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THE IMPLEMENTATION OF STATISTICAL AND FORECASTING TECHNIQUES IN THE ASSESSMENT OF SAFETY INTERVENTION EFFECTIVENESS AND OPTIMIZATION OF RESOURCE ALLOCATION

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ABSTRACT

Most engineering processes involving human and technical sub-systems are designed to achieve a set of objectives. In health and safety, the need to quantify these processes using statistical models cannot be over emphasized, since the high incident rates and ineffective allocation of resources could be costly to several organizations. The objective of this research is to use statistical and forecasting tools to develop an effective resource allocation program, based on the need to reduce incident rates and safety intervention costs. Five main safety intervention factors (Factor A: Leadership and Accountability; Factor B: Qualification Selection and Pre-Job; Factor C: Employee Engagement and Planning; Factor D: Work in Progress; Factor E: Evaluation, Measurement and Verification) were highlighted and investigated to show their effects on incident rate performance. A safety intervention factor is a group of safety and health activities which are implemented in order to reduce incident rates. Analysis of variance test showed that four safety factors (A, C, D, and E) were significant. Factor B was not selected for model development, since it was not significant. A safety model was developed to assist practitioners in making resource allocation decisions, and to better predict incident rates. Statistical techniques such as response surface designs and contour plots were used to determine the resource allocation method. The developed safety model recommended the allocation of 16.66% of the available resources to the significant safety intervention activities in order to achieve the desirable incident rate, and 10.34% of the available resources to achieve the lowest acceptable incident rate. The developed safety model was validated using the comparison between the actual incident rates in a one-year period and the predicted incident rates that was obtained using the double exponential smoothing technique (Holt's Model). Comparison of the actual and predicted incident rates indicated a forecast accuracy of 71.58%. The analysis of the forecasting error showed an unbiased forecast with a tracking signal of -4.08. This dissertation offers a new dimension into the practice of safety intervention evaluation. For the first time, this research contributes to the body of knowledge through the use of response surface design methodology and contour plots in the determination of an effective method for the allocation of resources, with the aim of reducing incident rates. Safety personnel, supervisors and managers could use the methods proposed and results obtained from this research work to develop an effective resource allocation program which would ultimately reduce safety intervention costs.

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CHAPTER 1

INTRODUCTION

1.1 History of the Problem

In 2006, the National Population Commission of Nigeria estimated the population of the most inhabited and most densely populated oil-rich country in the continent as over 140 million. Since the discovery of crude oil in the Niger-Delta area in 1956, Nigeria has depended heavily on the oil sector. Oil production and exportation currently accounts for over 95% of its export revenues thereby pushing agriculture which was the traditional mainstay of the economy in the 1950s and 60s to the background. With over 36.2 billion barrels of proven reserves as of 2008, Nigeria is the largest oil producer in Africa and the 6th largest in the world, averaging 3 million barrels per day (b/d) in the beginning of 2004 and 3.1 million in 2005 (Nigeria, Analysis Briefs).

Pipeline vandalism, kidnappings, and militant takeover of oil rigs and facilities have reduced crude oil production to approximately 2 million barrels per day in the beginning of 2008. According to the 2007 Country Analysis Briefs which was published by the United States Energy Information Administration, over 42% of Nigeria's crude oil is exported to the United States. This makes the United States to be Nigeria's leading exporting partner. Despite the huge dependence on crude oil, the Federal Government of Nigeria does not have any realistic safety regulating organization to monitor and implement health and safety policies in the oil and energy industry. Most factories and industries have put in place several safety policies aimed at minimizing incidents and improving their overall productivity. The gains of safety may not be effectively achieved in Nigeria due to the absence of a general safety enforcement and regulating institution (Nigeria, Analysis Briefs).

Although the Federal Ministry of Health is responsible for monitoring the overall health concern of the citizens, and has been quite effective in the health sector, the safety aspect has however been greatly neglected. The mission of the Federal Ministry of Health is “to develop and implement policies and programs as well as undertake other necessary actions that will strengthen the national health system to be able to deliver effective, efficient, high quality and affordable health services to improve health status of Nigerians, and to serve as the engine for the pursuit of accelerated economic growth and sustained development” (Source: The Federal Ministry of Health, Nigeria).

In order to minimize the high rate of on-the-job injuries, various oil companies, mostly owned by foreign countries have set up internal health and safety departments to cater to the needs of their local and international employees. This is necessary in order to compensate for the absence of a safety enforcement and regulating body in Nigeria. The transparency of these companies may however be questionable since inspections are conducted by the company safety employees and citations cannot be recommended.

Unlike Nigeria, the President of the United States signed the Occupational Safety and Health Act of 1970 which established the Occupational Safety and Health Administration (OSHA) and the National Institute for Occupational Safety and Health (NIOSH) in 1970 and 1971, respectively. While OSHA was established within the Department of Labor (DOL) and authorized to regulate health and safety conditions for all employers with few exceptions, NIOSH was established for the investigation of hazardous work conditions, to conduct research to prevent injury, to train safety and health professionals, and to develop educational materials and with recommendations for worker protection (DOL Website).

1.2 Significance of the Study

In the United States, the National Safety Council estimated the 2004 total cost of on-the-job injuries as approximately $142.2 Billion (National Safety Council, 2006). Since then, the costs of injuries have continued to increase annually. By 2007, the total cost of fatal and nonfatal unintentional injuries had increased to over $684.4 billion (National Safety Council- Highlights from Injury Facts, 2009). This is equivalent to about $2,300 per capita when considering the estimated population of 300 million inhabitants living in the United States. These are considered as 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.

According to a publication of the Customer Relationship Management and Marketing (CRM Today), previous research studies have shown that many companies' true environmental, health and safety (EH&S) costs are over 300 percent higher than recorded in their plant ledgers. Most of these are considered as overhead or indirect costs of environmental, health and safety to the employers. These include interruption or work shutdown, employee retraining, replacement of damaged equipment or tools, incident investigation and claims administration costs as shown in Table 1.1 (CRM Today, 2002).

Contemporary safety and health programs have over the years been based on theoretical and qualitative analysis. This has prevented industrial organizations and companies from adequately developing and implementing successful health and safety intervention programs aimed at decreasing or eliminating incidents. Numerous organizations have been known to keep records of past incidents for analysis, motivational and incentive programs, as well as employee training. Unfortunately, these record-keeping activities are based on qualitative measures which lack effective quantitative and statistical analysis. Past incident data could be instrumental in the establishment of safety intervention programs necessary for the effective allocation of resources. Table 1.1 below shows the economic costs of incident incurred by the employer, worker and the community.

Table 1.1. Economic costs incurred by the employer, worker and the community

Conceptual group	Total (T)	Employer (E)	Worker (W)	Society (S)
Production disturbance costs	Value of production (inc. overtime)	Overtime premium Employer excess payments Sick leave	Loss of income prior to RPR, net of compensation, welfare and tax	Compensation and welfare payments transferred to worker for temporary loss of wage; tax losses prior to RPR;
	Staff turnover costs	Staff turnover costs	Zero	Zero
Human capital costs	Present value of earnings before incident minus earnings after incident	Zero	Loss of income after RPR, net of compensation, welfare and tax	Compensation and welfare payments for lost income earning capacity; tax losses after RPR
Medical costs	Medical and rehabilitation costs incurred as a result of the injury	Threshold medical payments	Gap payments Private health insurance payments	Compensation medical payments Public health system payments
Administrative costs	Legal costs	Real legal costs incurred plus fines and penalties	Real legal costs incurred	Real legal costs incurred Deadweight costs of enforcement minus fines and penalties credit
	Investigation costs	Employer investigation costs	Zero/negligible	Real costs of running the compensation system (including investigation of claims)
	Travel costs	Zero/negligible	Travel costs net of compensation & concessions	Compensation for travel costs Travel concession
	Cost of funeral today's minus present value of future cost	Zero	Net costs of bringing forward funeral	Compensation for funeral costs
Transfer costs	Real deadweight costs of transfer payments (welfare and tax)	Negligible	Zero (accounted for in netting other items)	Deadweight costs of welfare payments (DSP, SA, Mobility Allowance, Rent Assistance) Deadweight costs of tax losses
Other	Suffering/early death	Zero	Suffering, early death (net of compensation)	Compensation payments for same
	Carers	Zero	Carer costs net of carer payment/allowance	Payments to carers plus deadweight cost
	Aids, equipment and modifications	Zero	Aids etc (net cost after reimbursements)	Reimbursements for aids etc plus deadweight cost

Source: Access Economics P/L 2004 Report on "The Costs of Work-related Injury and Illness"

This dissertation is focused on the use of statistical and forecasting tools to develop an effective resource allocation program, based on the need to minimize incident rates and safety intervention costs. The developed resource allocation program incorporated qualitative and quantitative techniques to relate past incident rates, human resources allocation procedures and intervention activities to assess the effectiveness of a loss prevention program. The double exponential smoothing technique was used to predict a better resource allocation strategy and optimization procedure to minimize manpower input, incident rates and safety costs.

Since most oil companies in Nigeria are foreign-owned, it is therefore necessary to create awareness programs aimed at enlightening the management and employees on the consequences of poor implementation of health and safety policies. Based on their understanding of increased safety costs which often occur as a result of high incident and fatality rates, these companies began conducting safety intervention projects. This research work was funded and supported by the Chevron Corporation. Chevron is a renowned oil company with operations in over 180 countries in the world and a leading US-based oil exploration and production organization in Nigeria (Chevron-Nigeria Website, Chevron: Company Profile).

Chevron Corporation is currently in a joint venture with the Nigerian National Petroleum Corporation and the Federal Government of Nigeria. Chevron sponsored this research work in an effort to reduce safety interventions costs and minimize incident rates. This is motivated by the need to determine the effectiveness of a desirable method for the allocation of resources. The operation chosen for initial incident rate evaluation and data collection is a Chevron-owned oil field and production unit in the Niger-Delta region of Nigeria with over 100 employees. The number of employees in the chosen oil field and production unit makes it possible for the easy determination of the incident rates.

1.3 Objectives of the Study

The objective of this research is to use statistical and forecasting tools to develop an effective resource allocation method based on the need to minimize incident rates and safety intervention costs. A statistical model is developed for predicting incident rates. Based on the application in this study, the developed safety model could be used to better predict the allocation and optimization of resources which in turn reduces the cost of incident prevention. This dissertation also provides a research foundation for the use of statistical techniques such as response surface methodology and contour plots to more effectively allocate resources and investigate the interactive effects of safety intervention factors obtained from the exploration and production units of the leading oil company in the Niger Delta region of Nigeria.

The developed safety model could also be used to help mitigate incident rates. Supervisors and managers could use the analysis obtained from this research work to develop an effective resource allocation program for planning and decision making purposes. 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. This research therefore, draws on, and contributes to the current literature in technical evaluations of health and safety intervention programs based on the need to apply quantitative analysis of past incident records to establish effective safety performances. This dissertation is an applied research which extends previous works based on the collected data to provide a foundation for the future possibility of the development of a generalized method of resource allocation in safety intervention evaluation.

1.3.1 Research Questions and Hypotheses

This research study was guided by the following research questions and hypotheses:

1. At which point does the additional allocation of resources no longer impact incident rate reduction? This means it will be necessary to determine what quantity and types of safety interventions will be considered ideal.
2. At what level of man-hour constraint is allocation of resources said to be effectively achieved for producing the lowest acceptable incident rate?

Hypothesis 1:

H_0: Incident rate does not depend on any of the safety intervention factor studied (null hypothesis).

H_1: Incident rate depends on at least one or more safety intervention factors studied (alternative hypothesis).

Hypothesis 2:

H_0: Transformational analysis of incident rate does not affect the choice of the selected statistical model (null hypothesis).

H_1: Transformational analysis of incident rate improves the model characteristics (alternative hypothesis).

Hypothesis 3:

H_0: Interaction effects of the safety intervention factors do not improve the level of model significance (null hypothesis).

H_1: The level of model significance is improved by the interaction effects of the safety intervention factors (alternative hypothesis).

1.4 Organization of the Study

Chapter 1 provides a historical overview of the problems affecting safety intervention activities in the Niger Delta region of Nigeria. These problems include militant attacks, kidnappings, deliberate sabotage, and ineffective governmental health and safety regulations. This section is concluded with the discussion of the need and significance of the study, including the objectives of this dissertation, as well as research questions and hypotheses. In Chapter 2, the historical perspective of safety intervention is discussed and the major safety intervention activities are classified into the organization of the safety management system which includes the technical and human sub-systems. Chapter 2 is concluded with the definition of the common terms used in safety intervention programs.

Chapter 3 provides a literature review of the relevant previous works which include qualitative, motivational and behavioral studies. Chapter 3 also provides a review of quantitative studies of safety intervention involving single and multiple factor interactions. This section is concluded with the review of the safety intervention activities which are evaluated in this dissertation. Chapter 4 discusses the methodology and design of the research. This includes the data collection method, the grouping of the safety intervention activities into factors, as well as the overview of the experimental design methodology used for the statistical analysis of the collected data.

The various statistical analyses used and the results obtained are reported in Chapter 5. The major statistical analyses applied in this dissertation include the use of the analysis of variance (ANOVA) to determine the significant safety intervention factors and interactions, the determination of the positive and negative effects using the Pareto chart, as well as the use of transformational analysis to determine the statistical characteristics and behaviors of the safety intervention model.

Chapter 6 discusses the development of the safety intervention model, the comparisons of the level of significance of the factor interactions, and hypotheses verification. Chapter 6 is concluded with the optimization of the developed safety intervention model using response surface designs and contour plots. In this section, the near-optimum point at which the additional allocation of resources no longer lowers the incident rate is determined, using the values obtained from the analysis of the response surface designs and contour plots.

Chapter 7 provides an overview on the use of forecasting techniques to predict incident rates. In this chapter, the early applications of the forecasting methodology in safety and health programs are reviewed. Based on the incident rates of the collected data, the double exponential smoothing method is used to predict current and future incident rates. The predicted incident rates are compared to the incident rates obtained based on the recommendations proposed by the developed safety intervention model. This section is concluded with the validation of the developed safety intervention model, using measures of incident rate forecast errors such as the accuracy of forecast, the level of bias, and the tracking signal.

Chapter 8 provides the overall conclusion to this dissertation. This includes the analytical summary, recommendations for organizations, and the potential areas of application of the developed safety intervention model, as well as the limitations of the study. Chapter 8 concludes with the suggestions for future work and areas of improvement. The appendices include the data collection sheet, the raw data obtained for the model development and validation, and the summary of the analysis of the model validation data.

CHAPTER 2

BACKGROUND

2.1 Historical Perspective of Safety Intervention

The historical perspective of safety practices could be traced back to the ancient times when incidents were considered as inevitable or as the will of the gods. Around 2500 BC, the Ancient Chinese adopted a traditional loss prevention method by spreading one in every six of their harvest on each of their six boats while transporting their farm products to the market. This was done in order to minimize the risk of loss associated with capsizing of a single boat containing all the agricultural goods. In 1750 BC, the Code of Hammurabi was created in an effort to better understand the safety and health implications associated with stone cutting operations by the Babylonian king (Hammurabi) for the people of Mesopotamia who lived under his rule. This code provided monetary compensation for workers and slaves injured during the performance of their duties.

This shows a striking resemblance to today's workers' compensation laws (Student's Encyclopedia on Safety). This code unified the empire by providing the standards and guidelines for moral values, class structure, gender relationships, and religion, which has been described as the most important of all Mesopotamian contributions to civilization. By 1600 BC, the ancient Egyptians had commenced recognizing the potential hazards associated with the inhaling of toxic fumes produced during the smelting of silver and gold. Between 460 - 377 BC, Hippocrates (the father of contemporary medicine) established a link between the respiratory problems of Greek stonecutters and the rock dust surrounding them (Student's Encyclopedia on Safety).

An article on the effects of the Industrial Revolution described the practice of safety management at the industrial level in the 19th century. Initially, employee safety was generally considered as a personal responsibility which shifted the blame and accident liabilities from the employer to the employees (Effects of the Industrial Revolution). Safety practices were not fully incorporated into the industrial sector until the various managers began to fully realize the consequences of industrial accidents, which often included interrupted production, increased operating costs, as well as reductions in the numbers of employees. In the mining industry, the severity of injuries and loss of lives led to the general awareness for safety consideration at the local and state levels.

According to the Institute of Medicine (2000), the first major legislation on safety was the Pennsylvania Mine Safety Act (PMSA), which was passed into law by the Commonwealth of Pennsylvania in 1864. Other states soon realized the need for safety laws and legislations by establishing inspection programs. In 1867, the Commonwealth of Massachusetts instituted the first factory inspection program sponsored by any state government (Institute of Medicine, 2000; Morrison, History of Safety). In 1891, the United States Congress passed the first federal statute to govern mine safety and health. This legislation marked the beginning of the federal government intervention towards regulating mining activities, which were aimed at protecting the employees (U.S. Department of Labor, 2007).

Subsequent federal laws and legislations were created to provide the opportunity for disabled workers to sue for damages. This led to the need for employers to carry insurance for employee injuries, which provided compensation packages for the injured employees. Over the years, the cooperation between the federal, state, and local governments enabled the creation of several environmental health and occupational safety laws, which were expected to be strictly followed by the companies. Other subsequent federal legislations passed into law include the U.S. Worker's Compensation Act, 1911; the Coal Mine Safety Act, 1952; the Federal Coal Mine Health and Safety Act, 1969; the Construction Safety Act,1969; the Occupational Safety and Health Act,1970 (Institute of Medicine, 2000). In the area of mining, the Federal Mine Safety and Health Act, 1977; and the Mine Improvement and New Emergency Response Act of 2006 were also enacted.

In its 2009 publication on workplace safety for petroleum industries in the United States, the American Petroleum Institute (API) reported that several oil companies have developed more stringent standards and guidelines for their organizations when compared to other private industries. This has been considered as part of the efforts to conform to the safety and health standards set by the government (American Petroleum Institute, 2009). Some of the stringent measures adopted include the allocation of more resources towards safety. This is based on the belief that "the more resources are allocated to environmental health and safety practices, the safer their work environment would be."

This often involves the incorporation of behavioral-based safety, job hazard/safety analysis, as well as the record-keeping for major incidents and near misses (U.S. Department of Energy, 2003). Near misses are often investigated and analyzed to further understand the root cause of incidents and to recommend appropriate measures to prevent the recurrence of such events in the future. Near misses have been described as potential incidents which have eventually led to loss of property, fatalities and workers compensation (Mansdorf, 2006).

2.2 Safety Intervention

A 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, a 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, inspections, hazard analysis activities, 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 towards the level of organization of the safety management system.

At the level of the 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, 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 a 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 Matthews, 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 contribution of the human sub-system 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 are shown in Figure 2.1.

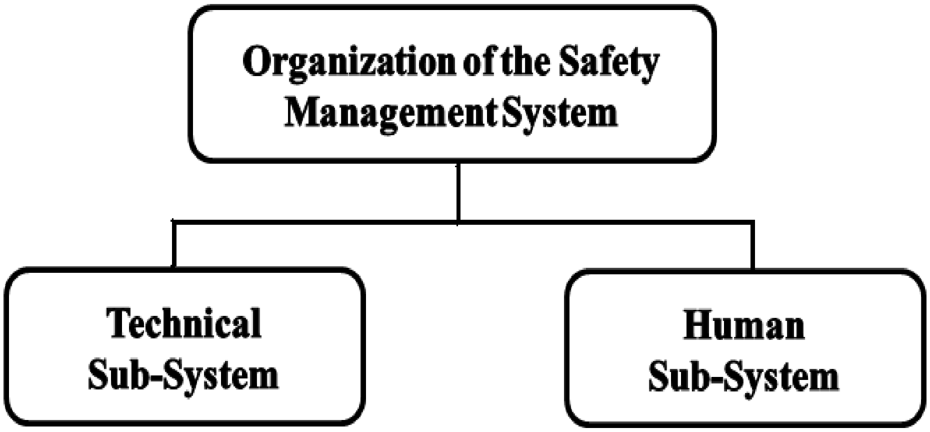

Figure 2.1. Organizational structure of the levels of safety intervention

(Adapted from Shakioye and Haight, 2008)

2.3 Safety Intervention Effectiveness Evaluation

The evaluation of a 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 develops an effective method for the allocation of resources towards safety interventions, 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 workplace, a 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, which could be based on the influence of the management or employee safety attitudes and behaviors. In situations where a particular safety 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 due to the problem of militant interference 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, human resources manager, as well as a 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. A 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 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).

2.4 Definitions

It is necessary to define the various terms commonly used in safety intervention activities. Safety personnel often collect and record incident data using the following definitions.

2.4.1 Incident

This is defined as the occurrence of any unexpected event which results in unfavorable consequences. An incident could be in the form of a fire, chemical and liquid spill, release of toxic fumes or gases, an explosion and any abnormality in the regular operation which could damage equipment or the equivalent of an "Occupational Safety and Health Administration (OSHA)" recordable injury (Haight et al. 2001a).

2.4.2 Incident Rates

Incident rates are used to evaluate how many incidents have occurred, or how severe these incidents were. Incident rates are measurements of only the past performance and are often used as the primary indicator of safety performance (Haight et al. 2001a). Incident rates are not indications of the future performance of an organization. Incident rates are easy to calculate and are often used as a comparative tool from one company to the other. The five major types of incident rates often confused with each other are recordable incident rate, lost-time case rate, lost workday rate, severity rate and days away/restricted or transfer rate (OSHA Website).

2.4.3 Recordable Incident Rate

Recordable incident rate is the most commonly used measurement of incident rates, and is often called the “total case incident rate” or simply as “incident rate.” The Occupational Safety and Health Administration (OSHA) defines incident rate as the total number of incidents that occur per 200,000 employee hours of human exposure (OSHA Website). The two major types of incident rates which are calculated in the workplace are the traditional incident rate and the total loss incident rate. Haight et al. (2001a) described traditional incident rate as the number of injuries, fires, motor vehicle accidents and environmental incidents per 200,000 employee hours of exposure. The total loss incident rate is the total summation of the traditional incidents plus other unplanned incidents such as equipment failures and shut downs per 200,000 employee hours of human exposure (Haight et al., 2001a). The 200,000 employee hours of exposure refers to the total hours worked by 100 workers, in 40 hours of work per week and 50 weeks of work per year.

2.4.4 Calculating Recordable Incident Rate

The Occupational Safety and Health Administration (OSHA) developed a mathematical equation for calculating Recordable Incident Rate (or Incident Rate). Incident rate (IR) could be obtained by multiplying the number of recordable incidents or cases by 200,000 employee hours of human exposure and then dividing the obtained result by the number of the total labor hours of employees in one year (OSHA Website). This is represented mathematically in Equation (2.1) as:

$$IR = \frac{\text{Number of recordable incident (cases) X 200,000 hours}}{\text{Total number of employee labor hours worked}} \qquad \textbf{(2.1)}$$

For example, a company has 18 full-time employees, 7 contractor employees and 6 part-time employees. The full-time employees and contractors each work 40 hours per week while each of the part-time employees work 20 hours per week. This equates to a total of 56,000 labor hours in a year. If the company experienced 3 recordable injuries, then the incident rate is calculated as:

$$IR = \frac{3 \text{ x } 200{,}000}{56{,}000} \Rightarrow \frac{600{,}000}{56{,}000} \Rightarrow 10.71$$

This shows that for every 100 employees, 10.71 employees have been involved in recordable injuries or illnesses.

2.4.5 Lost Time Case

The lost time case (LTC) is the second most commonly used incident rate. This is primarily used in companies with a large number of lost time cases. A lost time case includes any occupational injury or illness which prevents an employee from being able to work a full assigned work shift. Lost time cases occur in situations where there are no reasonable circumstances under which the injured employee could perform any meaningful work (OSHA Website). Sometimes, alternative job functions are allocated in order to accommodate the restrictive nature of the employee’s injury and could be assigned if it is assumed that the employee is able to work, despite the injury. In some cases, these may be regarded as light duties, which may be different from the normally assigned duties of the employee. This is considered as “restricted work days” if employees can report to their normal workplace, and they can be assigned and complete productive tasks to benefit the company. According to OSHA, an employee’s inability to perform any meaningful work as a result of fatality is not considered a lost time case

2.4.6 Lost Time Case Rate

The Lost Time Case Rate (LTC) could be calculated mathematically as the number of lost time cases per 100 full-time employees within a given period. This is calculated similarly to the recordable incident rate. Lost time case rate is calculated by multiplying the number of incidents involving lost time cases by 200,000 employee hours and then dividing the obtained result by the total labor hours of employees in a year (OSHA Website). This is represented mathematically in Equation (2.2) as:

$$\text{LTC Rate} = \frac{\text{Number of Lost Time Cases X 200,000 hours}}{\text{Total number of employee labor hours worked}} \qquad \textbf{(2.2)}$$

From the previous example, assuming that two of the three recordable cases had lost work days associated with the incidents. Then the lost work day rate (LTC rate) is calculated as:

$$LTCRate = \frac{2 \text{ x } 200{,}000}{56{,}000} \Rightarrow \frac{400{,}000}{56{,}000} \Rightarrow 7.14$$

This shows that for every 100 employees, 7.14 employees have suffered lost time due to work-related injuries or illnesses.

2.4.7 Lost Work Day Rate

The Lost Work Day (LWD) rate is mostly utilized by large companies. This is also known as the Severity Measure by the Mine Safety and Health Administration (MSHA). The LWD rate is calculated by multiplying the total number of lost work days for the year by 200,000 employee hours and then dividing the obtained result by the total labor hours of employees in that year (OSHA Website). This is represented mathematically in Equation (2.3) as:

$$\text{LWD Rate} = \frac{\text{Total Number of Lost Days X 200,000 hours}}{\text{Total number of employee labor hours worked}} \qquad \textbf{(2.3)}$$

From the previous example, assuming there were 8 lost days due to the injury, then the lost work day rate (LTC rate) is calculated as:

$$LWDRate = \frac{8 \text{ x } 200{,}000}{56{,}000} \Rightarrow \frac{1{,}600{,}000}{56{,}000} \Rightarrow 28.57$$

This shows that for every 100 employees, 28.57 days were lost from work due to work-related injuries or illnesses.

2.4.8 Severity Rate

The severity rate is used as a measure of the average number of lost days per recordable incident. This is also known as the Average Severity by the Mine Safety and Health Administration (MSHA). This is also defined as a mathematical calculation that describes the ratio of the number of lost days to the number of incidents giving lost time which occur within a given period. Since this is an averaging method, some companies do not consider severity rate as a safety performance measure. Severity rate is calculated by dividing the total number of lost work days by the total number of recordable incidents with lost time (OSHA Website). This is represented mathematically in Equation (2.4) as:

$$SR = \frac{\text{Total number lost work days}}{\text{Total number of recordable incidents}} \quad \textbf{(2.4)}$$

From the previous example, there were 8 lost work days and 3 recordable incidents. Then, the severity rate is calculated as:

$$SR = \frac{8}{3} \Rightarrow 2.67$$

This shows that for every recordable incident, an average of 2.67 days will be lost due to the occurrence of work-related injuries and illnesses.

2.4.9 Days Away/Restricted or Job Transfer Rate

The Days Away/Restricted or Job Transfer (DART) rate is a mathematical calculation that is used to determine the number of recordable injuries and illnesses which resulted in days away from work, restricted work activity and/or job transfer per 100 full-time employees within a given period (OSHA Website). DART is calculated by the summation of the number of incidents that had one or more lost days, one or more restricted days, one or more lost days that resulted in the transfer of an employee to a different job within the organization. The result obtained from this addition is multiplied by 200,000 employee hours and then divided by the total labor hours of employees in that year. This is represented mathematically in Equation (2.5) as:

$$\text{DART Rate} = \frac{\text{Total Number of DART incidents X 200,000 hours}}{\text{Total number of employee labor hours worked}} \quad \textbf{(2.5)}$$

From the previous example, assuming there are 3 incidents which caused lost work days and 2 recordable incidents which resulted in limited or restricted work activity that led to the transfer of the employees to a different job within the organization, then the DART rate is calculated as:

$$DARTRate = \frac{5 \text{ x } 200{,}000}{56{,}000} \Rightarrow \frac{1{,}000{,}000}{56{,}000} \Rightarrow 17.86$$

This shows that for every 100 employees, 17.86 days will be lost as a result of incidents which resulted in lost or restricted days or job transfer due to work-related injuries or illnesses.

2.4.10 Intervention

An intervention could be described as any implementation put in place by 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). The three levels of intervention include management, technical and human interventions. Management develops various intervention methods based on consideration of the implications of such intervention methods on the overall corporate or workplace performance. Such management interventions include the development of safety and health policy, safety and health procedures, safety and health awareness and communication mechanisms, setting up of a safety and health organizational structure such as safety committees, inspections schedules, and the provision of performance-based incentives.

Technical interventions are carried out based on the need to keep tools, equipment and machinery safe. This is achieved by implementing intervention strategies which take the physical work setting design into consideration. Other technical interventions include the redesign of production processes, equipment and facilities layout, as well as machine design. Human interventions could be considered to be the most complicated intervention method. It is not very easy to predict safety attitudes and employee perceptions. Safety knowledge cannot be easily evaluated or quantified; therefore, it is important to develop a measure to effectively measure safety knowledge. In most cases, management often coordinates the human aspect of a safety intervention by providing motivation-based incentives and implementing behavioral-based safety strategies which are aimed at improving the organizational safety culture.

2.4.11 Intervention Application Rate

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 rates is known as the intervention application rate (Haight et al., 2001a). In the quantitative analysis of a safety intervention, the incident rate is the dependent variable, while the intervention application rates for the safety activities (grouped into intervention categories or factors) are the independent variables.

2.4.12 Near Miss

A near miss could be described as an unplanned event having a potential but unrealized consequence for injury or damage to the environmental, property, reputation, or financial performance of an organization (OSHA Website). In most situations, near misses are reported, recorded and investigated in the same way as other incidents, based on their potential for injury and damage.

CHAPTER 3

LITERATURE REVIEW

3.1 Previous Studies

Until recently, most safety decision-making processes have been based on reliance on instincts, a 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 equipment 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 barriers 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 a 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. Behavioral safety is described by the National Safety Councils as "the science of observing workers' behaviors to determine where a different behavior or set of behaviors may have prevented or lessened the severity of injury." 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 needed to be improved. The use of a qualitative technique in the analysis of safety behaviors of the employees did not produce any meaningful result to the study (Health and Safety Executive, 1995).

Unsafe acts or behaviors have been identified as one of the major contributing factors to work-related incidents. Behavioral-based safety programs have been described by OSHA as an attempt to shift the responsibility of maintaining 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 the management to develop a hazard-free workplace. Guastello (1993) conducted a 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 which sometimes involve perception surveys. Bailey (1993) conducted a perception survey on four pairs of matched firms based on the relationships between employee perceptions of the 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.

Bailey also found that in low safety-performing companies, safety was perceived to be of little importance to the management, and the employees were less influenced by the efforts of the management to promote safety. Additional findings also indicated that the management was perceived to be more interested in keeping safety records than preventing accidents, while the 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 employees and management. Gregory (1996) identified seven critical steps from the behavioral perspective of the employee that could be used by management to develop a 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 (such as the age of the employees and social lives of the employees) could have affected the working environment indirectly. Figure 3.1 below shows the seven steps proposed by Gregory.

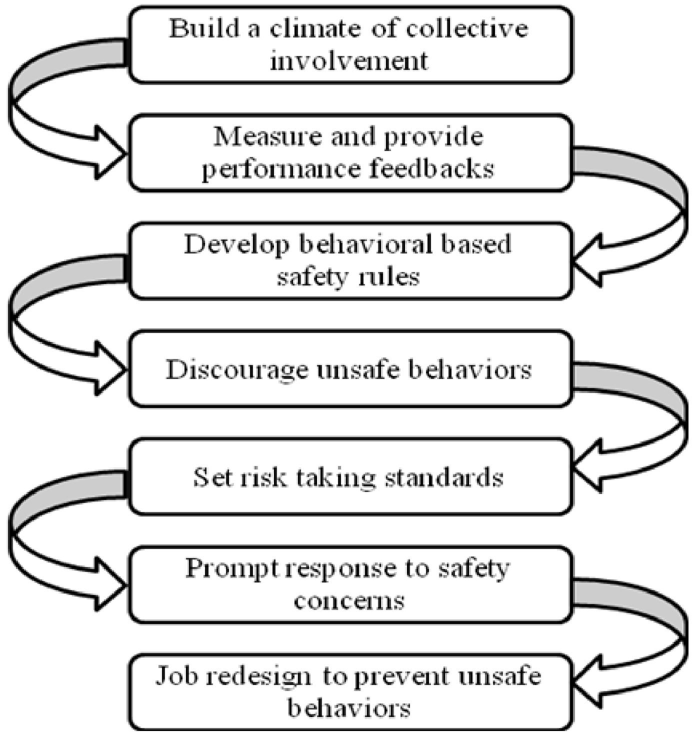

Figure 3.1. Seven steps to achieving safe working environment (Adapted from Gregory, 1996)

Several researchers have incorporated statistical methods into their qualitative intervention programs. Guastello (1993) conducted a statistical study using a regression-based model to relate incident rates and intervention factors. Ten types of accident intervention programs were selected from the fifty-three evaluations. A model was developed based on factors such as personnel selection methods, technological interventions, programs aimed at changing employee behaviors, near miss and accident reporting, and comprehensive ergonomics. The developed model was used to compare the prior incident rates to the collected data. A major drawback of Guastello's model is the assumption of the entire safety program as a single intervention. Due to 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 (Haight et al., 2001a and Iyer et al., 2004).

Petersen (1998) investigated the effectiveness of safety management policies and teamwork. The survey showed that good communication 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 as measures of effectiveness.

Several research works have been conducted in order to consider the possibilities of establishing relationships between safety intervention factors and incident rates. This is necessary for the creation of optimization models which could be used to predict future incident rates and enhance efficient allocation of resources (Shakioye and Haight, 2008). 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 equipment 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 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 to show 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 interventions (NIOSH, 1999).

In 2001, Haight et al. published two papers which could be considered as the foundation for the proper use of the analytical approach for the quantification of safety intervention programs in the oil industry. The first phase of the study showed the relationship between the incident rates and the intervention factor levels for the health and safety program. In the second phase of the research work, efforts were made to quantify a loss prevention program and a mathematical expression was developed. Regression analysis was used to compare the recorded interventions and incident rates (Haight et al., 2001a and b). Although the research studies incorporated past incident rates to evaluate loss prevention, the methodology did not provide enough information for the incorporation of forecasting techniques into the prediction of incident rates.

Iyer et al. (2004 and 2005) developed a mathematical relationship between the primary safety program intervention activity levels and the incident rates in a power plant. In the research studies, 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 such as regression analysis and forecasting techniques were used to validate the optimization model. Results from the studies showed a statistically significant, exponentially decreasing mathematical relationship, indicating the relationship between the incident rate and the intervention application rate. The studies showed that the effect of a particular safety intervention activity could last about six weeks. Despite their use of relevant statistical techniques for the analysis of incident rates, Iyer et al. did not recommend any appropriate methodology for the allocation of resources towards safety intervention in both studies.

3.2 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 competitive priorities and other strategies aimed towards 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 have begun to promote the development of health and safety programs (Shakioye and Haight, 2008).

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 their inability to implement successful safety intervention programs could be devastating to any organization. Unfortunately, the research work conducted by Fulwiler 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 towards 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 dissertation therefore, extends the investigation conducted by Haight et al. (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 further reduce the incident rate 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 highly impossible to achieve this objective in reality. 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 3.2.

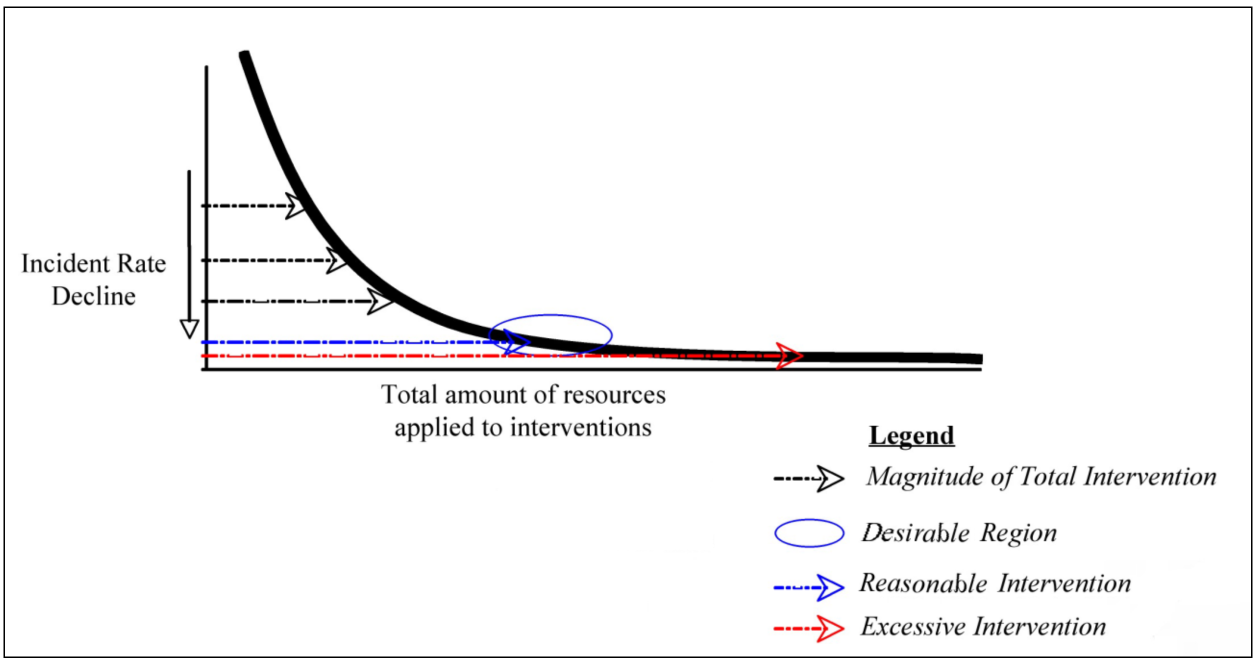

Figure 3.2. Exponential decay curve for incident rate
(Adapted from Shakioye and Haight, 2008)

For the first time in the quantitative evaluation of safety intervention activities, this dissertation applied statistical analyses such as the response surface methodology and contour plots to investigate the interactive effects of safety intervention factors using the data obtained from a leading oil company in the Niger Delta region of Nigeria. An attempt is made to develop a health and safety intervention program which would incorporate qualitative and quantitative techniques to relate past incident rates, human resources allocation procedures and intervention activities to assess the effectiveness of the health and safety program. This is needed in order to determine the point at which the additional allocation of resources no longer impacts incident rate reduction.

