2
Resource Allocation and Effectiveness Measures for Loss Prevention

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2.1
Introduction

Many workplace loss prevention and intervention programs in safety and health have been developed and implemented, yet few have undergone systematic evaluation to determine their quantifiable impact on health and safety and health outcomes, especially in terms of cost-effectiveness. This chapter is intended to provide crucial guidance and corrective feedback for current and future safety and health intervention and resource allocation decision-making efforts. The cost of workplace injuries and the effectiveness of safety and health programs designed to prevent them dramatically impact contemporary industrial activities.

Indeed, the National Safety Council estimates that the cost of all fatal and non-fatal unintentional injuries totaled US$684.4 billion in 2007 (National Safety Council, 2009). This is equivalent to about $2300 per capita based on the estimated 300 million resident population of the United States. These are considered a measure of the direct costs of incidents and other indirect costs such as the dollars spent and income not received due to accidents, injuries and fatalities, downtime, and property loss. These costs also include those which were directly paid out of pocket, through higher prices for goods and services, or through higher taxes to the American taxpayers (Oyewole *et al.*, 2010).

Current research efforts have been aimed at the evaluation and optimization of the mix of safety and health intervention program components to provide a prioritized decision-making strategy for decreasing injury rates and associated costs, while utilizing available resources more effectively. Past research in specific industries preliminarily indicates that this methodology can be implemented (Haight *et al.*, 2001a,b; Iyer *et al.*, 2004, 2005; Oyewole *et al.*, 2010; Shakioye and Haight, 2010).

Handbook of Loss Prevention Engineering, First Edition. Edited by J. M. Haight.

2.2
What Is Loss Prevention/Safety and Health Intervention?

Intervention could be described as any implementation put in place by the management with the aim of effectively reducing the occurrence of incidents within the workplace. This could include training and awareness programs, routine inspections, engineering interventions, safe job procedure designs, and other administrative procedures (Haight *et al.*, 2001a). 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 the form of a new program, practice, or initiative and idea which is intended to improve safety. Safety interventions in the workplace include job redesign, a training program, incentive programs for safety practices, and other administrative procedures. Safety intervention activities often take place at numerous levels of an industrial health and safety system. In the workplace, major safety decision-making and intervention efforts are often concentrated toward 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 the 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, and 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 affect 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 and 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, and behavior related to safety. Human behavior is complicated and cannot easily be 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, and other complicated variables (Conarda and Matthews, 2008).

Owing to the complexity of 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 h or more, without making any significant impact towards changing the behavior of the employees. Several research studies have highlighted the difficulties in predicting the contribution of the human sub-system to the level of errors in a safety model (Iyer *et al.*, 2004; Shakioye and Haight, 2010). This is evident especially in situations where the actual correlations between the technical sub-system, interventions, and incident rates are distorted.

Intervention application rate is the percentage of available man-hours appropriated to the development and implementation of safety and health intervention programs or any of the component activities in order to minimize incident rate (Haight *et al.*, 2001a). A defined work force, in this case 400 employees, is paid a specific hourly rate (although slightly different for each individual, based on years of experience, training, etc.) – an average hourly rate plus benefits costs is used to indicate how much a company pays to get its work done. For illustration purposes, \$15 per hour + a 40% benefits cost means that a company pays \$21 per hour to each employee to get its work done. If they spend 15% of those available human resource hours (400 employees work ~800 000 h per year), that would cost $800\,000\ \text{h} \times \$21\ \text{h}^{-1} \times 0.15 = \$2\,520\,000$ to implement the safety and health program. In the quantitative analysis of a safety and health intervention, the incident rate is the dependent variable, and the intervention application rates for the safety activities (grouped into intervention categories or factors) are the independent variables.

Workers are paid the same no matter what, but if the workers can be allocated to more productive work, this productivity improvement savings would be realized (Iyer *et al.*, 2004). A more traditional approach has been first to experience an unacceptable incident rate (unacceptable is subjectively determined), then subjectively determine that more effort is needed in the safety and health program. This then triggers the assignment and allocation of human resource hours to the intervention activities that are subjectively perceived to have the most effect on the incident rate; then the company implements, it waits, it hopes, and it determines what the resulting incident rate is.

2.3
Historical Perspective of Resource Allocation for Loss Prevention

The objective of successful performance of engineered systems is to ensure that their expected outcomes are realized. Regrettably, this has not been the case with most safety and health programs. The fact that this type of program involves extensive commitment of resources to prevent incidents (injuries, fires, etc.) without truly knowing if the significant commitment of resources is correct, working or not, or to what extent, is troubling. Currently, research that has tested and proven any means to measure truly the effectiveness of a complete, dynamic, and interactive safety and health program (which is made up of several interactive intervention activities) is very limited. Unfortunately, recent safety and health issues indicate that the industrial sector is in dire need of a better method of quantifying and measuring the cost-effectiveness of the safety and health program.

