ENGINEER - Vol. LVI, No. 02, pp. [77-86], 2023

DOI: https://doi.org/10.4038/engineer.v56i2.7577

Building a Proactive Safety Culture in Tunnel Construction Industry - Sri Lanka

S.W. Seneviratne, G.K.P. Wickramasinghe and R.D.D. Dayawansha

Abstract: Significant safety challenges can arise at tunnelling works as they are conducted in semi-enclosed environments. This study aimed to develop a safety risk assessment framework for drill and blast tunnel construction in Sri Lanka. Tunnelling expert surveys in three sites were used for collecting the necessary data. Initially, a Risk Score Analysis was conducted to identify the critical hazardous events. They were identified as: direct spraying of concrete on eyes and skin, being exposed to noxious dust, and constant exposure to noxious noise. A Bow Tie Analysis was conducted to analyse each critical hazardous event, identifying their causes, preventive measures, recovery measures, and consequences. A probability-based Event Tree Analysis that shows all possible outcomes following the success or failure of protective barriers was also conducted. For example, according to the event tree analysis of 'direct spraying of concrete on eyes and skin,' there is an overall probability of 19.1% such that significant consequences could be prevented. The research has justified the practicality of these risk analyses for drill and blast tunnelling sites. Also, recommendations are provided for the contractors and workers targeting continuous improvement of safety provisions at tunnelling sites.

Keywords: Tunnel safety, Drill and blast method, Risk score analysis, Bow tie analysis, Event tree analysis

1. Introduction

Tunnel construction is one of the world's most advanced fields of subsurface construction. However, tunnel construction works lead to serious safety challenges due to the activities conducted in a semi-enclosed environment [1]. Even with technological advancements, the possibility of experiencing a hazardous nature by a human during tunnelling work is higher. According to previous research studies conducted in Japan, tunnel construction has contributed 2% to the fatalities during construction work [2]. Safe practice of tunnel construction has been quite challenging, especially in difficult ground conditions. Therefore, the effective implementation of safety provisions at the workplace has become a significant concern for the tunnel construction industry [3].

In the Sri Lankan context, the most commonly practiced tunnelling method is the drill and blast method. Many research studies have been conducted on tunnelling work in foreign countries such as Turkey, Japan, Nepal, Pakistan, and China [4], [5], [6]. Nevertheless, there have been only a few research studies conducted on tunnel construction in Sri Lanka [7], [8]. However, there has been no research on tunnel construction safety and risk assessment in Sri Lanka. This research is mainly focused on the analysis of how hazardous events could be recognized through a systematic approach to risk assessment and how to come up with preventive and protective measures to eliminate or minimize the hazardous potential leading to an accident.

The overall research study aims to establish a safety risk management framework in the tunnel construction industry in Sri Lanka. The specific objectives are to identify the critical hazardous events that could occur during drill and blast tunnel construction and to conduct qualitative and quantitative risk analyses using the Bow-Tie and Event Tree analysis techniques.

Eng. (Dr.) S.W. Seneviratne, *AMIE (SL), PhD (Calgary), MSc(AIT), BSc Eng(Hons) (Ruhuna), Senior Lecturer in Civil and Environmental Engineering, University of Ruhuna, Sri Lanka*
Email:samanthi@cee.ruh.ac.lk
https://orcid.org/0000-0003-4933-6499
Mr. G.K.P. Wickramasinghe, *Undergraduate Student in Civil and Environmental Engineering, University of Ruhuna, Sri Lanka*
Email:gkalanaprabhath97@gmail.com
https://orcid.org/0000-0002-7260-3754
Eng. R.D.D. Dayawansha*, CEng, MIE(SL), BSc Eng(Hons) (Ruhuna), Civil Engineer, Ceylon Electricity Board*
Email:rdddayawanssa@yahoo.com
https://orcid.org/0000-0002-4255-4154

The practicality of these risk analysis techniques in the Sri Lankan tunnel construction industry is considered while conducting this research study. Given the growing number of construction projects involving tunnel construction in Sri Lanka, conducting this research study is timely. This research can be used as a reference to implement a safety risk management framework in the tunnel construction industry in Sri Lanka.

2. Literature Review and Risk Score Development

According to Occupational Safety and Health Administration (OSHA) Standards for underground construction (tunnelling), a 'tunnel' is defined as "an excavation beneath the surface of the ground, the longer axis of which makes an angle not greater than 20 degrees to the horizontal "[9]. Basic types of tunnel construction in everyday use can be listed as: cut-and-cover tunnels, drill and blast tunnels, bored tunnels using Tunnel Boring Machines (TBM), soft ground tunnels and so on [3].

