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Application of the BowTie Method in Accident Analysis:
Case of Kaziwiziwi Coal Mine

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Abstract

A BowTie is a diagram illustrating proactive and reactive risk management at any working environment. This case study applied the bowtie method to provide a simple visual analysis of the hazards that caused fatal accidents at Kaziwiziwi coal mine on 2nd November 2012 and 15th November 2019. Two coal miners were killed on the spot and others injured due to failure of a bucket hoisting system and hanging rock fall. The authors demonstrated that the bowtie method is an effective visualization tool that can be used to analyze the hazard, top event, threats, consequences, barriers and escalation factors of mining accidents; and therefore give an overview of everything not wanted around a certain hazard. Mining companies in Malawi will apply this new knowledge to proactively conduct situational audits of unwanted scenarios, and identify barriers to prevent accidents from happening so far as is reasonably practicable. In addition, the Department of Mines will find this bowtie visualization tool useful when carrying out accident analyses in the future which in turn will promote safety awareness and policy development in the mining industry, and suggest ways on how to keep the normal but hazardous aspects from turning into something unwanted.

Keywords: Bowtie Method, Incident Investigation, Malawi Mining Industry

1. Introduction

Malawi is a landlocked country whose main export is tobacco and its economy mostly relies on agriculture. Mining is still a budding sector in the country with a high potential to positively impact the economy. Most mining projects are still in the exploration phase and yet to start bankable feasibility studies. There is coal exploitation in the Northern region of Malawi done by Kaziwiziwi, Mchenga and Rukuru underground coal mines. These are the major producing coal mining companies, and supply coal at national and international level. Malawi has over 22 million tons of proven coal reserves in a number of coal fields across the country (Annual Economic Report 2012). The largest coal field is the Livingstonia coal field with probable reserves of over 2-5 million tonnes and proven reserves of 4 million tons of coal with ash content of 17 %, a sulphur of 0.5 % and a calorific value of 6,800 kcal /kg. Livingstonia coal field is a 90 km² stretch in Rumphi district in the Northern Region of Malawi (Annual Economic Report 2012). Mining sites are high hazard environments due to the nature

of the work being carried out. Present study focused on Kaziwiziwi coal mine because it recorded the most mining accidents in the past decade. On 2nd November 2012, Face of Malawi reported that a "hanging rock was ejected from the wall of the mine as the miners were digging around it and it crashed the miner and killed him on the spot". On 15th November 2019, sources at the mine said that "a coal miner was killed on the spot and others injured when a bucket filled with coal at a 75m deep hoisting system fell from above ground to the depth of the shaft where the men were. The men couldn't escape since the drive at the bottom was filled with a stockpile".

Malema (2017) established that the working conditions experienced at the two mining companies of Mchenga and Kaziwiziwi in Rumphi district are generally poor but did not research on how mining companies in Malawi can effectively carry out risk analysis to prevent or mitigate mining accidents and lost time due to injury. Yasidu (2019) only reported on the influences of water vapor on roof fall accidents at Mchenga and Kaziwiziwi underground coal mines in Malawi and they found that tensile failure at weak sedimentary planes due to the seasonal decrease in tensile strength by the vapor migration into the rock mass leads to roof falls at Malawian coal mines. Mining Safety Regulations (1982) states that "A manager or foreman or person in any similar supervisory capacity shall not, by his instruction, default or negligence, cause or permit to exist any state of affairs which is reasonably calculated to endanger the safety of persons or property". Therefore, there is a research gap on how coal mining companies can proactively identify hazards, assess risks and prevent accidents or 'any state of affairs' at mining sites. This in turn will help companies save compensation money, develop a safety & risk management culture, minimize lost time due to injury or deaths, and increase mineral production. The bowtie method has been used within the oil and gas, petrochemical, aviation and mining domains (Achield & Weaver, 2012; Burgess-Limerick, Horberry, & Steiner, 2014; Pitblado & Weijand, 2014; Saud, Israni, & Goddard, 2014; Dodshon, & Limerick, 2015). In Australia, the use of bowties is an accepted way to graphically demonstrate whether organisation controls have reduced the risk of a major incident so far as is reasonability practicable (Safe Work Australia, 2012; Dodshon, & Limerick, 2015).

