# Near-Miss Management Systems in the Chemical Process Industry

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## ABSTRACT

This paper provides a systematic framework for the analysis and improvement of near-miss programs in the Chemical Process Industries. Near-miss programs improve corporate Environmental, Health and Safety (EHS) performance through the identification and utilization of accident precursors. By remedying precursors that signal the potential for an accident, accident rates may be reduced. Effective near-miss programs encourage employee involvement in all stages of near-miss management. Based on over one hundred interviews at twenty chemical and pharmaceutical facilities, a seven-stage framework has been developed and is presented herein. The framework enables sites to analyze their own near-miss programs, identify weak management links, and implement improvements.

## 1. INTRODUCTION

In review of adverse incidents in the process industries, it is observed, and has become accepted, that for every serious accident, a larger number of incidents result in limited impact and an even larger number of incidents result in no loss or damage. This observation is captured in the well-known Safety Pyramid shown in Figure 1 (Bird and Germain, 1996).

Incidents at the pyramid pinnacle, referred to in this paper as accidents,[1] may result in injury and loss, environmental impact and significant disruption and downtime of production processes. These incidents are often obvious, are brought to the attention of management, and are reviewed according to site protocols. Near-misses comprise the lower portion of the pyramid. These incidents have potential to, but do not result in loss.

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[1] The term 'accident' is used to imply solely an incident that involves some form of loss to an individual(s), environment, property and/or process.

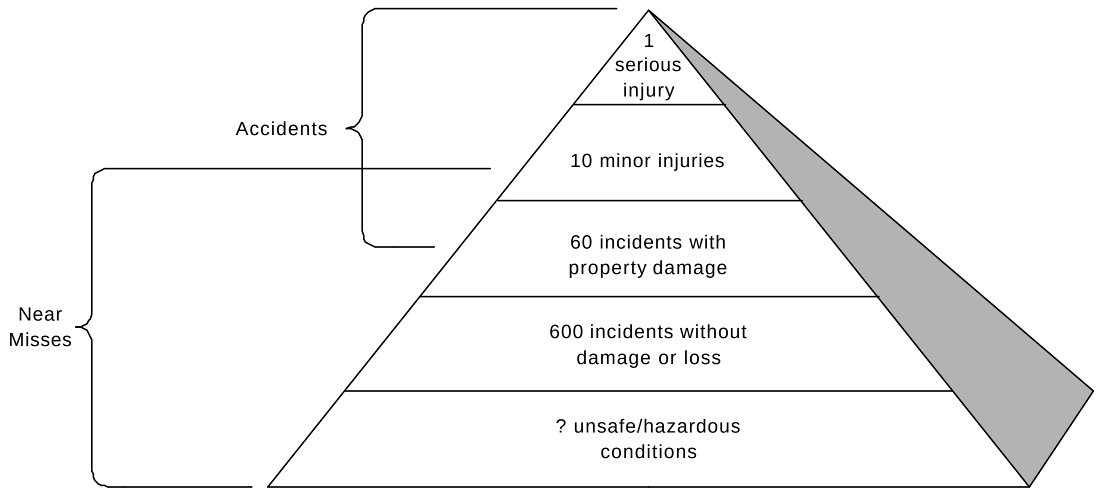


Figure 1. Safety Pyramid (the lowest strata, unsafe conditions, is not shown by Bird and Germain, 1996).

Near-misses are often less obvious than accidents and are defined as having little if any immediate impact on individuals or processes. Despite their limited impact, near-misses provide insight into potential accidents that could happen. As numerous catastrophes illustrate, management failure to capture and remedy near-misses may foreshadow disaster. Notable examples where near-miss precursors have been observed but not effectively managed include:

1. The 1986 Space-Shuttle Challenger explosion. Engineers had identified and reported degraded O-ring seals on previous missions dating back to 1982 with degradation increasing as ambient liftoff temperature decreased. The night before the disaster, management had been warned of the potential for catastrophic failure when lifting off at ambient temperatures of 53 °F or below (the liftoff temperature was 36 °F) (Vaughan, 1996).
2. The 1997 Hindustan refinery explosion in India. Sixty people died and over 10,000 metric tons of petroleum-based products were released to the atmosphere or burned. Written complaints of corroded and leaking transfer lines where the explosion originated went unheeded (Khan and Abbasi, 1999).
3. The 1999 Paddington train crash catastrophe in which 31 people died. From 1993-1999 eight near-misses, or 'signals passed at danger' (SPADS), had occurred at the location (Signal 109) where the eventual collision and explosion occurred. At the time of the crash, the signal was one of the 22 signals with the greatest number of SPADS (Cullen, 2001).
4. The 1998 Morton explosion and fire resulting from a reactor temperature excursion. Nine people were injured, two seriously. In an accident investigation, the Chemical Safety Board concluded, "Management did not investigate evidence in numerous completed batch sheets and temperature charts of high temperature

> excursions beyond the normal operating range." A disproportionate number of excursions resulted after the process was scaled-up (Chemical Safety Board, 2000).

As these examples illustrate, failure to utilize precursor data to identify and remedy systemic flaws can have catastrophic results. To reduce the likelihood of future catastrophe and further improve employee safety and process reliability, management systems that recognize operational weaknesses need to be developed to seek and utilize accident precursors (see March et al., 1991). These programs operate under the umbrella of Near-Miss Management Systems.

Near-miss management systems have been developed and are implemented across a range of industries including the chemical/process, airline, rail, nuclear and medical disciplines. A compilation of papers with a cross-industry perspective is provided in *Near-Miss Reporting as a Safety Tool* (Van der Schaaf et al., 1991). The book illustrates how management strategy and program implementation vary according to application area.

Within the chemical and process industries, analysis of near-miss management has been limited. The thesis of T.W. Van der Schaaf (1992) provides the most detailed study of near-miss management in the chemical industry known to us. The work presents a discussion of the human factors involved in reporting, and emphasizes that to encourage disclosure, site management should *not* infer or express the view that near-miss report rates are a desirable metric to decrease over time. The authors of the present paper found evidence to support this same recommendation (see Phimister et al., 2000).

The Van der Schaaf thesis provides a system for near-miss classification, the analysis of a group of near-miss reports, and the implementation of safety improvements. The foundation of the classification system is to use near-miss programs as a vehicle to analyze human behavior performance. Van der Schaaf applies this framework to a near-miss program at an Exxon Chemical facility in Holland. He argues that the integration of the program was successful in achieving higher levels of near-miss reporting (an increase of 300% was observed). Though, the site had a high safety standard prior to implementation of the program, hence Van der Schaaf was unable to assess to what degree the program may have actually improved safety performance.

Jones et al. (1999) provide an account of near-miss management systems successfully applied in the European chemical industries. Two examples of near-miss programs applied at Norsk Hydro's offshore and onshore are studied. In both cases, their results suggest that an increase in near-miss reports can yield improved safety performance. In off-shore drilling, over seven years a ten-fold increase in near-miss reporting also corresponded with a 60% reduction in lost time injuries. In on-shore activities, over a thirteen year span, an increase in reporting rates from zero to one-half per person per year corresponded with a 75% reduction in lost time injuries[2]. The authors note the recent

[2] Estimated from graphs in citation.

inclusion of near-misses in the Major Accident Reporting System (MARS) as a favorable step in encouraging sites to implement near-miss programs.

There has been notable work in the codifying and evaluation of precursor data through utilization of Bayesian Analysis (e.g. Bier and Yi, 1995; Bier and Mosleh, 1990; Kaplan, 1989). This approach has received considerable attention within the nuclear industry where modeling approaches are used to identify and assess potential precursors to reactor core meltdown (Johnson and Rasmuson, 1996, Kaplan, 1992). In the approach taken in the nuclear industry, a prior distribution is formed as a product of a precursor distribution and a distribution representing a final barrier failing, hence leading to core meltdown. When new observations of precursors, accidents or lack thereof, occur over time, an updated posterior distribution is generated from the prior. The Bayesian procedure can help identify sources for improvement to reduce the likelihood of both precursors and accidents. Upon updating distributions, shifts in the posterior distribution curves provide insight into increased and decreased accident likelihood resulting from the failure modes associated with specific precursors.