Sri Lanka, as a country bearing a precious history of ancient Civil Engineering practices, it is evident that the construction of tunnels had been practiced mainly for irrigation purposes. Despite the modern developments of tunnelling technologies, such as bored tunnelling using TBMs, the drill and blast method has been used in Sri Lanka for many tunnelling works as an economical method of tunnelling. Furthermore, the drill and blast method is better for complex geological conditions with zones of disturbances [9], generally experienced in underground tunnelling in Sri Lanka.

Due to the semi-enclosed nature of drill and blast construction, workplace safety is one of the most important aspects to consider in this hazardous Environment. Safety is an investment that provides tangible benefits in a high-hazard industry like tunnel construction. A 'proactive safety culture' is identified as a strategy of planning operations, discussing and assessing hazards and risks prior to taking actions, enhancing safe operations among workers, and facilitating these operations to be performed most safely. This intervention ensures that the likelihood of an accident can be minimized [5], [11].

2.1 Risk

A risk is a combination of the frequency of occurrence of a defined hazard and the likelihood of the consequences of the occurrence. A risk management process for the construction industry typically comprises the establishment of context, risk identification, risk analysis, risk evaluation, and risk response [12].

Risk analysis methods are either qualitative or quantitative. A quantitative risk analysis is based on a pre-defined risk rating scale which indicates the risk's effect and weight as a numerical representation. In contrast, qualitative risk analysis includes the categorization of risks, either source based or effect-based, and provides a qualitative approach to making decisions where there is uncertainty. Some commonly used qualitative risk analysis methods in the construction industry are Bow-Tie Analysis, What–If Analysis, Checklists, and Safety Flowcharts. Furthermore, the most commonly used quantitative risk analysis methods are Event Tree Analysis (ETA) and Failure Modes and Effects Analysis (FMEA) [1], [13].

2.2 Risk Score Development

Risk scoring is a process of calculating a score to help determine the risk level based on the factors such as the severity and likelihood of a hazardous event. The risk score value for a considered hazardous event that can occur at the work site is calculated as shown in Eq. (1) [1].

$$\textit{Risk Score} = \textit{Severity Rating} \times \textit{Likelihood Rating} \quad (1)$$

The hazard severity ratings (level of damage or harm a hazard could create) and likelihood ratings (the possibility of a potential risk occurring) were developed based on a literature review [1], [13]. They were presented to tunnelling experts in Sri Lanka, including tunnel consultant engineers, site engineers, occupational safety and health officers, and tunnel geologists. In-depth discussions with these experts were considered in revising and validating the scales according to the Sri Lankan context, as presented in Table 1 and Table 2. For example, in the likelihood classification, experts were advised to follow the likelihood rating concerning the occurrence probability for each activity. A non-linear scale that assures higher likelihood levels have higher occurrence probabilities was introduced after expert consultation.

According to these severity and likelihood ratings, the Risk Score Matrix was generated, as shown in Table 3. For example, a risk with a severity rating of 04 (critical severity level) and a likelihood rating of 03 (occasional likelihood) has a risk score of 12. Here, a colour coding of light yellow, yellow, orange, and red has been introduced to indicate the increasing level of hazardous nature from slight, marginal, and moderate to critical levels. The average risk score value ranges and the decision criteria were introduced following the literature [1], [13] and validated under expertise consultation, as shown in Table 4. According to the generated risk score matrix and the decision criteria, the hazardous events experienced in tunnel construction can be rated with the participation of tunnelling experts.

Table 1 - Hazard Severity Ratings

Description	Rating	Definition
Slight	01	Slight injury, slight occupational illness
Marginal	02	Minor injury, minor occupational illness
Serious	03	Moderate injury, moderate occupational illness
Critical	04	Severe injury, severe occupational illness
Catastrophic	05	Loss of life (Fatal consequences)

Table 2 - Hazard Likelihood Ratings

Description	Rating	Definition
Very unlikely	01	0-5% of occurrence probability while conducting the activity
Remote	02	5-20% of occurrence probability while conducting the activity
Occasional	03	20-40% of occurrence probability while conducting the activity
Probable	04	40-65% of occurrence probability while conducting the activity
Frequent	05	65-100% of occurrence probability while conducting the activity

Table 3 - Risk Score Matrix

Risk Score Factors	Slight (01)	Marginal (02)	Serious (03)	Critical (04)	Catastrophic (05)
Very unlikely (01)	01	02	03	04	05
Remote (02)	02	04	06	08	10
Occasional (03)	03	06	09	12	15
Probable (04)	04	08	12	16	20
Frequent (05)	05	10	15	20	25

