Assessing the Root Cause of Foundry Injuries

Hazards are ever-present in the steel plant environment, and a heightened awareness and emphasis on safety is a necessary priority for our industry. This monthly column, coordinated by members of the AIST Safety & Health Technology Committee, focuses on procedures and practices to promote a safe working environment for everyone.

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Comments are welcome. If you have questions about this topic or other safety issues, please contact safetyfirst@aist.org. Please include your full name, company name, mailing address and email in all correspondence.

The foundry industry continues to be challenged with higher injury rates than other manufacturing organizations and this has been true for many years. The U.S. Bureau of Labor Statistics has provided data on injury rates for both all private manufacturing and foundry categories and, as can be seen in Figs. 1 and 2, foundry injury rates have been and continue to be much higher than those for all private manufacturing.[1]

This continuing disparity in injury rates should create a strong motivation to focus on injury prevention and the institution of measures designed to reduce foundry injury rates and the human suffering that these rates represent.

In a search for the cause of industrial injuries, it is common to cite the highly influential and groundbreaking work of pioneering safety scientist Herbert William Heinrich.[2] Heinrich's work, *Industrial Accident Prevention: A Scientific Approach,* first published in 1931, would become the foundation for safety science over at least the next 50 years. Five editions of the book were published by McGraw Hill, the latest in 1980.[3]

Heinrich's work, while not in print today, continues to influence the thinking of modern safety professionals and plant managers. Heinrich's work is often remembered for two fundamental concepts: the ratio of causation of injuries between unsafe acts and unsafe conditions and his accident pyramid, expressing a statistical likelihood of minor safety events to major events.[4] This paper will focus on Heinrich's views and subsequent widespread adoption of the domino theory of accident causation, but this is not intended to tacitly support the accident pyramid theory, which this author would argue is both logically and empirically flawed.

Heinrich described the causation of injuries as a result of a sequence of factors, which he referred to as the domino theory, shown in Fig. 3.

Heinrich's five dominos are as follows:

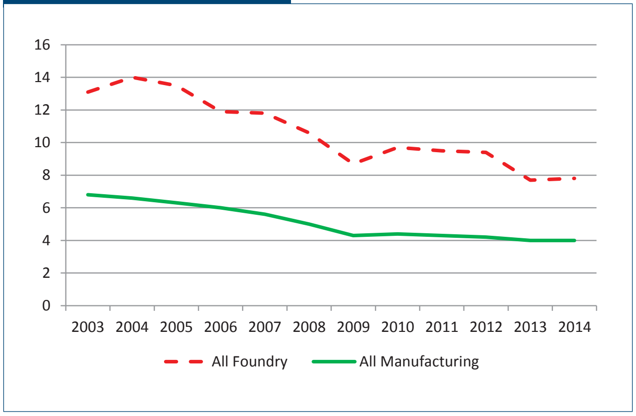
- Ancestry and social environment.
- Fault of the person.
- Unsafe act in the presence of a mechanical or physical hazard.
- The accident.
- The injury.

Heinrich's own view was that accident prevention should focus on human failures, and should employ psychological methodologies to get results in reducing industrial injuries. Heinrich wrote, "In the occurrence of accidental injury, it is apparent that man failure is the heart of the problem; equally apparent is the conclusion that methods of control must be directed toward man failure."[5]

The perspective that human error, arising from the person and ultimately the ancestral and social baggage that a person brings with them to work, is the proper focus and cause of industrial injury was not limited to Heinrich. As generations of safety professionals and manufacturing managers were taught this concept, it has found its way into the belief system of individuals and influential organizations.

