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Near-Miss Incident Management in the Chemical Process Industry

James R. Phimister,[1] Ulku Oktem,[1]* Paul R. Kleindorfer,[1] and Howard Kunreuther[1]

This article 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 management of near misses. Based on more than 100 interviews at 20 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 systemwide improvements.

KEY WORDS: Near-miss management; precursors; process industries; safety

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 Fig. 1.(1)

Incidents at the pyramid pinnacle, referred to in this article as accidents,[2] 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 the potential to, but do not, result in loss. Near misses are often less obvious than accidents and are defined as having little if any immediate impact on individuals, processes, or the environment. Despite their limited impact, near misses provide insight into accidents that could happen. As numerous catastrophes illustrate, management failure to capture and remedy near misses may foreshadow disaster. Notable examples where near misses 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 lift-off 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 lift-off temperature was 36°F).(2)
2. The 1997 Hindustan refinery explosion in India. Sixty people died and more than 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.(3)

[1] Risk Management and Decision Processes Center, Operations and Information Management, The Wharton School of Management, University of Pennsylvania.

* Address correspondence to Ulku Oktem, Director of the Near-Miss Project, Risk Management and Decision Processes Center, 1323 Steinberg Hall-Dietrich Hall, 3620 Locust Walk, Philadelphia, PA 19104-6366; Oktem@wharton.upenn.edu.

[2] The term "accident" is used to imply solely an incident that involves some form of loss to an individual, environment, property, and/or process.

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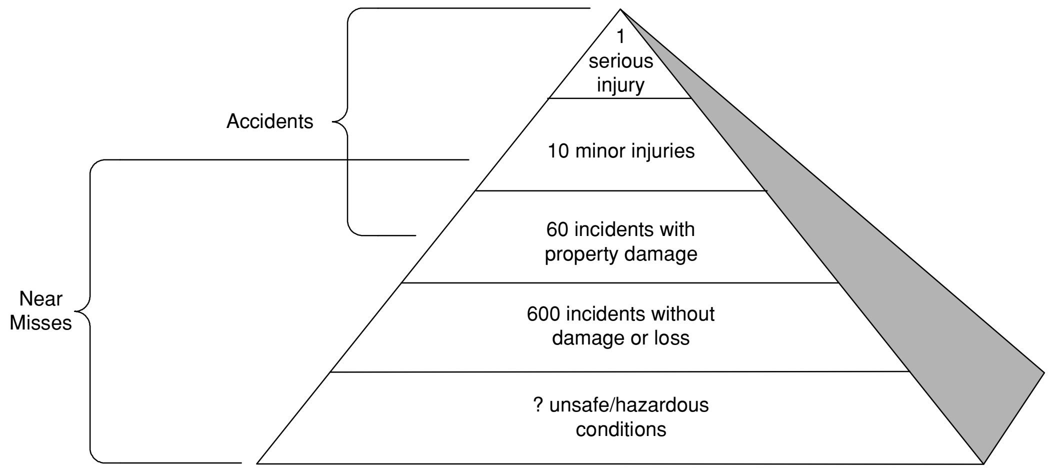

Fig. 1. Safety pyramid (the lowest strata, unsafe conditions, is not shown by Bird and Germain[1]).

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 where the eventual collision and explosion occurred (Signal 109). At the time of the crash, the signal was one of 22 signals with the greatest number of SPADS.[4]
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.[5]

As these examples illustrate, failure to benefit from near misses to identify and remedy systemic flaws can produce catastrophic results. To reduce the likelihood of future catastrophe and further improve employee safety, process reliability, and environment integrity, management systems that recognize operational weaknesses need to be developed to seek and utilize near-miss incidents.[6] 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 and 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*.[7] 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 most detailed study of near-miss management in the chemical industry known to us is the thesis of T. W. Van der Schaaf.[8] The work presents a discussion of the human factors involved in reporting, and emphasizes that to encourage reporting, site management should *not* express or infer the view that near-miss report rates are a desirable metric to decrease over time. The authors of this article found evidence to support this same recommendation.[9]

