Human Factors Analysis Classification System Relating to Human Error Awareness Taxonomy in Construction Safety

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Abstract: In several studies it is widely accepted that human error is the main reason for up to 80% of all incidents and accidents in complex high-risk systems that exist in the aviation, petrochemical, healthcare, construction, mining, and nuclear power industries. The construction industry, greatly impacted by accidents, is accountable for more than 1,000 fatalities in each of the past 14 years. The human factors analysis classification system (HFACS) is a general human error framework originally developed and tested as a tool for investigating and analyzing the human causes of accidents with applications to rail, air, and offshore environments. This paper introduces the concept of HFACS along with the framework of human error awareness training (HEAT) and their potential contribution to the construction industry. Based on the HEAT approach, this paper proposes a new error analysis educational and classification tool for safety within the construction industry. The primary difference between HFACS and HEAT is found in the structure, content, and presentation of the information allowing for higher effectiveness in incident investigation and safety education and training in construction.

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Introduction

Like aviation, the construction industry has a highly conducive environment for large human and monetary loss occurrences, either during construction, as occurred in the Texas City BP refinery explosion in 2005, or postcompleted operations, as experienced during the Kansas City skywalk collapse in 1981 (Holmstrom et al. 2006; Orr and Robinson 1983). Human error, as specified by Reason (1990) affecting both safety and quality, occurs across multiple levels within organizations, of which are present within the construction industry.

Historically, both simplistic and complex root cause analysis (RCA) models look chiefly at individual actions rather than within the organizational issues that are present, in particular, at the executive and operations level (Shappell and Wiegmann 1997). Furthermore, most accident investigating methods are employed by personnel with limited backgrounds in human error analysis or comprehensive human causal factors (Haste 2005). Failure to capture latent causes results in reoccurrence of incidents regarding both large and small losses, such as accidents involving injuries or fatalities that impact on-time and cost-effective operations.

As outlined in Shappell and Wiegmann (2001), if accidents are to be reduced further, more emphasis must be placed on human error as it relates to accident causation. Recently, the human factors analysis and classification system (HFACS) was developed to meet these needs as it applies to commercial aviation (Shappell and Wiegmann 1997 and 2000). The HFACS, a general human error framework, was originally developed for aviation accident analysis to identify the level of human error as it relates to the accident root cause. HFACS, based upon the Reason (1990) model of latent and active failures (illustrated in Fig. 1), appears to identify several areas within an organization that significantly contribute to incidents.

The initial area identified through HFACS is found within the "organizational influences" of a company that are latent or hidden, which contribute to accident or near-miss events (also known as "close by calls"). When examining organizational influences in greater detail, HFACS further identifies "operational, field personnel, and executive" levels to include the established production climate, as perceived at the field level within an organization and how each level contributes to either accident causation or prevention. Additional areas that contribute to accidents or incidents are identified at "supervisory" level and the contributing "preconditions" as well as direct "actions" by field personnel. HFACS differentiates between intentional errors (e.g., mistakes and violations) such as intentionally not complying with a procedure, and unintentional errors (e.g., slips and lapses) that may occur through lack of attention or memory failure.

The opportunity to reevaluate the accident investigation methodology, as well as accident prevention, is present within the HFACS framework. The need to develop an intuitive human error analysis program that will enable entities to address accident causation and prevention, in tandem with quality control, is significant. This becomes more relevant since the primary contribution of HFACS within the construction industry is that human error methods identify exposures that were previously not addressed when compared to current RCA methods and accident prevention education programs. After a review of the HFACS methodology, it is apparent that its framework can have a positive impact on the overall organizational philosophy of entities whose intent is accident reduction and productivity or mission success. Based upon

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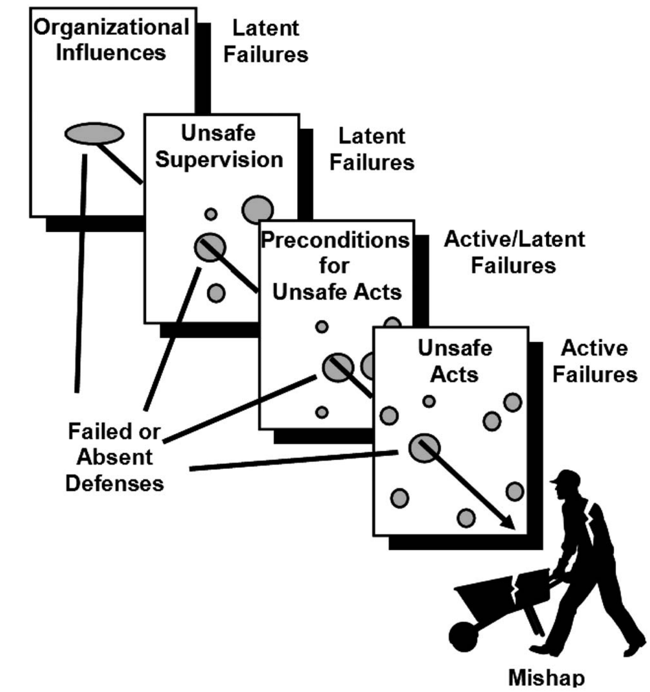

