Estimating and Controlling Workplace Risk: An Approach for Occupational Hygiene and Safety Professionals

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The protection of people and physical assets is the objective of health and safety professionals and is accomplished through the paradigm of anticipation, recognition, evaluation, and control of risks in the occupational environment. Risk assessment concepts are not only used by health and safety professionals, but also by business and financial planners. Since meeting health and safety objectives requires financial resources provided by business and governmental managers, the hypothesis addressed here is that health and safety risk decisions should be made with probabilistic processes used in financial decision-making and which are familiar and recognizable to business and government planners and managers. This article develops the processes and demonstrates the use of incident probabilities, historic outcome information, and incremental impact analysis to estimate risk of multiple alternatives in the chemical process industry. It also analyzes how the ethical aspects of decision-making can be addressed in formulating health and safety risk management plans. It is concluded that certain, easily understood, and applied probabilistic risk assessment methods used by business and government to assess financial and outcome risk have applicability to improving workplace health and safety in three ways: 1) by linking the business and health and safety risk assessment processes to securing resources, 2) by providing an additional set of tools for health and safety risk assessment, and 3) by requiring the risk assessor to consider multiple risk management alternatives.

Successful health and safety management is a process of protecting people by continuously making successful decisions. This article is an analysis of the ways in which the process of making successful health and safety management decisions can be expanded beyond traditional boundaries. Our premise is that health and safety decisions can be made with a broader array of processes, specifically those processes used in financial decision-making that are already familiar and recognizable to management. These include techniques such as return on investment and forecasting earnings. We propose that health and safety professionals avail themselves of financial decision making tools. This article shows that the benefits of adding financial analysis tools to the health and safety decision process will result in a stronger outcome prediction analysis and better management appreciation for how health and safety resource investments can produce improved business performance.

In many ways, the ability to forecast the outcomes of investments designed to prevent injuries, illnesses, and property damage is no different than forecasts made by company planners every day for capital investments. The belief that since many controls are required by regulations, evaluating their alternatives, costs, and benefits is unimportant and/or the lack of financial and business risk analysis training by health and safety professionals have created an obstacle that must be overcome. Our experience shows, in nearly every case where these techniques have been applied, the outcome has improved safety and health performance and reduced operating costs, thereby freeing resources to identify and control other workplace risks.

In this article we apply the forecasting techniques developed in *Mathematical Evaluation for Controlling Hazards*, published in 1971[1] by the U. S. Naval Ordnance Laboratory.

INCIDENT AND EXPOSURE FORECASTING—REAL LIFE ISSUES

The objective is to develop a forecasting approach that can be easily and efficiently applied to improving the understanding of the likely outcomes of investments in H&S using financial tools. An effective risk forecast model allows different investment levels to be checked against predictable outcomes before

they are instituted, which will provide an analysis of "return" on the health and safety investment.

Financial tools, which were applied in an occupational hygiene model by Birkner and Saltzman,[2] can be used to analyze certain elements of H&S investment proposals, such as a thorough analysis of the project's costs and benefits, the full costs of incidents, and forecasts of the number of incidents expected after the project is initiated. This article offers a methodology for incident forecasting—these forecasts can then be used as an input to the financial analysis models. Outcomes to consider include how the investment affects worker safety and health, worker productivity, production downtime, nonproductive time for medical leave, and accident investigations resources.

The most significant challenge in using this methodology involves responding to the ethical issue of mixing financial analysis into an area that impacts personal loss and suffering. One way to overcome this is to couple the analysis of financial risks and investments with a consideration of the non-financial benefits that accrue from having better outcome predictions. If this type of analysis is to be performed successfully and be accepted as credible by all stakeholders, the health and safety professionals must be mindful of this ethical challenge and address it before taking the next step.

Another key issue is responding to uncertainty when forecasting benefits. Many aspects of health and safety performance are not direct cause and effect in the sense that there are many intangible elements as to whether health and safety performance will improve or get worse. Using financial tools to analyze health and safety outcomes will reduce some aspects of uncertainty, but, because of the interaction of people in the process, financial analysis must be interpreted in the context of its impact on them and the environment. Investments in capital projects, new product development, employee hiring, advertising, quality, and even software upgrades, require decisions to be made with much uncertainty of the exact added value and human impacts. Perhaps what is most obvious is that all H&S investment proposals must compete for limited resources requiring management to make difficult opportunity-cost decisions. Finally, it is important to recognize that many H&S investment proposals may significantly influence productivity improvements, which are difficult to measure.