In this paper a seven-stage framework for the management of incidents and specifically near-misses is presented, with the emphasis on obtaining operational and strategic value from such incidents. The key finding of this paper is that near-miss management can be systematized and managed to provide an important reinforcing element of accident prevention and preparedness at hazardous facilities. To do so, however, requires a well-designed infrastructure for identifying, reporting, analyzing and disseminating the results of near-misses. This paper's intended contribution is to synthesize best practices for such an infrastructure from the companies in our interview sample and other near-miss systems reported in the literature. We believe that the general infrastructure proposed is widely applicable and can be customized to other companies and facilities to fit particular organizational and business needs.

The paper proceeds as follows. In the next section, we describe the structure of near-miss management systems and identify key stages in the life a near-miss from identification to resolution. We also point out similarities, differences and interactions with accident management systems. In Section 3 an overview of the data-sample and interview framework is provided. In Section 4 we then analyze each of the near-miss stages in our proposed framework in more detail and present data from our interviews on best practices for each stage. We conclude with observations on the implementation and continuous improvement of near-miss management systems, and a discussion of future research activities.

## 2. FRAMEWORK

We propose a framework that relates the effectiveness of a company's near-miss management system to the operational and strategic value that can be derived from a systematic analysis of such incidents. In this paper, we do not analyze in detail the valuation of near misses.[3] Here we will consider this value only in aggregate terms, and denote the value, *V*, and the potential value *PV(k)*, that can be derived from a near-miss incident of type *k*. While we will think of *PV* as a scalar metric, it might more generally be conceived as a multi-criteria metric, involving the value derived from near-misses for improving operations, for reducing strategic vulnerabilities, for promoting awareness of and participation in a company's accident prevention activities, and perhaps other objectives. Our interview data suggests that sites and companies often consider the potential value of near-misses relative to the immediate impact (*I*) of the incident. As a purely descriptive matter, this means that many companies only pay attention when there are actual and significant consequences from an incident.

We can illustrate this type of behavior as follows. Assume that the value extracted by a company's near-miss and accident management system(s) from any incident with observable direct consequences *I* has the form:

$$V(I) = a + bI^{g}$$

Sites that gain value only from incidents with significant impact and hence have poor near-miss management systems have $a$ and β near zero. (Figure 2A). A consequence of implementing an effective near-miss management system is to increase the value extracted from all levels of incidents, even if they may have little if any direct impact (effectively raising the observed values of $a$ and ß in *V(I)* as in Figure 2B).

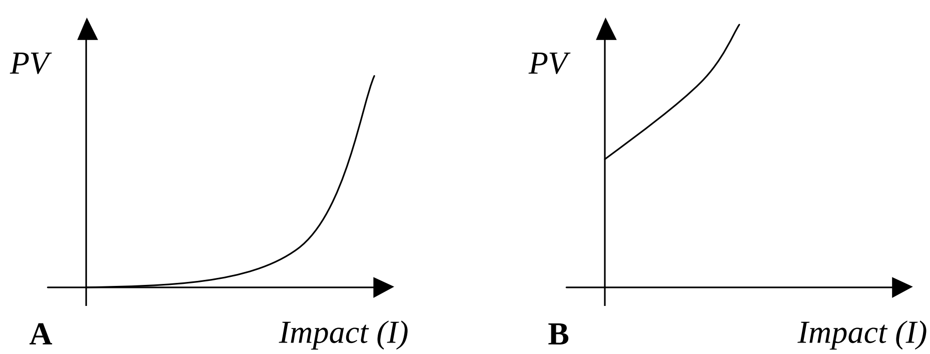


Figure 2. Value extracted from incidents at sites with A) Non-existent or under-performing near-miss management systems ($a$ and $b$ are low), B) Effective near-miss management systems ($a$ and $b$ are high).

While the above discussion suggests the objectives of near-miss systems, our field visits show that to improve near-miss management systems, one must focus on the details of the process by which near misses are reported and analyzed. We therefore propose a framework that links the value *V* a company extracts from incidents (whether near-misses or accidents) to the maximum potential value PV it might extract and to the effectiveness

[3] For a detailed discussion of valuation issues related to learnings from near-miss management systems, see Kleindorfer et al. (2001).

of several stages in the company's near-miss management system. Our field research and surveys of existing near-miss management systems delineate seven consecutive stages underlying the reporting and extraction of value from near misses. These stages, shown in Figure 3, are:

1. Identification: An incident is recognized to have occurred.
2. Disclosure: An individual or group reports the incident, and an incident file is opened.
3. Distribution: Information pertaining to the incident is transferred to those who will assess follow-up action. Information may also be broadcast to a wider audience to increase awareness.
4. Direct and Root-Cause Analysis: The causal and underlying factors that enable an incident are identified.
5. Solution Determination: For each cause solutions to prevent recurrence and/or mitigate potential impact are identified.
6. Dissemination: Follow-up 'action-items' to implement solutions are relayed to relevant parties. Information is broadcast to a wider audience to increase awareness.
7. Resolution: Action items that stem from identified solutions are implemented, and other necessary follow-up action is completed whereupon the incident file is closed.

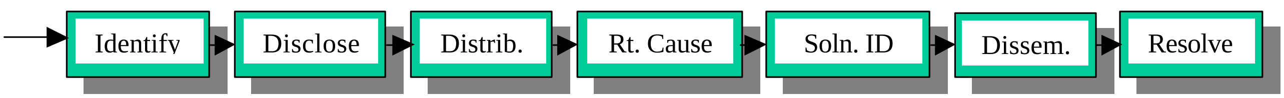


Figure 3. Incident processing stages.

Implicit in the above structure of near-miss reporting and analysis is that the value associated with near-miss management systems arises from two sources. Foremost, to achieve maximum potential of a near-miss is the successful execution of each stage. Thus, logically, near-misses that are not identified will not yield any value. Near misses that are not disclosed may lead to some value for local operators, but will not yield any broader lessons unless these near-misses are analyzed. Following this chain of implications, we are led to a model that reflects the fact that early stages in the near-miss management system have "conjunctive" or multiplier effects on later stages. Second, however, there may be value from the proper execution of each stage itself. Thus, near misses that are recognized as such may have an immediate benefit in increased awareness and prevention activities at the site at which they arise, whether or not they are reported, analyzed and disseminated further. Similarly, the introduction of appropriate quality and other analytic tools as a part of near-miss management can have direct benefits in promoting process excellence in general, whether or not these tools and techniques are used effectively for near-miss management. Thus, if *PV(k)* represents the potential value that might be extracted from incidents of type k, then the above discussion suggests the actual value *V(k)* extracted from such incidents as represented by the following functional form:

$$V(k) = v(PV(k), x, k) \qquad (1)$$

s.t.

$$\frac{\partial V(k)}{\partial x_i} \geq 0$$

$$x_i \in [0, 1], \quad i = 1, \ldots, 7$$

with the boundary condition: $V(k) = 0$, at $x_1 = 0$

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Using this framework it is apparent why many sites are often much more successful in extracting value from accidents, whereas gain considerably less value from near-misses. Consider Figure 4 which compares hypothetical stage efficiencies for accidents and near-misses, and the following formulation satisfying (1):

$$V(k) = \frac{PV(k)}{7} \sum_i^7 \prod_j^i x_j$$

In an accident, both identification and disclosure are all but guaranteed. In such instances the injury of an individual, environmental impact, large-scale property damage, and/or other undesirable outcomes force both identification and disclosure. The presence of legal and regulatory requirements, combined with other factors such as empathy, employee concern and desire to avoid event recurrence prompt a thorough investigation according to pre-defined investigation protocols. Such a thorough investigation will infer high latter stage efficiencies[4].