Fig. 1. Human error causation (modified, Reason 1990)

both the Reason (1990) model of latent and active failures and Shappell and Wiegmann's development of the HFACS framework, a further application has been developed in this research for application within the construction industry. This application is termed as the human error awareness training (HEAT).

The focus of the developed system is to provide an intuitive method for accident prevention education in addition to enhancing quality, production, and safety operations efficiency. To further define these efficiencies, we need to understand the impact of each discipline. Quality issues will be manifested in the amount of rework and overall cost of a project. Using HEAT to assist in preplanning of work activities and the development of quality control procedures will mitigate the exposures regarding errors committed by personnel during the construction phase. Production impacts will be manifested through the interruption of schedules, resulting in reactive measures that can further exacerbate FAST TRAK accelerated construction schedules, of which are a defined precondition of influences contributing to injury accidents or near-miss incidents. Safety operations, often also referred to as occupational health and safety management systems, are impacted by the lack of methods to mitigate exposures through proactive training of new hire and existing personnel. Additionally, the need to design effective policy and procedures to address potential exposures are paramount to achieve a reduction in personal injury accidents. HEAT looks at hidden or latent failures, relative to the construction industry, occurring at the organizational and supervisory levels and the preconditions that precipitate unsafe actions that are manifested through the actions of field personnel.

As previously stated, the most common accident investigation methods in use do not address the human causal factors in an easy to use or understand method. Although HEAT was built as an adjunct around the HFACS framework, the primary difference regarding HEAT lies within its intuitive approach to both education and hazard identification through the utilization of encoding methods, such as acronyms and imagery, which aid in retention and recall of risk information for utilization by operations and field personnel. Within a developed strategy, HEAT considers targeted organizational factors such as cultural influences, operations, resource management, and executive policy. In addition, HEAT looks at negative supervisory influences that cultivate planned unsafe events, acceptance of deficiencies, incompetence, and negligent behaviors. By continuing with this approach, preconditions resulting from adverse mental and physiological factors that affect individuals, i.e., fatigue, illness, task, environmental, tenure, and aptitude, are also addressed. The final area within HEAT occurs within the unsafe "acts" resulting from failure to follow procedures, complacency, overconfidence, focus, intent, technology, skill, decision, and perceptual errors as well as routine violations.

Background and Literature Review

It is widely accepted that the construction industry is a leading contributor to the economy of many countries. Its organization typically involves thousands of companies of which most typically employ less than ten people. Construction work can range from major and complex engineering projects, such as high rises, bridges, power stations, etc. to the simple retrofit. Safety in construction can easily become a critical factor for other project success factors (schedule, budget, quality, etc.) if understanding and practices among project stakeholders (owners, architects, structural designers, project managers, contractors, subcontractors, vendors, etc.) differ significantly.

In regard to safety, federal or local programs give guidance to companies that can lead to success in safety. The Occupational Safety and Health Organization, for example, offers safety related assistance and regulation, and by doing so improves the safety performance in construction and other industries through advice on training, reporting statistics, and through the punitive measures of fines.

As a workplace safety indicator, several accident reporting processes that rely on lagging indicators, collect and analyze data once injuries or accidents occur, for example, through measures like the total recordable incident rate. In regards to fatalities, the fatality statistics from the National Institute for Occupational Safety and Health's fatality assessment and control evaluation project reviewed 91 fatalities from 1982–1997. Several contributing factors were identified such as: lack of hazard recognition, lack of coordination of work tasks, worker inexperience, deviation from standard operating procedure, fast track scheduling, and employers lack of written task specific work procedures (NIOSH 2007).

