia & Herzegovina. Soc. Nat. Resour. 35, 816–835. https://doi.org/10.1080/08941920.2022.2079157

Tappin, D.C., Bentley, T.A., Ashby, L.E., 2015. An implementation evaluation of a qualitative culture assessment tool. Appl. Ergon. 47, 84–92. https://doi.org/10.1016/j.apergo.2014.08.012

Tata, J., Anthony, T., Lin, H., Newman, B., Tang, S., Millson, M., Sivakumar, K., 1996. Proportionate Group Size and Rejection of the Deviate: A Meta-Analytic Integration. J. Soc. Behav. Personal. 11, 739–752.

Teske, D.B.E., Adjekum, D.D.K., 2022. Understanding the Relationship between High Reliability Theory (HRT) of Mindful Organizing and Safety Management Systems (SMS) within the Aerospace Industry: A Cross-Sectional Quantitative Assessment. J. Saf. Sci. Resil. 0–38. https://doi.org/10.1016/j.jnlssr.2022.01.002

Tetzlaff, E.J., Goggins, K.A., Pegoraro, A.L., Dorman, S.C., Pakalnis, V., Eger, T.R., 2021. Safety Culture: A Retrospective Analysis of Occupational Health and Safety Mining Reports. Saf. Health Work 12, 201–208. https://doi.org/10.1016/j.shaw.2020.12.001

The Guardian, 2015. A brief history of British coal mining – in pictures. Guard. 1.

The University of Queensland, 2008. Minerals Industry Risk Management Maturity Chart. Brisbane.

The World Bank, 2022. Metadata Glossary: Total natural resources rents [WWW Document]. World Bank Gr. URL https://databank.worldbank.org/metadataglossary/adjusted-net-savings/series/NY.GDP.TOTL.RT.ZS#:~:text=The estimates of natural resources,of extraction or harvesting costs. (accessed 8.19.22).

Thomson, I., Boutilier, R.G., 2011. Social License to Operate, in: SME Mining Engineering Handbook. Society for Mining, Metallurgy, and Exploration, pp.

1779–1796.

Torma-Krajewski, J., J. Steiner, L., Burgess-Limerick, R., 2009. Ergonomics Processes Implementation Guide and Tools for the Mining Industry.

Torma-Krajewski, J., Steiner, L., Lewis, P., Gust, P., Johnson, K., 2006. Ergonomics and mining: Charting a path to a safer workplace.

Trice, H.M., Beyer, J.M., 1993. The Culture of Work Organisations. Prentice Hall.

Turner, B.A., Pidgeon, N., Vaughn, D., Rosenthal, U., 1997. Man-Made Disasters, Second. ed. Butterworth-Heinemann Ltd.

UK Parliament, 2021. Coal mines [WWW Document]. URL https://www.parliament.uk/about/living-heritage/transformingsociety/livinglearning/19thcentury/overview/coalmines/ (accessed 4.29.21).

UNDP, 2014. Social and Environmental Standards. United Nations.

UNEP, 2021. Making Peace with Nature, United Nations Environment Programme. https://doi.org/10.18356/9789280738377

Upadhyay, A., Laing, T., Kumar, V., Dora, M., 2021. Exploring barriers and drivers to the implementation of circular economy practices in the mining industry. Resour. Policy 72, 102037. https://doi.org/10.1016/j.resourpol.2021.102037

van der Plank, S., Walsh, B., Behrens, P., 2016. The expected impacts of mining: Stakeholder perceptions of a proposed mineral sands mine in rural Australia. Resour. Policy 48, 129–136. https://doi.org/10.1016/j.resourpol.2016.03.005

Vasquez, J., Aguirre, S., Puertas, E., Bruno, G., Priarone, P.C., Settineri, L., 2021. A sustainability maturity model for micro , small and medium-sized enterprises (MSMEs) based on a data analytics evaluation approach. J. Clean. Prod. 311, 127692.

Vastag, G., Rondinelli, D.A., 1996. Evaluation of corporate environmental management approaches: A framework and application. Int. J. Prod. Econ.

43, 193–211.

Visual Paradigm, 2022. Classical Project Management vs Agile Project Management [WWW Document]. URL https://www.visual-paradigm.com/scrum/classical-vs-agile-project-management/ (accessed 8.23.22).