Table 4 - Average Risk Score and Decision Criteria

Average Risk Score (X)	Effect to the System	Decision Criteria
$X = 1$	Slight	There is significantly less damage or effect on the continuation of the project work. It is optional to save the records of activities.
$01 < X \leq 06$	Marginal	Here, the event's effect on the overall project continuation is lower. However, it needs to be considered as a primary concern of safety.
$06 < X \leq 12$	Moderate	There is a significant effect of the event on the overall project continuation. Necessary measures need to be carried out to decrease the determined risks.
$12 < X \leq 20$	Unacceptable	The operation should be stopped, and the risk should be reduced to an acceptable level. The recovery measures need to be implemented as soon as possible.
$20 < X \leq 25$ Critical	Intolerable Region	Immediately stop operations and rectify until the risk is reduced to an acceptable level. Immediate recovery measures need to be implemented. If the outcome is far worse, the work may be precluded.

2.3 Bow Tie Analysis

Bow Tie analysis is a graphical representation of the causes, preventive measures, recovery (protective) measures, and consequences of a hazardous event. A hazardous event termed a 'top event' is located at the centre, and causes and consequences are listed on either side of the Bow Tie diagram, as seen in Figure 1.

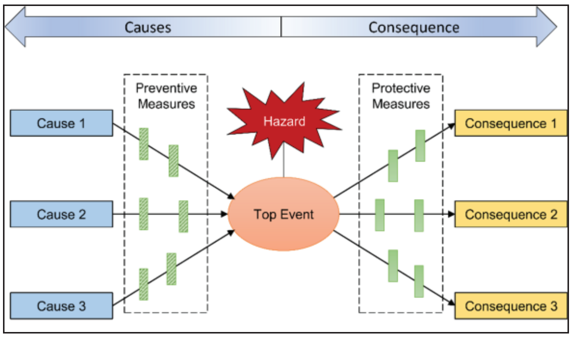

Figure 1 - Bow Tie Analysis Diagram
Source [13]

A Bow Tie diagram can identify the risks simultaneously, listing the causes and consequences of hazardous events in the drill and blast tunnelling industry [13].

2.4 Event Tree Analysis

Event Tree analysis [14] is a probability-based quantitative approach to analyse the consequences of a system failure due to a top hazardous event while providing the recovery measures or protective barriers which can be undertaken to mitigate the damage (Figure 2).

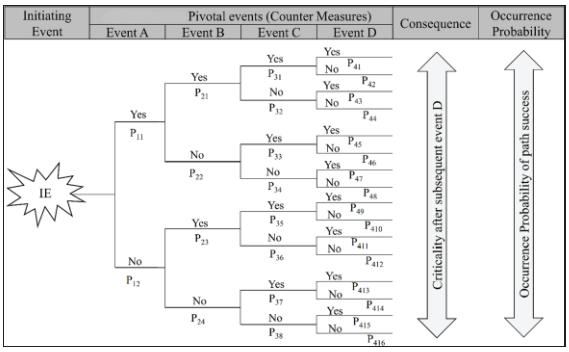

Figure 2 - Event Tree Analysis (Source [13])

Here, the initiating event (IE) can be related to the 'Top Event' of the Bow Tie diagram in Figure 1. Moreover, its pivotal events (countermeasures or barriers), which protect the IE from occurring, are considered for developing the event tree [13]. The event tree is a detailed quantitative analysis of the right side of a Bow-Tie diagram developed for a particular hazardous event.

3. Materials and Methods

Three case study sites undergoing drill and blast tunnel construction in Sri Lanka were selected, namely: Broadlands hydropower project-Kitulgala, (BHP) Kaluganga-Moragahakanda transfer canal project-Laggala (KMTC) and the North Western canal project-Galewela (NWC). Expert consultation via interview sessions, surveys (Expert Surveys I, II, and III), and discussions with workers during field visits were utilized in collecting the necessary data. The overall methodology is presented in Figure 3.

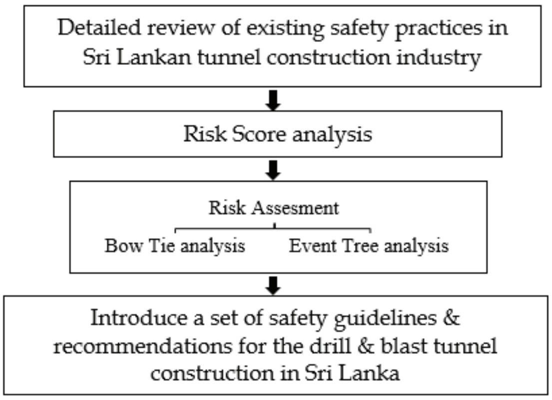

Figure 3 - Methodology of Data Analysis

During initial field visits, tunnelling experts were involved in refining and validating the hazard severity scale, hazard likelihood scale, and risk score decision criteria.