The Van der Schaaf thesis provides a system for (1) near-miss classification, (2) the analysis of a group of near-miss reports, and (3) the implementation of safety improvements based on near-miss events. In the Van der Schaaf approach, the causes of near misses are identified and classified and are used to analyze human 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). 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.*[10] 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 facilities are studied. In both cases, the results suggest that an increase in near-miss reports can yield improved safety performance. In off-shore drilling, over seven years a 10-fold increase in near-miss reporting corresponded with a 60% reduction in lost time injuries. In on-shore activities, over a 13-year span, an increase in reporting rates from zero, to one report per two employees per year corresponded with a 75% reduction in lost time injuries.[3] Jones *et al.* note the recent inclusion of near misses in the major accident reporting system[(11)] (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.[(12–14)] Precursors are sequences or events in accident chains; on some occasions a precursor event can be considered synonymous with a near miss. 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.[(15,16)] 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 article a seven-stage framework for the management of near misses is presented, with the emphasis on obtaining operational and strategic value from such incidents. The key finding of this article is that near-miss management can be systematized and provide an important reinforcing element of accident prevention and preparedness at hazardous facilities. To do so, however, requires a well-designed infrastructure for recognizing, reporting, analyzing, identifying, and implementing solutions to prevent future near misses and accidents. This article's intended contribution is to synthesize best practices for such an infrastructure from the companies in our interview sample and from other near-miss systems reported in the literature. Although the sample in our study was Fortune 500 companies, the sites visited ranged in size from 50 to several thousand full-time employees; hence we believe that the general framework proposed is widely applicable even though it should be customized to fit particular organizational and business needs.

The article proceeds as follows. In the next section, we describe the structure of near-miss management systems and identify key stages in the processing of 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 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 of near-miss management systems, and with 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. Our field research and surveys of existing near-miss management systems delineate seven consecutive stages underlying the identification and management of near misses. These stages, shown in Fig. 2, are:

1. *Identification*: An incident is recognized to have occurred.
2. *Reporting*: An individual or group reports the incident.
3. *Prioritization and Distribution*: The incident is appraised and information pertaining to the incident is transferred to those who will assess follow-up action.
4. *Causal Analysis*: Based on the near miss, the causal and underlying factors that could have enabled an accident are identified.
5. *Solution Identification*: Solutions to mitigate accident likelihood or limit impact of the potential accident are identified and corrective actions are determined.
6. *Dissemination*: Follow-up corrective actions are relayed to relevant parties. Information is broadcast to a wider audience to increase awareness.
7. *Resolution*: Corrective actions are implemented and evaluated, and other necessary follow-up action is completed.

The seven stages have a "conjunctive" effect on each other. Near misses that are not identified

[3] Estimated from graphs in citation.

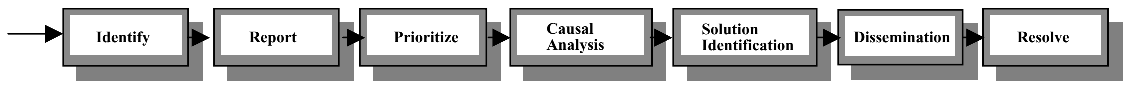

Fig. 2. Incident processing stages.

cannot be used to reduce risk exposure. Further, near misses that are identified but not reported, or identified and reported but not acted on further, will, at best, have a modest impact on reducing site-risk exposure. Implicit in the framework is that only through the successful execution of every stage is the maximum risk reduction achieved for a given near miss.

It is perhaps not surprising that sites often achieve significant risk reduction through forensic evaluation of accidents, although they may gain little benefit in the identification and management of near misses. In an accident, both identification and reporting are all but guaranteed. In such instances, the injury of an individual, an environmental impact, large-scale property damage, and/or other undesirable outcomes force both identification and reporting. The presence of legal and regulatory requirements, combined with other factors such as empathy, employee concern, and desire to avoid event recurrence, ensure that the incident is a high priority and that a prompt and thorough investigation according to predefined investigation protocols is conducted, with corrective actions disseminated and implemented. In contrast, for near misses, many may occur unnoticed. 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. And even for those near misses that are reported, many of the external factors that infer successful stage performance are not present.

Also implicit in the proposed framework is that near misses are analyzed with the intention of reducing the likelihood and/or severity of a potential accident, and not simply in an attempt to reduce the likelihood of a near miss recurring. This assumption presumes a linkage between near misses and accidents and we propose that near misses are linked to potential accidents through an "inherent AND," whereby a near miss *and* an additional event are necessary to culminate in an accident. Based on this observation, we illustrate how this linkage can help structure risk-mitigating decision making in the Causal Analysis and Solution Identification stages.

