Proceedings, 7th African Rift Geothermal Conference
Kigali, Rwanda 31st October – 2nd November 2018

Evaluation and Control of Accident Risk Factors in Geothermal Drilling Sites

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Keywords

Hazard, Accident, Risk factor

ABSTRACT

Unsafe acts and conditions in drilling sites coupled with personal and impersonal aspects increase risks of accidents which if left unchecked can escalate financial, legal and social implications that can hinder efficient exploration of geothermal resources. This paper evaluates the influence of six accident risk factors in Menengai Geothermal Project which include occupation, experience, operation, location, time of day and day of week on accident severity using chi-squared test for independence. Operation and time of day showed association with accident severity. Furthermore, root cause analysis for different accident severities determined that precautions to prevent minor accidents are similar to those required to avoid serious accidents and the former provide learning opportunities to minimize chances of the latter occurring. Proactive measures adopted in the project site considered which have contributed to reduced accident rates that include job safety analysis, safety induction and training, HSE management tools and employee involvement are also recommended .

1. Introduction

Accidents are unexpected occurrences that result in injury or damage to property. Different types of accidents leading to different injury severities which can occur in a geothermal drilling site include being struck by objects or striking against objects; getting caught between/in or on objects; slipping and falling to the same or different level; strains and sprains; cuts; and chemical contact, inhalation or exposure. The aforementioned accident types account for approximately 90% of lost time accidents based on International Association of Drilling Contractors (IADC) 2017 Summary of Occupational Incidents IADC (2018) over the last five years shown in Table 1

No	Accident Type	2017	2016	2015	2014	2013	Average
1	Caught Between/In	20.0%	11.1%	0.0%	25.0%	18.0%	14.8%
2	Struck By/Against	40.0%	88.9%	37.5%	50.0%	32.0%	49.7%
3	Slip/Fall Same Level/Different Level	30.0%	0.0%	0.0%	10.0%	23.0%	12.6%
4	Flame/Heat/Steam/Chemical Contact/Exposure	10.0%	0.0%	12.5%	0.0%	4.0%	5.3%
5	Electric Shock	0.0%	0.0%	12.5%	0.0%	4.0%	3.3%
6	Sprain	0.0%	0.0%	12.5%	0.0%	0.0%	2.5%
7	Vehicle	0.0%	0.0%	25.0%	0.0%	5.0%	6.0%
8	Other	0.0%	0.0%	0.0%	15.0%	14.0%	5.8%
Total		100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

Table 1: Accident Type Percentage Fatalities –Source: IADC (2014), IADC (2015) , IADC (2016), IADC (2017), IADC (2018c).

Struck by accidents contributed to almost half of the fatalities recorded in drilling rigs while caught between/in and slip and fall accident accounted for approximately 25%. Caught between/in is the second most frequent cause of fatal accidents after struck by which appears in all five years considered. Slip/fall and contact with hazardous substances are the third most frequent fatal accidents. Severe injury can be encountered in different types of accidents.

Fatalities associated with risk factors considered in this research which include drilling activity, occupation and experience over the last five years published by IADC are compared in Table 2, 3 and 4

No	Activity	2017	2016	2015	2014	2013	Average
1	Tripping in/out, Run Casing/Tubing	20.0%	12.5%	25.0%	39.0%	18.0%	22.9%
2	Material Handling	10.0%	0.0%	0.0%	5.0%	14.0%	5.8%
3	Routine Drilling Operations, Making Connection	20.0%	0.0%	0.0%	15.0%	18.0%	10.6%
4	Rig/Equipment Repairs/Maintenance	20.0%	12.5%	12.5%	20.0%	0.0%	13.0%
5	Rigging Up/Down	10.0%	25.0%	0.0%	10.0%	9.0%	10.8%
6	Well Control /BOP Stack Maintenance	10.0%	12.5%	0.0%	0.0%	14.0%	7.3%
7	Travel/ Transportation	10.0%	0.0%	37.5%	0.0%	5.0%	10.5%
8	Well Testing	0.0%	12.5%	0.0%	0.0%	0.0%	2.5%
9	Handling Riser, Laying Down/Picking Up Tubular	0.0%	12.5%	12.5%	0.0%	0.0%	5.0%
10	Mud Mixing/ Pumping	0.0%	12.5%	0.0%	0.0%	0.0%	2.5%
11	Special Operations, Other	0.0%	0.0%	12.5%	11.0%	22.0%	9.1%
Total		100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