This research also incorporates forecasting techniques into the existing statistical data in order to predict a better resource allocation strategy and a procedure to reduce manpower input to the most effective level for reducing incident rates. Safety personnel, supervisors and managers could use the analysis obtained from this research work to develop an effective resource allocation program which would seek the lowest costs associated with effective 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 safety intervention strategies involving multiple factors (Haight et al., 2001a; Iyer et al., 2004).

3.3 Leadership/Management Safety Commitment and Accountability

A major safety intervention activity is active leadership or management safety commitment and proper accountability. This could be considered as one of the most important factors aimed towards achieving effective safety intervention success. Philson (1998) described total management safety commitment as the foundation to achieving any process, policy, or cultural shift or change. Failure is often imminent in situations where the management is not fully committed to change. In a related literature, Erikson (1997) stated that high safety performance might not necessarily be achieved based on the mere presence of health and safety personnel, but a successful safety program could be guaranteed with the combination of active, continuous and full support of the management.

The three levels of the total management commitment to safety programs include management support, management concern, and the creation of a positive safety setting for the employees. Some types of management support include written philosophy and policy, location and prioritization, incorporation of safety and health into the organizational plans, impacts on other organizational concerns, performance tasks and work environment design, selection and training of employees, continuing education, and performance reviews and appraisals of trained employees.

Common types of management concern include safety awareness and knowledge, decision-making in terms of production or employee concerns, resource allocations, incident causation and root cause analysis. The creation of a positive employee setting would enable the management to make positive decisions, communicate effectively, and determine how to effectively treat the employees, encourage the creation of a safety-oriented innovative thought process, develop and implement an effective management feed back. Other benefits of the creation of a positive employee setting include the enhancement of employee commitment towards safety, development of programs aimed at increasing employee morale, and the development of organizational ethic standards fit for the employees.

In order for any safety intervention program to be effective, it is important for the organization and the management to be fully committed to the success of such a program by establishing policies and priorities needed. The management is also responsible for improving the communications and co-operations needed from the employees. For the safety intervention program of an organization to be successful, total management commitment towards safety must be accompanied by genuine actions that would not only convince the employees, but would also get them to be fully committed to the safety effort. Hansen (1994) suggested the development of a written health and safety policy as the foundational step needed by the management to show its commitments and goals towards safety.

Effective leadership accountability is needed by the management to demonstrate safety commitment stability to their employees. Philson (1998) emphasized that incorporating leadership accountability into safety programs will provide the opportunity for management to further strengthen the company’s commitment to safety by holding the subordinates and employees accountable for the safety activities of the organization. Stalnaker (1996) suggested that a better and more efficient safety performance could be achieved in the manufacturing assembly line if first-line supervisors are able to assess their own operations, processes, activities and facilities at the onset of production. This would in turn provide the opportunity for the identification and correction of any arising problem and make the supervisors more enlightened and knowledgeable about their safety responsibilities.

3.4 Technical Considerations and Job Design

Better engineering and job design are essential factors to be considered in order to achieve high safety performance. Until recently, behavioral studies and minor engineering controls such as inspection and maintenance have been considered the major indicators of ineffective safety performance. Poor working conditions such as excessive noise levels, ventilation, lightning, temperature, as well as inadequate utilization of properly designed personal protective equipment could increase incident rates in the workplace. Poor job designs have often led to bad judgment and errors. In recent times, many organizations have incorporated ergonomics and human factors into their health and safety programs, especially in companies with a high rate of musculoskeletal injuries.

According to the United States Bureau of Labor Statistics (BLS), approximately 62% of all illness cases reported in 1995 occurred due to musculoskeletal disorders associated with repeated trauma, without accounting for injuries associated with back pain or strain (NIOSH Facts). Work-related musculoskeletal disorders (WMSD) are very common in the workplace. Orr (1997) described a work-related musculoskeletal disorder as any type of injury of the muscles, tendons, ligaments, peripheral nerves, joints, cartilage, inter-vertebral discs, bones or supporting blood vessels in the upper and lower extremities, and the back. Work-related musculoskeletal disorders are generally accompanied by acute or chronic symptoms such as pain, swelling, numbness, loss of dexterity, aching, tingling, burning, and soreness of the affected body areas.

Several work-related musculoskeletal complaints and problems have occurred as a result of prolonged repetitive tasks and muscle fatigue. If symptoms are not identified and treated promptly, cumulative fatigue from repetitive motion may lead to reduction in the speed and accuracy at which tasks are performed and may increase poor judgment and thus increase work-related incidents. Savage and Pipkins (2006) emphasized the importance of altering workplace design and rescheduling workers' activities especially in situations where increased workplace incidents, reduction in productivity and low product quality are attributed to cumulative muscle fatigue or muscular illness. Setting up of effective ergonomic programs with great emphasis on increasing job redesign may be very important in significant reduction of occupational incidents.

Several researchers have advocated the need for management to provide adequate support for a safety-oriented ergonomics program. Bohr et al. (1997) recommended that management should design and implement ergonomics-oriented safety programs with the employees. Participatory efforts from the management and employees have been shown to be effective in reducing ergonomic hazards in the organization.

Bohr et al. (1997) measured the effectiveness of a participatory ergonomics-oriented safety program based on observation of three ergonomics teams. The observed activities include team interactions, effectiveness perceptions, ability to recognize safety problems and hazards, as well as reliability of the solutions implemented. Results of the research show that some teams experienced some obstacles in their ability to implement realistic solutions due to management constraints such as ineffective allocation of resources, prioritization and budgeting problems.

In a related study, Moore and Garg (1996) measured the effectiveness of two participatory teams with the aim of reducing musculoskeletal hazards in a meat-packaging company. The ergonomics-oriented safety assessment included several indicators such as the number of hazardous and high-risk jobs, as well as the responses and feedbacks from the team members. The study found that both teams easily identified and made efforts to reduce work-related hazards; the management, however, failed to provide effective learning and training opportunities for the employees.

3.5 Employee-Oriented Safety Commitment and Culture

The human sub-system in the hierarchy and organizational structure of the levels of safety intervention is believed to be the most complicated aspect of the safety process. This complexity is due to the various interventions put in place to change the human knowledge, behaviors, attitudes or perception towards safety. It is therefore important for organizations to create an effective safety culture which is aimed at promoting a high level of satisfaction among the employees. Kelly (1996) stated that unfavorable employee perception and a nonchalant attitude towards safety often influence negative behaviors, which could arise due to poor working conditions, hostility, as well as a limited sense of ownership. The study proved that several employees showed more seriousness and commitment in situations where a sense of ownership is perceived. It could therefore be beneficial to organizations seeking to improve their safety performances by incorporating positive culture change, modification of attitudes and behavioral training into new and existing safety intervention programs.

Several studies have argued that behavioral change is one of the essential components of achieving a successful safety and health intervention. Prochaska and DiClemente (1982) proposed the stage-of-change approach. The developed behavioral-change model is a psychological approach aimed at predicting changes in safety and health-related behaviors based on movement through five distinct stages. The stages include pre-contemplation (not considering changing); contemplation (thinking about changing); preparation (making plans to change); action (in the process of changing); and maintenance (working to prevent relapse and consolidate gains). The stage-of-change model which depicts how behavioral changes can be applied at either the level of the employee experience or the work environment is shown in Figure 3.3.

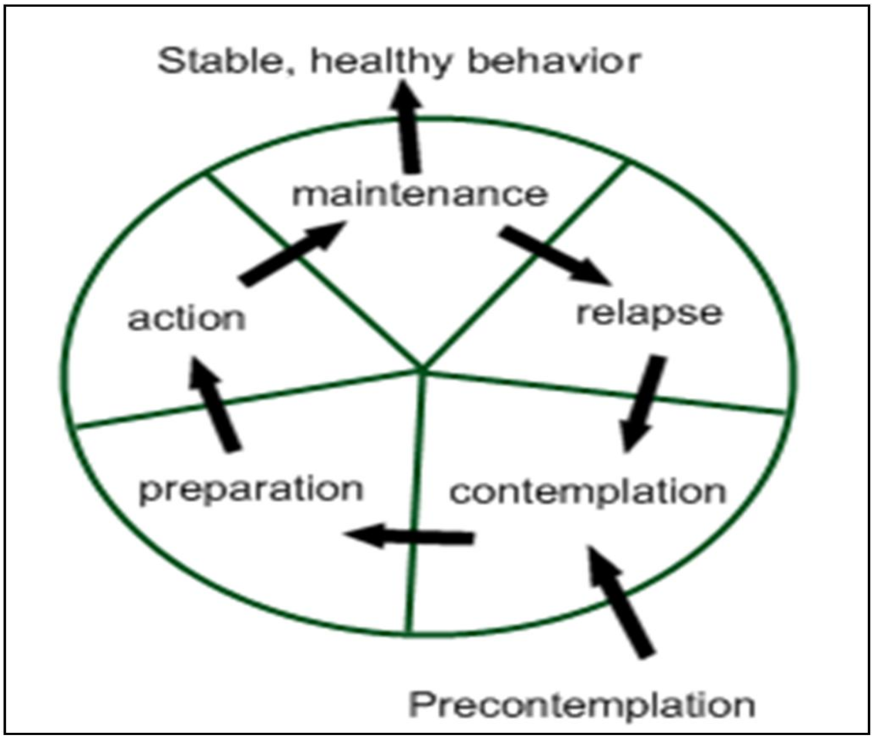

Figure 3.3. The stage-of-change model

(Adapted from Prochaska and DiClemente, 1982)

The Health and Safety Executive (1995) estimated that 70% of all workplace incidents are caused by unsafe acts and behaviors. In reality, 90% of the estimated workplace incidents could have been avoided if management had taken the necessary actions needed to minimize the incidents. It is important to minimize workplace incidents by improving employee morale and creating a safety-oriented environment based on a high level of trust, improved open communication and adequate sharing of information. A two-way employee-management behavioral feed back may be crucial to improve employee morale, attitude and safety performance in the workplace (Health and Safety Executive, 1995).

Koda et al. (1997) suggested that employee participation and empowerment in safety activities such as incident investigation and analysis, revision of safety manuals, safety training classes and mandatory use of personal protective equipment could reduce workplace incidents. Safety performances have been increased in organizations which encourage their employees to be involved in health and safety committees where the management and employees are equally represented. Tuohy and Simard (1993) stated that employee involvement in the safety process increases the overall organizational safety awareness, alleviates the safety burden of the management, and increases employee accountability. The study concluded that the management is primarily responsible for the enforcement of safety regulations, which ultimately relies on the cooperation of the employees.

3.6 Safety Education and Motivation

Safety training is often recommended for new employees in several organizations. In most safety-oriented companies, continuous training of employees is mandatory and additional training may be suggested for employees in high-risk work environments or those involved in repeated incidents. According to several studies, employee safety training alone may not be sufficient to improve and maintain the desired level of safety performance within an organization. Ray and Bishop (1995) stated that employee incidents due to unsafe practices in the workplace often occur as a result of inadequate safety procedure training and lack of motivation. The chances of a successful safety program are higher in situations where the management incorporates other supporting factors into safety training such as the creation of a favorable work environment and safety performance and motivational incentives.

Safety incentive and motivational programs have been recommended by several researchers to improve safety performance. Multiple studies have shown that while safety incentives tend to reduce workplace incidents when correctly utilized, improper use may, however, cause more problems for the organization (Geller, 1996; Hoemke, 2008; Schoonmaker, 2006). The inclusion of motivational programs such as goal setting, feed back and performance measurement tends to encourage safe behaviors within the organization.

Geller (1996) provided seven basic guidelines needed to establish an effective safety incentive and motivational program:

1. Behaviors required to achieve a safety reward should be specified and perceived as achievable by participants.
2. Everyone who meets behavioral criteria should be rewarded.
3. It is better for many participants to receive small rewards than for one person to receive a large reward.
4. Rewards should be displayable and represent safety achievement (i.e., coffee mugs, t-shirts, hats or jackets with a safety message).
5. Contests should not reward one group at the expense of another.
6. Groups should not be penalized (lose rewards) for failure by one individual.
7. Progress toward achieving a safety reward should be systematically monitored and publicly posted.

3.7 Safety Performance Evaluation, Measurement and Verification

Gregory (1996) emphasized the need for management to provide periodical written evaluation and appraisal of their organizational safety performance. Evaluations and appraisals could be used as enhancement tools to increase the level of seriousness and commitment of employees, especially in organizations with specific written safety objectives and responsibilities. Gregory argued that employees tend to perform better when being evaluated and appraised based on their overall safety performance. A classical example of this type of situation is the “Hawthorne Effect.”

In 1949, Mayo published a ground-breaking paper based on the results of the preliminary experiments conducted at the Hawthorne Plant of the Western Electric Company in Cicero, Illinois, from 1924 to 1927. The objective of Mayo's research was to study the effect of light on productivity and to argue that individual behaviors of employees may be altered when the workers know they are being studied. Mayo also wanted to determine the effect of fatigue and monotony on job productivity and how these physiological challenges could be controlled through the introduction of external variables such as rest breaks, work hours, temperature and humidity.

Six workers were selected and segregated from the rest of the other factory employees and were put under the surveillance of a supervisor who was more of a friendly observer than a disciplinarian. Frequent changes were made to the working conditions of the employees. The study showed that despite the experimental manipulations, the production of the workers continued to improve. The researchers argued that increased worker productivity was achieved due to the psychological stimulus and motivations created as a result of the separation of the employees from the others, thereby making them feel important (Mayo, 1949). Like the

Hawthorne Effect, safety performance evaluation could provide the opportunity to identify areas where improvements and modifications are needed in the safety intervention program. Such problematic areas could be promptly corrected or altered in order to achieve the initial focus and objective of minimum incidents and increased safety performance.

The ability of the management to regularly track, measure and verify health and safety activities could be another method of evaluating safety intervention programs. Timely investigation of incidents and near misses as well as prompt identification and correction of potential risks and hazards could also show the seriousness of the management towards safety. Budworth (1996) proposed that safety measurements and tracking of activities such as incident statistics, safety audit scores, near misses documentation, behavioral-based safety, inspections, and incident costs could be used as indicators or predictors of the organizational safety performance. Budworth suggested that no one measurement strategy of safety performance should be considered superior since every measurement has its limitations and benefits.

CHAPTER 4

METHODOLOGY AND RESEARCH DESIGN

4.1 Data Collection Method

The data used for the analyses in this research is based on the empirical observation study which was undertaken at an oil exploration and production company in the Niger-Delta area of Nigeria. For over 3 years, employees reported the amount of time spent implementing five categories of safety-related interventions as well as the incident rates on a weekly basis. This approach is similar to the data collection process adopted by Haight et al. (2001a) and Iyer et al. (2004). This data collection methodology is based on the assumption that external or uncontrollable factors could be taken into consideration. External or uncontrollable factors are regarded as nuisance factors. Nuisance factors are those factors that are known and uncontrollable which may affect the measured results, but not of primary interest.

Blocking can be used to reduce or eliminate the contribution to experimental error contributed by nuisance factors. These nuisance factors are also considered as “noise” which may interfere with the results of data analysis. In this study, the nuisance factors considered for blocking include government legislation, downtime due to militant rampages and kidnappings along the Niger Delta region of Nigeria, economic constraints, climate and humidity, previous safety records, and other environmental-related expenses and safety-associated costs such as royalties to the government and local citizens.

Thirty-four safety activities were identified and categorized into five major groups or safety intervention factors based on the similarities of the activities. The proposed 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. Approved employee lists are maintained
2. The employee qualification/selection 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 employees
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 the leadership/employee representatives 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 evaluation of safety performances periodically
3. Daily tailgate and regular HES meetings are conducted
4. Job safety analyses (JSA) are conducted
5. Pre-task hazard assessment 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 are conducted jointly 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 as part of evaluation
2. Results are communicated to employees and contractors
3. Lessons learned are evaluated and incorporated into future contracting efforts

In order to effectively document and organize the collected data, a weekly data sheet was used to record the man-hours allocated to the various safety intervention activities. This weekly data sheet was developed using Microsoft Windows Excel for easy data input. 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 five main factors as shown in the weekly data collection sheet in Appendix A.

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. These percentages (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 employee hours which is denoted as (y). Based on this, a statistical representation could be expressed for the interactive relationship between the independent and dependent variables as shown in Equation (4.1).

$$\mathbf{y = f\,(x_1, x_2, x_3, x_4, x_5, \varepsilon)} \tag{4.1}$$

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, x_2, x_3, x_4 and x_5 are represented in Table 4.1.

Table 4.1. List of input variables

Input variable	Factor	Safety Intervention Activity
x_1	A	Leadership and Accountability
x_2	B	Qualification, Selection and Pre-Job
x_3	C	Contractor Engagement and Planning
x_4	D	Work In Progress
x_5	E	Safety evaluation, Measurement and Verification

4.2 Experimental Design

The design of experiment (DOE) methodology was used to perform the experimental design. Statistical techniques incorporated into the experimental design include confounding, replication and blocking.

4.2.1 Confounding

Confounding is incorporated into the 3^5 factorial design in order to further determine the statistical characteristics of the data. Confounding is an experimental technique used for arranging a complete factorial experiment into blocks. Confounding could be 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 (Montgomery, 2008). The defining contrast for the 3^5 factorial design is shown in Equation (4.2).

$$\mathbf{I = A^2B^2C^2D^2E^2} \quad \textbf{(4.2)}$$

In this case, the defining contrast is aliased with the two degrees of freedom for the block effects. As a result of this, the 3^5 factorial design will be 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 a simplified method of analysis (Montgomery, 2008). The statistical 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 while k = number of factors.

Therefore, the defining contrast is denoted in Equations (4.3) and (4.4) as:

$$\mathbf{I = \alpha_1 x_1 + \alpha_2 x_2 + \ldots + \alpha_k x_k} \quad \mathbf{(4.3)}$$

$$\mathbf{I = 2x_1 + 2 x_2 + 2 x_3 + 2 x_4 + 2 x_5} \quad \mathbf{(4.4)}$$

4.2.2 Replication and Blocking

Replication and blocking is incorporated into the statistical analysis of the collected data. Replication in experimental design increases the sample size and is a method for increasing experimental precision. In this research, the experimental data is replicated 3 times using Design Expert Statistical Software, thereby increasing the number of runs from 243 to 729. Replicates were generated randomly based on the mean and standard deviation of the collected experimental data. 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). 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 uncontrollable and nuisance factors, it is important to incorporate blocking into the experimental design. 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. The incorporation of blocking into the experimental design enables the sensitivity of detecting significant treatment effects to be increased in situations where needed (Gardiner and Gettinby, 1998; Montgomery, 2008; and Telford, 2007).

CHAPTER 5

ANALYSES AND RESULTS

5.1 Analysis of Variance

Statistical analysis of the data was conducted using Design Expert, STATISTICA and MINITAB. The raw data used in the statistical analysis is shown in Appendix B. The data was analyzed through certain graphs and model adequacy testing. Analysis of variance tests for the 3-level factorial design was conducted using 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. Analysis of variance (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, 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 5.1.

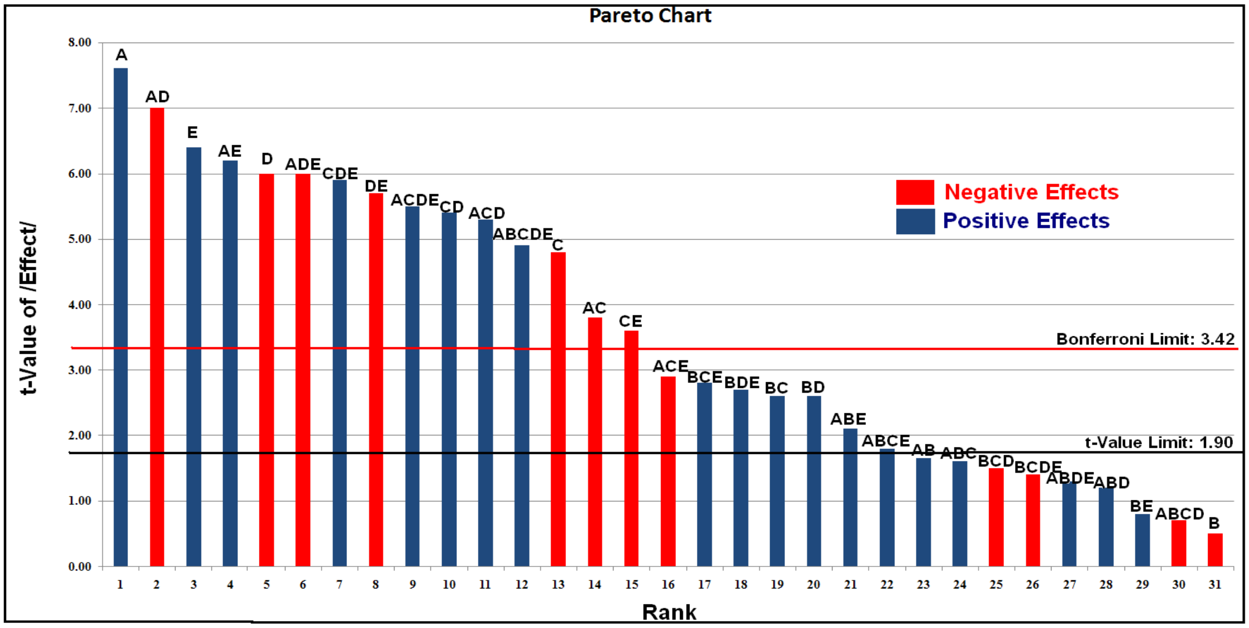

Figure 5.1. Positive and negative effects for factors and interactions

Figure 5.1 above shows 31 factors and interactions with 19 positive and 12 negative effects, respectively. Factors A and E show very significant positive effects with t-values of 7.61 and 6.40, respectively. Factor B (ranked 31^{st}) 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. 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. For example, the continuous implementation of Factor A (Leadership and Accountability) would continue to positively increase the importance of the safety policy, whereas, the continuous implementation of Factor B (Qualification Selection and Pre-Job) would reduce the level of significance of the safety model. 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 does 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.

For this particular oil exploration, production and marketing company, spending unnecessary capital or allocating 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 entirely separate allocation of resources on some positive effects shown to have interacted with one or more negative effects. 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, 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 26^{th}), 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 7^{th}). This suggests that BCDE could be improved upon by spending less time concentrating on the subsequent negative effects (BCD and B). In order to effectively manage and allocate resources, it will be necessary to concentrate more efforts on the significant factors (main effects), and the positive interaction effects. Table 5.1 shows the ranks and t-values of the effects.

Table 5.1. Ranks and t-values of positive and negative effects

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

In order to determine whether incident rates depend on at least one or more factors in the safety model, all factors and interactions were investigated using ANOVA (Table 5.2).

Table 5.2. 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			

Note: Significant model terms (factors and interactions) are denoted by the asterisks sign (*).

Even though significant, factor interactions BC, BD, BCE, BDE, and ABCDE were eventually screened from the safety intervention model due to their interaction with an insignificant safety intervention factor (Factor B). The statistical behavior of the safety intervention model in terms of standard deviation, mean, coefficient of variance (CV), prediction error sum of squares (PRESS), adequate precision and the R^2 values are shown in Table 5.3 below.

Table 5.3. Statistical summary of the safety model

Std. Dev.	1.99	R-Squared	0.5168
Mean	4.94	Adj. R-Squared	0.4952
C.V. %	40.29	Pred. R-Squared	0.4683
PRESS	3034.39	Adeq. Precision	27.694

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 5.4 shows the results obtained from the analysis of variance of the main effects and interactions for the safety model.

Table 5.4. Analysis of variance for main effects and interactions

Source	Degree of Freedom	Seq. Sum of Squares	Adj. Sum of Squares	Adj. Mean Square	F-Value	p-Value Prob>F
Main Effects	5	1064.7	247.65	49.53	12.52	0.000
2-Way Interactions	10	843.87	518.02	51.80	13.09	0.000
3-Way Interactions	10	819.48	837.53	83.75	21.17	0.000
4-Way Interactions	5	132.55	193.37	38.67	9.77	0.000
5-Way Interactions	1	88.63	88.63			0.000
Residual Error	697	2757.62	2757.62	3.96		
Lack of Fit	200	2726.50	2726.50	13.63	217.71	0.000
Pure Error	497	31.12	31.12	0.06		
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 5.2 shows a high level of adequacy in normality of the model. Also, the plotted histogram of residuals did not reveal any abnormality in the model (Figure 5.3).

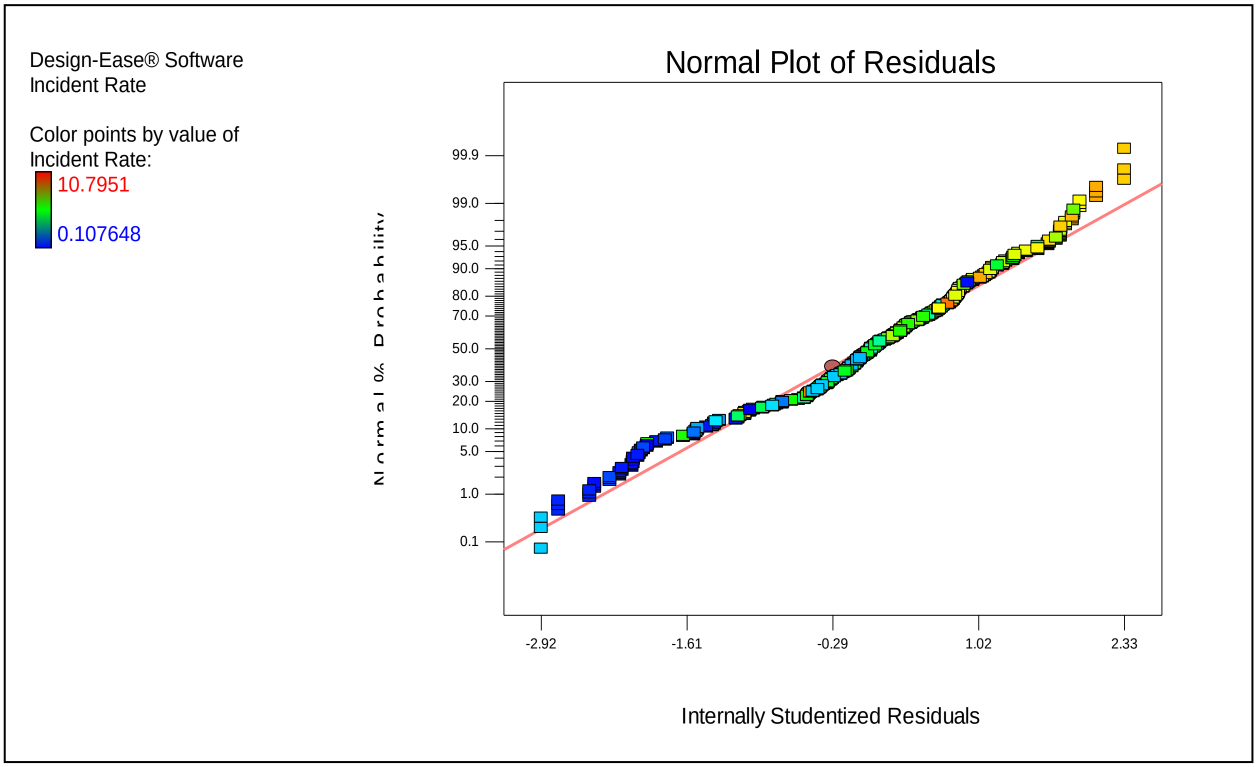

Figure 5.2. Normal plot of residuals for the safety model

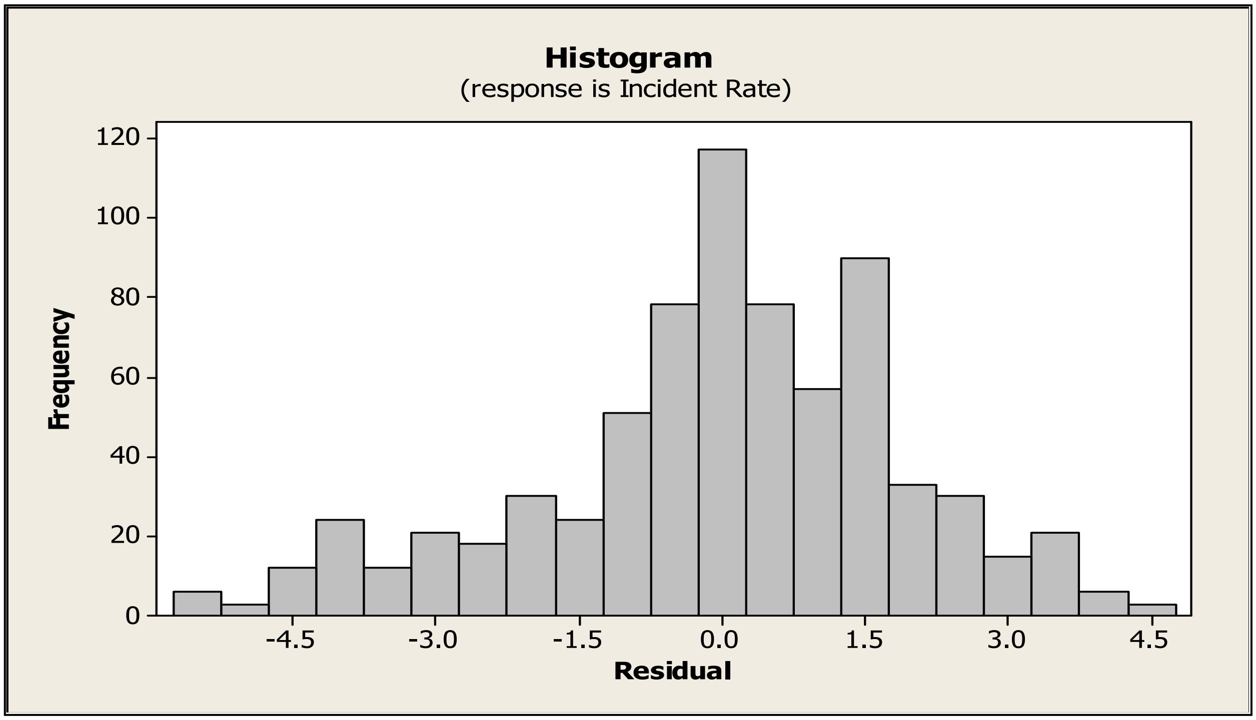

Figure 5.3. Histogram of residuals for the safety model

5.2 Transformational Analysis

In situations where the normal plot and histogram of residuals do not show any potential model adequacy failure, data transformation may be required in order to further investigate model accuracy. In this dissertation, the model was transformed using the square root, the natural log, the base 10 log, the inverse square root, and the inverse of the incident rate (y). The characteristics of each of the model transformations were compared to the normal model to determine the best results in terms of their analyses of variance, R^2 values, as well as their normal plot of residuals.

5.2.1 Square Root Transformation

The square root transformation of the incident rate (y) is given as (y'). This is represented mathematically as shown in Equation (5.1).

$$y' = \sqrt{y} \quad \textbf{(5.1)}$$

The analysis of variance for the square root transformation shows a high level of model significance; however, Factor B (p-value of 0.609) remained insignificant since its p-value is greater than 0.05 (Table 5.6). The R^2 value of the square root transformation is 0.48, which is lower than that of the normal model in Table 5.2 with R^2 value of 0.52. The statistical behavior of the square root transformation 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 5.5 below.

Table 5.5. Statistical summary of the square root transformation model

Std. Dev.	0.55	R-Squared	0.4793
Mean	2.09	Adj. R-Squared	0.4561
C.V. %	26.38	Pred. R-Squared	0.426
PRESS	233.8	Adeq. Precision	28.836

Table 5.6. Analysis of variance (ANOVA) for the square root transformation

Source	Sum of Squares	Degree of Freedom	Mean Square	F-Value	p-Value Prob>F
Block	0	2	0		
Model	195.23	31	6.3	20.64	< 0.0001
A-A	19.99	1	19.99	65.51	< 0.0001
B-B	0.08	1	0.08	0.26	0.609
C-C	7.1	1	7.1	23.26	< 0.0001
D-D	11.44	1	11.44	37.49	< 0.0001
E-E	13.8	1	13.8	45.21	< 0.0001
AB	1.37	1	1.37	4.49	0.0344
AC	5.02	1	5.02	16.45	< 0.0001
AD	17.18	1	17.18	56.32	< 0.0001
AE	13.94	1	13.94	45.7	< 0.0001
BC	1.15	1	1.15	3.78	0.0522
BD	0.82	1	0.82	2.7	0.1011
BE	0.29	1	0.29	0.95	0.33
CD	10.17	1	10.17	33.32	< 0.0001
CE	3.99	1	3.99	13.09	0.0003
DE	9.39	1	9.39	30.76	< 0.0001
ABC	0.31	1	0.31	1.03	0.3108
ABD	8.66E-04	1	8.66E-04	2.84E-03	0.9575
ABE	1.84	1	1.84	6.03	0.0143
ACD	9.29	1	9.29	30.45	< 0.0001
ACE	2.34	1	2.34	7.68	0.0057
ADE	12.71	1	12.71	41.65	< 0.0001
BCD	0.043	1	0.043	0.14	0.7067
BCE	2.21	1	2.21	7.24	0.0073
BDE	1.05	1	1.05	3.44	0.0639
CDE	11.66	1	11.66	38.22	< 0.0001
ABCD	0.037	1	0.037	0.12	0.7274
ABCE	0.79	1	0.79	2.58	0.1084
ABDE	4.04E-03	1	4.04E-03	0.013	0.9084
ACDE	9.25	1	9.25	30.3	< 0.0001
BCDE	0.12	1	0.12	0.4	0.5265
ABCDE	3.24	1	3.24	10.63	0.0012
Residual	212.06	695	0.31		
Lack of Fit	210.21	662	0.32	5.67	< 0.0001
Pure Error	1.85	33	0.056		
Cor Total	407.29	728			

In order to determine the normality of the square root transformation, the normal plot of residuals was analyzed. The normal plot of residuals shown in Figure 5.4 shows several outliers which indicate some inadequacies in the normality of the model obtained from the square root transformation.

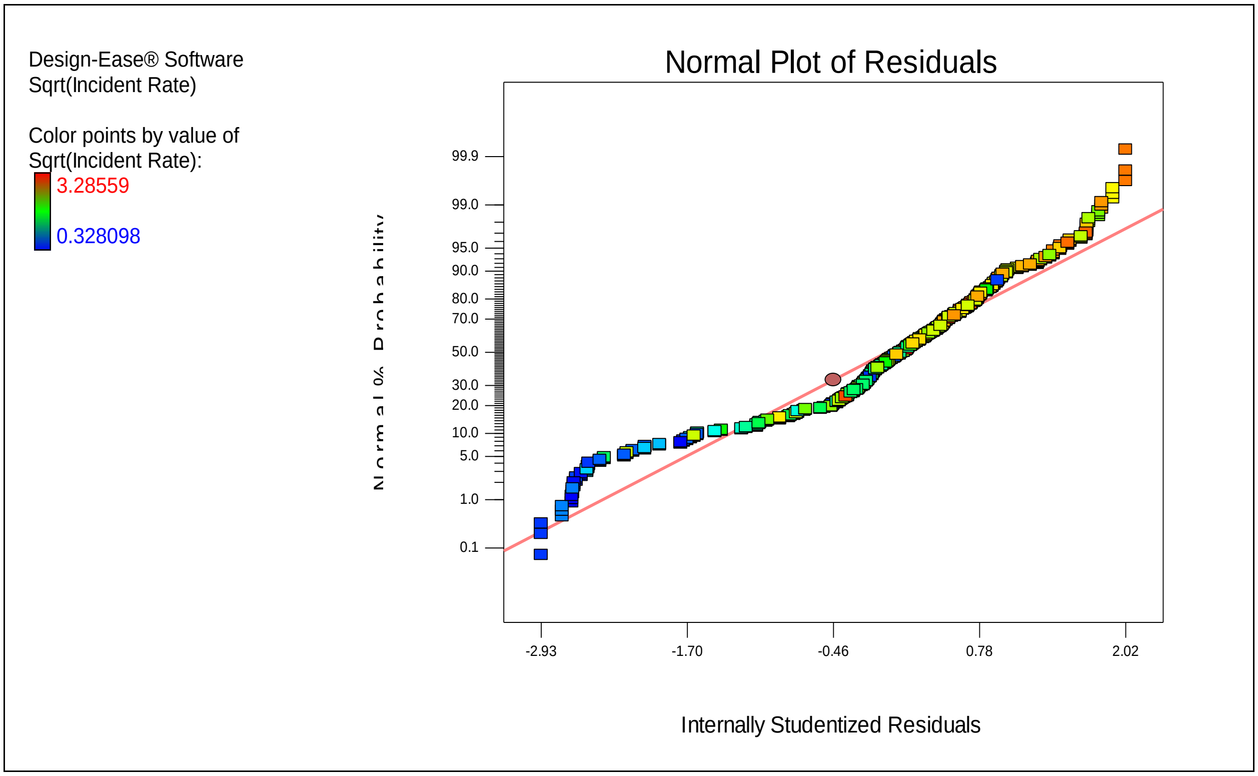

Figure 5.4. Normal plot of residuals for the square root transformation

5.2.2 Natural Log Transformation

The natural log transformation of the incident rate (y) is given as (y'). This is represented mathematically as shown in Equation (5.2).

$$y' = \ln(y) \quad \textbf{(5.2)}$$

The analysis of variance for the natural log transformation was conducted to determine the statistical behavior of the model. The analysis of variance for the natural log transformation shows a high level of model significance; however, Factor B (p-value of 0.1902) remained insignificant since its p-value is greater than 0.05 (Table 5.8). The R^2 value of the natural log transformation is 0.44, which is lower than that of the normal model in Table 5.2 with R^2 value of 0.52. The statistical behavior of the natural log transformation 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 5.7 below.