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 20 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 ones were near Philadelphia in Pennsylvania. Fifty-nine of the interviewees were hourly employees, consisting of laboratory technicians, plant operators, mechanics, and pipefitters. The others were site or company management that included EHS executives, engineers, and plant managers.

Interviews lasted between 20 and 40 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, Reporting, Prioritization and Distribution, Dissemination, and Resolution).

Due to the idiosyncratic nature of incidents and the expertise required to analyze them, interviews did not focus on site performance in the Causal Analysis or Solution Identification stages. However, management structure of these stages (e.g., Are the stages managed separately? Are analytical tools brought to bear? etc.) was analyzed.

4. DISCUSSION OF INDIVIDUAL STAGES

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 for successful stage performance are identified.
3. Common obstacles that impede successful stage performance are outlined.
4. General observations of practice to overcome these obstacles are presented.

4.1. 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, believed that near misses must have resulted in a threat to safety (though not the environment, or potential for significant process upset), or expressed the sentiment of "you know it when you see it."

To have an effective near-miss management system there is an overwhelming need for sites to have an encompassing and helpful near-miss definition that can be easily understood by *all* employees. 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 a situation from which site EHS performance may be improved. In search for a new definition, the tree shown in Fig. 3, which includes desirable definition features, is generated.

The following new definition, based on the elements depicted in Fig. 3, is:

> 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 and conditions are defined as near misses. These include:

- Unsafe conditions.
- Unsafe behavior.
- Minor accidents and 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, identification is encouraged, whereas restrictive definitions, and failure to recognize near misses as opportunities to improve EHS practice, present the possibility that many near misses may not be recognized. Two restrictions to near-miss definitions that were observed in the field are (1) near misses must entail an "event," or (2) 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 Fig. 4, 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 $P(A'/E)$ as the probability barrier A fails if challenged given incident E, $P(B'/EA')$ is 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

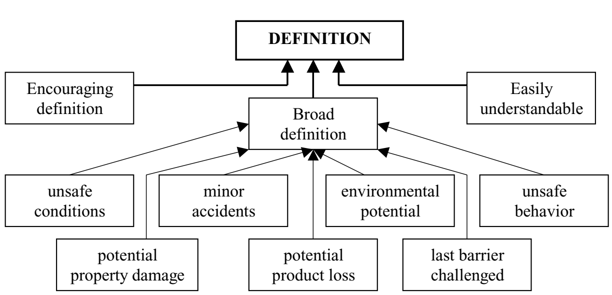

Fig. 3. Definition tree.

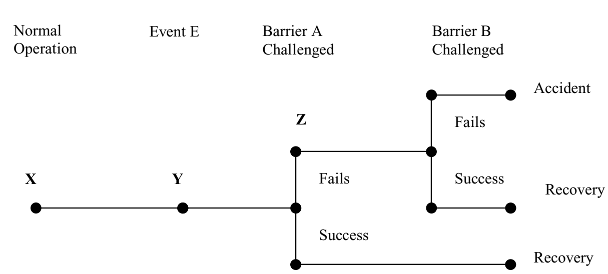

Fig. 4. Event tree with two barriers.

Z it is *P (B/EA')*. Furthermore, provided barriers A and B are in place:

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

where P_i(accident) is the probability of an accident at location *i*. Under these circumstances, a process that exhibits a last barrier challenged is indeed closer to an accident threshold than 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, than 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.

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 20-meter-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 that 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.

4.2. Reporting

A recognized near miss has only limited value, even to the person who recognized it, unless it is reported and properly analyzed with appropriate measures taken to prevent its recurrence. However, when a near miss is recognized, there is no assurance that it will be reported. The objective therefore in the Reporting stage is to ensure that all identified near misses are reported.

Bridges[17] focuses on barriers that inhibit reporting. To increase report rates, Bridges advocates that nine barriers be overcome. In this article 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).
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 reporting. The above barriers and corresponding solutions to address each one of them are presented below.

4.2.1. Reporting Recriminations

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 reporting.
3. *Direct Disciplinary Action*: Concern about receiving a verbal warning, the potential addition of the incident to the employee's record, up to and including job dismissal, will 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. Wide dissemination of submitted near-miss reports.