It is hoped that the knowledge gained from this research will promote risk and incident analysis by mining companies in Malawi thereby improving mineral production and safety culture. The most critical hazards at Kaziwiziwi coal mine comprise lifting/hoisting operations, working at height, driving machinery, drilling, blasting, coal processing, toxic contaminant, ventilation, coal dust, hanging rock, noise, and fire. This research focused on lifting/hoisting operations, working at height, driving machinery, and hanging rock as they are the most common hazards that lead to top events at the mining site. The bowtie method was applied to determine if it could help investigators or supervisors identify the risk controls that could have prevented the severity of the top event outcomes to an acceptable level of risk.

2. Materials and Methodology

2.1. Study Area

Kaziwiziwi coal mine is located at Latitude -10.626465 and Longtitude 34.106333 within the Livingstonia coal field in Rumphi district, northern Malawi (Fig. 1). The mine covers an approximate area of 17.5 km². Overall, the whole livingstonia coal field has probable reserves of 2-5 million tons and proven reserves of 4 million tons of coal with ash content of 17 %, sulphur content of 0.5 % and calorific value of 6.800 kcal/kg (Annual Economic Report 2012; Maneya 2012). Kaziwiziwi coal mining company started with four underground labour intensive long-wall faces (the mine bases) from where coal was loaded directly into trucks for transportation to customers. During that period, there were no facilities to clean and size the coal until 1987, when screening and sizing facilities were installed. Kaziwiziwi coal mine currently produces on average 65.45 metric tons of coal per month. With this current production, there is a 162 % increase in coal production compared to an average monthly production of 25 metric tons during the first 5 years of its operations. At full capacity, the mining company can produce an average of 2,100 metric tons of coal per month (Malema 2017).

Figure 1: Arial view of Kaziwiziwi coal mine (Google Earth 2020)

2.2. Procedure

Present study applied the bowtie method (Fig. 2) to provide a simple visual explanation of the hazards that caused fatal accidents at Kaziwiziwi coal mine on 2nd November 2012 and 15th November 2019. A bowtie representation was created for each hazard. Each bowtie model contained the following components of an accident/incident: threats, preventative risk barriers, top events, mitigation risk barriers, consequences and escalation factors.
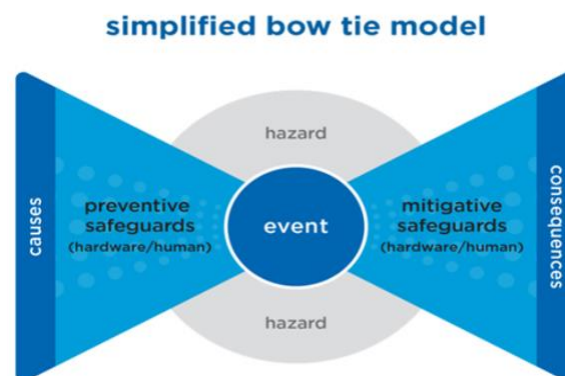

Figure 2. Simplified bowtie model

3. Results and Discussion

Observation was made between risk barriers present at the time of the accident/incident and those that were not. The authors based their research information on current and past mine workers; online articles & media reports; author's site visit experience and safety questions to site personnel. The collected risk components data in Table 1 is presented diagrammatically in Fig. 3 to Fig. 6 using the bowtie method. This gives a simple visual representation of proactive and reactive risk management controls that could have prevented or mitigated the mining accidents at Kaziwiziwi coal mine as far as is reasonably practicable. Results from the bowtie method indicate its usefulness as a communication tool to elicit further information and uncover holes in a company's

risk management; and identify the preventative & mitigatory risk barriers even before the start of a mining operation.