Table 2: Drilling Activity Percentage Fatalities – Source: IADC (2014), IADC (2015) , IADC (2016), IADC (2017), IADC (2018c)

Tripping in/running casing operations most frequently account for fatal injuries over the last five years with a peak in 2014 where they contributed to almost half of the recoded fatalities. Maintenance and Rigging up/down operations are the second most frequent cause of fatal injury. There could be a chance that some drilling operations present more hazardous conditions that could predispose personnel to higher risks of encountering more severe injury.

No	Occupation	2017	2016	2015	2014	2013	Average
1	Floorman	40.0%	22.2%	25.0%	15.0%	23.0%	25.0%
2	Motorman	0.0%	0.0%	0.0%	20.0%	23.0%	8.6%
3	Roustabout	10.0%	0.0%	0.0%	5.0%	9.0%	4.8%
4	Driller	10.0%	44.4%	25.0%	15.0%	9.0%	20.7%
5	Toolpusher	0.0%	0.0%	0.0%	0.0%	5.0%	1.0%
6	Engineer	0.0%	0.0%	0.0%	0.0%	4.0%	0.8%
7	Crane Operator	0.0%	0.0%	0.0%	5.0%	9.0%	2.8%
8	Welder	0.0%	0.0%	0.0%	0.0%	9.0%	1.8%
9	Mechanic	20.0%	0.0%	0.0%	5.0%	0.0%	5.0%
10	Maintenance/Other Supervisor	10.0%	11.1%	12.5%	5.0%	0.0%	7.7%
11	Electrician	10.0%	0.0%	12.5%	15.0%	0.0%	7.5%
12	Derrickman	0.0%	22.2%	0.0%	10.0%	0.0%	6.4%
13	Truck Driver	0.0%	0.0%	25.0%	0.0%	0.0%	5.0%
14	Other	0.0%	0.0%	0.0%	5.0%	9.0%	2.8%
Total		100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

Table 3: Occupation Percentage Fatalities - Source: IADC (2014), IADC (2015) , IADC (2016), IADC (2017), IADC (2018c)

Floormen and drillers are the most frequent victims of fatal injury followed by maintenance/other supervisors. The former account for slightly over half of the most severe accidents at 54.3%. A person's role in the drilling rig could influence risks of encountering more severe injury.

No	Accident Type	2017	2016	2015	2014	2013	Average
1	< 3 Months	0.0%	12.5%	0.0%	15.0%	4.0%	6.3%
2	> 3 Months < 6 Months	10.0%	0.0%	12.5%	0.0%	18.0%	8.1%
3	> 6 Months < 1 Year	20.0%	0.0%	12.5%	20.0%	9.0%	12.3%
4	> 1 Year < 5 Years	50.0%	50.0%	37.5%	35.0%	23.0%	39.1%
5	> 5 Years < 10 Years	0.0%	12.5%	25.0%	15.0%	9.0%	12.3%
6	10 Years +	20.0%	25.0%	12.5%	15.0%	32.0%	20.9%
7	Unknown	0.0%	0.0%	0.0%	0.0%	5.0%	1.0%
Total		100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

Table 4: Experience Percentage Fatalities - Source: IADC (2014), IADC (2015) , IADC (2016), IADC (2017), IADC (2018c)

Personnel with between one and five years' experience and those with greater than ten years' have the highest frequency of encountering fatal injury. They account for sixty percent of all recorded fatal accidents. Activities assigned to more experienced personnel in a rig site could predispose them to more unsafe acts and conditions which could increase their chances of encountering more severe injury than less experienced workers.

