Critical Thinking Concepts

Applications to incident investigation

By Jack Philley

THIS ARTICLE ADDRESSES application of critical thinking skills to incident investigation. In many instances, cause scenarios are not initially obvious. Useful physical evidence is often destroyed or distorted. Because information from direct eyewitnesses is not always reliable, accurate or complete, the investigation team is often confronted with conflicting information. In addition to finding the most likely causes and identifying potential measures to prevent a repeat incident, the investigation team must also justify why it has rejected alternate scenarios. For these reasons, incident investigation can be enhanced by application of critical thinking skills.

The term critical thinking is applied to various contexts and has different meanings to different groups. One simple definition is that critical thinking is "thinking about your thinking."

A more specific definition is, "the art of thinking about your thinking while you are thinking, in order to make your thinking better (thereby making your thinking more clear, more accurate or more defensible)"(Center for Critical Thinking). Another useful definition of critical thinking is "logical thinking that draws conclusions from the facts and evidence" (North Central).

Critical thinking applies concepts of logic and reasoning to problem-solving activities in order to produce more accurate and defendable investigation findings. It helps the investigation team:

•Identify credibly possible causes.

•Evaluate evidence in support of (or to refute) a proposed cause scenario hypothesis.

•Identify the need for additional specific evidence to confirm or refute a proposed cause scenario.

•Select the most appropriate cause scenario.

The scientific method is a systematic approach (Figure 1) that provides structure and enables investigators to apply critical thinking and analysis to identify the most likely causes and scenario (NFPA). For incident investigation, the first step—problem recognition—is usually not a concern. The recognized problem is that an accident has happened and the defined objective is to prevent a similar event.

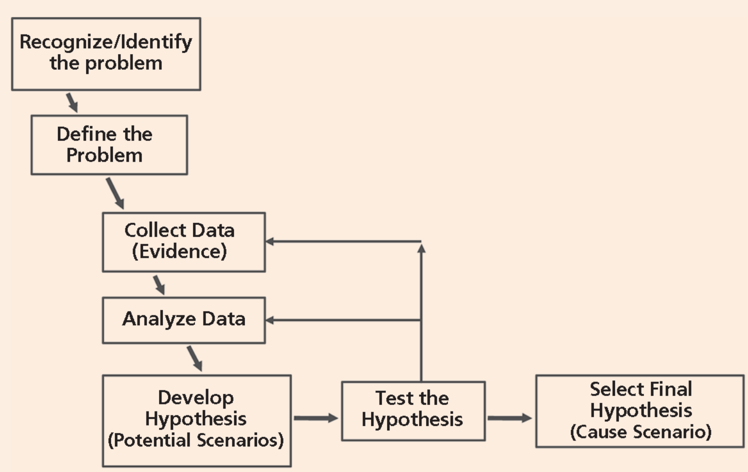
The second step—defining the problem—involves establishing the specific investigation scope (and boundaries) as well as developing an investigation plan appropriate to the complexity of the event and circumstances. The investigation plan addresses team organization, specific tasks and activities, resources, expectations for cause determination, and report, timetables and communications.

The next step is data collection. Applied to incident investigation, this step pertains to evidence. It is extensive and includes gathering:

Jack Philley, CSP, *is an incident investigator and senior consultant with Baker Engineering and Risk Consultants (BakerRisk) in Stafford, TX. He holds a B.S. in Chemical Engineering from Louisiana State University and has 21 years' in-plant experience in chemical manufacturing, loss prevention and process safety. Philley participated in development of the incident investigation guidelines published by the Center for Chemical Process Safety. He is lead instructor for the Mary K. O'Connor Process Safety Center training course in root-cause incident investigation. Philley is a professional member of ASSE's Gulf Coast Chapter and is Assistant Administrator of the Society's Engineering Practice Specialty.*

Figure 1

Scientific Method



Source: NFPA 921 Section 2.3

- physical evidence;
- information from witnesses;
- other relevant facts that could be useful to identify what happened, and how, when and why.