The tunnelling experts were presented with a hazard likelihood and hazard severing ratings with identified 53 hazardous events that could occur during drill and blast tunnelling. This event list included the work categories of drilling, blasting, excavation, mucking, rock scaling, tunnel lining, shotcreting, grouting, and axillary work. A section of the survey (Expert Survey I) is given in Figure 4.

Tunnelling experts were asked to give rating values for hazard severity and hazard likelihood of each hazardous event listed. The 'Purposive Sampling' method, in which tunnelling experts can introduce other tunnelling experts for the survey, was used to find respondents. Five to seven experts from each site participated in this survey and, the average risk score value for a particular hazardous event was calculated by taking the risk score values from all the experts' responses for that event. According to the survey responses, the hazardous events with greater risk score values were identified as the critical ones.

QUESTIONNAIRE SURVEY

Accidents (Hazardous Events) Occurred in Drill & Blast Method of Tunnelling in Sri Lanka

Note: Kindly fill the Table of Expert Details, prior to the Questionnaire Survey.

EXPERT DETAILS

Expert Name	Experience in Tunnel Project(s)	Position	Duration (yrs)
	1)		
	2)		
	3)		

KEY FOR THE QUESTIONNAIRE SURVEY

Hazard Likelihood Ratings

Description	Definition
Very unlikely (1)	0-5% of occurrence probability while conducting the activity
Remote (2)	5-20% of occurrence probability while conducting the activity
Occasional (3)	20-40% of occurrence probability while conducting the activity
Probable (4)	40-65% of occurrence probability while conducting the activity
Frequent (5)	65-100% of occurrence probability while conducting the activity

Likelihood Severity

Hazard Severity Ratings

Description	Definition
Slight (1)	Slight injury, slight occupational illness
Marginal (2)	Minor injury, minor occupational illness
Serious (3)	Moderate injury, moderate occupational illness
Critical (4)	Severe injury, severe occupational illness
Catastrophic (5)	Loss of life (fatal consequences)

SURVEY FORM

Please put a ✓ on the relevant check box for each event with respect to their likelihood **and** severity.

Activity	Hazardous Events	Likelihood					Severity				
		Very unlikely [1]	Remote [2]	Occasional [3]	Probable [4]	Frequent [5]	Slight [1]	Marginal [2]	Serious [3]	Critical [4]	Catastrophic [5]
Drilling	Constant exposure to noxious noise										
	Being exposed to noxious dust										
	Contact with abrasive minerals in the course of drilling										
	Meeting the hydrated layers and or drilling underground water table										
	Exposure to whole-body or hand–arm vibration resulting from the use and/or operation of tools, plant and machinery										
Blasting	Misfire										
	Unexpected blasting during transportation of explosives										
	Direct contact with blasting earth materials on eye and body										
Excavation	Difficulties due to varying air pressure (Hyperbaric atmosphere)										
	Work under excessive heat and humidity										
	Constant exposure to toxic gases such as CH4 & H2S										
	Contact with irritating and allergic construction materials										
	Respiratory issues due to Oxygen deficiency inside the tunnel										
	Exposure to radiation										
	Sudden ground collapse (Rock bursting)										
	Meet with unforeseen adverse ground conditions										
	Contact with contaminated water and soil										
	Inundation while tunnel construction										
	Falling from height										
	Falling at the level (slips & trips)										
	Falling of objects from height										
	Collapses of stacks, scaffoldings and supports										
	Musculoskeletal injuries										
	Allergies, skin problems										
	Heat stress and exhaustion										
	Snake, Bat biting										
Mucking work	Fall of mucking load on the workers.										
	Being struck or crushed by vehicle										
	Falling down from vehicle										
Rock scaling	Direct contact of scaled rocks on eye and body										
	Falling from stacks and support										
	Injuries occurred using cutting tools										
Tunnel Lining Work	Failures of arch and mesh installation										
	Injuries while welding and cutting										

Figure 4 – A Section of the Questionnaire Survey for Risk Score Analysis (Expert Survey I)

4. Results and Discussion

4.1 Risk Score Analysis Results

The risk score analysis results indicating the critical hazardous events with the highest risk score values in the case study sites are mentioned in Table 5.

Table 5 - Risk Score Analysis Results

Critical Hazardous Event	Average Risk Score		
	BHP	KMTC	NWC
Being exposed to noxious dust	12.5	13.0	12.6
Constant exposure to noxious noise	12.3	13.4	13.0
Direct spraying of concrete on eyes and skin (during shotcreting)	12.3	13.6	12.2

These critical hazardous events have a more significant effect on workplace safety in drill and blast tunnelling sites. All three case study sites have them as the top three critical hazardous events. Post-survey discussions with the experts and the labourers in the case study sites revealed that those are the events they mainly face during drill and blast tunnelling work. Given the existing tunnelling safety implementations by the contractor and 'unacceptable' and 'intolerable' events that lead to a shutdown of operations experienced in day-to-day tunnelling works are minimal. The risk score analysis has revealed the hazardous events experienced in the everyday work environment of a tunnelling site.