Accidents differ in severity resulting in death or injury which may require first aid, medical treatment, restricted work or lost time due to days away from work. They result in system and natural consequences that have direct and indirect cost implications. System consequences are negative internal or external actions taken due to accidents while natural consequences involve actual physical injury or property damage caused by the accident. Direct costs which are directly related to accidents include repair and replacement of damaged property, absent employee pay and prosecution fines. Indirect costs on the other hand include recruitment of replacement staff, production delays, overtime payments, retraining, and low staff morale. The Britain Health and Safety Executive note that indirect costs of accidents are between 8 and 36 times greater than direct costs HSE (1996). Direct costs are just a tip of the iceberg. Escalating accident costs due to onetime catastrophic accidents or recurrent fatal and lost time accidents can stagnate drilling operations.

Since severe accidents are more costly than less severe occurrences there is need to identify factors that influence severity and control measures necessary to minimize accident related costs. Using a representative log of rig site accidents recorded in Menengai Geothermal Project since commissioning, the objective of this research is to determine the relationship between six risk factors and accident severity in order to identify how to prevent occurrence and recurrence of more costly severe accidents that can significantly deter drilling operations. Control measures required to minimize risks of encountering different accident severities are determined through root cause analysis.

Proactive measures required to identify and control hazards before they result in accidents identified in this research can provide useful bearing to geothermal rig operators in developing and implementing effective safety programs that minimize accidents risks and associated costs.

2. Literature review

Three accident severity levels considered in this study are defined by IADC, (2018a) as follows:

i. First Aid Case – Work related injury treatment of minor scratches, cuts, burns, splinters and so forth, and any follow-up visit for the purpose of observation.

ii. Medical Treatment Only (MTO) - Any work related injury or illness requiring medical care or treatment beyond first aid (regardless of the provider of such treatment) that does not result in a Restricted Work/Transfer Case (RWTC) or Lost Time Incident (LTI).

iii. Lost Time Incident (LTI) - A work-related incident (injury or illness) to an employee in which a physician or licensed health care professional recommends days away from work due to the incident

Study of accident severity ratios by different researches reveal that more less severe accidents occur before a fatal or serious accident happens as shown in Figure 1. Friebott (2013) highlights that Frank E. Bird Jr. revealed that for each major accident with lost time, there were around 15 accidents requiring medical treatment, 30.2 property damage accidents and 600 near misses depicting a pyramid with a 1-10-30-600 ratio.

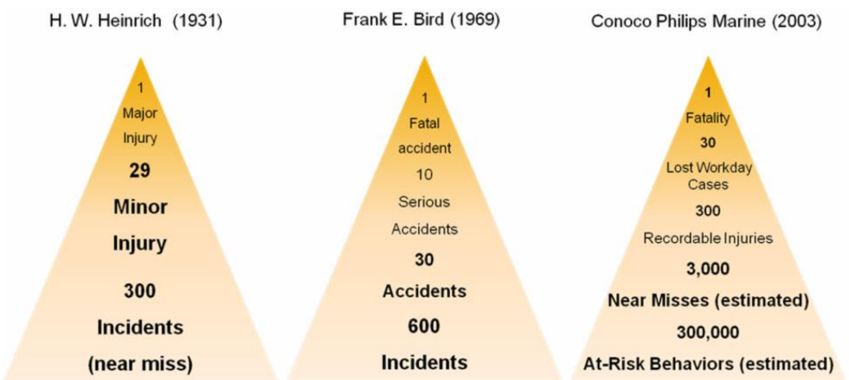

Figure 1: Accident severity ratios – Source: Friebott (2013)

According to Raouf (2011), multiple causation accident theories which evolved from single cause theories postulate that accidents are caused by many combinations of causes and sub-causes that can be categorized as environmental or behavioral factors. Early identification and control of factors which contribute to less severe accidents in the accident pyramid work toward preventing the occurrence of more severe accidents that are more costly to organizations

Previous study by Hull, Leigh, Driscoll, & Mandryk (1996) which relates severity of occupational accidents to all risk factors considered in this study in the mining industry identified that worker's age, part of the body injured, type of accident, agency of accident, and worker activity are significantly associated with injury severity. They further note that time into shift, previous hours worked, mine location of incident, occupation, work experience, frequency of task, shift, and mining region are not important or not significant in their relationship with injury severity.