Most safety and health decision-making processes have been based on reliance on instincts, a company's safety and health history, and experience of safety and health personnel. These types of safety and health decisions have been largely based on qualitative, motivational, and behavioral studies (Cohen, 1977; Bailey, 1993). Some safety and health behavioral studies and single intervention methods have attempted to incorporate quantitative analyses into their research work. Other safety and health programs have been designed to enlighten the employees on how to improve their safety and health 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 and health training, inspections, meetings, and behavioral-based observations, in addition to routine and pre-planned preventive maintenance of equipment and provision of performance-based incentives (Simon, 1996; Krause, 1998). Sadly, these investigations neglected to evaluate the interactive effects on the responses obtained from several safety and health behavioral intervention factors.

Over the years, most companies realized that traditional intervention methods have fallen short of providing the expected outcomes and results (Oyewole *et al.*, 2010). Failure of these safety and health practices has made it necessary to redefine the safety and health 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 and health behavioral studies and single intervention methods have attempted to incorporate quantitative analyses into their research (Bailey, 1993; Guastello, 1993). These investigations, however, neglected the interactive effects on the response from several intervention factors.

In the last 40 years, safety- and health-related intervention activity has been copiously studied (Fellner and Sulzer-Azaroff, 1984; Kalsher *et al.*, 1989; Guastello, 1993; Ray and Bishop, 1995; Tiraboschi, Weiss, and Blayney, 1997; Williams, 2002). Abundant research was in the area of return-on-investment (ROI) for intervention activities and strategies (Diehl and Ayoub, 1973; Oi, 1974; Laufer and Ledbetter, 1986; Donaldson, 1988; Hansen and Knight, 2002; Veltri, Dance, and Nave, 2003). A large body of evidence exists that evaluates behavioral safety and health programs (Smith, Anger, and Uslan, 1978; Sulzer-Azaroff, 1982; Hopkins, Conard, and Smith, 1986; Hopkins *et al.*, 1986; Fox, Hopkins, and Anger, 1987; Geller *et al.*, 1987; Mattila and Hyodynmaa, 1988; Ray, Purswell, and Bowen, 1993; Simard and Marchand, 1994; DePasquale and Geller, 1999; Kamp, 2001; Krause, 2002; Chandler and Huntebrinker, 2003). Numerous methods including scorecard, matrix, and survey-based research offers evidence rating safety and health program effectiveness (Smith *et al.*, 1978; Cleveland *et al.*, 1979; Bailey and Petersen, 1989, 1997; Petersen, 1998; Ingalls, 1999; Taggart and Carter, 1999; Stricoff, 2000; Jervis and Collins, 2001; Toellner, 2001).

These previous studies were designed to explore and estimate system variation in implemented levels of the safety and health programs intervention activities (input variable) and variation in the incident rates (output variable). Unfortunately, none of these earlier studies encompassed a research design that allows the measurement and analysis of a complete and dynamic safety and health program and its interactive effects (especially in the United States). The first efforts of their kind evaluated the effectiveness of a complete and interactive safety and health program in an oil production company (Haight *et al.*, 2001a,b) and the forestry operations of a power company (Iyer *et al.*, 2004, 2005) in overseas locations. The field of safety and health has yet to study fully the complete, integrated effect of interacting safety and health intervention program activities on injury prevention and cost reduction.

Until 2001, no research work had evaluated the interactive effects of individual intervention activities, nor had anyone developed a statistical or mathematical relationship between intervention activity and incident rates. Previous research work attempted to establish relationships between safety and health intervention factors and incident rates. This was based on the need to create optimization models which could be used to predict future incident rates and enhance efficient allocation of resources (Haight *et al.*, 2001a,b; Iyer *et al.*, 2004, 2005). The need for quantitative analysis of incident records in the establishment of effective safety and health intervention programs has led recent researchers to focus their attention on multiple factor intervention strategies (Oyewole *et al.*, 2010; Shakioye and Haight, 2010).

In an effort to establish a relationship between cost-effectiveness and incident rates, Attwood, Khan, and Veitch (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 motivational incentives. Although the developed model showed that incident costs decrease over time, the research lacked sufficient data to show adequately the correlation or mathematical relationship between the predicted man-hours and the incident frequency. To determine adequately the relationship between the incident rate and the total human resource (man-hours) allocated to intervention, the National Institute for Occupational Safety and Health (NIOSH) conducted a research study which showed that an increased level of man-hour allocation actually reduced the incident rate. The study showed that incident rate decline is based on the level of the application of safety and health intervention (NIOSH, 1999).

Previous research studies have shown that improperly implemented safety and health intervention activities do not reduce incident rates and often end up becoming very costly to the organization. Haight *et al.* (2001a) reported that an organization allocating 36% of its available man-hours to implement its safety and health program interventions experienced little improvement in their incident rate over when they were expending 15–17% of their available man-hours in preventing incidents. This result is significant in illustrating that the overall program effectiveness was in question. Conceptually, the research indicated that redirecting only

20% of the available man-hours among the more effective prevention activities could have led to more effective achievement of the desired injury rate reduction.

Recent work in safety and health intervention has revealed the importance of providing an economic justification for resource allocation planning. Oyewole *et al.* (2010) adopted the use of response surface design and contour plots to determine the point at which additional allocation of resources no longer provides justification for incident rate and intervention cost reduction. The research, however, did not attempt to validate the developed resource allocation strategy. While many workplace interventions have been implemented, there has been little research on the evaluation of the effectiveness of these activities. Before workplace intervention strategies can be universally applied, there is a critical need for information on the effectiveness of the many strategies and approaches currently used or planned.