Table 5.7. Statistical summary of the natural log transformation model

Std. Dev.	0.78	R-Squared	0.4383
Mean	1.28	Adj. R-Squared	0.4133
C.V. %	61.35	Pred. R-Squared	0.3751
PRESS	475.64	Adeq. Precision	32.084

Table 5.8. Analysis of variance (ANOVA) for the natural log transformation

Source	Sum of Squares	Degree of Freedom	Mean Square	F-Value	Prob >F p-Value
Block	0	2	0		
Model	333.63	31	10.76	17.49	< 0.0001
A-A	48.39	1	48.39	78.66	< 0.0001
B-B	1.06	1	1.06	1.72	0.1902
C-C	17.38	1	17.38	28.25	< 0.0001
D-D	24.91	1	24.91	40.49	< 0.0001
E-E	32.78	1	32.78	53.29	< 0.0001
AB	5.41	1	5.41	8.79	0.0031
AC	12.13	1	12.13	19.71	< 0.0001
AD	40.58	1	40.58	65.96	< 0.0001
AE	34.87	1	34.87	56.68	< 0.0001
BC	1.65	1	1.65	2.68	0.102
BD	0.61	1	0.61	0.99	0.3199
BE	2.43	1	2.43	3.95	0.0473
CD	24.10	1	24.1	39.18	< 0.0001
CE	9.62	1	9.62	15.64	< 0.0001
DE	20.72	1	20.72	33.68	< 0.0001
ABC	0.40	1	0.4	0.65	0.4188
ABD	0.33	1	0.33	0.53	0.4673
ABE	7.36	1	7.36	11.96	0.0006
ACD	21.36	1	21.36	34.72	< 0.0001
ACE	5.60	1	5.6	9.10	0.0027
ADE	31.06	1	31.06	50.48	< 0.0001
BCD	0.076	1	0.076	0.12	0.7253
BCE	4.52	1	4.52	7.34	0.0069
BDE	0.70	1	0.7	1.14	0.2863
CDE	25.92	1	25.92	42.13	< 0.0001
ABCD	0.56	1	0.56	0.91	0.3397
ABCE	1.59	1	1.59	2.59	0.1078
ABDE	0.46	1	0.46	0.75	0.3853
ACDE	19.71	1	19.71	32.04	< 0.0001
BCDE	0.067	1	0.067	0.11	0.742
ABCDE	1.13	1	1.13	1.84	0.1758
Residual	427.55	695	0.62		
Lack of Fit	424.68	662	0.64	7.37	< 0.0001
Pure Error	2.87	33	0.087		
Cor Total	761.18	728			

In order to determine the normality of the natural log transformation, the normal plot of residuals was analyzed. The normal plot of residuals shown in Figure 5.5 shows several outliers which indicate some inadequacies in the normality of the model obtained from the natural log transformation.

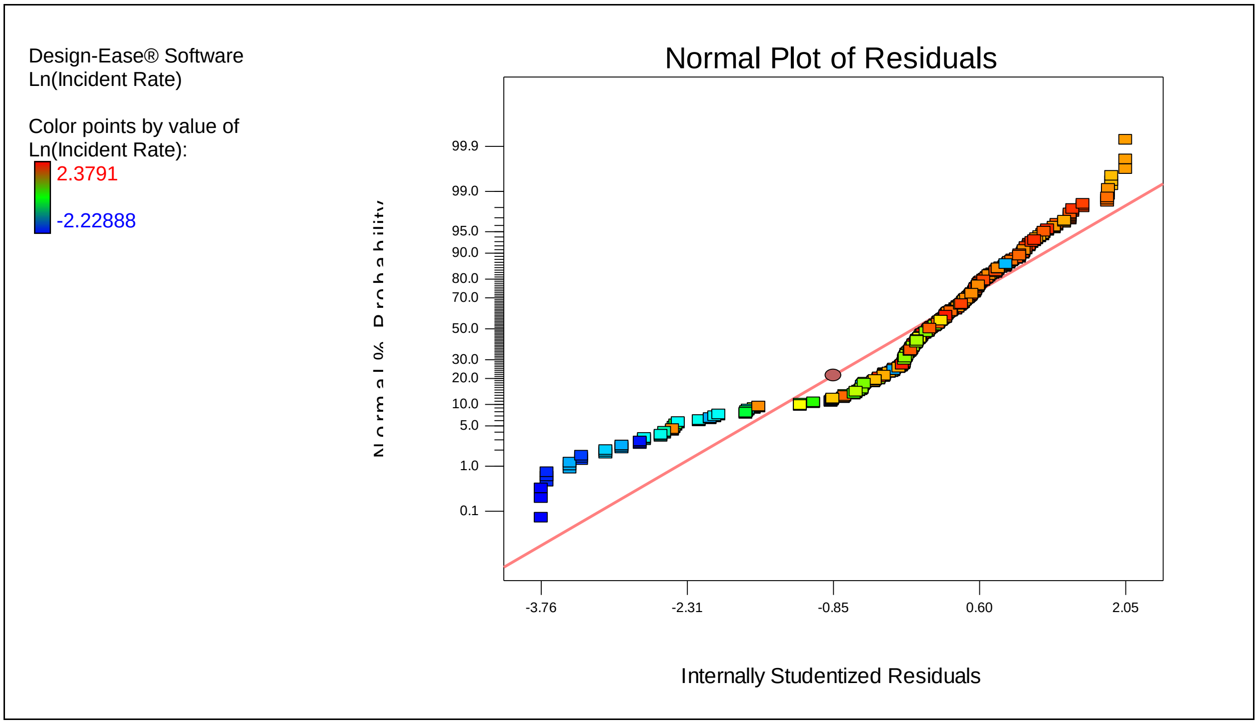

Figure 5.5. Normal plot of residuals for the natural log transformation

5.2.3 Base 10 Log Transformation

The base 10 log transformation of the incident rate (y) is given as (y'). This is represented mathematically as shown in Equation (5.3).

$$y' = \log_{10}(y) \tag{5.3}$$

The analysis of variance for the base 10 log transformation was conducted to determine the statistical behavior of the model. The analysis of variance for the base 10 log transformation shows a high level of model significance; however, Factor B (p-value of 0.1902) remained insignificant since its p-value is greater than 0.05 (Table 5.10). The R^2 value of the base 10 log transformations is 0.44, which is lower than that of the normal model in Table 5.2 with R^2 value of 0.52. The statistical behavior of the base 10 log transformation 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 5.9 below.

Table 5.9. Statistical summary of the base 10 log transformation model

Std. Dev.	0.34	R-Squared	0.4383
Mean	0.56	Adj. R-Squared	0.4133
C.V. %	61.35	Pred. R-Squared	0.3751
PRESS	89.71	Adeq. Precision	32.084

Table 5.10. Analysis of variance (ANOVA) for the base 10 log transformation

Source	Sum of Squares	Degree of Freedom	Mean Square	F-Value	Prob >F p-Value
Block	0	2	0		
Model	62.93	31	2.03	17.49	< 0.0001
A-A	9.13	1	9.13	78.66	< 0.0001
B-B	0.2	1	0.20	1.72	0.1902
C-C	3.28	1	3.28	28.25	< 0.0001
D-D	4.7	1	4.70	40.49	< 0.0001
E-E	6.18	1	6.18	53.29	< 0.0001
AB	1.02	1	1.02	8.79	0.0031
AC	2.29	1	2.29	19.71	< 0.0001
AD	7.65	1	7.65	65.96	< 0.0001
AE	6.58	1	6.58	56.68	< 0.0001
BC	0.31	1	0.31	2.68	0.102
BD	0.11	1	0.11	0.99	0.3199
BE	0.46	1	0.46	3.95	0.0473
CD	4.55	1	4.55	39.18	< 0.0001
CE	1.81	1	1.81	15.64	< 0.0001
DE	3.91	1	3.91	33.68	< 0.0001
ABC	0.076	1	0.076	0.65	0.4188
ABD	0.061	1	0.061	0.53	0.4673
ABE	1.39	1	1.39	11.96	0.0006
ACD	4.03	1	4.03	34.72	< 0.0001
ACE	1.06	1	1.06	9.10	0.0027
ADE	5.86	1	5.86	50.48	< 0.0001
BCD	0.014	1	0.014	0.12	0.7253
BCE	0.85	1	0.85	7.34	0.0069
BDE	0.13	1	0.13	1.14	0.2863
CDE	4.89	1	4.89	42.13	< 0.0001
ABCD	0.11	1	0.11	0.91	0.3397
ABCE	0.30	1	0.30	2.59	0.1078
ABDE	0.088	1	0.088	0.75	0.3853
ACDE	3.72	1	3.72	32.04	< 0.0001
BCDE	0.013	1	0.013	0.11	0.742
ABCDE	0.21	1	0.21	1.84	0.1758
Residual	80.64	695	0.12		
Lack of Fit	80.1	662	0.12	7.37	< 0.0001
Pure Error	0.54	33	0.016		
Cor Total	143.57	728			

In order to determine the normality of the base 10 log transformation, the normal plot of residuals was analyzed. The normal plot of residuals shown in Figure 5.6 shows several outliers which are not very close to a straight line, thereby indicating some inadequacies in the normality of the model obtained from the base 10 log transformation.

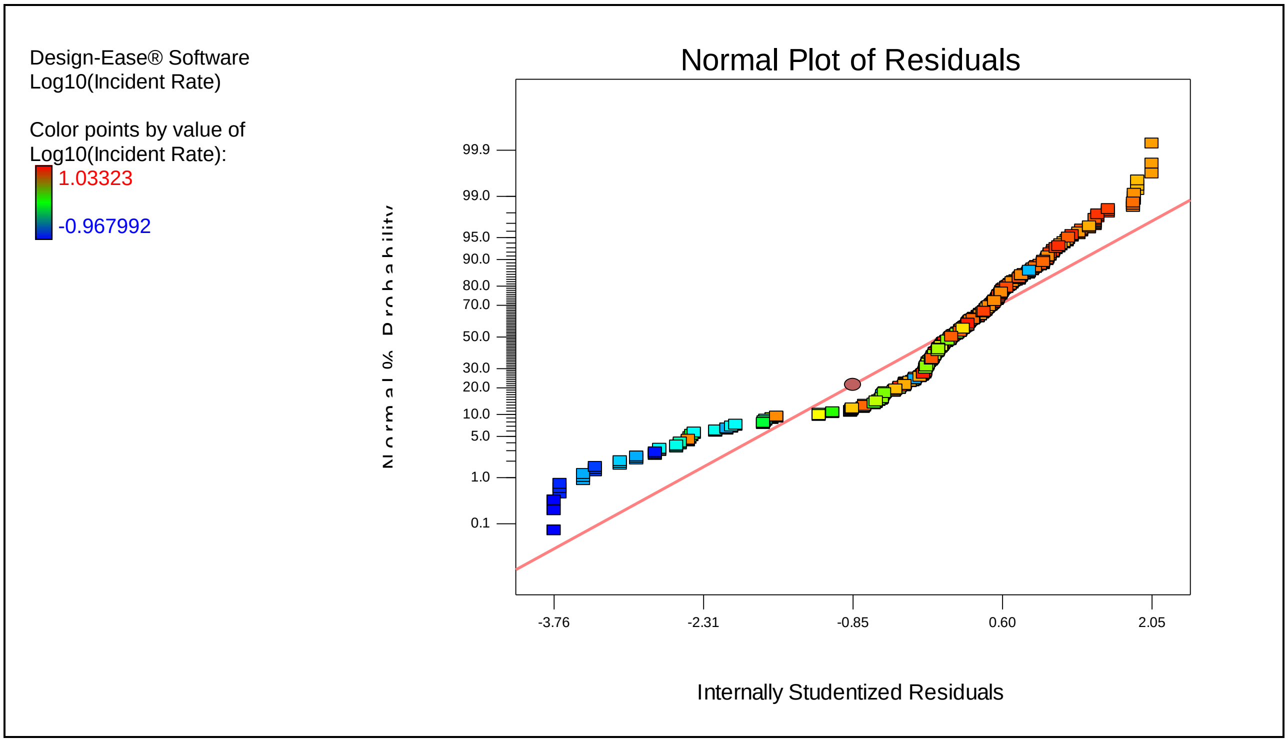

Figure 5.6. Normal plot of residuals for the base 10 log transformation

5.2.4 Inverse Square Root Transformation

The inverse square root transformation of the incident rate (y) is given as (y'). This is represented mathematically as shown in Equation (5.4).

$$\mathbf{y'} = \frac{1}{\sqrt{y}} \tag{5.4}$$

The analysis of variance for the inverse square root transformation was conducted to determine the statistical behavior of the model. The analysis of variance for the inverse square root transformation shows a high level of model significance; however, Factor B (p-value of 0.107) remained insignificant since its p-value is greater than 0.05 (Table 5.12). The R^2 value of the inverse square root transformation is 0.41, which is lower than that of the normal model in Table 5.2 with R^2 value of 0.52. The statistical behavior of the inverse square root transformation 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 5.11 below.

Table 5.11. Statistical summary of the inverse square root transformation model

Std. Dev.	0.39	R-Squared	0.4056
Mean	0.63	Adj. R-Squared	0.3791
C.V. %	62.59	Pred. R-Squared	0.3298
PRESS	120.56	Adeq. Precision	32.208

Table 5.12. Analysis of variance (ANOVA) for the inverse square root transformation

Source	Sum of Squares	Degree of Freedom	Mean Square	F-Value	Prob >F p-Value
Block	0	2	0		
Model	72.97	31	2.35	15.30	< 0.0001
A-A	13.01	1	13.01	84.54	< 0.0001
B-B	0.40	1	0.40	2.61	0.107
C-C	5.00	1	5.00	32.5	< 0.0001
D-D	6.41	1	6.41	41.66	< 0.0001
E-E	9.25	1	9.25	60.10	< 0.0001
AB	1.57	1	1.57	10.17	0.0015
AC	3.45	1	3.45	22.42	< 0.0001
AD	10.82	1	10.82	70.35	< 0.0001
AE	9.96	1	9.96	64.74	< 0.0001
BC	0.44	1	0.44	2.87	0.0906
BD	0.051	1	0.051	0.33	0.5646
BE	1.13	1	1.13	7.34	0.0069
CD	6.66	1	6.66	43.3	< 0.0001
CE	3.09	1	3.09	20.09	< 0.0001
DE	5.74	1	5.74	37.3	< 0.0001
ABC	0.12	1	0.12	0.80	0.3701
ABD	0.19	1	0.19	1.21	0.2718
ABE	2.57	1	2.57	16.68	< 0.0001
ACD	5.77	1	5.77	37.5	< 0.0001
ACE	1.79	1	1.79	11.63	0.0007
ADE	8.92	1	8.92	57.97	< 0.0001
BCD	0.08	1	0.08	0.52	0.4714
BCE	1.00	1	1.00	6.49	0.0111
BDE	0.013	1	0.013	0.085	0.7711
CDE	7.16	1	7.16	46.53	< 0.0001
ABCD	0.19	1	0.19	1.25	0.264
ABCE	0.34	1	0.34	2.19	0.1396
ABDE	0.45	1	0.45	2.89	0.0893
ACDE	5.31	1	5.31	34.49	< 0.0001
BCDE	1.15E-03	1	1.15E-03	7.49E-03	0.931
ABCDE	0.015	1	0.015	0.099	0.753
Residual	106.93	695	0.15		
Lack of Fit	105.52	662	0.16	3.72	< 0.0001
Pure Error	1.41	33	0.043		
Cor Total	179.9	728			

In order to determine the normality of the inverse square root transformation, the normal plot of residuals was analyzed. The normal plot of residuals shown in Figure 5.7 shows numerous outliers which indicate high level of inadequacies in the normality of the model obtained from the inverse square root transformation.

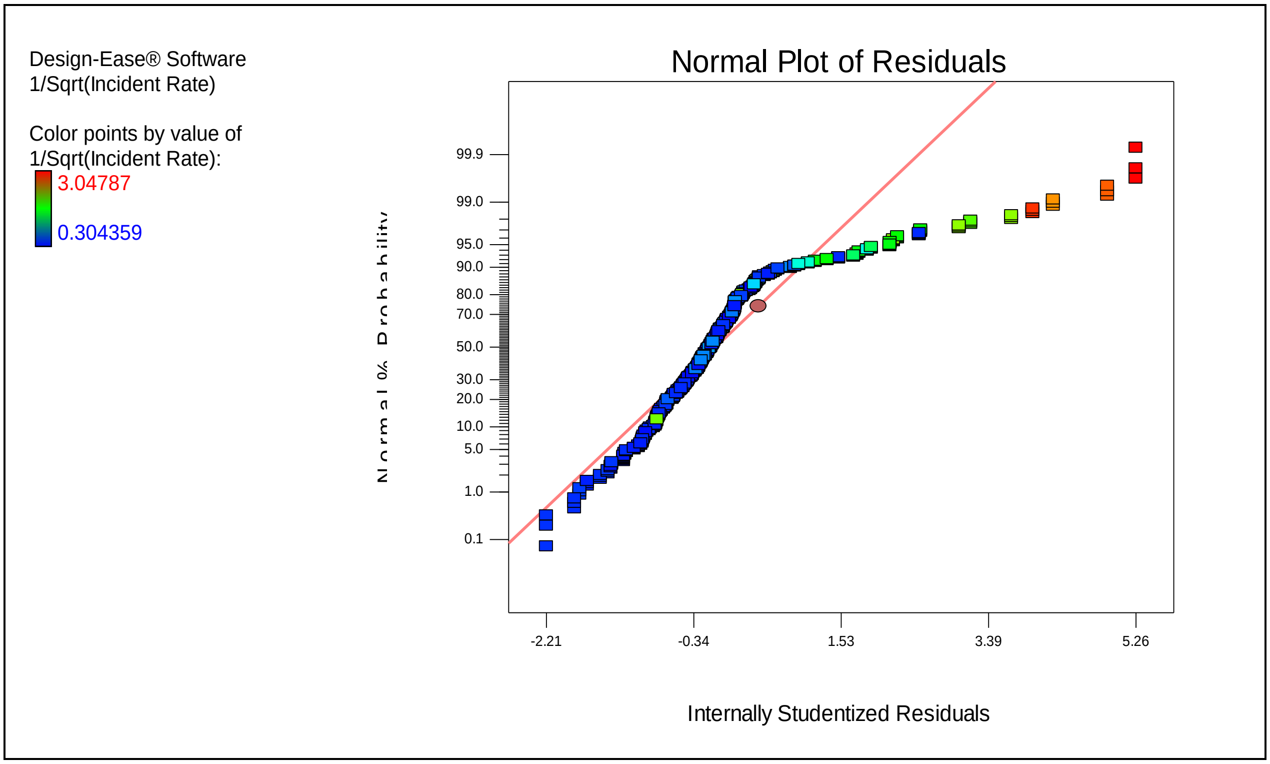

Figure 5.7. Normal plot of residuals for the inverse square root transformation

5.2.5 Inverse Transformation

The inverse transformation of the incident rate (y) is given as (y'). This is represented mathematically as shown in Equation (5.5).

$$y' = \frac{1}{y} \tag{5.5}$$

The analysis of variance for the inverse transformation was conducted to determine the statistical behavior of the model. The analysis of variance for the inverse transformation shows a high level of model significance; however, Factor B remained insignificant (p-value of 0.2728) since its p-value is greater than 0.05 (Table 5.14). The R^2 value of the inverse transformation is 0.36, which is lower than that of the normal model in Table 5.2 with R^2 value of 0.52. The statistical behavior of the inverse transformation 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 5.13 below.

Table 5.13. Statistical summary of the inverse transformation model

Std. Dev.	1.11	R-Squared	0.3644
Mean	0.64	Adj. R-Squared	0.3361
C.V. %	173.53	Pred. R-Squared	0.2763
PRESS	974.57	Adeq. Precision	28.705

Table 5.14. Analysis of variance (ANOVA) for the inverse transformation

Source	Sum of Squares	Degree of Freedom	Mean Square	F-Value	Prob >F p-Value
Block	0	2	0		
Model	490.77	31	15.83	12.86	< 0.0001
A-A	90.63	1	90.63	73.60	< 0.0001
B-B	1.48	1	1.48	1.20	0.2728
C-C	38.45	1	38.45	31.22	< 0.0001
D-D	44.75	1	44.75	36.34	< 0.0001
E-E	71.29	1	71.29	57.89	< 0.0001
AB	7.45	1	7.45	6.05	0.0141
AC	26.47	1	26.47	21.50	< 0.0001
AD	75.88	1	75.88	61.62	< 0.0001
AE	75.59	1	75.59	61.38	< 0.0001
BC	6.00	1	6.00	4.87	0.0276
BD	0.55	1	0.55	0.45	0.5036
BE	8.89	1	8.89	7.22	0.0074
CD	50.64	1	50.64	41.12	< 0.0001
CE	28.63	1	28.63	23.25	< 0.0001
DE	45.17	1	45.17	36.68	< 0.0001
ABC	2.19	1	2.19	1.78	0.1826
ABD	0.68	1	0.68	0.56	0.4562
ABE	18.56	1	18.56	15.08	0.0001
ACD	43.74	1	43.74	35.52	< 0.0001
ACE	16.6	1	16.6	13.48	0.0003
ADE	69.24	1	69.24	56.23	< 0.0001
BCD	0.34	1	0.34	0.27	0.6012
BCE	6.32	1	6.32	5.13	0.0238
BDE	7.02E-03	1	7.02E-03	5.70E-03	0.9398
CDE	57.93	1	57.93	47.04	< 0.0001
ABCD	0.60	1	0.60	0.49	0.4846
ABCE	2.01	1	2.01	1.64	0.2014
ABDE	4.48	1	4.48	3.63	0.057
ACDE	43.05	1	43.05	34.96	< 0.0001
BCDE	1.19E-04	1	1.19E-04	9.70E-05	0.9921
ABCDE	1.52	1	1.52	1.23	0.2677
Residual	855.86	695	1.23		
Lack of Fit	831.28	662	1.26	1.69	0.0331
Pure Error	24.59	33	0.75		
Cor Total	1346.63	728			

The normality of the inverse transformation was determined by the analysis of the normal plot of residuals. The normal plot of residuals shown in Figure 5.8 shows numerous outliers which indicate high level of inadequacies in the normality of the model obtained from the inverse transformation.

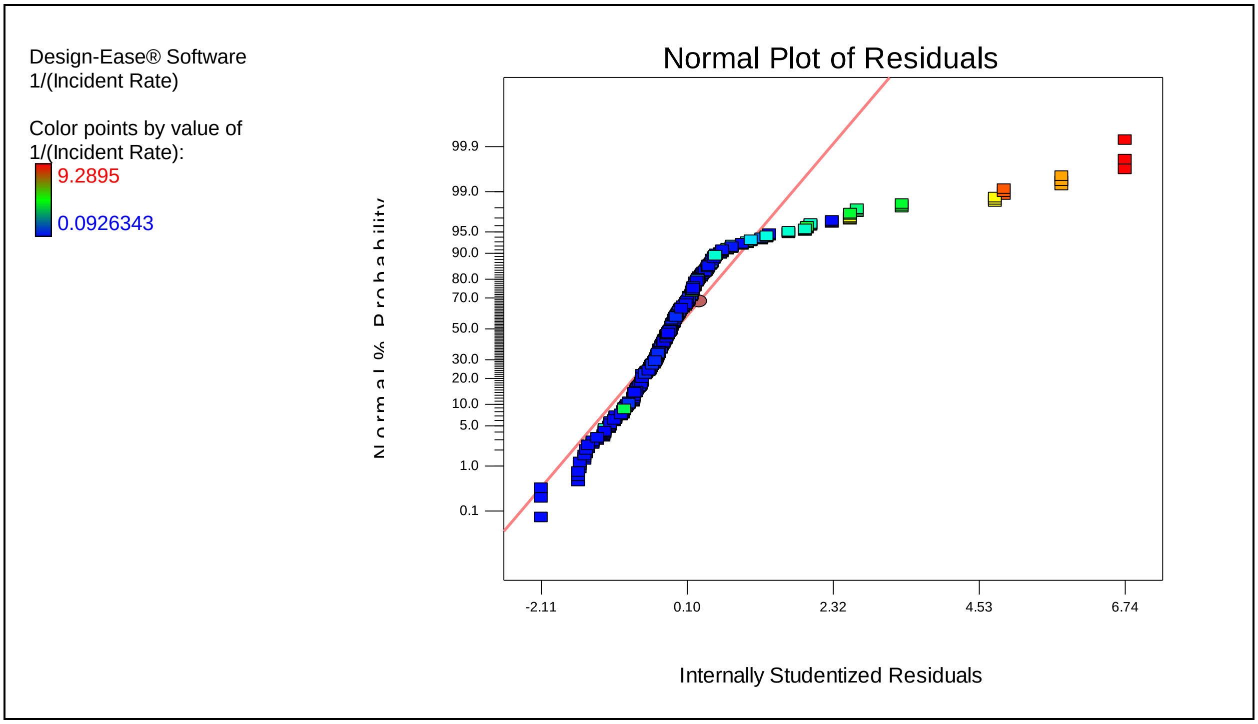

Figure 5.8. Normal plot of residuals for the inverse transformation

5.2.6 Summary of Transformational Analysis

Transformational analysis was conducted on the safety intervention model to determine any model inadequacies and to determine any model improvement. The transformational analyses of the response variable did not provide any improvement to the normal model. As a result of this, the normal model was selected for further analysis and optimization. Transformations of the independent variables were not considered in this research since the transformations of the response variable (the variable of interest) revealed that the model characteristic is not improved. Table 5.15 below shows the summary of the characteristics of each transformation.

Table 5.15. Summary of statistical characteristics of the model transformation

Transformation	Normal Model (y)	Square Root of (y)	Natural log of (y)	Base 10 Log of (y)	Inverse Square Root of (y)	Inverse of (y)
F-Value	23.98	20.64	17.49	17.49	15.30	12.86
R^2 value	0.52	0.48	0.44	0.44	0.41	0.36
Normality	Yes	No	No	No	No	No

It should be noted that the model F-value decreases with each transformation. An increasing F-value indicates high levels of significance. Since the normal model exhibits the highest F-value, then it can be deduced that the untransformed model is the most significant. The comparison of the R^2 values was another method used for the selection of the best model for this research. The R^2 value is described as the proportion of the variability in the data explained by the ANOVA model (Montgomery, 2008). A higher R^2 value is desired, however due to the large number of human-related data (n =729), it may be unrealistic to obtain an extremely high value of R^2. Table 5.15 shows that the normal model exhibits the highest R^2 value. Like the F-value, the R^2 value decreases with each transformation of the normal model.

CHAPTER 6

DISCUSSION

6.1 The Safety Intervention Model

The transformational analysis showed no improvement in the model characteristics of the normal safety model. As a result of this, further investigations of interaction effects were conducted on the selected model. The analysis of variance results in Table 5.2 showed the calculated p-values for Factors A, B, C, D and E as < 0.0001, 0.9057, < 0.0001, < 0.0001 and < 0.0001, respectively. Model terms are considered significant if their p-values are less than 0.05. This shows that Factors A (leadership and accountability), C (contractor engagement and planning), D (work in progress) and E (safety evaluation, measurement and verification) are the significant factors. Factor B (qualification, selection and pre-job) is not a significant model term since its p-value is greater than 0.05. Other significant interactions are AC, AD, AE, BC, BD, CD, CE, DE, ACD, ACE, ADE, BCE, BDE, CDE, ACDE, ABCDE.

The selected model F-Value of 23.98 implies the model is significant. This analysis also shows that there is only a 0.01% chance that a “Model F-Value” this large could occur due to noise. This is low and very reasonable for this model when compared to the confidence interval of 95%. This shows that the confidence interval may actually be increased to 99.99%. Allocating more resources toward Factors A, C, D and E would initially reduce incident rates in a significant manner, but would likely diminish over a period of time. Allocating resources towards the combination of positive effects and negative effects may not provide any immediate improvement on the safety model. The incident rate Equation obtained when all factors and interactions are considered, regardless of the level of significance is shown in Table 6.1.

Table 6.1. Incident rate equation for all factors and interactions

Incident Rate (y)	=
-62.16153	
-102.3857	* A
35.33625	* B
1.05183	* C
28.066	* D
4.57215	* E
0.98571	* A * B
25.18293	* A * C
12.70549	* A * D
139.24425	* A * E
-3.88255	* B * C
-9.57642	* B * D
-29.12686	* B * E
-6.32195	* C * D
11.0243	* C * E
-7.41656	* D * E
-1.00681	* A * B * C
1.52071	* A * B * D
-3.04101	* A * B * E
-1.65807	* A * C * D
-34.67542	* A * C * E
-24.85945	* A * D * E
2.01382	* B * C * D
3.65689	* B * C * E
6.81309	* B * D * E
0.61596	* C * D * E
-0.59838	* A * B * C * D
1.22335	* A * B * C * E
-0.017111	* A * B * D * E
5.48501	* A * C * D * E
-1.29584	* B * C * D * E
0.10478	* A * B * C * D * E

From Table 5.2, the summary of the statistical behavior of the safety model reveal that the "Pred R-Squared" value of 0.47 is in reasonable agreement with the "Adj R-Squared" of 0.50 and “R-Squared” of 0.52. A negative "Pred R-Squared" of the model would imply that the mean values for the factors would have been a better predictor of the response (incident rate) than the current model. This is not the case in this analysis since all the R^2 values obtained are positive. Also, model development based on the mean values would eliminate the tail-end effects of the data. Since the data is normally distributed, all values are considered in this analysis.

Adequate precision is the term used to describe the statistical measure of the signal to noise ratio in a model. The minimum desirable level of adequate precision ratio is 4. Therefore, the obtained adequate precision ratio of 27.69 indicates a very adequate signal which indicates that this model could be used to navigate the design space (within the available man-hour constraint). The correlations in the level of interaction effects of the model terms were analyzed to determine the margin of effect. Figures 6.1 - 6.10 show the various interaction effects for Factors A, B, C, D, and E (Similar to interaction effects for other significant factors).