In contrast, for near-misses, many may occur unnoticed, thereby diminishing Identification efficiency. Even for recognized near-misses, factors such as concern for personal culpability, investigation time commitments, and belief that change might not result, can discourage reporting, thereby diminishing Disclosure efficiency. For those near-misses that are reported, many of the external factors that drive accident investigations are not present. As a consequence, management has less motivation to ensure that full value is extracted from a reported near-miss. If a 50% stage efficiency is assumed for managing near-misses only 14% of the *PV* is extracted from the average incident (again only with respect to recognition and performance of each stage). A more detailed example of how differing values may be achieved from an incident is presented in Example 1. As is intuitive from the preceding discussion, and as the example makes clear, a central aspect of the proposed framework is the interdependence and effectiveness of stage performance to capture value from near-misses for accident diagnosis and prevention.

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[4] For illustrative purposes if for an accident, identification, disclosure and distribution efficiencies are assumed to be 100% and the following four stages have 90% efficiencies, 87% of the *PV* is extracted.

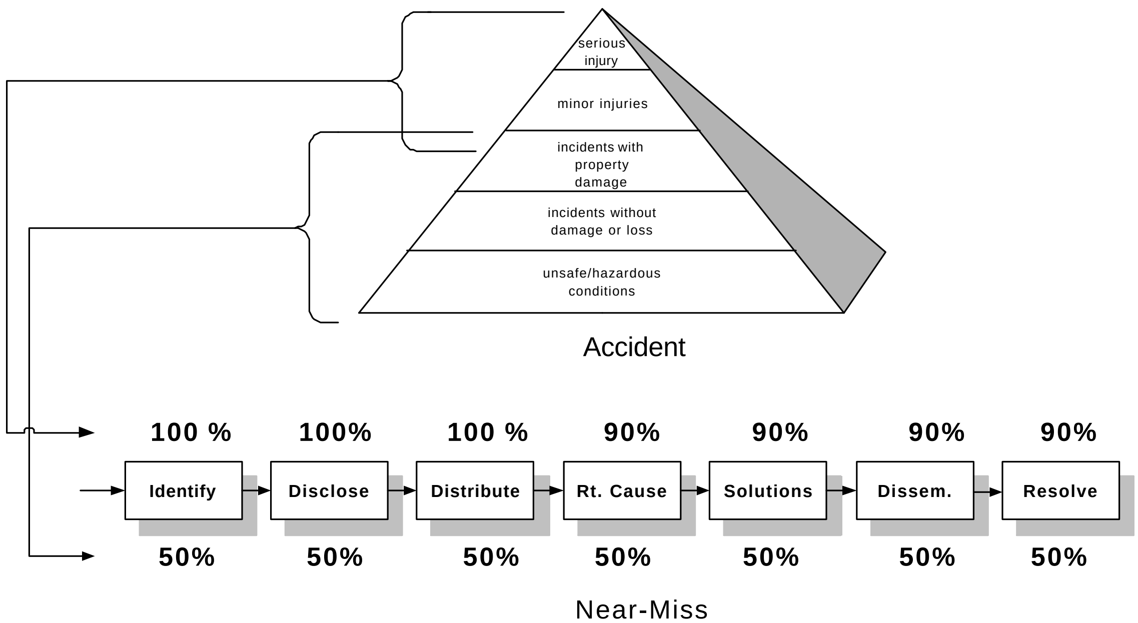


Figure 4. Example of stage performance for accidents and near-misses. (Percentages indicate stage efficiencies).

**Example 1.** 'Value' extracted from a vapor release incident.

The following example is used to illustrate stage efficiencies in near-miss incident processing. An interviewee presented the example during a site visit.

A mechanic is to replace a pressurized tank pressure-relief valve. Prior to performing the task the mechanic is informed the tank has been purged and is isolated. The mechanic confirms all isolation valves have been closed, and removes the relief valve. On removal of the valve, heavy flammable gas is discharged. Fearing a possible explosion, the mechanic radios to have all ignition sources removed from the immediate vicinity. Shortly thereafter the gas disperses without damage. The incident is reported, the mechanic, EHS and the mechanic's supervisor review the incident and similar past incidents. A root-cause investigation determines that a misplaced isolation valve located outside the tank housing was left open. Among other conclusions, it is determined had the valve been correctly placed inside the tank housing and closer to the tank, the incident would have been averted. A work order is placed to move the valve, management of change issues are considered, and within a week the old valve is removed and a new isolation valve is installed inside the tank housing and nearer the tank. An incident report is relayed site-wide to inform others of the incident and determined solutions. The new valve is rechecked a day after installation to ensure satisfactory operation. Other tanks are also examined for similar hazards. On completion the mechanic is informed of the solution and the incident is closed.

While stage efficiencies are subjective, it is evident in this scenario that all seven stages are being performed with some degree of success. The incident is recognized for its potential value ($x_1$), it is reported ($x_2$), distributed to decision makers ($x_3$), causes are identified ($x_4$) and solutions determined ($x_5$), disseminated ($x_6$) and tracked until completion ($x_7$). Hence, a near maximum $PV$ is attained.

Three alternative scenarios that might have occurred illustrate the interaction of stage efficiencies:

Scenario 1: The mechanic partially removes the valve and leaves the area without realizing that gas is being released. On return all gas has dispersed and the mechanic performs the maintenance. The incident is not identified and no further remedial actions ensued. For this scenario, stage efficiency $x_i$ is 0 for all stages, and hence the 'value' gained from the incident is zero, and the latent potential for catastrophe remains.

Scenario 2: The mechanic realizes that an incident occurs ($x_1 = 1$), assumes that he had mistakenly not checked all valves, and does not report the incident due to fear of reprisal. The incident is not disclosed, $x_2 = 0$ and there is no follow-up. Hence, the value gained from the incident is minimal. In this case some marginal value is gained with the mechanic potentially scrutinizing maintenance work more carefully; however, most of the latent potential for catastrophe remains.

Scenario 3: The mechanic realizes that an incident occurs ($x_1 = 1$), and reports the incident to his supervisor ($x_2 = 1$). The supervisor performs the analysis without aid of EHS or the mechanic ($x_3 = 0.5$). The supervisor concludes the incident would have been avoided had the mechanic been more careful ($x_4 = 0.1$). The determined solution is for the mechanic to be more careful in future ($x_5 = 0.1$). The supervisor implements the solution by having a discussion with the mechanic but does not distribute the information to a wider audience to increase awareness ($x_6=0.5$, $x_7=1$). The realized value from this incident is thus likely to be significantly less compared to the base case.

## 3. THE INTERVIEW PROCESS AND STRUCTURE

The seven-stage framework presented in this document and the elements intrinsic to successful stage performance were derived from 106 interviews. The interviews were performed between June and November 2000 at twenty sites of five Fortune 500 chemical and pharmaceutical companies. Of the sites visited seven were in the Houston, Texas area, two were in Delaware and the remaining were near Philadelphia in Pennsylvania. Fifty nine of the interviewees were hourly employees, consisting of operators, mechanics and pipe-fitters. The others were site- or company management that included EHS executives, engineers and plant managers.
Interviews lasted between twenty and forty minutes. The interview started with a short discussion of the purpose of the interview, and a discussion of the interviewee's responsibilities. The remainder of the interview focused on five of the seven stages of the proposed framework (Identification, Disclosure, Distribution, Dissemination and Resolution)[5].

## 4. DISCUSSION OF INDIVIDUAL STAGES

The seven-stage framework helps sites focus energies to improve program performance. In the following sections elements intrinsic to the successful performance of each stage are discussed. In each section:

1. Stage objectives are defined.
2. Key elements of high efficiency performance are identified.
3. Common obstacles that impede stage performance are outlined.
4. General observations of practice to overcome these obstacles are presented.

### Identification

To harvest value from a near-miss it must be identified. To successfully identify a near-miss, individuals must recognize an incident or a condition, with potential for serious consequence.

To aid in near-miss identification, individuals require an understanding of what is a near-miss. In our study, 40 (68%) of the hourly employees expressed confusion as to what constitutes a near-miss, believe that near-misses must have resulted in a threat to safety (though not the environment, or potential for significant process upset), or express the sentiment of 'you know it when you see it'.