2. The formation of employee teams to evaluate and prioritize near-miss reports.
3. Publicizing of improvements that result from reported near misses.
4. Requiring a specified number of near misses be reported per person per year (e.g., one per person per year).

Broad dissemination of near-miss reports may be considered counterintuitive to alleviating peer pressure if one thinks an individual would be reluctant to report if he or she believed it was to be widely publicized. However, we found that if near misses are widely disseminated, individuals are exposed to many incidents and an additional report does not draw attention to the reporter, thus 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 that anonymous reporting is problematic because (1) it is often necessary to follow-up with the reporter to ascertain incident causes, and (2) anonymity does not infer that near misses are desirable learning opportunities. Three sites visited offered anonymous reporting, though at these sites anonymity systems were run in conjunction with incentive schemes that encouraged identity disclosure, and hence anonymous reporting was rarely utilized.

Our assessment of existing near-miss systems also suggests that reporting should be quick and simple as completion of long forms discourages reporting. Though follow-up action may necessitate a thorough investigation, a short summary of the near miss and time and location of the incident or observation normally suffices. Including a brief appraisal of causes and potential solutions at the time of reporting is desirable but should not be a reporting requirement. Note that even if completion of the report form is a quick process, if retrieving near-miss forms is difficult, or involves trolling through websites, reporting rates will be adversely affected.

To remove fear of disciplinary action, sites may wish to develop a nondisciplinary 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 corrective actions that result from near-miss investigations might be perceived as punishment. In such cases, alternate solutions should be sought.

4.2.2. Lack of Incentive

Interviewees at 14 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 appropriate remedial action when necessary. Management can also 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, or something similar.
2. *Lottery Systems*: Each near miss constitutes a lottery ticket, with drawings held quarterly, biannually, or annually. Lottery prizes observed at sites included cash prizes, dinner at a local restaurant, event tickets, and a day off.

Of the sites visited, lottery programs showed higher participation levels than giveaway programs, although most sites did not adopt either. The four sites that had "tchotchkes" giveaways had an average near-miss reporting rate of 0.9 per person per year, whereas the two sites that had lottery systems had reporting rates that averaged 3.0 reports per person per year.

Senior and site management should not create disincentives to report near misses. Van der Schaaf[7] 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 although 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, the site's 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 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 submitted near-miss reports as a metric that is desirable to decrease over time.

4.2.3. 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 reporting. 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 a safety event communication was:

> *Could someone benefit by learning from the event?*

It was believed that this simple test encouraged reporting.

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

4.2.4. Lack of Management Commitment

Failure of management to remain committed to near-miss programs can decrease employee reporting and 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 actively seeks to reduce program participation.

Passive failures can be avoided by:

1. Regular report generations and postings that highlight program participation, resulting improvements, and other benefits of the near-miss program.
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 that 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 near-miss program participation correlates favorably with EHS performance.

Active measures by site management to reduce near-miss reporting can stem from inability of site management to process a high level of participation, and management concern about being liable due to inaction on 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 can greatly reduce the resource burden of a 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.[18]

4.3. Prioritization and Distribution

This stage incorporates two tasks: near-miss prioritization and distribution. These two activities are performed in unison to allocate the appropriate time, expertise, and resources to follow-up on an incident.

Prioritization is very important for a near-miss program with a high number of near-miss reports. For these systems, most near misses will be investigated by the reporter and/or his or her supervisor. However, occasionally, some near misses may be flagged as being of a higher priority. Such "high priority" incidents may have some of the following characteristics:

1. Expertise beyond the reporter's/supervisor's capabilities is required to investigate the incident.
2. The incident has significant potential for major loss, environmental damage, costs, and so forth.
3. The incident is recognized as part of a trend and similar or identical to previous near misses and accidents.
4. The potential for "lessons learned" is farther reaching than the majority of near-miss reports.

Correspondingly, high priority reports may have separate distribution channels to ensure that the incident is trafficked to the appropriate parties.

Common obstacles that limit Prioritization and Distribution performance include:

- Lack of understanding of the characteristics of high priority near misses.
- Lack of guidelines or tools to distinguish low and high priority near misses.
- Lack of protocols for low and/or higher priority near misses.
- Slowness in relaying near-miss information.
- Paper distribution systems that do not specify a time frame for near-miss review.
- Distribution systems where information is transferred in series and not in parallel.
- Overprioritizing where investigators are required to analyze in detail relatively straightforward reports.
- Nontargeted distributions where reports do not reach the necessary expertise.

