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Making the Business Case: Assessment of Safety Intervention and Optimization of Resource Allocation

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Introduction

This paper intends to provide an overview of a statistical technique to assess a safety intervention program from a business perspective. A mathematical model is developed for predicting incident rates. The developed model could be used to better predict the allocation and optimization of resources which in turn minimizes the cost of incident prevention. The safety model is obtained using analysis of variance while response surface methodology and contour plots are used to optimize the incident rates. Overall, this model presents the foundation for the use of response surface methodology for the prediction and optimization of incident rates. This offers a new dimension into the practice of safety intervention.

Safety intervention could be described as an attempt to alter or change how things are done in order to improve safety. In the industrial sector, safety intervention could be in form of a new program, practice, or initiative and idea which is intended to improve safety. Safety interventions in the work place include job redesign, training program, incentive programs for safety practices, and other administrative procedures. Safety interventions occur at different levels of an industrial safety system. In the workplace, major safety decision making and intervention efforts are often concentrated around the level of organization of the safety management system.

At the level of organization of the safety management system, various interventions are put in place by respective local, state and federal governments, industries, professional bodies, and others in order to change workplace safety policies, procedures, structures and organizations. These include several laws, regulations, standards and programs such as restructuring of the safety committee, setting up periodic inspection schedules, hazard assessment, as well as implementation of safety performance incentives. To facilitate this work, the organization of the safety management system was divided into the technical and human sub-systems. Although the regulations put in place at the level of the organization of the safety management system affects these sub-systems, numerous management planning activities are performed at the level of the technical sub-system. These include all controllable measures and policies which are thought to be instrumental to the reduction of incident rates. At this level, various interventions are put in place in order to change the organization. These include changes to the job procedures, the implementation of new design or redesigning the work/task as well as the working environment.

The most complicated aspect of the safety process occurs at the level of the human sub-system. This involves various interventions put in place to change the human knowledge or cognition. These include competence, attitude, motivation or behavior related to safety. Human behavior is quite complicated and cannot be easily predicted (Widdershoven, 1999). Behavioral patterns in humans vary and are subject to change at any time. These behavioral patterns could be a function of physiological conditions, individual opinions and state of mind, stress level, cognitive workload as well as other complicated variables (Conarda and Matthewsb, 2008).

Due to the complexity of the human behavioral patterns, it may be difficult to determine the quality of the safety intervention. One method of dealing with this difficulty is to assume that the quality of the intervention is constant and acceptable for all safety activities. For this research work, the safety interventions are measured in man-hours which do not necessarily reveal the true quality of the safety intervention. For example, an ineffective safety awareness program or training session may last for 3 hours or more without making any significant impact towards changing the behavior of the employees. Several research works have highlighted the difficulties in predicting the human sub-system contribution to the level of errors in a safety model (Iyer et al., 2004; Shakioye and Haight, 2008). This is evident especially in situations where the actual correlations between the technical sub-system, interventions and incidents rates are distorted. The hierarchy and organizational structure of the levels of safety intervention in the workplace is shown in Figure 1.

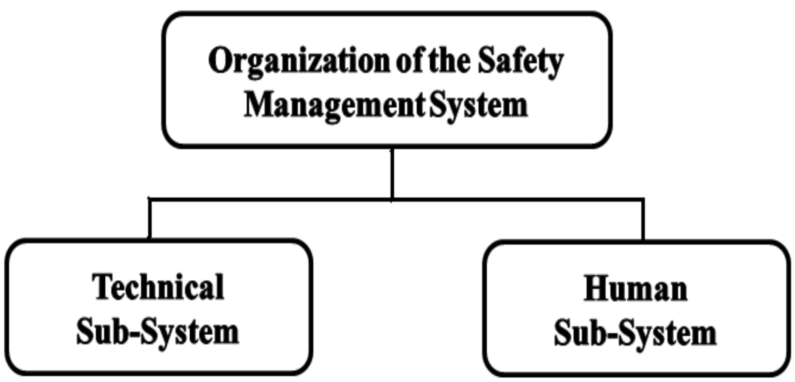

Figure 1. Organizational structure of the levels of safety intervention. (Adapted from Shakioye and Haight, 2008)

Safety Intervention Effectiveness Evaluation

The evaluation of the safety intervention is often considered a major interest to the leadership or management of an organization. This is important in order to prevent the unnecessary expenditure of resources towards an ineffective safety program. Since this research work proposes an effective method for the allocation of resources towards safety intervention, it is important to evaluate the effectiveness of the safety intervention program. Safety intervention effectiveness evaluation could be described as the obtained outcome of an initiative which determines whether a safety intervention achieved its intended effect. In the work place, needs assessment could be conducted in order to determine the type of intervention required for a particular safety problem. Stout (1995) defined needs assessment as *"a systematic exploration of the way things are and the way they should be. These "things" are usually associated with organizational and/or individual performance"*. In situations where a particular safety issue arises, needs assessment may be used to determine the type of intervention to be selected or designed to address the identified need. For example, incident rates could increase due to the problem of militant interfering with oil production activities in the Niger Delta region. Needs assessment is achieved by conducting analysis of injury statistics, evaluating incident reports, developing questionnaires for employee surveys, and conducting interviews with key workplace personnel such as safety and loss prevention manager, human resources manager, as well as representative of labor and trade union (Kelley, 1996; Stout, 1995).

The safety intervention process evaluation method could be used to determine whether the recommended safety intervention is being implemented appropriately. Safety intervention process evaluation is described as the examination of the early development and actual implementation of the safety intervention strategy or program. This involves the assessment of the strategies to determine whether the safety intervention activities were implemented as planned and whether the expected outcome was actually achieved. Safety intervention process evaluation is performed after a new safety initiative is selected and introduced to the workplace. The process evaluation is used to determine the extent to which new processes have been put in place. It is also useful in obtaining and evaluating the reactions of the employees affected by the newly introduced interventions. This is necessary in order to review the implementation of the new initiative before measuring the effectiveness. It may not be necessary to perform safety intervention effectiveness immediately if results of the process evaluation show that the new initiative is not being implemented as recommended. It should be noted that conducting safety intervention effectiveness evaluation may be time consuming and expensive to perform, especially in situations where safety intervention experts or professionals are needed (Stout, 1995).