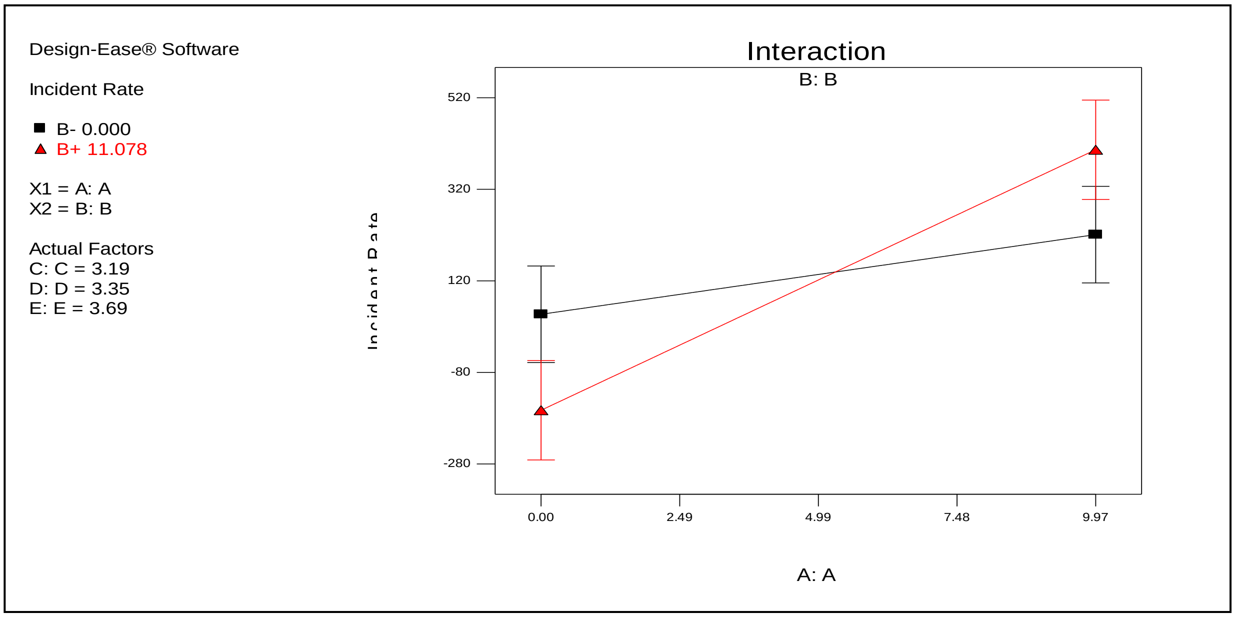

Figure 6.1. Comparison of significance in interactive effects in ABCDE

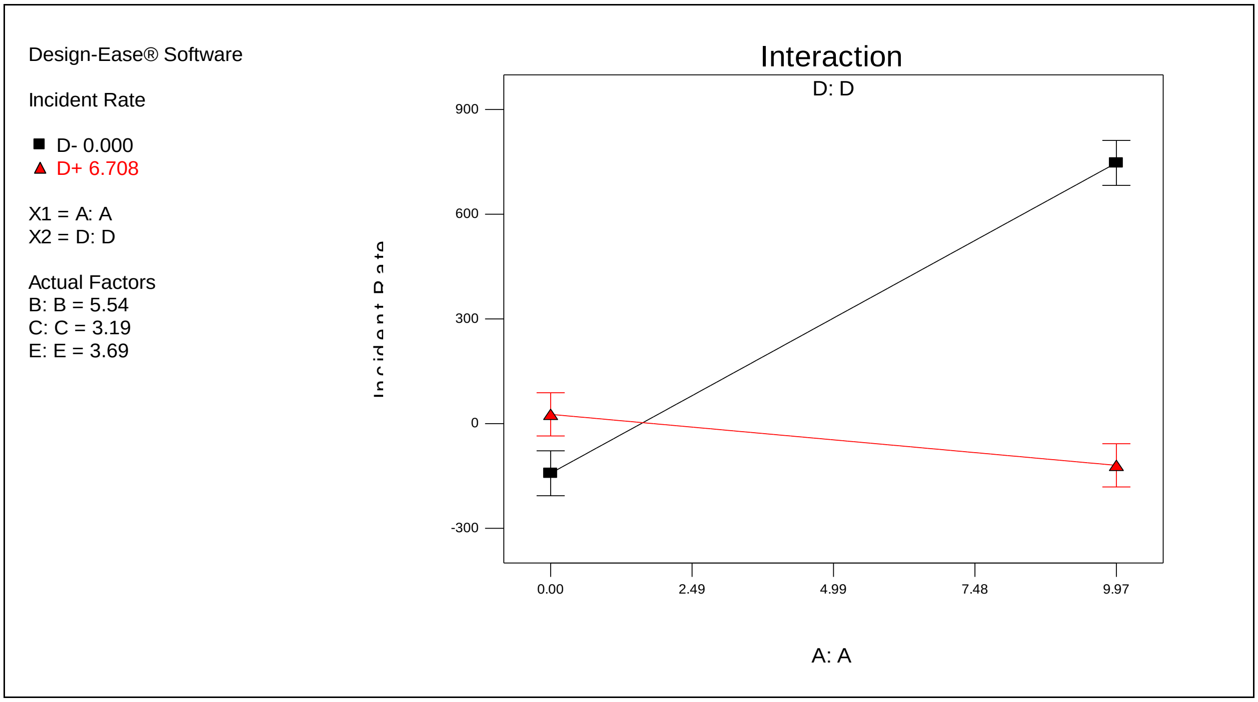

Figure 6.2. Comparison of significance in interactive effects in AD

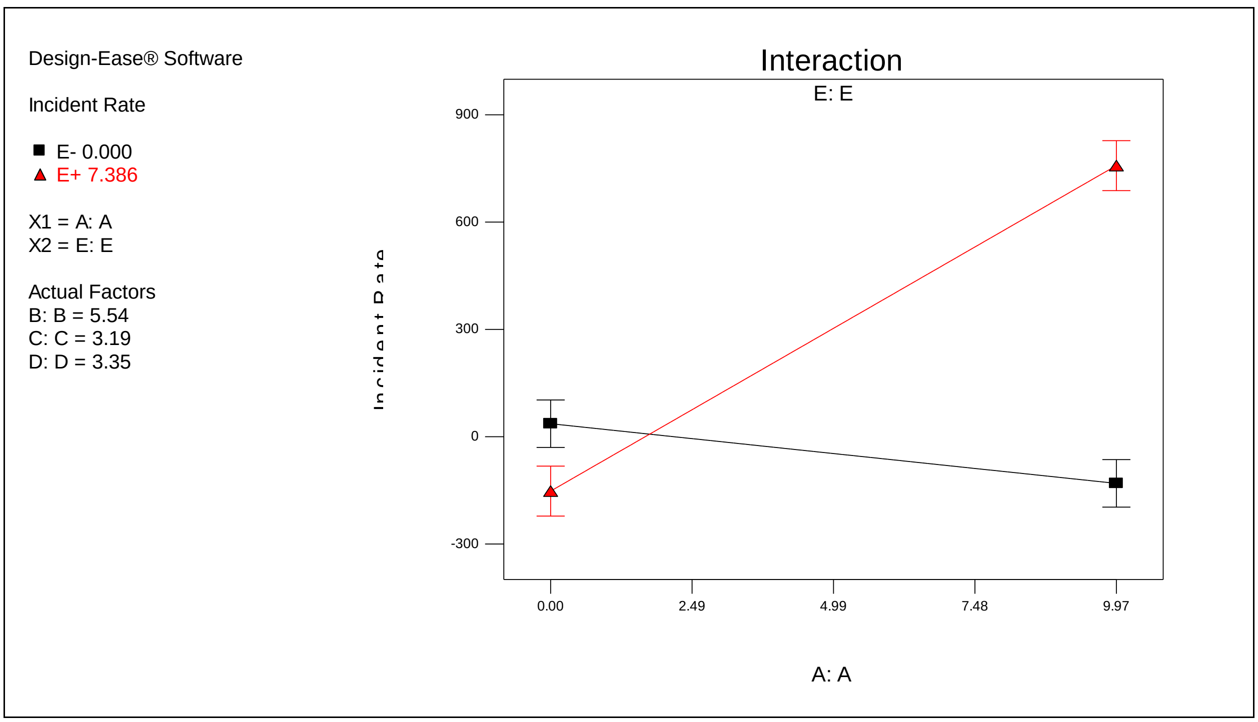

Figure 6.3. Comparison of significance in interactive effects in AE

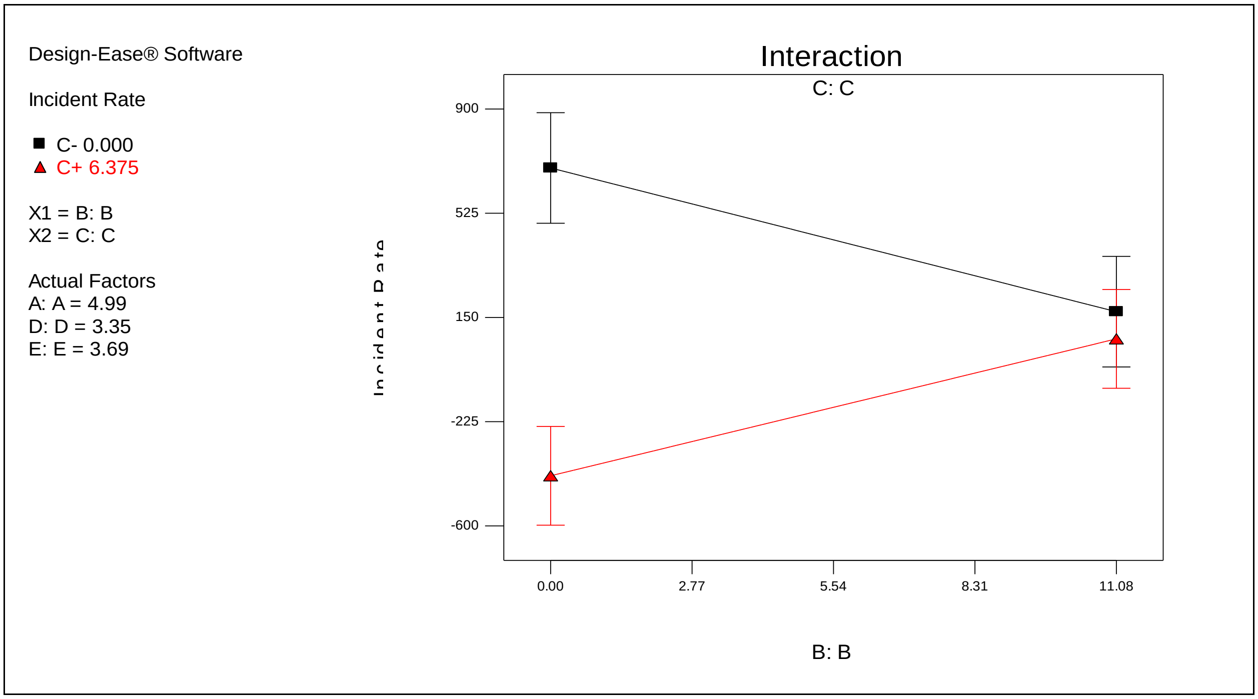

Figure 6.4. Comparison of significance in interactive effects in BC

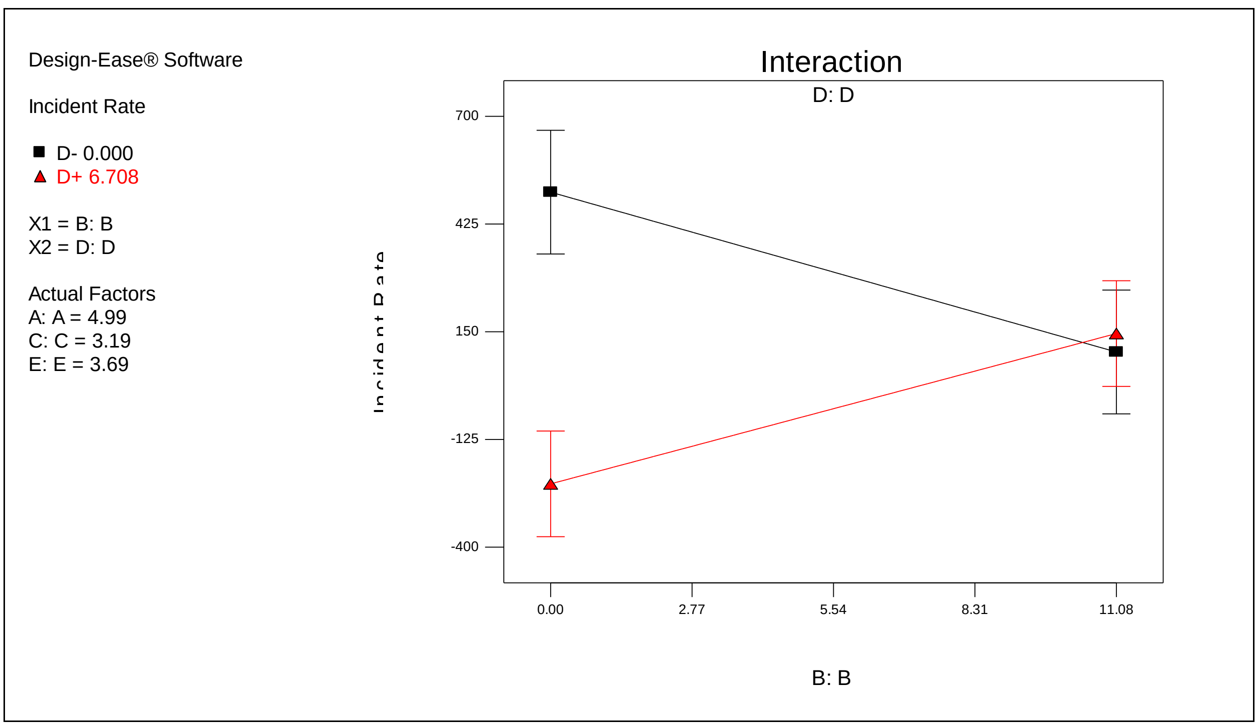

Figure 6.5. Comparison of significance in interactive effects in BD

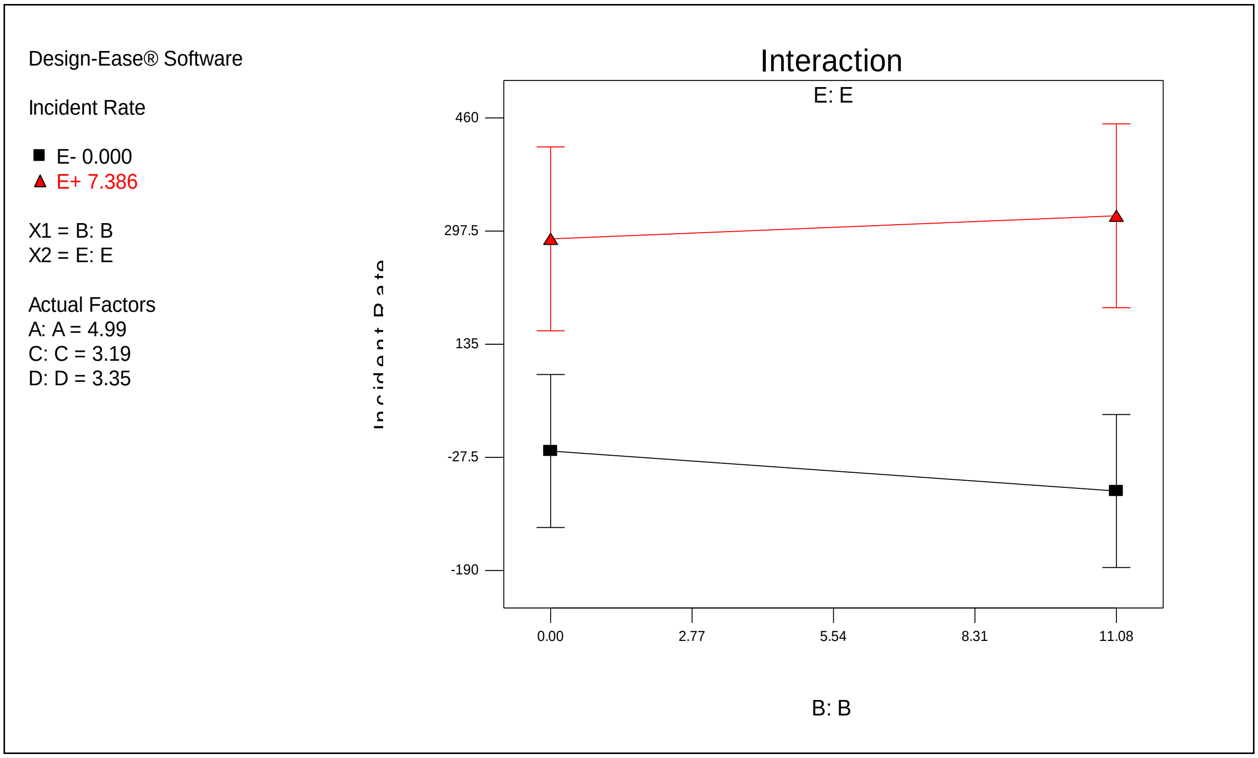

Figure 6.6. Comparison of significance in interactive effects in BE

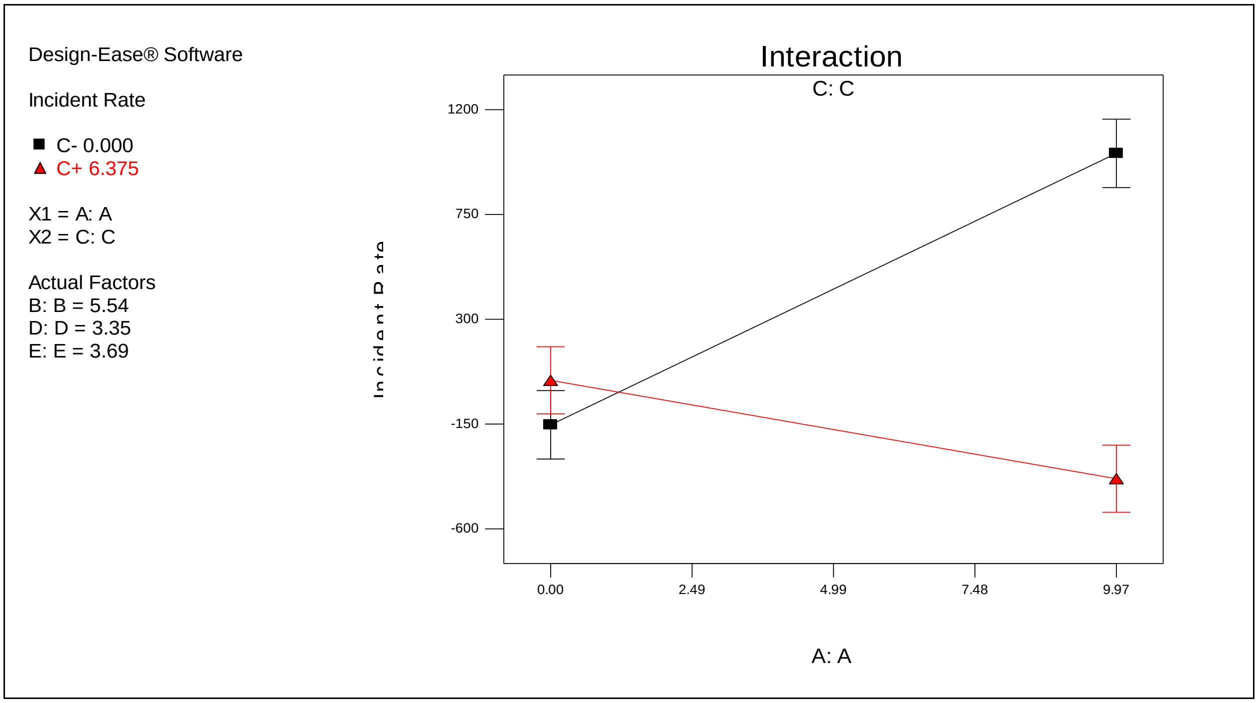

Figure 6.7. Comparison of significance in interactive effects in AC

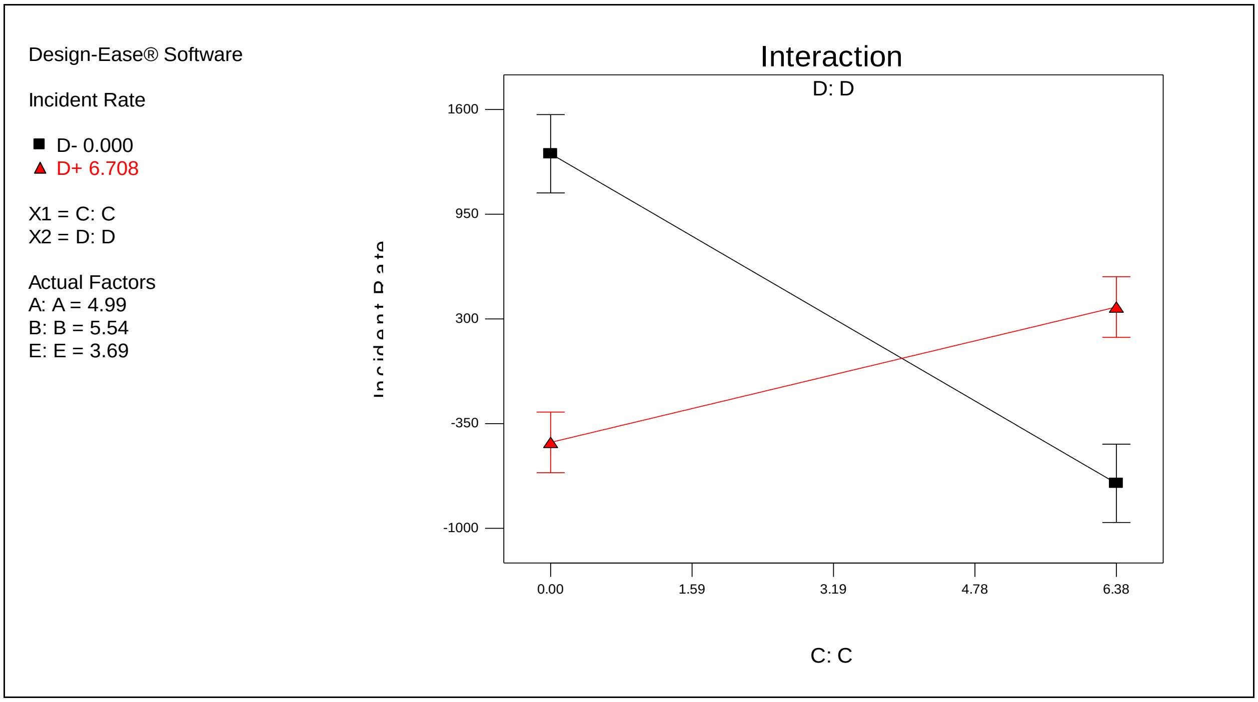

Figure 6.8. Comparison of significance in interactive effects in CD

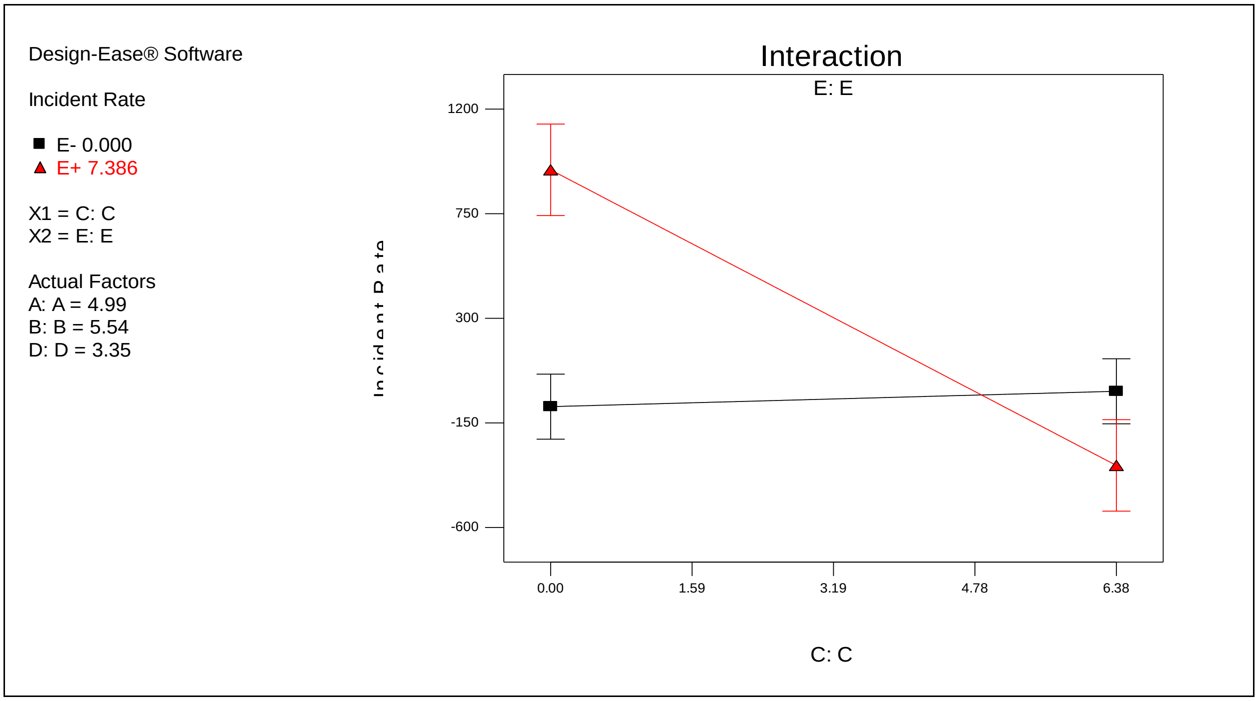

Figure 6.9. Comparison of significance in interactive effects in CE

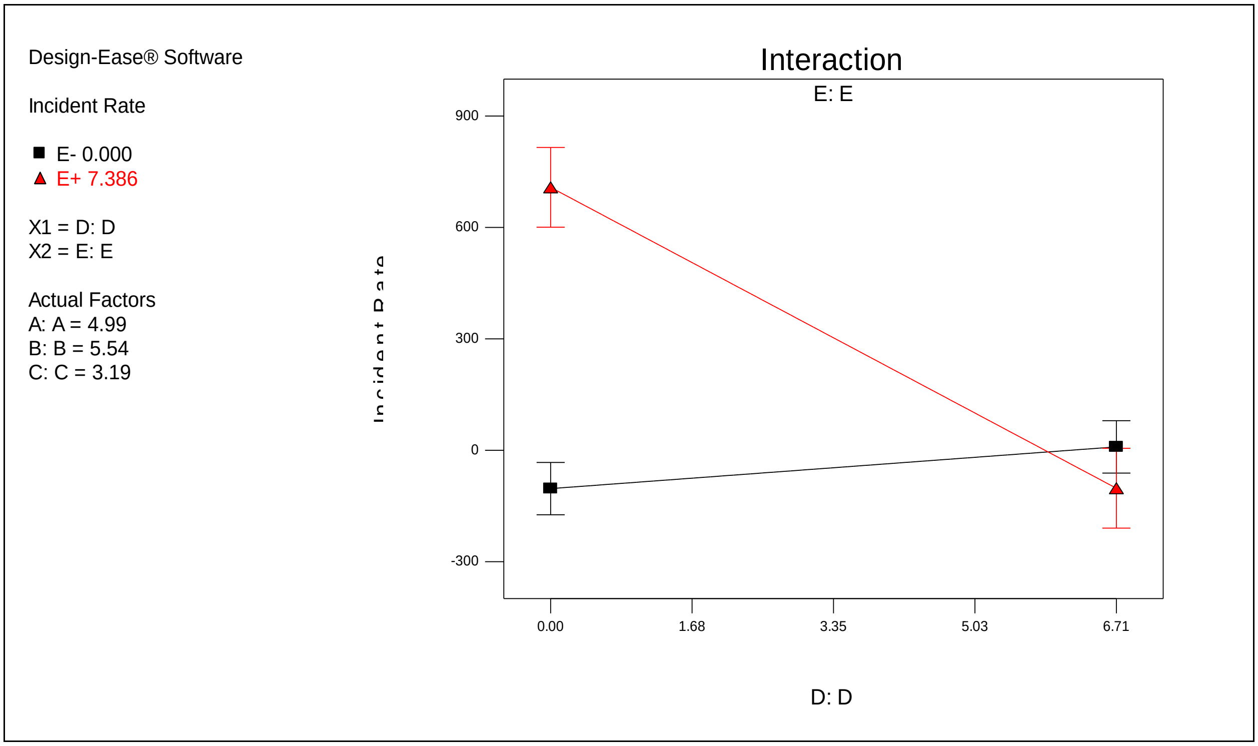

Figure 6.10. Comparison of significance in interactive effects in DE

It could be seen that that all the investigated factor interaction effects show significant levels of interaction except Figure 6.6. The interaction in BE does not show any level of interaction, which indicates a negative effect and non-significance (not recommended to reduce incident rates). The wide margin of separation and non-significance in interactive effect in BE is in conformity with the obtained P-value of 0.7603 (See Table 5.2). The comparison of significance in interactive effects of other model terms such as the 3-or 4-way interactions shows similar plots as shown in Figures 6.1 - 6.10. The level of improvement of the model significance based on the interaction effects of the factors was determined using the studentized effects generated by comparing the level of contributions of each factor and interaction in the model. A higher percentage of contribution indicates increased level of significance (See Table 6.2).

Table 6.2. Effect list for factors and interactions

Source	Term Intercept	Stdized Effect	Sum of Squares	Contribution (%)
Model	A-A	371.5553	57.6382	1.0100
Model	B-B	-5.7883	211.5585	3.7071
Model	C-C	-227.6091	623.6144	10.9275
Model	D-D	-302.5008	75.7032	1.3265
Model	E-E	320.1003	96.1812	1.6854
Model	AB	68.3449	1.4383	0.0252
Model	AC	-191.3375	26.1444	0.4581
Model	AD	-350.7105	169.5762	2.9714
Model	AE	309.5442	440.1378	7.7124
Model	BC	109.4426	1.2897	0.0226
Model	BD	100.9805	20.7118	0.3629
Model	BE	14.9108	44.8536	0.7860
Model	CD	269.0063	0.0962	0.0017
Model	CE	-180.2019	77.7268	1.3620
Model	DE	-278.4322	61.8996	1.0847
Model	ABC	60.9793	45.8581	0.8036
Model	ABD	31.8593	41.3330	0.7243
Model	ABE	85.5820	53.5706	0.9387
Model	ACD	259.0995	108.9014	1.9083
Model	ACE	-138.3365	118.6828	2.0797
Model	ADE	-302.4975	192.7922	3.3783
Model	BCD	-49.8963	5.2865	0.0926
Model	BCE	123.7836	78.1071	1.3687
Model	BDE	110.1470	115.1159	2.0172
Model	CDE	300.1628	59.8322	1.0484
Model	ABCD	-13.7071	4.6773	0.0820
Model	ABCE	73.1234	14.1400	0.2478
Model	ABDE	34.1618	0.1135	0.0020
Model	ACDE	271.2959	112.8043	1.9766
Model	BCDE	-42.3881	0.8163	0.0143
Model	ABCDE	230.8962	88.6319	1.5531
Error	Lack of Fit		2726.5038	47.7759
Error	Pure Error		31.1208	0.5453
Margin of Error (ME)	Lenth's ME	49.3120		
Simultaneous Margin of Error (SME)	Lenth's SME	79.3314		

The significant model terms in the analysis of variance Table 5.2 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, using forward regression method to develop a safety intervention model which gives a better prediction of the dependent variable (incident rate). 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 be relevant for the model development. If non-significant variables were allowed to come into the model, the R-squared would continue to increase, even though the predictive capability of the regression gets worse. Thus non-significant variables definitely should not be allowed into the model. The regression equation is:

$$\text{Incident Rate} = 21.41 - 2.19A - 4.47C - 6.37D - 21.80E + 1.60AC + 1.69AD + 3.69AE + 1.65CD + 3.83CE + 7.55DE - 0.63ACD - 0.83ACE - 2.01ADE - 1.70CDE + 0.53ACDE \quad \textbf{(6.1)}$$

The incident rate Equation (6.1) 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 (6.2) below:

Where y is the independent variable and x_1, x_3, $\mathbf{x_4}$ and x_5 are the input variables.

$$(y) = 21.41 - 2.19x_1 - 4.47x_3 - 6.37x_4 - 21.80x_5 + 1.60x_1x_3 + 1.69x_1x_4 + 3.69x_1x_5 + 1.65x_3x_4 + 3.83x_3x_5 + 7.55x_4x_5 - 0.63x_1x_3x_4 - 0.83x_1x_3x_5 - 2.01x_1x_4x_5 - 1.70x_3x_4x_5 + 0.53x_1x_3x_4x_5 \quad \textbf{(6.2)}$$

The analysis of variance for the significant factors and interactions shown in Table 6.3 proves that the safety model is significant.

Table 6.3. Analysis of variance for significant factors and interactions

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			

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

The R-squared in this model (R^2= 0.54) is slightly higher when compared to the R-squared of all factors and interactions produced in the analysis of variance test shown in Table 5.2 (R^2= 0.52). The Adjusted R-squared in this model (R^2= 0.53) is slightly higher when compared to the R-squared of all factors and interactions (R^2= 0.50). This shows that the significant factors and interactions are better predictors of the safety model.

From Equation 6.1, incident rates could be predicted from the input variables, and the regression model could be developed to recommend an effective intervention policy based on these factors and interactions. Equation (6.2) is the desired safety intervention model. 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 6.11 below.

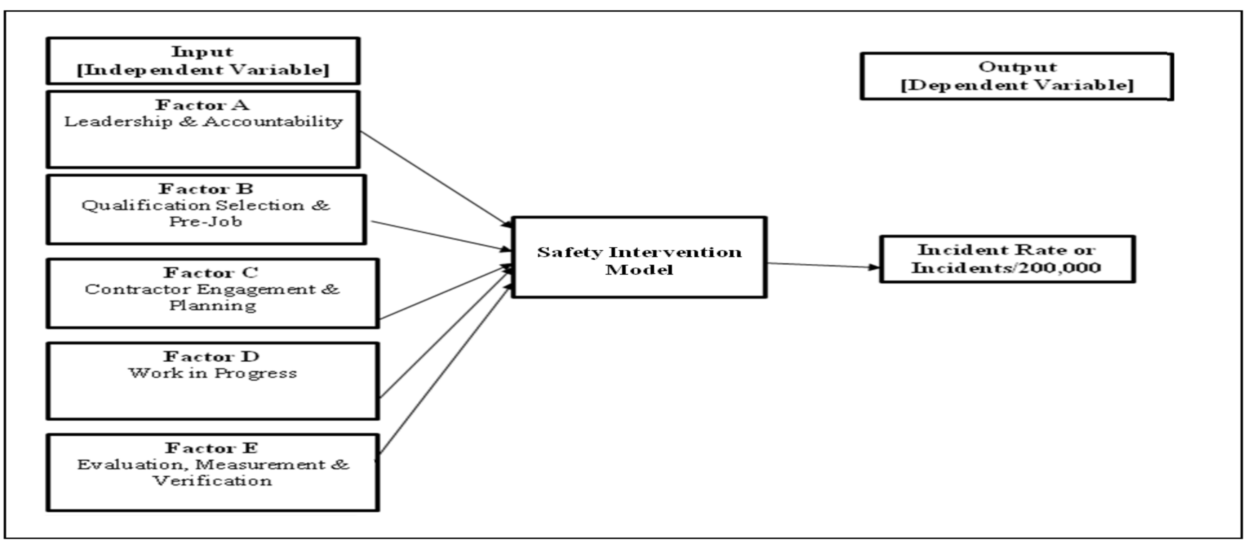

Figure 6.11. Representation of the safety intervention model

(Adapted from Haight et al., 2001a)

6.2 Hypotheses Verification

Hypothesis 1 was verified based on the results of the analysis of variance shown in Table 5.2. Factors A, C, D, and E are significant model terms, thereby indicating that the incident rate depends on more than one factor. Since incident rates depended on more than one safety intervention factor in this study, the null hypothesis statement (H_0) is rejected, while the alternative hypothesis statement (H_1) is accepted in Hypothesis 1. In order to verify Hypothesis 2, transformational analysis was conducted to determine the choice of the selected safety model. The safety model was transformed by converting the incident rate or response variable (y) into the square root of y, the natural log of y, the base 10 log of y, the inverse square root of y, and the inverse of y. Since analysis results show that the model characteristics did not improve when transformed, the null hypothesis statement (H_0) is accepted while the alternative hypothesis statement (H_1) is rejected in Hypothesis 2.

Hypothesis 3 was verified by checking whether the interaction effects of the factors improve the level of model significance. The results of the analysis of variance shown in Table 5.2 shows 5 factors and 26 factor interactions, with 4 factors and 16 factor interactions being significant. Further analysis of the factor and interaction effects shown in Table 6.2 revealed that Factors A-E contributed 18.66% in effects to the safety model. Significant factors A, C, D, and E contributed 14.96% while Factor B contributed 3.71%. The overall contribution of the factor interactions was 33.03% in effects. The 16 significant factor interactions contributed 29.31% while the 10 non-significant interactions accounted for the remaining 3.72%. Since the 16 significant factor interactions contributed the highest percentage in effects, the null hypothesis statement is rejected (H_0), while the alternative hypothesis statement (H_1) is accepted in Hypothesis 3.

6.3 Use of Response Surface Designs and Contour Plots for Resource Allocation

Since optimality cannot be guaranteed, near-optimum levels of incident rates could be estimated through the use of response surface and contour plots. The 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). Near-optimum values of the response variables could be determined based on the values of the factors which produce the near-optimality in the response surface design and contour plots.

In this research, the regression equation obtained for the safety intervention model (Equation 6.2) is a fourth-order function. Since the dependent variable (incident rate) is described adequately by the two-factor interactions (See Figures 6.1 – 6.10), then it is assumed that a second-order regression equation could be used to obtain a desirable condition (indicating the lowest level of incident rate). It should be noted that the level of complexity of the factor interactions in the fourth-order is further simplified based on the use of the second-order regression equation. Therefore, Equation 6.2 could be written in the form of a second-order (quadratic) response surface function as shown in Equation (6.3) below:

$$\mathbf{y} = \boldsymbol{\beta}_0 + \sum_{i}^{k} (\boldsymbol{\beta}_i \mathbf{x}_i) + \sum_{i=1}^{k} \left(\boldsymbol{\beta}_{ii} \mathbf{x}_i^2\right) + \sum_{i=1}^{k-1} \sum_{\substack{j=2 \\ i<j}}^{k} (\boldsymbol{\beta}_{ij} \mathbf{x}_i \mathbf{x}_j) + \varepsilon \qquad \textbf{(6.3)}$$

Where:

k = the number of significant factors,

$x_1, x_2, ..., x_k$ = input variables which influence the response (y),

β_0 = the overall mean response,

β_i = the main effect for each significant 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 (such as nuisance factors or noise).

Based on the second-order response surface function (Equation 6.3), the response surface and contour plots for the factor interactions were obtained using STATISTICA. It should be noted that incident rate is minimized in the depressed region of the response surface plots while the elevated point depicts the region of increased incident rates. 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.

A sensitivity analysis could be performed on response surface designs in order to achieve near-optimum or desirable values of the response variable due to changes in the factor levels. Sensitivity analysis of the response surface design provides the opportunity for the model to indicate the direction of future exploration of the likely near-optimum. This is based on an attempt to predict the direction of movement of the factor levels in order to achieve incident rates which are close to optimality. Figures 6.12 - 6.23 represent the response surface designs and contour plots for the relationship between incident rate and the significant Factors A, C, D and E.

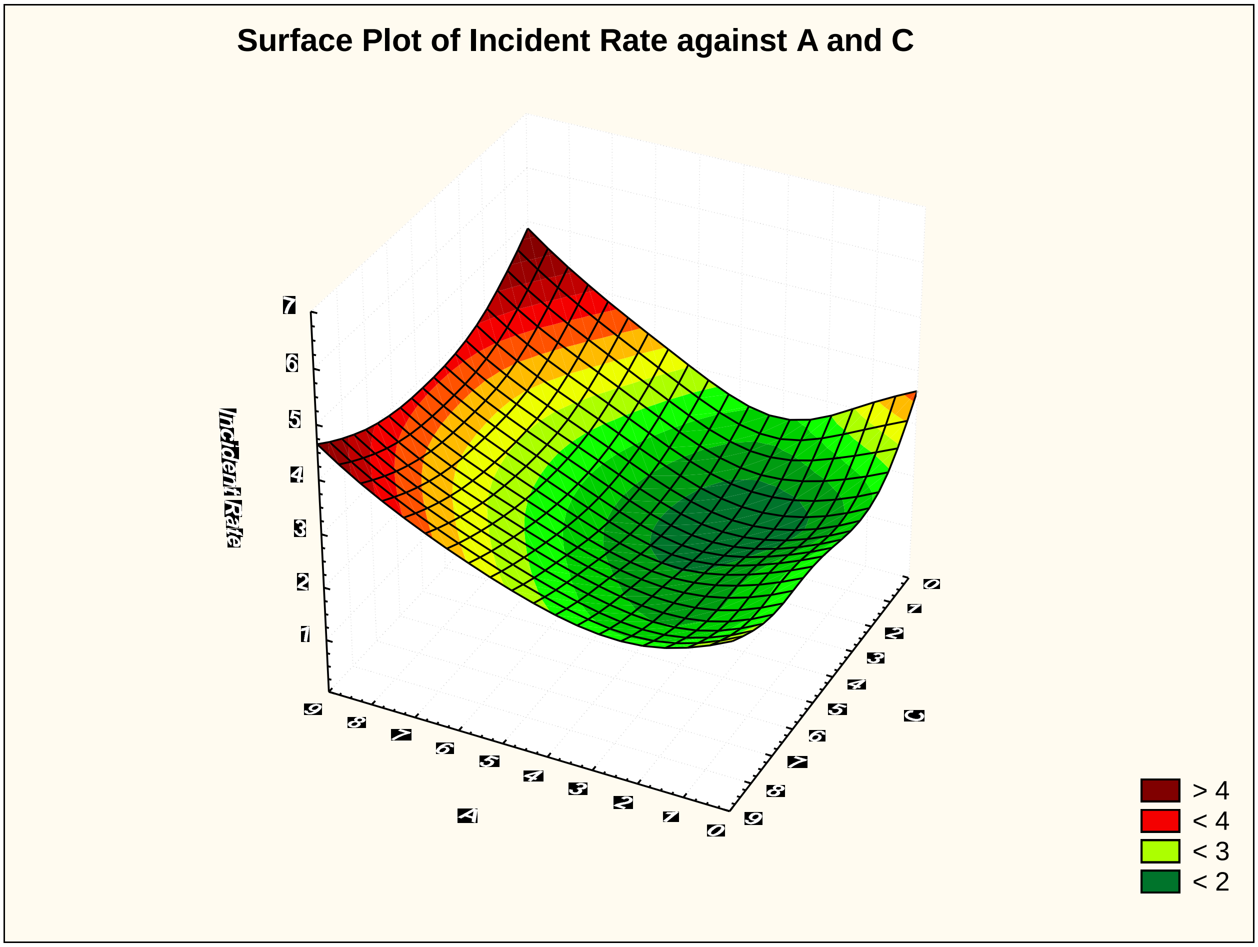

Figure 6.12. Response surface plot of incident rate vs. Factors A and C

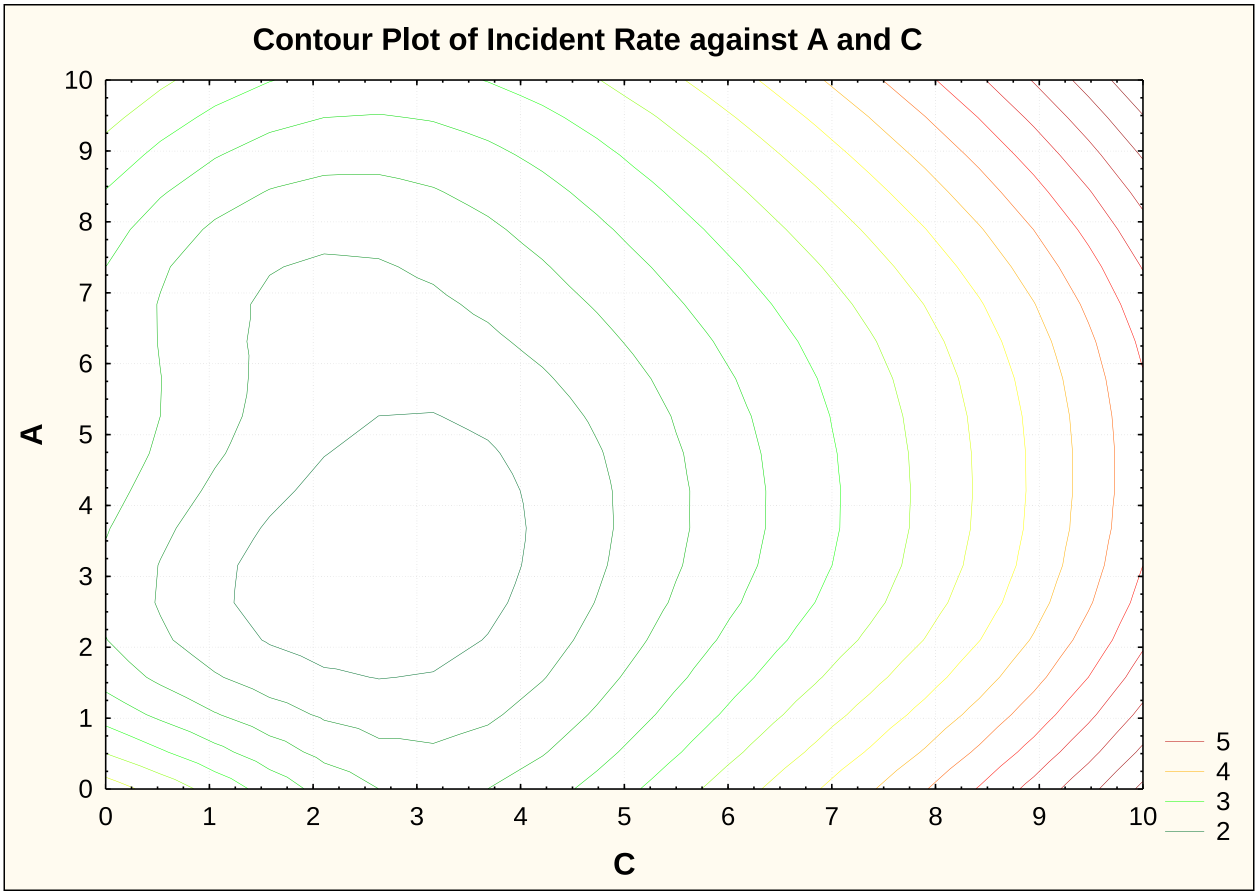

Figure 6.13. Contour plot of incident rate vs. factors A and C

From Figures 6.12 and 6.13 above, the near-optimum (desirable) incident rate is achieved when the organization allocated 3.5% of its available resources or man-hours to Factor A and 3% to Factor C. In order to further evaluate the behavior of the response, a senstitivity 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.