Unlike modern TBM technology, drill and blast tunnelling involve highly labor-intensive cycle works with low levels of automation and mechanized processes. With these conditions, drill and blast tunnelling sites suffer from poor work environments in which critical hazardous events mentioned in Table 5 are inevitable [1],[10].

4.2 Bow Tie Analysis Results

A graphical analysis of the critical hazardous events via a Bow Tie analysis was conducted for each critical hazardous event mentioned in Table 5. Here, both information obtained via literature review and the discussions with tunnelling experts have been incorporated in developing a Bow Tie Diagram for each critical hazardous event. A Bow Tie diagram for the analysis conducted for the critical hazardous event 'direct spraying of concrete on eyes and skin (during shotcreting)' is shown in Figure 5.

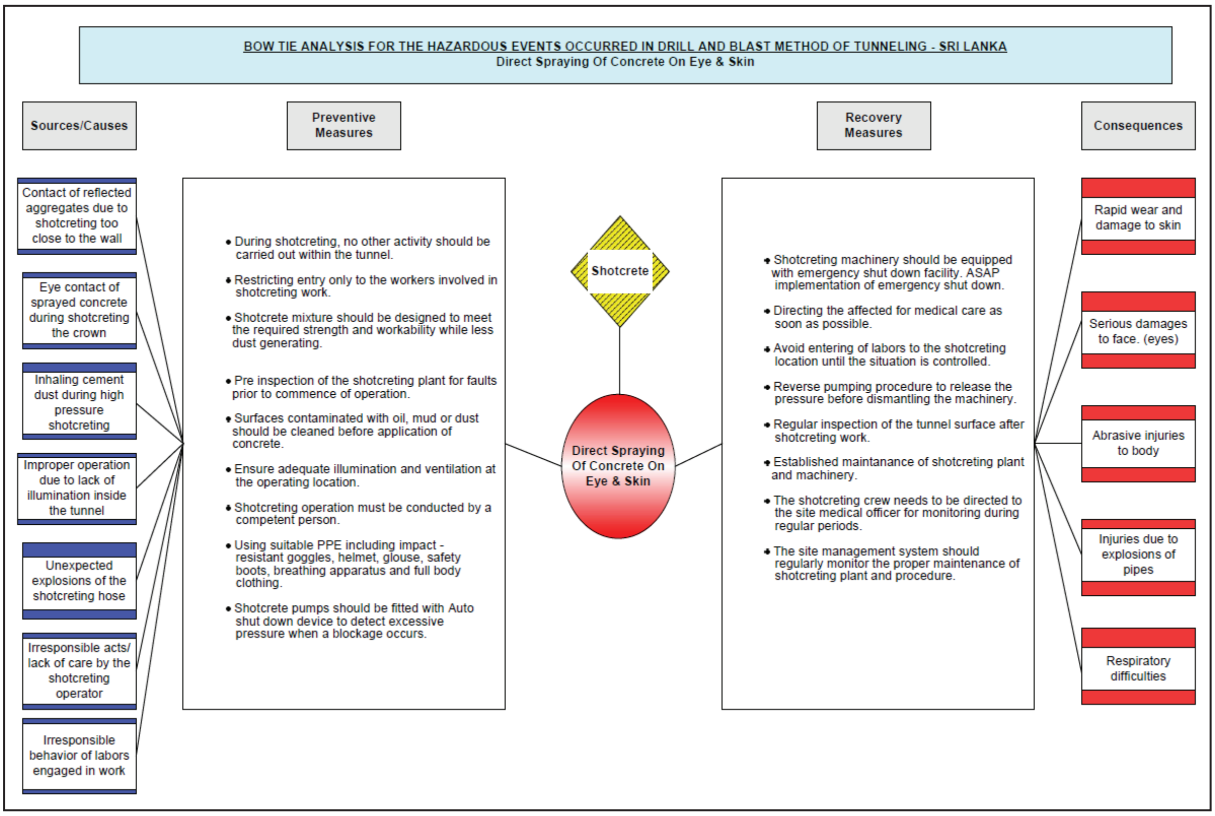

Figure 5 – Bow Tie Analysis for 'Direct Spraying of Concrete on Eyes and Skin'

The Bow Tie analysis model for the critical hazardous event 'direct spaying of concrete on eyes and skin' is illustrated in Figure 5. Here, a set of preventive measures that can be taken at the project site proactively and, recovery measures that can be taken to minimize the consequences in the event of an accident have been listed. When the soil surface of the tunnel is weak, or there is a necessity to support the ground due to higher water inrush (inundation), shotcreting of the surface is very important to stabilize the tunnel and prevent ground collapse. However, this labour-intensive activity of shotcreting should be carried out with great attention to preventive measures and recovery measures to reduce the possibility of accidents during the commencement of this activity [15].