Literature Review

Until recently, most safety decision making has been based on reliance on instincts, company's safety history and experience of safety personnel. These types of safety decisions have been largely based on qualitative, motivational and behavioral studies (Bailey, 1993 and Cohen, 1977). Some safety behavioral studies and single intervention methods have attempted to incorporate quantitative analyses into their research works. Other safety and health programs have been designed based on the need to enlighten the employees on how to improve their safety behaviors and performances with the aim of providing an incident free working environment. These include the establishment of awareness programs and policies such as safety training, inspections, meetings, and behavioral based observations, as well as routine and pre-planned preventive maintenance of equipments and provision of performance based incentives (Krause, 1998 and Simon, 1996).Unfortunately, these investigations neglected the interactive effects on the responses that could be obtained from several intervention factors.

Over the years, most companies realized that these traditional intervention methods have fallen short of providing the expected outcomes and results. The failure of these safety practices has led to the need to redefine the safety activities which should be incorporated into a particular safety and health program. This has also led to the need to determine the level of resources to be allocated to the implementation of the safety and health program. Some safety behavioral studies and single intervention methods have attempted to incorporate quantitative analyses into their research. These investigations however, neglected the interactive effects on the response from several intervention factors.

The idea of quantifying safety intervention activities originated from the traditional qualitative approach such as behavioral based intervention (Gregory, 1996; Kelley, 1996; Simon, 1996; Krause, 1997). Whysall et al. (2005) conducted a study to investigate the implementation of safety and health interventions from the behavioral perspective to examine musculoskeletal disorder (MSD) related occupational health problems. In their study, twenty-four intervention activities were selected and monitored for a short period (4 – 6 months). Qualitative analysis was used to identify the factors considered as key barrier to the effective implementation of the intervention programs. Most of the intervention barriers identified were employee and management related. These include resistance to changes in the attitude and behaviors of the employees, and low level of managerial commitment and interest in activities involving safety and health. The intervention barriers were not considered as significant factors which could be analyzed quantitatively.

Most behavioral based studies have considered intervention as a single factor which failed to observe the interactive effects of other safety activities. The evaluation and implementation of a single intervention factor could be justifiable in situations where the other interactive factors are assumed constant. In the 1995 research conducted by the Human Factors in Reliability Group of the United Kingdom Health and Safety Executive, the role of unsafe human behaviors was considered as the major contributory factor in industrial or workplace accidents. Four types of unsafe behaviors were highlighted and management oriented intervention was recommended as the applicable solution. Their study provided a safety audit survey technique which incorporated a questionnaire and interview system to identify areas of the safety program which needs to be improved. The use of qualitative technique in the analysis of safety behaviors of the employees did not produce any meaningful result to the study.

Unsafe acts or behaviors have been identified as one of the major contributing factors to work related incidents. OSHA claims that behavior-based safety programs have been described by OSHA as an attempt to shift the responsibility for a safe workplace totally on the employees, thereby preventing the management from investigating workplace related hazards which are often the incident root causes. In an attempt to improve the working environment, several researchers have suggested the creation of a safety culture which enables management to develop hazard free workplace. Guastello (1993) conducted statistical study using a regression based model to relate incident rates and intervention factors. The developed model was used to compare the prior incident rates to the collected data. A major draw back of Guastello’s model is the assumption of the entire safety program as a single intervention. As a result of this assumption, no interactions could be made for a single intervention.

Statistical studies have shown that a safety program is made up of several intervention activities. Petersen (1998) investigated the effectiveness of safety management policies and teamwork. The survey showed that good communications skills could improve safety management policies, but quantitative analysis of the improvement was neglected. Most of the results of behavioral surveys are based on human perceptions which may not be a true representation of the required intervention program. Perception surveys are useful in complementing safety and health programs but cannot be used a measure of effectiveness. Bailey (1993) conducted a perception survey on four pairs of matched firms based on the relationships between employee perceptions of management behaviors, actions and safety outcomes. The study utilized the Minnesota Perception Survey for the collection of data. The Minnesota Perception Survey, which was initiated in 1976 to analyze the safety of the United States railroad industry, was based on the need to understand the major weaknesses of safety programs.

Bailey found that previous audit tools were unsuccessful in recognizing the impact of behavioral factors on safety performance, thereby leading to unsuccessful attempts to develop solutions to behavioral and management problems. The study also found that in low safety-performing companies, safety was perceived to be of little importance to management, and employees were less influenced by the efforts of the management to promote safety. Additional findings also indicated that the management were perceived to be more interested in keeping their safety records than preventing accidents, employees were perceived to be inadequately trained for their jobs, and were not collectively setting goals for safety. Although Bailey claimed that the firms examined were matched, no information was provided about the exact matching characteristics of the organizations represented. The study was also based on a very small sample size without any statistical analysis of the data.

Performance measurement and feed back have been suggested as the major methods of motivating safe behavior in both employee and management. Gregory (1996) identified seven critical steps from the behavioral perspective of the employee that could be used by the management to develop safe working environment. The study claimed that the provision of positive feed back to employees working in a safe manner would continue to motivate the employees to maintain positive safety behaviors. The safety intervention strategy proposed by Gregory did not fully consider or evaluate other external factors which are not related to the working environment. These external factors could have affected the working environment indirectly. The Figure 2 below shows the seven steps proposed by Gregory.

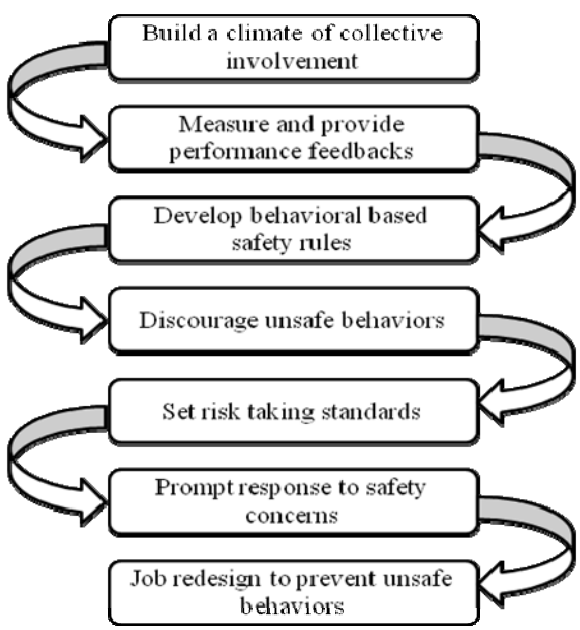

Figure 2. Seven steps to achieving safe working environment. (Adapted from Gregory, 1996)

In order to understand the effect of safety intervention programs, several industries have been investigating the individual influence of each intervention on incident rates. These companies have sponsored research works to consider the possibilities of establishing relationships between safety intervention factors and incident rates. This necessary in order to create optimization models which could be used to predict future incident rates and enhance efficient allocation of resources. Haight et al. (2001a and b) set the foundation for the use of an analytical approach for the quantification of safety intervention programs in the oil industry by comparing current incident rates to the past incidents. The study showed the relationship between the incident rates and the intervention factor levels for the health and safety program.