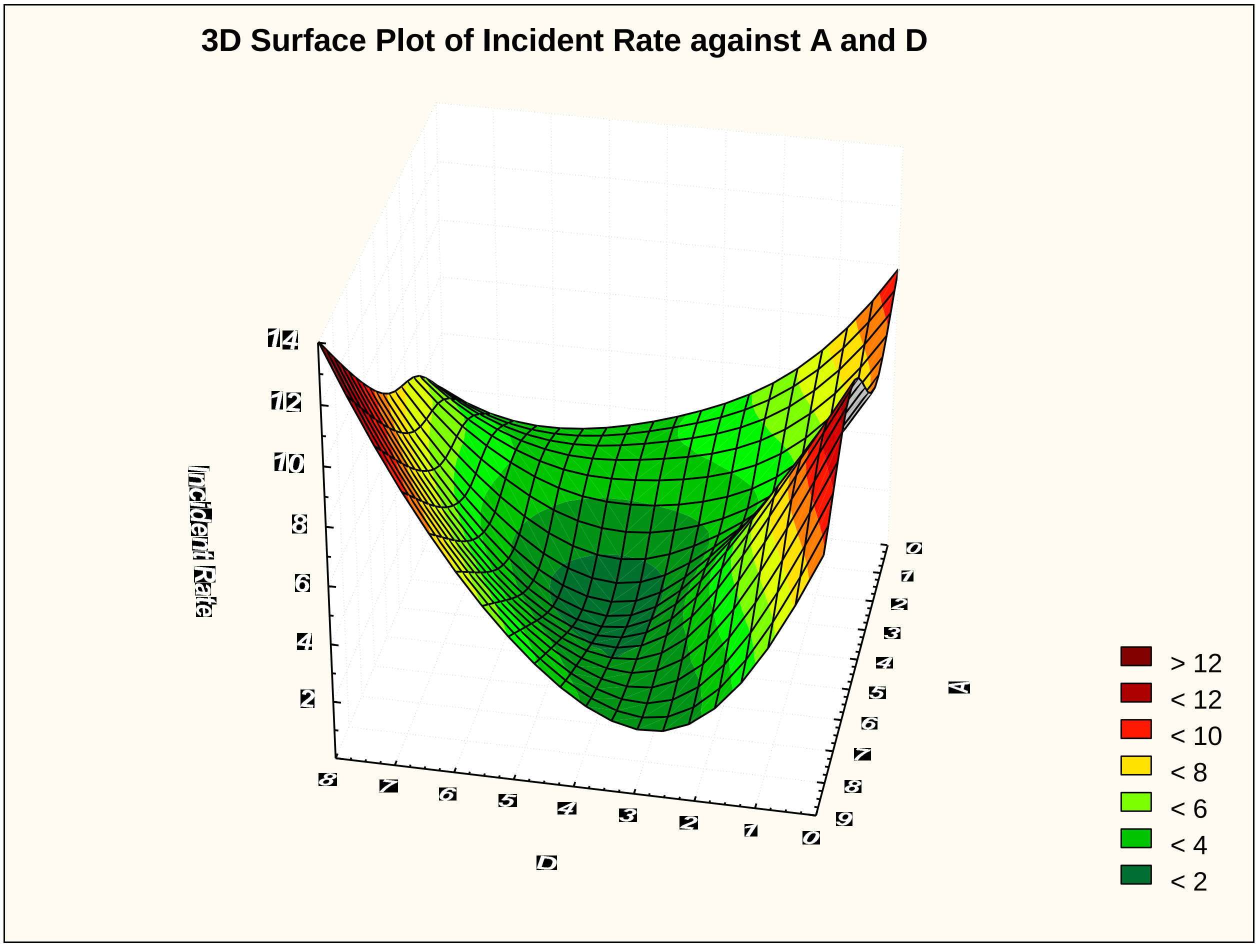

Figure 6.14. Response surface plot of incident rate vs. factors A and D

Figure 6.15. Contour plot of incident rate vs. factors A and D

Figures 6.14 and 6.15 above 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 4.5% to Factor D. Senstitivity analysis indicated that the lowestacceptable 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.

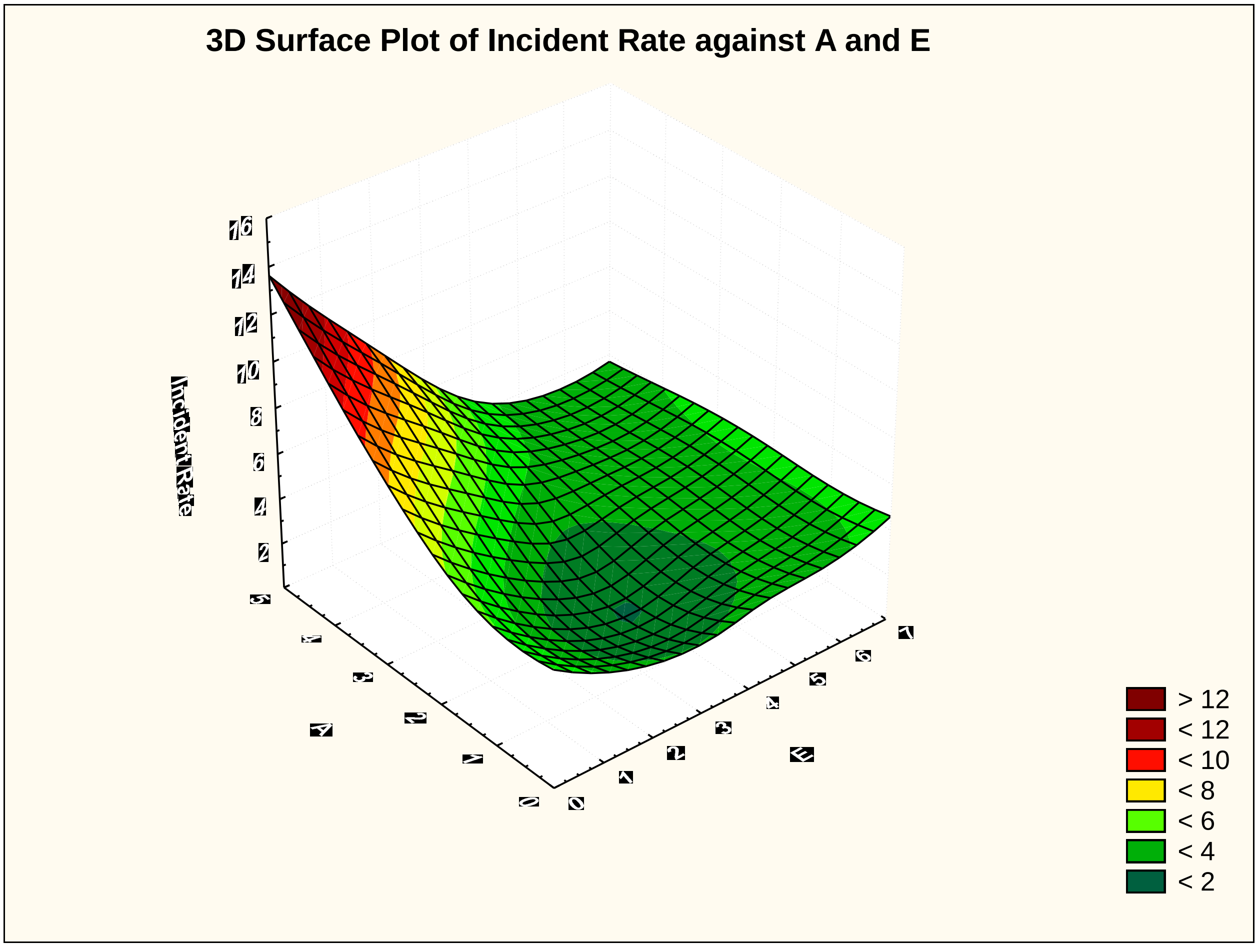

Figure 6.16. Response surface plot of incident rate vs. factors A and E

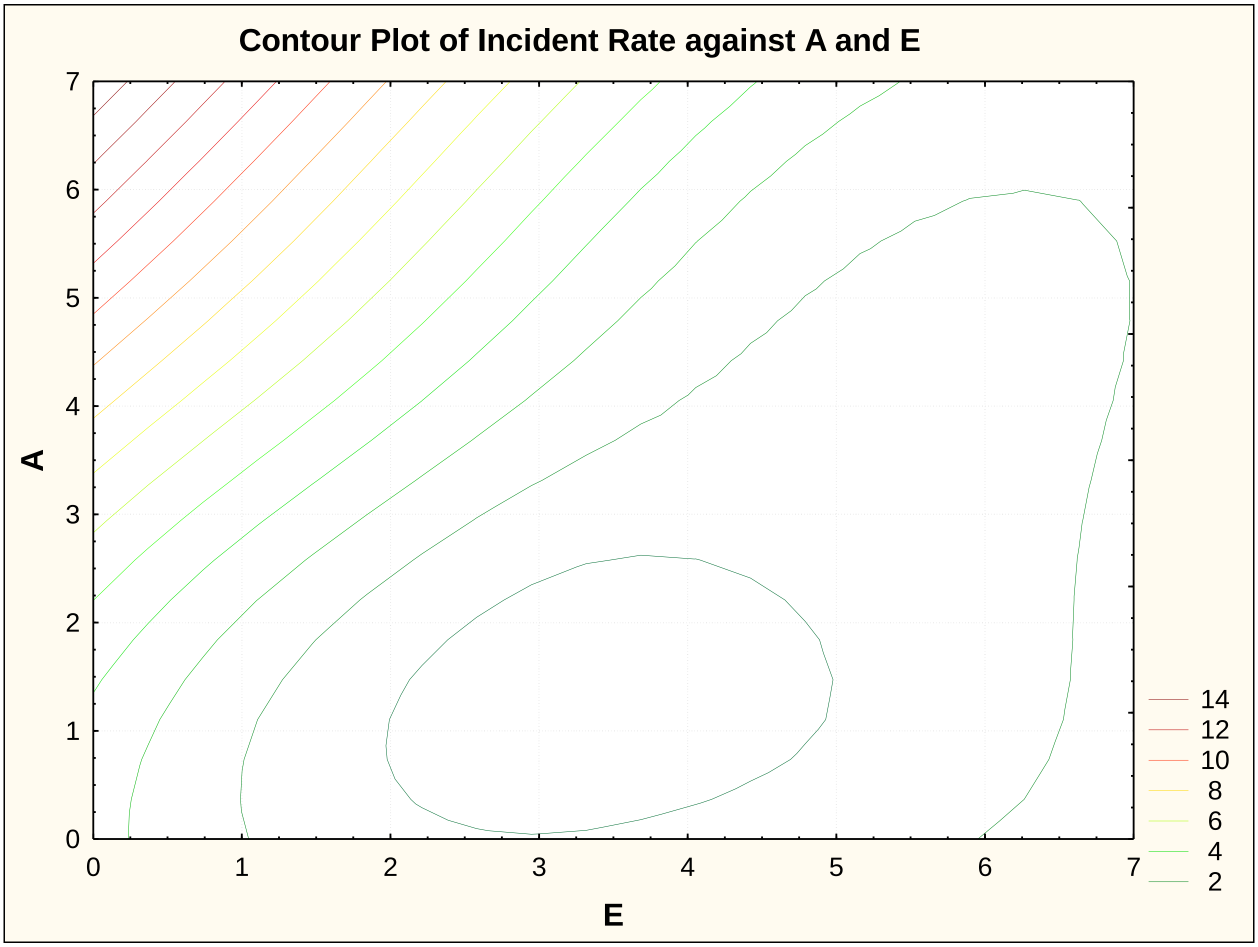

Figure 6.17. Contour plot of incident rate vs. factors A and E

From Figures 6.16 and 6.17, 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, 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 indicates that the additional allocation of resources towards safety intervention activities do not necessarily reduce incident rates.

Sensitivity analysis of the response surface design and contour plots shown in Figures 6.16 and 6.17 showed 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 show Factors A and E to be very significant positive effects with t-values of 7.61 and 6.40, respectively (Figure 5.1), then it is reasonable that 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 Figures 6.16 and 6.17 above.

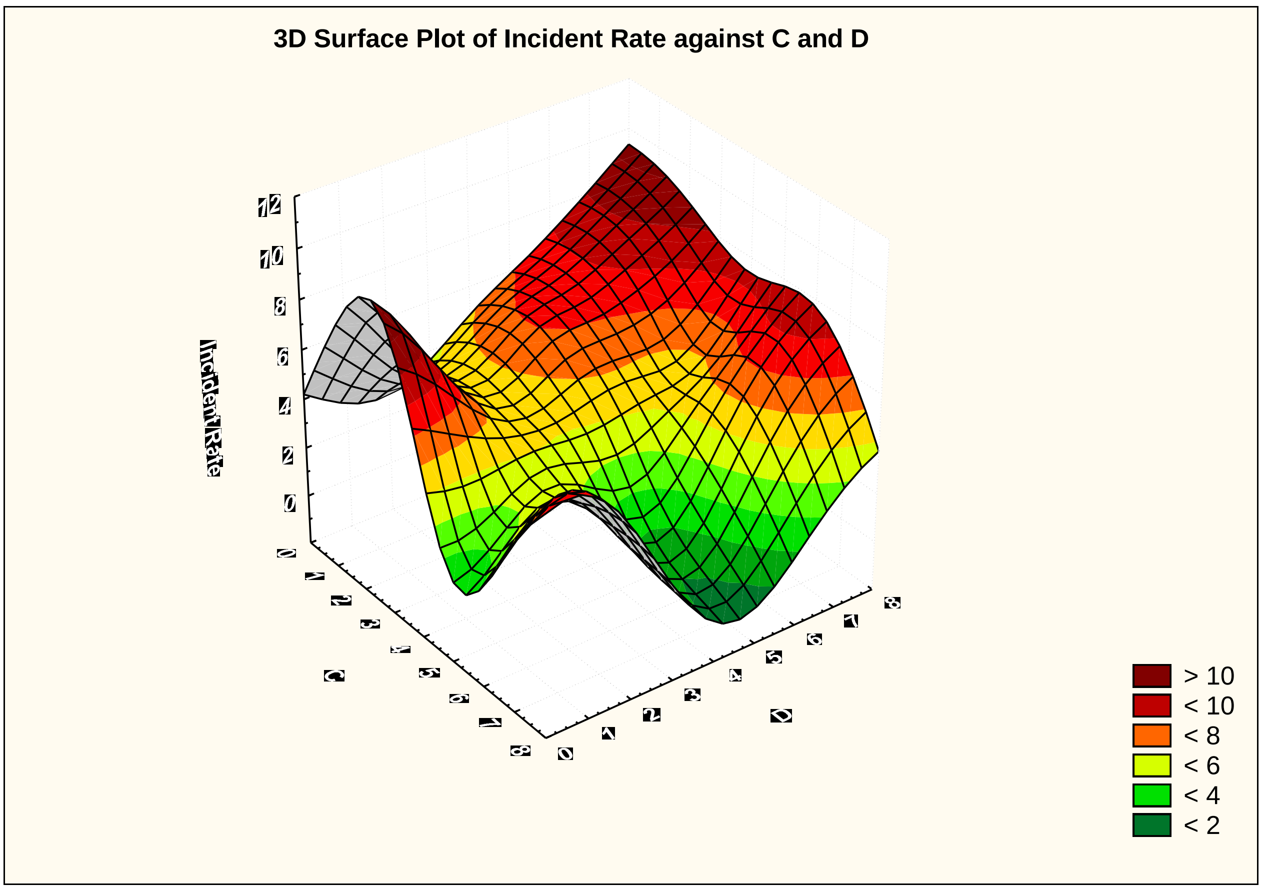

Figure 6.18. Response surface plot of incident rate vs. factors C and D

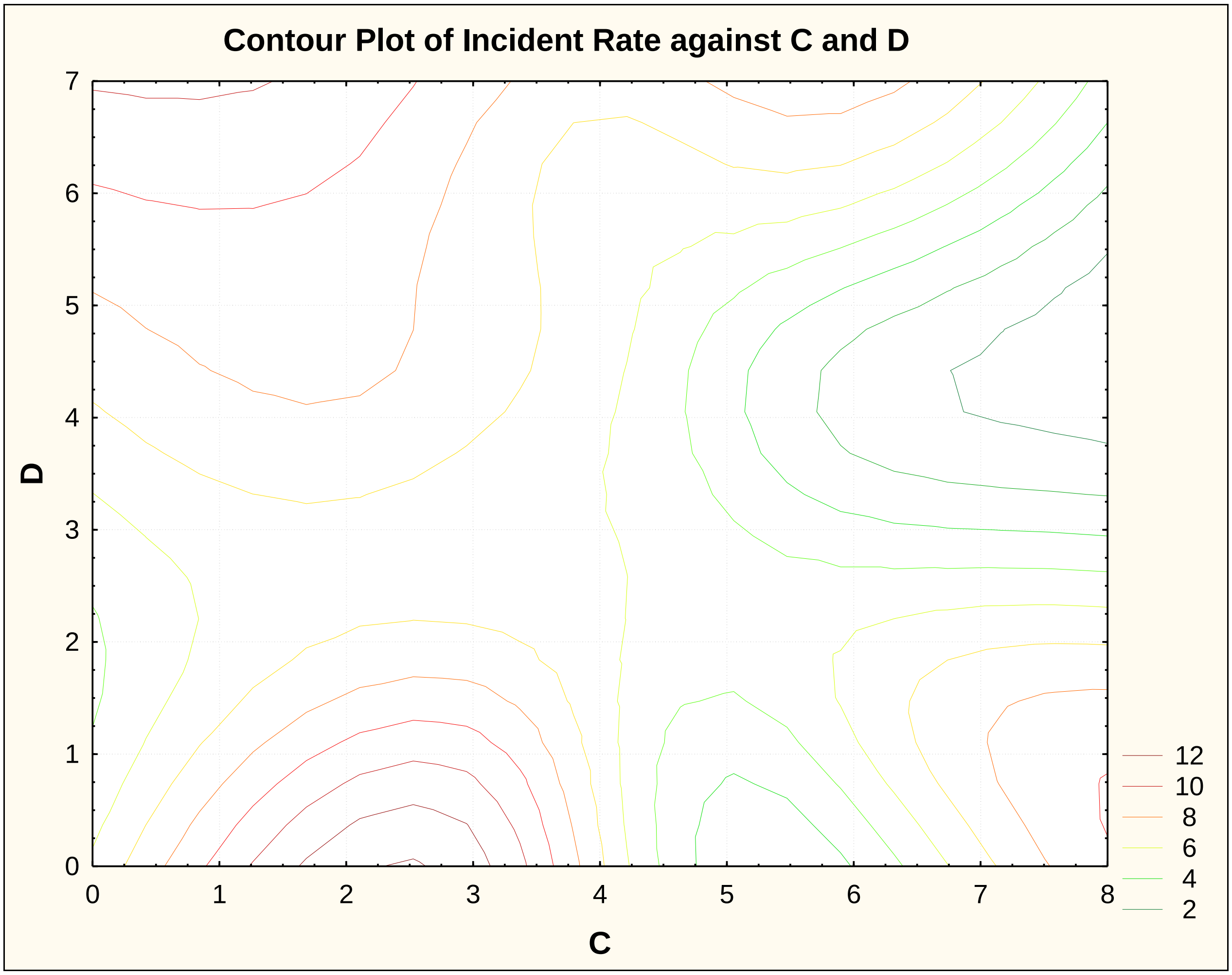

Figure 6.19. Contour plot of incident rate vs. factors C and D

From Figures 6.18 and 6.19 above, the desirable incident rate is achieved when the organization allocated 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 further evaluate the behavior of the response, a senstitivity 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.

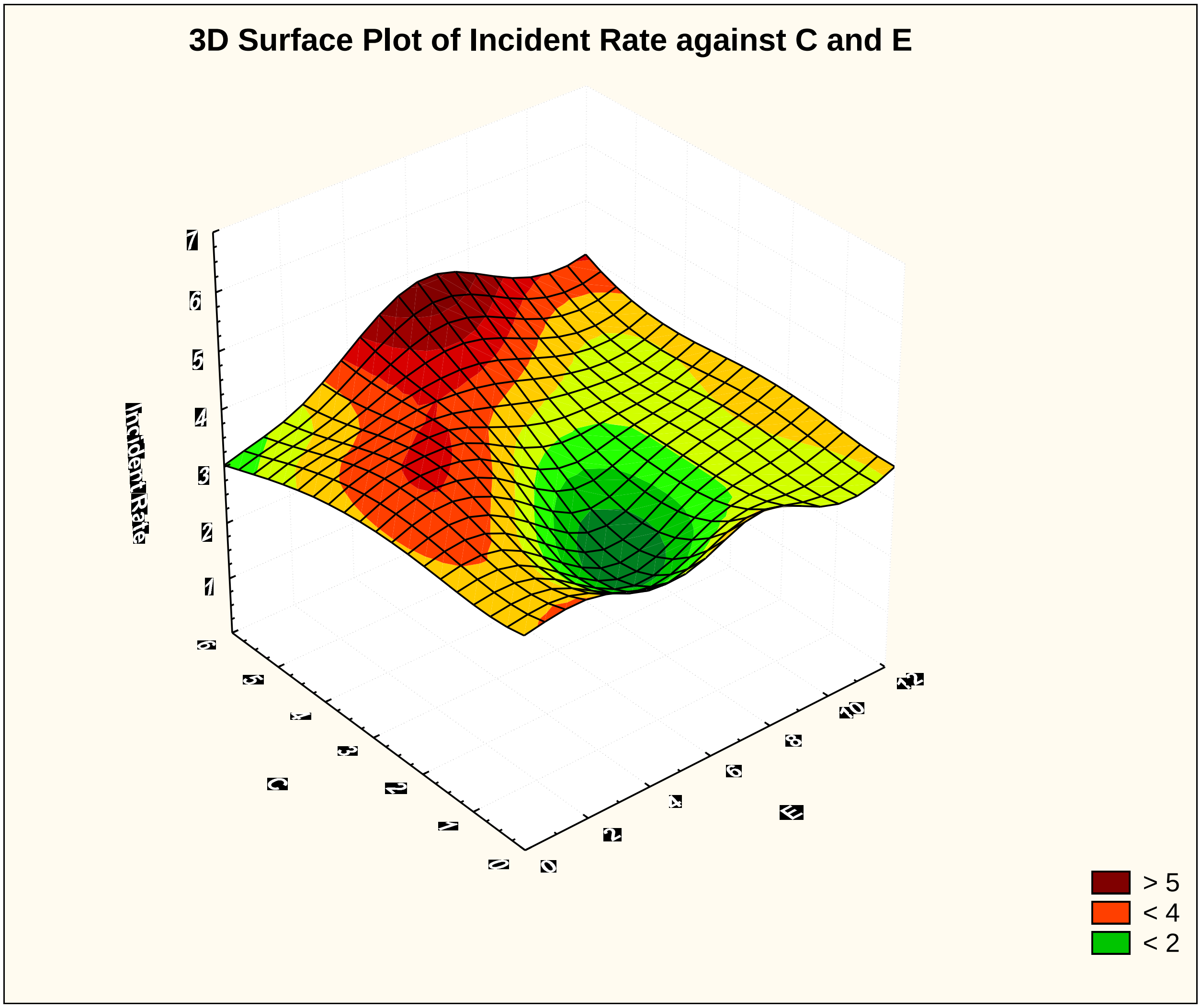

Figure 6.20. Response Surface Plot of Incident Rate vs. factors C and E

Figure 6.21. Contour Plot of Incident Rate vs. factors C and E

Figures 6.20 and 6.21 above shows that the desirable level of incident rate is achieved when the organization allocated approximatelty 1.5% of its available resources or man-hours to Factor C (employee engagement and planning), and 6% to Factor E (evaluation, measurement and verification. Senstitivity analysis indicated that the lowest acceptable incident rate is achieved when the organization allocated 1% of its available resources to Factor C and 3% to Factor E.

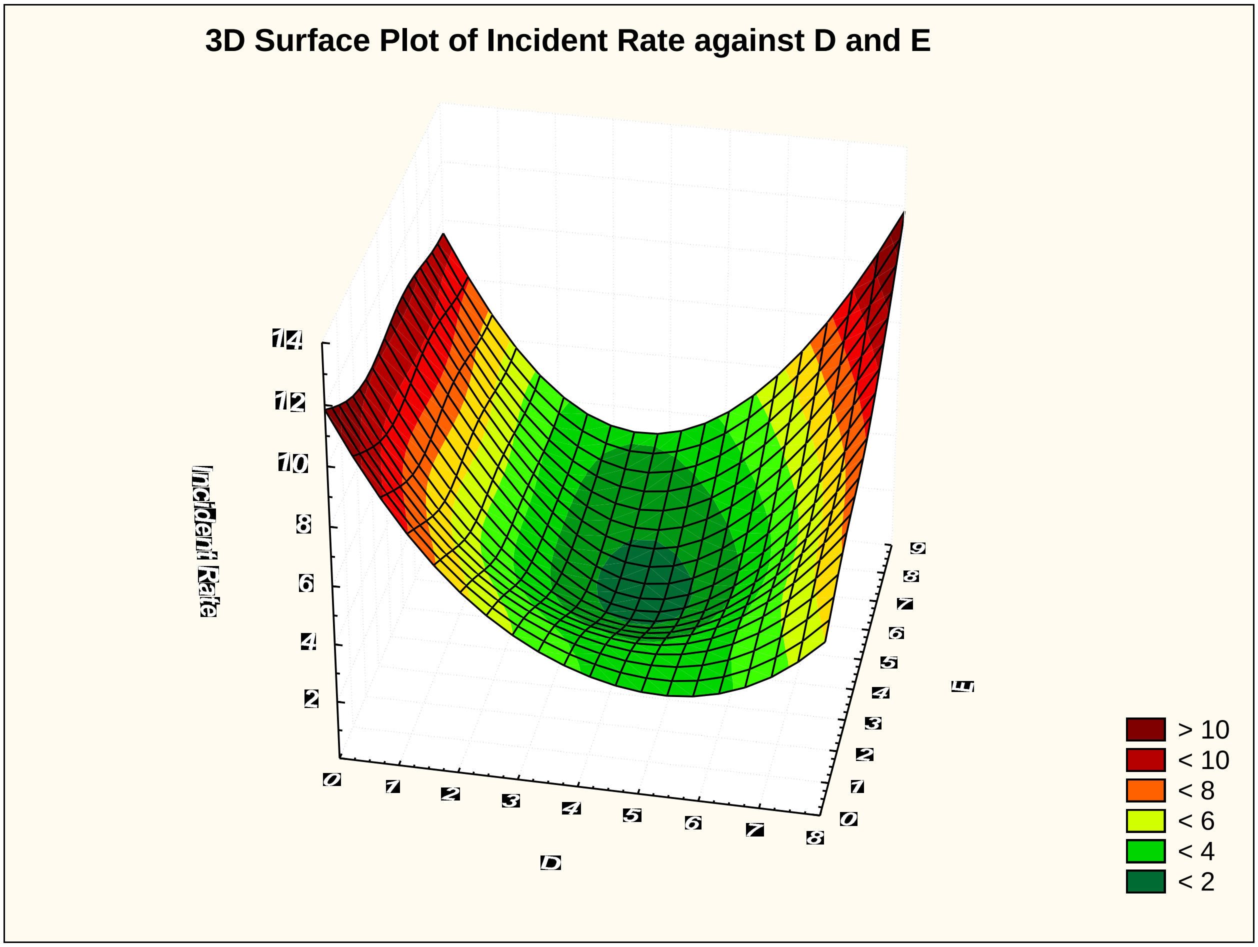

Figure 6.22. Response surface plot of incident rate vs. factors D and E

Figure 6.23. Contour plot of incident rate vs. factors D and E

From Figures 6.22 and 6.23 above, the desirable incident rate is achieved when the organization allocated 4.5% of its available resources or man-hours to Factor D (work in progress) and 5% to Factor E (evaluation, measurement and verification. Senstitivity analysis indicated that the lowest acceptable incident rate is achieved when the organization allocated 3% of its available resources to Factor D and 4% to Factor E.

The response surface and contour plots show the relationship between incident rsate and the significant safety intervention factors A, C, D and E. The use of the response surface and contour plots provides the foundation for the determination of the regions at which the additional allocation of resources no longer achieve 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 factors 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 and contour plots (Figures 6.12 – 6.23) as shown below:

$AC \Longrightarrow A = 3.5\%$

$C = 3.0\%$

$AD \Longrightarrow A = 5.0\%$

$D = 4.5\%$

$AE \Longrightarrow A = 1.5\%$

$E = 3.5\%$

$CD \Longrightarrow C = 7.5\%$

$D = 4.5\%$

$CE \Longrightarrow C = 1.5\%$

$E = 6.0\%$

$DE \Longrightarrow D = 4.5\%$

$E = 5.0\%$

Taking the averages,

$$A = \frac{3.5 + 5.0 + 1.5}{3} = 3.33\%$$

$$C = \frac{3.0 + 7.5 + 1.5}{3} = 4.00\%$$

$$D = \frac{4.5 + 4.5 + 4.5}{3} = 4.50\%$$

$$E = \frac{3.5 + 6.0 + 5.0}{3} = 4.83\%$$

$$Total = 16.66\%$$

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 (Research Question 1). Figure 6.24 below shows an improvement from Figure 3.2 based on the inclusion of the recommended 16.66% of resources applied to safety intervention activities.

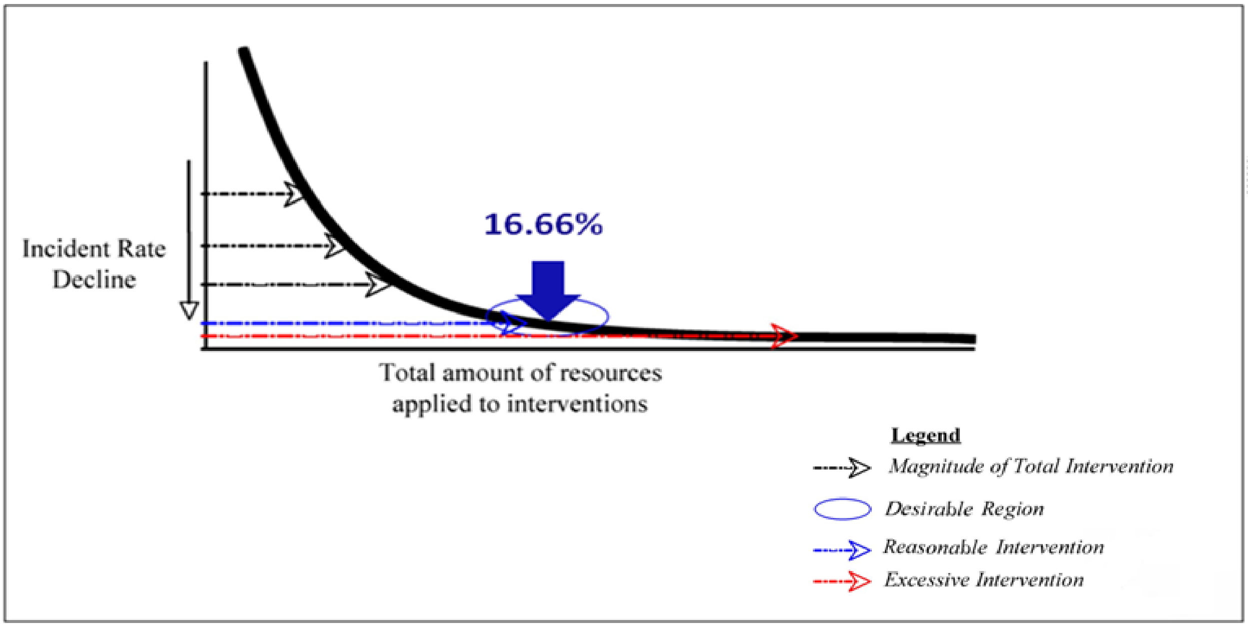

Figure 6.24. Exponential decay for incident rate (indicating the desirable allocation)

Based on the determination of the desirable point on the curve (or combined variable region in the multi-dimensional response surface) at which any additional allocation of resources no longer lowers the incident rate (Research Question 1). It should be noted that a lower rate of change may be observed, this is however, insignificant to be considered a sizable incident rate reduction. From Figure 6.24 above, the level of man-hour constraint at which the allocation of resources is said to be effectively achieved in producing the lowest acceptable incident rate could be obtained. In some situations, it may not be possible to achieve the desirable level of incident rate reduction due to external factors such as budget constraints or executive decisions; however, the lowest acceptable incident rate could be obtained using the following proposed methodology. This could be achieved (using the same methodogy as above) from the the sensitivity analyses performed on the response surface and contour plots (Figures 6.12 – 6.23) as shown below:

AC $\Longrightarrow$ A = 2.0%

C = 1.5%

AD $\Longrightarrow$ A = 3.5%

D = 4.0%

AE $\Longrightarrow$ A = 1.0%

E = 2.0%

CD $\Longrightarrow$ C = 5.0%

D = 1.0%

CE $\Longrightarrow$ C = 1.0%

E = 3.0%

DE $\Longrightarrow$ D = 3.0%

E = 4.0%

Taking the averages,

$$A = \frac{2.0 + 3.5 + 1.0}{3} = 2.17\%$$

$$C = \frac{1.5 + 5.0 + 1.0}{3} = 2.50\%$$

$$D = \frac{4.0 + 1.0 + 3.0}{3} = 2.67\%$$

$$E = \frac{2.0 + 3.0 + 4.0}{3} = 3.00\%$$

$$Total = 10.34\%$$

This indicates that using 10.34% of the available resources, the lowest acceptable incident rate could be achieved. Although the organization desires to achieve the desirable incident rate, external factors such as labor and budget constraints could prevent the additional allocation of 6.32% of its resources to reach 16.66%, which is necessary to achieve the desirable level of incident rate (Research Question 2). The Figure 6.25 below shows an improvement from Figure 3.2 based on the inclusion of the recommended 10.34% of resources applied to safety intervention activities in order to achieve the lowest acceptable incident rate.