These Bow Tie analysis models can be demonstrated at the project site, site office, and safety meetings. They can be explained to all the parties involved in tunnelling work to make them aware of what hazardous events to expect during each activity and how preventive measures and recovery measures can be taken to minimize or, if possible, eliminate the exposure to hazards by the workers. With a clear idea taken from Bow tie, the workers are aware of the causes of any accident, how to minimize them, and the consequences they face if protective and recovery measures are not taken when carrying out each tunnelling activity. This practice develops a culture for the workers to go inside the tunnel with greater attention, awareness, and concern. Hence, the Bow Tie analysis is a practical example of graphically illustrating the importance of a proactive safety culture in the tunnelling industry.

4.3 Event Tree Analysis Results

With the expert consultation and referring to literature, four of the most effective barriers were recognized per each critical hazardous event in the sequence they will be activated in preventing accidents due to the particular hazardous event. They were presented to the tunnelling experts to obtain each barrier's success probability in preventing an accident that could happen due to a critical hazardous event (Expert Survey II). A section of a survey form for the critical hazardous event 'direct spraying of concrete on eyes and skin' is available in Figure 6, and the results are available in Table 6. The event tree analysis was developed taking all the combinations of successes or failures of each barrier into account as presented in Figure 7.

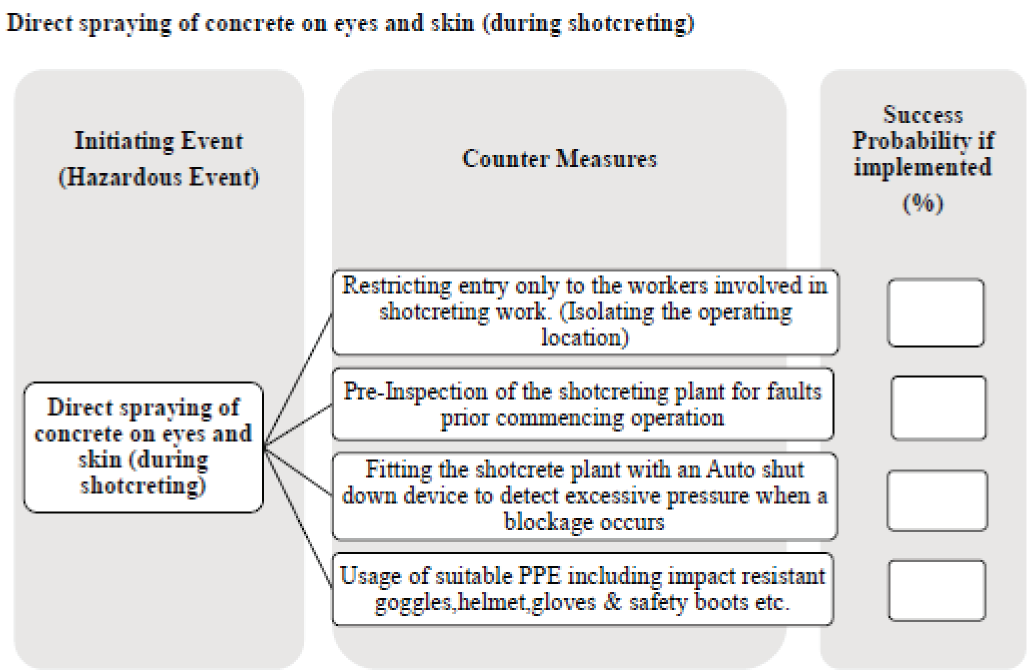

Figure 6 – A section of the Survey to obtain Probabilities (Expert Survey II)

Table 6 - Countermeasures (Barriers) and the Average Probability of Prevention of an Accident

Critical Hazardous Event	Countermeasures (Barriers)	Average Probability of Prevention (%)
Direct spraying of concrete on eyes and skin	Barrier (I) Restricting entry only to the workers involved in shotcreting work (isolating the operating location)	85
	Barrier (II) Pre-inspection of the shotcrete plant for faults prior to commencing operation	78
	Barrier (III) Fitting the shotcrete plant with an Auto shut down device to detect excessive pressure when a blockage occurs	72
	Barrier (IV) Use suitable personal protective equipment (PPE), including impact-resistant goggles, helmets, gloves, and safety boots	82