In the study, efforts were made to quantify a loss prevention program and a mathematical expression was developed. Regression analysis was used to compare the recoded intervention and incident rates. Iyer et al. (2004) developed a mathematical relationship between the leading safety program intervention activity levels and the incident rates. The developed model was used to optimize the safety and health program in a power company. Statistical methods and regression analyses were used to validate the optimization model. Results from this study show a statistically significant, exponentially decreasing mathematical relationship which indicates the relationship between the incident rate and the intervention application rate. This study shows that the effect of safety intervention could last about six weeks.

In this paper, the researchers use statistical techniques such as response surface methodology and contour plots to investigate the interactive effects of safety factors obtained from a leading oil company in the Niger-delta region of Nigeria. The mathematical model obtained from the data could be used to predict incident rates. The developed mathematical model could also be used to minimize incident rates and better predict allocation and optimization of resources. Supervisors and mangers could use the analysis obtained from this research work to develop an effective resource allocation program which would minimize costs associated with safety. The need for quantitative analysis of incident records in the establishment of effective safety intervention programs has led recent researchers to focus their attention on multiple factor intervention strategies.

Attwood et al. (2006) proposed a model to predict incident costs by incorporating multiple factors such as the quality of the protective equipments utilized by the employees, the frequency of training programs adopted by the organization, and the frequency of motivational incentives provided. Although the developed model shows that incident costs decrease over time, the research lacked sufficient data to adequately show the correlation or mathematical relationship between the predicted man-hours and the incident frequency. In an effort to determine the relationship between incident rate and the total man-hours allocated, the National Institute for Occupational Safety and Health (NIOSH) conducted a research study which argued that increasing the level of man-hour allocation tend to reduce incident rate. The study showed that a decline in incident rate is based on the level of the application of safety intervention (NIOSH, 1999). Haight et al. (2001b) argued that at some point, an additional allocation of man hour will no longer necessarily impact incident rate reduction in a substantial manner.

This research therefore, goes a step further in identifying the region at which any additional allocation of man-hours will no longer provide a realistic justification for continuous allocation of resources. It should be noted that additional application of resources in an effort to further minimize incident rate beyond the "optimum region" will lead to an unnecessary increase in safety costs. Although, most companies may be willing to allocate huge resources and capital towards achieving incident rates of zero, it may be highly impossible to achieve this objective in reality. The exponential curve which depicts exponentially decaying relationship between incident rate and total man-hours applied to safety intervention activities is shown in Figure 3.

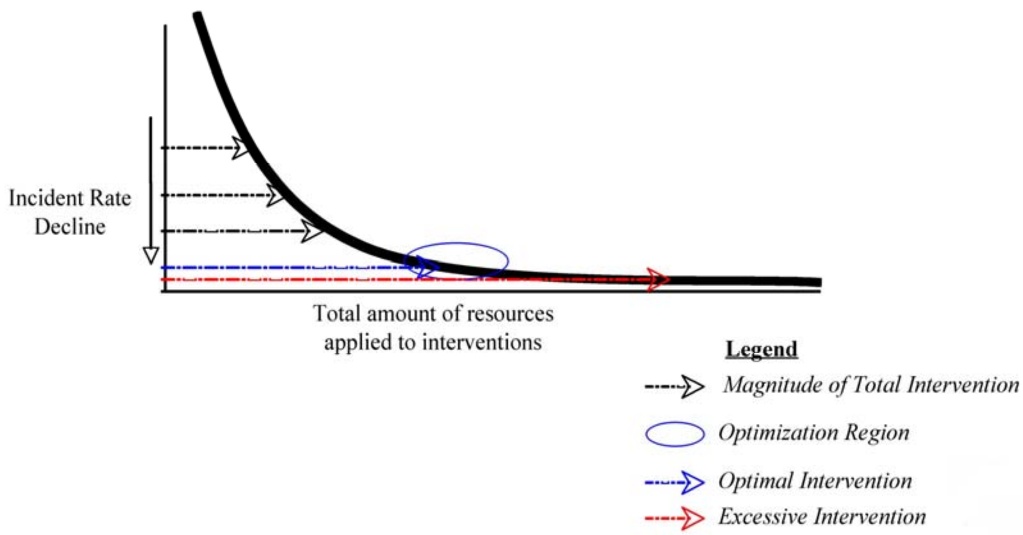

Figure 3. Exponential Decay for Incident Rate. (Adapted from Shakioye and Haight, 2008)

Haight et al. (2001a and b) conducted research works which set the real foundation for the use of analytical approach in the quantification of safety intervention programs in the oil industry. This study showed the relationship between the incident rates and the intervention factor levels for the health and safety program. In their studies, efforts were made to quantify a loss prevention program and a mathematical expression was developed. Regression analysis was used to compare the recorded intervention and incident rates. Iyer et al. (2004 and 2005) developed a mathematical model to evaluate the relationship between the leading safety program intervention activity levels and the incident rates. In these research works, incident rates were compared to the recordable past incidents and the developed model was used to optimize the safety and health program in a power company. Statistical methods and regression analyses were used to validate the optimization model. The results obtained from the study showed that the model is statistically significant, with an exponentially decreasing mathematical relationship between the incident rate and the intervention application rate. The study showed that the effect of safety intervention could last about six weeks.

Importance of Multiple Factors in Safety Intervention

In the current global economy, companies tend to be more competitive by endeavoring to keep the good reputation of their organization while maintaining high productivity at the same time.