3. Methodology

Owing to limited time, all injury accident records for four operational rigs in Menengai Geothermal Project collated in August 2014 for the period between December 2010 and July 2014 were considered. A total of 98 injuries were recorded in the period. The data which represents 62.82% of all accidents recorded as at December 2017 is representative of the whole sample. The association between accident severity and both behavioral and environmental risk factors was determined using chi-squared statistical test for independence in Equation 1.

$$X_{df}^2 = \sum_{i=1}^{k} \left[\frac{(O_i - E_i)^2}{E_i}\right] \text{------ Equation 1}$$

Where:

O_i = the observed frequency in the i^{th} category

E_i = the expected frequency in the i^{th} category

And the degrees of freedom are:

$df = (r-1)(c-1)$

Where r = number of rows and c = number of columns

Expected frequency for i^{th} row and j^{th} column in frequency table with r rows and c columns is calculated using the formula below

$$x_{i,j=\frac{\sum_{i=1}^{c} x_i}{\sum x_{i,j}} \times \sum_{j=1}^{r} x_j} \text{------ Equation 2}$$

Null (H_o) and alternative (H_1) hypothesis for each chi square test is stated as

H_0: $O_i = E_i$ No relationship between variables (independent), $O_i - E_i$ is small for each category

H_1: $O_i \neq E_i$ Related variables (dependent), $O_i - E_i$ is large for each category

The calculated c^2 value is compared to chi-square critical value (X_t^2) read from the chi square table for significance level of 0.05 and df degrees of freedom

H_o is valid for $X_{df}^2 < X_t^2$ and H_1 is valid for $X_{df}^2 > X_t^2$

Risk factors considered were categorized into two groups as follows:

i. Personal (behavioral) – Occupation, Experience
ii. Impersonal (environmental) – Operation, Location, Time of Day, Day of Week

Root cause map defined by Rooney & Heuvel (2014) was used to determine corrective actions for each category of accident severity considered.

4. Date Presentation, Analysis and Interpretation

This section presents the frequency of three accident severities and their relationship with personal and impersonal risk

4.1 Personal Risk Factors

4.1.1 Occupation

In line with Table 3, Table 5 indicates that most accidents are encountered by floormen. This implies that they could be more exposed to hazardous conditions and activities than other functions in the rig site. Effort intensive tasks such as making up and breaking out connections which involve movement of tubular predispose them to greater risk of injury. Technician activities which mainly involve equipment maintenance - disassembly and replacement of parts also seem to increase their risks of injury which is second to the percentage encountered by floormen. The trend of different accident severities across different occupations is more or less consistent with first aid injury being the highest followed by medical treatment and lost time injury. Chi square test is applied to validate or invalidate the alternate hypothesis that the variables considered dependent i.e. some workers are more predisposed than others to more severe of accidents at the rig site.

Occupation	LTI	MTI	FAC	TOTAL
Floorman	2.0%	18.4%	29.6%	50.0%
Technician	1.0%	4.1%	11.2%	16.3%
Assistant	0.0%	3.1%	6.1%	9.2%
Roustabout	0.0%	2.0%	6.1%	8.2%
Derrickman	0.0%	3.1%	3.1%	6.1%
Engineer	0.0%	2.0%	2.0%	4.1%
Driver	0.0%	0.0%	4.1%	4.1%
Driller	0.0%	0.0%	2.0%	2.0%
TOTAL	**3.1%**	**32.7%**	**64.3%**	**100%**

Table 5: Accident severity and occupation

A X_{14}^{2}value of 7.1776 is obtained. Since this value is less than the chi square table critical value of 23.685 for a significance level of 0.05 and 14 degrees of freedom, the alternate hypothesis is invalid. In line with Hull, Leigh, Driscoll, & Mandryk (1996) findings, there is no relationship between the severity of an accident and the occupation of the worker. All persons in the rig are equally exposed to risks of encountering different severities of injury including fatal injury irrespective of their occupation.