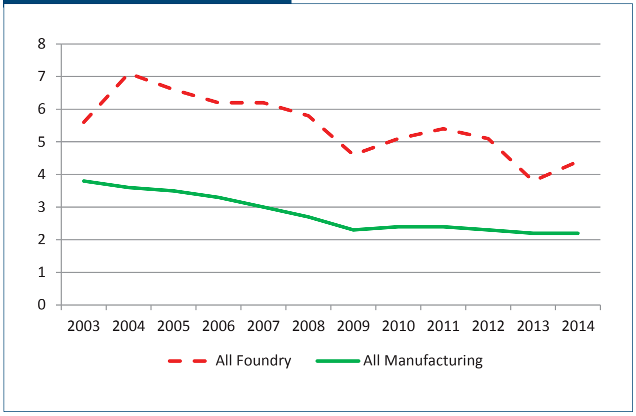
Dong Chul Seo of Indiana University Bloomington reviewed the research on industrial accident causation and cited at least 10 research papers from 1972 to 1996 that supported the statement that

Figure 1



Total case incident rate (TCIR) using the standard formula found in Table SNR05 of the U.S. Bureau of Labor Statistics (BLS).

Figure 2



Incident rate for days away and restricted time (DART) using the standard formula found in Table SNR05 of BLS.

the primary root cause of industrial injuries was the unsafe actions of employees.[6]

A typical example of such teaching within the foundry industry is found among the safety training video series for the Non-Ferrous Founders' Society. Video 4008A, titled "Human Behavior: Reducing Unsafe Acts" is described as follows: "The vast majority of accidents in the workplace are caused, in whole or in part, by the unsafe acts of employees. The emphasis of this video is reducing unsafe acts triggered by human behavior through education and awareness."[7]

This article intends to address the error in problem-solving that exists when human behavior is understood as the root cause of accidents and injuries and to describe a more accurate way to evaluate human behavior as a part of the chain of cause and effect leading to foundry injury. It is hoped that by shining light on this issue, preventive actions and responses to incident investigations will be better directed, ultimately leading to a lower injury rate in the foundry.

Figure 3

Heinrich's illustration of the domino theory of accident causation. The unsafe act and mechanism hazard constitute the central factor in the accident sequence (a). The removal of the central factor makes the action of preceding factors ineffective (b).

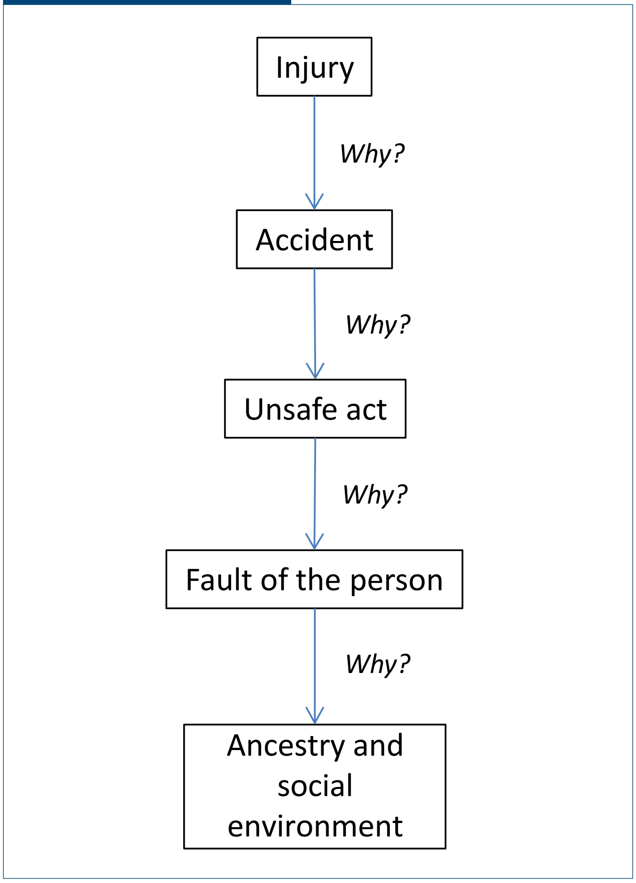
Why Human Error Is Not a Root Cause

It cannot be disputed that human acts are involved in a majority of foundry injuries. Seldom is it true that a worker, properly engaged in his duties, is suddenly and without his/her own action injured by their environment. The question is whether the actions of the worker are the root cause of such injury. To assist in making this distinction, Heinrich's dominoes can be examined using a common quality problem solving tool of "why-why" analysis. The result is found in Fig. 4.