Data analysis is then conducted to identify and evaluate credibly possible scenarios based on an understanding of the information currently available. This information is used to refine the understanding and either validate, modify or reject the speculated cause hypothesis. Alternate explanations (hypotheses) are developed and examined (tested) in an iterative approach based on increasingly accurate and complete understanding of the facts, conditions and possible causes. Scenarios that do not match the facts are ultimately rejected. Data collection, data analysis and hypothesis identification are iterative activities, accompanied by a feedback loop as shown in Figure 1.

The final outcome of the scientific method applied to incident investigation is accurate selection of the most likely cause scenario. This process is iterative and critical thinking is necessary to prevent erroneous and premature conclusions, inaccurate assumptions and incorrect cause determinations. Critical thinking also has application in the evaluation and decision process when considering alternate potential cause scenarios.

Critical thinking encompasses deductive, inductive and lateral thinking. The deductive approach reasons from the general case to the specific instance. Deductive thinking looks back in time to identify and examine preceding events that were necessary and sufficient to produce the designated result. In deductive incident investigation, a given failure is specified, then one attempts to determine what set of credible causes, enabling conditions, events, facts and circumstances could have produced this result. Fault tree analysis is a common application of deductive investigation approach (Roland and Moriarty).

A second reasoning approach is the inductive approach through which a given fault (or failure such as an accident) is speculated; the investigation team then identifies and analyzes probable outcomes that result from this specific failure. The inductive approach generally looks forward in time to consider "what would happen if?" A common application of inductive thinking is hazard and operability study (HAZOP) during which a particular failure deviation is speculated, and the study team examines the affect on the behavior of the system (consequences) (CCPS).

Lateral thinking is another useful concept in incident investigation. Such thinking is popularly characterized as "thinking outside the box." When applying lateral thinking, investigators search for alternate or nontraditional explanations or solutions that fit a given set of conditions.

Critical Thinking Validation of Cause Scenarios

A primary challenge to every investigation is accurate and rapid determination of the most likely cause scenario(s). Validating a speculated scenario is fundamental to investigation success. When attempting to prove a theory or hypothesis, a set of six validity tests is often applied (Lett). In a purely academic research environment, these tests are applied and subjected to peer review. These validation principles can be applied to enhance investigation effectiveness.

1) Is the scenario logical?
2) Is it comprehensive in addressing all known evidence?
3) Are causes sufficient to create the result?
4) Can it be tested to prove it to be true or false (falsifiability)?
5) Can it be replicated?
6) Does it have honesty and integrity?

Logical Scenario

The first validity test is to confirm that the scenario and associated facts agree with accepted logic principles. Logic is defined as "the scientific study of the principles of reasoning, especially of the method and validity of deductive reasoning" (Webster's).

Any argument offered as evidence to support or disprove a suspected incident cause hypothesis must follow accepted rules of logic. Two excellent examples of the logic test application are the fact-hypothesis matrix (CCPS) and the use of truth tables when testing the output of binary electronic circuits or when diagnosing/troubleshooting instrumentation systems. To investigate complex events, a deductive logic diagram similar to a fault tree is often developed. A properly executed logic diagram can quickly highlight information that is inconsistent or contradicts aspects of a proposed incident cause scenario.

Figure 2 presents an example of an incident investigation logic diagram. This diagram illustrates a slip-trip-fall accident. It shows the relationship between known or suspected facts, conditions and event outcomes. The team applies critical thinking to develop the diagram in an iterative manner in order to identify what conditions and actions may have been present or were needed for the accident to occur. The diagram will highlight missing or contradictory information and can guide the team to gather additional focused evidence or data.