[5] Due to the idiosyncratic nature of incidents, the potential subjective assessment of causes identified and efficacy of subsequent solutions, as well as the expertise required to analyze incidents, interviews did not focus on site performance in *Direct and Root-Cause Analysis* or *Solution Determination* stages. However, the structure of these stages (e.g. is there a tiered-classification systems, are the stages managed separately, are analytical tools brought to bear, etc.) was analyzed.

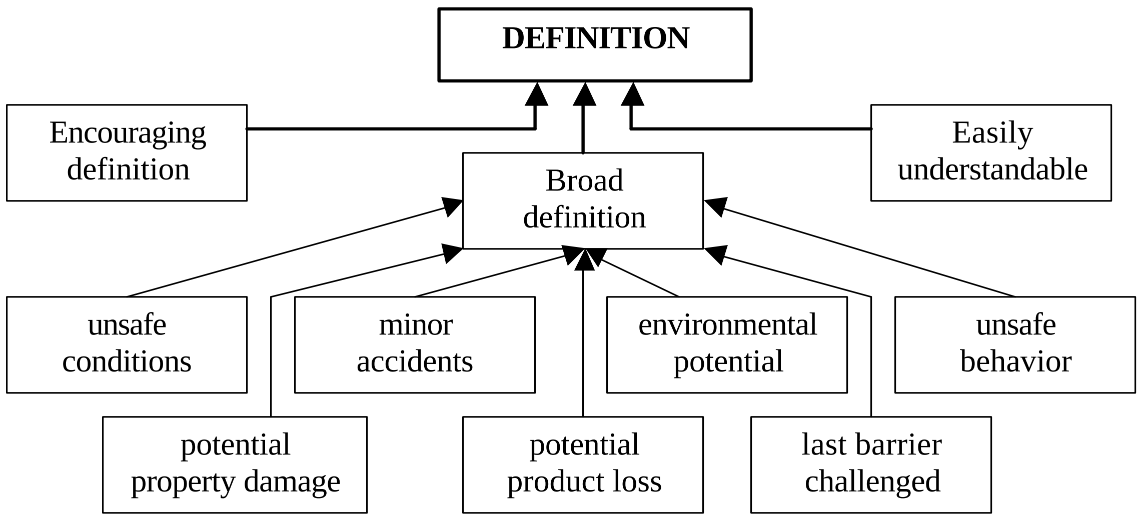


Figure 5. Definition Tree

To have an effective near-miss system there is an overwhelming need for an encompassing and helpful near-miss definition. We believe, in providing a site- or corporate wide definition the issue should not be whether an occurrence is an event with potential for more serious consequences, an accident or simply the identification of an unsafe condition or unsafe behavior. Rather, the definition should focus on identifying an incident from which site EHS performance be improved. In search for a new definition the tree shown in Figure 5, which includes desirable definition features, is generated. The following new definition is based on the elements depicted in Figure 5:

> Near-miss: *An opportunity to improve environmental, health and safety practice based on a condition, or an incident with potential for more serious consequence.*

By this definition a wide variety of incidents are defined as near-misses. These include:

- Unsafe conditions
- Unsafe behavior
- Minor accidents/injuries that had potential to be more serious
- Events where injury could have occurred but did not
- Events where property damage results
- Events where a safety barrier is challenged
- Events where potential environmental damage could result

The definition proposed captures the ephemeral quality of a near-miss, without dwelling on how an event should be classified. Near-misses are opportunities. If the underlying hazard is quickly identified and remedied, the likelihood of the event recurring is greatly reduced or eliminated. If not identified, disclosed and properly managed the incident may be forgotten and the latent potential for damage remains. Through utilization of a broad near-miss definition, and dissemination of reports that capture a range of incidents and observations, identification is encouraged.

Restrictive near-miss definitions, and failure to recognize near-misses as opportunities to improve EHS practice, presents the possibility that many near-misses may not be recognized. Two restrictions to near miss definitions that were observed in the field are i) near-misses must entail an ‘event’, or ii) near-misses must involve a last barrier being challenged. The rational for these restrictions may be the perception that when an event occurs or a last barrier is challenged an operation is closer to an accident threshold. Consider Figure 6, which illustrates a process in operation, and how it responds after an event E. In the case of event E, two barriers, A and B, are in place to prevent an accident coming to fruition, and an accident occurs only if A and B fail. Defining *P(E)* as the probability event E occurs over a given time frame, and *P (A¢/E)*, the probability barrier A fails if challenged given incident E, *P (B¢/EA¢)* the probability B fails if challenged given incident E, and A failing.

It will be noted that at point X, the probability of an accident occurring is *P(E)P(A¢/E)P (B¢/EA’)*, at Y the accident probability is *P (A¢/E)P (B¢/EA’)* and at Z it is *P (B/EA’)*. Furthermore, provided barriers A and B are in place:

$$P_X(\text{accident})<P_Y(\text{accident})< P_Z(\text{accident})$$

Consequently, under these circumstances, a process that exhibits a last barrier challenged is indeed closer to an accident threshold then a process operating at location X. However, consider if barriers A and B had been temporarily removed (e.g. for maintenance). Then, if:

*P(E) > P (B¢/EA)*

The operation is closer to an accident threshold at location X, where an event has not been expressed nor a barrier challenged, then if the barriers *A* and *B* are functioning and the last barrier is challenged. Given the proximity of the operation to the accident threshold, the operation should be considered a near-miss, even though no event has occurred.

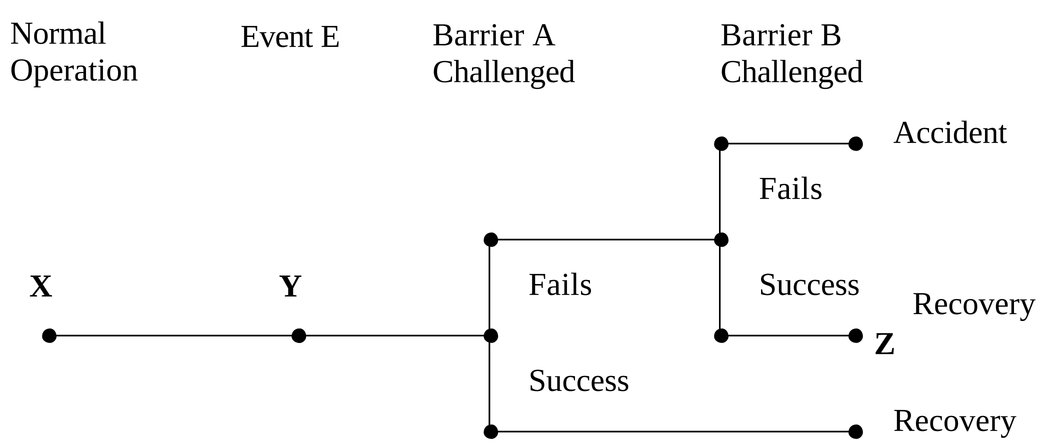


Figure 6. Event tree with two barriers.

To illustrate the benefit of encompassing near-miss definitions, an incident discussed by a plant mechanic is presented. The mechanic's responsibilities involved the maintenance of a distillate stream at the top of a 20m high column. The mechanic, who was positioned on a platform at the top of the column, was short in stature and required a step-ladder to reach the pipework. Prior to climbing the ladder, the mechanic noted that to reach the pipework his positioning would be precarious, and would result in his leaning over a guardrail. He reported the unsafe condition through the site near-miss program, a short investigation proceeded and subsequently the guardrail was raised.

When the above incident was discussed with interviewees, some indicated they did not consider the incident a near-miss and hence would not report it. However, they countered, had the individual climbed the ladder, slipped and not been injured, then it was a near-miss. If management conveys that near-misses must be 'event-driven' or the result of a last barrier being challenged, many similar opportunities may go unreported.