4.1.2 Experience

The more frequently one performs a task the more he/she becomes used to it and aware of things that can go wrong to cause accidents. It can therefore be expected that more experienced workers are more careful or aware of the workplace situations and activities such that they are able to identify and predict unsafe conditions and correct them before accidents occur. From Table 6, staff with the median range of experience have encountered most of the recorded accidents. This could imply that they are assigned more challenging and risky work compared to personnel with less experience which predisposes them to greater risk of injury than the latter. Staff with less than or equal to half a year experience feature to have the second highest number of accidents at 17.3%. Naivety of green hands could therefore increase the probability of prevailing hazards to cause injury. The general trend of table 6 corresponds to that of table

4. Chi square test is applied to determine if there could be any relationship between the severity of accidents and years of experience

Experience	LTI	MTI	FAC	TOTAL
<=0.5	1.0%	4.1%	12.2%	17.3%
>0.5 & <=1	0.0%	1.0%	10.2%	11.2%
>1 & <=1.5	0.0%	6.1%	8.2%	14.3%
>1.5 & <=2	0.0%	10.2%	13.3%	23.5%
>2 & <=2.5	0.0%	4.1%	5.1%	9.2%
>2.5 & <=3	1.0%	1.0%	8.2%	10.2%
>3	1.0%	6.1%	7.1%	14.3%
TOTAL	**3.1%**	**32.7%**	**64.3%**	**100.0%**

Table 6: Accident severity and worker experience

A X_{12}^{2}value of 10.4982 obtained is less than the chi square table critical value of 21.026 for a significance level of 0.05 and 12 degrees of freedom. The null hypothesis is valid. In line with Hull, Leigh, Driscoll, & Mandryk (1996) findings, there is no relationship between the severity of an accident and a workers experience. Newly employed and seasoned employees are equally susceptible to experiencing severe accidents in GDC drilling rigs. There is need for all persons employed to follow prescribes safe operating procedures. Ignoring correct procedure and taking short cuts even by experiences staff can still result in severe injury. Experienced personnel stuck to using unsafe procedures form the start are therefore caught up with accidents in later years of work

4.2 Impersonal Risk Factors

4.2.1 Operation

Different activities executed in the rig site utilize different equipment and different procedures which can be expected to predispose personnel involved to different risks of encountering severe injury. Table 7 indicates that for the project site being studied, most accidents occur during drilling ahead which takes the longest duration in the drilling cycle followed by rig move operations which involve hoisting and relocation of heavy equipment. Chi square test was applied to determine relationship between the severity of accidents and the operation at the time of accident.

Operation	LTI	MTI	FAC	TOTAL
Drilling ahead	0.0%	17.0%	29.2%	46.2%
Rig move/rigging	0.9%	8.5%	17.0%	26.4%
Maintenance	4.7%	3.8%	11.3%	19.8%
Cementing/Running in casing	0.9%	2.8%	3.8%	7.5%
TOTAL	6.6%	32.1%	61.3%	100.0%

Table 7: Accident severity and rig operation

The X_{6}^{2}value obtained – 15.27447 is greater than the chi square table critical value of 12.59 for a significance level of 0.05 and 6 degrees of freedom. The null hypothesis is invalid. In line with Hull, Leigh, Driscoll, & Mandryk (1996) research, there is a significant relationship between the severity of an accident and the drilling operation at hand. Different operations present different risks of encountering severe injury. Personnel should adjust implementation of hazard control strategies to adequately address all hazards associated with different activities executed at the rig. Interacting activities, especially simultaneous operations require use of work permits to reduce chances of conflict or creation of new hazards to reduce risks of more encountering more severe injury

4.2.1 Location

Different hazards are encountered in different locations of geothermal drilling rig. Such hazards vary from high pressure lines in the compressor area, slip and fall hazards in the rig mast and monkey board to rotating blades, sparks and flames in the welding shop. It can be expected that the different hazards present different severities of injury to vary severities by location. Some locations could present risks of sustaining more severe injury than others. Table 7 indicates that more accidents are recorded at the rig floor than in any other location at the rig site. This is consistent with Table 5 which indicates that half of the rig workers who suffer injury are rig floormen predominantly stationed at the rig floor. Chi square test is applied to determine if there is a relationship between the severity of accidents and the location in which the accident occurred.