Several companies consistently seek to improve their overall performances by adopting various strategies aimed towards cost reduction, improved lead time, product quality and flexibility in design. In most cases, non-profit oriented or “invisible” aspects such as health and safety are ignored and as a result, resources are not often allocated for these functions in the budget. With the increasing costs associated with industrial incidents and in an effort to maintain good reputation, several organizations have begun to promote the development of health and safety programs.

Numerous studies have proposed multiple variables or factors which are important in the development of successful safety intervention programs. Fulwiler (1996) described successful health and safety programs as a key driver in the maintenance of positive organizational reputation. Since it is important for companies to remain competitive, loss of good reputation as a result of the failure to implement successful safety intervention program could be devastating to any organization. It is therefore important to understand the importance of the safety activities needed for the fulfillment of successful safety programs.

Experimental Design

The empirical observation study for this paper was undertaken at an oil exploration and production company in the Niger Delta region of Nigeria. The foreign-owned company operates using the American style of safety program. For over 200 weeks, employees reported the amount of time spent implementing five categories of safety-related interventions as well as the incident rates for each of those weeks. This approach is similar to the data collection process adopted by Haight et al. (2001a and b) and Iyer et al. (2004). External or uncontrollable factors are regarded as nuisance factors. Nuisance factors are those factors that are known and uncontrollable. They may affect the measured results, but are not of primary interest. Blocking can be used to reduce or eliminate the contribution to experimental error contributed by nuisance factors. In this study, the nuisance factors considered for blocking include government legislation, downtown due to militant rampages and kidnappings along the Niger-delta, economic constraints, climate and humidity, previous safety records, and other environmental and safety associated costs such as royalties to the government and local citizens.

In order to effectively document and organize the collected data, a weekly data sheet was used to record man-hours allocated to the various intervention activities. This weekly data sheet was developed using windows excel for easy data input. Thirty- four safety activities such as process sponsor engagement in health and safety, identification, supervision, training and management of short service employees, pre task hazard assessment by the contract crew, and other types of safety methods were grouped into the five major categories or factors based on the similarities of the activities. The groups include leadership attitudes towards safety and accountability, qualification selection and pre-job safety activities, employee/third-party or contractor engagement and planning, safety activities related to work in progress, and activities based on evaluation, measurement and verification of the adopted safety program. The thirty-four safety activities selected for this research work are based on the health, environment and safety management information of the organization listed below.

Factor A: Leadership and Accountability

1. Process sponsor engagement in employee health, environmental and safety management

2. Process advisor engagement in employee health, environmental and safety management
3. Organizational targets are established for performance indicators
4. The company leadership periodically reviews employee health, environmental and safety (HES) performance, recommends and implements improvement
5. The company leaders and managers establish, provide resources and participate in employee health, environmental and safety management

Factor B: Qualification Selection and Pre-Job

1. An approved employee lists are maintained
2. The employee qualification and selection process addresses HES performance considerations
3. Employees apply HES requirements to contractors or third parties
4. Pre-Job meetings with employees are conducted prior to start of work
5. A Pre-Job "HES plan" is developed for all work projects
6. Identification, supervision, training and management of short service employee
7. A motivational/safety incentive for the employees is in place
8. Skills development training and verification by individual
9. HES training development and verification

Factor C: Employee Engagement and Planning

1. Local Tenets of operational excellence (OE) are communicated to employees and incorporated into employee work process
2. Periodic meetings between company leadership and employee representatives are conducted.
3. Joint employees-contractor meetings are held
4. Regular field visits are conducted by company managers and supervisors for the purpose of discussing HES performance with employees
5. Specific local strategies and plans are developed and implemented to improve local employee HES performance
6. An employee safety plan that addresses all risk assessment is in place.
7. HES expectations and requirements are clearly communicated to the employee and contractor prior to contract execution

Factor D. Work in Progress

1. Incident investigation and review (II&R) process
2. Employee health, environmental and safety management process audits and evaluates safety performances periodically
3. Daily tailgate and regular HES meetings are conducted
4. Job safety analysis (JSA) are conducted
5. Pre-task hazard assessments are conducted by the employee and contract crew
6. On-site HES monitoring is provided for high risk and or large jobs
7. Field reviews are conducted
8. Management reviews conducted joint on employees and contractors
9. Safety permits are issued and used
10. Third party and contractor activities included within the facility Management of Change procedure

Factor E. Evaluation, Measurement and Verification

1. Joint post-job evaluations are conducted part of evaluation
2. Results communicated to contractors
3. Lessons learned are evaluated and incorporated into future contracting efforts.

The percentage of each of these five factors to the total available man-hours corresponds to x_1, x_2, x_3, x_4 and x_5 where x_1, x_2, x_3, x_4 and x_5 are regarded as the independent variables. The dependent variable is the total incident rate recorded per 200,000 hour which is denoted with y. Based on this, a mathematical representation is expressed for the interactive relationship between the independent and dependent variables is shown in equation 1.

$$\mathbf{y = f\,(x_1, x_2, x_3, x_4, x_5, \varepsilon)\ldots\ldots\ldots\ (1)}$$

From the above representation, ε denotes the human and process error in the intervention which includes the uncontrollable and nuisance factors. The input variables or controllable factors, $x_{1,\ldots,}$ x_5 are represented as:

x_1 = Factor A → Leadership And Accountability
x_2 = Factor B → Qualification, Selection and Pre-Job
x_3 = Factor C → Contractor Engagement and Planning
x_4 = Factor D → Work In Progress
x_5 = Factor E → Evaluation, Measurement and Verification
ε = the experimental random error.

In order to further determine the statistical characteristics of the data, confounding was incorporated into the 3^5 factorial design. Confounding could be described as an experimental technique used for arranging a complete factorial experiment in blocks. This technique is implemented in situations where full factorial designs have to be run in blocks and the block size is smaller than the number of different treatment combinations in the design (Montgomery, 2008). The defining contrast for the three-level five factorial design is shown in equation 2.

$$\mathbf{I=A^2B^2C^2D^2E^2\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (2)}$$

In this case, the defining contrast is aliased with the two degrees of freedom for the block effects. As a result, the 3^5 factorial design is confounded into 3 blocks (Mod 3), each with 81 data points. This type of confounding method is considered incomplete block design since each block does not contain all the treatments or treatment combinations. It should be noted that incomplete block designs allow for simplified method of analysis. The mathematical representation of the non-randomized incomplete block design for the 3^5 factorial design is shown as:

x_i = level of the i^{th} factor appearing in a particular treatment combination
α_i = the exponent (power) appearing on the i^{th} factor in the effect to be confounded. In this case, α_i = 0, 1 or 2.
k = number of factors.