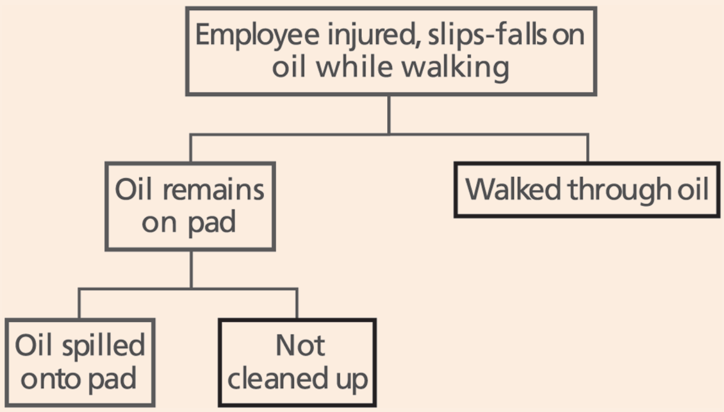
Once sufficient evidence is found to refute a particular cause or condition branch, further development of that branch is terminated and documented. In the case illustrated in Figure 2, the investigation team would proceed to gather information and evidence in order to validate or refute each branch of the logic diagram. Near the final stage of the investigation, logic diagrams can be used in a quality assurance mode to verify that known facts meet logic principles and that each branch is in agreement with all other branches.

Traditional fault trees have two fundamental logic gate relationships—the OR gate and the AND gate (Roland and Moriarty). The OR gate represents a situation/scenario where any one of several input events will lead to the output event. An incident investigation example would be the initial search for a source of ignition for an accidental fire. Potential input events to the ignition source OR gate might include: welding spark, electrical short circuit, spontaneous ignition or

Abstract: *Critical thinking concepts can help incident investigators identify and determine the most likely cause scenario(s). This article examines critical thinking techniques applicable for developing, evaluating, proving and disproving potential cause hypothesis scenarios. Several common but avoidable mistakes in scenario determination are addressed as well.*

Figure 2

Partial Logic Diagram for a Slip/Fall Incident



employee smoking. If any one of these sources were present, they could function as an ignition source. A critical thinking approach will also consider the possibility that more than one cause could be present.

The AND gate represents a condition in which all of the inputs must be present in order for the output event to occur. For an accidental fire incident, all three inputs (fuel, oxidizer and ignition source) must be present. If any one is absent, then the output (accidental fire) will not occur.

In the example depicted in Figure 2, the incident investigation team is faced with several credibly possible failure modes and scenarios. During the early stages of an investigation, the team may not be able to determine whether the braches of the logic diagram are connected in an OR gate or an AND gate relationship. One of several credibly possible failure modes could have occurred (OR gates). The relationships may not be sufficiently understood (is the relationship an OR gate or AND gate). As additional information is gathered and analyzed, the relationships between facts and conditions are better understood, and the logic tree is refined. In these cases, logical and critical thinking can be applied to identify what additional evidence (or information) should be gathered or what restructuring of the logic tree is needed.

Comprehensiveness

The second validity test confirms that all known information has been considered. The team does not have the prerogative to reject facts that do not support its preferred hypothesis (cause scenario). Most investigators have a natural desire to welcome information that supports the preferred cause scenario hypothesis and a desire to disregard or reject information which does not support or fit into that hypothesis. At the conclusion of the investigation, if any evidence contradicts the cause scenario, reasons for refuting this contradictory information should be adequately documented, well understood and accepted by the investigation team (Gilovich).

Sufficiency

The third validity test is sufficiency. Evidence offered in support of a cause scenario must be adequate to establish proof. If a scenario requires three components to be present (AND gate relationship), then the investigation team must establish the credible presence of all three components.

Falsifiability

The fourth validity test, falsifiability, has a curious and potentially confusing title. The test of falsifiability requires that it must be possible to design and conduct a test which has the potential to prove a suspected scenario to be false. It must be theoretically possible to find evidence that has the potential to refute the hypothesis. The investigation team would then search for this evidence during the investigation.