Construction Safety Research

The impact on safety can result from many factors. Most construction companies are differently organized and managed (Levitt 1975) and can thus vary significantly in the safety culture that is in place (Molenaar et al. 2002; Mohamed 2002). The safety performance in construction can largely be influenced by workforce turnover, crew management, different production techniques, available tools, and worker's attitude toward a team environment (Hinze 1996; Abdelhamid and Everett 2000). Unsafe practices often lead to incidents or accidents since work execution is influenced by project condition, schedule, and budget constraints (Jaselskis et al. 1996), as well as the lack and less frequency in safety training, availability of proper safety equipment,

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and wrong or no enforcement of safety rules or best practices (Contruction Industry Institute 2006). In recent years these studies have led to accident causation analysis research (Hinze and Wiegand 1992; Toole 2002; Gambatese et al. 2005; Abraham et al. 2004) which resulted in new approaches in design for safety, understanding of worker's errors (Rasmussen et al. 1994; Mitropoulos et al. 2005), and technological innovations (Huang et al. 1996; Gambatese et al. 1997; Teizer et al. 2007; and others).

Practiced Incident and Accident Investigation

A primary purpose for investigating any accident or incident must be to obtain learning and initiate change when appropriate. Lessons learned are generally drawn from investigation reports that try to determine the root cause. Although construction accident reporting is a well established routine, finding the cause of the accident or incident can become overly complex. A few examples are the failure mode and effects analysis, Ishikawa diagram, fault tree analysis, Pareto principle, and others.

An underlying fear of culpability causes a resistance on the part of individuals and companies to participate making it difficult for the cause of an accident to be found and making it difficult for the cause of accidents to be found "in their true origin."

For legal reasons, under mediation, the real cause of a major accident is often not communicated to bodies within an industry, which would wish to learn from it and to avoid similar accidents from occurring (Gambatese et al. 2005).

Within the construction industry, the established criteria classify the severity of accidents and as a consequence the extent of the investigation required, which often make the severity as the sole criterion for the comprehensiveness of the investigation, failing to capture the value of the lessons learned from the investigation of incidents. As Van der Schaaf and Hale (1991) described it, the frequency of accidents to incidents has been likened to an iceberg since there are many more incidents than accidents.

Since investigators typically focus solely on accidents, it is important that information from incidents is also "captured." Opportunities exist for us to learn from both and it is important that information from incidents is also obtained. From the investigation of similar incidents a greater understanding of the particular situation can be gained together with any trends. It was found that "an incident investigation can often produce better accident prevention results than can an accident investigation" (International Civil Aviation Organization 1993). The challenge in any industry is how much time should be spent investigating incidents as opposed to accidents and how and by whom should they be conducted. The accident investigation process is not only essential in providing the information on "what" has happened, but also in providing valuable information on "why" the accident happened. In recent years many industries focused on a term called human factors as a tool to answer these questions.

Theoretical Human Factor Frameworks

Muir and Thomas (2004) described the widely and variously used term "human factors" as the area to reflect the issues affecting people's performance at work, or to identify possible contributions to the causes of accidents or incidents. A widely used definition suggests that "human factors concern the interaction between people—their characteristics and abilities, organization, and management—and technology" (Dekker 1998). In the meaning of accident investigation, the term human factors can be used to encompass all of those considerations, which affect an individual's ability to perform a task.

In accident causation it is important to differentiate between the two factors: (1) causal factors "cause" accidents and are typically failures of critical pieces of equipment or actual human errors; and (2) contributory factors to human errors, which include a probability of risk to each task, or describe the conditions under which the task is carried out. An error in human tasks can be defined as a breach of acceptability or tolerance (Muir and Thomas 2004).

Many theoretical perspectives and frameworks have been proposed to investigate accidents. Theoretical frameworks that assist the understanding of the multifaceted nature of accidents include the HFACS. Based on the Reason (1990) model of latent and active failures (Shappell and Wiegmann 1997), HFACS was developed as a tool for investigating human errors. The cognitive reliability and analysis method is a classification system, which is based on a theory which allows for the analysis and prediction of errors (Hollnagel 1998).

The techniques for retrospective analysis of cognitive errors was developed for use in air traffic management (Shorrock and Kirwan 2002). The integrated safety investigation methodology is the accident investigation methodology used by the Transportation Safety Board in Canada. The Canadian Board uses this methodology within the marine, rail, aviation, and pipeline industries for accident investigation. The United Kingdom Marine Accident Investigation Branch uses a human factor classification for accident investigation, which operates in parallel with an accident database (MAIB 2000). The classification scheme includes "external bodies liaison" (policy and legislation), "company and organization," "crew factors," "equipment," "working environment," and "individual." The casualty analysis methodology for maritime operations has recently been developed for the purpose of providing integrated human factors and accident investigations within Europe. This instrument is intended to focus on "fact finding" rather than guilt finding (Caridis 1999). A useful review of these systems used in parts of the transportation industries can be found in Thomas et al. (2005).