The usefulness of any analytical tool is limited by the accuracy of the data and methodologies they employ. Business and financial tools are used to simplify and improve the decision-making process; the tool's analytical outcomes are driven and bounded by the user's assumptions and input data. The key to effective use of these tools is to understand their limitations and to consider the many factors they may not include or oversimplify, such as employee morale, public opinion, and customer satisfaction.

FUNDAMENTAL CONCEPTS

The fundamental concepts of incident prevalence and probability and cost-benefit analysis used in this article were devel-oped by Spiling et al.[3] in their development and analysis of costs and benefits of musculoskeletal system injuries. They compared business alternatives in connection with investment decisions and profitability impact forecasts at a manufacturing plant. Additionally, Bailey[4] developed the concept of cost-benefit logic by formulating an approach for assessing cost and benefits when the recipient of the benefit may not be paying for them, as in government projects. This is important to understand since, in health and safety projects, there are many different benefits that can accrue to multiple recipients, while there is generally only one party with the burden of costs. Then Kolleru et al.[5] created a link between the risk assessment process and business or governmental organizations to help value the resources at risk, especially human life, and develops the concept, employed in this article, of evaluating risk reduction and risk avoidance alternatives. Finally, Covello and Merkhoffer[6] defined many risk assessment models and formulated them into a common framework for their application. They then assessed the methods' models and described their strengths and weaknesses. These authors established a foundation for the descriptive risk assessment process used in this article.

To assure credibility with management, who must agree to finance health and safety investments, the risk analysis methodology described in this paper is similar to the methods used by today's mainstream business and financial community. Fundamental to this methodology is the analysis of multiple project alternatives that have the potential for achieving equivalent outcomes and comparing them to a base case, such as the current situation. When these methods are applied to H&S investment proposals, they parallel management's experience and remove many of the barriers experienced by health and safety professionals when seeking resources for enhancing worker health and safety.

When presenting operational investments, credibility is further enhanced when historic results are used in the analysis. Unfortunately, without having a system in place for tracking outcomes to health and safety investments, the health and safety argument is more difficult. The lack of historical data can be overcome by using risk bracketing—establishing a risk scenario range around the most likely investment outcome. This means additional effort must be put toward developing scenarios that bracket the range of likely investment outcomes (see Figure 1). Ideally, investments can be designed that push toward the upper right quadrant—that is, designing investments that together push toward improved H&S and financial outcomes, making it easier to achieve management support. Health and safety professionals should carefully track investment performance outcomes over time to help justify future resource requests.

In addition to historical assessment, applying standard business financial analysis creates another important quantitative element. It provides a value that takes into account the dollars invested in the past and the value of today's dollars not lost due to improved health and safety outcomes, generally known as a discounted cash flow analysis.[7] A compelling approach for
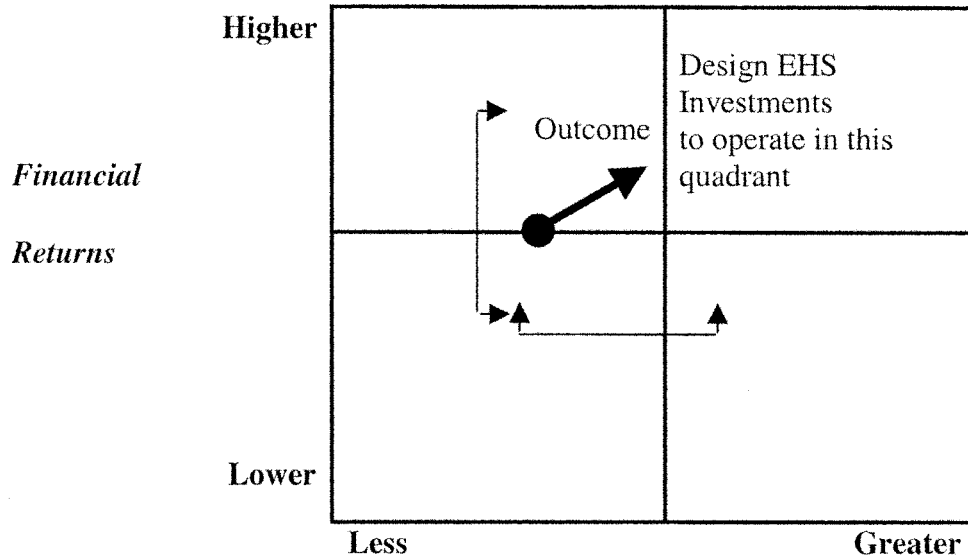
FIGURE 1
Bracketing analysis within probable outcome scenarios.