Only one site in our study had an incident prioritization step that was conducted upon reporting the incident, though EHS managers at sites with high reporting rates often expressed the need for such a system. The one site that did prioritize reports used a two-tier rating of low and high priority, with corresponding protocols for each level. Two sites in our study reviewed near-miss reports periodically (monthly or quarterly) in an attempt to discern trends and to flag incidents that required more investigation.

To improve report distribution, four strategies are recommended:

1. Merge incident distribution with reporting. This can be performed relatively easily in automated systems, where decisionmakers, whether supervisors, EHS managers, engineers, or others, are copied upon initial reporting.
2. Specify 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 certain time frame.
3. Automate systems to ensure cross-checking. These systems require management review to confirm accurate prioritization.
4. Enable reporters and supervisors to perform most investigations. Such systems that engage reporters and supervisors to perform investigations involve employees, quicken investigations, and decrease investigator and EHS workload.

4.4. Causal Analysis

Once a near miss is reported and transferred to appropriate parties, it is necessary to carry out steps to ensure that the near miss does not recur. The objective in Causal 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. Although in structuring near-miss programs it is important to recognize the interaction between Causal Analysis and Solution Identification, it is equally important to recognize that these are two distinct activities.

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

1. Lack of tools or frameworks to analyze near misses.
2. Insufficient expertise to analyze near misses.
3. Dilution of relevant information due to information transfer or lapsed time prior to incident investigation.

The presence of the feedback loop between Causal Analysis and Reporting must be recognized in structuring stage activities. There can be a tradeoff between high reporting rates and comprehensive investigations in that if all reported near misses are thoroughly investigated, near-miss reporting may be adversely affected due to concern over lengthy proceedings. As a consequence, many sites may wish to forego a lengthy investigation for most reported near misses. At the same time, and as indicated during our interviews, reporters must have some involvement in the investigation, for failure to consider what the reporter views as causes may discourage future reporting.

In sites visited, root-cause analysis tools were generally not used to analyze near misses; rather, sites appeared to base corrective actions on incident descriptions. There are a number of techniques to aid in Causal Analysis that are widely used in accident investigations. These include:

1. *Event and Causal Factor Diagrams*: The detailing of events leading up to, during, and following an incident, followed by the

deconstruction of each subevent into enabling causal factors linked through AND/OR gates.
2. *Event-Tree Analysis*: An evaluation of successive outcomes that could occur after an initiating event.
3. *Fault-Tree Analysis*: A deconstruction of an event based on possible or required prior failures or events.
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.

Many of these methods can equally be applied to near-miss investigations although it is outside the scope of this article to provide a thorough presentation of these methods. Readers are referred to Soukas and Rouhiainen,[19] Greenberg and Cramer,[20] and Paradies and Ungar[21] for presentations of analytical tools available. In addition, Bird and Germain[1] provide a discussion of accident investigation procedures and incident interviewing methods.

Four sites provided questions on the report form that attempted to gauge the "most-likely accident scenario" had the near miss been an accident. None of the sites asked what would have been the additional contributing factors or events (nonmaterialized key events) necessary to occur for the near miss to be an accident. It is noted that these three events—the near miss, the potential accident, and a contributing event—can be linked through the fault tree shown in Fig. 5.

As an example, one story we heard concerned an individual who was replacing a light bulb on a platform several stories high. The light bulb that was being removed was hot, and upon being removed lightly burned the individual. The light bulb slipped out of the person's hand and shattered on the platform grating, spraying shards of glass onto lower levels. An accident was averted as no one was walking below. Fig. 6 illustrates how this near-miss's accident potential can be represented as a simplified fault tree.

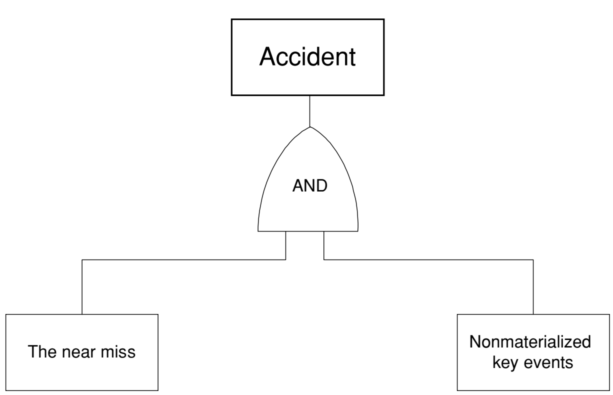

Fig. 5. Near-miss fault tree.