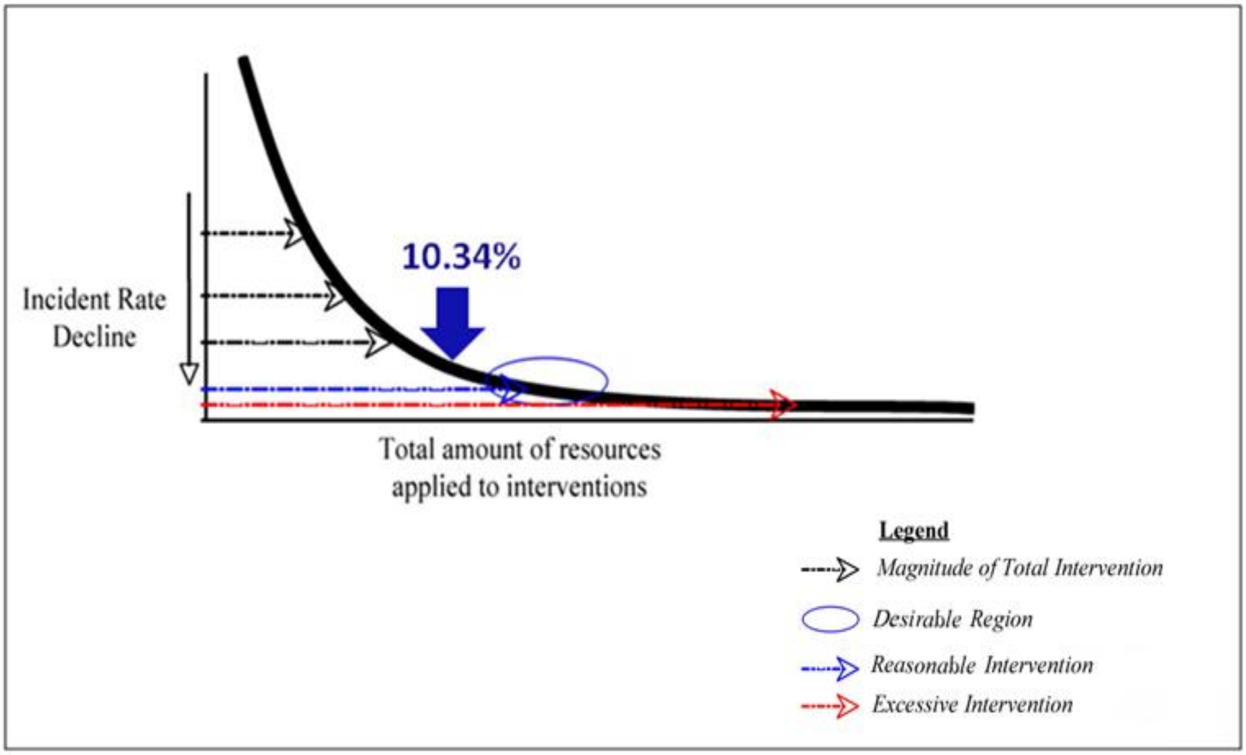

Figure 6.25. Exponential decay for incident rate (indicating the acceptable allocation)

CHAPTER 7

FORECASTING METHODS AND MODEL VERIFICATION

7.1 Overview of Forecasting in Health and Safety

Forecasting could be described as the process of utilizing previous or current situations to estimate or predict future unknown situations. Forecasting is often applied to several aspects of human lives (Armstrong, 2001). Forecasting is often used by many organizations to make strategic (long term), tactical (medium range) and operational (short term) decisions. Forecasting is widely used in meteorology (to predict climate, weather, hurricanes, tornadoes and flooding); supply chain (to make demand forecasts); economics and business (to make predictions for investment on stocks and bonds); transportation planning (to predict the number of passengers); seismology (to predict earthquakes); and petroleum engineering and geology (to predict oil reserves). Some other recent applications of forecasting include population growth, healthcare, sports (to predict winning chances of players and teams) as well as politics (to predict winners in elections). Several decision makers use forecasting as the readily available tool to plan ahead and make predictions based on uncertainty (Armstrong, 2001).

Since a forecast is an inference of what is likely to occur in the future, forecasts do not always provide the accurate estimates of the actual situations; therefore, the accuracy of a forecast is determined based on the differences in the actual and the predicted values (forecast error). It should be noted that long-term forecasts are usually less accurate than short-term forecasts. This is due to the larger value of the standard deviation of error relative to the mean (Chopra and Meindl, 2006). Forecasting is used in situations involving time series or trends. In non-stationary (moving) data, forecasting is used to estimate the mean of the probability of the distributions.

Previous research studies have advocated the incorporation of probabilistic processes used in financial decision-making to the risk assessment concepts and methodologies used by health and safety professionals. Toffel and Birkner (2002) argued that since health and safety programs often require the allocation of financial resources, which needs to be approved by business and governmental managers, then the utilization of business-oriented techniques into the safety and health policies would make it easier for the management to better understand and appreciate the safety and health programs. Safety and health programs which are designed based on strategies used in business would be easily approved since the decision makers and managers are familiar with the financial decision-making and risk assessment concepts.

In their research, Toffel and Birkner (2002) demonstrated the use of incident probabilities, historic outcome information, and incremental impact analysis in the estimation of risks involving multiple alternatives in the chemical process industry. The findings of the research indicated that certain, easily understood and applied probabilistic risk assessment methods used by business planners and managers to assess financial and outcome risks could be adopted into health and safety analysis. The researchers suggested that safety and health programs could be improved upon by linking the business decision-making activities with health and safety risk assessment processes to securing resources. Also, safety and health policies could be easily understood by managers when additional set of tools for health and safety risk assessment are provided. Toffel and Birkner concluded their research by suggesting that the incorporation of financial tools into the evaluation of safety and health programs would make it easy for the safety personnel to consider multiple risks and provide different decision-making alternatives to the management.

In agreement with the suggestions proposed by Toffel and Birkner (2002), Iyer et al. (2005) used forecasting techniques to predict incident rates based on the mathematical model developed in an earlier research (Iyer et al., 2004). In their research, the values obtained from the forecast were used to validate their model over a period of 22 weeks. Iyer et al. (2005) adopted weighted moving averages and exponential smoothing techniques to identify changes in the statistical relationship between interventions and incident rates (Haight et al. 2001a and b). In their study, the researchers integrated and related past safety performances (incident rates) with the current rates to obtain an estimate of the future incident rates.

The exponential moving average and the moving average of errors were used to obtain the incident rate forecast. Although Iyer et al. (2005) provided the background for the incorporation of forecasting techniques into the prediction of incident rates, the study did not propose any additional study for the investigation of the behaviors of the observed trend. The exponential smoothing method used in the research assumed constant level time series. This is actually not the case in reality, incident rates are not constant, and several factors could account for the changes in the trend levels of varying incident rates.

Contrary to the forecasting methodologies adopted by Iyer et al. (2005), this study utilizes the trend-corrected exponential smoothing technique (Holt’s model) to predict the incident rates based on the developed safety intervention model. Holt’s model is an improvement or modification of the simple exponential smoothing method which accounts for changes in continuing trends (Chopra and Meindl, 2006). Holt’s model is very applicable for predicting incident rates due to its trend correction capability. The Holt’s model is also known as the double exponential smoothing method.

7.2 Double Exponential Smoothing Method (Holt's Model)

Time series could be described as a set of observations which are generated sequentially over time. In situations where the set is continuous, then a trend is generated. The double exponential smoothing (Holt's model) is a refinement of the simple exponential smoothing method, but the addition of the trend-corrected component into the exponential smoothing takes into account the behavior of any trend in the data. The simple exponential smoothing method works best with data with no trend or seasonality. The simple exponential smoothing does not often make reasonable forecasts in situations where the data exhibits either an increasing or decreasing trend over time. The double exponential smoothing method is therefore designed to address this type of trend situation in data series (Chopra and Meindl, 2006).

The double exponential smoothing method is used for modeling the behavior of time series (trends) based on a simple linear regression equation obtained in situations where the intercept and slope of the plots of the observations vary slowly over a given time. Unlike the simple exponential smoothing method, Holt's model applies unequal weighting on the exponentially decaying parameters so that newer observations get a higher weighting than older ones (Bowerman and O'Connell, 1993). The degree of exponential decay is determined by the parameter α, where $\alpha \in [0, 1)$. The evolving regression equation could be used to make incident rate predictions.

7.3 Application of Holt's Model to Incident Rate Prediction

Incident rate forecasts could be obtained using Holt's model when the incident rate is assumed to have a level and a trend (where incident rate (y) = level + trend). It is therefore necessary to obtain the initial estimate of the level (l_0) and trend (b_0) by running a linear regression between incident rate (y_t) and the time period t as shown in Equation (7.1).

$$\mathbf{Y_t = m(t) + c} \tag{7.1}$$

The constant, (c) measures the estimate of the incident rate at period t = 0, which is the required estimate of the initial level (l_0). The slope (m) measures the rate of change in the incident rate per period, which is the required estimate of the initial trend (b_0). The trend at time (t) could therefore be given as (b_t) while the level at time (t) is given as (l_t), then the incident rate could be predicted using the following trend-corrected exponential smoothing Equations (7.2) and (7.3):

$$l_t = \alpha y_t + (1-\alpha)[l_{t-1} + b_{t-1}] \tag{7.2}$$

$$b_t = \gamma[l_t - l_{t-1}] + (1-\gamma)b_{t-1} \tag{7.3}$$

Where α and γ are smoothing constants between 0 and 1.

The initial values l_0 and b_0 could be obtained based on the estimates of the previous incident rates. Summing up Equations 7.2 and 7.3, and the τ-step-ahead incident rate forecast from t for $y_{t+\tau}$ the predicted incident rate [$F_{t+\tau}$] at time t is = t + τ could be given as shown in Equation (7.4).

$$\hat{y}_{t+\tau} = l_t + \tau b_t \tag{7.4}$$

The 95% prediction interval could be obtained for y_{t+1} (when $\tau = 1$) as shown in Equation (7.5).

$$(l_t + b_t) \pm z_{.025} s \tag{7.5}$$

From Equation (7.5), the 95% prediction interval for the τ-step forecast of $y_{t+\tau}$ could be obtained as shown in Equation (7.8).

$$(l_t + \tau b_\tau) \pm z_{.025} s \times \sqrt{1 + \sum_{j=1}^{\tau-1} \alpha^2 (1 + j\tau)^2} \tag{7.6}$$

Where, the standard deviation is obtained as shown in Equation (7.7)

$$s = \sqrt{\frac{SSE}{n-2}} = \sqrt{\frac{\sum_{j=1}^{t} [(y_j - (l_{j-1} + b_{j-1})]^2}{t-2}} \tag{7.7}$$

7.4 Measures of Incident Rate Forecast Error

It should be noted that every instance of the incident rate forecast has a random component which is considered as the forecast error. The proper estimation of incident rate forecast errors would enable the management to determine whether the forecasting method accurately predicts incident rates. The accuracy of the incident rate forecast is necessary in order to effectively plan ahead based on the need to adequately allocate resources to the safety intervention activities which minimizes incident rates. The estimation of the incident rate forecast could also be used to determine whether the forecasting technique adopted is consistently producing very positive error (overestimation) or negative error (underestimation).

Forecasting errors that are within historical error estimates indicate a high level of consistency and accuracy of the forecasting technique. Forecast errors which are well beyond the historical estimates could indicate that the forecasting method is no longer accurate or appropriate. The commonly measured types of forecasting errors include the forecast or residual error, forecast accuracy, the mean squared error (MSE), absolute deviation (AD), mean absolute deviation (MAD), the mean absolute percentage error (MAPE), the percent mean absolute deviation (PMAD), bias (BIAS), and tracking signal (TS).

7.4.1 Forecast/Residual Error

The forecast or residual error (in terms of incident rate) is the difference between the forecast for period (t) and the actual incident rate in period (t). It may be important for the safety personnel to estimate the forecast error of incident rates far in advance. This is necessary in order to make decisions and planning on the type of resources to be allocated to a particular safety intervention activity before the occurrence of any incident. The forecast error (E_t) is measured as shown in Equation (7.8) below:

$$\mathbf{E_t = F_t - Y_t} \qquad \textbf{(7.8)}$$

Where F_t is the forecast at period (t) and Y_t is the actual incident rate at period (t).

The percent forecast error is measured as the ratio of the forecast error and the forecast at period (t).The mathematical representation of the Error (%) is shown in Equation (7.9) below:

$$\textbf{Error (\%) =} \quad \frac{/\, F_t - Y_t \,/}{Y_t} \Rightarrow \frac{/\, Actual_t - Forecast_t \,/}{Forecast_t} \qquad \textbf{(7.9)}$$

The forecast error could be larger than the forecast or the actual incident rate at time (t), but not both. A zero forecast accuracy or very inaccurate forecast is obtained in situations where the percent forecast error [Error (%)] is higher than 100%.

7.4.2 Forecast Accuracy

Forecast accuracy is described as the proportion of deviation of the actual incident rate from the predicted incident rate in a period (t). Decreasing errors indicate increasing accuracy since the intention of the forecast is to predict incident rates that are identical to the actual values (Chopra and Meindl, 2006). Forecast accuracy is measured as shown in Equation (7.10).

$$\textbf{Accuracy (\%)} = [1 - \textbf{Error (\%)}] \qquad \textbf{(7.10)}$$

In most situations, several forecasts yield accuracies which are between 0 and 100%. A perfect forecast is achieved when accuracy is 100%, while an absolutely incorrect or inaccurate forecast is obtained when accuracy is 0%.

7.4.3 Mean Squared Error

The mean squared error (MSE) is related to the variance of the forecast error. In this case, the random component of the incident rate is assumed to have a mean of zero and a variance of MSE. The mean squared error (variance of forecast error) is shown in Equation (7.11) as:

$$MSE = \frac{\sum_{t=1}^{N} E_t^2}{N} \qquad \textbf{(7.11)}$$

Where N = Total number of observations or sample size.

7.4.4 Absolute Deviation

The absolute deviation (A_t) of an incident rate forecast in period (t) is defined as the absolute value of the forecast error (E_t) in period (t). The mathematical representation of the absolute deviation of the incident rate forecast is shown in Equation (7.12) as:

$$A_t = | E_t | \quad \textbf{(7.12)}$$

7.4.5 Mean Absolute Deviation

The mean absolute deviation (MAD) or the mean absolute error (MAE) is described as the average of the absolute deviation of the incident rate forecast for the total observations (Chopra and Meindl, 2006). The mean absolute deviation is expressed mathematically as shown in Equation (7.13).

$$MAE = \frac{\sum_{t=1}^{N} |E_t|}{N} \quad \textbf{(7.13)}$$

In situations where the random component of the incident rate forecast is normally distributed, then the estimate of the standard deviation (σ), with the mean equal zero, could be obtained as shown in Equation (7.14).

$$\sigma = 1.25 \text{ MAE} \quad \textbf{(7.14)}$$

7.4.6 Mean Absolute Percentage Error

The mean absolute percentage error (MAPE) is described as the average value obtained from the summation of the absolute values of all the percentage errors (Chopra and Meindl, 2006). The mathematical representation of the mean absolute percentage error is shown in Equation (7.15).

$$MAPE = \frac{\sum_{t=1}^{N} \left| \frac{E_t}{Y_t} \right|}{N} \tag{7.15}$$

7.4.7 Percent Mean Absolute Deviation

The percent mean absolute deviation (PMAD) could be described as the parameter obtained form the division of the absolute total errors and the absolute total of the predicted incident rates. This is mathematically represented as shown in Equation (7.16).

$$PMAD = \frac{\sum_{t=1}^{N} |E_t|}{\sum_{t=1}^{N} |Y_t|} \tag{7.16}$$

7.4.8 Bias

The errors of a truly random, non-biased forecast should fluctuate around zero, with the best straight line passing through zero (Chopra and Meindl, 2006). The bias of the incident rate forecast could be obtained by summing up all the forecast errors as shown in Equation (7.17).

$$Bias_N = \sum_{t=1}^{N} E_t \tag{7.17}$$

7.4.9 Tracking Signal

The tracking signal (TS) could be described as the ratio of the bias and the mean absolute deviation (MAD). This is represented as shown in Equation (7.18).

$$TS_t = \frac{Bias_t}{MAD_t} \qquad \textbf{(7.18)}$$

The range of any tracking signal (TS) is $\pm$ 6. A forecast is either underestimated/ biased (TS < -6) or overestimated (TS > +6).

7.5 Model Validation

In order to validate the developed safety intervention model, an additional 52 weeks (1 year) of data were collected from the oil exploration and production company in the Niger Delta region of Nigeria. The collected data were based on the recommendations and the application of the suggested desirable resource allocation method (See Figure 6.23).The collected data for the validation of the developed safety intervention model is shown in Appendix C. Using the averages of the past 52 weeks of the model development data, Holt's double exponential smoothing method was used to predict the incident rates for the next 52 weeks. Setting each of the alpha (α) and gamma (γ) levels to 0.25, the Holt's double exponential smoothing technique was used to predict the incident rate as shown in the Figure 7.1 below.

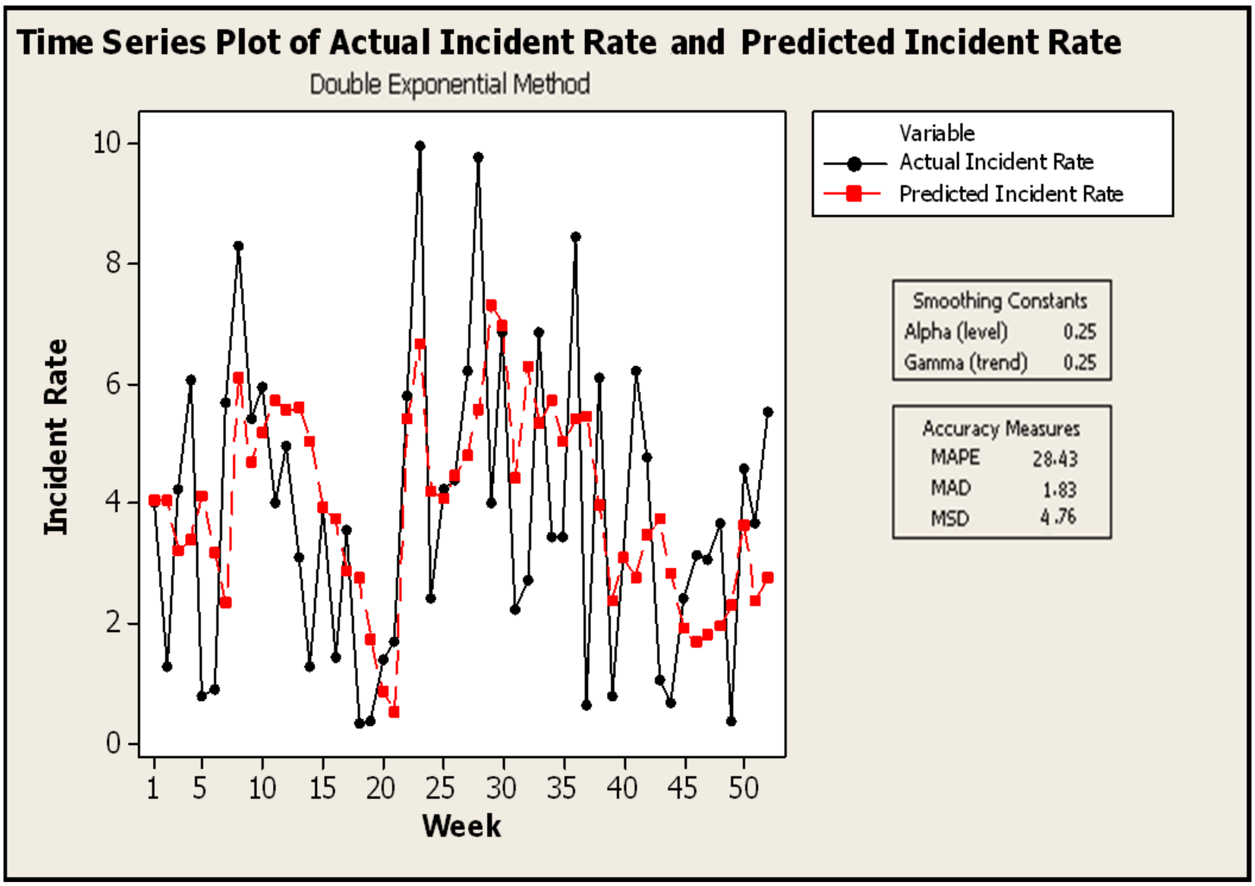

Figure 7.1. Time series plot for incident rate (predicted vs. actual)

The predicted incident rates and the actual incident rates (based on the developed model) were compared using statistical measures and forecasting errors such as the forecast or residual error, forecast accuracy, mean squared error (MSE), absolute deviation (AD), mean absolute deviation (MAD), mean absolute percentage error (MAPE), the percent mean absolute deviation (PMAD), bias (BIAS), and tracking signal (TS). The statistical measurements used for the comparison of the predicted incident rates and the actual incident rates (based on the developed model) include the mean, median, quartile, and standard deviation. The statistical comparison of the smoothed/predicted incident rates and the actual incident rates is shown in Table 7.1 below.

Table 7.1. Measures of statistical comparison for incident rates (predicted vs. actual)

Statistical Measure	Smoothed/Predicted Incident Rates	Incident Rates (Actual)
Mean	3.75	3.82
Median	3.83	3.65
Standard Deviation	1.69	2.45
1st Quartile (Q1)	2.49	1.49
3rd Quartile (Q3)	5.04	5.63
Sample Size	52	52

The box plots and the normal probability plots for the predicted incident rates and the incident rates (model) obtained from the analysis are shown in Figures 7.2 and 7.3 respectively.

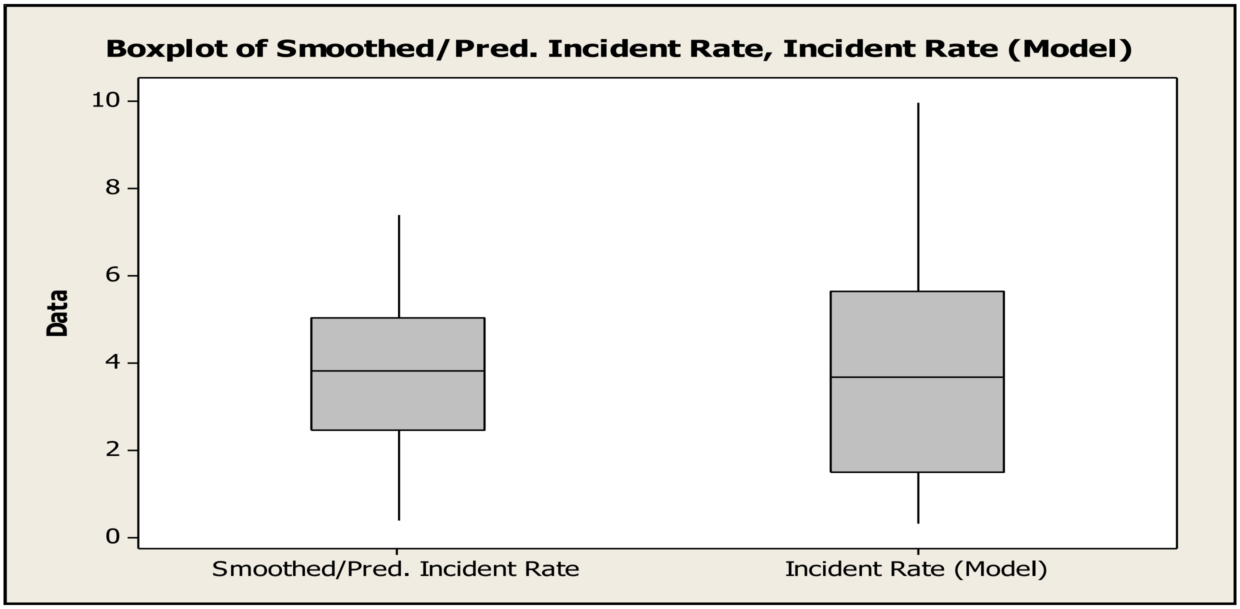

Figure 7.2. Box Plots for predicted and actual incident rates

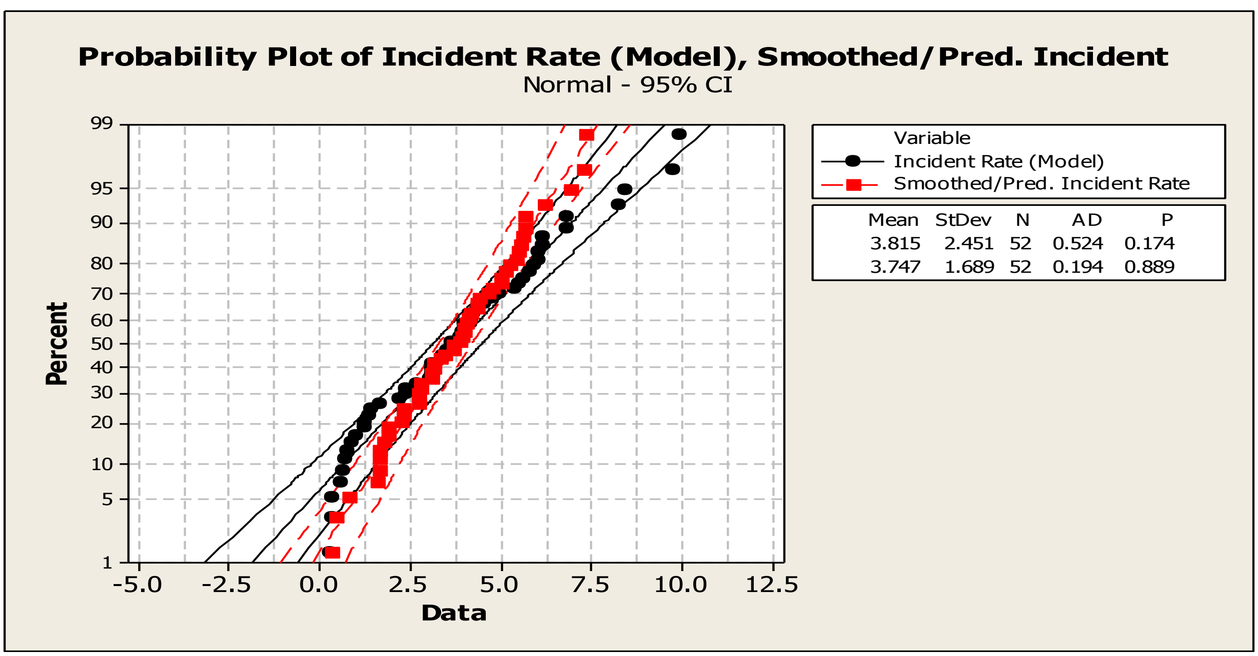

Figure 7.3. Normal probability plots for incident rates (predicted vs. actual)

The histogram plots for the predicted incident rates and the incident rates (model) obtained from the analysis are shown in Figures 7.4 and 7.5, respectively.

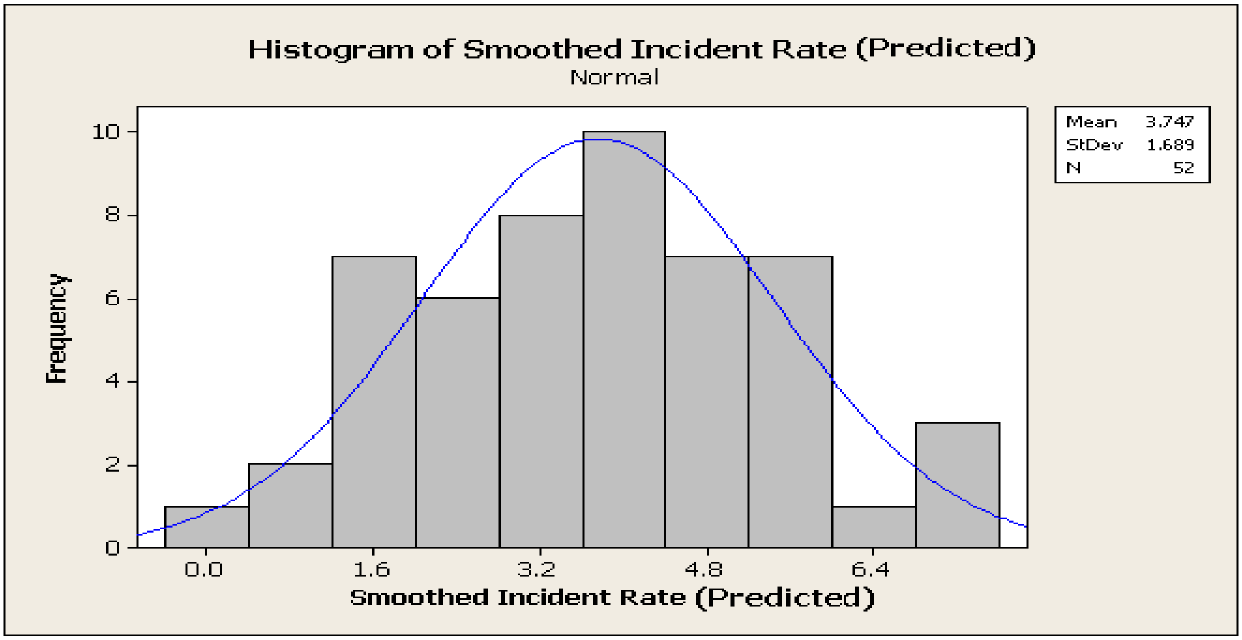

Figure 7.4. Histogram plot for predicted incident rates

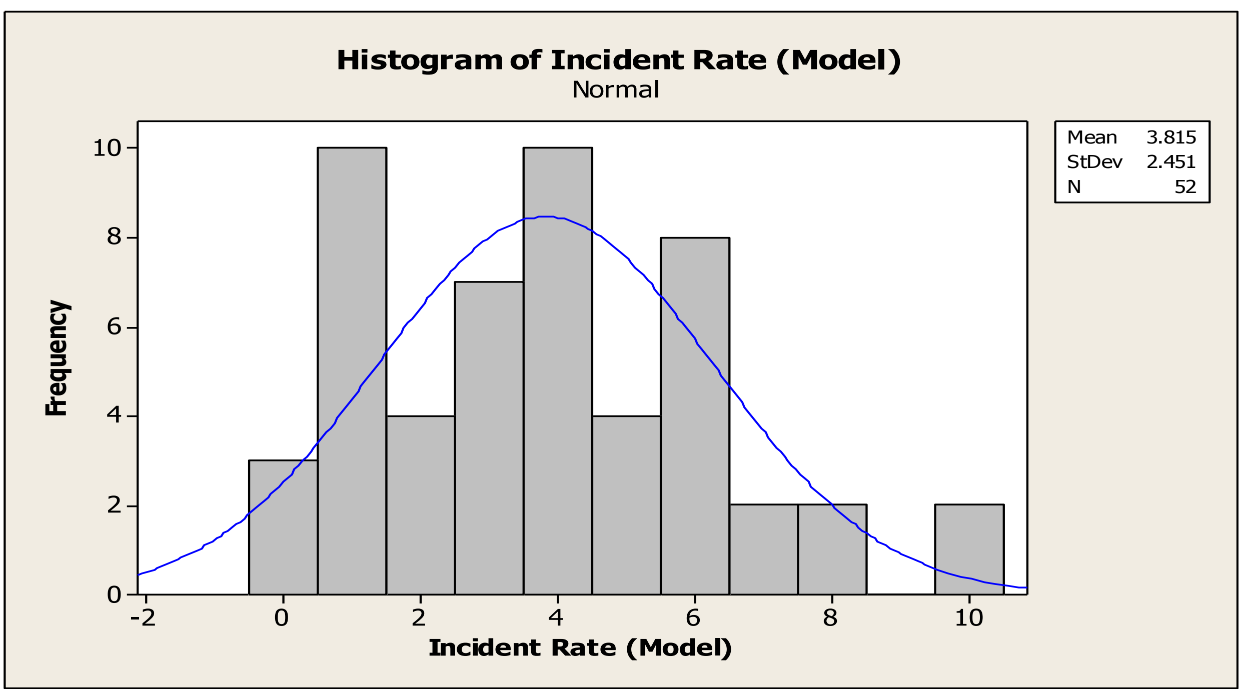

Figure 7.5. Histogram plot for actual incident rates (model)

The model validation process, which was based on the measures of the forecasting errors, indicated that using the appropriate forecasting techniques, incident rates could be accurately predicted. Table 7.2 below shows the values obtained from the analysis of the predicted and model incident rates based on the forecast or residual error, forecast accuracy, mean squared error (MSE), absolute deviation (AD), mean absolute deviation (MAD), mean absolute percentage error (MAPE), the percent mean absolute deviation (PMAD), bias (BIAS), and tracking signal (TS). The summary of the analysis obtained for the measures of forecasting errors is shown in Appendix D.

Table 7.2. Measures of forecasting error for predicted incident rates

Measure of Forecasting Error	Obtained Values
Mean Forecast/Residual Error	0.07
Forecast Accuracy (%)	71.58
Mean Squared Error (MSE)	4.76
Absolute Deviation (AD)	7.46
Mean Absolute Deviation (MAD)	1.83
Mean Absolute Percentage Error (MAPE)	28.43
Percent Mean Absolute Deviation (PMAD)	3.62
Bias (BIAS)	-7.46 (slope = 0.018)
Tracking Signal (TS)	-4.08

From Table 7.2, the obtained forecast accuracy value of 71.58% is within the acceptable limit of 0% to 100%. Based on the value of the obtained forecast accuracy, incident rates could be accurately predicted in more than 70% of the time. The obtained level of forecast accuracy (71.58%) could be explained due to the similarities in seasonality or trends. For example, periodic militant activities (sometimes occurring twice in a three-month period) could be a reason for the high spikes or outliers in the actual and the predicted incident rate data. An outlier could be described as an observation or data point which lies at an abnormal distance, when compared to the other values in the data.

Despite this observation, the obtained 71.58% incident rate prediction accuracy could be viewed as a starting advantage for health and safety decision makers, since it would enable the safety personnel to effectively plan ahead and appropriately allocate resources to the safety intervention activities which would further lower incident rates. A bias value of -7.46 (with a slope value of 0.018) indicates that the forecast error is truly random and not biased in anyway. Figure 7.6 below shows the plot of the best straight line, indicating a slope value of +0.0184 for the linear equation of the forecast error. The slope value is not significant and revolves around zero.

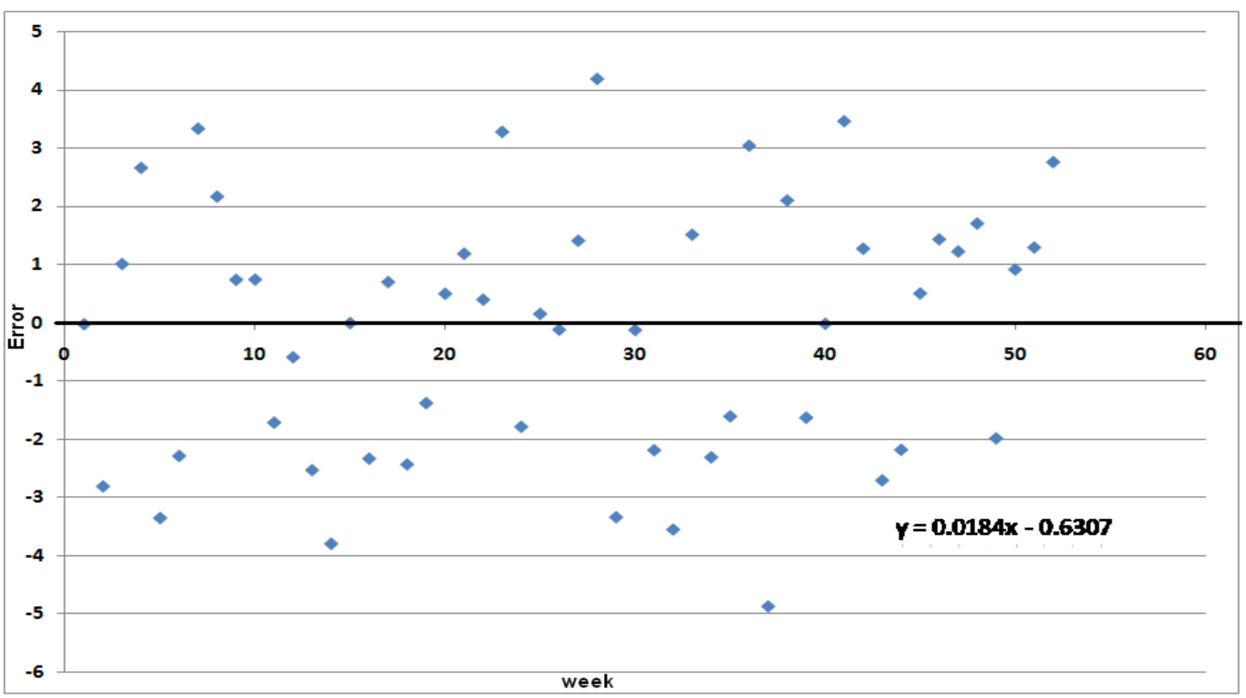

Figure 7.6. Residual plot of forecast error

The obtained value of the tracking signal (-4.08) shows that the signal for the forecast is not biased and within the acceptable range (TS $\pm$ 6). The negative sign of the tracking signal could be explained based on the use of the averaging technique for the initial estimates of the incident rate and level. An excessively large negative value of the tracking signal could indicate the underestimation of the incident rate, while an excessively large positive value of the tracking signal could indicate the overestimation of the incident rate. This is not the case in this study, since the obtained value of the tracking signal is within the acceptable range.

The use of the double exponential smoothing technique (Holt's model) to predict incident rates provided the opportunity to validate the developed safety intervention model, based on the analysis of the measures of the forecasting errors. The obtained prediction accuracy (71.58%) could be improved upon in situations where sensitivity analysis is incorporated into the double exponential smoothing technique. Sensitivity analysis could be performed on the forecasting methodology in order to further reduce bias, improve the value of the tracking signal and ultimately increase the level of the forecast accuracy. The adjustment of the alpha (α) and gamma (γ) levels based on the preference of the safety personnel, as well as the selection of a better estimation technique for the initial value of the incident rate and trend level could also improve the prediction capability and accuracy of the forecasting methodology.

