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Fatality risk management: Applying Quinlan's Ten Pathways in Western Australia's mining industry

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ABSTRACT

In 'Ten Pathways to Death and Disaster' Professor Michael Quinlan (2014) identified a series of ten common catastrophic incident risk factors, known as the Ten Pathways, contributing to major incidents in mining and other high hazard industries. This study applies the Quinlan methodology in two separate phases. The first phase of the study explored employee perception of employer effectiveness of fatality prevention against each of the Ten Pathways through a questionnaire of $n = 2009$ participants at the 2017–2019 Western Australian Government Mines Safety Roadshows. Respondents generally perceived their employer as having a relatively good understanding of the role of risk assessments and their importance in preventing injuries yet perceived their employers as generally ineffective in management system auditing. In the second phase of the study, 71 fatality reports on the Western Australian Government Department of Mines Fatalities register were assessed to identify the Ten Pathways involved in the fatality. The analysis identified fatalities typically included four or five of the Ten Pathways, although none of the investigations analysed all Ten Pathways. A combined assessment of employee perceptions of employer's effectiveness at fatality prevention and pathways present in the Mines Fatalities register identified which Quinlan Ten Pathways mining organisations should prioritise for fatality prevention. It is recommended that benchmarking safety performance, incident investigations, and reviews of effectiveness of safety management systems include an examination and verification of the organisation's response to Ten Pathways, a relatively straight forward task which may highlight latent issues or weaknesses that may otherwise remain undetected.

1. Introduction

In 2019–2020 the West Australian mining industry contributed $135.3 billion Australian dollars to the State economy, approximately 43% of the State GDP (Government of Western Australia, 2021). In 2020, the State mining industry employed 140,000 workers, approximately 10% of the West Australian (WA) workforce (ABS, 2021). Between 2000 and 2020 there were 77 mining fatalities reported to the West Australian Government, 15% of all fatalities in WA (Department of Mines Industry Regulation and Safety, 2021; SafeWork Australia, 2020). Therefore, it appears the West Australian mining industry is over-represented in the States fatality statistics, and there is room for improvement. This research aims to offer suggestions for improvement based on lessons learnt from a review of fatalities conducted by Professor Quinlan.

The Department of Mines, Industry Regulation and Safety ('DMIRS') is the Work Health and Safety (WHS) Regulator for all West Australian industry, responsible for ensuring the "*State's safety, health and environmental standards are world best practice and consistent with relevant State and Commonwealth legislation, regulations and policies*" (DMIRS, 2019., para. 2).

Amongst a variety of roles and services, DMIRS collects occupational incident and fatality information from West Australian mining organisations, in particular, to identify areas for safety performance improvement. The 'Fatalities register for all Western Australian mining fatalities' is a collation of fatality incident information from 71 fatalities between January 2000 and December 2018 (DMIRS, 2018). This freely available online Register assists organisations learn from previous

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incidents, a useful method to improve fatality prevention (DMIRS, 2018b, Hinze & Russell, 1995; Quinlan, 2014).

In 2014, Professor Michael Quinlan (2014) published "Ten Pathways to Death and Disaster: Learning from Fatal Incidents", a systematic analysis of fatalities in the mining industry which occurred in five countries from 1996 to 2011. From an assessment of this historical data, Quinlan (2014) identified ten themes which repeatedly occurred in these fatalities (Table 1).

From the fatalities assessed by Quinlan, there was clear evidence of one or more of the 'ten pathways' not being effectively addressed by the fatally injured persons employer prior to the incident, and it is suggested that this may have contributed to the causes of the fatality (Quinlan, 2014).

1.1. Background

Despite a plethora of advice on the development of safety performance, the consultation, co-operation and co-ordination between an organisation's risk stakeholders is the contemporary foundation for improvement (SafeWork Australia, 2011). In effect, for an organisation to progressively manage risk to an acceptable level, it should involve its internal stakeholders in the development of a consistent approach to a safe system of work, communicate it, monitor its performance and update it to manage changes and new requirements i.e., the Plan, Do, Check, Act cycle (International Organization for Standardization, 2018). External stakeholders, such as the Regulators have a role in the development of an organisation's safety performance, by their objective assessment of compliance, and where necessary action to ensure compliance. Also, previous research has indicated that the economic environment contributes to the safety performance of organisations through availability of resources and changes to risk profiles, organisations must consider the impact of economic cycles on safety performance (Jenke, 2021).

A fatality prevention program should be communicated to an organisation's employees, particularly those at risk. Feedback from employees could indicate it's effectiveness and identify if there are gaps in safety performance that require improvement. If 'at risk' employees perceive their employer's fatality prevention program as effective versus ineffective, this may give the employer a greater level of confidence in the program. If the program is perceived as ineffective, this may prompt the employer to investigate this feedback. Whilst employee perception of the fatality prevention program may not forecast or measure the risk of fatality, if the participants in a perception questionnaire represent a large proportion of the workforce, this feedback may be valuable. By comparing perception between groups of employees or over time, an organisation could create a risk profile to assist determine progress towards an 'acceptable', and in response modify the program to improve performance to a level as low as reasonably practicable by implementing controls that meet the standards of relevant good practice (Gadd, Keeley, & Balmforth, 2003).