Before the framework for a HEAT approach for the construction industry is presented, it is important to remember its potential contribution to the accident investigation process. The process by which humans take in information from the external world and make decisions about what is occurring and what actions to take is complex. Human performance in any situation will be influenced by what individuals expect to happen, what has happened to them in similar situations in the past, and their assessment of the consequences for themselves and important others such as coworkers. Thus how humans behave in an incident that can lead to an accident, either as the machine operator or as part of the ground workforce, will be influenced by what they expect, their previous experience, and their estimate of consequences.

Emotional factors such as fear and stress, together with workload, fatigue, and time pressure can also be important influences on human performance and decision making. The purpose of HEAT is not only to identify, develop, and train competent skills but also to rapidly build up experience. The following paragraphs describe how HEAT can assist organizations through educating personnel in regard to the exposures found within the various influences being represented.

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ORGANIZATIONAL	SUPERVISORY	PRE-CONDITIONS	ACTS/EVENTS
CULTURE Value Interaction Pride Empower Recognition	PLANNED Time Info Manpower Equipment	FATIGUE Schedule Environment Task	PROCEDURES Selection Literacy Application Comprehension
OPERATIONS (C^3) Communication Coordination Crew Resource Mgt.	ACCEPTED (R^4) Repair Report Retrain Removal	APTITUDE Skill Experience Training	ROUTINE Complacency OVERCONFIDENCE Ability Attitude
RESOURCE MGT Personnel Equipment Technology	INADEQUATE Selection Training Oversight Performance	INCAPACITATED (I^3) Intoxication Illness Injury	FOCUS Multi-Tasking Attention Personal
EXECUTIVE MGT (Policy) C.Q.I. Oversight Recalibration Execution	NEGLIGENT Directed Initiated Encouraged	LEADERSHIP Mentoring Altruism Depth Education (Continued)	INTENTIONAL Sedition Criminal Abusive Monetary TECHNOLOGY Systems Tools Equipment PPE (Personal Protective Equipment)

Fig. 2. HEAT introduction

Human Error Awareness Taxonomy Approach

Generally, one of the primary difficulties found within safety training programs for accident prevention or investigation, is the ability by the participants to recall program contents (Ebbinghaus 1962). The primary intent within the creation of HEAT was to provide an intuitive, easy to remember, accident prevention educational, and investigative tool for use within the construction industry. The title of HEAT itself, was chosen as an easy to recall acronym that identifies the two values important to this approach, such as the study or taxonomy of human error relating to project preplanning to avoid incidents and accidents, and the training needed in accident investigation.

Although HEAT was built as an adjunct around the HFACS framework, the primary difference regarding HEAT lies within its intuitive approach to both education and hazard identification through the utilization of encoding methodology and imagery, which aid in the retention and recall of risk information, for utilization by operations and field personnel during the course of their work. When considering the Ebbinghaus effect (Ebbinghaus 1962), HEAT was designed along with the framework of HFACS using specific encoding systems, ranging from acronyms to iconic strategies, with the specific intent to aid in the retention of the material for later recall in the field, where it matters most. Through the usage of encoding systems, HEAT allows for the utilization of integrated messaging for ongoing educational campaigns aimed at sustaining an organization's greatest strength—its culture. A secondary difference in HEAT is its application toward accident prevention education and project preplanning.

As illustrated in Fig. 2, using a HEAT model in conjunction with the integrated messaging allows for an intuitive examination of human error influences found throughout each area of an entity such as (1) organizational influences; (2) supervisory influences; (3) preconditions; and (4) acts/events.

To further define the contents of HEAT, the presentation of the material by degree of importance needs to be considered. HEAT identifies the primary influence affecting positive outcomes, as organizational, with culture at its CORE.

Using the acronym CORE, we first approach the issue of culture by identifying positive contributing factors. Culture, as discussed further during the accident investigation process, is defined by identifying and communicating value from the organization to the employee through the utilization of cultural gap analysis, in addition to third party reporting systems. The logic behind HEAT is its value in first identifying the employee's values or vision for their professional and personal goals, which are critical when shaping a corporate vision in synchronizing with its greatest resource—the human being. These values are presented as organic values that must be appraised and communicated from the executive level, as having maximum worth when creating, and as important, sustaining organizational culture. This cultural gap analysis begins the taxonomy of human error awareness and contributes to developing HEAT.

In addition, HEAT has identified within CORE several operational influences common to the construction industry that are addressed within HEAT such as the coordination of reactive scheduling at the operations level, in addition to the leveraging and utilization of technology to ensure communication for quality assurance, in conjunction with real time inspection data for accident prevention efforts.

The next influence identified within CORE is resource management, specific to personnel, equipment, and training. HEAT identifies the need for proactive human resource management strategies that interface personnel with equipment such as the use of three dimensional modeling for the creation of site specific safety programs, equipment simulation training, real time near miss reporting systems, and behavior based safety reporting methods.