Therefore, the defining contrast is denoted in equations 3 and 4 as:

$$\mathbf{I = \alpha_1\ x_1 + \alpha_2\ x_2 + \ldots + \alpha_k x_k\ldots\ldots\ldots..(3)}$$

$$\mathbf{I = 2x_1 + 2\ x_2 + 2\ x_3 + 2\ x_4 + 2\ x_5\ \ldots\ldots\ldots(4)}$$

Replication and Blocking

Replication in experimental design increases the sample size and is a method for increasing experimental precision. In terms of statistical characteristics, replication increases the signal-to-noise ratio in situations where the noise originates from uncontrollable nuisance variables. A replicate is a complete repetition of the same experimental conditions, beginning with the initial setup (Telford, 2007). In this research, the experiment is replicated 3 times, thereby increasing the number of runs from 243 to 729. Another major advantage of replication in experimental design is the ability to obtain an estimate of the experimental error. The estimation of error is necessary in order to determine the observed statistical differences in the data (Montgomery, 2008).

Since the human and process error in the safety intervention often includes some uncontrollable and nuisance factors, it is important to incorporate blocking into the design of the experiment. Blocking is an experimental design method used to increase the precision with which the comparison of the factors of interest are made. Blocking is used to remove the effect of variability obtained from nuisance factors and can be used as a method of removing variability from the experimental error. Incorporating blocking into experimental design enables sensitivity of detecting significant treatment effect to be increased in situations where needed (Gardiner and Gettinby, 1998; Montgomery, 2008; and Telford, 2007). In this research, the 3^5 factorial design is confounded into 3 blocks so as to remove the effects of uncontrollable nuisance factors.

Results

Statistical analysis of the data was conducted using Design Expert, STATISTICA and MINITAB. The data was analyzed through certain graphs and model adequacy testing. Analysis of variance tests for the 3-level factorial design was conducted with a confidence interval of 95%. The safety activities and incident rates for each week were analyzed in order to determine whether incident rates are dependent on the percentages of resources and times allocated to each safety activity. Analysis of variance (ANOVA) test was conducted to in order to determine factor and interaction relationships in the model. Using the Pareto chart, positive and negative effects were indentified. Positive effects are factors and interactions which increase the level of significance of a model, while the negative effects are factors and interactions which reduce the level of significance of a model. A total of 31 effects were identified for the model, 19 positive and 12 negative effects of the factors and interactions obtained are shown in the Pareto chart in Figure 4.

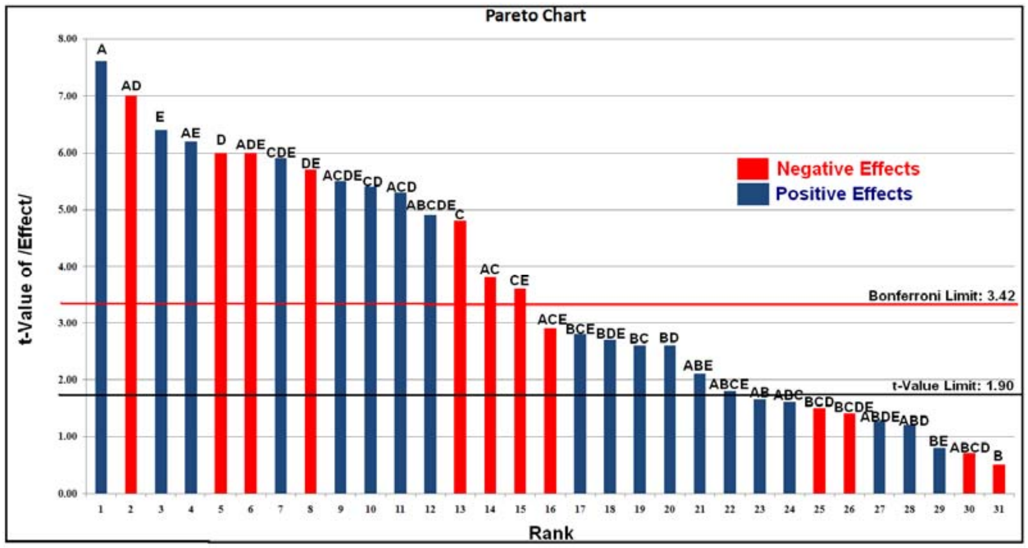

Figure 4. Positive and Negative Effects for Factors and Interactions.

Figure 4 above shows 31 factors and interactions with 19 positive and 12 negative effects respectively. Factors A and E show a very significant positive effects with t-values of 7.61 and 6.40 respectively. Factor B (ranked 31st) shows a negative effect with a t-value of 0.50. This shows that spending more man-hours conducting safety intervention of factor B (Qualification, Selection and Pre-Job) does not have a positive significant impact on the incident rate. Allocation of resources towards Factor B may not be recommended as a result of this. For this particular oil exploration unit, spending unnecessary capital or allocating resources on factors and interactions which show negative effects do not have any immediate positive impact on minimizing incident rates. In practical terms, other contributing reasons may be responsible for these negative effects, which when corrected could create positive effects. It may therefore be necessary to investigate the reasons why these factors and interactions show negative effects, however, concentrating on these negative effects would end up increasing safety costs.

In some situations, it may be difficult to entirely separate allocation of resources on some positive effects shown to have interacted with one or more negative effects. The only realistic method of optimization of resources would involve allocating limited resources towards the negative effect and at the same time, apportioning higher resources to those effects which are considered positive. Negative effects could be changed to positive effect when the most negative interaction is eliminated or assumed to be negligible. For example, the positive effects interacting with negative effects in the interactions of factors BCDE (Qualification, Selection and Pre-Job, Contractor Engagement and Planning, Work In Progress, and Evaluation, Measurement and Verification) could be improved by considering B as negligible or ineffective. The t-value of BCDE which is a negative effect is 1.48 (ranked 26th), while the interactions of factors C (Contractor Engagement and Planning), D (Work In Progress), and E (Evaluation, Measurement and Verification) - CDE has a t-value of 5.90 (ranked 7th). This suggests that BCDE could be improved upon by spending less time concentrating on the subsequent negative effects (BCD and B). In order to effective manage and allocate resources, it will be necessary to concentrate more efforts on the significant factors and positive interactive effects. In order to determine whether incident rates depend on at least one or more factors in the normal model, all factors and interactions were investigated using ANOVA as shown in Table 1.