In this research we comment on the combined assessment of employee perception of their organisation's effectiveness on fatality prevention along with a review of 71 fatalities using the Quinlan Ten Pathways.

2. Aims and objectives

The research aims to identify which of the Quinlan Ten Pathway mining organisations should prioritise in order to be more effective in fatality prevention. To achieve this aim the following objectives were established:

1. Use the results of a Quinlan Ten Pathways employee perception questionnaire to develop a profile of West Australian mining industry fatality prevention effectiveness.

Table 1
Description of Quinlan Ten Pathways (2014).

Pathway	Description of Pathway
Pathway 1: Design, engineering, technical and maintenance flaws	The flaws in engineering, design and maintenance were mostly the result of poor decision making by management and were often known or should have been identified well before the fatal incident.
Pathway 2: Prior warnings or causes for alarm ignored	In many of the fatal incidents, Quinlan observed that clear warnings and causes for alarm were ignored. For example, prior to the Beaconsfield collapse the stress and seismicity of two previous rock falls were not properly managed or investigated to identify the root cause. In many cases, employees or supervisors had expressed their safety concerns prior to the fatal incident.
Pathway 3: Failures in risk assessment	Quinlan stated a causal factor of many of the fatal incidents was a failure to undertake risk assessments or undertake them accurately. Effective risk assessments are based on informed knowledge of the hazard, evaluation of the effectiveness of risk treatments and control measures, and monitoring and review of the situation to detect change in risk.
Pathway 4: Failures in management systems and hazard management plans	Quinlan reported that Work Health and Safety management systems which focus on behavioural change, Lost Time Injuries and poorly selected Key Performance Indicators can lead to complacency when it comes to major hazards. Furthermore, the catastrophic risk increases when well-documented procedures are not implemented and when there are major changes to work design, for example the increased use of contractors.
Pathway 5: Failures in auditing	Auditing ensures that Work Health and Safety Management Systems are designed and implemented effectively and identifies areas for improvement. Auditing needs to be rigorous across all parts of the Work Health and Safety Management System. Quinlan considered overly routinized audits that do not act on information may overlook catastrophic hazards.
Pathway 6: Economic pressures compromising safety	This pathway highlights the failure to control the influence of personal financial incentives and pressure on individuals to contribute to the production expectations. Quinlan stated that financial pressures such as the use of incentive- or bonus-based regimes are commonly found to undermine safety.
Pathway 7: Failures in regulatory oversight and inspection	The failure of the Regulator to provide feedback to an organisation on their compliance with legislation and safety performance was found by Quinlan to be a common catastrophic incident pathway.
Pathway 8: Worker and others expressing concern prior to the incident	In most investigations it seemed to Quinlan to be remarkable how seldom workers were asked their views on safety at the mine, including evidence of concerns both prior to and pertaining to the incident. Quinlan found failure to heed well-founded concerns was a common pathway of mine fatalities.
Pathway 9: Poor management – worker communication and trust	This pathway concerns the flow of critical information to and from the workers as well as the willingness to act on that information. Quinlan found ineffective communication and trust may result in a variety of poor outcomes including mixed messages, inconsistent messages and lack of engagement with the work force which undermines their participation.

(*continued on next page*)

Table 1 (*continued*)

Pathway	Description of Pathway
Pathway 10: Emergency and rescue resources and procedures	Effective emergency management procedures play a critical role in mitigating the escalation of an incident. Failure to develop and implement effective emergency management systems endanger lives including safeguarding rescue personnel.

2. Compare the fatality incident information in the DMIRS fatality register to the Quinlan Ten Pathways to create a profile of West Australian mining industry fatalities.
3. Combine the outcomes of the profiles from the employee perception questionnaire and the fatality register to identify priorities for improvement in West Australian mining industry fatalities.

3. Method

The study was conducted in two phases:

In Phase 1 an anonymous questionnaire designed to collect an employee's perception of their employer's effectiveness in each of the Quinlan Ten Pathways was provided to attendees of the DMIRS Mines Safety Roadshow (i.e., neither the participant nor their employer's name were collected). The questionnaire asked participants to rank, on 10-point Likert scale, their perception of their employer's performance in each of the Quinlan's Ten Pathways, from 1 to 10, with 10 being the most effective. The questionnaire was administered each year to participants from 11 towns/cities and 2 mine sites totalling 2009 participants (n) over the 3-year study, in 2017 n = 768, in 2018 n = 695, and in 2019 n = 546.

Since the Mines Safety Roadshow attendees were from diverse employers results from the 13 locations were collated into four regions (i.e. as individual participants and their employers could not be identified):

1. Perth Region: Questionnaires from participants of the Perth, Mandurah and Bunbury events. These regional cities are the location of many mining organisation Corporate Offices.
2. Mid Region: Questionnaires from participants of from four towns approximately 400–850 km from Perth.
3. North Region: Questionnaires from participants of the four towns approximately 1400–1600 km north of Perth.
4. Mines: Questionnaires from participants at the Roadshow located at two operating Mine sites. Whilst anonymous, most of the participants at the two Mines were likely to be closely associated with the mining organisation which operates the mine.