presenting the information is to examine the net profit generated by a particular facility and compare the direct value of injuries through workers' compensation claims and other direct payouts, including lost productivity. It is sobering when management is advised that it takes a facility a month or two to generate enough net income to cover the safety and health losses.

The risk analysis component provides the foundation upon which the financial analysis is based. It is customary to conduct a sensitivity analysis of the outcome measures to identify which variables drive the greatest change. Providing a range for variables, which have a large bearing on outcomes, further builds credibility. Referring to Figure 1, the factors that influence the H&S outcomes or financial returns must be identified and each varied while keeping the other constant. The variables that create the greatest movement in the desired results are those to which the outcome is most sensitive, and, therefore, particular attention should be focused on these factors.

THE BASE CASE

When a base case risk analysis demonstrates that deploying ongoing initiatives (for example, allowing a training program more time to achieve its results) is part of the decision making process, the cash flows are calculated and are used as the point of comparison for alternate scenarios and risk assessments. The ability to estimate the potential reduction in health, safety, and business risk resulting from alternative proposals permits a more precise resource allocation, allowing the health and safety professional to optimize overall employee protection. Risk outcomes can be measured by fewer injuries or illnesses and by productivity factors that ultimately impact financial performance. The objective is to demonstrate, with a reasonable

degree of accuracy, that "investing in program A will reduce the number of injuries by X% and enhance productivity by Y% as compared to the base case."

QUANTIFYING INCIDENT OUTCOME PREDICTIONS

The objective of the methodology is to develop a quantitative understanding of how health and safety investment proposals—aimed primarily at reducing injury or illness rates—also affect the bottom line. Equation 1 forms the basis for quantifying the financial consequences of incidents and serves as the most concise synopsis of this approach. In this equation, as in all those provided in this article, if more than one occurrence is expected in a year, then *number of incidents* may be substituted for *probability*.

Equation 1: Incremental Financial Impact

$$F = \left(P_{(x)} * C_{(x)}\right) - \left(P_{(b)} * C_{(b)}\right) \tag{1}$$

F = Incremental Financial Impact (Probabilities)
$P_{(x)}$ = Probability of H&S incidents in a year for a given project X (investment)
$C_{(x)}$ = Average full cost of an incident after investment X is made
$P_{(b)}$ = Probability of H&S incidents in a year given the current scenario (base case)
$C_{(b)}$ = Average full cost of an incident given the current scenario (base case)

Less direct impacts of reducing health and safety incidents may include reducing regulatory scrutiny, maintaining a positive

corporate image, and becoming a preferred employer or supplier. However, these important issues, as well as the many ethical issues found in making investment decisions regarding health and safety, are beyond the focus of the methodology offered in this article, which is meant to supplement (but not replace) the analysis of these business considerations.

This article provides a methodology for forecasting the number of incidents expected when project alternatives are compared to a base case. For projects that are expected to result in less than one incident per year, such as catastrophic events, a special section is provided below to offer methods to convert probabilities into incident rate forecasts. This enables the analyst to convert a series of probability figures into a series of whole numbers to ultimately obtain cash flow projections based on figures with which some managers may feel more comfortable.

Equation 1 can be widely applied to investment decisions that are designed to address a variety of health and safety issues, including (a) worker illness and injuries, (b) regulatory compliance, (c) product or material damage, and (d) property damage. When using this methodology in a practical setting, it accommodates incidents that impact more than one of these categories, such as an explosion that injures workers and causes property damage. However, for purposes of clarity, the following example will consider incidents that have only one kind of impact.