Table 1. Analysis of Variance (ANOVA) for the Safety Intervention Model.

Source	Sum of Squares	Degree of Freedom	Mean Square	F-Value	p-Value Prob>F
Block	0	2	0		
Model	2949.23	31	95.14	23.98	< 0.0001
A-A	229.51	1	229.51	57.84	< 0.0001
B-B	0.056	1	0.056	0.014	0.9057
C-C	86.13	1	86.13	21.71	< 0.0001
D-D	152.13	1	152.13	38.34	< 0.0001
E-E	170.34	1	170.34	42.93	< 0.0001
AB	7.77	1	7.77	1.96	0.1623
AC	60.86	1	60.86	15.34	< 0.0001
AD	204.48	1	204.48	51.54	< 0.0001
AE	159.3	1	159.3	40.15	< 0.0001
BC	19.91	1	19.91	5.02	0.0254
BD	16.95	1	16.95	4.27	0.0391
BE	0.37	1	0.37	0.093	0.7603
CD	120.3	1	120.3	30.32	< 0.0001
CE	53.99	1	53.99	13.61	0.0002
DE	128.88	1	128.88	32.48	< 0.0001
ABC	6.18	1	6.18	1.56	0.2124
ABD	1.69	1	1.69	0.43	0.5145
ABE	12.18	1	12.18	3.07	0.0802
ACD	111.61	1	111.61	28.13	< 0.0001
ACE	31.81	1	31.81	8.02	0.0048
ADE	152.12	1	152.12	38.34	< 0.0001
BCD	4.14	1	4.14	1.04	0.3074
BCE	25.47	1	25.47	6.42	0.0115
BDE	20.17	1	20.17	5.08	0.0245
CDE	149.79	1	149.79	37.75	< 0.0001
ABCD	0.31	1	0.31	0.079	0.7791
ABCE	8.89	1	8.89	2.24	0.1349
ABDE	1.94	1	1.94	0.49	0.4846
ACDE	122.36	1	122.36	30.84	< 0.0001
BCDE	2.99	1	2.99	0.75	0.3859
ABCDE	88.63	1	88.63	22.34	< 0.0001
Residual	2757.62	695	3.97		
Lack of Fit	2726.5	662	4.12	4.37	< 0.0001
Pure Error	31.12	33	0.94		
Cor Total	5706.86	728			

The significant model terms in the analysis of variance Table 2 are A, C, D, E, AC, AD, AE, CD, CE, DE, ACD, ACE, ADE, CDE, and ACDE. Other significant model terms interacting with Factor B were screened from the model since Factor B is not significant. The selected significant model terms were further analyzed to develop a regression model which gives a better prediction of the dependent variable (incident rate). The regression model is shown in equation 5 as:

Incident Rate = 21.41 -2.19A - 4.47C -6.37D -21.80E +1.60AC +1.69AD + 3.69AE + 1.65CD +3.83CE +7.55DE -0.63ACD -0.83ACE -2.01ADE -1.70CDE+0.53ACDE...... (5)

The incident rate model (equation 5) could be written in terms of x_i where i = 1,2,3,4, and 5 and A= x_1, B= x_2, C = x_3, D = x_4, and E = x_5. The safety intervention model could therefore be written as shown in equation 6.

$$(y) = 21.41 - 2.19x_1 - 4.47x_3 - 6.37x_4 - 21.80x_5 + 1.60x_1 x_3 + 1.69x_1 x_4 + 3.69 x_1 x_5 + 1.65x_3x_4 + 3.83x_3x_5 + 7.55x_4x_5 - 0.63x_1x_3x_4 - 0.83x_1x_3x_5 - 2.01x_1x_4x_5 - 1.70x_3x_4x_5 + 0.53x_1x_3x_4x_5 \ldots\ldots (6)$$

Where y is the independent variable and x_1, x_3, x_4 and x_5 are the input variables.

The statistical behavior of the safety model in terms of standard deviation, mean, coefficient of variance (C.V), prediction error sum of squares (PRESS), adequate precision and the R^2- values are shown in Table 2 below.

Table 2. Statistical Summary of the Safety Model.

Source	DF	Sum Sq.	Mean Sq.	F	P
Regression	14	3589.90	256.42	86.63	0.000
Residual Error	714	2116.96	2.96		
Total	728	5706.86			

S = 7.09972 R-Sq = 54.3% R-Sq(adj) = 53.4%

Further analysis of the model was conducted in order to analyze model adequacy. The analysis of variance for incident rates was performed in order to determine the level of significance of the factor interactions. Table 3 shows the results obtained from the analysis of variance for the main effects and interactions for the model. The analysis of variance for the factor interactions shown in Table 3 proves that the safety model is significant.

Table 3. Analysis of Variance for Main Effects and Interactions.

Source	Deg. of Freedom	Sum of Squares	Adj. Sum of Squares	Adj. Mean Square	F-Value	p-Value Prob>F
Main Effects	5	1064.7	247.65	49.5294	12.52	0.000
2-Way Interactions	10	843.87	518.02	51.8025	13.09	0.000
3-Way Interactions	10	819.48	837.53	83.7533	21.17	0.000
4-Way Interactions	5	132.55	193.37	38.6732	9.77	0.000
5-Way Interactions	1	88.63	88.63			0.000
Residual Error	697	2757.62	2757.62	3.9564		
Lack of Fit	200	2726.5	2726.5	13.6325	217.71	0.000

Pure Error	497	31.12	31.12	0.0626		
Total	728	5706.86				

In order to determine the normality of the model, the normal plot of residuals was analyzed to determine whether the normal probability plot passes the "fat pencil" test. The "fat pencil" test is a terminology used to determine the level of closeness of the data points to a straight line. The normal plot of residuals shown in Figure 5 shows a high level of adequacy in normality of the model.