**Disclosure**

A recognized near-miss has only limited value, even to the person who recognized it, unless it is disclosed to others to be properly analyzed and to have measures taken to prevent its recurrence. When a near-miss is recognized, there is no assurance that it will be reported. The objective therefore in the Disclosure stage is to ensure that all recognized near-misses are reported.

Bridges (2000) focuses on barriers that inhibit disclosure. To increase report rates, Bridges advocates that nine barriers be overcome. In this paper we group these barriers as:

1. Potential recriminations for reporting (fear of disciplinary action, fear of peer teasing, and investigation involvement concern)
2. Motivational issues (lack of incentive and management discouraging near-miss reports)
3. Lack of management commitment (sporadic emphasis, and management fear of liability). I
4. Individual confusion (confusion as to what constitutes a near-miss and how it should be reported).

Based on our interviews we provide corresponding solutions to help overcome these four groups. In developing near-miss programs, site and EHS managers should identify the barriers at their sites that inhibit disclosure. The above barriers and corresponding solutions to address each one of them are presented below in detail.

<u>Reporting Recriminations</u>

Employees may be reluctant to report near-misses due to potential recriminations that could result. Potential recriminations are:

1. Peer Pressure. Employees may feel pressure from colleagues not to report.
2. Investigation style. Lengthy investigations that require employee participation may discourage future reporting.
3. Direct disciplinary action. Concern of receiving a verbal warning, addition of incident to employee record, up to and including job dismissal discourage reporting.
4. Unintended disciplinary action. For example, upon incident investigation, additional job tasks or wearing cumbersome PPE may be perceived as punishment for reporting.

To overcome peer pressure, it is recommended management consider:

1. The formation of employee teams to evaluate and prioritize near-miss reports.
2. Wide dissemination of submitted near-miss reports.
3. Publicizing of improvements that result from reported near-misses.
4. Enabling the reporter to decide to whom a near-miss report is sent.
5. Requiring a specified number of near-misses be reported per person per year.

Broad dissemination of near-miss reports may be considered counter-intuitive to alleviating peer pressure if one thinks an individual would be reluctant to report if they believed it was to be widely publicized. If near-misses are widely reported, individuals are exposed to many incidents and an additional report therefore does not draw attention to the reporter thereby alleviating peer pressure.

For the chemical process industries the authors do not favor schemes where employees remain anonymous upon submitting a report. Our field work strongly underscores the view by practitioners at all levels that anonymous disclosure is problematic on several dimensions: (i). it is often necessary to follow-up with the reporter to ascertain incident causes, and (ii) anonymity does not infer that near-misses are desirable opportunities to learn from, but rather suggests that they should be held secret. Three sites visited offered anonymous disclosure, though at these sites anonymity systems were run in conjunction with incentive schemes that encouraged identity disclosure, and hence anonymous disclosure was rarely utilized.

Our assessment of existing near-miss systems also suggests that reporting should be quick and simple since completion of long forms discourages disclosure. Though follow-up action may necessitate a thorough investigation, the least that is required is reporting with a quick summary of the near-miss incident or observation. Including a brief appraisal of causes and potential solutions at the time of disclosure would be desirable but would not be one of the essential disclosure requirements. Note, even if completion of the disclosure form is a quick process, if retrieving near-miss forms is difficult, or involves trolling through web sites, disclosure rates will be adversely affected.

To remove fear of disciplinary action, sites may wish to develop a non-disciplinary policy. Such a policy could be based around the following statement:

> *Provided a cardinal rule has not been broken and no damage done, disciplinary action will not be taken.*

If implemented, this policy must be rigidly adhered to; damage that results from management failure to adhere to their policies can take years to undo. Moreover, safeguards to help catch instances when management fails to abide by this policy should be considered.

Finally, on determining solutions management must scrutinize whether action items that result from near-miss investigations result in solutions that are perceived as punishment. In such cases, alternate solutions should be sought.

<u>Lack of Incentive</u>

Interviewees at fourteen sites expressed a lack of incentive to report near-misses. Perhaps the largest enticement to submit a near-miss report is the knowledge the report will be handled seriously and appropriately, with remedial action taken if appropriate. Management can provide additional encouragement through implementation of incentive programs. Two types of incentive programs observed during site visits are:

1. ‘Tchotchkes’ giveaways – a near-miss report entitles the reporter to a T-shirt, mug, etc.
2. Lottery systems - each near-miss constitutes a lottery ticket, with drawings held quarterly, bi-annually or annually. Lottery prizes observed at sites include cash prizes, dinner at a local restaurant, event tickets and a day-off.

Of the sites visited lottery programs showed higher participation levels then giveaway programs, though most sites did not adopt either. Four sites had ‘token’ giveaways with a near-miss reporting rate of 0.9 per person per year, whereas two sites had lottery systems with a reporting rate of 3.0 reports per person per year. Based on our discussions with several EHS professionals, we believe that having an incentive system with some variety in the rewards offered can be more effective than having the same type of incentive for several years.

Senior and site management should not create disincentives to report near-misses. Van der Schaaf (1992) reports of a site where senior management conveyed to personnel that high near-miss reporting correlated directly with poor safety performance. It was speculated that though this site was subsequently successful in reducing the number of near-misses reported, the actual number of near-misses experienced likely remained constant and hence due to inaction their risk exposure actually increased. Confusion of whether high near-miss reporting rates are positive or negative indicators of safety performance remains. Eleven sites in our study viewed the number of near-miss reports as a metric that was desirable to increase or keep constant over time. These sites expressed the common view that near-miss reports were a gauge of employee EHS awareness and involvement. The remaining nine sites either did not maintain a view on this issue, or viewed near-miss reports submitted as a metric that is desirable to decrease over time.

Individual Confusion

Since near-misses can be subjective, there can be confusion as to what constitutes a near-miss. As discussed in the Identification section an encompassing near-miss definition can facilitate understanding, and thereby encourage disclosure. One site in our study, referred to near-misses as 'safety event communications' which were shared over the site intranet. The 'litmus test' for sharing an EHS related incident was:

*Could someone benefit by learning from the event?*

It was believed that this simple test encouraged disclosure.

Another site in our study included a similar definition on the back of the near-miss report form. Interviewees, when questioned as to their definition of a near-miss, referred the interviewer to the back of the form.

In addition to understanding what constitutes a near-miss, individuals must know to whom, and how to report near-misses. Multiple mechanisms (e.g. both paper based and intranet based) can aid reporting as can management emphasis and training.

Lack of Management Commitment

Failure of management to remain committed to near-miss programs, can, in turn decrease employee reporting, and can result in employee accusations that near-miss programs are 'a flavor of the month'. Commitment failure can be both passive, where management stops emphasizing program participation due to inattention, or active, where management seeks to reduce program participation.

Passive failures can be avoided by:

1. Automated report generations and postings that highlight program participation, resulting improvements and other benefits of near-miss programs.
2. Integrating near-miss program components with other site management mechanisms, such as work-order entry, action item tracking, and accident investigation systems. This approach utilizes employee familiarity with current procedures which would otherwise have to be instilled if new systems are implemented.
3. Linking process with outcome. Specifically, sites may wish to attempt to show that EHS performance correlates favorably with near-miss program participation.

Active measures by site management to reduce near-miss reporting can stem from inability of site management to handle a high level of participation, and management concern of being liable due to inaction of reported near-misses. Addressing each of these items:

1. Integration of management systems, distributing management responsibilities and implementing a two or higher tier-investigation classification system (see also root-cause analysis) can greatly reduce the burden of a successful near-miss program with high levels of participation.
2. Ensuring that every identified cause has an accompanying solution, or solutions, and that systems are in place to track solutions until implemented can alleviate liability concerns. (minutes of Wharton roundtable meeting, 2000).

**Distribution**

At this stage it is critical to distribute near-miss information to a broader audience for their information especially to qualified people who can then assess the situation, such as: i) if initial reporting includes any analysis or remedial action, whether these are adequate or further investigation is necessary; ii) identify potential broader implications of the near miss, if any, and make sure that the given near-miss is addressed at a level that is necessary to prevent similar occurrences from happening elsewhere in the organization.