3.1. Preventative Risk Barriers

The most frequently identified preventative risk barriers comprised risk management, training, safety culture, procedures, auditing, supervision, maintenance, lighting and warning or proximity detection systems.

3.2. Mitigatory Risk Barriers

The most frequently identified mitigatory risk barriers comprised berms/escape ramps, emergency response, rescue teams, seatbelts, rockfall barriers, and rockbolts.

Table 1: Examples of components that form the BowTie model

Threat	Preventative barrier	Hazard Top event	Mitigation barrier	Consequence
1. Load too heavy 2. Incorrect loading 3. Strong winds 4. Snagging of gear/load 5. Operator overextends load 6. New mine worker 7. Lack of operating procedures 8. Lack of maintenance 9. Poor lighting 10. Non-compliance due to minimal supervision 11. Structural failure of mine hoisting system 12. Power failure	1. Check safe working load manifest; Check inspection status of hoist/bucket; Mine hoist system design 2. Limited lift stability check 3. Monitor and adhere to weather criteria-stop lift if exceeded 4. Use lifting plan; Use camera/CCTV monitoring for blind angles; Use a banksman for blind lifts 5. Check that operator is competent enough for the operation of hoist plant; Use camera/CCTV monitoring. 6. Induction training; Restrict access to hoisting area 7. Management operating procedures to ensure pre-operational checks. Safety culture 8. Adequate maintenance to identify safety defects. Regular replacement of old ropes with new ones 9. Hazard lights to be used under all low light conditions 10. Presence of supervisor at every hoisting operation 11. Check inspection status of hoist; Pre-lift hoist check; Proper mine shaft design 12. Back-up generator (Escalation Factor: No fuel in generator); Inspection/maintenance of electrical systems	Underground Mine Hoisting Operation Failure of hoist rope carrying bucket/skip	1. Restrict access to hoisting area 2. Every hoist to have an emergency escape route/ramp 3. Coal stockpile & waste rock not to be too close to escape routes/ramps. 4. Emergency response plan 5. Mine rescue teams 6. Emergency repair of primary bleeder	1. Mine worker hit by bucket leading to fatality or injury. 2. Bucket impacts ground. 3. Production losses. 4. Damage equipment. 5. Damage ventilation mechanisms
1. Lack of reinforcement/ ground control design 2. Improper rock support installation 3. Loose wedges/ rocks 4. Minimal inspection and monitoring of working environment/ personnel 5. Lack of	1. Mine design; Install rockbolts/ support 2. Only trained technicians to install rock support 3. Roof testing (sound the rock & listen for the drummy sounds that signal loose rock) & scaling of loose rock 4. Regular inspection/monitoring of roof and side walls; Provide sufficient lighting in working area; Watch out for support/rock cracking sound; Provide signposts in rockfall risky areas; Report unsafe condition to supervisor 5. Install warning devices; Use of photogrammetry, total station or LIDAR	Underground Mine Hanging rock Rockfall	1. Rockfall protection barriers e.g. high tensile steel wire. 2. Restrict entry to rockfall affected area 3. Warning devices e.g. microseismic monitoring systems	1. Killing or injuring miner. 2. Damage equipment 3. Disrupt ventilation system. 4. Blockage of installed emergency escape routes 5. Production losses