2.4
Loss Prevention/Safety and Health Intervention Effectiveness Evaluation

The evaluation of a loss prevention strategy or safety and health 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 on an ineffective safety and health program. Safety and health intervention effectiveness evaluation could be described as the obtained outcome of an initiative which determines whether a loss prevention/safety and health intervention achieved its intended effect. In the workplace, a needs assessment could be conducted in order to determine the type of intervention required for a particular safety and health 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, which could be based on the influence of the management or employee safety and health attitudes and behaviors.’’ In situations where a particular safety and health issue arises, a 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 owing to the problem of interference by militants with oil production activities in the Niger Delta region. Needs assessment is achieved by conducting an analysis of injury statistics, evaluating incident reports, developing questionnaires for employee surveys, and conducting interviews with key workplace personnel such as a safety and loss prevention manager, a human resources manager, and representatives of labor and trade unions (Stout, 1995; Kelley, 1996).

The safety and health intervention process evaluation method could be used to determine whether the recommended safety intervention is being implemented appropriately. A safety and health 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 and health intervention process evaluation is performed after a new safety initiative is selected and introduced to the workplace.

The process evaluation method 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 an immediate safety intervention effectiveness evaluation if results of the process evaluation show that the new initiative is not being implemented as recommended. Performing a safety intervention effectiveness evaluation may be time consuming and expensive to manage, especially in situations where safety intervention experts or professionals are needed (Stout, 1995).

2.5
Importance of Multiple Factors in Loss Prevention

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 competitive priorities and other strategies aimed at cost reduction, improved lead time, product quality, and flexibility in design (Okudan and Akman, 2004). 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 to these functions in the budget. With the increasing costs associated with industrial incidents and in an effort to maintain their good reputation, several organizations actively promote the development of health and safety programs (Shakioye and Haight, 2010).

Numerous studies have proposed multiple variables or factors which are important in the development of successful safety intervention programs. Fulwiler (1998) 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 their inability to implement successful safety intervention programs could be devastating to any organization. Unfortunately, the research work conducted by Fulwiler (1998) did not provide an adequate basis for understanding the importance of the safety activities needed for the fulfillment of successful safety programs.

Successful safety programs are not often evaluated based on the amount of capital or resources allocated to the safety intervention activities. In reality, the additional allocation of resources to any particular program may experience diminishing returns at a certain point. Haight *et al.* (2001a) argued that at some point, an additional allocation of resources would no longer necessarily impact incident rate reduction in a substantial manner. This section of the chapter therefore describes the extension of the investigation conducted by Haight *et al.*

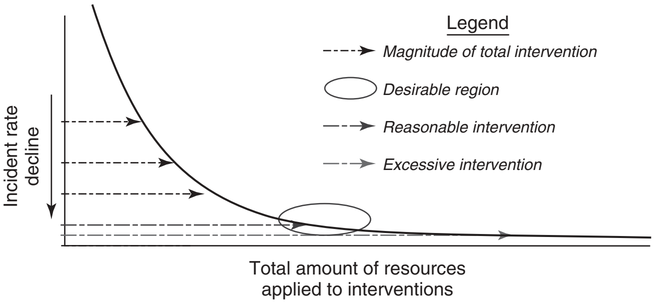

Figure 2.1 Exponential decay curve of incident rate. (Adapted from Shakioye and Haight, 2010.)

(2001a), by identifying the region at which any additional allocation of man-hours no longer provides a realistic justification for the continuous allocation of resources.

It should be noted that additional application of resources in an effort to reduce the incident rate further beyond the "desirable region" would often lead to an unnecessary increase in safety costs. Although most companies might be willing to allocate a huge amount of resources and capital towards achieving incident rates of zero, it may be unrealistic to achieve this objective truly. The exponential curve which depicts the exponentially decaying relationship between incident rate and total man-hours applied to safety intervention activities based on the available resource constraint is shown in Figure 2.1.

2.6
Research Methodology in Resource Allocation for Loss Prevention

Qualitative and quantitative methods were applied to relate past incident rates, human resources allocation procedures, and intervention activities to develop a strategy for assessing the effectiveness of safety and health intervention programs. The present author's study provided an analytical background for the development of an effective safety and health intervention program that was aimed at reducing incident rates (Oyewole *et al.*, 2010). Safety and health intervention data were collected from an oil and gas production company in the Niger Delta region of West Africa. A safety and health intervention model was developed to determine the significant, value-adding safety, and health factors and interactions which minimized incident rates and produced a better resource allocation strategy. The main objectives of this research were as follows:

1) To apply statistical techniques such as response surface methodology and contour plots to optimize the allocation of resources and investigate the interactive effects of safety and health intervention activities.
2) To determine the region or point at which additional allocation of human resources no longer provided a positive impact on incident rate reduction.

2.7
Experimental Method

The data analyzed in this research were based on the empirical observation study which was undertaken at an oil exploration and production company in the Niger Delta region of West Africa. For more than 3 years, safety and health administrators reported the amount of human resource time spent on the implementation of 34 safety- and health-related intervention activities, and also the incident rates on a weekly basis. Possible nuisance or uncontrollable factors taken into consideration and considered for blocking included government legislation, downtime due to militant rampages and kidnappings along the Niger Delta region, economic constraints, climate and humidity, previous safety and health records, and other environmental-related expenses and safety- and health-associated costs such as royalties to the government and local citizens.