For H&S incidents that entail worker injuries or regulatory compliance, the issues to consider are included in Eq. 2.

Equation 2: Probability of H&S Incident (Worker Illnesses or Injuries)

$$P_I = P_{(h)} * P_{(e)} * P_{(i)} * N_{(w)} \qquad [2]$$

P_I = Probability of an H&S incident expected in a year
$P_{(h)}$ = Probability of a hazardous condition occurrence taking place in a year
$P_{(e)}$ = Probability of one worker being exposed when a hazardous condition occurs
$P_{(i)}$ = Probability of an incident when one worker is exposed to hazardous condition
$N_{(w)}$ = Typical number of workers exposed to a single hazardous condition

Explanations of each term in Eq. 2 are provided below.

Probability of a Hazardous Condition Occurring in a Year ($P_{(h)}$)

A hazardous condition occurrence is defined as the creation of a physical condition that has the potential to harm the health and safety of a worker. A hazardous occurrence can range from an explosion to the operation of an unguarded powered saw, or from an excavation in a field with poison oak to a toxic contaminant in a confined space. The creation of a hazardous condition is assumed to be periodic, meaning over a long period of time a frequency of occurrence can be developed. This term is the rate at which hazardous occurrences are expected to take place over some unit of time (e.g., once per month) or a number of

production units (e.g., one per 1000 units produced). A hazardous occurrence that takes place once every 4 hours evokes a probability of occurrence of 0.25 per hour. Alternatively, for occurrences that last a period of time, this term can be defined as the proportion of occurrence time (e.g., a band saw that operates 4 hours out of 8 hours has a probability of 0.5). The hazardous occurrence must be defined first before estimating its frequency or probability.

Probability of One Worker Being Exposed During a Hazardous Occurrence ($P_{(e)}$)

This often represents the proportion of time during which workers are exposed to the hazardous occurrence. For our equation, we calculate the probability as a number that ranges between 0 and 1. A worker exposed all the time would be "1" and a worker never exposed at any time would be "0." If more than one worker can be exposed, this figure should reflect the average of each worker's proportion of time directly affected by the hazardous condition.

Probability of an Incident When One Worker Is Exposed to Hazardous Condition ($P_{(i)}$)

This probability also ranges from 0 to 1 because it reflects how often an incident occurs when a worker is exposed to the hazardous condition. If the unguarded saw cut someone every time it was used unguarded, the probability would be 1. If it cuts someone once every 100 times it is used unguarded the probability is 0.01. Generally, health and safety programs, personal protective equipment, effective management, employee training, workplace design, work experience, and other factors work toward mitigating the probability of an incident. In a well-managed operation, this number tends to be very low.

Typical Number of Workers Exposed to a Single Hazardous Condition ($N_{(w)}$)

This term should represent how many workers are typically exposed when a hazardous condition is present and workers are exposed. If the hazardous occurrence were a band saw operated by a single employee, this figure would be 1. However, if the hazardous occurrence is a large explosion, this figure may be the number of staff on an entire shift.

Product or Material Damage

When an H&S incident is likely to damage materials including raw materials, work-in-progress, and finished goods, the terms from Eq. 2 are adjusted slightly to reflect the number of units ($N_{(u)}$) instead of workers. Thus, when product or material damage is of concern, Eq. 3 should be used.

Equation 3: Probability of H&S Incident (Product Damage)

$$P_I = P_{(h)} * P_{(e)} * P_{(i)} * N_{(u)} \qquad [3]$$

Property Damage

For H&S incidents that involve property damage but not worker injuries, the second and third terms on the right side of Eq. 2 merge into *probability of an incident when a hazardous condition occurs* ($P_{(c)}$) and the fourth term is dropped, yielding Eq. 4.

Equation 4: Probability of H&S Incident (Property Damage)

$$P_I = P_{(h)} * P_{(c)} \qquad [4]$$

The above equations are presented to differentiate the types of H&S incidents an investment proposal may target. When using this methodology, it is easier to consider only one type of incident at a time. The following discussion focuses on H&S incidents that entail worker injuries, although a similar approach can be applied to H&S incidents that damage property, products, or materials.