Hence, there are two objectives in the Distribution stage:

1. To inform EH&S and (other) management investigators of the near-miss.
2. To alert a broader audience of the hazard, and any interim solutions in place.

Common obstacles that limit Distribution performance include unwillingness of supervisors to relay near-miss information, paper distribution systems that do not specify a timeframe for review, distribution systems where information is transferred in series and not in parallel, and over-distribution where many investigators are required to analyze relatively straightforward reports. All four of these barriers slow information transfer at this critical juncture.

To improve stage performance, five strategies are observed in the field:

1. Merge the Distribution stage with Disclosure. This can be performed relatively easily in automated systems, where decision makers, whether supervisors, EHS managers, engineers or others are copied upon initial reporting.

2. Automate the Distribution stage. Automation of distribution through electronic, intranet systems enables instantaneous transfer of information. In addition, checks can be added to ensure that reported incidents are considered and action taken.

3. Specification of time frames on information transfer.  This has been observed in paper based systems where protocols specify that reported near-misses must be reviewed by EHS managers within a time frame.
4. Automate systems to ensure EHS review.  These systems require EHS management to respond to the reporter, or reporter's supervisor to confirm review.
5. Enable reporters and supervisors to perform initial investigations.  In many instances direct causes and solutions are obvious.  Allowing reporters and supervisors to perform investigations engages employees, quickens investigations and decreases EHS workload.

Lastly, stage performance may improve by integrating distribution of near-miss information with mechanisms used to distribute accident related information.  This strategy familiarizes site management with accident information distribution protocols, and eliminates duplicate energies expended to design two separate distribution systems.

**Direct and Root-Cause Analysis**

Once a near-miss is disclosed and transferred to appropriate parties, it is necessary to carry out steps to ensure that the near-miss does not recur.  Two stages are performed in determination of remedying actions:

1. Identification of direct and root causes (herein referred to as Root-Cause Analysis).
2. Based on identified causes, identification of solutions or action items that significantly reduce the likelihood of recurrence, and/or significantly reduce potential impact in the event of recurrence.

The objective in Root-Cause Analysis is to determine what are the direct and underlying factors that enable an incident or unsafe condition.  Short-term solutions resolve direct causes, farther-reaching and more permanent solutions rectify root-causes.  While in structuring near-miss programs it is important to recognize the interaction between Root-Cause Analysis and Solution Determination it is equally important to recognize that these are two distinct activities.

There are a number of obstacles that limit Root-Cause Analysis performance.  Factors that deteriorate stage performance include:

1. Lack of availability of tools or frameworks to analyze incidents.
2. Insufficient expertise available to analyze the incident.
3. Dilution of relevant information due to information transfer or lapsed time prior to incident investigation.

The presence of the feedback loop between Root-Cause Analysis and Disclosure must also be recognized in structuring stage activities.  There can be a trade-off between high disclosure rates and comprehensive investigations, in that, if all reported near-misses are thoroughly investigated, disclosure may be adversely affected due to concern of lengthy proceedings. As a consequence, many sites may wish to forego a lengthy investigation and solution determination for most reported near-misses. A question that is asked by most corporations' representatives that are participating in our studies is "how to determine the near-misses that require in-depth root-cause analysis?" Although we do not have a definite answer to this question clearly repetitive near-misses similar in nature and near-misses that occur at critical process steps, such as related to reactor or pressure vessel operations, have to be analyzed in more detail. At the Wharton Risk Management Center, as an extension of this project, further studies are underway to identify non-obvious indicators for detailed near-miss analyses.

As indicated during our interviews lack of reporter involvement in the investigation, or failure to address what the reporter views as causes, may also discourage future reporting[6].

There are a number of techniques to aid in Root-Cause Analysis. Among many approaches, methods in the literature include[7]:

1. Event and Causal Factor Diagrams: The detailing of events leading up to, during and following an incident, followed by the deconstruction of each sub-event into enabling causal factors linked through AND/OR gates.
2. Event tree analysis: The deconstruction of an event linked through AND/OR gates of the sub-events that would have to, or had to occur to lead to the undesired incident.
3. Fault tree analysis: A deconstruction of an event based on system and component failures.
4. Failure mode and effect analysis: An evaluation of individual subsystems, assemblies and components and assessment of how subsystem failures interact to lead to total system failures. . .
5. The 'Why Test': A recursive procedure for challenging premises of potential root-causes. (Eckes, 2000)
6. Factorial and Taguchi Methods: Experimental procedures for evaluating influencing factors on measurable outputs. (Peace, 1992 and Eckes, 2000)

Bird and Germain (1996) provide an excellent discussion of accident investigation procedures including incident interviewing methods and investigation structure. Many of these methods can equally be applied to near-miss investigations.

[6] The case study provided in Example 1 is based on an account by the operating mechanic. The interviewee thought the causes during the investigation were inconsistent to what he believed the actual causes were. As he was not solicited for input, he believed that he would be less likely to report incidents in future.
[7] It is outside the scope of this paper to provide a thorough presentation of these methods. Readers are referred to Soukas and Rouhiainen (1993), Greenberg and Cramer, eds. (1991), and Paradies and Ungar (2000) for a presentation of analytical tools available.

In developing systems to overcome Root-Cause Analysis obstacles, management systems should ensure:

- Reporter Involvement. The reporter is often intrinsic in understanding what caused a near miss and how it may be avoided in the future. Hence, where possible, the discloser must be involved in determining event causes.
- Two-tiered or above, classification. Having a tiered classification system to assist in the processing of incidents is recommended and was practiced by fifteen out of twenty sites in the study. Multi-tiered investigation systems enable a large number of near-misses to be reported without straining EHS resources or deterring disclosure.

  Some sites in our study classified incidents as High Potential (HP) or Low Potential (LP). At these sites, accidents and some near-misses were classified as HP, with most near-misses classified as LP. HP incidents involved the formation of a team to investigate the incident with investigations performed according to accident investigation protocols. For LPs, a team investigation is not performed and a root-cause analysis and solution determination is performed between discloser and direct supervisor. Having the reporter and supervisor perform RCA and Solution Determination can be beneficial as the first five stages of near miss processing are quickly managed between two individuals.
- Basic Training. With a two-tier system in place, team investigations will likely not occur for most near-misses, consequently all individuals who decide on potential remedying solutions should have an understanding of investigation procedure and a basic method for root-cause analysis.
- Listed Root-Causes. Investigation forms should have entries for multiple direct and root causes. In addition, if solutions are linked in an adjoining column the structure provides a framework to help ensure each cause has a corresponding solution or solutions.
- Integrated systems: The majority (60 %) of near-miss programs analyzed in our study are run independently of accident investigation programs. This can be unfortunate as integrated systems help streamline investigation systems, eliminate system duplication and improve employee understanding that near-misses are intrinsically related to accidents that result in loss. System integration may improve near-miss root-cause analysis with tools developed for accident investigations being similarly applied to near-miss investigations.

**Solution Determination**

It is important that at least one solution be identified for each cause determined in the previous stage. In most cases a given solution may address more than a single cause. Some solutions may be easy to implement while some others may require extensive resources. We recommend identifying all potential solutions but selecting only the ones that can be implemented based on the potential impact (value) of the incident, effectiveness of the solution and the available resources.

The process is achieved through three sub-stages:

1. Generation of potential solutions for a given cause.
2. Comparative evaluation of solutions.
3. Selection of solutions to be implemented.

Generating multiple solutions from which one or several solutions are selected enables investigators to better understand problems at hand, and base decisions on what is effective and also practical. Non-confrontational ‘brainstorming’ activities can be performed between two or more people to obtain an initial list from which solutions may be culled (Eckes, 2000 and Peace, 1992). Where possible, brainstorming solutions should address both incident mitigation (reducing the likelihood of an incident recurring) and incident contingency (reducing impact in the event of recurrence).