Location	LTI	MTI	FAC	TOTAL
Floor	2.3%	15.1%	22.1%	39.5%
Pipe rack	0.0%	8.1%	17.4%	25.6%
Mud pump	0.0%	3.5%	10.5%	14.0%
Cellar	0.0%	4.7%	5.8%	10.5%
Stores	1.2%	3.5%	0.0%	4.7%
Compressor	0.0%	1.2%	2.3%	3.5%
Derrick	0.0%	0.0%	2.3%	2.3%
TOTAL	**3.5%**	**36.0%**	**60.5%**	**100%**

Table 8: Accident severity and accident location

The X_{12}^2value obtained - 15.2509 is less than the chi square table critical value of 21.026 for a significance level of 0.05 and 12 degrees of freedom. The alternative hypothesis is invalid. In line with Hull, Leigh, Driscoll, & Mandryk (1996) findings, there is no relationship between the severity of an accident and the location it occurs. All rig locations present equal risk of encountering severe injury. Personnel should not drop their guard by considering some locations to be safety havens. This means that a severe accident may even occur in the safe briefing area if required precautions are not taken.

4.2.2 Time of day

It can be considered that fatigue increases in the course of work and more accidents are expected to occur in later hours of the day especially towards the end of working hours when personnel are tired. From Table 8, more accidents are encountered during afternoon hours followed by morning and night hours. This could imply that effects of fatigue brought about by consuming carbohydrates and sugary foods for lunch together with body thermoregulation due to higher afternoon temperatures could increase risks of injury in the afternoon hours. Lower number of accidents at night implies that safety critical activities could mainly be executed during the day. It is worth noting that rig move activities which accounted for the highest number of fatal accidents in IADC (2017) are only scheduled during the day from 0800Hrs to 0500Hrs

Time of Day	LTI	MTI	FAC	TOTAL
Morning	3.39%	11.86%	20.34%	35.59%
Afternoon	1.69%	22.03%	15.25%	38.98%
Night	0.00%	8.47%	16.95%	25.42%
TOTAL	**5.08%**	**42.37%**	**52.54%**	**100.00%**

Table 9: Accident severity and time of day

Applying chi square test for independence gives 12.3012. This value is greater than the chi square table critical value of 9.488 for a significance level of 0.05 and 4 degrees of freedom. Contrary to Hull, Leigh, Driscoll, & Mandryk (1996) findings, the alternative hypothesis is valid. There is a relationship between the severity of an accident and the time of day it occurs. Weakness and lethargy brought about by increased fatigue in the afternoon increase risks of sustaining more severe injury. Safety critical activities executed only during the day decrease chances of obtaining more severe injury at night when visibility could be compromised to varying extents. It is therefore critical to schedule hazardous work early morning when visibility is good and crew are active to reduced risks of severe injury. Variation of the findings of this study with those of Hull, Leigh, Driscoll, & Mandryk (1996) are probably due to the fact that all mining activities occur in a dark environment where visibility variations due to daylight and night time are not felt as opposed to land drilling rigs where changes are more significant

4.2.3. Day of week

It can be expected that more accidents occur when worker focus on the job is distracted towards end of shift tour when one is longing to get home and bond with family or at the beginning of tour when unsorted issues at home are carried over to work. Table 9 indicates that most accidents increase from Saturday to Sunday and start declining from Monday though to Wednesday. There is an increase from Wednesday to Friday. The general trend takes the shape of a sinusoidal curve with two crests and the beginning and end of week with a midweek trough. This implies that the shift cycle could have some influence on accident rates.

Day	Serious	MTI	FAC	TOTAL
Mon	1.0%	7.1%	9.2%	17.3%
Tue	0.0%	3.1%	13.3%	16.3%
Wed	0.0%	4.1%	6.1%	10.2%
Thu	1.0%	3.1%	8.2%	12.2%
Fri	0.0%	3.1%	10.2%	13.3%
Sat	1.0%	5.1%	5.1%	11.2%
Sun	0.0%	7.1%	12.2%	19.4%
TOTAL	**3.1%**	**32.7%**	**64.3%**	**100%**

Table 10: Accident severity and day of week

Applying chi square test for independence obtains a X_{12}^2 value of 9.3679. This is less than the chi square table critical value of 21.026 for a significance level of 0.05 and 12 degrees of freedom. In line with Hull, Leigh, Driscoll, & Mandryk (1996) findings, the null hypothesis is valid. There is no relationship between the severity of an accident and the day of week it occurs. Extremely severe accidents can occur at the rig site at any day of the week irrespective of the influence shift change and reduction in situational awareness due to the same. Rig crew have to be conscious and focused on work throughout the shift since the risk of being involved in a sever accident is not a function of the day of week or shift cycle.