The final acronym in CORE is found at the executive level. The focus of HEAT upon the executive level influences begins with the examination of continuous quality improvement methods and the capturing, or loss, of lessons learned from nearly every level within the organization. In addition, third party oversight functions are examined at the executive level to ensure organizational improvement processes and metrics are verified. Recalibration of executive leadership and revision of processes from an active lessons learned library are also critical in identifying contributing factors to human error occurrence.

Putting forth an example, within the area of organizational influences/operations (1), the failure to adequately achieve crew resource management (CRM) with respect to lack of coordination of work tasks could contribute to an unsafe event, and in some cases, a planned unsafe event. Supervisors have the knowledge of safety rules and procedures but often take "shortcuts" due to TIME (as illustrated in Fig. 1 under supervisory influences). The TIME acronym is broken down into (1) time; (2) information; (3) manpower; and (4) equipment. These latent failures, in the identified influences, can be linked to each other. The failure in this instance is not only due to the supervisory influence of a planned unsafe act, but rather to the failure at the operations level of anticipating solutions that are presented when schedules collapse, manpower is short, the right equipment is unavailable, or the right information is not supplied, as evidenced in an incomplete job hazard analysis.

Additionally, within organizational influences/resource management, the failure to ensure that an effective training program is functional, which can address exposures to the short service employee, would become evident at the supervisory level (2), along with other special conditions found within fast track schedule demands that can become another contributor to a potential non-injury incident or injury accident. Furthermore, under organizational influences/executive management, the failure to ensure that written task specific procedures are in place at the operations level, can also contribute to an incident. Other influences identified through a human error awareness taxonomy account for the

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precondition (3) identified with the untrained, or improperly trained, employee. Identifying employee and field supervisory personnel behavioral traits and motivators are extremely important in the management and development of those employees, which will further mitigate situational exposures.

The last influence identified and found within the human error model is under acts (4) and demonstrates the impact of the employee who deviates from the standard operating procedures as identified in the acronym of PROFIT The acronym PROFIT begins with "procedures" and the failure of employees at the field level to fully comprehend, perhaps due to literacy, procedures or job hazard analysis, which can result in incidents or accidents.

The impact of the HEAT approach on each of the important areas within a construction organization that can significantly contribute to incidents is discussed next and in the order of (1) organizational culture; (2) supervisory influences; (3) preconditions; and (4) unsafe acts.

Incident Investigation Process—Organizational Culture (1)

Although the following discussion will be focused primarily on the accident investigation process, HEAT can also make a significant contribution in the accident prevention education process and is currently in limited and proprietary use in the oil and gas industry. Although a detailed analysis of the effectiveness of HEAT training is underway, contrary to the aforementioned example, accident investigation processes within the construction industry primarily focus on the failure of line level employees to follow procedures outlined in job hazard analysis or regulatory requirements (NIOSH 2007). Rarely do companies fully look at the latent organizational influences, which are present, that sustain the occurrence and reoccurrence of incidents and accidents.

Within the evaluation of human error, several factors were identified such as culture and climate. When accidents occur, both are identified as the influencing factors at the organizational level, and upon examination, are indicators of a company's financial and quality performance. Culture can be a primary identifier of "how things get done" within an organization. Climate may be defined as the working atmosphere within the organization. In the absence of comprehensive project front end planning, the primary occurrence of accidents is most typically manifested at the field level, which may be the weakest point in the organizational chain. To further define culture, or climate, examination must take into account perceptions of personnel at the executive, operations, and especially at the field levels, where accidents culminate.

Defining the organizational culture, as perceived at the field level, can reveal failures in communication, training, and execution among many others. The overall culture, as defined at the field level, reveals several basic human desires such as the need for communication, feedback, and appreciation. Culture gap analysis tools can measure the perceived level of job execution and job satisfaction of executive, operations, and field personnel (Coble et al. 1999). A review of job satisfaction and quality, or work execution is another potential indicator of loss and inferior quality.

Within an effective and productive culture, as defined by field personnel, a need exists for established, supported, and ongoing opportunities to have interaction between field, operations, and executive level personnel. Direct communication and feedback between both parties is a primary value to establish what type of culture may exist. Another important impact factor on a safe corporate environment is internal programs that allow executive and operations management to establish, build, and sustain a culture that enables field personnel to achieve communication and foster a climate of appreciation. Based upon research by Tosi et al. (2000) a correlation between job satisfaction and task performance appeared to be a primary reason why "many organizations pay close attention to attitudes by conducting periodic attitude surveys."