With a set of potential solutions identified, the solution set must be reduced to determine which to implement. Gauging how well identified solutions successfully reduce risk exposure is not a simple endeavor since generally metrics are not easily applied. Nonetheless, proposed safety improvements can be rated from most to least beneficial by the following ranking:

1. The solution eliminates the hazard.
2. The solution reduces the hazard level.
3. Safety devices are installed to manage incident recurrence.
4. Warnings are installed to alert people of hazard.
5. Standard Operating Procedures (SOPs) are changed to account for hazard.
6. Employee awareness is increased.

In addition to the proposed solutions reducing the likelihood or impact of the exposed hazard, the solution must also not infer new risks. Hence, solutions must be carefully screened to ensure new and unexpected risks are not inferred upon implementing new solutions.

It is noted that often the remedying of one problem can result in other unforeseen hazards, particularly when changes are subtle. Dowell and Hendershot (1997) provide examples where changes intended to improve safety or process reliability resulted in operations with unexpected risks (the widespread implementation of airbags and the unexpected risks these infer on children is cited as one example). They recommend implementation of Management of Change programs where all process changes are considered. Failure Mode and Effect Analysis in the location of the instituted process changes is one method that can be applied to assess whether changes infer new risks (See Soukas and Rouhiainen, 1993). If new risks are unacceptable alternative solutions must be identified.

Solutions should also be evaluated across non-risk dimensions, to assess the 'ease of implementation'. It is noted selecting solutions based solely on risk-reduction is very undesirable. If solutions are unfavorable to either management or employees further participation in a site near-miss program may be adversely affected. Among other dimensions, solutions should be assessed according to:

1. Solution cost.
2. Potential increased revenue on solution implementation .
3. Potential improved process/product quality of implementation.
4. Employee acceptance of solution.
5. Management acceptance of solutions.
6. Time duration to implement the solution.

An activity to assess solutions to implement is to spatially represent identified solutions on a graph with the abscissa representing solution effectiveness in reducing risk exposure (both directly and in incurring of new risks) and the ordinate representing ease of implementation (the amalgamation of non-risk solution dimensions). Figure 7 provides an example of nine solutions represented in this fashion. Solutions in the upper-right quadrant (i.e. G, B and H) of the graph represent those that appear most favorable.

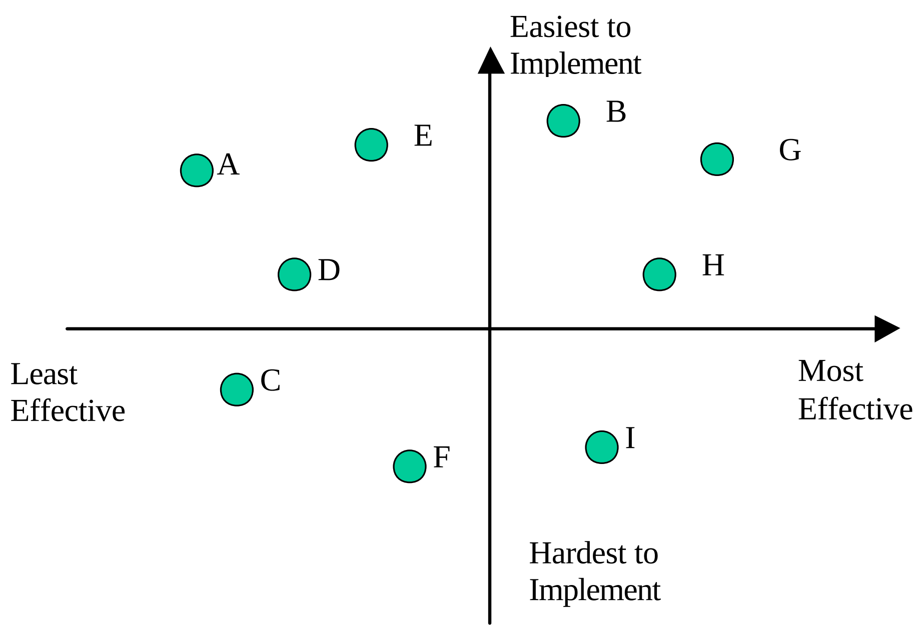


Figure 7. Representation of selection process of nine solutions.

Solutions in other quadrants may be of limited benefit or practicality. Referring to the vapor release case study in Example 1, Solution A, might be to inform the mechanic to be more careful in future – an action item that is easy to complete relative to other solutions, but does little to reduce risk exposure. Solution I, could be to redesign the process such that the tank is not present in process operations. Though the solution would eliminate risk exposure to the described incident, the cost of implementation might be formidable and the time required for implementation unacceptable. Potential solutions in Quadrant 1 might be:

G: Color coding pipework to and from the pressurized tank to aid in isolation.
H: Moving all isolation valves to within the tank housing.
B: Reviewing lock-out/tag-out procedures with site personnel.

In addition to approaches outlined above the following can improve Solution Determination performance:

- Link Solutions to Causes. Report form structure can help ensure that remedying solutions help resolve identified causes. Clear mappings where a solution or solutions are linked to causes reduce the likelihood of spurious solutions being applied. EHS incident reviews should evaluate whether solutions are fulfilling their intended purpose.
- Work-Order Integration. Work orders that stem from an investigation should, where possible be seamlessly integrated with the investigation file. Such that on reviewing a file, it is clear which work-orders remain outstanding and on reviewing a work order it is evident whether the work order resulted from an incident investigation and if so, what were the investigation findings.

Common obstacles that limit Solution Determination success are:

1. Failure to generate more then one solution for an identified cause.
2. Lack of procedures to reduce the number of identified solutions to implement.
3. Failure to address Management of Change issues, whereupon solutions can give rise to unrecognized new risks.
4. Identified solutions fail to achieve their intended purpose. Specifically, the solution does not remedy the identified cause.

Adhering to above practices during solution determination would help to eliminate these obstacles.

**Dissemination**

Upon suitable action being determined for a cause, corresponding action-items are disseminated to implementers. Also, at this point, having completed the incident analysis and determined the remedying actions it becomes prudent to inform the appropriate broader audience of the information collected and decisions made related to this incident.

Hence, the Dissemination stage has two objectives:

1. Transfer action items that stem from a near-miss investigation to implementers.
2. Inform a broader audience of the incident to increase awareness.

In addition, in the event that EHS has not been involved in the investigation to this stage, EHS must review the incident to determine if further investigation is warranted. A more detailed evaluation of the incident may be necessary, if on review it is evident that the near-miss is a repeat incident, indicating previous near-misses were not suitably addressed, or if it is believed that additional root-causes could be uncovered, or farther reaching solutions found.

Common obstacles that limit successful Dissemination include EHS not reviewing incidents, delays in transfer of information to implementers, and under-dissemination, where all whom could benefit learning of the near-miss do not receive the report. One of the most significant problems that deteriorate stage performance is when intended action items are not possible, or resources to complete action items are not available. In such instances it is critical that EHS or similar incident overseers intervene to determine suitable alternative solutions that satisfy the same intended purpose.

Recommendations provided in the Distribution stage apply equally to Dissemination. Particularly intranet systems can be excellent vehicles to transfer information, initiate action item tracking and inform a broad audience of the incident. Action item monitoring to ensure that individuals or departments are not overwhelmed with assignments that stem from incident investigation have been observed and applied successfully.

**Resolution**

Resolution is the final stage where all investigation action items are completed and that all remaining activities prior to closing an incident report are fulfilled. Remaining activities prior to closing an incident file include:

1. Updating the incident report if deviations from the intended action item were implemented.
2. Reviewing/auditing the action items upon completion to ensure the implemented action item fulfills its intended purpose.
3. Informing the reporter, and others when appropriate, that all items that stemmed from the report were completed and the incident file is closed.

Although, sites in our study generally tracked action items successfully until completion, not all sites consistently implemented the three activities listed above. Sites that *did* complete the three activities successfully had update fields on incident investigation forms to track deviations from initially intended actions, had pre-specified audit protocols to review action items on completion, and auto-generated emails that informed the initial reporter when all action items were completed and an incident was closed out. In addition, some companies generated monthly status reports to provide a ‘picture’ of the near-miss programs, and to highlight recently closed incidents and outstanding action items.