Consider this falsifiable cause scenario. Chlorine gas was released when a control system malfunctioned. The investigation team speculated that one possible cause scenario was the freezing of a water-glycol mixture in a section of instrument air process piping. This may have created an obstruction that interrupted instrument air supply to a control valve and caused the valve to malfunction.

The team knew that occasionally this glycol mixture was found in portions of the instrument air supply system. The freeze point of the mixture had never been determined and the team was unsure that its freezing was a credibly possible cause scenario. The team speculated that the process temperature could have reached -2ºF. If this obstruction was present, it could have resulted in an upset to a primary control valve, which could then malfunction and subsequently cause a release of chlorine gas to the atmosphere.

For the team's hypothesis to meet the test of falsifiability, it must be possible to devise a test to determine behavior of the water-glycol mixture at temperatures at -2ºF. During the investigation, the team was able to determine by actual controlled testing that this particular mixture would freeze at temperatures at or below -2ºF. In this example, there was the potential ability to gather evidence that could disprove (falsify) the speculated hypothesis. If the mixture did not freeze at -2º F, the team's suspected cause hypothesis would be proven false. In this particular case, the proposed scenario satisfied the test of falsifiability.

Replicability

The validity test of replicability requires that all evidence based on experimental results must be capable of being duplicated by others using the same conditions. One well-known example of non-replicability is the cold fusion controversy. In 1989, two University of Utah researchers believed they had discovered a method for cold fusion (Shermer). It became evident that other scientists could not replicate the results claimed by these scientists and the cold fusion hypothesis was ultimately rejected.

An example of this test in an industrial setting would be confirming or refuting a proposed cause scenario. If the investigation team believed the accident was caused by the presence of a contaminant in the reactor feed streams initiated by an adverse chemical reaction and no unreacted liquid remained after the accident, then the team could attempt to replicate (on a smaller scale) the inadvertent chemical reaction to determine whether this was a valid cause scenario.

Honesty

The final validity test is honesty. While this test seems to be an obvious requirement, in handling and presentating evidence, opporunities exist for misleading or incomplete representation of the facts. The investigation team must exercise a high degree of honesty and integrity, even in cases where the findings may not favor the organization's reputation. Omission of pertinent information can have a significant affect on litigation findings. Evidence must be evaluated honestly and truthfully with as much objectivity as possible. The team is obligated to draw rational conclusions after considering all available information and to document any unresolved inconsistencies.

Critical Thinking Applied to Incident Investigation

Logic

Investigators must apply logic and reason effectively. Reason is the ability to discern logical relationships between concepts and propositions. For example: If the temperature in tank A was higher than in tank B and if the temperature in tank B was higher than in tank C, then, by logic and reason, the temperature in tank A must have been higher than in tank C.

Truth (Honesty & Accuracy)

Another challenge is to determine which information is actually true. Investigators will often encounter apparently contradictory statements from witnesses. Most witness statements are combinations of actual true facts, personal opinions and judgments on the part of the witness (Schacter). Witness statements are most often a combination of first-hand (first-generation) information, assumptions, perceptions, conclusions and hearsay (second- generation information). Information relayed in a verbal manner is subject to distortion and inaccuracy. In some cases, people are not even aware that they are modifying information during the transfer. Absolute truth is not created by consensus of opinion. Just because a group of people believes information to be true does not make it a fact.

Incident investigators often encounter cases of subjective opinion, misperceptions, misunderstandings or miscommunications masquerading as truth. Consider the several categories of "truth." A necessary truth is a statement that cannot by definition be false. Examples of necessary truth are:

- Two + two = four.
- Bachelors are single.
- Red is a color.

A necessary falsehood is a statement that cannot by definition be true. Examples are

- Two + two = five.
- Bachelors are married.
- Red in not a color.