The reliability of the questionnaire was determined using SPSS version 25 (IBM Corp, 2017). The completed questionnaire results were transcribed to Qualtrics software (Qualtrics, 2018) and descriptive statistical analyses were conducted using SPSS version 25 (IBM Corp., 2017). The questionnaire results were used to statistically calculate a profile for each year, regional location and Quinlan pathway, which may inform activities to develop performance.

In Phase 2, the incident description, precautions and prevention information from each of the 71 entries in the DMIRS mining fatality register was coded (by author JB and verified by MC) to the relevant Quinlan Ten Pathways. The frequency each pathway occurred was calculated.

4. Results

4.1. West Australian mining industry fatality prevention effectiveness profile

4.1.1. Questionnaire reliability and data validity

The questionnaire indicated a high reliability, Cronbach's $\alpha = 0.98$. With a mining industry working population of 140,000 (DMIRS, 2020) and using a confidence level of 95%, a 5% margin of error, a representative sample of the West Australian mining using G Power was 383. This study exceeded this number on each of the three years, and therefore the results are somewhat representative of the West Australian mining industry, although the roles and functions of the participants is unlikely to represent the diversity of mining industry roles.

Assessment of linearity was completed for the entire data set and tests for normality and homoscedasticity was completed on residual data and all assumptions were met. An analysis of residuals was conducted and there did not appear to be any outliers.

4.1.2. Response rate

The total attendance at the Mines Safety Roadshows was provided by DMIRS to calculate the questionnaire participation rate. In 2017, 768 participants of the Mines Safety Roadshow took part in the questionnaire giving a 94% response rate; in 2018, 748 participants took part in the questionnaire giving an 86% response rate; while in 2019, 546 participants completed the questionnaire, a response rate of 92%. The total number of questionnaire respondents over the three years questionnaires was 2009.

4.1.3. Questionnaire descriptive analysis

Analysis of questionnaire data from 2017, 2018 and 2019 was completed to determine the perceived organisational effectiveness of fatality prevention based on the Ten Pathways. Fig. 1 compares the Ten Pathway questionnaire responses from 2017 to 2019.

The mean of each questionnaire for 2017, 2018 and 2019 was 6.55, 6.96 and 6.71 out of 10, respectively. This indicates that the perceived organisational fatality risk on Ten Pathways was seemed to be effective for 2017, 2018 and 2019, however there is an opportunity for organisations improve fatality prevention towards a score of 10.

Pathways 1, 2, 4, 5 and 7 show an increasing trend in perceived organisational risk effectiveness increasing from 2017 to 2019 for all questionnaire respondents. Data was not collected on Pathways 1,7 and 8 in 2018 and Pathway 2 in 2019 due to time constraints, however the trend for Pathways 1, 2 and 7 indicate an improvement from 2017 to 2019. For Pathway 8 it is possible that a decrease in effectiveness is perceived, however additional data would need to be collected. Due to the large sample size of the total dataset and subsequent years these Pathways were included in the analysis, however aggregate analysis of the questionnaire was not completed due to missing data.

A two-way ANOVA was conducted on the complete dataset of 2009 questionnaire responses to determine if there was a difference in the responses between the 3 years as well as between the Ten Pathway questions. Results indicate that there was a statistically significant difference between the years and questions, $F = (2008, 9) = 9.31$ $p < 0.05$. This indicates that employee's perception of their employer's effectiveness of fatality prevention was different between the 3 years of study and within each of the pathways assessed in the questionnaire.

Table 2 provides a summary assessment of the mean score of perceived organisational effectiveness according to the Ten Pathways. In 2017 and 2019, Pathway 3: Failures in risk assessment had the highest mean score of the surveyed pathways; in 2018, the highest was Pathway 10: Emergency and rescue resources and procedures. The Pathway with the lowest mean score in 2017 and 2018 was Pathway 5: Failures in Auditing and in 2019 the lowest score was Pathway 1: Design, engineering, technical and maintenance failure. Reviewing Pathway 6: Economic pressures compromising safety indicates a drop in

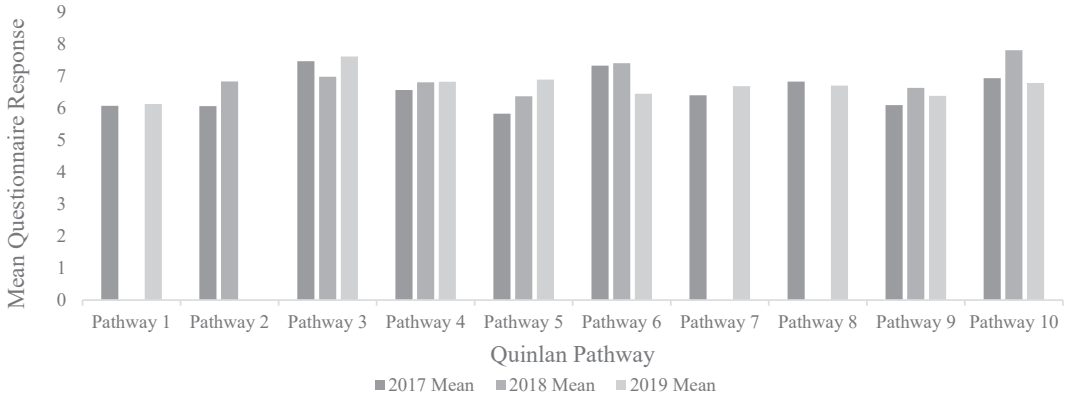

Fig. 1. Comparison of perceived organisation risk effectiveness based on Quinlan Ten Pathways from questionnaire data from 2017 to 2019 Mines Safety Roadshow in Western Australia. Note: Some data points are missing as not all Pathways were queried each year due to time constraints.