THE ANALYSIS

To analyze the financial impact of an H&S investment, incident rates over the duration of the analysis must be forecast for both the current situation (generally the base case) and for each investment scenario. This provides the basis for evaluating the incremental benefits for each scenario.

The first step is to calculate the probability of the incident by setting up the equations noted above. This sets up the base case for each investment alternative. If there is no current situation to consider as the base case, such as when a new facility is built, one investment alternative can be considered the base case and all other alternatives should be compared against it. Health and safety professionals are able to identify high probability potential incidents, but perhaps not with mathematical rigor. Reasonable estimates of probability are needed to drive the financial analysis, so more rigorous thought must be given to estimating probabilities to assure that the financial analysis that relies on the probability estimates are reasonable and can be defended as reliable. In order to develop an investment strategy to utilize the base case, the root cause of the probable incident should be defined. This process will assist the health and safety professional in developing a series of investment options designed to reduce the probability or severity of an undesired outcome and permit the differential comparison of the base case to the options being assessed.

There are (at least) four ways to analyze the impact of investment alternatives on incident probability and to design mitigation options. The first is to change the nature of the hazard (substitution or engineering controls) itself and thereby affect the probability that a hazardous condition will occur. Examples of this type of project include discontinuing the use of a hazardous chemical, reducing the storage quantity of hazardous chemicals, or reducing the hours of band saw operation. The second analysis considers the hazardous circumstances and thereby affects the probability of a hazardous condition occurring (work practices, training, and dynamic monitoring programs). Examples of projects that address the circumstances that create the hazard include: increasing preventive maintenance, changing work regimens, and instituting aggressive monitoring programs to drive workplace exposures to lower levels. Reducing the probability of worker exposure to a hazardous condition is the third method. Projects may attempt to reduce the probability of worker exposure to hazardous conditions by strengthening or increasing the barriers that protect workers from hazards (engineering, personal protective equipment, and work practices). This objective may be realized by better containment of the hazard, training workers, redesigning the process, or by moving or eliminating workers from the hazardous area.

The fourth approach focuses on the time workers are exposed to hazardous conditions in order to protect them (administrative controls). This objective may be accomplished by adjusting work schedules to control exposure time and overall exposure. The focus of the analysis is the assessment of exposed workers and/or property, and then focusing attention on identifying and implementing controls, such as installing or improving a fire suppression system, installing a safety hand switch that when *not* pressed by both hands ("dead-man switch") interrupts a machine's power supply, or by re-engineering a ventilation system or providing personal protective equipment.

DETAILED EXAMPLE

The following example clarifies this portion of the methodology.

Base Case

The H&S outcome is the increased risk of an acute worker illness from exposure to benzene. In an Asian Pacific country, during periodic petrochemical processing unit maintenance, open drain channels and a sump are used to de-inventory benzene from process equipment. This maintenance occurs four times per year (one time each, on four separate processing units) and causes benzene to be released into the working environment in concentrations far exceeding safe and accepted standards during one day of each 14-day maintenance operation. Therefore, the H&S incident is defined as worker exposure to benzene in excess of safe limits during the maintenance operations. The hazardous condition is defined as de-inventory of benzene during the maintenance operation. The worker exposure is defined as workers who are in the area when the benzene is released.

We use Eq. 2 to forecast the annual probability of incidents. We assume there are four maintenance operations in a year, de-inventorying occurs during one day of each turnaround period, and there are 260 workdays per year. The probability of a hazardous condition occurring is 4 days out of 260 days, or 0.0154. To calculate the probability of a worker being exposed to the hazardous condition during the benzene de-inventorying process, a worker is within the contaminated area for an average of four hours of the 8-hour contamination period. Therefore, the probability of one worker being exposed given a hazardous condition

TABLE I

Comparison of the number (and probability) of acute benzene exposure incidents in the
Base Case (current situation), and those in Control Project 1 and Control Project 2

Incident #/Probabilities	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Base case	0.227	0.227	0.227	0.227	0.227	0.227
Control project 1	0.204	0.204	0.204	0.204	0.204	0.204
Control project 2	0.000	0.000	0.000	0.000	0.000	0.000

is 0.5. With airline respirator used appropriately 95 percent of the time, and protecting the workers 99 percent of the time when used, this yields 0.941, which is the probability of workers being protected when exposed to benzene. We are interested in the inverse: the probability of a catastrophic respirator failure resulting in acute exposure, which is simply $1 - 0.941$, or 0.059.* With 500 employees working in the contaminated area, the probability calculation is 0.227.