CHAPTER 8

CONCLUSION

8.1 Analytical Summary

From Table 5.2, the value of the F-statistic was found to be 23.98 for all factors and interactions, while 12.52 was found for the main effects of factor interactions in Table 5.4. Both analyses show a p-value of less than 0.0001, which indicates the level of significance of the safety intervention model. Factors A (Leadership and Accountability), C (Contractor Engagement and Planning), D (Work In Progress), and E (Safety evaluation, Measurement and Verification) as well as the factor interactions AC, AD, AE, CD, CE, DE, ACD, ACE, ADE, CDE, and ACDE are shown to be the significant model terms. Factor B (Qualification, Selection and Pre-Job) and other interactions involving Factor B are shown to be insignificant. This means that allocating resources towards Factor B would not likely improve the overall safety intervention program, thereby leading to indiscriminate waste of resources and capital. Safety intervention would be positively affected by Factors A, C, D and E. Allocation of more resources toward significant factors would further lower incident rates.

Although the model characteristics and behavior could possibly be improved upon using transformational analysis, the model characteristics remained nearly the same despite the incorporation of transformational analysis. The analysis of all factors and interactions show that the model is significant ($p<0.001$ and $R^2= 0.52$) and Factors A, C, D and E are the significant independent variables (From the analysis of variance test in Figure 5.2). The non-significant factor (Factor B) and interactions were eliminated from the model and a new model was developed based on the significant factors. The analysis of the significant factors and interactions show that the new model is significant ($p<0.001$ and $R^2= 0.54$).

The t-values for Factors A (7.61) and E (6.40) are higher when compared to those of Factors C (4.50) and D (6.00) as shown in Figure 5.1. This shows that Factors A, D and E are very significant factors. Due to the high t-values of Factors A, D and E, it is therefore important for the management to concentrate more efforts and resources in these very significant factors. From the business point of view, this would positively increase the effectiveness of the safety intervention model. From Table 6.2, it could be seen that the significant factors A, C, D, and E only contributed an overall percentage point of 14.96%. Factor A accounts for 1.01% of the safety model, Factor C (10.93%), Factor D (1.33%) and Factor E (1.69%).

This means that the management is not effectively allocating adequate resources towards the significant safety intervention factors or the interventions implemented are not giving the expected desirable results. The organization could improve its overall safety intervention policy by spending more time and allocating more resources to the significant factors and their interactions. The high level of significance of these factors shows that the organization would be able to predict and achieve desirable incident rates if safety interventions are accurately performed by environmental, health and safety personnel.

8.2 Recommendations and Applications

This research study shows that statistical techniques such as response surface design and contour plots could be used to obtain the near-optimum incident rates based on the relative inputs (percentages) of the significant safety intervention factors. This dissertation also indicates that the allocation of additional resources to safety intervention activities do not necessarily minimize incident rates (See Figures 6.12 – 6.23). The organization could achieve the desirable incident rate using the recommended 16.66% of its available resources on significant safety intervention activities. In situations where it may be impossible to achieve near-optimum incident rates due to labor and budget constraints, the organization could use 10.34% of its available resources to achieve the lowest acceptable incident rate.

The incorporation of a forecasting technique (Holt's double exponential smoothing) for the model validation shows that using the appropriate forecasting methodology, incident rates could be predicted. The use of measures of forecasting errors to compare the model recommended incident rates and the predicted incident rates indicated the accuracy of forecasting could be improved upon. The prediction accuracy obtained in this research was 71.58%, which is reasonable since the incident rates are often affected by other uncontrollable external factors such as militant attacks. The analysis of the predicted incident rate also indicated that the tracking signal could indicate the direction of the forecast. The obtained value of the tracking signal in this research (-4.08) could be considered to be within the acceptable range (TS $\pm$ 6). The test of forecast bias also indicated that the forecast error is truly random (unbiased) since the obtained slope of the residual errors revolved around zero (0.018).

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 lead to the achievement of desirable incident rates.

This research also shows that Factors A (Leadership and Accountability) and E (Evaluation, Measurement and Verification) are very significant factors (See Figure 5.1). This means that the allocation of resources to safety activities involving leadership and accountability as well as 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. 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 on 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. 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.

In addition to its numerous benefits, safety personnel, supervisors and managers could use the analysis obtained from this research 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 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 turn reduces employee turnover rate, increases profitability and improves the public shareholder value.

8.3 Limitations of the Study

The data collected for this study was obtained in a socio-politically unstable region of the country (Niger Delta). This could have an indirect impact on the incident rate, since employees may be prone to militant attacks. As a result of this, some employees could be psychologically overstressed and this could reduce their cognitive capability. In an effort to quickly complete their task before any militant attack, some employees could make bad judgments by taking short-cuts in the performance of their jobs, thereby increasing incident rates.

Although not obviously identified in this study, the problem of militant activities in the Niger Delta region could have led to the seasonal or periodic spikes in the incident rate data (See Figure 7.1). This makes it difficult to relate the obtained results to other regions or other oil companies that are not affected by militant activities. In some situations, the generalization of a cultural model (such as the one developed in this research) to other countries may be difficult to achieve since safety activities vary from one oil producing region to the other. Also, safety activities in the energy industry may not be the same as those implemented in other industries such as the manufacturing or service industries. However, this research and the results obtained from the analyses could be applicable in similar situations.

Another limitation of this research is that results obtained from the study could not be overwhelmingly accepted as universal. For example, the findings show Factor B (Qualification, Selection and Pre-Job) to be insignificant and the allocation of more resources to the other significant safety intervention factors or activities was recommended. In reality, Factor B 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 one or more significant factors identified in this study could become non-significant with little or no effect towards the minimization of incident rates.

Despite these limitations, this research provides the basis for the application of statistical techniques to predict effective allocation of resources, which in turn minimize incident rates and safety intervention costs. Even though it may not be possible to accommodate every limitation in this study, the incorporation of “blocking” into the analysis of the data was adequate enough to reduce or eliminate nuisance factors which may be uncontrollable.

8.4 Suggestions for Future Work

It would be important to further expand this work by developing a graphical user interface to show the interactive potential of the developed model. This would be executed using a computer program to analyze the developed safety intervention program by adapting to changes in incident rates over time. The interactive user interface would incorporate qualitative and quantitative techniques to relate past incident rates and predict effective resource allocation policies which would in turn minimize the unnecessary commitments towards non effective or significant intervention programs.

The expansion of the current sample size of the data by incorporating and comparing safety activities from other units or organizations would be beneficial to this research work. Increasing the data sample size would allow the management to adequately understand the impact of allocating sufficient budget and resources to the various tasks, operations, intervention activities and safety programs which reduces 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 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.

REFERENCES

Attwood, D., F. Khan and B. Velich (2006). "Occupational Accident Models- Where have we been and where are we going?" Journal of Loss Prevention in the Process Industries 19(6): 664-682.

Access Economics (2004) Costs of Workplace Injury and Illness to the Australian Economy: Reviewing the Estimation Methodology and Estimates of the Level and Distribution of Costs, Report prepared for the National Occupational Health and Safety Commission.

AFL-CIO Safety and Health (2007). Facts about Worker Safety and Health (OSHA). Retrieved from: http://www.aflcio.org/issues/safety/memorial/upload/wmd_safetyfacts.pdf

American Petroleum Institute (2009), "Workplace Safety for the United States Petroleum Industry. Retrieved from: http://www.api.org/statistics/accessapi/surveys/upload/2009-007_WORKPLACE_SAFETY.pdf

Armstrong, J.S. (2001).Principles of Forecasting - A Handbook for Researchers and Practitioners (International Series in Operations Research & Management Science). Kluwer Academic Publishers, Norwell, MA.

Bailey, C. (1993). Improve Safety Program Effectiveness with Perception Surveys. Professional Safety, Volume 38, Number 10, pp. 28-32.

Bohr, P.C., Evanoff, B.A., and L.D. Wolf (1997). Implementing Participatory Ergonomics Teams among Health Care Workers. American Journal of Industrial Medicine, Vol.32, No.3, pp.190-196.

Bowerman, B.J. and R.T. O'Connell (1993). Forecasting and Time Series: An Applied Approach. Duxbury Thomson Learning.

Budworth, N. (1996). Indicators of Performance in Safety Management. Safety and Health Practitioner, Vol.14, No.11, pp.23-29.

Chevron – Company Profile. Retrieved from: http://www.chevron.com/about/leadership/

Chevron – Nigeria. Retrieved from: http://www.chevron.com/countries/Nigeria/

Chopra, S and P. Meindl (2006). Supply Chain Management – Strategy, Planning and Operation, 3rd edition, Prentice Hall.

Cohen, A. (1977). Factors in Successful Occupational Safety Programs. Journal of Safety Research, Volume 9, Number 4, pp.167-178.

Conarda, M.A. and R. A. Matthews (2008). Modeling the stress process: Personality eclipses dysfunctional cognitions and workload in predicting stress. Personality and Individual Differences, Volume 44, Issue 1, Pages 171-181.

Customer Relationship Management and Marketing (2002). Managing Environmental, Health, and Safety Costs with Activity-Based Costing.CRM Today. Retrieved from: http://www.crm2day.com/events/info/EpkFkZAklFgzrUjTsv.php.

Erikson, J.A. (1997). The Relationship between Corporate Culture and Safety Performance. Professional Safety, Vol. 12, No.42, pp.29-32.

Fulwiler, R.D. (1998). People, Public Trust and Profit: Modeling Safety for Lasting Success. Occupational Hazards, April, pp. 36-39.

Gardiner, W. P., and G. Gettinby. (1998). Experimental Design Techniques in Statistical Practice — A Practical Software-based Approach, 335, Ellis Horwood, Chichester, Sussex, UK.

Geller, E.S. (1996). The Truth About Safety Incentives. Professional Safety, Vol.41, No.10, pp.34-39.

Gregory, E.S. (1996). Building an Environment that Promotes Safe Behavior. Professional Safety, Vol.41, pp.20-27.

Guastello, S.J., (1993). Do we really know how well our occupational accident prevention programs work?. Safety Science 16, (3-4), pp. 445–463.

Haight, J. M., R. E. Thomas, L. A. Smith, R. L. Bulfin Jr. and B. K. Hopkins (2001a). Intervention Effectiveness Research: Phase 1, Developing a Mathematical Relationship between Interventions and Incident Rates for the Design of a Loss Prevention System. American Society of Safety Engineers Technical Forum: 38-44

Haight, J. M., R. E. Thomas, L. A. Smith, R. L. Bulfin Jr. and B. K. Hopkins (2001b). Intervention Effectiveness Research: Phase 2 Design, Optimization & Verification of the Loss Prevention System & Analysis Models. Professional Safety - The Journal of the America Society of Safety Engineers: 33-37.

Hanson, L. (1994). Rate Your B.O.S.S.: Benchmarking Organizational Safety Strategy. Professional Safety, Vol.39, No.6, pp. 37-43.

Health and Safety Executive, Human Factors in Reliability Group (1995). Improving Compliance with Safety Procedures: Reducing Industrial Violations. Health and Safety Executive, U.K., pp.1-63.

Hoemke, D. (2008). Safety and Health Incentives. Occupational Health & Safety, Waco, Vol. 77, Issue 3, p. 63.

Immigration and Refugee Board of Canada, Country Fact Sheet: NIGERIA (2007). Issue Papers, Extended Responses and Country Fact Sheets. Retrieved from: http://www.irb-cisr.gc.ca/en/research/publications/index_e.htm?docid=358&cid=0&sec=CH01

Industrial Revolution - Effects of the Industrial Revolution. Retrieved from: http://science.jrank.org/pages/3574/Industrial-Revolution-Effects-Industrial-Revolution.html

Iyer, P., Haight, J.M., del Castillo,E., Tink, B.W., and P.W. Hawkins (2004). Intervention effectiveness research: Understanding and optimizing industrial safety programs using leading indicators. Chemical Health and Safety, 11(2), 9-19.

Iyer, P., Haight, J.M., del Castillo,E., Tink, B.W., and P.W. Hawkins (2005). A Research Model – Forecasting Incident Rates from Optimized Safety Program Intervention Strategies, Journal of Safety Research, Vol. 36, Number. 4, pp. 341-351.

Kelley, F.R. (1996). Worker Psychology and Safety Attitudes. Professional Safety, Vol.41, Number 7, pp. 14 -17.

Koda, S., Nakagiri, S., Yasuda, N., Toyota, M., and H.Ohara (1997). A Follow-up Study of Preventive Effects on Low Back Pain at Worksites by Providing a Participatory Occupational Safety and Health Program. Industrial Health, Vol.35, No.2, pp. 243-248.

Krause, T. R. (1997). Trends and Developments in behavioral-Based Safety. Professional Safety, Vol.42, Number 10, pp.20-25.

Krause, T. R. (1998). Safety Incentives from a Behavioral Perspective: Presenting a Balance Sheet. American Society of Safety Engineers, pp. 24-28.

Mansdorf, Z. (2006). "Occupational Hazards." The Authority on Occupational Safety, Health and Loss Prevention.

Mason, R. L., Gunst, R. F. and J. L. Hess (1989). Statistical Design and Analysis of Experiments. New York: Wiley.

Mayo, E. (1949), Hawthorne and the Western Electric Company, The Social Problems of an Industrial Civilisation, Routledge.

Montgomery, D.C. (2008). Design and Analysis of Experiments, Wiley, New York, 7th edition.

Moore, J.S. and Garg, A. (1996). Use of Participatory Ergonomics Teams to Address Musculoskeletal Hazards in the Red Meat Packing Industry. American Journal of Industrial Medicine, Vol.29, pp. 402-408.

Morrison, C. “A History of Safety.” (Online Article). Retrieved from: http://EzineArticles.com/?expert=Charles_Morrison

National Institute for Occupational Safety and Health (NIOSH).
Retrieved from: http://www.cdc.gov/niosh/homepage.html

National Institute for Occupational Safety and Health (NIOSH), US Department of Health and Human Services: Performance Highlights of the National Institute for Occupational Safety and Health. 1995 – 1999.

National Safety Council. (2006). Injury facts 2005-2006 edition.

National Safety Council (2009). New Study in NSC Journal Aims to Enhance Behavioral Approach to Workplace Safety.
Retrieved from: http://www.nsc.org/news/jsr_behavior.aspx

National Safety Council (2009). Report on Injuries in America (Highlights from Injury Facts, 2009 Edition). Retrieved from: http://www.nsc.org/lrs/injuriesinamerica08.aspx

Nigeria - Oil. Country Analysis Briefs. US Energy Information Administration (2007).
Retrieved from: http://tonto.eia.doe.gov/country/country_energy_data.cfm?fips=NI

NIOSH Facts: Work-Related Musculoskeletal Disorders.
Retrieved from: www.cdc.gov/niosh/muskdsfs.html

Occupational Health and Safety Administration (OSHA). Retrieved from: www.osha.gov

Occupational Safety and Health Administration (OSHA). Facts about Worker Safety and Health. Retrieved from: http://www.aflcio.org/issues/safety/memorial/upload/wmd_safetyfacts.pdf

Okudan, G.E. and G. Akman (2004), Manufacturing Performance Modeling and Measurement to Assess Varying Business Strategies, Global Journal of Flexile Systems Management, Vol. 5, No. 2, pp. 51-99.

Orr, G. B. (1997). Ergonomics programs for healthcare organizations. Occupational Medicine State of the Art Reviews, volume 12, Issue 4, pp. 687-700

Petersen, D. J. (1998). The Four Cs of Safety: Culture, Competency, Consequences and Continuous Improvement. Professional Safety, pp. 32-33.

Philson, C.S. (1998). Workplace Safety Accountability. Occupational Health and Safety, Vol.67, No.4, pp. 20-24.

Prochaska, J.O. and C.C. DiClemente (1982). Transtheoretical therapy: toward a more integrative model of change. Psychotherapy: Theory Research and Practice; 19, pp. 276-288.

Ray, P.S. and Bishop, P.A. (1995). Can Training Alone Ensure a Safe Workplace? Professional Safety, Vol.40, No.4, pp. 56-59.

Safety: In Student's Encyclopedia. Retrieved from Britannica Student Encyclopedia: http://student.britannica.com/comptons/article-207621

Savage, M. and Pipkins, D. (2006). The Effect of Rest Periods on Hand Fatigue and Productivity. Journal of Industrial Technology, Volume 22, Number 3, pp. 1-6.

Schoonmaker, D. (2006). Safety-Incentive Programs Are Mixed Bag. Grand Rapids Business Journal. Grand Rapids. Vol. 24, Issue 8, p. B4.

Shakioye, S. and J.M.Haight (2008). Intervention Effectiveness Research – Computer Modeling of Safety and health Program Design and Incident Rate Forecasting. In the Proceedings of the American Society of Safety Engineers Professional Development, Conference, Las Vegas, NV.

Simon, R.A. (1996). The Trust Factor in Safety Performance. Professional Safety, pp. 28-33.

Stalnaker, C.K. (1996). Line Management Self-Assessment of Safety Performance. Professional Safety, Vol.41, No.8, pp. 32-34.

Stout, D., (1995). Performance Analysis for Training. Niagara Paper Company, Niagara, WI.

Telford, J. K. (2007). A Brief Introduction to Design of Experiments, Johns Hopkins APL Technical Digest, Volume 27, Number 3, pp. 224 -232.

The Federal Ministry of Health, Nigeria. (The Ministry of Health Mission Statement). Retrieved from: http://nigeria.gov.ng/NR/exeres/CC1F04E3-5DC4-414C-A8B7-2FF98B3CD9D0.htm

The Institute of Medicine (2000). Safe Work in the 21st Century: Education and Training Needs for the Next Decade's Occupational Safety and Health Personnel. National Academy Press, Washington, DC.

The United States Department of Energy (2003). Good Practices For The Behavior-Based Safety Process. DOE Handbook.
Retrieved from: http://www.hss.energy.gov/CSA/CSP/BBS/BBS102403.pdf.

The United States Department of Labor (USDOL), Occupational Safety and Health Act of 1970. Retrieved from: http://www.dol.gov/Compliance/Guide/Osha.Htm

The United States Department of Labor: US Factory Inspection Legislation (2007). Retrieved from: http://www.dol.gov/oasam/programs/history/mono-regsafepart02.htm

Toffel, M. W. and L. R. Birkner (2002).Estimating and Controlling Workplace Risk: An Approach for Occupational Hygiene and Safety Professionals. Applied Occupational and Environmental Hygiene, Volume 17, Number 7, pp. 477-485(9).

Tuohy, C, and Simard, M. (1993). The Impact of Joint Health and Safety Committee in Ontario and Quebec. (Prepared for the Canadian Association of Administrators of Labour Law), pp.1-49.

Whysall, Z.J., Haslam, C., & Haslam, R.A. (2005). A staged approach to reducing musculoskeletal disorders (MSDs) in the workplace, Health & Safety Executive, RR379 HSE Books, Sudbury, pp.1-77.

Widdershoven, G. (1999). Cognitive Psychology and Hermeneutics: Two Approaches to Meaning and Mental Disorder Philosophy, Psychiatry, and Psychology. Vol.6, No 4, pp. 245-253.

APPENDIX A

SAMPLE DATA COLLECTION AND TABULATION SHEET

Contractor Health, Environment and Safety Management
Data Collection Sheet

Data Period | From: ____________ | Date to: ___

Data input representative (Company Employee and contractor)							
Safety Activities	Check for Index 0	Check for Index 1	Check for Index 2	Week 1	Week 2	Week 3	Week4
Factor A. Leadership & Accountability							
1.Process sponsor engagement in employee and contractor management				2	2	1	1
2. Process advisor engagement in employee and contractor management				1	2	1	1
3 SBU Targets are established for performance indicators			x	2	2	1	0
4 Company and contractor leadership periodically review contractor HES performance and implement improvemen			x	2	2	2	2
5 Company leaders and managers establish, provide resources & particiapate in employee and contractor process				2	2	2	2
	TOTAL INTERVENTION HRS / WEEK			9	10	7	6
Factor B. Qualification Selection & Pre-Job							
1. An approved contractor list is maintained				1	1	2	2
2. The contractor qualification and selection process addresses HES performance considerations				2	2	2	2
3. Contractors apply HES requirements to subcontractors	x			1	1	1	1
4. Pre-Job meetings with contractors are conducted prior to start of work				2	2	2	2
5. A Pre-Job "HES plan" for all work projects				2	1	2	2
6. Identification, supervision, training and management of short service employee and contractor		x		2	2	1	2
7. A contractor incentive is in place				1	0	2	1
8. Skills development training & verification by individual				2	2	1	2
9. HES training development & verification				2	2	2	2
	TOTAL INTERVENTION HRS / WEEK			15	13	15	16
Factor C. Contractor Engagement & Planning							
1. Local Tenets of OE are communicated to contractors and incorporated into contractor work process				2	2	2	2
2. Periodic meetings between Company leadership and individual contractor management are conducted.				2	2	2	2
3. Joint Company Employee and contractors-contractor meetings are held				1	0	2	2
4. Regular Field visits are conducted by managers for the purpose of discussing HES performance with contractors				2	2	1	2
5. Specific local strategies and plans are developed and implemented to improve local contractor HES performance				0	0	2	2
6. Contractor Safety plans that addresses all risk assessment.				2	2	2	2
7. HES expectations and requirements are clearly communicated to the contractor prior to contract execution			x	2	2	2	2
	TOTAL INTERVENTION HRS / WEEK			11	10	13	14
Factor D. Work in Progress							
1. II&R Process				2	2	1	2
2. Employee and contractor process audits and HES performance evaluations of contractors are conducted periodically				2	1	2	0
3. Daily tailgate and regular HES meetings are conducted			x	2	2	2	2
4. JSA are conducted,			x	2	1	2	2
5. pre task hazard assessment by the contract crew				2	2	1	2
6. On site HES monitoring is provided for high risk and or large jobs				2	0	2	2
7. Field reviews are conducted				2	1	2	2
8. Management reviews conducted joint company employee & contractors			x	2	2	1	1
9. Issuing Permits			x	2	1	2	2
10. Contractor activities included within the facility Management of Change procedure				2	2	1	2
	TOTAL INTERVENTION HRS / WEEK			20	14	16	17
Factor E. Evaluation, Measurement & Verification							
1. Joint Post Job evaluations are conducted part of evaluation				2	2	2	1
2. Results communicated to employees and contractors				2	1	0	2
3. Lessons learned are evaluated and incorporated into future contracting efforts		1		2	2	2	0
	TOTAL INTERVENTION HRS / WEEK			6	5	4	3

	Week 1	Week 2	Week 3	Week 4
TOTAL REC. INCIDENTS / WEEK	12	6	14	5
TOTAL HRS OF EXPOSURE / WEEK	4944	5793	7086	6764
TOTAL INCIDENT RATE / WEEK	9.307	3.984	7.599	2.843

PERCENTAGE (%) OF TOTAL MAN-HOURS	Week 1	Week 2	Week 3
Factor A. Leadership & Accountability	2.747%	3.475%	5.332%
Factor B. Qualification Selection & Pre-Job	3.254%	4.985%	6.443%
Factor C. Contractor Engagement & Planning	4.431%	5.647%	4.334%
Factor D. Work in Progress	5.348%	6.455%	5.326%
Factor E. Evaluation, Measurement & Verification	0.834%	1.445%	2.331%

Note: Index 0 → Does not exist
Index 1 → Exists but not adequate & functional
Index 2 → Exists , adequate & functional

Supervisor's Signature ________________________________ **Date** ________________________

APPENDIX B

Raw Data: Table of Safety Intervention Factors, Incident Rate and Significant Factor Interactions

Week	Factors (% of Available Man-hours)					Incident Rate	Significant Factor Interactions									
	A	B	C	D	E		AC	AD	AE	CD	CE	DE	ACE	ADC	CDE	ACDE
1	1.152	3.969	2.539	6.018	0.400	0.444	2.924	6.931	0.461	15.280	1.015	2.407	1.169	17.598	6.111	7.038
2	2.789	3.971	2.497	6.080	0.344	2.764	6.963	16.955	0.960	15.179	0.860	2.094	2.398	42.331	5.228	14.579
3	2.747	3.899	3.147	5.296	0.892	2.491	8.643	14.547	2.451	16.667	2.808	4.727	7.713	45.779	14.874	40.853
4	2.704	3.887	3.138	5.347	0.810	2.221	8.486	14.462	2.189	16.779	2.540	4.329	6.870	45.380	13.584	36.738
5	2.662	3.876	3.129	5.398	0.727	1.954	8.330	14.373	1.935	16.891	2.274	3.923	6.054	44.969	12.275	32.681
6	2.620	3.865	3.120	5.449	0.644	8.793	8.175	14.279	1.687	17.001	2.009	3.509	5.264	44.547	10.947	28.685
7	2.578	3.853	3.111	5.500	0.561	9.044	8.020	14.181	1.447	17.110	1.745	3.086	4.500	44.112	9.601	24.752
8	2.536	3.842	3.102	5.551	0.478	9.295	7.866	14.078	1.213	17.219	1.483	2.655	3.762	43.667	8.235	20.885
9	2.494	3.958	3.093	5.602	0.395	9.546	7.713	13.972	0.986	17.326	1.223	2.215	3.050	43.210	6.852	17.087
10	2.452	3.959	3.084	5.653	0.313	9.797	7.560	13.861	0.766	17.433	0.964	1.767	2.364	42.741	5.450	13.362
11	1.219	3.961	3.075	5.704	0.230	10.048	3.749	6.955	0.280	17.538	0.707	1.311	0.862	21.385	4.030	4.914
12	4.036	3.962	3.529	3.529	1.765	10.299	14.246	14.246	7.123	12.457	6.228	6.228	25.140	50.279	21.982	88.728
13	4.706	3.964	3.386	5.588	1.176	0.235	15.936	26.298	5.536	18.924	3.984	6.574	18.748	89.055	22.264	104.771
14	5.095	3.965	3.529	4.556	1.176	0.142	17.984	23.213	5.995	16.078	4.152	5.359	21.158	81.928	18.916	96.386
15	1.501	3.967	4.118	4.412	1.176	2.752	6.181	6.623	1.766	18.166	4.844	5.190	7.272	27.270	21.372	32.082
16	2.468	3.968	2.858	4.706	1.765	3.537	7.053	11.612	4.354	13.450	5.044	8.304	12.446	33.189	23.736	58.568
17	4.102	3.545	2.647	4.499	1.874	5.538	10.858	18.456	7.686	11.910	4.960	8.431	20.344	48.854	22.316	91.537
18	3.823	3.212	3.824	5.545	1.260	6.467	14.616	21.196	4.818	21.201	4.819	6.989	18.421	81.044	26.721	102.143
19	5.139	3.911	3.235	4.706	1.765	6.349	16.626	24.183	9.069	15.225	5.709	8.304	29.339	78.238	26.867	138.067
20	3.771	4.632	3.529	4.118	1.176	10.294	13.308	15.526	4.436	14.533	4.152	4.844	15.656	54.797	17.097	64.467
21	2.936	4.913	4.118	5.588	1.765	4.104	12.088	16.405	5.180	23.010	7.266	9.862	21.331	67.549	40.607	119.205
22	2.790	3.824	3.092	5.588	1.292	3.799	8.627	15.592	3.605	17.280	3.995	7.220	11.147	48.212	22.326	62.291
23	1.224	3.281	2.941	4.412	1.765	0.765	3.599	5.398	2.159	12.976	5.190	7.785	6.351	15.877	22.898	28.018
24	2.873	2.877	2.647	5.294	0.588	3.316	7.605	15.210	1.690	14.014	1.557	3.114	4.473	40.261	8.243	23.683
25	2.831	2.834	3.165	5.194	1.058	3.039	8.960	14.705	2.995	16.440	3.349	5.496	9.480	46.540	17.395	49.242
26	2.488	2.792	3.156	5.245	0.975	2.740	7.854	13.053	2.427	16.554	3.078	5.116	7.659	41.195	16.144	40.175
27	2.377	2.750	3.003	5.342	1.011	2.484	7.139	12.698	2.403	16.043	3.035	5.399	7.215	38.135	16.214	38.543

Raw Data: Table of Safety Factors, Incident Rate and Significant Factor Interactions (cont.)

Week	Factors (% of Available Man-hours)					Incident Rate	Significant Factor Interactions									
	A	B	C	D	E		AC	AD	AE	CD	CE	DE	ACE	ADC	CDE	ACDE
28	2.266	2.708	2.961	5.403	0.955	2.238	6.709	12.242	2.164	15.999	2.828	5.161	6.408	36.250	15.282	34.625
29	3.917	2.666	2.919	5.465	0.900	6.956	11.434	21.408	3.524	15.951	2.626	4.917	10.287	62.485	14.350	56.215
30	2.777	2.623	4.118	5.000	1.141	6.843	11.435	13.885	3.169	20.588	4.699	5.706	13.049	57.175	23.494	65.244
31	5.706	2.581	4.118	4.706	1.765	6.922	23.494	26.850	10.069	19.377	7.266	8.304	41.459	110.559	34.195	195.103
32	2.377	4.412	3.529	4.706	1.099	0.371	8.389	11.185	2.613	16.609	3.880	5.173	9.222	39.477	18.258	43.398
33	0.496	2.941	2.941	5.882	1.176	0.375	1.459	2.918	0.584	17.301	3.460	6.920	1.716	8.582	20.354	10.097
34	1.030	3.529	3.263	4.693	1.855	0.235	3.361	4.835	1.911	15.315	6.055	8.708	6.237	15.776	28.416	29.273
35	2.395	5.117	3.824	5.588	1.875	0.118	9.156	13.382	4.490	21.367	7.169	10.477	17.167	51.167	40.061	95.933
36	0.775	4.142	3.617	5.296	1.632	7.297	2.804	4.106	1.265	19.155	5.901	8.641	4.574	14.849	31.253	24.227
37	1.872	3.783	3.293	5.502	1.856	2.455	6.164	10.299	3.474	18.118	6.112	10.211	11.440	33.916	33.626	62.945
38	1.785	3.926	3.727	1.000	1.892	4.477	6.651	1.785	3.377	3.727	7.051	1.892	12.584	6.651	7.051	12.584
39	1.698	3.890	3.745	5.626	1.935	2.346	6.358	9.551	3.286	21.069	7.248	10.888	12.305	35.768	40.776	69.224
40	1.611	3.854	3.763	5.673	1.979	2.327	6.061	9.136	3.187	21.350	7.447	11.225	11.993	34.384	42.245	68.037
41	1.523	3.818	3.782	5.720	2.022	2.309	5.761	8.714	3.081	21.632	7.647	11.566	11.650	32.953	43.742	66.636
42	1.436	3.782	3.800	5.767	2.066	2.291	5.458	8.283	2.967	21.915	7.849	11.912	11.274	31.476	45.267	65.015
43	1.349	3.746	3.819	5.814	2.109	2.273	5.152	7.844	2.845	22.201	8.053	12.261	10.865	29.952	46.820	63.166
44	1.262	2.196	3.837	5.861	2.152	3.565	4.842	7.397	2.716	22.488	8.258	12.615	10.422	28.380	48.402	61.083
45	1.175	2.239	3.855	5.908	2.196	3.388	4.529	6.941	2.580	22.777	8.465	12.972	9.945	26.760	50.012	58.758
46	1.088	2.283	3.874	5.955	2.239	3.200	4.213	6.478	2.436	23.068	8.674	13.334	9.435	25.092	51.652	56.183
47	1.001	2.326	3.892	6.002	2.283	3.002	3.894	6.006	2.284	23.360	8.884	13.700	8.889	23.374	53.320	53.352
48	0.913	2.369	3.910	6.049	2.326	2.793	3.572	5.526	2.125	23.654	9.095	14.070	8.308	21.607	55.018	50.258
49	0.826	2.413	3.929	6.096	2.369	2.574	3.246	5.038	1.958	23.950	9.308	14.444	7.692	19.791	56.746	46.891
50	0.739	2.456	3.947	6.143	2.413	2.344	2.918	4.541	1.784	24.248	9.523	14.822	7.040	17.924	58.503	43.246
51	0.652	2.500	3.965	6.190	2.456	2.104	2.586	4.037	1.602	24.547	9.740	15.204	6.351	16.007	60.291	39.314
52	0.565	2.543	3.984	6.237	2.500	1.854	2.251	3.524	1.412	24.848	9.958	15.590	5.625	14.038	62.109	35.088
53	0.478	2.586	4.002	6.284	2.543	1.594	1.912	3.003	1.215	25.151	10.177	15.981	4.863	12.017	63.957	30.560
54	0.391	2.630	4.020	6.331	2.586	1.325	1.571	2.474	1.010	25.455	10.398	16.375	4.062	9.945	65.836	25.721

Raw Data: Table of Safety Factors, Incident Rate and Significant Factor Interactions (cont.)

Week	Factors (% of Available Man-hours)					Incident Rate	Significant Factor Interactions									
	A	B	C	D	E		AC	AD	AE	CD	CE	DE	ACE	ADC	CDE	ACDE
55	0.304	2.673	4.039	6.378	2.630	1.045	1.226	1.936	0.798	25.762	10.621	16.774	3.224	7.820	67.746	20.565
56	0.216	2.717	4.057	6.426	2.673	0.757	0.878	1.391	0.579	26.070	10.845	17.176	2.347	5.642	69.687	15.082
57	0.129	2.760	4.076	6.473	2.717	2.036	0.527	0.837	0.351	26.379	11.071	17.583	1.431	3.411	71.660	9.265
58	0.042	2.803	4.094	6.520	2.760	2.017	0.173	0.275	0.116	26.691	11.299	17.994	0.476	1.125	73.664	3.106
59	2.954	3.171	4.112	1.000	2.803	1.999	12.149	2.954	8.282	4.112	11.528	2.803	34.057	12.149	11.528	34.057
60	1.537	3.135	4.131	6.614	2.847	1.981	6.350	10.168	4.377	27.319	11.759	18.827	18.078	42.000	77.769	119.563
61	5.426	3.099	4.149	6.661	2.890	1.963	22.512	36.141	15.682	27.635	11.991	19.250	65.064	149.948	79.869	433.370
62	1.488	3.063	4.167	6.708	2.934	1.945	6.199	9.978	4.364	27.953	12.225	19.677	18.186	41.584	82.002	121.987
63	6.100	3.963	4.118	3.377	1.179	1.926	25.118	20.599	7.194	13.905	4.856	3.982	29.622	84.820	16.398	100.027
64	1.034	4.487	4.118	5.588	1.176	1.908	4.257	5.777	1.216	23.010	4.844	6.574	5.008	23.787	27.071	27.985
65	1.917	3.593	2.900	4.412	0.000	5.210	5.561	8.459	0.000	12.796	0.000	0.000	0.000	24.535	0.000	0.000
66	3.286	2.532	2.647	5.753	1.799	2.540	8.698	18.904	5.910	15.229	4.761	10.348	15.645	50.040	27.391	90.003
67	4.124	4.954	3.824	5.368	1.176	5.761	15.767	22.135	4.851	20.524	4.498	6.315	18.549	84.632	24.145	99.567
68	3.411	4.706	3.805	4.612	1.765	2.289	12.977	15.729	6.019	17.548	6.715	8.139	22.901	59.849	30.968	105.616
69	2.932	3.824	4.118	2.910	1.037	1.480	12.073	8.533	3.040	11.984	4.270	3.018	12.520	35.138	12.427	36.437
70	2.863	4.437	3.691	4.602	1.309	0.476	10.567	13.174	3.748	16.987	4.833	6.025	13.834	48.631	22.239	63.666
71	2.793	4.484	3.708	4.586	1.314	3.670	10.358	12.811	3.670	17.005	4.871	6.025	13.608	47.502	22.340	62.407
72	2.724	4.530	3.725	4.570	1.318	0.849	10.147	12.450	3.591	17.022	4.910	6.025	13.377	46.370	22.441	61.133
73	2.655	4.576	3.741	4.554	1.323	2.071	9.933	12.090	3.512	17.038	4.950	6.025	13.141	45.234	22.540	59.843
74	2.586	4.623	3.758	4.538	1.328	2.104	9.717	11.734	3.433	17.054	4.989	6.024	12.900	44.095	22.640	58.539
75	2.516	4.669	3.775	4.522	1.332	1.266	9.498	11.379	3.352	17.069	5.028	6.024	12.653	42.952	22.738	57.219
76	2.447	4.715	3.791	4.506	1.337	6.504	9.278	11.027	3.271	17.083	5.068	6.023	12.402	41.805	22.837	55.884
77	2.378	4.761	3.808	4.490	1.341	5.857	9.055	10.676	3.190	17.098	5.108	6.023	12.146	40.655	22.934	54.534
78	2.309	4.808	3.825	4.474	1.346	5.015	8.829	10.328	3.107	17.111	5.148	6.022	11.884	39.503	23.031	53.169
79	2.239	4.854	3.841	4.458	1.351	4.949	8.602	9.983	3.024	17.124	5.188	6.021	11.617	38.346	23.127	51.789
80	2.170	4.900	3.858	1.000	1.355	6.480	8.372	2.170	2.941	3.858	5.228	1.355	11.345	8.372	5.228	11.345

Raw Data: Table of Safety Factors, Incident Rate and Significant Factor Interactions (cont.)