Table 2
Summary Statistics of perceived organisational performance on Quinlan's (2014) Ten Pathways.

Quinlan's (2014) Ten Pathways	2017			2018			2019		
	N	2017 Mean	Std. Deviation	N	2018 Mean	Std. Deviation	N	2019 Mean	Std. Deviation
Pathway 1: Design, engineering, technical and maintenance failure	746	6.06	1.66	0	–	–	532	6.12	1.87
Pathway 2: Prior warning or causes for alarm ignored	761	6.05	1.63	680	6.82	1.46	0	–	–
Pathway 3: Failures in risk assessment	765	7.45	1.88	683	6.97	2.04	536	7.60	1.93
Pathway 4: Failures in management systems and hazard management plans	752	6.55	2.07	673	6.79	2.18	533	6.81	1.83
Pathway 5: Failures in Auditing	764	5.82	3.00	654	6.36	2.39	527	6.88	2.00
Pathway 6: Economic pressures compromising safety	764	7.32	2.13	680	7.39	2.25	519	6.44	2.49
Pathway 7: Failures in regulatory oversight and inspection	736	6.39	2.43	0	–	–	502	6.67	2.20
Pathway 8: Workers and others expressing concern prior to the incident	763	6.82	1.84	0	–	–	532	6.69	2.07
Pathway 9: Poor management – worker communication and trust	757	6.08	2.01	682	6.62	1.98	523	6.37	2.23
Pathway 10: Emergency and rescue resources and procedures	760	6.93	2.02	685	7.80	1.62	532	6.77	2.14

Note: 0 or - indicates that no data was collected for this pathway for the corresponding year

organisational effectiveness from 2017 to 2019. Statistically significant differences in the mean scores were found from 2017 to 2019 indicating that the mean score is different for each year for Pathway 3: Failures in risk assessment $F(2, 1981) = 18.350$, $p < .001$, Pathway 6: Economic pressures compromising safety, $F(2, 1960) = 31.098$, $p < .001$, Pathway 9: Poor management – worker communication and trust $F(2, 1959) = 12.171$, $p < .001$, and Pathway 10: Emergency and rescue resources and procedures $F(2, 1974) = 53.803$, $p < .001$. This indicates that for these four pathways the employee perception was not dependent on year in which the response was provided.

4.1.4. Questionnaire responses by role

Participants were asked for their role in their organisations as Pathway 6: Economic pressures compromising safety and Pathway 9: Poor management – worker communication are concerned with the perceived behaviour of an organisation's leadership team. Analysis of the questionnaire responses by Health and Safety representatives compared to Superintendents/Managers is summarised in Table 3, for 2017, 2018 and 2019. Employees without leadership or supervisory roles accounted for 31% of participants in 2017, 34% in 2018, and 48% in 2019. Those with leadership roles accounted for 27% in 2017, 38% in 2018, and 48% in 2019.

When assessing the Ten Pathway values there are differences between the responses for those in leadership roles compared to those who are not in leadership roles. When assessing Pathway 1: How do you rate your employer's maintenance activities, the mean score for Superintendents/Managers (M = 6.82) was higher compared to Health and Safety representatives (M = 5.79) F (4,526) = 6.106, P < .001.

Table 3
Number of participants in each employee role

Role	Year		
	2017	**2018**	**2019**
Employee (i.e., No Supervisory role)	239	238	261
Health & Safety Representative	–	362	–
Superintendent or Manager	111	106	93
Team Leader or Supervisor	94	47	64
Advisor or Coordinator	–	114	104
Safety professional	168	–	–
Other	36	37	22

Note: the '–' indicates the data was not collected; the sum may not equal the total described in the text as participants could indicate more than one role).

For Pathway 6: Economic pressures compromising safety, had the most significant difference between mean score for Superintendents/Managers (M = 7.19) compared to Health and Safety representatives (M = 6.05) F (4,514) = 4.617, p = .001. This indicates that there is a variance in the perceived priority between workers and supervisors when it comes to how important safety is compared to profitability.

Employee perception of Pathway 7: Failures in regulatory oversight and inspection was assessed with two questions: 'Are there an adequate number of Government safety inspectors?' F (4,498) = 3.503, p < .05 and 'How do you rate your organisation's compliance with the current health and safety law?' F (4,528) = 5.007, p < .001. Both questions

demonstrated a significant difference between Health and Safety representative (M = 6.37 and 7.08, respectively) and Superintendents/Managers (M = 7.21 and 8.01, respectively). This indicates that employees perceive the Regulator to be less effective than the Managers.

Pathway 8: Workers and others expressing concern prior to the incident, was assessed with two questions: 'How do you rate the worker-management relationship?' $F(4,518) = 10.685$, $p < .001$ and 'Are health and safety issues addressed in a timely manner?' $F(4,527) = 7.843$, $p < .001$. Like Pathway 7, Health and Safety representatives had a lower mean score compared to Superintendent/Managers.