Applying Equation 2: Probability of H&S Incident (Worker Injuries)

$$P_I = P_{(h)} * P_{(e)} * P_{(i)} * N_{(w)} \qquad [2]$$

Probability of an H&S incident expected in a year
$$= 0.0154 \times 0.5 \times 0.059 \times 500 = 0.227$$

Further assuming in this example that the risk will not change over the duration of the analysis, we then forecast different probabilities for different investment scenarios. Building a closed system to de-inventory the benzene would greatly reduce the chances of benzene exposure to only when there would be an engineering failure, which over the term of this example would be negligible over six years. However, the high cost of this approach needs to be balanced against the costs of other options that could also drive risk to extremely low levels (see Table I).

Another option is a less expensive, partial-engineering solution that entails hard piping process equipment to an open sump. This reduces the area of contamination and thus reduces the number of workers requiring respirators. Because some operators can work more efficiently now that they are no longer constrained by respirators, the duration of the dangerous benzene environment is reduced from 8 hours to 4 hours. There are still 4 unit turnaround operations per year, so the probability of a hazardous condition is now 6 hours—three quarters of an 8-hour workday. Three-quarters of a workday × 4 turnarounds each year (260 workdays per year) yields a probability of 0.0115 hazardous conditions per year. However, because the covered sump requires more time to clean, the average duration each worker is exposed to the benzene-contaminated area is increased

to the full 6-hour contamination period. Therefore, the probability of one worker being exposed, given a hazardous condition, is the full 6 hours of the contaminated period, or 1.0. We assume the effectiveness of wearing respirators is unchanged, so the probability of an incident given exposure remains 0.003. With Control Project 1 (Table I) 300 workers would be exposed to the contaminated area. Applying Eq. 2 yields the following:

Equation 2: Probability of H&S Incident (Worker Injuries)

$$P_I = P_{(h)} * P_{(e)} * P_{(i)} * N_{(w)} \qquad [3]$$

Probability of an H&S incident expected in a year
$$= 0.0115 \times 1.0 \times 0.059 \times 300 = 0.204$$

If the results of the investment are not realized immediately and are expected to change over time—either diminishing or improving—this should be taken into consideration and incorporated within probability forecasts. For simplicity, we assume the results of Control Project 2 are realized immediately, yielding the incident probabilities in Table I.

This illustrates that the change in the process reduces the probability of exposure approximately 10 percent and is most likely not a good candidate for the investment. A different control strategy with greater risk reduction should be considered. For example, perhaps the manufacturing process itself can be redesigned to eliminate the benzene exposure during the maintenance—Project 2 (Table I). This would effectively reduce the risk to zero.

If that could not be achieved, perhaps other options could be considered, or the money could be used in another part of the plant where an overall greater risk reduction could be achieved.

CONVERTING PROBABILITIES INTO INCIDENT RATE FORECASTS

Thus far, the methodology provides a structured approach for considering how alternative investments may influence the probability of an incident (or number of incidents) occurring in each year of the analysis. For those cases where annual probability estimates forecast less than one incident per year, this section proposes three methods to utilize these probability estimates in a business analysis. Three of these offer techniques to convert annual probability figures (which are fractions) into whole numbers. Regardless of which option is chosen, it should

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*This example assumes that PPE failure or leakage leads to acutely toxic exposures.

TABLE II

Comparison of the projected year of an incident occurrence in the Base Case (with a probability of occurrence of 0.227) to those occurring in Control Project 1 (with a probability of occurrence of 0.204) and Control Project 2 (with a probability of occurrence of 0). The periodicity is rounded down and the incidents are projected to occur sometime in the middle year of the period

Expected number of incidents	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
			4.4 Year Period			
Base case	0	1	0	0	0	1
Control project 1	0	1	0	0	0	0
			4.9 Year Period			
Control project 2	0	0	0	0	0	0

be consistently used across every project alternative to assure that the financial analysis (based on the risk analysis) permits a comparison of all projects being reviewed for funding in a given period. For the techniques described below, we use the analysis from the benzene example.