With an examination of Heinrich's theory via why-why analysis, it is clear why Heinrich recommends various psychological and awareness strategies to the correction of industrial accidents. He recognizes that he cannot address the true root cause (in his view) of the background of the employee, their upbringing and socialization prior to coming to work for a company, so he must attack the problem at the next level up: the employee himself.

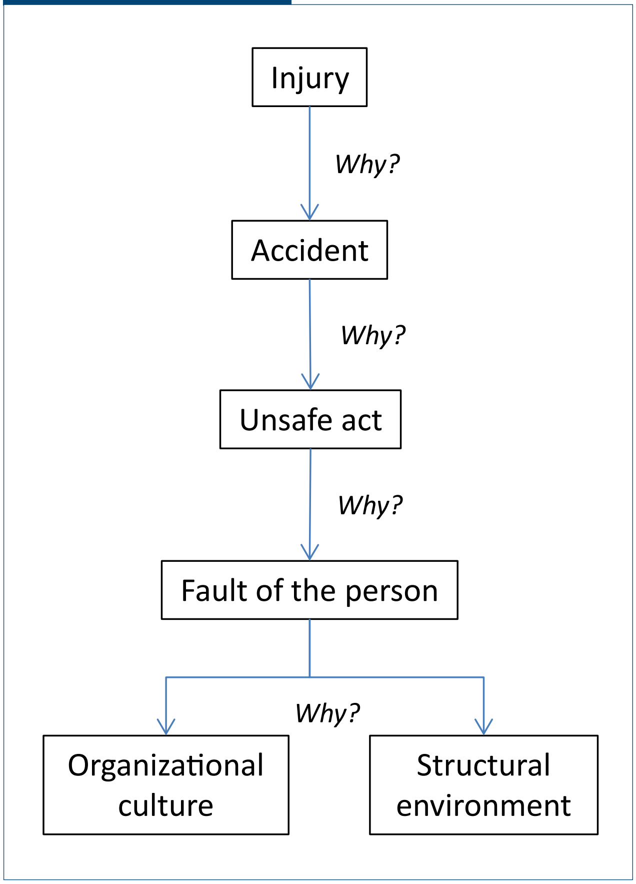
But the tacit assumption in Heinrich's view is that the prevailing influence on employee behavior is already established prior to their hire, external to the organization, and that this influence is largely a detriment to good safety performance. This ignores the massive amount of current research on the significant correlation between an organization's culture and the safety performance of that organization.[8–11] Heinrich's link between employee action and their past social environment and ancestry also ignores the structural influences that exist through management choices that directly or indirectly influence worker behavior. These two alternate answers to the final "why" in Fig. 4 are explored below and illustrated in Fig. 5.

Figure 4



Heinrich's domino theory of accident causation expressed in a "why-why" analysis.

Figure 5



A revision of the why-why analysis based on Heinrich's domino theory that provides two alternatives for the root causes of unsafe acts.

Organizational Culture

Organizational culture can be defined as the shared perceptions among employees concerning the procedures, practices, and kinds of behaviors that get rewarded and supported with regard to a specific strategic focus.[12] These shared perceptions are driven by a number of contributing factors, including:

- Leadership values and consistency of action.
- Supervisory communication and follow-up.
- Reward systems.
- Measurement systems.
- Processes for investigation, communication and closure of incidents.[13, 14]

The practical experience of a number of foundries has supported the link between safety climate/culture and the safety performance of their organizations and specifically the safety-oriented behaviors of individual employees.[15–17]

Structural Environment

From the perspective of a quality engineer, the analysis of the root cause of a human behavior looks for specific structural elements that are present in the environment that may lead to the worker's actions. This follows from the fundamental orientation that the worker's actions — or the worker him or herself—is never the root cause of any problem since management is responsible for the decisive factors in worker performance.[18–20]

There are several structural elements that can influence worker safety behavior. These include the environment, the process layout, the documented method, the available process time (perceived or actual), the tools provided to the worker, and the type and nature of the personal protective equipment (PPE) provided.