The 34 safety and health intervention activities were grouped into five major categories of safety and health intervention factors based on the similarities of the activities: Factor A, Leadership and Accountability; Factor B, Qualification, Selection, and Pre-Job; Factor C, Employee Engagement and Planning; Factor D, Work in Progress; and Factor E, Evaluation, Measurement, and Verification. The 34 safety and health intervention activities selected for this work were site-specific, based on the health, environment and safety, and health management information of the organization. The percentage of each of these five safety and health factors with respect to the total available man-hours corresponds to x_1, x_2, x_3, x_4, and x_5, and these percentages are regarded as the independent variables. The dependent variable is the total incident rate recorded per 200 000 employee-hours, denoted y. A statistical representation is expressed for the interactive relationship between the independent and dependent variables as shown in Eq. (2.1):

$$y = f\,(x_1,\ x_2,\ x_3,\ x_4,\ x_5,\ \varepsilon) \tag{2.1}$$

where ε denotes the human and process error in the intervention, while the input variables or controllable factors are $x_1, \ldots, x_5$.

2.8
Analysis and Results

Statistical analysis of the collected data was performed using the operating platforms Design Expert®, STATISTICA®, and MINITAB®. Analysis of variance (ANOVA) tests for the experimental design was conducted based on a confidence level 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. ANOVA tests were conducted in order to determine factor and interaction relationships in the model. Using the Pareto chart, positive and negative effects were identified. Positive effects are factors and interactions which increase the level of significance of a model, whereas the

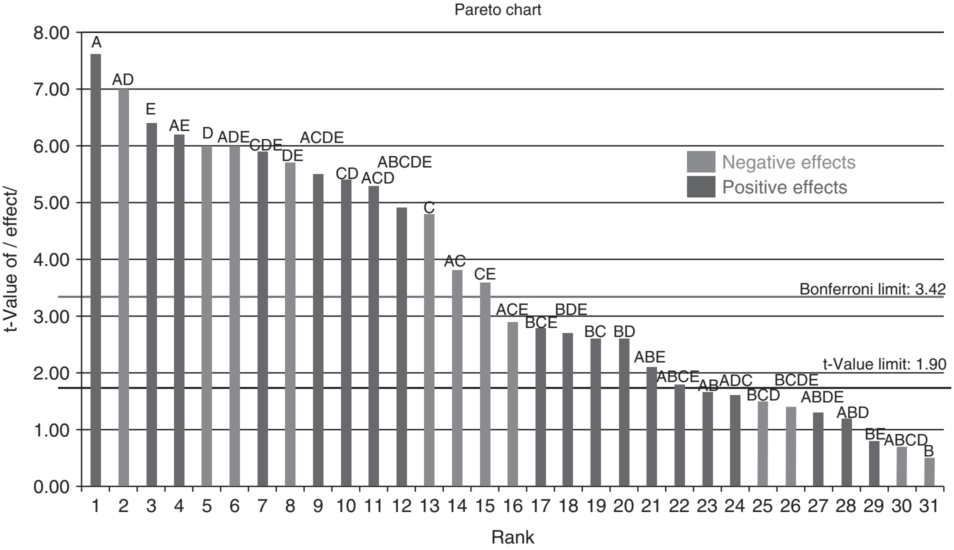

Figure 2.2 Positive and negative effects for factors and interactions (Oyewole *et al.*, 2010).

negative effects are factors and interactions which reduce the level of significance of a model (see Figure 2.2).

From Figure 2.2, it can be seen that 31 factors and interactions yielded 19 positive and 12 negative effects. Factors A and E show 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 implementing safety interventions from the Factor B category (Qualification, Selection, and Pre-Job) do not have a positive significant impact on the incident rate. A positive or negative effect does not indicate that a factor or factor interaction is significant or not. A safety intervention factor or factor interaction could be indicated as a positive effect when it is capable of increasing the value or level of the model significance. The allocation of resources to Factor B might not be recommended as a result of this. It should be noted that negative effects are those factors or factor interactions which do not add value to the level of model significance. Most negative effects are converted to positive effects when interacted or combined with one or more positive effects.

Allocating and spending unnecessary capital or resources on safety intervention factors and interactions which show negative effects do not have any immediate positive impact on reducing 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 intervention costs. In some situations, it may be difficult to separate entirely the allocation of resources on some positive effects shown to have interacted with one or more negative effects (Oyewole *et al.*, 2010).

Table 2.1 Ranks and *t*-values for intervention factors and factor interactions (Oyewole *et al.*, 2010).