Week	Factors (% of Available Man-hours)					Incident Rate	Significant Factor Interactions									
	A	B	C	D	E		AC	AD	AE	CD	CE	DE	ACE	ADC	CDE	ACDE
81	2.101	4.947	3.875	4.426	1.360	3.908	8.140	9.298	2.857	17.149	5.269	6.018	11.068	36.026	23.318	48.986
82	2.031	4.993	3.891	4.410	1.364	3.826	7.905	8.959	2.772	17.160	5.309	6.017	10.785	34.861	23.413	47.563
83	0.826	5.039	3.908	4.394	1.369	2.574	3.229	3.631	1.131	17.171	5.350	6.015	4.421	14.189	23.507	19.425
84	0.739	3.495	3.947	6.143	2.413	2.344	2.918	4.541	1.784	24.248	9.523	14.822	7.040	17.924	58.503	43.246
85	0.652	3.459	3.965	6.190	2.456	2.104	2.586	4.037	1.602	24.547	9.740	15.204	6.351	16.007	60.291	39.314
86	2.606	3.423	3.984	6.237	2.500	3.112	10.383	16.256	6.514	24.848	9.958	15.590	25.952	64.761	62.109	161.872
87	5.171	3.055	3.015	3.803	1.765	6.263	15.588	19.663	9.125	11.463	5.320	6.711	27.508	59.275	20.230	104.602
88	1.174	3.529	4.118	4.511	1.176	0.790	4.835	5.297	1.381	18.576	4.844	5.307	5.688	21.812	21.854	25.662
89	2.846	2.789	3.235	5.294	0.711	1.274	9.209	15.069	2.024	17.128	2.300	3.764	6.547	48.752	12.177	34.660
90	5.228	3.235	2.941	4.374	0.538	2.859	15.376	22.865	2.814	12.864	1.583	2.354	8.276	67.250	6.924	36.197
91	5.942	4.303	2.941	5.882	0.476	4.250	17.477	34.954	2.831	17.301	1.401	2.803	8.327	102.807	8.243	48.981
92	1.219	4.706	3.820	5.882	1.765	4.208	4.658	7.173	2.152	22.473	6.742	10.381	8.221	27.402	39.659	48.357
93	4.238	5.000	3.529	3.529	2.765	6.865	14.957	14.957	11.716	12.457	9.758	9.758	41.352	52.789	34.439	145.947
94	4.556	5.774	3.734	4.386	2.051	6.966	17.013	19.985	9.346	16.377	7.659	8.997	34.896	74.620	33.592	153.061
95	4.875	6.364	3.881	4.184	2.385	7.067	18.918	20.398	11.625	16.236	9.253	9.977	45.111	79.153	38.717	188.749
96	5.194	6.953	4.027	3.982	2.718	7.168	20.916	20.681	14.116	16.037	10.946	10.823	56.850	83.288	43.587	226.378
97	5.512	7.542	4.174	3.780	3.051	7.269	23.008	20.836	16.820	15.777	12.737	11.534	70.208	86.970	48.143	265.379
98	5.831	8.131	4.321	3.578	3.385	6.260	25.194	20.862	19.736	15.459	14.625	12.110	85.276	90.140	52.326	305.106
99	6.149	8.721	4.468	1.000	3.718	5.584	27.473	6.149	22.865	4.468	16.611	3.718	102.150	27.473	16.611	102.150
100	6.468	9.310	4.614	3.174	4.052	6.409	29.846	20.528	26.206	14.644	18.695	12.859	120.923	94.721	59.333	383.771
101	6.787	9.899	4.761	2.972	4.385	4.463	32.312	20.168	29.760	14.148	20.877	13.031	141.687	96.018	62.039	421.039
102	7.105	10.489	4.908	2.770	4.718	6.539	34.871	19.678	33.526	13.592	23.157	13.068	164.537	96.577	64.134	455.691
103	7.424	11.078	5.055	2.567	1.052	4.897	37.524	19.061	7.809	12.977	5.316	2.700	39.468	96.343	13.650	101.334
104	7.743	5.085	5.201	2.365	5.385	6.202	40.271	18.314	41.695	12.303	28.010	12.738	216.868	95.257	66.254	512.976
105	8.061	5.132	5.348	2.163	5.719	7.665	43.111	17.439	46.099	11.569	30.583	12.371	246.537	93.263	66.161	533.333
106	8.380	5.178	5.495	1.961	6.052	5.131	46.045	16.435	50.714	10.776	33.254	11.869	278.665	90.305	65.219	546.524
107	8.698	5.224	5.642	1.759	6.385	6.440	49.072	15.302	55.543	9.924	36.023	11.233	313.346	86.325	63.370	551.221

Raw Data: Table of Safety Factors, Incident Rate and Significant Factor Interactions (cont.)

Week	Factors (% of Available Man-hours)					Incident Rate	Significant Factor Interactions									
	A	B	C	D	E		AC	AD	AE	CD	CE	DE	ACE	ADC	CDE	ACDE
108	9.017	5.270	5.788	1.557	6.719	6.246	52.193	14.040	60.584	9.013	38.890	10.462	350.674	81.268	60.555	546.024
109	9.336	5.317	5.935	1.355	1.052	6.409	55.407	12.650	9.823	8.042	6.245	1.426	58.300	75.076	8.462	78.995
110	1.200	5.548	4.091	4.218	1.420	2.591	4.910	5.063	1.704	17.256	5.808	5.988	6.971	20.712	24.496	29.401
111	1.131	5.594	4.108	4.202	1.424	2.467	4.646	4.752	1.611	17.261	5.850	5.984	6.616	19.521	24.582	27.802
112	1.062	5.641	4.124	4.186	1.429	2.341	4.379	4.444	1.517	17.265	5.893	5.981	6.256	18.330	24.667	26.189
113	1.547	5.687	4.141	4.170	1.433	3.160	6.405	6.449	2.217	17.268	5.936	5.977	9.180	26.707	24.752	38.281
114	1.477	5.363	4.025	4.282	1.401	3.053	5.946	6.326	2.070	17.233	5.639	6.000	8.331	25.458	24.146	35.671
115	1.408	5.409	4.041	4.266	1.406	2.942	5.690	6.007	1.979	17.239	5.681	5.997	7.999	24.274	24.235	34.123
116	1.339	5.456	4.058	4.250	1.410	2.828	5.433	5.690	1.888	17.246	5.723	5.994	7.662	23.088	24.322	32.562
117	1.270	5.502	4.075	4.234	1.415	2.711	5.173	5.375	1.796	17.251	5.765	5.991	7.319	21.901	24.410	30.988
118	1.112	5.548	4.091	4.218	1.420	2.991	4.550	4.691	1.579	17.256	5.808	5.988	6.459	19.193	24.496	27.245
119	5.130	4.929	3.824	5.294	1.765	5.136	19.616	27.161	9.054	20.242	6.747	9.343	34.617	103.852	35.722	183.268
120	1.452	2.941	3.324	5.343	1.176	1.070	4.828	7.759	1.709	17.763	3.911	6.286	5.680	25.796	20.898	30.348
121	2.382	3.648	3.824	5.812	0.529	3.581	9.108	13.845	1.259	22.222	2.021	3.072	4.815	52.938	11.747	27.983
122	2.495	4.083	3.728	5.272	1.156	3.570	9.300	13.152	2.884	19.653	4.310	6.095	10.751	49.028	22.721	56.680
123	2.607	3.933	3.691	5.380	1.127	3.544	9.623	14.026	2.939	19.858	4.161	6.065	10.849	51.772	22.388	58.366
124	2.720	3.782	3.654	5.488	1.099	3.501	9.938	14.925	2.988	20.056	4.015	6.029	10.919	54.542	22.034	59.922
125	2.832	3.632	3.618	5.596	1.070	3.443	10.245	15.848	3.030	20.245	3.871	5.987	10.962	57.333	21.661	61.342
126	2.944	3.481	3.581	5.704	1.041	3.371	10.544	16.795	3.066	20.426	3.729	5.939	10.979	60.144	21.268	62.622
127	3.057	3.331	3.544	5.812	1.012	3.284	10.835	17.766	3.095	20.600	3.589	5.885	10.970	62.971	20.857	63.758
128	1.219	3.180	3.508	5.920	0.984	2.321	4.277	7.218	1.200	20.766	3.451	5.824	4.208	25.320	20.429	24.909
129	1.164	5.000	3.529	3.529	1.765	1.045	4.109	4.109	2.055	12.457	6.228	6.228	7.252	14.503	21.982	25.594
130	2.793	3.724	3.416	5.588	0.708	5.313	9.541	15.607	1.977	19.092	2.418	3.955	6.753	53.320	13.513	37.740
131	1.219	3.529	4.118	4.560	1.765	2.321	5.021	5.560	2.152	18.778	7.266	8.048	8.860	22.896	33.137	40.405
132	2.121	5.000	3.529	3.529	1.765	3.006	7.484	7.484	3.742	12.457	6.228	6.228	13.208	26.415	21.982	46.615
133	5.882	3.824	4.135	4.470	1.176	6.634	24.326	26.294	6.920	18.485	4.865	5.259	28.619	108.737	21.747	127.926
134	2.151	5.148	3.824	5.747	0.734	3.809	8.224	12.363	1.578	21.975	2.805	4.216	6.033	47.269	16.120	34.673

Raw Data: Table of Safety Factors, Incident Rate and Significant Factor Interactions (cont.)

Week	Factors (% of Available Man-hours)					Incident Rate	Significant Factor Interactions									
	A	B	C	D	E		AC	AD	AE	CD	CE	DE	ACE	ADC	CDE	ACDE
135	4.525	4.412	3.031	4.412	1.765	5.763	13.712	19.961	7.985	13.370	5.348	7.785	24.197	60.493	23.594	106.753
136	2.467	4.118	3.529	4.706	1.176	7.200	8.707	11.609	2.902	16.609	4.152	5.536	10.243	40.974	19.540	48.204
137	1.271	5.294	3.824	5.882	1.765	2.579	4.860	7.477	2.243	22.491	6.747	10.381	8.576	28.588	39.691	50.449
138	3.936	4.570	3.235	4.608	1.765	5.583	12.736	18.138	6.947	14.907	5.709	8.131	22.475	58.683	26.307	103.558
139	1.667	3.960	3.529	5.076	1.263	1.909	5.884	8.463	2.106	17.915	4.458	6.412	7.433	29.869	22.631	37.731
140	4.706	4.412	3.824	3.073	1.176	2.758	17.993	14.461	5.536	11.750	4.498	3.615	21.168	55.294	13.823	65.051
141	3.147	4.046	2.941	5.000	0.588	5.842	9.256	15.735	1.851	14.706	1.730	2.941	5.445	46.280	8.651	27.224
142	3.215	4.503	4.109	5.882	1.176	4.456	13.210	18.911	3.782	24.170	4.834	6.920	15.541	77.705	28.435	91.418
143	6.294	3.235	2.941	4.706	1.765	13.302	18.512	29.619	11.107	13.841	5.190	8.304	32.668	87.116	24.425	153.734
144	0.745	4.118	3.688	5.861	1.765	1.087	2.748	4.367	1.315	21.612	6.508	10.342	4.849	16.104	38.139	28.420
145	1.386	4.412	2.941	5.506	1.176	1.457	4.075	7.628	1.630	16.193	3.460	6.477	4.794	22.436	19.051	26.395
146	2.932	5.000	4.096	4.412	0.693	3.625	12.011	12.936	2.033	18.073	2.840	3.059	8.327	52.990	12.529	36.736
147	2.941	4.154	3.503	5.092	1.017	3.438	10.302	14.976	2.990	17.839	3.561	5.177	10.474	52.463	18.136	53.335
148	2.950	4.117	3.501	5.109	0.963	3.251	10.328	15.070	2.840	17.889	3.371	4.918	9.943	52.767	17.221	50.798
149	2.959	4.080	3.500	5.126	0.909	3.062	10.354	15.165	2.689	17.938	3.180	4.658	9.409	53.071	16.301	48.228
150	2.967	4.044	3.498	5.142	0.855	2.873	10.380	15.260	2.537	17.988	2.990	4.396	8.872	53.376	15.376	45.626
151	2.976	4.007	3.496	5.159	0.801	2.683	10.405	15.355	2.384	18.037	2.800	4.132	8.333	53.682	14.445	42.992
152	2.985	3.971	3.494	5.176	0.747	2.492	10.431	15.450	2.230	18.086	2.610	3.866	7.791	53.988	13.509	40.325
153	2.994	3.934	3.493	5.192	0.693	2.301	10.457	15.546	2.075	18.135	2.420	3.598	7.246	54.296	12.567	37.625
154	3.003	3.897	3.491	5.209	0.639	2.109	10.482	15.642	1.919	18.184	2.231	3.329	6.698	54.603	11.620	34.893
155	3.012	3.861	3.489	5.226	0.585	1.916	10.508	15.738	1.762	18.234	2.041	3.058	6.148	54.912	10.668	32.129
156	3.020	3.824	3.487	5.243	0.531	1.723	10.533	15.835	1.604	18.283	1.852	2.785	5.595	55.221	9.711	29.331
157	3.960	3.788	3.486	5.259	0.477	7.228	13.805	20.829	1.890	18.332	1.663	2.510	6.588	72.602	8.748	34.646
158	4.001	4.347	3.686	4.839	1.544	7.354	14.748	19.361	6.177	17.832	5.690	7.470	22.767	71.356	27.529	110.157
159	4.043	4.359	3.691	4.846	1.550	7.481	14.922	19.590	6.268	17.888	5.723	7.514	23.137	72.312	27.735	112.119
160	4.084	4.371	3.697	4.853	1.557	7.610	15.097	19.819	6.359	17.944	5.757	7.558	23.509	73.273	27.942	114.102
161	2.779	4.383	3.703	4.861	1.564	4.827	10.291	13.509	4.346	17.999	5.791	7.602	16.094	50.022	28.150	78.231

Raw Data: Table of Safety Factors, Incident Rate and Significant Factor Interactions (cont.)

Week	Factors (% of Available Man-hours)					Incident Rate	Significant Factor Interactions									
	A	B	C	D	E		AC	AD	AE	CD	CE	DE	ACE	ADC	CDE	ACDE
162	3.254	4.328	3.824	3.529	1.765	5.081	12.441	11.484	5.742	13.495	6.747	6.228	21.955	43.910	23.814	77.488
163	6.169	4.066	3.188	3.998	1.765	5.679	19.670	24.668	10.887	12.749	5.627	7.056	34.712	78.651	22.498	138.796
164	3.941	2.890	2.941	5.882	1.176	4.778	11.592	23.184	4.637	17.301	3.460	6.920	13.638	68.188	20.354	80.221
165	3.992	3.851	3.492	4.857	1.136	4.800	13.941	19.390	4.536	16.964	3.968	5.519	15.840	67.718	19.276	76.944
166	4.042	3.831	3.491	4.848	1.135	4.822	14.112	19.598	4.588	16.926	3.963	5.503	16.019	68.419	19.213	77.665
167	4.295	3.731	3.485	4.802	1.130	4.918	14.966	20.623	4.851	16.735	3.936	5.424	16.905	71.871	18.903	81.180
168	4.345	3.711	3.484	4.793	1.128	4.935	15.137	20.826	4.903	16.697	3.931	5.408	17.080	72.551	18.841	81.866
169	4.396	3.691	3.482	4.784	1.127	4.951	15.307	21.027	4.955	16.659	3.926	5.393	17.255	73.226	18.780	82.546
170	4.446	3.671	3.481	4.775	1.126	4.966	15.477	21.228	5.007	16.621	3.920	5.377	17.430	73.898	18.718	83.221
171	4.496	3.650	3.480	4.765	1.125	4.980	15.647	21.427	5.059	16.583	3.915	5.361	17.604	74.566	18.657	83.889
172	4.547	3.630	3.479	4.756	1.124	4.994	15.817	21.626	5.110	16.545	3.910	5.346	17.777	75.230	18.595	84.552
173	4.597	3.610	3.477	4.747	1.123	5.007	15.987	21.824	5.162	16.507	3.904	5.330	17.950	75.890	18.534	85.209
174	4.648	3.590	3.476	4.738	1.122	5.019	16.157	22.020	5.213	16.469	3.899	5.314	18.123	76.547	18.473	85.861
175	4.698	3.570	3.475	4.729	1.121	5.031	16.327	22.216	5.265	16.431	3.894	5.299	18.295	77.200	18.412	86.507
176	4.749	3.550	3.474	4.719	1.119	5.041	16.496	22.411	5.316	16.393	3.889	5.283	18.466	77.850	18.351	87.147
177	4.799	3.530	3.472	4.710	1.118	5.051	16.665	22.605	5.367	16.356	3.883	5.267	18.637	78.495	18.291	87.782
178	4.850	3.510	3.471	4.701	1.117	5.061	16.834	22.798	5.418	16.318	3.878	5.252	18.807	79.137	18.230	88.411
179	4.068	3.490	3.470	4.692	1.116	7.853	14.115	19.085	4.540	16.280	3.873	5.236	15.753	66.223	18.169	73.909
180	4.084	4.270	3.643	4.596	1.761	8.004	14.878	18.772	7.191	16.743	6.414	8.093	26.196	68.383	29.481	120.407
181	4.101	4.293	3.635	4.569	1.796	8.155	14.906	18.734	7.365	16.608	6.529	8.206	26.774	68.102	29.829	122.319
182	4.117	11.000	3.628	4.541	1.831	8.305	14.935	18.695	7.540	16.472	6.644	8.317	27.353	67.818	30.169	124.206
183	4.134	4.338	3.620	4.513	1.867	8.454	14.963	18.656	7.717	16.338	6.758	8.425	27.933	67.531	30.499	126.069
184	4.150	4.360	3.612	4.486	1.902	8.602	14.991	18.615	7.894	16.203	6.871	8.532	28.515	67.242	30.821	127.905
185	4.166	4.383	3.605	4.458	1.938	8.749	15.019	18.573	8.072	16.069	6.984	8.637	29.099	66.950	31.134	129.717
186	4.183	4.405	3.597	4.430	1.973	8.895	15.046	18.530	8.252	15.936	7.097	8.740	29.684	66.656	31.439	131.502
187	4.199	4.428	3.589	4.402	2.008	9.040	15.073	18.487	8.433	15.802	7.208	8.841	30.270	66.359	31.734	133.261
188	4.216	4.450	3.582	4.375	2.044	9.183	15.100	18.443	8.615	15.670	7.320	8.940	30.858	66.059	32.022	134.994

Raw Data: Table of Safety Factors, Incident Rate and Significant Factor Interactions (cont.)

Week	Factors (% of Available Man-hours)					Incident Rate	Significant Factor Interactions									
	A	B	C	D	E		AC	AD	AE	CD	CE	DE	ACE	ADC	CDE	ACDE
189	4.232	8.000	3.574	4.347	1.000	9.326	15.127	18.397	4.232	15.537	3.574	4.347	15.127	65.757	15.537	65.757
190	8.000	4.495	3.567	4.319	2.114	9.467	28.533	34.555	16.914	15.406	7.541	9.132	60.326	123.245	32.571	260.568
191	4.265	4.518	3.559	4.292	2.150	9.607	15.179	18.304	9.168	15.274	7.650	9.225	32.629	65.144	32.833	140.033
192	4.281	4.540	3.551	4.264	2.185	9.745	15.205	18.256	9.355	15.143	7.760	9.316	33.223	64.834	33.087	141.658
193	4.298	4.563	3.544	4.236	2.220	9.883	15.231	18.207	9.542	15.013	7.868	9.406	33.817	64.522	33.332	143.256
194	4.314	4.585	3.536	4.209	2.256	10.019	15.256	18.157	9.731	14.882	7.976	9.493	34.413	64.207	33.569	144.827
195	4.331	4.608	3.529	4.181	2.291	10.153	15.282	18.106	9.922	14.753	8.084	9.578	35.010	63.890	33.798	146.369
196	0.667	4.630	3.521	4.153	2.326	0.705	2.348	2.770	1.552	14.623	8.191	9.661	5.463	9.753	34.018	22.688
197	2.337	2.851	4.440	3.491	1.176	4.793	10.374	8.157	2.749	15.499	5.223	4.107	12.204	36.216	18.234	42.606
198	0.187	3.800	3.940	5.000	1.712	0.266	0.735	0.933	0.319	19.701	6.745	8.559	1.258	3.675	33.725	6.291
199	5.890	3.508	3.858	4.817	1.176	10.305	22.721	28.370	6.929	18.583	4.539	5.667	26.731	109.446	21.862	128.760
200	3.263	3.882	3.529	4.937	1.765	5.444	11.518	16.111	5.759	17.425	6.228	8.712	20.325	56.863	30.750	100.346
201	5.027	4.070	3.032	5.002	1.665	5.714	15.242	25.142	8.368	15.167	5.048	8.327	25.375	76.238	25.250	126.919
202	5.971	3.406	3.127	5.203	1.274	6.743	18.672	31.067	7.605	16.271	3.983	6.627	23.782	97.152	20.725	123.744
203	4.013	3.529	3.529	5.000	1.176	5.480	14.164	20.066	4.721	17.647	4.152	5.882	16.664	70.821	20.761	83.318
204	5.428	4.504	4.118	3.942	1.176	5.880	22.349	21.393	6.385	16.230	4.844	4.637	26.293	88.090	19.094	103.636
205	1.835	3.028	3.531	5.588	1.162	4.181	6.478	10.254	2.133	19.730	4.103	6.495	7.529	36.202	22.930	42.074
206	2.544	5.294	2.891	5.882	1.688	3.703	7.357	14.967	4.295	17.008	4.880	9.929	12.417	43.275	28.707	73.043
207	4.210	3.598	4.305	4.860	1.176	8.284	18.125	20.460	4.953	20.920	5.065	5.717	21.323	88.078	24.611	103.621
208	6.053	4.117	3.824	4.288	1.892	10.923	23.145	25.956	11.451	16.395	7.233	8.112	43.783	99.242	31.015	187.738
209	4.118	4.019	3.529	5.000	1.765	6.576	14.533	20.588	7.266	17.647	6.228	8.824	25.646	72.664	31.142	128.231
210	3.824	3.529	3.824	3.946	1.821	7.253	14.621	15.089	6.962	15.088	6.961	7.185	26.620	57.694	27.471	105.043
211	3.837	4.431	3.529	4.412	1.765	6.856	13.544	16.930	6.772	15.571	6.228	7.785	23.901	59.752	27.478	105.445
212	3.878	4.312	3.668	4.816	1.524	6.979	14.227	18.679	5.909	17.666	5.589	7.338	21.676	68.517	26.916	104.392
213	3.919	4.324	3.674	4.824	1.530	7.103	14.400	18.906	5.998	17.721	5.622	7.382	22.036	69.458	27.119	106.294
214	1.457	4.336	3.680	4.831	1.537	1.145	5.362	7.039	2.240	17.777	5.656	7.426	8.241	25.902	27.324	39.813
215	4.781	4.412	3.529	5.882	0.517	2.061	16.875	28.125	2.473	20.761	1.825	3.042	8.727	99.264	10.737	51.336

Raw Data: Table of Safety Factors, Incident Rate and Significant Factor Interactions (cont.)

Week	Factors (% of Available Man-hours)					Incident Rate	Significant Factor Interactions									
	A	B	C	D	E		AC	AD	AE	CD	CE	DE	ACE	ADC	CDE	ACDE
216	2.337	3.235	2.941	4.829	0.522	4.793	6.872	11.283	1.221	14.202	1.536	2.523	3.590	33.185	7.419	17.336
217	0.851	3.800	3.940	5.000	1.712	1.464	3.353	4.254	1.457	19.701	6.745	8.559	5.739	16.763	33.725	28.696
218	1.636	2.941	3.529	5.214	1.765	2.607	5.774	8.531	2.887	18.404	6.228	9.202	10.190	30.109	32.477	53.134
219	6.075	4.118	3.495	5.381	1.239	5.896	21.233	32.693	7.524	18.808	4.329	6.665	26.298	114.265	23.295	141.522
220	4.525	2.725	4.118	2.840	1.765	5.763	18.631	12.850	7.985	11.694	7.266	5.012	32.878	52.910	20.636	93.371
221	3.720	4.118	3.529	4.706	1.176	3.468	13.129	17.505	4.376	16.609	4.152	5.536	15.446	61.784	19.540	72.687
222	3.256	3.824	3.001	5.588	1.176	5.732	9.770	18.194	3.830	16.769	3.530	6.574	11.494	54.599	19.729	64.234
223	4.019	4.825	3.955	5.294	1.176	1.173	15.896	21.278	4.728	20.939	4.653	6.228	18.702	84.157	24.634	99.008
224	4.525	5.000	2.941	5.000	0.000	5.763	13.308	22.623	0.000	14.706	0.000	0.000	0.000	66.538	0.000	0.000
225	1.123	4.118	3.529	4.706	1.176	1.752	3.965	5.286	1.322	16.609	4.152	5.536	4.664	18.658	19.540	21.950
226	2.033	3.824	3.529	5.882	1.176	5.522	7.176	11.959	2.392	20.761	4.152	6.920	8.442	42.209	24.425	49.658
227	5.281	4.706	3.824	5.882	1.765	10.499	20.191	31.063	9.319	22.491	6.747	10.381	35.631	118.770	39.691	209.595
228	1.267	5.294	3.008	5.015	1.765	2.769	3.813	6.355	2.236	15.086	5.309	8.849	6.728	19.118	26.623	33.738
229	2.176	5.000	3.824	5.882	1.293	3.743	8.318	12.798	2.813	22.491	4.943	7.605	10.754	48.932	29.077	63.259
230	3.374	3.235	4.118	4.224	1.765	6.597	13.892	14.249	5.954	17.391	7.266	7.453	24.514	58.672	30.690	103.539
231	2.881	4.696	3.590	5.283	1.469	2.969	10.343	15.221	4.232	18.965	5.273	7.760	15.192	54.639	27.856	80.257
232	1.152	3.969	2.539	6.018	0.400	0.444	2.924	6.931	0.461	15.280	1.015	2.407	1.169	17.598	6.111	7.038
233	2.789	3.971	2.497	6.080	0.344	2.764	6.963	16.955	0.960	15.179	0.860	2.094	2.398	42.331	5.228	14.579
234	2.747	3.899	3.147	5.296	0.892	2.491	8.643	14.547	2.451	16.667	2.808	4.727	7.713	45.779	14.874	40.853
235	2.704	3.887	3.138	5.347	0.810	2.221	8.486	14.462	2.189	16.779	2.540	4.329	6.870	45.380	13.584	36.738
236	2.662	3.876	3.129	5.398	0.727	1.954	8.330	14.373	1.935	16.891	2.274	3.923	6.054	44.969	12.275	32.681
237	2.620	3.865	3.120	5.449	0.644	8.793	8.175	14.279	1.687	17.001	2.009	3.509	5.264	44.547	10.947	28.685
238	2.578	3.853	3.111	5.500	0.561	9.044	8.020	14.181	1.447	17.110	1.745	3.086	4.500	44.112	9.601	24.752
239	2.536	3.842	3.102	5.551	0.478	9.295	7.866	14.078	1.213	17.219	1.483	2.655	3.762	43.667	8.235	20.885
240	2.494	3.958	3.093	5.602	0.395	9.546	7.713	13.972	0.986	17.326	1.223	2.215	3.050	43.210	6.852	17.087
241	2.452	3.959	3.084	5.653	0.313	9.797	7.560	13.861	0.766	17.433	0.964	1.767	2.364	42.741	5.450	13.362
242	1.219	3.961	3.075	5.704	0.230	10.048	3.749	6.955	0.280	17.538	0.707	1.311	0.862	21.385	4.030	4.914
243	4.036	3.962	3.529	3.529	1.765	10.299	14.246	14.246	7.123	12.457	6.228	6.228	25.140	50.279	21.982	88.728

APPENDIX C

Raw Data: Table of Safety Intervention Factors, and Incident Rate (Model Recommended)

	Factors (% of Available Man-hours)				
Week	**A**	**C**	**D**	**E**	**Incident Rate**
1	1.113	2.437	5.747	0.381	4.002
2	2.696	2.397	5.806	0.328	1.244
3	2.655	3.021	5.058	0.849	4.217
4	2.614	3.012	5.107	0.770	6.039
5	2.574	3.004	5.155	0.692	0.781
6	2.533	2.995	5.204	0.613	0.886
7	2.492	2.986	5.253	0.534	5.668
8	2.452	2.978	5.302	0.455	8.279
9	2.411	2.969	5.350	0.376	5.412
10	2.370	2.960	5.399	0.298	5.916
11	1.179	2.952	5.448	0.219	4.008
12	3.902	3.388	3.371	1.679	4.958
13	4.549	3.251	5.337	1.120	3.091
14	4.926	3.388	4.351	1.120	1.257
15	1.451	3.953	4.213	1.120	3.922
16	2.385	2.744	4.494	1.679	1.421
17	3.965	2.541	4.297	1.783	3.549
18	3.695	3.671	5.295	1.199	0.319
19	4.968	3.106	4.494	1.679	0.337
20	3.645	3.388	3.932	1.120	1.357
21	2.838	3.953	5.337	1.679	1.689
22	2.697	2.968	5.337	1.230	5.792
23	1.183	2.824	4.213	1.679	9.954
24	2.777	2.541	5.056	0.560	2.412
25	2.737	3.038	4.961	1.007	4.242
26	2.406	3.030	5.009	0.928	4.359

Raw Data: Table of Safety Intervention Factors, and Incident Rate (Model Recommended) (cont.)

	Factors (% of Available Man-hours)				Incident
Week	**A**	**C**	**D**	**E**	**Rate**
27	2.298	2.883	5.102	0.962	6.199
28	2.190	2.843	5.160	0.909	9.760
29	3.787	2.802	5.219	0.856	3.978
30	2.685	3.953	4.775	1.086	6.842
31	5.516	3.953	4.494	1.679	2.227
32	2.298	3.388	4.494	1.046	2.723
33	0.480	2.824	5.618	1.120	6.831
34	0.996	3.133	4.482	1.766	3.417
35	2.315	3.671	5.337	1.784	3.428
36	0.749	3.472	5.058	1.553	8.457
37	1.810	3.161	5.254	1.766	0.600
38	1.725	3.578	0.955	1.801	6.085
39	1.641	3.595	5.373	1.842	0.748
40	1.557	3.613	5.418	1.883	3.094
41	1.473	3.631	5.462	1.924	6.207
42	1.388	3.648	5.507	1.966	4.741
43	1.304	3.666	5.552	2.007	1.020
44	1.220	3.683	5.597	2.048	0.638
45	1.136	3.701	5.642	2.090	2.409
46	1.052	3.719	5.687	2.131	3.129
47	0.967	3.736	5.732	2.172	3.034
48	0.883	3.754	5.777	2.214	3.652
49	0.799	3.772	5.822	2.255	0.331
50	0.715	3.789	5.867	2.296	4.550
51	0.630	3.807	5.912	2.338	3.656
52	5.309	4.208	3.109	3.175	5.524

Appendix D

Validation Analysis Summary

Week/ Period (t)	Incident Rate (Model)	Smoothed Inc. Rate (Predicted)	Residuals (Forecast Error)	Sum of Squares (SS)	Absolute Error /E/	Percent Error [Error (%)]	Mean Abs. Percent Error (MAPE)	Prediction Interval (Lower)	Prediction Interval (Upper)
1	4.002	4.017	-0.015	0.000	0.015	0.004	0.004	-6.249	10.221
2	1.244	4.042	-2.798	7.829	2.798	0.692	2.249	-6.224	7.438
3	4.217	3.197	1.020	1.041	1.020	0.319	0.242	-7.069	11.256
4	6.039	3.370	2.669	7.126	2.669	0.792	0.442	-6.896	12.905
5	0.781	4.122	-3.341	11.159	3.341	0.811	4.277	-6.144	6.895
6	0.886	3.162	-2.276	5.181	2.276	0.720	2.569	-7.104	7.960
7	5.668	2.327	3.341	11.164	3.341	1.436	0.589	-7.939	13.577
8	8.279	6.105	2.174	4.728	2.174	0.356	0.263	-4.161	12.410
9	5.412	4.664	0.748	0.560	0.748	0.160	0.138	-5.602	10.984
10	5.916	5.164	0.752	0.566	0.752	0.146	0.127	-5.102	10.988
11	4.008	5.711	-1.703	2.901	1.703	0.298	0.425	-4.555	8.533
12	4.958	5.539	-0.581	0.337	0.581	0.105	0.117	-4.727	9.655
13	3.091	5.610	-2.519	6.347	2.519	0.449	0.815	-4.655	7.716
14	1.257	5.040	-3.783	14.310	3.783	0.751	3.009	-5.226	6.453
15	3.922	3.917	0.005	0.000	0.005	0.001	0.001	-6.349	10.241
16	1.421	3.742	-2.321	5.385	2.321	0.620	1.633	-6.524	7.915
17	3.549	2.840	0.709	0.503	0.709	0.250	0.200	-7.426	10.945
18	0.319	2.740	-2.421	5.859	2.421	0.884	7.588	-7.526	7.815
19	0.337	1.706	-1.369	1.873	1.369	0.802	4.062	-8.560	8.867
20	1.357	0.849	0.508	0.258	0.508	0.598	0.374	-9.417	10.744
21	1.689	0.494	1.195	1.429	1.195	2.421	0.708	-9.772	11.431
22	5.792	5.385	0.407	0.166	0.407	0.076	0.070	-4.881	10.643
23	9.954	6.667	3.287	10.807	3.287	0.493	0.330	-3.599	13.523
24	2.412	4.187	-1.775	3.149	1.775	0.424	0.736	-6.079	8.461

Validation Analysis Summary (cont.)

Week/ Period (t)	Incident Rate (Model)	Smoothed Inc. Rate (Predicted)	Residuals (Forecast Error)	Sum of Squares (SS)	Absolute Error /E/	Percent Error [Error (%)]	Mean Abs. Percent Error (MAPE)	Prediction Interval (Lower)	Prediction Interval (Upper)
25	4.242	4.080	0.162	0.026	0.162	0.040	0.038	-6.186	10.398
26	4.359	4.468	-0.109	0.012	0.109	0.024	0.025	-5.798	10.127
27	6.199	4.781	1.418	2.010	1.418	0.297	0.229	-5.485	11.654
28	9.760	5.565	4.195	17.600	4.195	0.754	0.430	-4.701	14.431
29	3.978	7.305	-3.327	11.068	3.327	0.455	0.836	-2.961	6.909
30	6.842	6.957	-0.115	0.013	0.115	0.016	0.017	-3.309	10.121
31	2.227	4.404	-2.177	4.740	2.177	0.494	0.978	-5.862	8.059
32	2.723	6.262	-3.539	12.528	3.539	0.565	1.300	-4.003	6.696
33	6.831	5.309	1.522	2.316	1.522	0.287	0.223	-4.957	11.758
34	3.417	5.716	-2.299	5.286	2.299	0.402	0.673	-4.550	7.937
35	3.428	5.024	-1.596	2.548	1.596	0.318	0.466	-5.242	8.640
36	8.457	5.408	3.049	9.295	3.049	0.564	0.361	-4.858	13.285
37	0.600	5.457	-4.857	23.586	4.857	0.890	8.094	-4.809	5.379
38	6.085	3.975	2.110	4.452	2.110	0.531	0.347	-6.291	12.346
39	0.748	2.367	-1.619	2.621	1.619	0.684	2.164	-7.899	8.617
40	3.094	3.101	-0.007	0.000	0.007	0.002	0.002	-7.165	10.229
41	6.207	2.737	3.470	12.042	3.470	1.268	0.559	-7.529	13.706
42	4.741	3.459	1.282	1.643	1.282	0.371	0.270	-6.807	11.518
43	1.020	3.714	-2.694	7.260	2.694	0.725	2.642	-6.551	7.541
44	0.638	2.807	-2.169	4.706	2.169	0.773	3.400	-7.458	8.066
45	2.409	1.896	0.513	0.263	0.513	0.271	0.213	-8.370	10.749
46	3.129	1.687	1.442	2.079	1.442	0.855	0.461	-8.579	11.678
47	3.034	1.801	1.233	1.521	1.233	0.685	0.406	-8.465	11.469
48	3.652	1.939	1.713	2.934	1.713	0.883	0.469	-8.327	11.949
49	0.331	2.305	-1.974	3.895	1.974	0.856	5.963	-7.961	8.262
50	4.550	3.625	0.925	0.855	0.925	0.255	0.203	-6.641	11.161
51	3.656	2.353	1.303	1.698	1.303	0.554	0.356	-7.913	11.539
52	5.524	2.757	2.767	7.657	2.767	1.004	0.501	-7.509	13.003

VITA

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Education

- Ph.D. Industrial Engineering, The Pennsylvania State University (2009)
- M.Eng. Industrial Engineering, The Pennsylvania State University (2009)
- B.Sc. Industrial Engineering, The University of Ibadan, Nigeria (2002)

Teaching Experience

Co-Instructor, Pennsylvania State University, Department of Energy and Mineral Engineering, 2007-2009. Courses:

- IHS 420: Fire Protection Engineering
- IHS 430: Industrial Health and Safety Program Management

Instructor, Pennsylvania State University, School of Information Science and Technology, 2006-2007. Courses:

- IST 220: Organization of Data
- IST 404W: Information Sciences and Technology Integration and Problem Solving

Teaching Assistant, Pennsylvania State University, School of Information Science and Technology, 2005-2006. Courses:

- IST 220: Organization of Data
- IST 404W: Information Sciences and Technology Integration and Problem Solving

Research Experience

- Graduate Research Assistant/Engineer, Chevron Corporation/ Pennsylvania State University, Department of Energy and Mineral Engineering (2007-2009)
- Graduate Research Assistant, Pennsylvania State University, School of Information Science and Technology (2006-2007)
- Doctoral Dissertation: "The Implementation of Statistical and Forecasting Techniques in the Assessment of Safety Intervention Effectiveness and Optimization of Resource Allocation"
- Masters Scholarly Paper: "The Ergonomic Design of Classroom Furniture/Computer Work Station for First Graders in an Elementary School"
- Undergraduate Honors Research Project: "Preventive Maintenance Scheduling in an Aluminum Extrusion Plant"

Honors and Awards

- Pennsylvania State University, Minority engineering graduate student scholarship (2005)
- Federal Government of Nigeria undergraduate scholarship (2000-2002)
- Best graduating student in industrial quality control, University of Ibadan (2002)

Professional Activities

- Member, American Society of Safety Engineers (ASSE)
- Member, Human Factors and Ergonomics Society (HFES)
- Member, Institute of Industrial Engineers (IIE)
- Member, Society for Industrial and Applied Mathematics (SIAM)