Investigators must apply critical thinking to recognize necessary truths and falsehoods. Investigators should also be alert for dogmatic statements that are not supported by actual evidence. Dogmatism is establishing conclusions based on primarily rules, conditions, protocols and prescriptions established by some authority. For example, the fact that oxygen tests are required by policy and/or are stated in written procedures does not mean that a test was actually conducted before the confined space involved in the particular incident was entered. Dogmatic requirements should not be mistaken for actual facts. The investigation team must verify assumptions. Any stipulations should be clearly and thoroughly documented.

Memory Challenges

Memory inefficiency is another variable that investigators must manage. Here again, investigators must apply critical thinking skills when faced with apparently contradictory information from different witnesses.

Significant differences in witness statements can be traced to the imperfect memory mechanisms of humans. A person's memory does not function like a tape recorder. When a person remembers, s/he is recalling and reconstructing a perception of what s/he believes was seen (Schacter; Carroll). A person recalls what s/he believes (perceive) to have happened, not necessarily what actually happened. The mind automatically fills in missing details and adjusts perception. Whenever two witnesses discuss the incident with each other, each person's understanding of the event changes and, therefore, the perceived memory of the event is invariably altered (Shick and Vaughn). Perceptions can change over time as a person loses the ability to recall details (for example, a person's name) and as additional information is gained from interaction with other people and other information sources.

Filtering

One obstacle to evidence analysis is natural information filtering mechanisms that are part of a person's normal thinking processes. The perception of reality is actually a mental construction of several components (Gilovich). The three primary components are:

- inputs from the senses;
- expectations based on prior experiences;
- pre-existing set of beliefs and convictions.

When faced with incomplete or potentially contradictory information, the brain attempts to fill in the blanks to allow a person to process and make sense of the incoming information. The most common example of this is the optical illusion, where the brain makes a determination when faced with ambiguous input (Figure 3).

Lateral Thinking

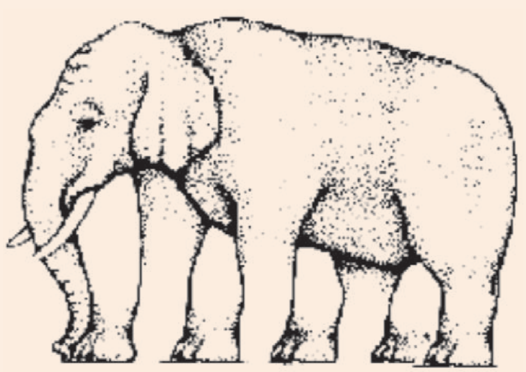
Lateral thinking refers to the concept of seeking alternate (nontraditional) explanations for a given set of information or circumstances. Lateral thinking allows and encourages investigators to deviate from normal conventions and expectations. Creativity is used to identify alternate explanations. Lateral thinking concepts are extremely useful during early stages of an investigation and when apparent inconsistencies exist in evidence.

When presented with a set of circumstances, a person's first response is to seek a traditional explanation that fits the facts as they are understood. A lateral thinking strategy would expand that process to include alternate, less-probable explanations for the same set of facts. Alternate possible scenarios remain on the table until clear reasons emerge for rejecting them.

In the lateral thinking approach, investigators are encouraged to temporarily put aside conventional norms and look for lower probability explanations and circumstances. These types of thinking skills ensure that all credibly possible scenarios and causes are identified and evaluated.

Figure 3

Optical Illusion



How many legs does this elephant have?

Creative thinking is not always welcomed, however. Sometimes, it generates extra work for the investigation team, as the group must document why alternate explanations were rejected. Nevertheless, it adds to the overall quality of the investigation and makes the ultimate findings more credible and defendable. Another application of creative thinking is to make a conscious effort to identify what is missing that one would expect to be present. It is more difficult to spot omissions than it is to spot extra or erroneous items.