Pathway 9 measured worker-management communication and trust, and the results indicate that those in leadership roles scored higher (M = 7.73) compared to employees (M = 6.36) $F(4,526) = 9.029$, $P < .001$. Interestingly, this indicates the Manager perceive the trust relationship more favourably than the employees.

Overall, assessment of the pathways by role indicates a trend whereby the Superintendents/Managers have a higher perceived organisational performance when compared to Health and Safety representatives. There was no statistically significant difference in the responses based on roles for Pathways 2 to 5, 8 or 10, which suggests that the perception of effectiveness of the Quinlan Ten Pathways at an organisation level is not based on an individual's role.

4.1.5. Questionnaire responses by regional category

Assessment of the Quinlan questionnaire response data by 4 Regional categories: Perth, Mid-Region, North Region and Mines indicates variable perceived organisational performance across each category for 2017, 2018 and 2019 (See Table 4).

In 2017, Pathway 5: Failures in Auditing had the lowest means (M = 5.79) in the Perth region and in the North Region (M = 5.56). In 2019, this pathway increased by approximately 1.0 in these regions.

In 2018, the North region had the highest means for Pathways 3: Failures in risk assessment, Pathway 6: Economic pressures compromising safety, and Pathway 10: Emergency and rescue resources and procedures across each region. The mean for these pathways was higher than in 2017, showing an increasing trend in perceived organisational performance from 2017 to 2018 for this regional category. However, the mean dropped for each of these pathways in 2019, with a decrease in mean of 1.3 in Pathway 10 in 2019. For the Mid region Pathway 1: Design, engineering, technical and maintenance failure, and Pathway 4: Failures in management systems and hazard management plans had the lowest mean across each of the four regions in for 2017, 2018 and 2019.

In 2018, the North region had the highest mean across each of the 4 regions for Pathways 6: Economic pressures compromising safety and Pathway 10: Emergency and rescue resources and procedures. This indicates that the perceived organisational performance was the highest in this region compared to the other regions for 2018.

In 2019 the overall mean for the Mine region was higher than the other three regions, with Pathway 10 scoring the highest reported mean (M = 8.66) followed by Pathway 5 (M = 8.40) and Pathway 3 (M = 8.38). When comparing this to the data in 2018 and 2017 it indicates that the attendees at the 2 mining sites perceive organisational risk to be the most effective in this region compared to Perth, Mid and North regional categories. Pathway 5 indicated the largest variation in perceived effectiveness of auditing with a mean score of 5.79 in 2017 in the Perth Region and 8.40 in 2019 in the Mines, this suggests that there is a difference in perception between headquarters and those operating at sites.

4.2. West Australian mining industry fatalities profile

A review of the DMIRS Fatalities Register, found 66% of fatal incidents included information regarding multiple Pathways. In contrast, 18% of fatal incidents on the Register included information from just one Pathway. As shown in Table 5, for 15% of fatal incidents, no Pathway could be identified from the data and information from the register. The allocation of Pathways was completed by the authors based on review of the information provided in the Register.

In rank order, the most frequently occurring pathway on the Fatality Register was Pathway 1: design, engineering, technical and maintenance flaws (i.e. 66% of incidents). This was followed by Pathway 4: failures in safety management systems (i.e. 55% of incidents); Pathway 3: failures in risk assessment (i.e. 41% of incidents); Pathway 2: prior warning or causes for alarm ignored (i.e. 39% of incidents); Pathway 5: failures in auditing (i.e. 14% of incidents); Pathway 7: failures in regulatory oversight (i.e. 8% of incidents); Pathway 9: Poor management – worker communication and trust (i.e. 4% of incidents); and Pathway 8: Worker and others expressing concern prior to the incident (1% of incidents). Pathways 6 and 10 were not identified in the Fatalities Register.

4.3. Combining fatality profiles

When combining the results from Phase 1 (questionnaire of employee perception) to Phase 2 (a review of Quinlan Ten Pathways on the Fatalities register) there are 4 pathways that are of interest.

- Pathway 1: design, engineering, technical and maintenance flaws, has the second lowest score from the questionnaire results and is the most common on the fatalities register.
- Pathway 4: failures in safety management systems, was the second most common pathway on the register.
- Pathway 5: failures in auditing, has the lowest score on the questionnaire and is the 5th most common pathway identified on the fatalities register.
- Pathway 9: Poor management – worker communication and trust, was the third lowest mean in the questionnaire.

Based upon the combined assessment it is recommended that these pathways are proactively prioritised by mining organisations. While there were some pathways that were not assessed each year in Phase 1, these pathways were identified on the Fatalities register in Phase 2. Combining the assessments from Phase 1 and Phase 2 not only provided

Table 4
Mean score of perceived organizational risk effectiveness on Quinlan's (2014) Ten Pathways at the 4 Regional Categories