Environment — It has been demonstrated that the physical environment, specifically temperature, humidity and air quality, have a direct impact on worker fatigue.[21] This fatigue leads to a variety of compensation strategies as workers cope with the environmental stress. Fatigue has also been demonstrated to lead to a reduction in vigilance. Vigilance is a necessary part of worker safety to ensure, for example, that safety check lists are used in job preparation; that various safety protocols are engaged prior to work; and that conditions are observed that might signal a safety risk.[22]

Process Layout — It is well known that ergonomic safety is related to the physical manipulations required of the worker by the process layout.[23] Examples include the relative heights of work tables, tools and materials, the relative spacing and positions of these objects, and the weights and forces involved in the process. These physical characteristics of the workplace also contribute to the fatigue and vigilance decay noted earlier.[24] Yet process layout can also lead to an injury or accident that, on a superficial analysis, might be attributed to worker inattentiveness or other character trait. In one jobsite observed by the author, the scrap tub at an inspection station was located across an aisle with heavy fork truck traffic. Workers were required to turn around, carry the scrap part to the scrap bin and then return. This process required extreme vigilance to avoid the traffic in the aisle. The work required focused attention on the inspection task, yet workers were required by the layout to cross that traffic and immediately shift their attention to the greater surroundings. This was an accident waiting to happen that could not be blamed on worker inattention, and no amount of warning or signage could compensate for the lack of safety oversight and poor planning in the process layout.

Documented Method — Workers generally follow documented instructions that are provided to them and on which they have been trained. Where such instructions include appropriate safety precautions and where the instructions describe a safe and practical method, the frequency of problems resulting from these operations is greatly reduced. However, when foundry operations do not subject their work instructions to a safety-specific review and do not create instructions that accurately represent the real world, safety performance problems will result. Impractical or wrong instructions that reference different machines or process conditions, or refer to other documents that do not exist and so on lead workers to improvise and establish non-standard work practices that can often be detrimental to safety. Work instructions that are written primarily from a quality perspective (not safety) or are not reviewed by workers and/or a safety professional to identify safety risk or other defects in the process description can be the cause of foundry accidents and injuries. These may look like purely worker decision errors, but could have been prevented by adequate planning and instruction.

Process Time — The time available to the worker is a structural element in his/her environment. This time may be dictated by the machine cycle time, the overall pace of work or other constraints. Fast pacing leads to fatigue and compensation techniques where safe work practices may be compromised deliberately to keep up, get a scheduled break on time, etc. Fast pacing may simply not leave adequate time for the specified safe work practice to be carried out.[25]

Available time may be perceived and not driven directly by a machine cycle or automated tempo. The worker's perception of available time is dictated by a number of signals from the work environment, including:

- The rate at which other workers are progressing, as there is a natural drive in workers to "keep up" in order to please supervision and not stick out among the peer group.
- Implicit or explicit messages from supervision that a faster rate or greater work output is needed to satisfy customer demand or some target of performance.
- Bonus programs that reward higher worker output regardless of what might be physically appropriate for ergonomic or physical safety.

Tools — Generally, tools are provided in the foundry to increase the efficiency of the work and improve the capability of the worker to perform the task. Similar to work instructions, poorly planned or reviewed tools can lead to a variety of impromptu decisions on the part of workers that do not optimize safety.[26]

"Failure to follow instructions" is perhaps the most frequent attribution as to cause of industrial accidents. This statement is clearly pointing to a human failure — the worker him or herself is responsible. He or she knew what to do to stay safe and chose not to do it. A few examples in the tool category help illustrate the need to dig deeper than blaming the worker:

Example 1: A worker in a cleaning room received burns on his fingers from contact with a hot casting. The worker had defeated the protection of his right hand by cutting off the fingers of his glove. Upon investigation, it was discovered that the actuator switch for a tool he was required to use had a guard with inadequate clearance for a gloved finger. The worker had compensated for the poorly designed tool by cutting the glove's fingers off, permitting him to use the tool as intended.