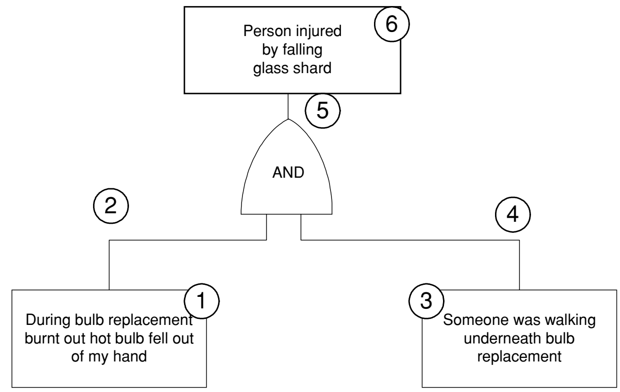

Fig. 6. Near-miss fault tree for bulb-breaking incident (circles 1–6 represent leverage points for corrective actions; see Solution Identification).

In developing systems to address weaknesses in the Causal Analysis, the following practices were observed:

- *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 reporter must be involved in determining causal factors.
- *Listed 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*: Although the majority (60%) of near-miss programs analyzed in our study are run independently of accident-investigation programs, some integrated accident and near-miss systems to 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.

4.5. Solution Identification

The objective in the Solution Identification stage is to determine corrective actions that will remedy causes of the potential accident.

The process is achieved through three substages.

1. Generation of potential corrective actions.
2. Comparative evaluation of corrective actions.
3. Selection of corrective actions to implement.

None of the sites in our survey had a widely applied procedure for generating corrective actions to prevent future near misses. Rather, appropriate corrective actions were generally thought to be identifiable by the reporter and/or supervisor. All sites did have management of change procedures to screen corrective actions for the possibility of new risks created by the corrective action, but the application of these procedures was not assessed.

The authors believe the generation of multiple corrective actions from which one or several are selected for implementation enables investigators to better determine corrective actions that are both effective and also practical. Generation of multiple solutions can be achieved through nonconfrontational "brainstorming" activities between two or more people to obtain an initial list from which solutions may be culled.[22,23] Alternatively, corrective actions can be determined for the fault-tree leverage points shown in Fig. 6 using the following guidelines.

- *Leverage Point 1*: Based on the near-miss description, corrective actions are determined to reduce the likelihood of the *near miss* occurring again.
- *Leverage Point 2*: Assuming the near miss described in Leverage Point 1 occurs, a "barrier" is constructed to make it less likely that the event can be joined with the *nonoccurring* key event.
- *Leverage Point 3*: Based on the description of the other key event, corrective actions are determined to make the occurrence of this nonevent less likely.
- *Leverage Point 4*: Assuming the nonoccurring event described in Leverage Point 3 occurs, a "barrier" is constructed to make it less likely that the event can be joined with the near miss.
- *Leverage Point 5*: Assuming both the near miss and the other nonoccurring event occur and that any barriers constructed at Leverage Points 3 and 4 fail, a barrier is determined to make the accident less likely.
- *Leverage Point 6*: Assuming that the accident occurs, contingency plans to lessen the severity of the accident are determined.

Table I. Potential Corrective Actions for Bulb-Breaking Incident Based on Incident Leverage Points

1A:	Always wait for bulbs to cool prior to replacement.
1B:	Wear gloves while replacing bulbs.
2A:	Put drop blanket below area of bulb replacement.
3A:	Install warning signs or cones on floors below signaling overhead work.
4A:	Rather than grating each floor, put covers on each floor to prevent objects falling through.
5A:	Use shatter-proof bulbs.
5B:	Continue to ensure hard-hat compliance.
6A:	Put first aid stations closer to platforms.
6B:	Train personnel in removing glass shards.

Table I shows potential corrective actions for the bulb-breaking example depicted in Fig. 6, at each leverage point.