4.3. Accident Risk Controls

Based on accidents considered in this research, immediate causes of different accident severities were used to determine root causes and recommended controls outlined below using Rooney & Heuvel (2014) root cause map.

No	Severity	Immediate Cause of Injury	Root Causes	Recommended Controls
1	First Aid Cases	1.1 Fingers caught between mowing parts 1.2 Lifting loads heavier than personnel lifting capacity 1.3 Abrasive or sharp object 1.4 Moving/swinging equipment, tubular ,hand tools, beams, broken part, snapped sling 1.5 Knocking against stationary objects 1.6 Sliding into uncovered floor openings/flat ground, missing step, tripping on obstacle 1.7 Whipping horse due to pressure release. 1.8 Dropping tool, pin, tubular	1.1.1 Equipment manual handling provision design LTA 1.1/2/3.1 Training in proper manual handling techniques LTA 1.3.1 Personal protective equipment LTA 1.4/5.1 OTJ task hazard identification and control LTA 1.4.2 Equipment inspection & preventive maintenance LTA 1.5/6.1. Housekeeping LTA 1.5/6.2. Job site walkthrough not implemented or LTA 1.7.1 Hazardous energy control procedures LTA. 1.8.1. Dropped object management procedures not implemented or LTA	1.1.1.1 Determine requirements for additional handling points, fabricate, clearly mark, train and supervise proper use 1.x.1.1 Train staff on proper manual handling techniques 1.x.1.1 Develop/improve OTJ hazard identification and control procedures, train staff and supervise compliance 1.4.2.1 Develop/ improve equipment inspection procedures, train workers and supervise compliance 1.5.x.1 Develop/improve housekeeping procedures based on 5S methodology, train workers and monitor compliance 1.7.1 Develop/improve hazardous energy control procedure, procure additional tools required, train staff and enforce compliance 1.8.1.1.develop/improve dropped object management procedures, train workers and ensure compliance

No	Severity	Immediate Cause of Injury	Root Causes	Recommended Controls
2	Medical Treatment Injury	2.1 Pressure horse failure 2.2 Flying broken equipment part	2.1/2.1. Equipment preventive maintenance LTA	1.4.2.1 Develop/ improve equipment inspection procedures, train workers and supervise compliance
		2.3. Swinging load	2.3.1 LTA training and procedures in proper rigging and slinging	2.3.1.1. Develop lift planning and lifting procedures / checklists, train and certify workers and enforce compliance
		2.4. Body part caught between tubular and equipment, tubular and post 2.5 Contact with hazardous chemical 2.6 Swinging hand tools, backlashing tongs	2.4/5/6.1 OTJ hazards identification and control procedures LTA	2.x.1.1 Develop/improve OTJ hazard identification and control procedures, train staff and supervise compliance
		2.7 Moving/rotating equipment, closing valves	2.7.1Missing of LTA procedures to control hazardous energy	2.7.1.1 Develop/improve hazardous energy control procedure, procure additional tools required, train staff and enforce compliance and supervise compliance
		2.8 Dropped tools, tubular	2.8.1. Inadequate dropped object management system	2.8.1.1.develop/improve dropped object management procedures, train workers and ensure compliance
		2.9. Slippery ground, obstructed pathways	2.9.1 Housekeeping LTA 2.9.2. Pre tour walkthrough absent or LTA	2.9.1/2.1 Develop/improve housekeeping procedures, train workers and monitor compliance
3	Lost Time Injuries	3.1 Dropped load/ bridle line	3.1.1 LTA training and procedures in proper manual handling, rigging and slinging	3.1.1.1. Develop lift planning and lifting procedures / checklists, train and certify workers and enforce compliance
		3.2. Hoisting equipment failure	3.2.1 Equipment preventive maintenance LTA	3.2.1.1 Develop/ improve equipment inspection procedures, train workers and supervise compliance
		3.3. Closing valve	3.3.1Missing of LTA procedures to control hazardous energy	3.3.1.1 Develop/improve hazardous energy control procedure, procure additional tools required, train staff and enforce compliance and supervise compliance