Example 2: A worker in the meltshop fell and was injured during fluxing and dross off of an aluminum holding furnace. Investigation revealed he had been issued a drossing tool that had a relatively short handle, creating substantial heat burden on the worker.

The meltshop employees had welded an extension to the handle to allow the worker to be farther away from the melt. This had broken suddenly during operation, resulting in a fall and fracture.

Example 3: A worker in a rework area was struck by an overhead fixture and required stitches to his head. The worker, to reduce the trip hazard from the excessively long hose/cable connections to his tool, had wrapped them around a fixture on his work station to get them out of the way. Fatigue on the fixture from the cabling and hoses finally overcame the fixture attachment and it struck the worker while falling.

In each of these cases a poorly reviewed tool was provided to the worker. The worker, faced with the dilemma of his desire to do the job well while still using the deficient tool, made the situation work — perhaps for a long time — until the safety risk and probability caught up. Only with the most superficial of analyses can these cases be designated as worker-caused injuries.

Personal Protective Equipment — Management is responsible for providing appropriate PPE to workers. Workers are required to wear this equipment and failure to do so is normally attributed as a worker responsibility. Yet management also has an obligation to make the PPE wearable for the duration required, fit properly and instruct on proper fit and sizing, and provide accommodation in the job routine for the limitations and constraints associated with PPE use. Injuries where PPE was not worn must be investigated beyond the simple observation that proper PPE was not worn. Workers must be able to do the task (repetitively) with the PPE in place; it must work as required and not entail other problems that drive workers to compensate. For example, poorly designed or ill-fitting eyewear leading to fogging or unstable fit with headgear will only be periodically worn (or perhaps completely ignored) by workers. It is hardly appropriate to settle an investigation of such a situation by blaming the worker for failure to use the PPE.

Harm in the Belief of Human Error Causality of Foundry Injury

The belief that most foundry injuries and accidents are the result of human error is not only misguided but has severe negative consequences.

Recurrance — Failure to identify and address the root cause of any problem means that the problem will recur. Just as clipping the top off a dandelion growing in a garden will only have a short-term effect, so too problems that are addressed only at a symptomatic level will recur. Tragically, recurrence of the problems in a foundry is tallied in a human cost, not just time wasted weeding again. Recurrence of safety problems wastes valuable people resources by implementing programs that are ineffective, misguided and sedative in their effect. By "sedative in effect," it is meant that short-term improvements often result from a focus on safety performance, and operator attention and vigilance will increase temporarily. This leads the organization into the false belief that this improvement is sustainable and that early results will continue long term. Often this experience leads organizations to try another program with similar emphasis, thinking it was a flaw in the implementation or the particular character of the individual program that caused initial results to fade rather than rethinking the premise behind such programs. "Program of the month" cycles harm the motivation of those tasked with deployment of resources and build calluses in mental pathways toward right thinking.

Shift in Focus — Beyond recurrence, belief that the workers themselves are the primary focus in preventing injury shifts responsibility for correction from management to the worker. This comfortable thinking permits management to evade its true responsibility, namely to provide that which their workers need to be safe and successful. Executive management has a stewardship responsibility for the people they employ, not just for their company's reputation and their capital investments. It is axiomatic that all major changes in organizations are successful only as they are supported by top management. If top management views safety performance as the one area where their actions are ultimately ineffective because it relies on the "ancestry and social environment" workers bring into the workplace a la Heinrich, then the most powerful change agent in the building has been effectively negated. Unfortunately, this is a comfortable false belief in that it entails less work (and soul-searching) for management and permits accountability and hard work to be avoided (or moved elsewhere).

Defeatism — When problems are not effectively addressed by hard work and sincere effort, or when problems appear out of effective reach, this leads to frustration and eventually to the belief that not all injuries can be prevented. Arising from this frustration and mindset are other harmful practices. If a widespread belief is held that workers themselves are diligent and precise about their work or are careless and lazy, then it follows that the key attribute of safety performance depends on a character attribute that cannot be filtered by the hourly hiring process. Belief that some people are just "injury prone" leads to employment practices that tend to hunt to identify those individuals who have had frequent first aid or recordable injuries and remove them from the team. This is logical if one believes worker behavior can only be demonstrated in practice and that unsafe behavior results largely from the worker's own actions. These beliefs, when widespread, harm a true evaluation of the root cause of injuries. They also lead to a focus on a "compliance to regulations" mentality that follows the law but goes no further because results beyond that rely on worker attitudes — something that cannot be reached — rather than a cultural or structural element in the foundry environment.