Rank	Effect	*t*-Value
1	A	7.61
2	AD	7.00
3	E	6.40
4	AE	6.20
5	D	6.00
6	ADE	6.00
7	CDE	5.90
8	DE	5.70
9	ACDE	5.50
10	CD	5.40
11	ACD	5.30
12	ABCDE	4.90
13	C	4.80
14	AC	3.80
15	CE	3.60
16	ACE	2.90
17	BCE	2.80
18	BDE	2.70
19	BC	2.60
20	BD	2.60
21	ABE	2.10
22	ABCE	1.80
23	AB	1.65
24	ABC	1.60
25	BCD	1.50
26	BCDE	1.40
27	ABDE	1.30
28	ABD	1.20
29	BE	0.80
30	ABCD	0.70
31	B	0.50

The only realistic method of effectively reducing resources would involve allocating limited resources towards the negative effect and, at the same time, apportioning higher resources to the effects which are considered positive. Negative effects could be changed to positive effects 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, Employee Engagement and Planning, Work in Progress, and Evaluation, Measurement, and Verification) could be improved by considering B as negligible or ineffective. Table 2.1 shows the ranks and *t*-values of the safety intervention factors and factor interactions.

The *t*-value of BCDE is 1.48 (ranked 26th), whereas 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 manage and allocate resources effectively, it is necessary to concentrate more efforts on the significant factors (main effects), and the positive interaction effects.

This shows that Factors A, D, and E are very significant safety intervention factors in this research. Owing to the high *t*-values of Factors A, D, and E, concentration of more efforts and resources on these very significant factors is highly recommended. This means that the allocation of resources to safety activities involving leadership and accountability and also the evaluation, measurement, and verification of safety interventions would indeed achieve desirable incident rates. It is therefore important for the management to concentrate more efforts and resources on these very significant factors.

Further analysis of the model was conducted in order to determine the adequacy of the model. ANOVA for incident rates was performed in order to determine the level of significance of the factor interactions. From the analysis, the significant model terms obtained were 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, using the forward regression method to develop a safety intervention model which gives a better prediction of the dependent variable (incident rate). The forward regression method is commonly used in multiple regression analysis; after the first (highest correlated variable) comes in, the relationship of the other variables changes. The same happens when the next variables enter the model based on significance testing. Eventually, only significant variables will be relevant for the model development. If non-significant variables were allowed to come into the model, then R^2 would continue to increase, even though the predictive capability of the regression gets worse. Hence non-significant variables definitely should not be allowed into the model. The regression equation obtained is

$$\begin{aligned}\text{incident rate} = {} & 21.41 - 2.19A - 4.47C - 6.37D - 21.80E + 1.60AC + 1.69AD \\ & + 3.69AE + 1.65CD + 3.83CE + 7.55DE - 0.63ACD \\ & -0.83ACE - 2.01ADE - 1.70CDE + 0.53ACDE \end{aligned} \tag{2.2}$$

The ANOVA for the significant factors and interactions is shown in Table 2.2 and indicates that the safety model is significant.

From Eq. (2.2), incident rates could be predicted from the input variables, and a regression model could be developed to recommend an effective intervention policy based on these factors and interactions. The input variables could be fed into the safety intervention model (regression equation) in order to generate an output (incident rates), as shown in Figure 2.3.

Response surface designs which show the relationship between incident rate and the significant safety intervention factors A, C, D, and E were further used

Table 2.2 Analysis of variance for significant factors and interactions (Oyewole *et al.*, 2010).

Source	**DF**	**SS**	**MS**	***F***	***p***
Regression	14	3589.90	256.42	86.63	0.000
Residual error	714	2116.96	2.96	—	—
Total	728	5706.86	—	—	—

Standard deviation = 7.01; $R^2 = 54.3\%$; $R^2(\text{adj}) = 53.4\%$.

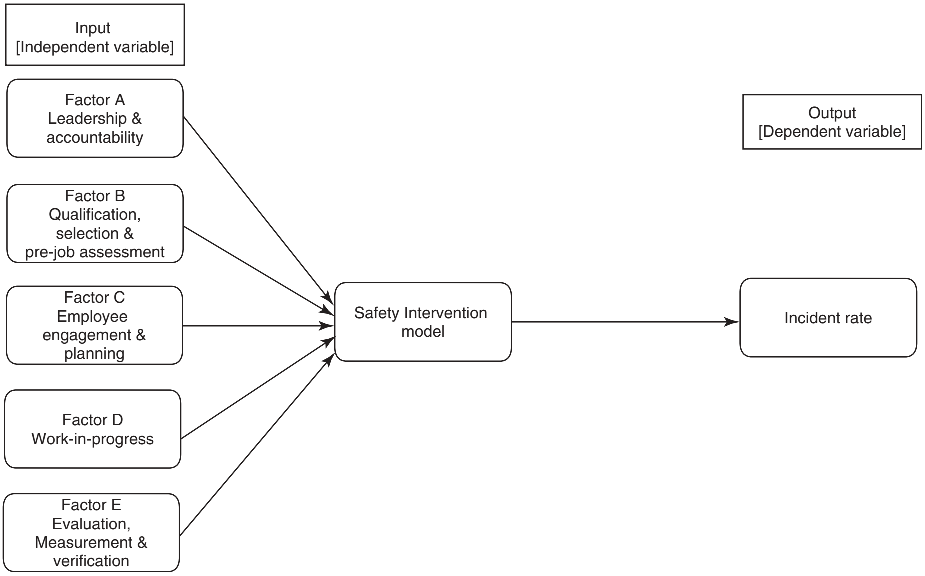

Figure 2.3 Representation of the safety intervention model. (Adapted from Haight *et al.*, 2001a.)

to determine the resource allocation strategy. The use of the response surface provides the foundation for the determination of the regions at which the additional allocation of resources no longer achieves a reduced level of incident rates. This desirable point could be obtained by taking the average value of the near-optimum percentage of resources allocated to each safety intervention Factor A, C, D, and E. Adding up the average values of these near-optimum percentages then yields the recommended near-optimum combined region at which the additional allocation of resources no longer lowers the incident rate. The determination of the average values of the near-optimum percentages could be achieved from the values obtained from the response surface design plots for the relationship between incident rate and the significant Factors A, C, D, and E (see Figures 2.4–2.9).