	Perth region			Mid region			North region			Mines		
	2017	2018	2019	2017	2018	2019	2017	2018	2019	2017	2018	2019
Q1	6.23	–	6.02	5.88	–	6.51	6.03	–	6.46	6.45	–	7.13
Q2	6.00	6.99	6.77	6.17	6.68	7.18	5.85	7.00	7.39	6.16	6.63	7.81
Q3	7.76	6.98	7.39	7.34	6.55	7.52	7.63	7.84	7.74	7.57	6.61	8.38
Q4	7.07	7.24	6.63	6.38	6.66	6.76	6.40	6.57	6.68	6.49	6.69	7.32
Q5	5.79	6.65	6.69	5.98	6.32	6.80	5.56	6.26	6.71	6.18	5.94	8.40
Q6	7.44	7.49	6.14	7.42	7.36	6.48	7.16	7.95	6.90	7.49	6.77	7.31
Q7	6.31	–	6.65	6.80	–	7.19	5.89	–	6.97	6.17	–	7.41
Q8	6.97	–	6.48	7.03	–	6.91	6.77	–	6.91	6.83	–	7.30
Q9	5.96	6.90	5.94	6.33	6.55	6.91	6.26	6.95	6.52	5.96	5.38	6.42
Q10	6.67	7.70	6.48	6.78	7.09	6.53	6.74	8.27	6.97	7.61	7.08	8.66

Table 5
Fatalities in the West Australian mining industry between 2000 and 2017 and the Quinlan (2014) Ten Pathways leading to the fatality.

				Quinlan's Ten Pathways									
#	Year	# fatalities	Hazard details from DMIRS Fatalities Register	1	2	3	4	5	6	7	8	9	10
1	2000	1	Mobile crane operator fell from crane deck										
2	2000	1	Load-haul-dump operator sustained crush injury from moving vehicle										
3	2000	1	Haul truck reversed over edge when dumping onto stockpile										
4	2000	3	A fill barricade ruptured causing a slurry inrush	1	2		4			7			
7	2000	1	Drill jumbo operator crushed by rock fall	1		3	4						
8	2001	1	Underground manager struck by lightening		2	3							
9	2001	1	Integrated tool carrier roll over		2								
10	2001	1	Electrocution from live electrical wire during switchboard upgrade	1	2		4						
11	2001	1	Bulldozer went over the edge of pit wall		2	3	4						
12	2001	1	Crush injury sustained when caught in block making machine	1									
13	2001	1	Fall from height	1		3	4						
14	2002	1	Electrocution from live cables during installation of starter box	1						7			
15	2002	1	Ramp collapsed while haul truck traveling and the truck rolled	1		3	4						
16	2003	1	Vehicle runaway causing fatal injuries to diesel fitter	1	2		4						
17	2003	1	Crush injuries sustained from rock fall	1	2		4						
18	2003	1	Worker struck by wheel assembly or tyre parts during inflation	1			4						
19	2003	1	Crush injuries sustained from a vehicle runaway	1									
20	2003	1	Demolition worker fell or was pulled 11m by collapsing structure		2								
21	2004	1	Mechanical fitter crushed between chute and splitter gate	1	2								
22	2004	1	Maintenance worker sustained severe burns from dust/gas explosion	1			4						
23	2004	1	Apprentice struck by torque wrench	1	2	3	4						
24	2004	1	Rope detached causing prospector to fall 25m	1		3							
25	2005	1	Road train driver sustained multiple injuries during a vehicle collision										
26	2005	1	Project manager crushed between two haul truck headboards	1			4						
27	2005	1	Crush injuries sustained from rock fall	1	2	3	4			7			
28	2005	1	Electrocution from contact with live cables during restoration of pump										
29	2006	1	Multiple injuries sustained from projectile exploding in barrel	1									
30	2006	1	Crush injuries sustained in vehicle collision		2								
31	2006	1	Air-leg miner sustained crush injuries from rock fall	1	2		4						
32	2007	1	Transport truck driver sustained crush injuries from falling tyre	1			4						
33	2007	1	An agitator driver lost control of vehicle and struck the side wall										
34	2007	1	Driller offsider struck by sample hose and deflector box	1									
35	2007	1	LHD unit went over the edge of the stope		2	3		5		7			
36	2008	1	Haul truck driver sustained multiple injuries in vehicle collision										
37	2008	1	Crush injury sustained from scissor lift	1		3	4						
38	2008	1	Mobile maintenance supervisor struck by grab-arm	1	2		4						
39	2008	1	Apprentice sustained multiple injuries from vehicle collision	1		3	4	5					
40	2009	1	Fatal injuries sustained from fall from height	1									
41	2009	1	Track maintenance machine operator struck by passing train	1	2	3	4						
42	2009	1	Rigger/scaffolder sustained multiple injuries from fall from height	1	2	3	4					9	
43	2009	1	Heavy duty fitter crushed by bulldozer belly plate	1		3	4					9	
44	2009	1	Serviceman sustained multiple injuries from fall from height	1									
45	2009	1	De-scaler operator sustained multiple injuries from fall from height	1	2	3	4					9	
46	2010	1	Underground loader operator sustained multiple injuries vehicle over edge	1	2	3	4						
47	2010	1	Multiple injuries sustained from fall from height										
48	2010	1	Exploration geologist suffered dehydration from heat exhaustion/exposure		2		4						
49	2010	1	Fitter struck by suspension strut from a sudden release of high-pressure gas	1	2		4						
50	2011	1	Scaffolder drowned from fall from height into sea			3	4						
51	2011	1	Crush injury sustained by moving equipment	1	2								
52	2011	1	Heavy duty fitter crushed by cylinder for loader bucket										
53	2013	1	Crush injuries sustained around moving machinery.	1		3							
54	2013	1	Crush injuries sustained from movement of tailings pipe.			3	4						
55	2013	1	Crush injuries from suspended load when installing operator's cab.	1		3							
56	2014	1	Fall of ground in underground mine.	1		3	4						
57	2014	1	Operator crushed by mast of forklift truck.			3	4						
58	2014	1	Electrician crushed between lift car and lift shaft.	1		3	4						
59	2015	1	Maintenance worker pinned by bulldozer belly plate.	1		3	4						
60	2015	1	A load-haul-dump operator was struck by rolling rock at stope draw point.	1		3	4						
61	2015	1	Underground worker crushed between charge-up basket and roof.	1		3	4						
62	2015	1	Dump truck roll over.										
63	2015	1	Underground operator collapses underground from heat exhaustion.		2								
64	2015	1	Scaffolder falls from height in a process vessel at a refinery.	1	2		4						
65	2016	1	Drill fitter crushed by rod centraliser arm when it moved unexpectedly.	1	2	3	4				8		
66	2016	1	Failed gantry bridge crushes boilermaker working in thickener tank.	1		3							
67	2017	1	Field technician collapsed from heat exposure during exploration activities.		2	3	4						
68	2018	1	CEO fell from truck deck to ground				4						
69	2018	1	Surveyor had an anaphylactic response to a bee sting										
70	2018	1	Crush injuries sustained by moving machinery	1									
71	2018	1	Multiple injuries sustained from a vehicle accident	1									