With a set of potential solutions identified, the solution set must be reduced to determine which corrective action or actions 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 loosely rated from most to least beneficial by the following ranking.

1. The corrective action eliminates the hazard.
2. The corrective action reduces the hazard level.
3. The corrective action manages incident recurrence.
4. The corrective action alerts people of hazard (e.g., through alarms or signs).
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, corrective actions must be carefully screened to ensure that new and unexpected risks are not inferred upon implementing new solutions. Here it is stressed that the remedying of one problem can result in other unforeseen hazards, particularly when changes are subtle. Dowell and Hendershot[24] provide examples of changes intended to improve safety or process reliability resulting 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.[19] If new risks are unacceptable, alternative solutions must be identified.

Corrective actions should be evaluated across nonrisk dimensions to assess the "practicality" of the solution. It is noted that selecting corrective actions based solely on risk reduction may not be practical. If solutions are unfavorable to either management or employees, future reporting and 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 solution.
6. Time needed to implement the solution.

Preference diagrams can assist in the screening of corrective actions. These diagrams 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 practicality (the amalgamation of nonrisk solution dimensions). Fig. 7 provides a hypothetical preference diagram for the bulb-breaking example. This diagram is generated by placing a corrective action on the diagram and positioning other corrective actions relative to the first (and each other). The corrective actions in the upper-right quadrant are deemed the most preferable.

In addition to approaches outlined above, the following can improve Solution Identification 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 corrective actions are resolving identified causes.
- *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 the investigation findings were.

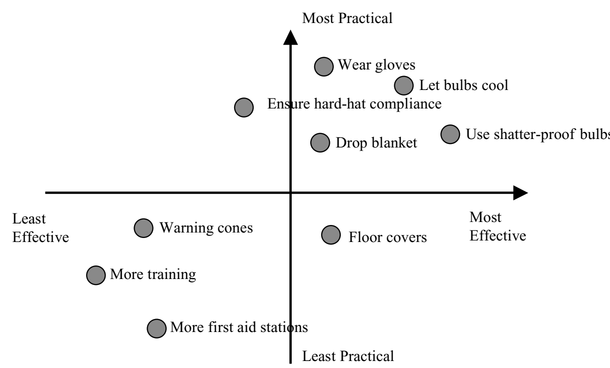

Fig. 7. Preference diagram for bulb-breaking incident.

Common obstacles that limit Solution Identification success are:

1. Failure to generate more than one corrective action for a near miss.
2. Lack of procedures to reduce the number of identified corrective actions to just a few for implementation.
3. Failure to address management of change issues, whereupon solutions give rise to unrecognized new risks.
4. Identified corrective actions fail to achieve their intended purpose. Specifically, the solution does not remedy the identified cause.

Adhering to above practices during Solution Identification should help to eliminate these obstacles.

4.6. Dissemination

Upon suitable corrective actions being determined, they are disseminated to implementers. Also, at this point, having completed the near-miss analysis and determined the remedying actions it becomes prudent to inform a broader audience of the information collected and decisions made.

Hence, there are two objectives in the Dissemination stage.

1. Transfer corrective actions that stem from a near-miss investigation to implementers.
2. Inform a broader audience of the incident so as to increase awareness.

In addition, if EHS has *not* been involved in the investigation to this stage, it may be desirable for EHS to 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, thus indicating that previous near misses were not suitably addressed, or if it is believed that additional root causes could be uncovered, or farther-reaching solutions found.

The two objectives have corresponding challenges. One of the most significant problems that deteriorate stage performance when transferring action-item information is when intended corrective actions are not possible (e.g., due to lack of resources). In such instances it is critical that EHS or similar incident overseers intervene to determine suitable alternative solutions that satisfy the same intended purpose. Common obstacles that limit the sharing of lessons learned include both underdissemination, where all who could benefit from learning of the near miss do not receive the near-miss report, and overdissemination, where reports are not read or absorbed due to the high number of reports disseminated.

Recommendations provided in the Prioritization and Distribution stage apply equally to Dissemination. Particularly, intranet systems can be excellent vehicles for transferring information, initiating action tracking, and informing a broad audience of the report. Corrective-action monitoring to ensure that individuals or departments are not overwhelmed with assignments that stem from investigations have been observed and applied successfully.