Vogus, T.J., Sutcliffe, K.M., 2007. The Safety Organizing Scale: Development and Validation of a Behavioural Measure of Safety Culture in Hospital Nursing Units. Med. Care 45, 46–54. https://doi.org/10.1097/01.mlr.0000244635.61178.7a

Vu, T., De Cieri, H., 2014. Safety culture and safety climate definitions suitable for a regulator : A systematic literature review 1–92.

Walsh, B., van der Plank, S., Behrens, P., 2017. The effect of community consultation on perceptions of a proposed mine: A case study from southeast Australia. Resour. Policy 51, 163–171. https://doi.org/10.1016/j.resourpol.2016.12.006

Wang, L., Xu, S., Qiu, J., Wang, K., Ma, E., Li, C., Guo, C., 2020. Automatic Monitoring System in Underground Engineering Construction: Review and Prospect. Adv. Civ. Eng. 2020. https://doi.org/10.1155/2020/3697253

Wang, X., Lo, K., 2021. Just transition: A conceptual review. Energy Res. Soc. Sci. 82, 102291. https://doi.org/10.1016/j.erss.2021.102291

WCML, 2022. Nationalisation of the mines [WWW Document]. Work. Cl. Mov. Libr. URL https://www.wcml.org.uk/about-us/timeline/nationalisation-of-the-mines/ (accessed 4.19.22).

Weick, K.E., Sutcliffe, K.M., 2007. Managing the Unexpected: Resilient Performance in an Age of Uncertainty, 2nd ed. John Wiley & Sons Ltd.

Weick, K.E., Sutcliffe, K.M., 2001. Managing the unexpected: Assuring high performance in an age of complexity. Jossey-Bass, San Francisco.

West, J., Haywood, M., Dunn, P., Eger, T., Grenier, S., Whissel, C., 2007. Comparison of operator line-of-sight (LOS) assessment techniques: Evaluation of an underground load-hauldump (LHP) mobile mining vehicle.

J. South. African Inst. Min. Metall. 107, 315–322.

Westrum, R., 2004. A typology of organisational cultures. Qual. Saf. Heal. Care 13, 22–27. https://doi.org/10.1136/qshc.2003.009522

Williamson, A.M., Feyer, A.M., Cairns, D., Biancotti, D., 1997. The development of a measure of safety climate: The role of safety perceptions and attitudes. Saf. Sci. 25, 15–27. https://doi.org/10.1016/S0925-7535(97)00020-9

Wilson, J.R., 2000. Fundamentals of ergonomics in theory and practice. Appl. Ergon. 31, 557–567. https://doi.org/10.1016/S0003-6870(00)00034-X

Winn, M.I., Angell, L.C., 2000. Towards a Process Model of Corporate Greening. Organ. Stud. 21, 1119–1147. https://doi.org/https://doi.org/10.1177/0170840600216005

Winstanley, I., 2016. UK Mining Disasters 1820-39. CMHRC.

Womack, J.P., Jones, D.T., 2003. Lean Thinking: Banish Waste And Create Wealth In Your Corporation, 2003 Editi. ed. Simon & Schuster/Free Press.

Wright, L., Van Der Schaaf, T., 2004. Accident versus near miss causation: A critical review of the literature, an empirical test in the UK railway domain, and their implications for other sectors. J. Hazard. Mater. 111, 105–110. https://doi.org/10.1016/j.jhazmat.2004.02.049

Yang, F., Huang, Y., Tao, J., Reniers, G., Chen, C., 2023. Visualized analysis of safety climate research: A bibliometric data mining approach. Saf. Sci. 158, 105973. https://doi.org/10.1016/j.ssci.2022.105973

Zohar, D., 2010. Thirty years of safety climate research: Reflections and future directions. Accid. Anal. Prev. 42, 1517–1522. https://doi.org/10.1016/j.aap.2009.12.019

Zohar, D., 2008. Safety climate and beyond: A multi-level multi-climate framework. Saf. Sci. 46, 376–387. https://doi.org/10.1016/j.ssci.2007.03.006

Zohar, D., 2002. The effects of leadership dimensions, safety climate, and assigned priorities on minor injuries in work groups. J. Organ. Behav. 23, 75–92. https://doi.org/10.1002/job.130

Zohar, D., 1980. Safety Climate in Industrial Organizations: Theoretical and Applied Implications. J. Appl. Psychol. 65, 96–102. https://doi.org/10.1037/0021-9010.65.1.96

Zohar, D., Luria, G., 2005. A Multilevel Model of Safety Climate: Cross-Level Relationships Between Organization and Group-Level Climates. J. Appl. Psychol. 90, 616–628. https://doi.org/10.1037/0021-9010.90.4.616