Data Quality

The quality (accuracy, completeness) of information encountered during investigations varies widely. This range can best be viewed as a spectrum (Figure 4). Incident investigators must work with the entire spectrum and should use critical thinking when evaluating quality of the data and information being considered as evidence. At the highest end of the spectrum are facts. Facts are verifiable, measurable, precise and accurate. Tests and scientific analyses conducted on physical evidence will yield factual information that is reproducible. Just below facts on the data quality spectrum is the category of inferred information. For example, if it is known that a methanol pump was started at 1801 hours, if the hydrocarbon gas detector system noted the presence of flammable vapors at 1802 hours and if no other activity occurred in the immediate vicinity, then it can be logically inferred that a causal relationship exists between these two events.

The next category is anecdotal information, which is based primarily on personal experience or observation. For example, a person may have observed automobiles involved in accidents and made a judgment based on that experience that yellow-colored vehicles are less likely to be involved in accidents than vehicles of other colors. The underlying reason for this outcome may not be known. It could be related to the visibility of the color at night and during rainy/foggy conditions, or it could be the personality of those who prefer yellow-colored vehicles, or it could be the result of some other factor that has not yet been identified.

Opinions are next on the spectrum. Such information could be based on consensus group discussions or on assumptions and commonly accepted beliefs that may or may not be true. One example of opinion masquerading as fact was the widely accepted belief that the earth was flat.

The lower tiers of the data quality spectrum include hearsay, guesses, brainstorming and fantasy. Information provided by these sources has less accuracy, yet may be useful as a stepping stone to help investigators gather more-reliable evidence. Hearsay information is slightly better than guesses. Educated guesses are considered to be generally more reliable than information generated by brainstorming.

At the bottom of the spectrum is the imaginary information believed by a witness to be the truth. Information from witness interviews can contain a mixture of all types of data quality. The challenge to investigators is to accurately determine and recognize the quality of information being used in the investigation, and to make adjustments and confirmations where appropriate.

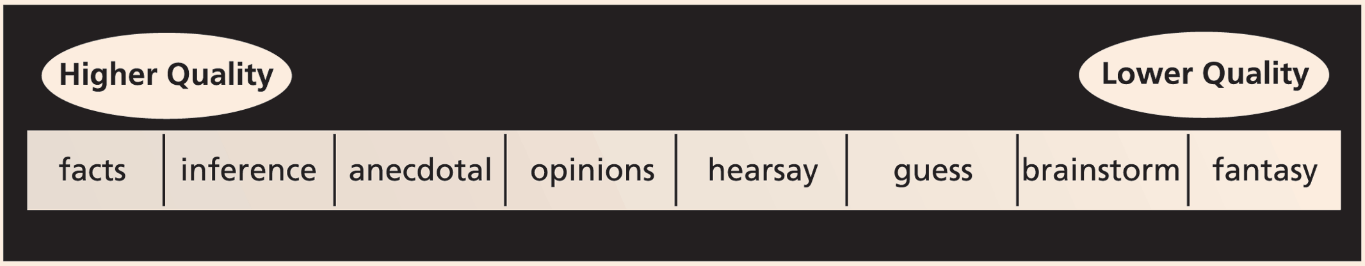
In the practical world of industrial incident investigation, one encounters varying degrees of credibility regarding the accuracy of information. Inconsistent or conflicting information is common when analyzing details gathered from witnesses. Not all information available to the team has the same degree of truthfulness and accuracy. It is difficult in some cases to determine which information is most accurate. The team will often be initially faced with apparently contradictory information. Application of critical thinking concepts can help resolve these apparent contradictions and inconsistencies. In most cases, these concerns can be resolved by gathering additional clarifying information. For remaining unresolved conflicts, the team must document the inconsistencies and provide explanations wherever possible.

Challenges to Selection of Cause(s) & Scenario

Identification of the causes and most likely scenario can be adversely affected by several factors.