A Word About Behavior-Based Safety Programs

It would seem, given the foregoing discussion, that behaviorally based safety (BBS) programs would be among the least-effective approaches to improving safety performance. This is not the case; many implemented BBS programs have been recognized as effective, both in the short and long term.[27–29] This apparent disparity deserves an explanation.

Description of BBS Programs — BBS programs generally contain four critical elements.[30] First there is a deliberate effort made to identify and categorize the critical behaviors necessary for safe work. Second, data is gathered regarding the frequency of unsafe behaviors through observation. This permits a focus on the high-frequency, higher-risk behaviors. Third, management encourages, though direct communication and incentives of various kinds, two-way feedback on the causes of at-risk behaviors. Fourth, continuous improvement activities are promoted by management and implemented in the workplace to address the barriers to safe behaviors.

Reese, in his recent textbook on health and safety management, cited in Reference 30, identifies some common barriers to safe performance typically uncovered in a BBS program:

- Operators do not know that they are at risk in how they do their job.
- The right way is inefficient or ineffective, forcing a work-around.
- Disagreement exists on what the right way is.
- Company culture values speed over safety.
- Rewards are given for work done unsafely (perhaps because it saved time or money in the short term).
- The facility has unsafe conditions.
- Worker conditions such as fatigue, illness, stress or medications are ignored.
- Terrorism (human choices at odds with conditions).

Why BBS Programs Are Often Effective — It is clear from Reese's description that properly conceived BBS programs do not cease their root cause investigations at the point of identifying the worker's unsafe behavior. These programs instead see worker behavior as the springboard for a deeper investigation as to cause. To quote Reese further,

> "First, BBS is based on the general principles that behavior causes the majority of accidents, but this does not excuse employers from providing a safely engineered workplace with all controls in place to prevent the occurrence of incidents. Behavior is the outward manifestation of values and attributes that are deep-seated within the employee and the company or corporate culture."

Thus, it can be observed that BBS programs, while focused initially on worker behavior, are committed to tracing that behavior to sources in a properly safety-engineered workplace or to a culture that either supports or erodes proper worker behavior.

BBS programs that are effective have significant management presence and look beyond the behavior and implement root-cause corrective action. Typical features of well-established BBS programs stress open communication about safety between workers and supervisors, have active management involvement and support of correction of identified hazards, and formal tracking systems of safety performance, including a common language of safety. These are all correlated with excellent safety performance.[31–33]

Where BBS programs fail to initiate long-term improvement in safety performance they are often aimed at behavioral modification only, either through peer pressure or other reward/punishment schemes. Behavioral modification techniques do not address the root cause of unsafe acts and treat the behavior itself as the concern rather than the result of a concern in the workplace or culture.[34]

Conclusion

Heinrich's idea that worker behaviors are part of the chain of cause and effect leading to workplace injuries was largely correct but did not go far enough, and left safety practitioners with the notion that prevention of injury requires the right kind of worker. These ideas persist with harmful consequences for organizations and individuals in the foundry industry and in the manufacturing sector as a whole.[35]

As the foundry industry searches for improvement in its safety performance going forward, it must look beyond behavior and the social and cultural backgrounds of its workers to the company cultural and environmental elements of the workplace. Management must lead the effort, authorizing it by personal presence and practical support, such that the root causes of unsafe behaviors are addressed.[36,37]

Behaviorally based safety programs can be an effective tool in a formal approach to safety improvement, but they do not provide a valid substitute for good management, driven by values such as a high view of human life, the desire for open communication and linkage throughout the organization of company core values of integrity and continual improvement.

Acknowledgment

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