A typical ‘action-traction’ algorithm to ensure action items are completed is shown in Figure8. To account for the obstacles that can impede stage performance, observed variations to the action-traction algorithm include:

1. Inclusion to allow for updates in the case of changes to intended design.
2. Audits to evaluate action item effectiveness in satisfying the intended item purpose.
3. Procedures to return the action item to the initiator if implementation of the proposal is not possible. .
4. Priority levels that affect when alerts are sent to implementers for outstanding action items.

Lastly, prior to closing the incident file it may be beneficial to disseminate incident descriptions, findings and actions taken off-site, if the learning value is of significant benefit.

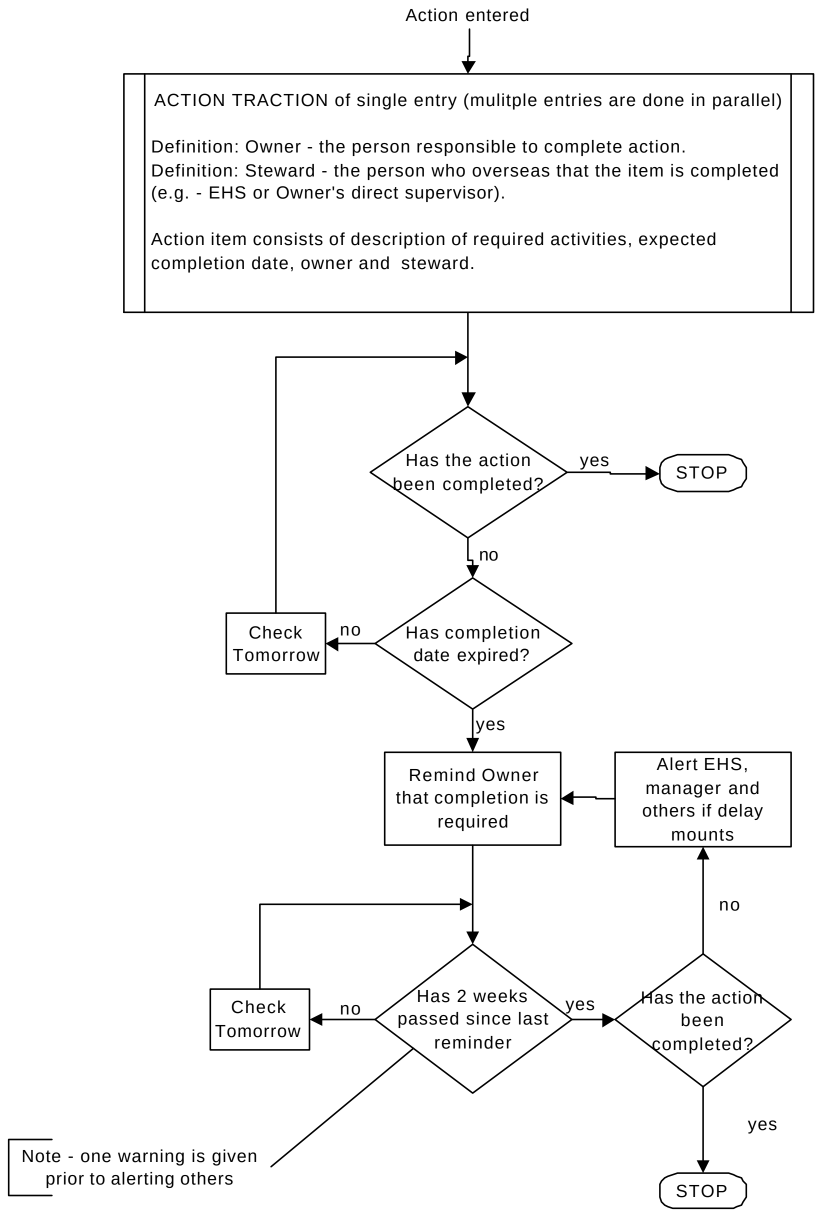


Figure 8. 'Action Traction' algorithm

## 4. CONTINUOUS NEAR-MISS PROGRAM REVISION

Near-misses and accidents provide insight into both potential failure points within the system being analyzed, such as a chemical process, yet also can highlight weaknesses in the management system itself. For, as can be evident in retroactive analysis of accidents, failure in one or more of the seven stages may have occurred. As such, new incidents, whether near-misses or accidents, can provide an opportunity to address and remedy potential weaknesses in the management system. This is particularly the case when new incidents appear to be 'repeats' of previous events, for this indicates that one of the seven stages may have failed to ensure hazards exposed by the previous incident were fully remedied.

Figure 9 is a proposed logic diagram to navigate and address under-performing stages. The diagram illustrates how a company might identify which stages might have under-performed in the event of repeat incidents or an accident. The diagram is only illustrative, but it does indicate the symptoms likely to appear when one or more stages are performing at a sub-par level. For example, following the main flow from the top, suppose that a similar event has occurred in the past. Suppose further (following the flow chart on the right-hand branch) that the previous incident investigation was closed, and the incident occurred on the same site but at a different location. Assuming that due to the skillful site personnel the right level of analysis had been performed and the right precautions were identified and implemented, such a constellation of facts would lead to the suspicion that there may be problems with the dissemination stage of the near-miss management system.


Figure 9. Identifying Potential Weaknesses in Near-Miss Management Program Stages Based on Repeat Incidents or Accidents (potential weaknesses shown in ovals)

## 5. CONCLUSIONS AND FUTURE STUDIES

This paper proposes a near-miss management system model which adds operational and strategic value to corporate Environmental, Health and Safety practice. Since our field visits show that to improve near-miss management systems one must focus on the details of the process by which near misses are reported and analyzed, we identified a seven-stage framework which helps corporations to accomplish this objective. Each one of these stages is critical for the effectiveness of the overall system and is recommended to be processed as follows: "Identification" of a near-miss, "Disclosure" and "Distribution" of relevant information, "Direct and Root Cause Analysis", "Solutions" to prevent recurrence, "Dissemination" of remedial action, and "Resolution" through tracking.

To achieve best results, all seven stages have to be performed interdependently since each stage can only take place if the previous stages have already been completed successfully. Hence, earlier stages in the near-miss management system have "conjunctive" or multiplier effects on later stages.

Although it is important to have a near-miss system where every reported case is completely processed through each and every one of the seven stages, development of such a system is contingent upon thorough understanding of fundamental issues. For example, it is extremely important to avoid cumbersome reporting forms for disclosure, requirements for lengthy analysis for each near-miss, implementation of a solution which creates new problems, etc. Any of these defects could cause near-miss management to do more harm then good to the overall safety process.

Implicit in the structure of our model is that the value associated with near-miss management systems arises from two sources: first, is the conjunctive value of fully executing an investigation; second, is the value derived from an individual stage itself. In addition, there are strong relationships between the near-miss systems, accident management, total quality control, and other strategic and operational components of corporate management. Further discussion of valuation and integration of near-miss systems are presented in Kleindorfer et.al (2001).

Future studies on near-miss management systems will include adaptation of various statistical tools for each one of the seven stages to improve their efficiency, effectiveness, and quality control. Two critical and highly desired research areas that can contribute significantly to corporate management operations are:

- Development of tools for identification of the level of resources to be dedicated to each near-miss based on the potential impact of a given near-miss (with minimum differentiation between the near-misses that are precursors of major accidents from the ones whose impact is more tolerable.)
- Identification of management tools to justify the level of near-miss systems for a given operation.

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**DISCLAIMER**

Although the authors believe the systems described in this paper are an accurate depiction of successful near-miss management systems at Fortune 500 or similarly large companies, no warranty or representation, expressed or implied, is made with respect to any or all of the content herein, and hence no legal responsibility is assumed. The views expressed in this paper are those of the authors and do not necessarily represent views of companies that participated in the study.

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