Technique A. Expected Values

The expected value method simply uses the probability estimate as the estimated incident rate. For example, if the probability of experiencing an incident in the current situation in a given year is 0.5, the incident rate is considered to be 0.5 incidents per year.

Advantages

This is the simplest method. By spreading the occurrences of incidents over time, this method most accurately reflects the best estimates made in the earlier portion of the methodology. The method avoids the challenging task of having to predict exact years in which incidents are experienced, and instead allocates the number of expected incidents (and thus their costs) over the years of the analysis.

Disadvantages

This method will never reflect reality, as the actual number of incidents that will occur will be integers, not fractions. While fractions may be mathematically sound, this can be confusing to management and complicates the accuracy of forecasts.

Application: Using the Expected Values Method with the Example

The probabilities from the benzene example are used in Table I to represent the number of expected incidents.

Technique B. Periodic Ranges for Low Probability Incidents

The periodic range method uses the inverse of a probability estimate to determine the average period (in years) between occurrences. In this method, one incident is entered per period,

beginning with the middle year of the period. To be conservative, all calculations should be rounded down to the nearest year. For example, if the probability of experiencing an incident over a number of years is 0.227, the average period is calculated as 1/0.227 or 4.4 years. The middle year of the period is Year 2, so the first incident is expected in Year 2 and every 4.4 years thereafter, as illustrated in Table II.

Advantages

This relatively simple method may reflect better than the Expected Values method because it calls for the number of incident forecasts in each year to be provided as an integer. Unlike Technique C, below, this method does not involve running the analysis twice to test the assumption through sensitivity analysis.

Disadvantages

Simplifying assumptions that incidents occur periodically may be unrealistic. Forecasting the first incident halfway through the period is a simplifying assumption that may be viewed as arbitrary.

Application: Using the Periodic Ranges Method with the Example

In Technique B, we calculated the expected period for the current situation to be 4.4 years, which means one incident is expected to occur on average every 4.4 years.[†] Following the method described above, the middle of the period as calculated as 4.4 years is 2.2 years. Adding multiples of the period to this starting time, incidents are expected in the following years: Year 2.2, Year 6.6 (calculated as 2.2 + 4.4), Year 11.0 (calculated as

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[†]Perhaps a more convenient way to think of this is to convert this ratio of 1 incident per 4.4 years to whole numbers by multiplying it by a convenient form of 1, is this case by five-fifths:

$$\frac{1 \text{ incident}}{4.4 \text{ years}} \times \frac{5}{5} = \frac{5 \text{ incidents}}{22 \text{ years}}.$$

From this equation, we can expect 3 incidents every 4 years for the current situation.

TABLE III

Demonstration of the Periodic Range Method to evaluate the average period between incident occurrences. For the example it is assumed that the probability of experiencing and incident is 0.4 and a period of 2.5 years. Bracketing the assumption of the year in which the first incident occurs

Expected number of incidents	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
			2.5 Year Period			
Control example—1st analysis	1	0	0	1	0	0
Control example—2nd analysis	0	0	1	0	0	1

6.6 + 4.4), Year 15.4, Year 19.8, etc. To be conservative, the calculated years in which incidents are expected are truncated as follows: Years 2, 6, 11, 15, and 19. Because the duration of the analysis is 6 years, incidents expected beyond this duration are not considered.

Under Control Project 2, the hazardous condition was eliminated. Therefore, no incidents are expected.

In Control Project 1, the probability of incidents is 0.204. Thus, the average period between incidents is 4.9 years (calculated as 1/0.204). Following the method described above, calculate the middle of the period of 4.9 years, which is 2.45 years. Adding multiples of the periods to this starting time, expect incidents in the following years: Year 2.45, Year 7.35, Year 12.25, and so on. The years in which incidents are expected are truncated to Years 2, 7, and 12. For this example, only incidents that occur within the first 6 years (the duration of the analysis) are considered (see Table II).