As shown in Figure 2.4, the near-optimum (desirable) incident rate is achieved when the organization allocated 3.5% of its available resources or man-hours to

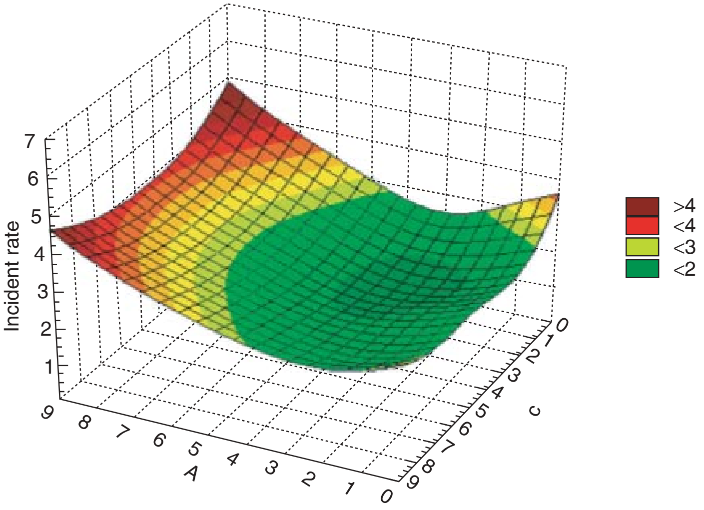

Figure 2.4 Response surface plot of incident rate versus factors A and C (Oyewole *et al.*, 2010).

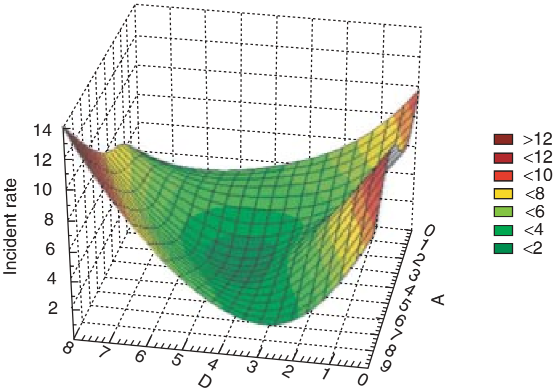

Figure 2.5 Response surface plot of incident rate versus Factors A and D (Oyewole *et al.*, 2010).

Factor A and 3% to Factor C. In order to evaluate the behavior of the response further, a sensitivity analysis was performed on the surface design. Based on the results of the sensitivity analysis, the lowest acceptable incident rate could be obtained when the organization allocated 2% of its available resources to Factor A (Leadership and Accountability) and 1.5% to Factor C (Employee Engagement and Planning). Since external factors (such as labor and budget constraints) could prevent the effective allocation of resources necessary to obtain the desirable incident rate, the lowest acceptable allocation strategy could be beneficial. Figure 2.5 shows that the desirable incident rate is achieved when the organization allocated 5% of its available resources or man-hours to Factor A (Leadership and Accountability) and

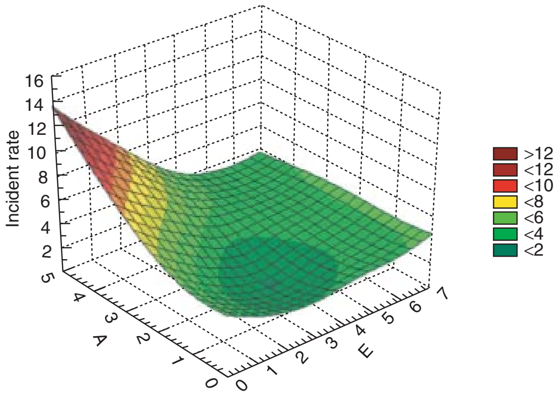

Figure 2.6 Response surface plot of incident rate versus Factors A and E (Oyewole *et al.*, 2010).

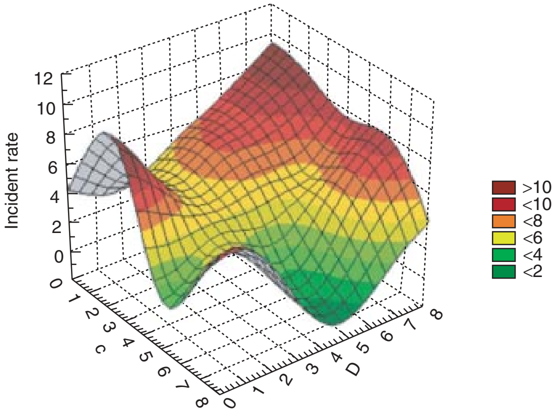

Figure 2.7 Response surface plot of incident rate versus Factors C and D (Oyewole *et al.*, 2010).