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monitoring equipment/ technology 6. Presence of fault zones/discontinuities 7. Sudden change in geologic structures 8. Influx of groundwater	to monitor movement of rocks 6. Dewatering techniques			
1. Slippery surface 2. Unstable surface 3. Material obstructing surface	1. Anti slip coating on surface 2. Adequate condition of scaffold/ladder 3. No excessive equipment on workfloor	Working at height Slips and trips on height	1. PPE worn 2. First aid and stabilization 3. Emergency lifting equipment	1. Cuts and bruises due to impact 2. Fractures due to impact 3. Person stuck at height
1. Poor haul road condition 2. Poor machine maintenance 3. Faulty machine 4. Poor visibility 5. Learner operator 6. Driver loss of attention (due to phone, fatigue, eating, chatting) 7. Intoxicated driving	1. ABS, regular road inspection and maintenance 2. Daily machine inspection and scheduled maintenance 3. Dispose machine at end of its life; Purchase new machinery; Maintenance 4. Listen to weather report and adjust driving schedule accordingly 5. Experienced operator; Defensive operation 6. Regular refreshment breaks, all gadgets to be kept by supervisor 7. Breathalyzer	Driving machinery Losing control over the machinery	1. Forward collision warning system, airbag, wearing seatbelt 2. Designated walkways for miners with barricades 3. Rollover protection	1. Crash into other machine 2. Hitting a mine worker 3. Machine rollover
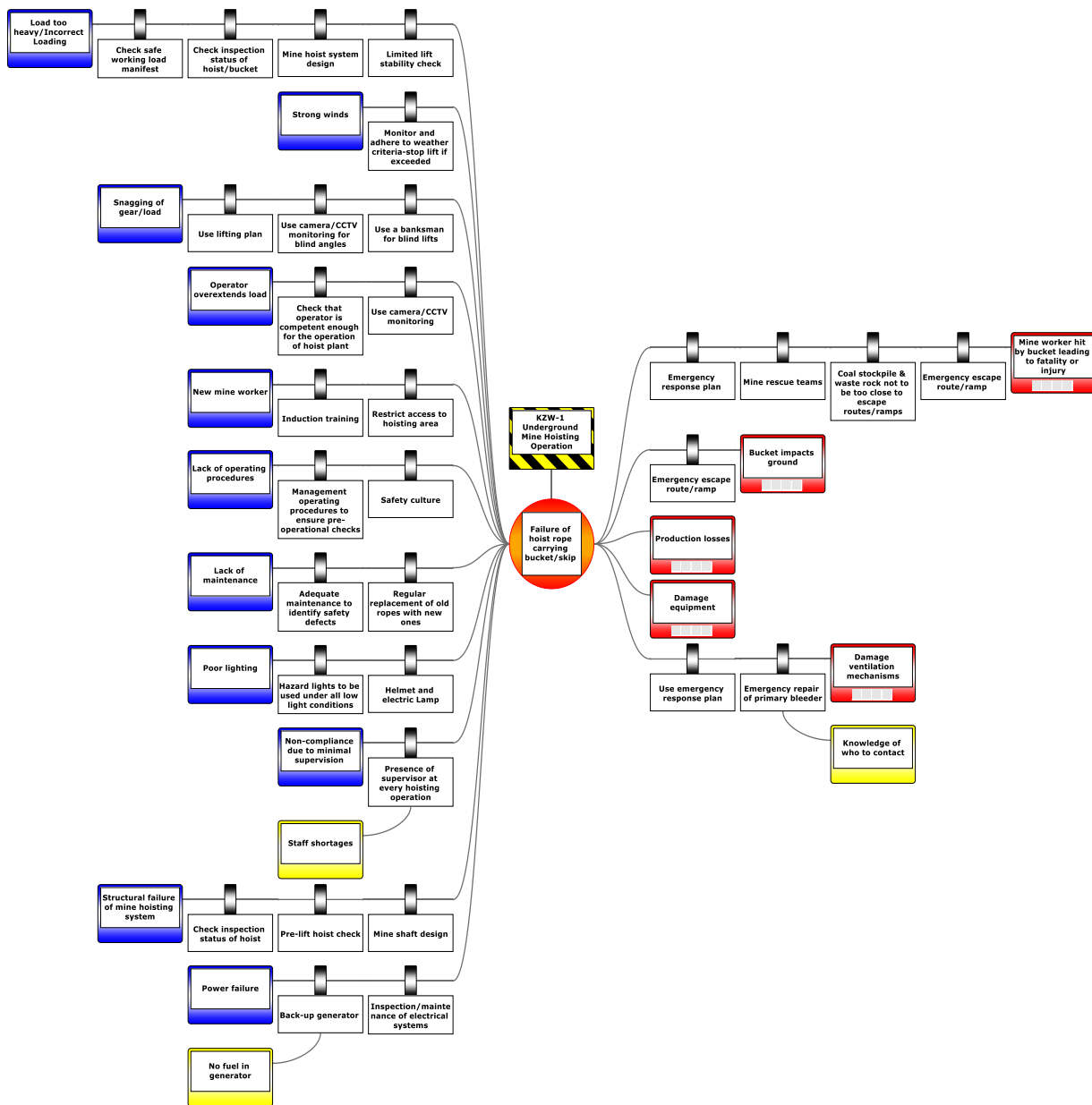
Figure 3: An illustrative BowTie risk model for a hoisting operation at Kaziwiziwi coal mine
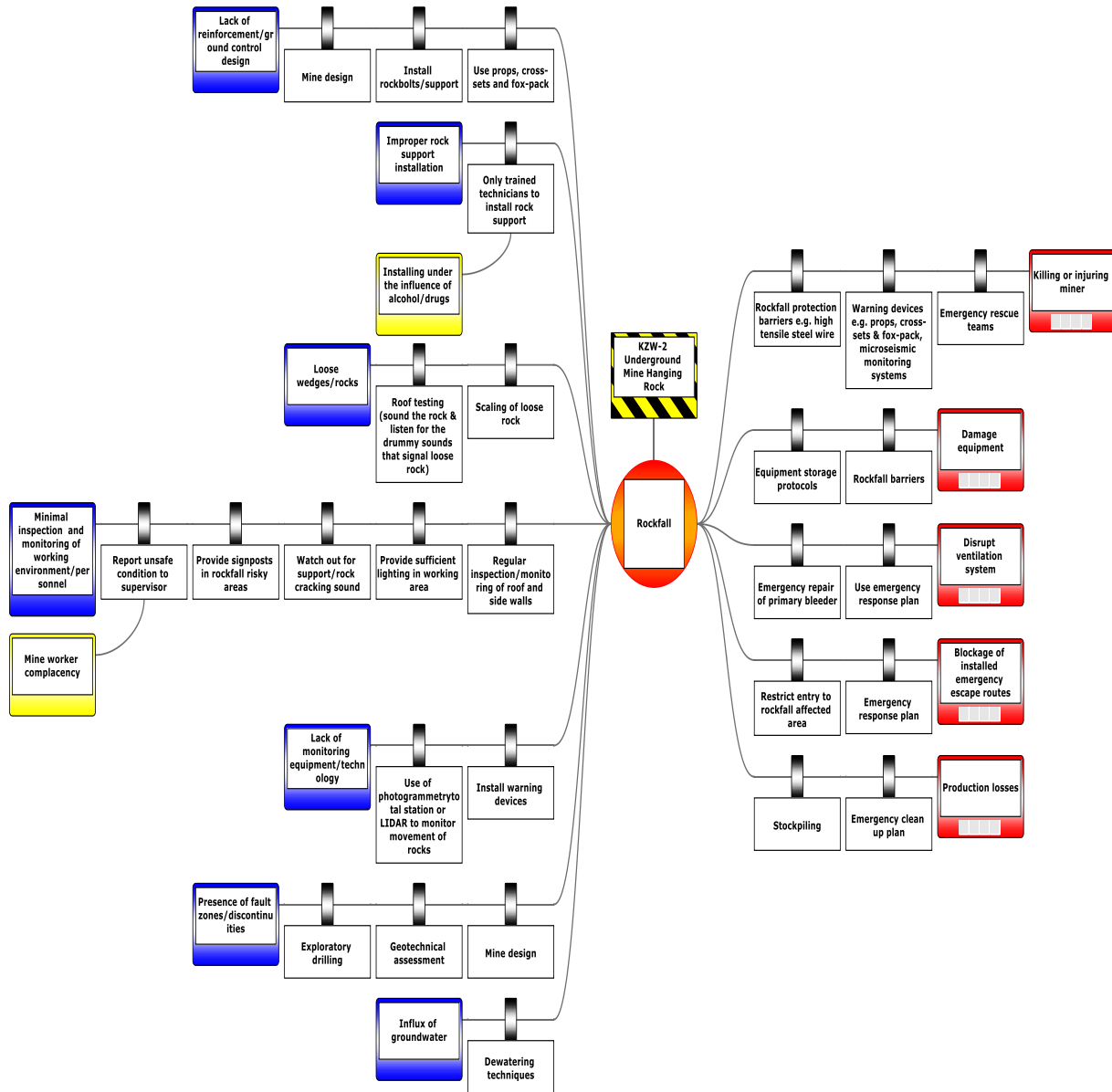
Figure 4: An illustrative BowTie risk model for hanging rock at Kaziwiziwi coal mine
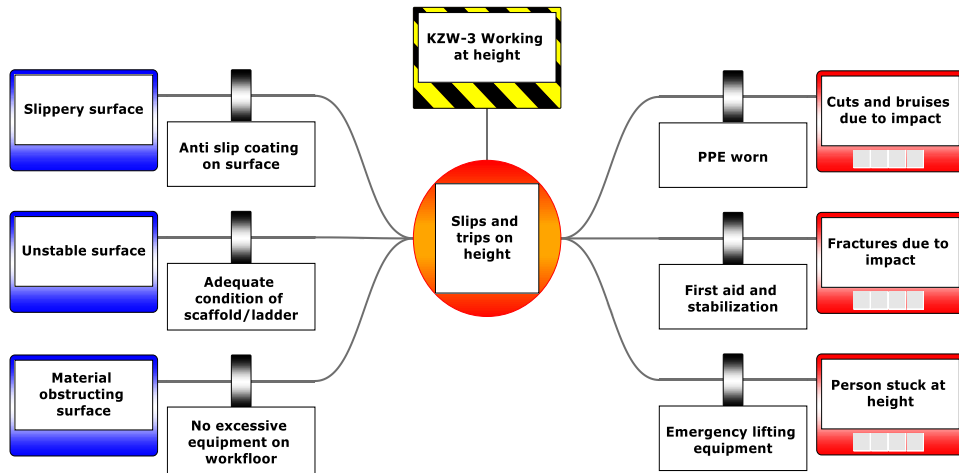
Figure 5: An illustrative BowTie risk model for working at height at Kaziwiziwi coal mine
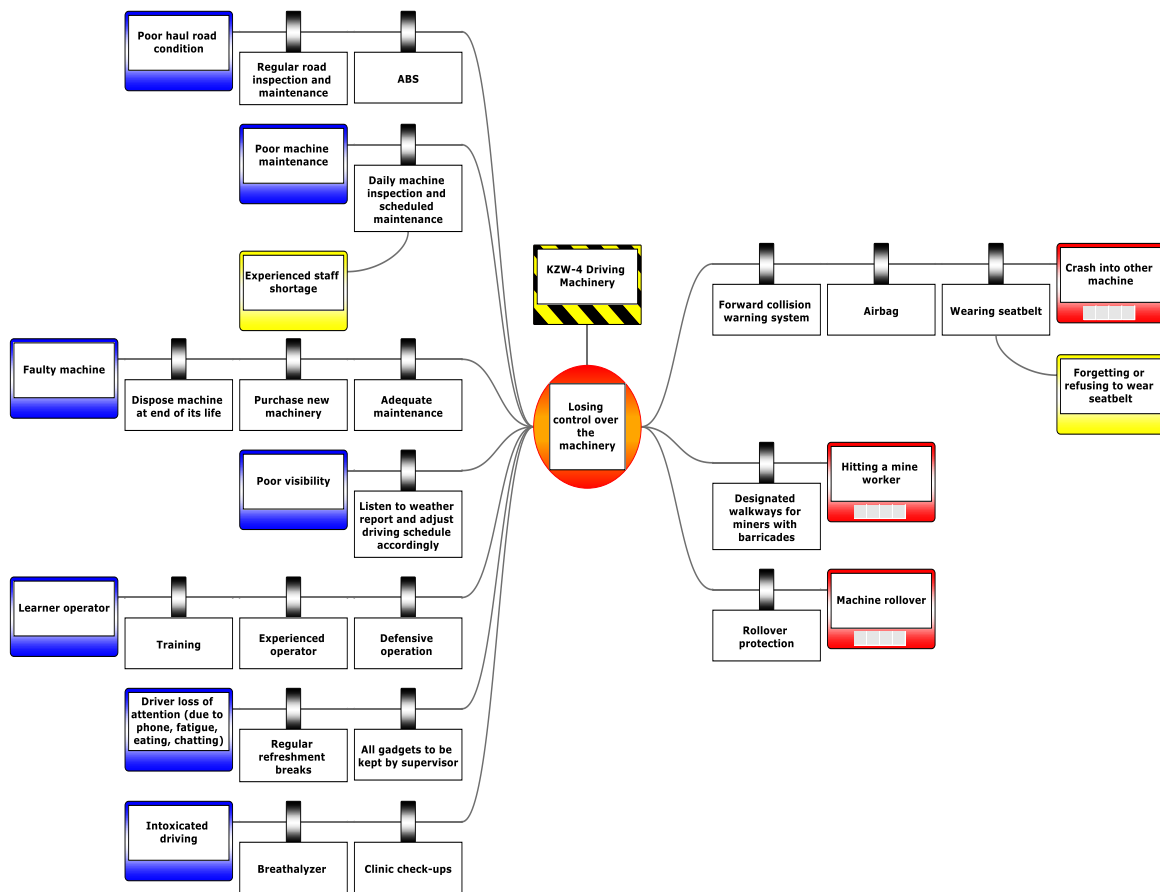
Figure 6: An illustrative BowTie risk model for driving machinery at Kaziwiziwi coal mine