Technique C. Periodic Range Method with Sensitivity Analysis

This approach relies on the Periodic Range method to calculate the average period between incident occurrences, but goes one step further by bracketing the assumption of which year this period will begin. The analysis should be run twice: first with the average period beginning in Year 1 of the analysis, and then a second time but with the assumption that the first incident occurs toward the end of the average period. For example, if the probability of experiencing an incident in a given year is 0.4, the period is 2.5 years (1 year /0.4). Based on this method, the number of incidents is entered as shown in Table III.

Running the analysis in these two ways enables the analyst to understand how the results change by modifying the assumption of when the first incident is expected. This sensitivity analysis produces a range of results that illustrates the criticality of this assumption. The greater the results vary, the more critical the assumption, and the more care that needs to be taken when explaining these results to management.

Low probability incidents may have average periods that are longer than the duration of the project analysis. For example, if the probability of an incident occurring is 0.01, this yields a 100-year average period, which is greater than the duration of most project analyses. In these cases, consider assessing both the "worst case" and "best case." Worst-case analysis would show

the impact of an incident occurring once within the analysis time frame.[‡] The best-case analysis would have no incident occurring within the time frame. Comparing the impacts of how financial and operational metrics are impacted by this assumption sets up a sensitivity analysis.

Advantages

Compared to the Expected Values method that results in predictions in fractions of incidents, this method better reflects reality in that incidents are predicted to either occur or not occur in a given year, which allows for easier comprehension of analysis. The key advantage this method offers is that it tests the importance of the assumption of when incidents are expected to occur.

Disadvantages

This method is slightly more time consuming than Technique B, as its sensitivity analysis requires analyzing each investment alternative twice.

Application: Using The Periodic Range Method and Sensitivity Analysis with the Example

No incidents are expected under Project 2. The period under Project 1 is 4.9 years. In the first analysis, the assumption is made that the first incident will occur in Year 1 and then every period afterward: Year 5.9, Year 10.8, etc. To be conservative, these are truncated to Years 2, 7, and 12, but we are only interested in those within the six-year analysis period.

In the second analysis, using Technique C, the assumption is made that the first incident will occur in the last year of the 4.9 year period, and then every period thereafter: in years 9.8, 14.7, etc. These truncate to Years 4, 9, and 14, and since we are only interested in the six-year analysis period, we only consider the Year 4 event. See Table IV.

MODELING APPROACHES

Many analytical methods have been developed to estimate a series of numbers given certain probabilities. A user well versed

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[‡]The actual worst case may result from a low probability incident occurring more than once within the analysis' duration. Consider using a number that reflects the estimate of how many times the low probability conditions could actually occur in the worst case. For simplicity, 1 is used to develop the concept.

TABLE IV

Application of the Periodic Range Method with Sensitivity Analysis for Control Project 2 in the benzene example. Here the average period is 4.9 years. In first analysis, it is assumed that the first incident occurs in year 1. In the second analysis, it is assumed that the incident occurs at the end of the period

Expected number of incidents	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Control project 1—1st analysis	1	0	0	0	1	0
Control project 1—2nd analysis	0	0	0	1	0	0

in statistics may wish to use simulation models that use Monte Carlo simulation, random number generators, and various probability distribution curves such as normal and Weibull analysis. These methods allow for more sophisticated analyses based on more realistic possibilities that even an incident with a probability of occurrence of 0.25 can actually occur in consecutive years, multiple times in one year, or may occur less frequently than once every four years.

DISCUSSION

By developing a financial analysis format using quantitative language familiar to management, health and safety professionals can analyze and more strongly present health and safety investment opportunities. This type of methodology makes explicit key underlying assumptions about incident reductions that can help management develop a deeper understanding of the health and safety process, and bring many benefits to the business. Companies using this process should greatly improve their ability to learn from the accuracy of past forecasts and thereby improve upon them—while enhancing accountability. Instead of presenting health and safety outcomes of different investment options as judgment calls, a more analytical approach adds credibility to H&S professionals and assures greater success in obtaining the resources necessary to improve health and safety performance. The long-term key to success, however, lies in using this approach to track the performance of H&S investments, so that each future judgment and decision builds on that knowledge base.

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