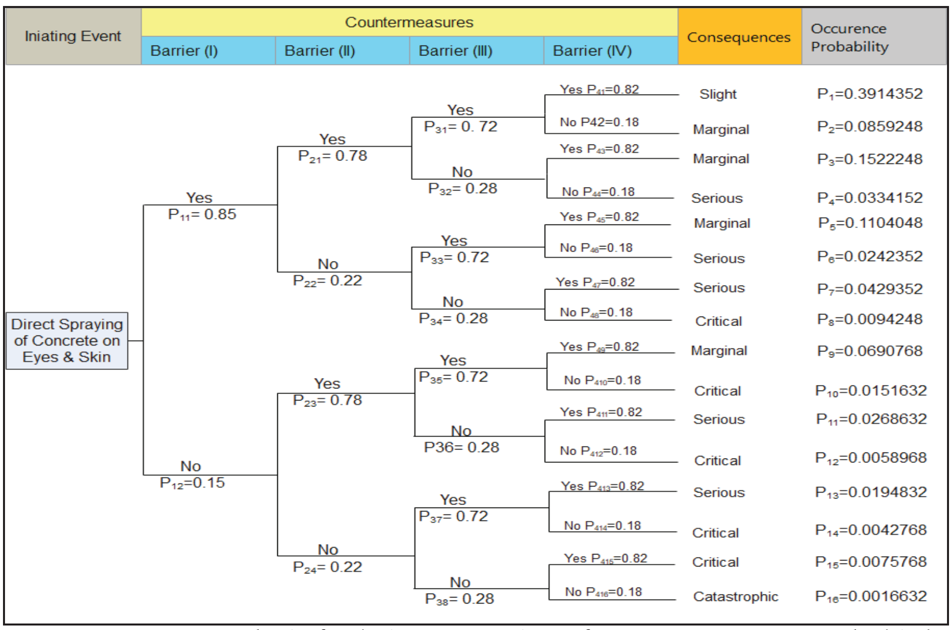

Figure 7 - Event Tree Analysis for 'Direct Spraying of Concrete on Eyes and Skin'

Table 7 – A Section of the Survey Conducted to Obtain Consequence Levels for each Path of the Event Tree Analysis (Expert Survey III)

1) Direct spraying of concrete on eyes and skin (during shotcreting)

Counter measure implemented (YES/NO)				Severity of consequences				
Restricting entry only to the workers involved in shotcreting work. (Isolating the operating location) (Average Prevention Probability = 85%)	Pre-Inspection of the shotcreting plant for faults prior commencing operation (Average Prevention Probability = 78%)	Fitting the shotcrete plant with an Auto shut down device to detect excessive pressure when a blockage occurs (Average Prevention Probability =72 %)	Usage of suitable PPE including impact resistant goggles, helmet, glove & safety boots etc. (Average Prevention Probability =82 %)	Slight	Marginal	Serious	Critical	Catastrophic
YES	YES	YES	YES	✓				
YES	YES	YES	NO		✓			
YES	YES	NO	YES		✓			
YES	YES	NO	NO			✓		
YES	NO	YES	YES		✓			
YES	NO	YES	NO			✓		
YES	NO	NO	YES			✓		
YES	NO	NO	NO				✓	
NO	YES	YES	YES		✓			
NO	YES	YES	NO				✓	
NO	YES	NO	YES			✓		
NO	YES	NO	NO				✓	
NO	NO	YES	YES			✓		
NO	NO	YES	NO				✓	
NO	NO	NO	YES				✓	
NO	NO	NO	NO					✓

It has taken the success probability of each barrier (p) into account in the 'Yes' branch, while the failure probability derived (1-p) is indicated in the 'No' branch. The occurrence probability is the multiplication of all the probabilities in the path. Each of the 16 paths leads to a consequence level of slight, marginal, serious, critical, or catastrophic level. These consequence levels for each branch of the event tree, consisting of each countermeasure implemented or not (YES/NO) situations, were determined through a survey of tunnelling experts (Expert Survey III), as indicated in Table 7. Three tunnelling experts gave their judgment on the consequence level of each path. They were averaged to get the closest consequence levels for each path. According to this analysis, in the event of successfully implementing all the barriers, there is a high probability of preventing an accident related to shotcreting activities (0.391). As revealed by the experts, the average consequence level is 'slight' as shown in the top branch of the event tree in Figure 7 and the top row in Table 7. In contrast, in the absence of all the barriers, the probability of preventing an accident is very low (approximately 0.002). This situation can lead to a 'catastrophic' consequence due to a fatal accident.