Figure 4

Investigation Data Quality Spectrum



One obstacle is the temptation to prematurely select the most likely cause scenario. The investigation must eventually identify and examine all credible possible cause scenarios and ultimately select one scenario as the most likely based on the available evidence. Selecting one proposed scenario as "the most likely scenario" is not a mistake as long as alternate scenarios remain under consideration until sufficient evidence allows them to be rejected.

Premature selection of a cause scenario can create avoidable mistakes. It delays identification of the actual cause, as the team invests time, money and resources following a false trail. It can also trigger irrational defense of an invalid scenario. Most investigators are slow to abandon a preferred cause scenario, even when faced with evidence that would clearly disprove it. Furthermore, the team's credibility is reduced if it must announce that its initial findings and conclusions were incorrect. This casts an extra amount of doubt on all future findings, which has an adverse impact, especially in instances where litigation is involved.

Determination and selection of the cause scenario involves rationalization. According to Singer, numerous experiments have confirmed human's natural behavior regarding how people develop hypotheses and conclusions (Shermer). Typically, people quickly form a hypothesis, then proceed to seek confirming evidence. People do not inherently seek evidence which might disprove that hypothesis. Instead, they stick to (and vigorously defend) the original hypothesis even when faced with conflicting evidence that might disprove it. Therefore, investigators should make a strong and conscious effort to take an open, unbiased approach, especially during the early phases of an investigation.

One potential trap for investigators is the self-fulfilling prophecy. In some instances, evidence collection is narrowly focused on confirming a single proposed cause while all other evidence is excluded. In these cases, all the evidence confirms the hypothesis because no other evidence or information is collected or analyzed. In incident investigation, this concept manifests itself through the use of leading questions, omitted questions and decisions not to examine alternate solutions. Through the application of the six validity tests, critical thinking can minimize the likelihood or severity of this mistake.

People often see what they expect to see and force mental interpretations where no clearly established pattern may exist. People rely on past personal experiences and conventional wisdom (conventions and expectations) accumulated over time to draw conclusions and make judgments about what was observed. Even after the team establishes a probable scenario, its members should continue to evaluate incoming information objectively.

Another challenge to investigators is the false or hidden assumption. It is easy to make incorrect assumptions regarding the association between truly random events, thus generating a cause-and-effect correlation where no such relationship exists Hidden assumptions can cause problems as well, such as when a team makes an assumption without realizing that it has done so. Assumptions and stipulations should be clearly identified, verified and documented in all cases.

Misjudging likelihood/probabilities can also lead to erroneous determinations. In such cases, the team may reject a potential cause scenario because it believes the cause event is too remote; consequently, the investigation fails to thoroughly evaluate this particular potential cause.

Most people are not naturally proficient at estimating likelihood or probabilities of events based on limited personal experiences. One classic example is the birthday odds probability. Given a random group of 36 people, what are the odds that two of the people share the same birth date (month and day)? Since a year has 365 days and since 36 people are present in the room, most people would estimate an approximate one in 10 chance; however, the actual

Validity Test for Cause Scenario Selection

- Is the scenario logical?
- Is it comprehensive in addressing all known evidence?
- Are the causes sufficient to create the result?
- Can it be tested to prove it to be true or false?
- Can it be replicated?
- Does it have honesty and integrity?

Checklist for Critical Thinking During Investigations

- Objective review and consideration for all evidence.
- Be aware of filtering when analyzing incoming information.
- Make a serious and objective attempt to disprove the favored hypothesis at several stages during the investigation.
- Determine whether the team is dealing with first-generation or later information. Treat second-generation information with a different degree of accuracy.
- Make a conscious effort to delay final selection of the cause scenario until all credible alternatives have been objectively evaluated.
- Apply the six validity checks before making a final decision on the cause scenario.

odds are about 50/50 (Webb). When tossing a coin, it is easy to overlook the fact that on a single toss, the odds of tossing heads are always one out of two (or 50 percent) regardless of what the previous results have been.