4.5% to Factor D. Sensitivity analysis indicated that the lowest acceptable incident rate is achieved when the organization allocated 3.5% of its available resources to Factor A (Leadership and Accountability) and 4% to Factor D.

In Figure 2.6, the near-optimum or desirable incident rate is achieved when the organization allocates 1.5% of its available man-hours or resources to Factor A (Leadership and Accountability) and 3.5% of its available man-hours or resources to Factor E (Evaluation, Measurement, and Verification). On the other hand, the incident rate is increased when the organization doubles the allocation of its available man-hours or resources to Factor A from 1.5 to 3.0%, but the allocation of the available man-hours or resources to Factor E is kept the same at 3.5%. This shows that the additional allocation of resources to safety intervention activities does not necessarily reduce incident rates.

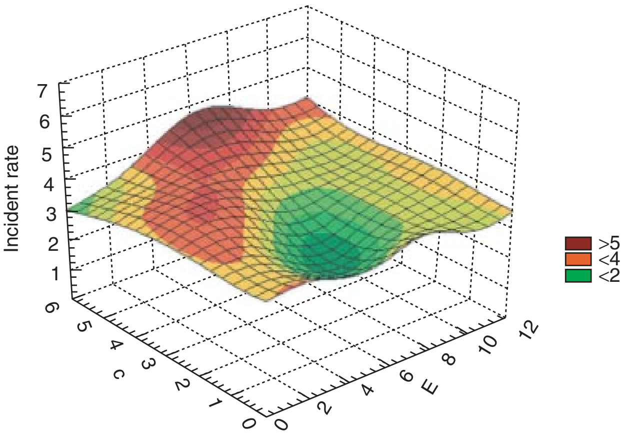

Figure 2.8 Response surface plot of incident rate versus Factors C and E (Oyewole *et al.*, 2010).

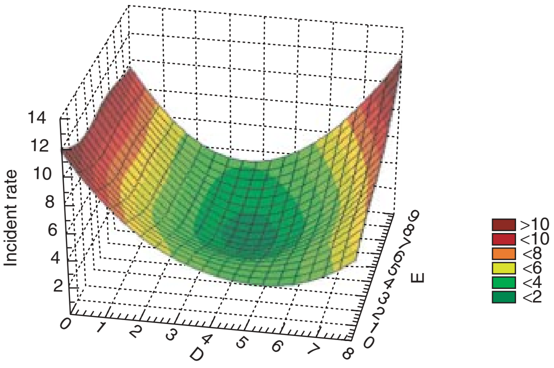

Figure 2.9 Response surface plot of incident rate versus Factors D and E (Oyewole *et al.*, 2010).

Sensitivity analysis of the response surface design shown in Figure 2.6 demonstrated that the minimum acceptable incident rate could be achieved when the organization wishes to reduce the allocation of the resources to 1% for Factor A, and 2% for Factor E. Since the Pareto analysis of factors and interactions shows Factors A and E to be very significant positive effects with *t*-values of 7.61 and 6.40, respectively (see Table 2.1), then it is reasonable that the incident rate is minimized with the additional allocation of resources to these factors. It should be noted that increasing the percentage of resources allocated to Factors A and E would continue to yield the lowest acceptable incident rate, but the lowest level of incident rate reduction is only achieved in the desirable region indicated in Figure 2.6.

In Figure 2.7, the desirable incident rate is achieved when the organization allocates 7.5% of its available resources or man-hours to Factor C (Employee

Engagement and Planning) and 4.5% to Factor D (Work in Progress). In order to evaluate the behavior of the response further, a sensitivity analysis was performed on the surface design. Based on the results of the sensitivity analysis, the lowest acceptable incident rate could be obtained when the organization wishes to allocate approximately 5% of its available resources to Factor C (Employee Engagement and Planning) and 1% to Factor D (Oyewole *et al.*, 2010).

Figure 2.8 shows that the desirable level of incident rate is achieved when approximately 1.5% of the available resources or man-hours is allocated to Factor C (Employee Engagement and Planning), and 6% of the resources is allocated to Factor E (Evaluation, Measurement, and Verification). Sensitivity analysis indicated that the lowest acceptable incident rate is achieved when the organization allocates 1% of its available resources to Factor C and 3% to Factor E. In Figure 2.9, the desirable incident rate is achieved when the organization allocates 4.5% of its available resources or man-hours to Factor D (Work in Progress) and 5% to Factor E (Evaluation, Measurement, and Verification). Sensitivity analysis indicated that the lowest acceptable incident rate is achieved when the organization allocates 3% of its available resources to Factor D and 4% to Factor E (Oyewole *et al.*, 2010).