The sum of the occurrence probability values of paths having 'slight', 'marginal', 'serious' 'critical', 'catastrophic' levels of consequences have been summarized in Table 8. Here, adhering to expert consultation, the paths with serious, critical, and catastrophic consequences were considered to have 'significant' consequences due to a critical hazardous event at tunnelling work, as highlighted with a red colour margin.

Table 8 - Sum of Occurrence Probability Values for each Consequence Level of Direct Spraying of Concrete on Eyes and Skin

Consequence	Overall Probability of Prevention of an Accident
Slight	0.391
Marginal	0.418
Serious	0.147
Critical	0.042
Catastrophic	0.002
Significant Consequence Probability =0.191	

According to this recognition, there is an overall probability of only 19.1% that significant consequences could be prevented in a drill and blast tunnelling site where some of the above-mentioned four barriers are unavailable. This finding alarms the importance of having more barriers so that the significant consequences of shotcreting related accidents could be minimised even if some of the barriers will not work for some reason.

5. Discussion

The risk score, as a numerical measure calculated considering the severity and likelihood of occurrence of a hazardous event, helps determine the risk level related to the occurrence of an accident. The risk scoring and decision criteria development resulted from a participatory exercise conducted with tunnelling experts. Validation of the risk scoring and decision criteria was done utilizing their experience and wisdom.

The Bow Tie method provides a detailed visualization of the preventive and protective measures for a particular hazardous event. Bow Tie diagrams can be utilized to educate workers. Also, a detailed Bow Tie diagram can be used as a protocol in safety auditing works.

The Event tree analysis can be recognized as a forward-thinking process that indicates the gravity of the safety functions implemented to reduce the unfavorable consequences of a hazardous event. It is a probabilistic approach that can be further developed by adding countermeasures. Also, the weaknesses of the safety system (countermeasures having lesser prevention probability values) can be identified, and appropriate actions can be taken proactively. Despite these advantages, there can be issues regarding the success probability values of the countermeasures as they are subjective to the experts' experience. Hence, averaging the probability values taken from several tunnelling experts is recommended.

6. Recommendations

Based on tunnel safety literature, including the British standards for tunnel safety (BS6164-Health and Safety in Tunnelling in the Construction Industry) [3], and experts' opinions, recommendations are provided to improve safety in drill and blast tunnelling sites.

6.1 Recommendations for the Contractors

Contractors are recommended to establish security, safety measures, and health controls necessary for the safe execution of drill and blast tunnel construction work [12]. Especially the contractor should appoint a safety officer responsible for ensuring safety at the workplace [15]. The safety officers can be advised to conduct detailed risk analyses [16] [17] and maintain 'live' risk registers which are continuously reviewed and revised as appropriate in order to come up with preventive and recovery measures to help mitigate the accidents [18]. An adequately maintained safety register, including the daily reports of injuries and incidents, should also be a mandatory responsibility of the contractor [11]. As highlighted by tunnelling experts, information on the gravity of risk should be issued in lay person's terms for the workers.

6.2 Recommendations for the Workers

It is recommended that the workers must be attentive and conscious of the work conducted at the tunnelling site and should always keep following safer practices when working inside a tunnel [2], [15]. They should strictly follow the safety warnings and signs when working inside the tunnel. The workers also should share their knowledge regarding safety matters and risk conditions within the tunnel site with their co-workers so that hazardous environments are correctly identified [2]. Using personal protective equipment is a mandatory requirement, and workers should question the issues regarding the quality of their PPE [17]. Also, all the workers have the responsibility to communicate any safety issues to the management body.

7. Conclusions

This paper outlines a safety risk assessment for drill and blast tunnel construction, which is intended to help move towards a proactive safety culture in the tunnel construction industry in Sri Lanka.

Risk score analysis identified the critical hazardous events that could occur during drill and blast tunnel construction in Sri Lanka: direct spraying of concrete on eyes and skin, exposure to noxious dust, and constant exposure to noxious noise. Graphical representation of critical hazardous events through Bow Tie diagrams is a significant output of this research. Such a representation captures how the tunnel construction industry can stop a particular critical hazardous event from happening. The event tree analysis results for the same critical hazardous event revealed that there is only around a 20% probability that significant consequences could be prevented in a drill and blast tunnelling site where some of the four barriers mentioned are unavailable. It was revealed that implementing more barriers (countermeasures) is a safety strategy for minimizing the probabilities of 'significant' consequences. Overall, the risk assessment methodology of this study can be used as a framework by the safety officers to conduct risk assessments in collaboration with other experts on site.

Acknowledgement

The authors wish to acknowledge the assistance from the experts and workers in the three tunnelling sites: Broadlands Hydropower Project, Kaluganga Moragahakanda Transfer Canal Project, and the North Western Canal Project.

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