Note. The shaded areas of the Table indicate no Quinlan pathway found in the information for that entry on the Register.

insight into employee's perception and common pathways identified on the Fatalities Register, it also assisted the authors in resolving some of the gaps in data to provide both a qualitative and quantitative assessment of fatality prevention using the Quinlan Ten Pathways.

5. Discussion

This study has suggested several priorities for improving fatality risk management and safety performance using the Quinlan Ten Pathways

(2014). The questionnaire detected differences in each of the ten pathways, over time and in different locations, and therefore we expect it could be useful at an organisational level. We expect that if the questionnaire was used within one organisation there would be a reduction in the variance we have seen, which we consider was due to the small number of people from each organisation (i.e. relative to the number at each location), and the diversity of organisations which took part in the surveys.

Based upon the ranking of mean scores by year and the frequency of the Quinlan Ten Pathways from the Fatalities Register we suggest that West Australian mining organisations should focus on the following Pathways:

- Pathway 1: Design, engineering, technical and maintenance flaws
- Pathway 4: Failures in safety management systems
- Pathway 5: Failures in Auditing
- Pathway 9: Poor management – worker communication and trust

Organisations outside of Western Australia should rank the Quinlan Pathways to their internal equivalent to the Fatality Register (i.e. register which details the causes of incidents) and administer the Quinlan survey, this can assist organisations in identifying which of the Quinlan Ten Pathways are the greatest contributors to fatalities in their region.

Although the questionnaires results are representative of the Western Australia's state mining industry, the results are not wholly applicable to a single organisation or site. Pathways 1 and 4 were also frequently identified as pattern failures in Quinlan's systematic assessment across mining fatalities across 5 countries (Quinlan, 2014). This suggests that globally, organisations often have improvement opportunities in safe design and management systems.

5.1. Informing performance improvement

The mean scores for the Quinlan Ten Pathways for 2017 to 2019 ranged from 5.82 to 7.80 out of 10. These scores suggest the States mining organisations are addressing the Ten Pathways to some degree. We suggest that it would be challenging to achieve a 10 out of 10 for the Pathways across the State of Western Australia, the four regions or in an organisation. However, if the sharing of lessons learnt via the Quinlan Ten Pathways is a useful approach to risk reduction, progression towards 10 may contribute to an improvement in fatality prevention. We recommend that organisations familiarise themselves with Quinlan's Ten Pathways and use their employee's perception of their effectiveness in the Pathways to inform their safety improvement plans.

Further use of the questionnaire and mapping to a Fatality Register, or similar organisational information, may also indicate an "acceptable" level of risk which could be defined as when the perception of effectiveness is high compared to last year and the frequency each Pathway occurs in incidents is low.

5.2. Auditing: Pathway 5

Quinlan (2014) suggested auditing of safety management systems should be an independent process conducted by a qualified person, it should assess the whole system and its performance against the Ten Pathways. Failures in auditing (Pathway 3) had the lowest mean score from the questionnaire for all 3 years. Considering the importance of auditing to the continuous improvement of the safe system of work, we suggest organisations review the effectiveness of this Pathway, for example improving communication around the auditing process and their outcomes. Since there did not appear to be a difference in the responses across roles it appears communication of auditing results across all stakeholders would be beneficial. An audit finding and associated actions should give people a clear justification and highlight the benefit for change, which may assist improvement if people are otherwise reluctant to change (Ford, Ford, & D'Amelio, 2008). It is suggested that organisations adopt the Plan, Do, Check, Act model (International Organization for Standardization, 2018), with auditing to ensure there is continuous improvement and communication being disseminated to all stakeholders.