Communication vehicles that are found within behavior based safety programs for example, allow field personnel opportunities to voice observations and actively participate in loss control actions. Employees can utilize observation programs, to create or enhance near miss (also known as close-by-call) reporting and lesson's learned components within a safety program. Other examples, such as the usage of telephone safety reporting hotlines, also allow field personnel to actively participate and interact with management. Safety incentive programs alone do not satisfy or sustain an environment of job satisfaction. In 2004, researcher Prichard stated— "Incentives ignore reasons. They deflect attention away from the real issues and can disguise genuine deficiencies and strategic flaws that exist within the organization or the safety management, and construction management process."

To create or sustain a climate of appreciation, direct communication from both the executive and operations level to field personnel is required. Innovative and unconventional programs that allow recognition of individual contributions are imperative. Programs developed across the executive, operations, and field level should be tailored within the organizational budgetary capabilities that produce unconventional benefits. Ongoing participation or the lack thereof, by field personnel in the analysis, improvement, and sustainability of the corporate culture programs is another metric by which culture can be measured.

Organizational Operations

Operations in regard to the study of human error have multiple areas of concern that require examination. Miscommunication, beginning at the operations level, account for a significant amount of all supervisory preconditions that cultivate the environs in which unsafe acts are created. Failure to convey proper information to supervisors regarding quality control protocols or loss control best practices account for a significant amount all of incidents involving rework and accidents from lack of safe practices (CII 2006).

Failure in the coordination of schedule, on fast track projects for example, can cause a domino effect on jobsite wide safety. This global impact can result in an increase in the pace of work sequence, which can further enhance preconditions leading to both quality and safety failures. Operations personnel, at the project manager and superintendent level, may overlook the benefits of schedule compression techniques when faced with engineering, coordination, environmental, and procurement issues. The effects of the schedule failures will translate from the project management and operations level into front line supervisory influences (Fig. 2).

CRM failures, present within organizational influences, are found at various management levels; from within operations personnel, to the project superintendents or foremen, overseeing activities in the field latent weaknesses, in communication capabilities, fully defined internal accountability, problem solving, planning in conjunction with decision making, and personnel utilization, can likely contribute to near miss events and accidents.

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Successful execution of the construction schedules, depend on an effective two-way-communication that include feedback and identification of communication barriers. Problem solving should be cultivated across all organizational levels and encourage subordinate personnel to participate and actively learn. Organizational cultures that support a synergistic process create a climate of interaction necessary to enhance the overall culture and encourage the development of a shared mental model regarding issues facing a team that is putting the work into place. Team building is critical in establishing successful quality and loss control programs.

Resource Management

Personnel, equipment, and technology are basic elements that comprise simple resource management. Personnel selection, screening that includes substance abuse, orientation, intercommunication programs, and ongoing defined mentoring program, are several areas of review found within human error studies. Targeted recruitment and retention methods also impact operational capabilities.

Sustainability of the workforce and the cultivation of a positive culture are achieved through several methods such as, supporting external continuing education programs through the establishment of educational trusts, or foundations, and access to corporate retreats. These allow employee's families to participate and utilize corporate timeshares or other investments, which further enhance retention. Cultivating a climate of pride in the corporation through the establishment of other innovative programs sustains and reinforces the desire for productive work execution, quality, and safety.

Defined equipment management programs can encourage employee ownership and support field operations. These include internal accountability and tracking of equipment resources, and communicating to employees the need to support and maintain corporate assets from the most expensive down to the least. Value is placed on maintaining the team's resources.

Value, as established at the executive and operations level, is placed on providing the best resources to the field team, through the ongoing rotation of tools or equipment through a managed maintenance program, or the purchase of replacements along with defined accountability.

The use of available technologies and field controls also clearly communicate the vision and climate of the organization. Providing personnel with state of the art communication methods regarding quality assurance/quality control (QA/QC) and loss control activities can further enhance productivity when properly implemented. Planning, design, and use of field controls, such as embedded fall protection, trench shields, real-time proximity tracking, and others, further demonstrate management commitment to personnel value, professionalism, corporate productivity, quality, and safety (Abraham et al. 2004; Huang et al. 1996; Teizer et al. 2007).

Executive Leadership

Corporate philosophy, regarding the value of continuous quality improvement, is also a metric in which quality and loss control is measured. Programs that encourage and support employee involvement, regarding continuous quality improvement, are critical in providing climates in which lessons learned are captured and maximized. Communication vehicles allowing field employees, who are putting the work in place, to provide design and engineering feedback on cost and overall execution are also critical in capturing exposures.