People remember confirming events much more effectively than those events that do not confirm a perception. For example, despite repeated studies, no confirming scientific evidence has been found that a full moon is accompanied by increased birth activity. Yet, people remember births that occur during a full moon and note them as confirmation of the belief that a larger number of births occur during a full moon.

Examination of high-profile disasters such as the space shuttle *Challenger* accident, the Bhopal, India toxic chemical release and the *Exxon Valdez* oil spill indicate that these events were the final outcome of a series of low-probability events where multiple safeguards failed. Application of critical thinking skills can be helpful when considering all likely scenarios and applying accurate estimates of probabilities. Critical thinkers will identify and evaluate the source, applicability and accuracy of the probability data used by the investigation team.

Misplaced credibility of information represents a challenge to rapid and accurate determination of the cause scenario. All other things being equal, people give more credibility to the first version of the story they hear. Subsequent versions that differ from the initial version are given less credibility because people activate their natural mental filters (Gilovich).

Conclusion

Critical thinking concepts are familiar issues for experienced incident investigators. Some investigation management systems incorporate critical thinking skills into the written investigation procedure and investigation team training. For improved investigation effectiveness, consider using lateral thinking in the early stages to develop possible cause scenarios. Seek alternate explanations (e.g., nonconventional, anomalies, lower probability events and conditions) that could provide another explanation for the available information and facts as they are understood. Remember to be open-minded if additional information becomes available late in the investigation that does not support the chosen cause scenario. The following questions are helpful in ensuring that investigators are applying critical thinking skills and are considering all credible cause scenarios for a given incident.

Ensuring Critical Thinking During Investigations

- Has all evidence been objectively reviewed and considered?
- Are investigators aware of filtering when analyzing incoming information?
- Has the team made a serious, objective attempt to disprove its favored hypothesis at several stages during the investigation?
- Is the team dealing with first-generation information? Has the different degree of accuracy of second-generation information been recognized?
- Has the team made a conscious effort to delay final selection of the cause scenario until all credible alternatives have been objectively evaluated?
- Were the six validity checks been applied before making a final decision on the cause scenario? ■

References

Carroll, R.T. *Skeptics Dictionary.* New York: John Wiley & Sons, 2003.

Center for Chemical Process Safety (CCPS). *Guidelines for Investigating Chemical Process Safety Incidents.* New York: American Institute of Chemical Engineers, CCPS, 1992.

Center for Critical Thinking. "Glossary of Critical Thinking Terms." Wye Mills, MD: Center for Critical Thinking. <http://www.criticalthinking.org>.

Gilovich, T. *How We Know What Is Not So: The Fallibility of Human Reason in Everyday Life.* New York: Maxwell Macmillan, 1991.

Lett, J. *A Field Guide to Critical Thinking*. New York: Rowman and Littlefield Publishers, 1997.

National Fire Protection Assn. (NFPA). "Guidelines for Fire and Explosion Investigation." Publication 921, Section 2.3. Quincy, MA: NFPA, 2001.

North Central Regional Educational Laboratory. "Glossary of Educational Terms." Naperville, IL: North Central Regional Educational Laboratory.

Roland, H.E. and B. Moriarty. *System Safety Engineering and Management.* 2nd ed. New York: John Wiley & Sons, 1990.

Schacter, D. *Searching for Memory.* New York: Basic Books, 1997.

Shermer, M. *Why People Believe Weird Things.* New York: W.H. Freeman & Co., 1997.

Shick, T. & L. Vaughn. *How to Think about Weird Things: Critical Thinking for a New Age.* 2nd ed. Mountain View, CA: Mayfield Publishing Co., 1999.

Webb, P. "The Layman's Guide to Probability Theory." Technical paper. London: Peter Webb. <http://www.peterwebb.co.uk> and <http://www.probabilitytheory.info>.

Webster's II New Riverside Dictionary. Office Edition. New York: Houghton Mifflin Co., Burkley Publishing, 1984.