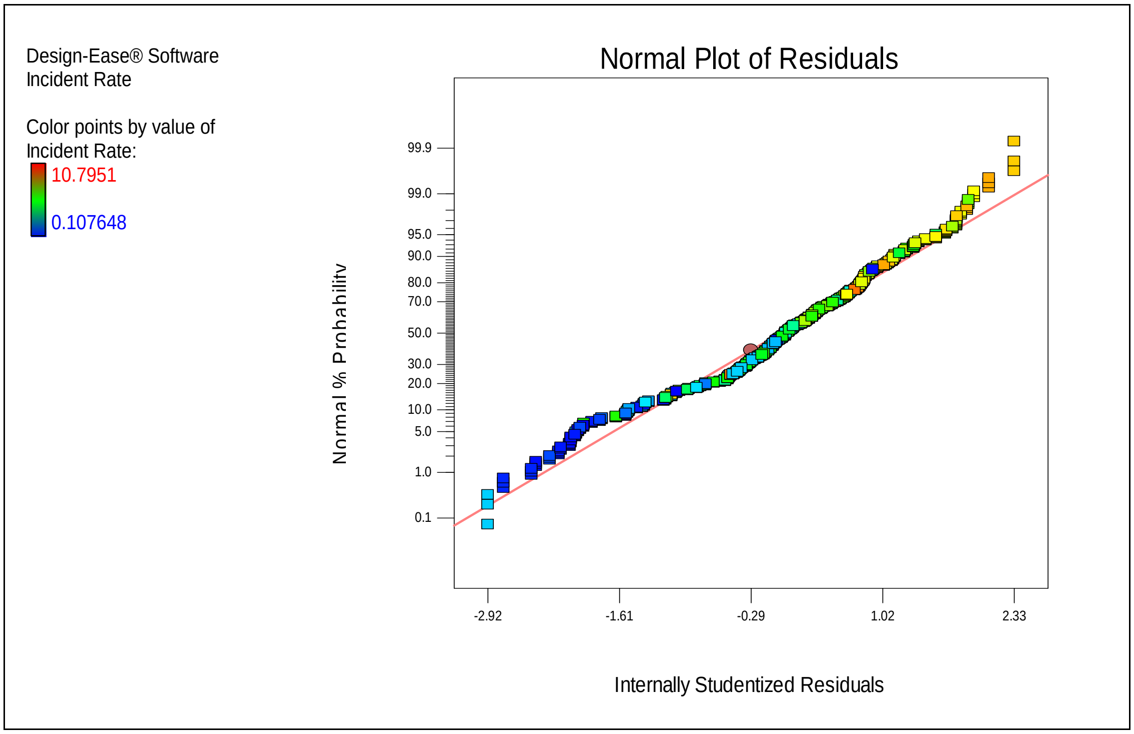

Figure 5. Normal Plot of Residuals for the Safety Model.

Model Optimization Using Response Surface and Contour Plots

Optimum levels of incident rates could be estimated through the use of response surface and contour plots. Response surface methodology is described as the geometric representation of the plot of a response variable considered as a function of one or more quantitative factors. Contour plots are curves which identify the values of the factors for which the response is constant (Mason et al., 1989). Optimum values of the response variables could be determined based on the values of the factors which produce the optimality in the response surface design and contour plots. In this research, the form of response surface used is the second-order (quadratic) function which is mathematically represented in equation 7 as:

$$\mathbf{y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k + \varepsilon} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\mathbf{(7)}$$

The second order response surface function is given in equation 8 as:

$$\mathbf{y} = \boldsymbol{\beta}_0 + \sum_{i}^{k} (\boldsymbol{\beta}_i\, \mathbf{x}_i) + \sum_{i=1}^{k} (\boldsymbol{\beta}_{ii}\, \mathbf{x}_i^2) + \sum_{i=1}^{k-1} \sum_{\substack{j=2 \\ i<j}}^{k} (\boldsymbol{\beta}_{ij}\, \mathbf{x}_i\, \mathbf{x}_j) + \varepsilon \quad \textbf{....(8)}$$

Where;

k = the number of factors;

$x_1, x_2, \ldots, x_k$ are the input variables which influence the response (y)

β_0 = the overall mean response,

β_i = the main effect for each factor (i = 1, 2,..., k),

β_{ij} = the two-way interaction between the i^{th} and j^{th} factors,

β_{ii} = the quadratic effect for the i^{th} factor, and

ε = the experimental random error.

Figure 6 represent the response surface designs depicting the relationship between incident rate and Factors A, and E. It should be noted that incident rate is minimized in the depressed region of the response surface plots (local minimum) while the elevated point depicts the region of increased incident rates (local maximum).

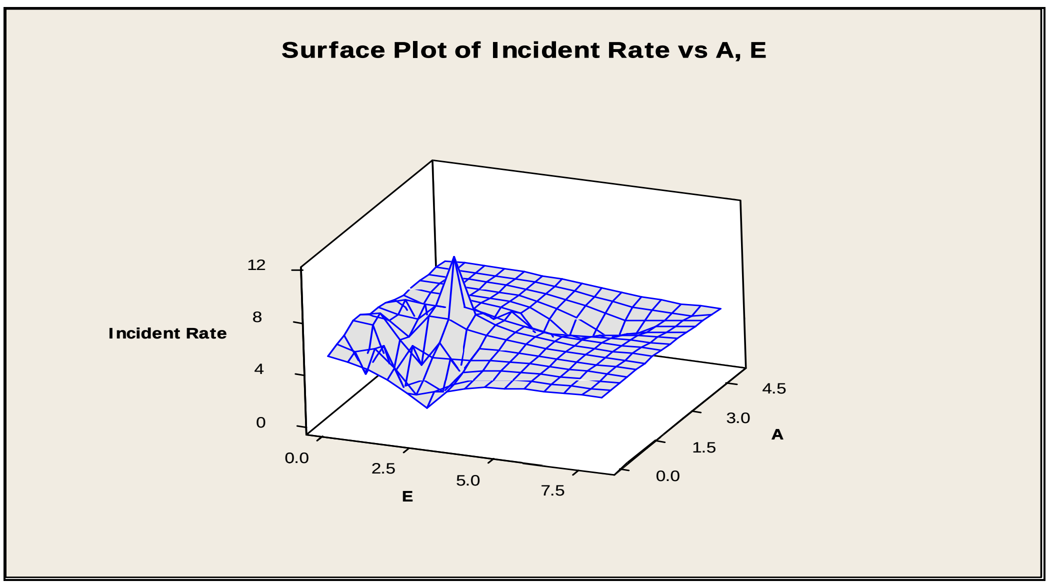

Figure 6. Response Surface Plot of Incident Rate vs. Factors A and E.