4. Conclusion and Recommendation

Present study has applied the bowtie method to assess the most significant underground mining hazards being faced by mineworkers at Kaziwiziwi coal mine. The application of the bowtie method to identifying risk barriers from accident/incident reports in the mining industry uncovers a large number of different preventative and mitigation risk barriers. The authors demonstrated that the bowtie method is an effective visualization tool that can be used to analyze the hazard, top event, threats, consequences, barriers and escalation factors of mining accidents; and therefore give an overview of everything not wanted around a certain hazard. This new knowledge will help mining companies improve in their identification of risk controls during accident/incident investigation studies. Best practices comprising engineering design, mining methods, hoisting systems, ground/roof support, human factors and equipment choice will prevent mining risks from happening so far as is reasonably practicable, and create safer working environments at Kaziwiziwi coal mine.

In relation to the improvement of safety at the mining site which directly correlates with the welfare of mine workers, the labour statistics by the Annual Economic report 2012 indicates that a total of 21,022 workers were employed in the mining sector by 2011 representing an increase of 82 % from 11,565 in 2009. Of the total 2011 sector employees, 907 were in coal, 859 in uranium mining activities, 12,030 in the quarry aggregate production, 1,260 in gemstones minerals specimens, 195 in minerals exploration activities and the rest in other mineral production activities (Malema 2017). Therefore, to improve the safety and risk awareness culture, it is recommended to have a safety database of all possible accidents/incidents at mining sites in Malawi, and introduce safety training workshops in the mining industry. The bowtie risk analysis model is a reliable tool which will be used by the private and public sector to visualize their safety adherence. The Department of Mines will find this bowtie visualization tool useful when carrying out accident analyses in the future which in turn will promote safety awareness and policy development in the mining industry, and suggest ways on how to keep the normal but hazardous aspects from turning into something unwanted. In addition, mining companies will apply this new knowledge to proactively conduct situational audits of unwanted scenarios, and identify barriers to prevent accidents from happening so far as is reasonably practicable.

Future work can look into the impact of mental illness to mining related injuries and how mental awareness can be incorporated into safety management programmes at mining sites.

Conflict of Interest
The authors have not declared any conflict of interest.

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