Table 11: Accident causes and control measures

From the root cause analysis above, it is evident that all measures required to prevent most severe lost time injuries also appear medical treatment and minor first aid accident controls. Controls required to prevent rig accidents center around implementing worker centered job the hazard identification and control procedures, control of hazardous energy release through permit to work procedures, proper housekeeping, preventive equipment maintenance, proper lifting techniques, training and supervision. There is need for personnel deployed in rig sites to report all accidents however minor to aid in identification and control of hazards that have led to minor injury and related hazards which have the potential of causing more severe injury. This concurs with Nichol (2012) proposition that major injuries are rare events and many opportunities are afforded by the more frequent, less serious events to take actions to prevent the major losses from occurring.

4.4 Proactive measures

Other than hazard control measures identified through root cause analysis above, the following proactive efforts which have contributed to reduced accident rates in the project site examined are worth mentioning

4.4.1 Job Safety Analysis - JSA

Jobs performed at the rigs site have been broken down into specific tasks for which hazards and mitigations are tabulated. Rig supervisors review JSA forms with rig crew in pre-job safety meetings as a reminder of hazards that are expected in the current job plan and the responsibility of each person in implementing mitigations required to prevent injury. Job safety analysis forms have been indexed in an on-job safety training manuals which is used for on-job training of new staff and interns. JSA forms have further been used to develop quality management system safe work procedures and instructions

4.4.2 Safety Induction and Safety Awareness Training

All persons deployed to the rig site undergo general safety induction to make them aware of precautions required in different locations of the rig. Furthermore, a structured internal rig personnel safety training program is implemented and monitored by the drilling and safety advisers. Safety topics covered include and are not limited to hydrogen sulfide, rigging and lifting, fire safety, manual handling, fall protection, dropped object management, confined space entry and hazardous energy control. Induction and safety training have significantly contributed to improving employee safety awareness with subsequent reduction in accident rates.

4.4.3 Safety management tools

Other than the supervisory role played rig engineers, each rig has a dedicated safety advisor to guide effective implementation if HSE management tools which include and are not limited to HSE statistics, HSE score card, personnel on board, permit to work system, accident investigation and reporting, rig communications, safety training observation program, hazard communication program, emergency drills and emergency rescue procedures. These tools have been very useful in managing unsafe acts and conditions.

4.4.4 Staff involvement, safety awards and sanctions

In order to motivate ownership of job safety programs and procedures, rig crew are involved in the developing them to enhance ownership and the desire to realize positive results from their contribution. Staff are awarded for surpassing key safety performance indicators and penalties are administered to personnel who intentionally and repeatedly violate safety requirements by putting themselves or others at risk of injury. Applicability of consequences has promoted a safe working culture in drilling rigs.

5. Conclusion

Evaluation of personal and impersonal risk factors has identified that as much as relationships can be drawn between the factors and total accidents recorded, no association exists between the severity of accidents and four of the six factors considered. Worker occupation, experience, location and day of week are not related with accident severity while rig operation and time of day has an influence on the same. As much as some occupations and locations predispose personnel to greater risks of injury coupled with the fact that there could be higher probability of encountering accidents during different periods of a shift cycle, these factors have no impact on the severity of injury experienced. Only operation and the time of day have a consequence. It can therefore be concluded that all persons in a drilling rig are at equal chance of encountering severe injury irrespective of the four independent risk factors. Furthermore, safety critical activities should be scheduled when time of day fatigue effects due to exhaustion and diminished visibility at night have not set in to reduce risks of severe injury. Personnel should adjust implementation of hazard control strategies to adequately address all hazards associated with different activities executed at the rig. Root cause analysis of accidents considered revealed that all precautions to prevent more severe accidents are also required to prevent less severe ones. The former provide learning opportunities to prevent accidents that are more costly to organizations. Controls required to prevent rig accidents mainly focus on worker centered hazard identification and control, prevention of hazardous energy release, proper housekeeping, equipment maintenance, safe lifting techniques, training and supervision. From the experience of the geothermal project site considered, proactive implementation of job safety analysis, safety induction and training, HSE management tools and employee involvement play a vital role in reducing accident risks to acceptable levels.

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