4.7. Resolution

Resolution is the final stage—all investigation corrective actions are completed and all remaining activities prior to closing an incident report are fulfilled. Remaining activities prior to closing an incident file include:

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

Although sites in our study generally tracked corrective actions until completion, not all sites consistently implemented the three activities listed above. Sites that *did* complete the three activities had update fields on report forms to track deviations from initially intended actions, prespecified audit protocols to review completed corrective actions, and autogenerated emails that informed the initial reporter when all corrective actions were completed and the report was closed. 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 corrective actions.

A typical "action-traction" algorithm to ensure corrective actions are completed is shown in Fig. 8. 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 offsite if the learning value is of significant benefit.

5. CONCLUSIONS AND FUTURE STUDIES

This article proposes a near-miss management framework that 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 identified,

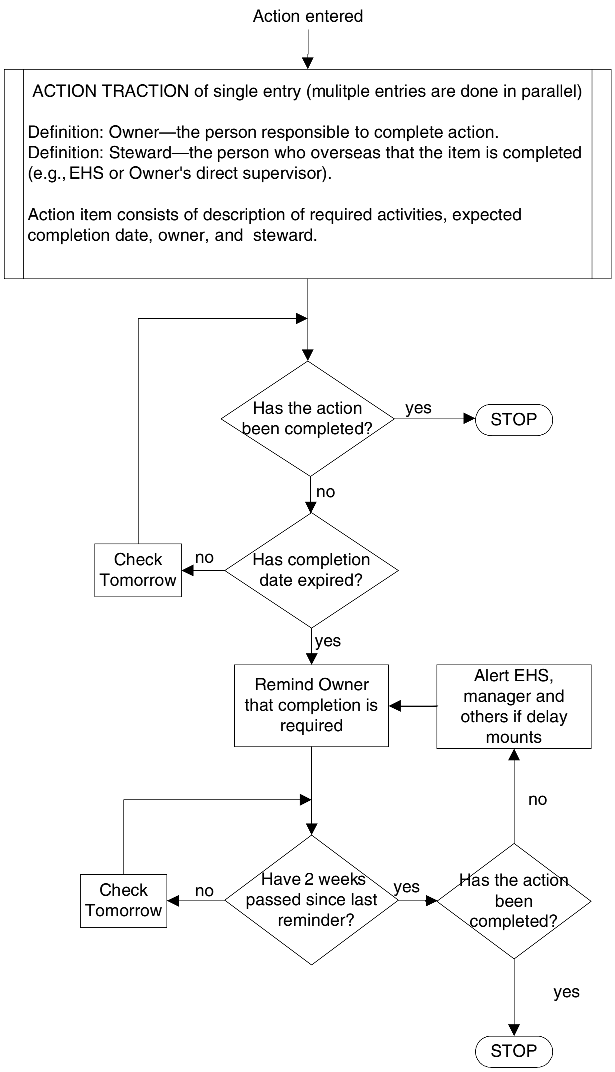

Fig. 8. Action-traction algorithm.

reported, analyzed, and, where appropriate, corrective actions implemented, we identify a seven-stage framework that helps sites accomplish this objective. Each one of these stages is critical for the effectiveness of the overall system, with incidents recommended to be processed as follows: *Identification* of a near miss, *Reporting* and *Prioritization and Distribution* of relevant information, *Causal Analysis*, *Identification of Solutions* to prevent recurrence, *Dissemination* of remedial action, and *Resolution* through tracking. To achieve best results, all seven stages must be performed in sequential fashion.

Since each stage can take place only if the previous stages have already been completed successfully, earlier stages in the near-miss management system have "conjunctive" effects on later stages. Although it is important to have a near-miss system where all stages perform successfully, development of such a system is contingent upon thorough understanding of fundamental issues. For example, it is important to avoid cumbersome reporting forms, lengthy analysis for every near miss, corrective actions that discourage future reporting, and so forth. Any of these defects could cause near-miss management to do more harm then good to the overall safety process.

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 the identification of resource levels to be dedicated to each near miss based on the potential impact of the incident (thereby differentiating between near misses that illuminate potential for major accidents from ones whose impact is more tolerable).
- Identification of tools for the leveraging of knowledge that is collected and stored in near-miss databases.

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DISCLAIMER

Although the authors believe the systems described in this article 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 article are those of the authors and do not necessarily represent views of companies that participated in the study.

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