Oversight, regarding operations, resource management, cultural gap analysis, as well as policy and procedures, provide executive and operations personnel with objective data to measure the internal climate. On-time and cost-effective operations may reflect profit, however, review of all organizational influences will mitigate exposures, improve processes, and achieve a goal all companies seek: a sustained competitive advantage.

Through the accomplishment of oversight, revision of procedures and policies can also be realized. Annual revision of methods, captured from lessons learned, further support improvement in execution of work as it relates to schedule, quality, and loss control.

Evaluation of enforcement practices, regarding subcontractor management practices also ensure the communication of an internal culture, externally. Team building opportunities that include subcontractors' help develop effective partnerships and demonstrate a degree of professionalism required from the organization.

Incident Investigation Process—Supervisory Influences (2)

One of the obvious primary causes of incident and accidents are inadequate supervision of personnel. Latent, or hidden, failures occur within the supervisory types identified through human error evaluation. As previously stated in CRM, the need for effective communication, partnership, education, and team building is essential to on-time and cost-effective operations. Identification of behaviors and education will assist in the development of CRM strategies.

Although there area many types of behaviors, to create an intuitive basic method, HEAT looks at the four basic types of supervisors: the negligent supervisor, the inadequately trained supervisor, the passive supervisor, and the supervisor who actually plans an unsafe act. Although revealing to some, many supervisors take intentional shortcuts. The reason for the shortcuts begins in the culture and operational influences of the organization.

Planned Act Supervisor

The planned act supervisor often is affected by fast track scheduling failures, originating from within the operations level. Field supervisors routinely feel the impact of the production schedule and fast track schedule failures, which are affected by engineering or procurement issues, and always, with certainty, cascade down to the field level where incidents or accidents occur. Miscommunication, regarding directives lacking in clarity, combined with a culture where questions are not encouraged or incorrect information is supplied regarding job hazard procedures, further cause incidents and accidents.

Reactive and poorly planned resource management of personnel also contribute to poor decision making by field supervisors. In essence, field supervisors plan unsafe events in the hope the event will save time and not result in injury or rework. An example that is common in practice is although needing two personnel for material handling, only one employee is available. Mishandling oversized objects results in damage to the materials and the human asset as well.

Failure to leverage technology are manifested in a lack of defined equipment and tool management programs, which also impact on field supervisors, who at the front line may need a hammer but instead use a wrench, for example, due to the proper tools not being available. This lack of available equipment also translates across production tools and into loss control equipment, or the lack thereof. For example, grinding work that needs to be

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done rapidly begins immediately without the proper usage of a face shield resulting in an eye injury. The lack of time management and communication skills, manpower, and inadequate equipment support this type of supervisory behavior.

Negligent Supervisor

The negligent supervisor instructs employees to disregard safety procedures due to their own lack of respect for the safety methods, which is fostered from an organizational climate that only imitates, rather than promotes safety. Although some companies have safety programs in place, their programs are rarely found to be actively and effectively used in the field. Additionally, the negligent supervisor also actively demonstrates techniques to shortcut safety procedures. It may be as simple as removing a guard from a hand grinder to cut an object at a sharp angle and, in addition, failing to use protective eye glasses and a face shield. It may be further demonstrated to subordinates by working at a height without proper fall protection. There are many examples of this behavior.

The final negligent supervisor behavior is to passively encourage subordinate personnel, by not providing safety gear, communicating through body language, or display of impatience, and the need to just get the job done quickly.

Passive Supervisor

The passive supervisor simply accepts everything with the attitude to avoid identification and resolution of problems. This equates to not having to address the problems. Problems regarding repair of equipment, for example, find this type of supervisor forcing employees to use broken or ill functioning equipment. Additionally, this passive supervisor chooses to not report malfunctioning or broken equipment, again with the mindset that if no one knows it will not be his or her problem to fix or work around.

Further, seemingly minor employee issues regarding performance are also not dealt with by this passive supervisor. The employee issues avoided by this passive supervisor can range from subordinates not complying with safe work practices to substance abuse.

Inadequately Trained Supervisor

The inadequately trained supervisor, does not comprehend standard operating procedure in regard to either QA/QC or safety, and is usually selected and placed into a leadership position based upon manpower shortage or the fact they are the only one with a driver's license. Training regarding managing human assets may also be limited or nonexistent. The lack of oversight for these individuals may also further prolong bad habits and increase overall operational exposure regarding QA/QC and safety issues. These basic supervisory influences, tied along with organizational influences, lead directly toward preconditions that cultivate unsafe actions.