From Figure 6, the optimum or desirable incident rate (zero) is achieved when the organization allocates 1.5% of its available man-hours or resources to Factor A (Leadership and Accountability) and 2.5% of its available man-hours or resources to Factor E (Evaluation, Measurement and Verification). On the other hand, incident rate is drastically increased (a value of 12) when the organization doubles the allocation of its available man-hours or resources from 1.5% to 3.0% to Factor A, but the allocation of the available man-hours or resources to Factor B is kept the same at 2.5%. This indicates that the additional allocation of resources towards safety intervention activities do not necessarily minimize incident rates.

Sensitivity analysis could be performed on response surface designs in order to achieve optimum or near optimum values of the response variable due to changes in the levels of the factors. Sensitivity analysis of the response surface design provides the opportunity for the model to indicate the direction of future exploration of the likely optimum. This is based on an attempt to predict the direction of movement of the factor levels in order to achieve optimality. Contour plots are used for the visualization of the shape of a three-dimensional response surface design. The lines or curves of a contour plot represent the heights of the response surface. The location of the maximum value of the response is known as the point of maximum response of the contour plot. Figure 7 represent the contour plots for the response surface design shown in Figure 6.

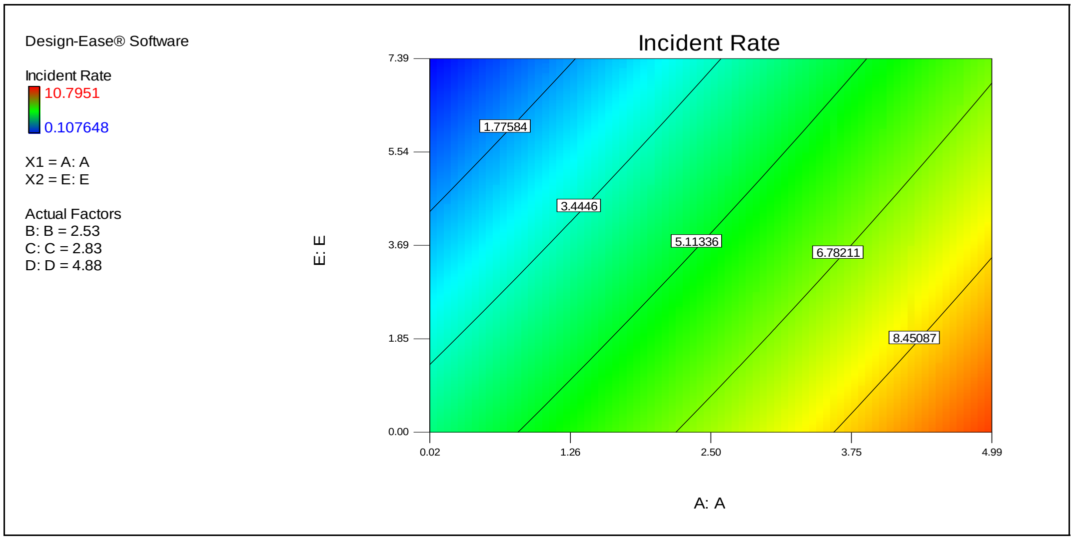

Figure 7. Contour Plot of Incident Rate vs. Factors A and E.

Conclusion

This research study shows that the allocation of additional allocation of resources towards safety intervention activities do not necessarily minimize incident rates (See Figure 6). Also, the allocation of resources to Factor B (Qualification, Selection and Pre-Job) would not likely improve the safety intervention program, thereby leading to indiscriminate waste of resources and capital. This means that the qualifications of the employees do not impact safety activities within the organization examined. The types of selection methods for tasks, as well as other safety activities such as the implementation of incentive programs and individual safety training do not necessarily minimize incident rates.

This research also shows that Factors A (Leadership and Accountability) and E (Evaluation, Measurement and Verification) are very significant factors (See Figure 4). This means that the allocation of resources to safety activities involving leadership and accountability as well as the evaluation, measurement and verification of safety intervention would indeed minimize incident rates. It is therefore important for the management to concentrate more efforts and resources to these very significant factors. From the business perspective, this would positively increase the effectiveness of the safety intervention model. The organization could also improve its overall safety intervention policy by spending more time and allocating more resources to safety evaluation, measurement and verification. The high level of significance of Factor E (Evaluation, Measurement and Verification) shows that the organization would be able to predict and minimize incident rates if quantitative evaluation, measurement and verification of safety interventions are accurately performed by environmental, health and safety employees. Quantitative evaluations often include the performance of investigative studies and research to examine the areas of the safety intervention program which needs to be addressed or improved upon.

In addition to the numerous benefits, supervisors and managers could use the analysis obtained from this research work to develop an effective resource allocation program which would minimize costs associated with safety. Mathematical modeling of intervention activities provides the opportunity for efficient management of the safety system based on the developed resource allocation methodology. The ability of an organization to apply quantitative evaluation, measurement and verification strategies to their safety program helps in the creation of an effective safety culture which in turn reduces workplace incidents. Industrial incident-associated costs, such as compensation, down time costs are reduced in situations where an organization is aware of the various safety intervention factors needed to reduce incident rates. Increased workplace safety improves the level of image preservation and reputation of a safety-conscious organization. This in turns reduces employee turnover rate, increases profitability and improves the public shareholder value.

Future Work

We intend to further expand this work by verifying the developed model based on the recommendations from this work. Using optimization techniques, the developed safety intervention model would be able to predict incident rate values based on these input variables (factors). A critical step in the expansion of this work is to set safety decision making standards by incorporating weights to the factors. This is intended to provide a more realistic value of incident rates and could indicate the level of willingness of the management in the allocation of resources towards the safety activities. The weighted safety model would incorporate quantitative techniques and the preference of the management based on past incident rates to predict effective resource allocation policies which will minimize ineffective intervention programs.

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