The response surface plots show the relationship between incident rate and the significant safety intervention factors A, C, D, and E. The use of the response surface plots provides the foundation for the determination of the regions at which the additional allocation of resources no longer achieves reduced levels of incident rates. This desirable point could be obtained by taking the average value of the near-optimum percentage of resources allocated to each safety intervention Factor A, C, D, and E. Adding up the average values of these near-optimum percentages then yields the recommended near-optimum combined region at which the additional allocation of resources no longer lowers the incident rate. Using the averaging method, an approximation of the point in the desirable region at which incident rate is entirely reduced could be made. This indicates that any additional allocation of input beyond 16.66% of the available resources would no longer lower the incident rate (Oyewole *et al.*, 2010).

Figure 2.10 shows an exponential decay curve for incident rate based on the recommended resource allocation method, which indicates the additional allocation

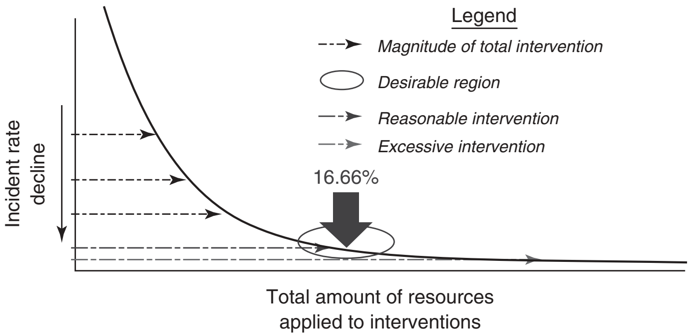

Figure 2.10 Exponential decay of incident rate (indicating the desirable allocation).

of 16.66% of the available resources to the significant safety intervention activities (Oyewole *et al.*, 2010). Iyer *et al.* (2005) also indicated that additional allocation of between 15 and 17% of the available resources would in fact lower the incident rate. Overall, researchers have attempted to validate their models with similar studies, but in the exact application of the results of the model produced results which are difficult to achieve in actual practice.

2.9
Conclusion

The findings from this research show that the allocation of additional resources to Factor B (Qualification, Selection, and Pre-Job) would not likely improve the overall 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 and other safety activities such as the implementation of incentive programs and individual safety training do not necessarily lead to the achievement of desirable incident rates. Safety intervention would be positively affected by Factor A (Leadership and Accountability), Factor C (Employee Engagement and Planning), Factor D (Work in Progress), and Factor E (Evaluation, Measurement, and Verification). The allocation of additional resources to significant factors would further reduce incident rates. The analysis of all factors and interactions shows that the model is significant ($p < 0.001$ and $R^2 = 0.54$).

From the business perspective, committing more resources to safety activities would positively increase the effectiveness of the safety intervention model. The organization could also improve its overall safety intervention policy by spending more time on and allocating more resources to safety evaluation, measurement, and verification. The high level of significance of Factor E shows that the organization would be able to predict and achieve desirable incident rates if quantitative evaluation, measurement, and verification of safety interventions are accurately performed by environmental, health, and safety employees or other field-level people. Quantitative evaluations include conducting investigative studies and research to examine the areas of the safety intervention program which need to be addressed or improved upon.

Overall, this line of research shows that statistical techniques such as response surface design plots could be used to obtain the near-optimum incident rates based on the relative inputs (percentages) of the significant safety intervention factors. This work also indicates that the allocation of additional resources to safety intervention activities does not necessarily minimize incident rates (see Figures 2.4–2.9). This organization could achieve the desirable incident rate using the recommended 16.66% of its available resources on significant safety intervention activities. In addition to its numerous benefits, safety personnel, supervisors, and managers could use the analysis obtained from this work to develop an effective resource allocation program which would reduce the costs associated with safety.

The other benefits of this research to a safety-conscious organization is that statistical modeling of intervention activities provides the opportunity for efficient management of the safety system based on the 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. Unplanned industrial incident-associated expenses such as equipment repair, liability and compensation, administrative, and downtime 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 turn reduces employee turnover rate, increases profitability, and improves the public shareholder value.

The data collected for this study were obtained in a socio-politically unstable region (Niger Delta). This could have an indirect impact on the incident rate, since employees may be prone to militant attacks. As a result, some employees could be psychologically overstressed and this could reduce their cognitive capability. In an effort to complete their task quickly before any militant attack, some employees could make bad judgments by taking short-cuts in the performance of their jobs, thereby increasing incident rates. The non-significant factor (Factor B: Qualification, Selection, and Pre-Job) and other insignificant factor interactions could be considered as "silent effects," since their impacts are not as obvious as the significant factors or interactions.

The silent nature of the effects of Factor B and other interactions could be transformed into a dominant nature in situations where a different set of data is collected from other oil exploration and production units, or another country. This means that one or more significant factors identified in this study could become non-significant, with little or no effect on the minimization of incident rates, especially in other industries. It is important to note that safety activities in the energy industry may not be the same as those implemented in other industries such as the manufacturing or service industries.

Future work will include the expansion of the current sample size of the data by incorporating and comparing safety activities from other units or organizations that would be beneficial to this research work. Increasing the data sample size would allow the management to understand adequately the impact of allocating sufficient budget and resources to the various tasks, operations, intervention activities, and safety programs which reduce incident rates. If properly managed, this could uncover the untapped opportunity that exists for companies to enhance both their profitability and their environmental health and safety performance.

Another critical step in the expansion of this work is to set safety decision-making standards by incorporating weights in 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 to 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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