5.3. Leadership: Pathway 2, 8, 9

The International Organization for Standardization (2018) Occupational Health and Safety standard stresses the importance of the leadership team's commitment to safety. As the responses to Pathway 9: Poor management – worker communication and trust were perceived to be low by employees, it appears further engagement, consultation, listening to warning signs (Pathway 2) and management-worker communication and trust (Pathway 8 and 9) in the mining industry may improve the scores in these Pathway.

In most cases, respondents with leadership roles (i.e., superintendent/manager) scored their organisations performance higher on pathways than those in front line roles (e.g. employees). Supervisors/managers scored significantly higher on Pathways 1, 6, 7, 8 and 9 (i.e. maintenance and design, prioritising safety, adequate number of Government inspectors, health and safety issues addressed in a timely manner, worker-management relationship). This suggests communication and cultural issues, highlighting potentially dangerous gaps between employee expectations of management (e.g. to prioritise their safety) are a reality. It also reflects the significant difference between the two employment levels in Pathway 9: Poor management – worker communication and trust. Additionally, those in leadership roles, perceived a better worker relationship compared to employees in the front line. It is suggested that West Australian mining organisations ensure systems and processes are in place to foster a collaborative and transparent work environment.

Significant differences were observed between the Perth and other regions for Pathway 7, 8 and 9 (prioritising safety, adequate number of Government inspectors and worker-management relationships). Regional attendees scored significantly lower than the Perth region personnel possibly indicating a disconnect between operating site and head office, which reflects the significant difference found in Pathway 9: Worker-Management relationship, possibly illustrating a difference between work as planned by the corporate office, versus, work as done by the operations.

5.4. Quinlan's Ten Pathways in past fatalities

Quinlan (2014) observes that most of the catastrophic incidents reviewed to inform the Ten Pathways comprised multiple pathways, although no single incident included all pathways.

Pathways 1 to 4 were the most-commonly identified in the DMIRS Fatality Register, with Pathways 5, 7, 8 and 9 appearing sporadically, and Pathway 6 and 10 not appearing in any of the West Australian fatalities. Whilst these differences may indicate priorities for action, we suggest organisations address all, in particular as they were developed from actual fatalities.

Pathways 6, 8 and 10 rarely appeared or did not appear in any of the fatalities reported on the DMIRS Fatality Register. We suggest that this may be a result of data on these pathways is not captured as part of the Fatality Register assessment and that they are contributing to fatalities.

Research into the impact of economic cycles on safety performance has identified that injury rates in the mining industry increase during economic growth within Western Australia (Jenke et al. (2021). This suggests that as increased demand for production occurs occupational injury rates increase, however it is possible that an external view of fatalities is not recorded as part of the Fatalities register and thus not captured. It is recommended that both external and internal factors are assessed with investigating fatalities. Moreover, the reporting process does not require this information to be included, therefore, it is unlikely this information would be reported in the Fatalities Register even if it

were a contributory factor. This information would need to be obtained from other sources such as the Coroner's Report to confirm West Australian mining organisations perform these Pathways well.

Given that four Pathways were most prominent in the DMIRS Fatalities Register and the remaining six were not, it is argued that the type of information required for reporting does not require an organisation to publicly address all Ten Pathways. It is recommended that reporting include a mechanism for addressing all Ten Pathways, so that other organisations can effectively learn from past fatal incidents. Brady (2019) suggested that in order for the Queensland mining industry to decrease fatalities identification and control of hazards is crucial, these correspond to Pathways 1–4.

5.5. Limitations and future direction

There are some limitations to this study. Firstly, the number of Pathways that were examined in the questionnaire in 2017, 2018 and 2019 were different. Specific pathways were removed due to time constraints, limiting our ability to compare the results for all Ten Pathways across the year. To address this, results were not averaged over the three years to prevent skewing of results. We recommend future studies address this issue to provide a better understanding of industry performance on all common causes of fatalities. Secondly, while the perceptions of Health and Safety Representatives of their employers' effectiveness to control fatalities are an indicator worth investigating, they are not an absolute measure of an organisation's safety performance. We recommend that future studies continue to monitor perceived effectiveness of control over time to gain a better understanding of trends in safety performance, which would enable organisations to benchmark their performance against industry performance. Finally, an assessment of the Fatalities Register indicated that no fatality contains all Ten Pathways, and further investigation is suggested to define how the fatality register is compiled and understand the additional contributing factors to fatalities.

6. Conclusion

This study sought to assist the West Australian mining industry in learning from past fatalities and provide direction for controlling fatality risks in their facilities and operations. Overall, the perception of those working in the mining industry indicate West Australian mining organisations moderately control (i.e. scored between 5 and 7 out of 10) risks associated with Quinlan's Ten Pathways. It is argued that communication and improvement in safety leadership and culture could assist in the efficacy of safety controls implemented in the mining industry. The simplicity of the Ten Pathways makes them a valuable risk communication tool, and could readily be used to commence discussions, for example at safety meetings, or implemented in a reporting tool to allow for more effective safety learnings, it could also be used as a self-audit tool or an internal company assessment to benchmark against the findings published in this study.

Declaration of Interests

Martin Ralph and Andrew Chaplyn developed the concept of using Quinlan's 10 pathways at the Mines Safety Roadshows. DMIRS provided funding to Marcus Cattani to investigate safety knowledge at the Mines Safety Roadshows. Martin Ralph and Andrew Chaplyn gave permission for their work to be added to the funded project.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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