Incident Investigation Process—Preconditions (3)

Shappell and Wiegmann's research support the findings of human factors preconditions that identify adverse mental, physiological, and environmental states, as latent contributions relating to the cause of incidents or accidents (Shappell and Wiegmann 2001). As previously stated, recognition, or omission, regarding identification of preconditions combined with supervisory and organizational influences can either strengthen or weaken QA/QC and loss control efforts.

Adverse mental states influenced by physical limitations, brought about by fatigue as a result of working within extreme weather environments found in construction, experience greater potential for quality and safety performance failures. Tasks that call for heavy physical demand due to poor or nonexistent planning regarding CRM at the operations level or inadequate resource management of tools or equipment also affect employees working within hot weather environments, exceeding 95° in high humidity. Combined with a fast track schedule, employees will experience greater potential for errors in regard to the execution of work methods. In combining adverse mental states and physiological states, employee's who are exposed to fast track overtime scheduling practices, such as working 10-h days, 6 or 7 days a week, do not obtain adequate rest, which also affect judgment and physical performance. Employees working night or early morning schedules also face circadian dysrhythmias and exposure to greater spatial disorientation found in low light conditions, which can contribute to visual errors.

Incapacitation, in regard to intoxication of employees who work within organizations that function without established substance abuse testing programs, further enhance the potential for quality and safety performance failures. Unreported medical illness found in individuals who do not report their usage of prescribed medications can also contribute to preconditions of physiological failures. Certain over-the-counter and prescribed medications, for example, may cause dizziness or decreased reaction time when operating equipment, also contribute to preconditions. Unreported injuries may also affect overall crew performance regarding simple tasks such as material handling activities.

Leadership failures found in supervisory influences regarding poor management of exposures in relation to these basic preconditions will contribute to sustaining a precondition of quality or safety failures. Established leadership and mentoring programs that develop supervisory personnel and provide techniques to identify and mitigate preconditions are essential to reduce quality and safety failures.

Altruistic organizational culture that is effectively communicated to employees supports and cultivates their desire to achieve and improve. An example of a positive culture is found in available and fully supported, internal and external educational programs that allow for better educated employees. Continuing education programs advocate the further strengthening of the organizational human resource.

Incident Investigation Process—Unsafe Acts (4)

Unsafe acts occur for a variety of reasons ranging from the failure to follow established safety procedures, to intentional acts, and to technology failures. Beginning with safety procedures, many employees become selective in complying with the set procedures that are jointly influenced by organizational culture, supervisory, and preconditions. Literacy also plays a significant role in the compliance with written procedures. The construction industry is attractive to individuals who may not have completed basic education skills. The typical construction laborer prefers an outdoor environment and may have not felt comfortable in the confines of a typical classroom, leading to their leaving of school prematurely. Originating at the operations level and continuing into the supervisory level, misapplication or comprehension of procedures regarding quality or safety, also contributes to failures. Poorly prepared job hazard analysis or superficial RCA techniques, further contribute to quality or safety failures.

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As previously alluded to in preconditions, mental states regarding complacency and overconfidence can also contribute to unsafe acts. Complacent mentalities found in personnel who are performing a job for an extended duration contribute to failures. Seasoned well trained electricians die each year due to complacency. Overconfident equipment operators may possess aggressive attitudes that may exceed abilities when placed in certain preconditions found, for example, in adverse mental, physiological, or environmental states.

Intentional unsafe acts at the labor level also occur. Sociological behaviors brought on by intertrade conflicts can contribute to unsafe acts. Union versus non union and trade versus trade reflect a potential environment where employees intentionally damage another's equipment or materials. Criminal acts brought on by theft can further contribute. Employees with substance abuse, gambling, or financial problems steal to compensate or satisfy their own need. Positive cultures will empower a majority of employees with a desire to protect their team, its equipment, and work against these types of criminal individuals.

In addition, personnel who have little regard for organizational equipment or other assets will have a better likelihood of being mentored by senior field employees who fully understand an organizational culture that is positive and supports its employees. Organizational culture that instills pride in its employees will have employees that exhibit behavior, which is protective of its own organization.

The last area of unsafe acts is in regard to engineered systems and technology exhibited through methods, tools, and equipment. The usage of proper application of technologies communicates a clear message of improvement and support of quality and loss control efforts. Proper usage of these technologies begins with training personnel in its limitations and application. Regarding safety, behavior based reporting systems require that the personnel understand how to collect data along with the ongoing employee training regarding behavior observations. Employees can become excellent data collection resources if they are fully trained in their own limitations. Tools, methods, equipment, and personal protective devices need to be properly applied and maintained. Embedded fall protection systems need to be used in ways that do not exceed its intended use. Trenching and excavation protective systems need to be properly applied and used every time. Personal protective equipment need to be used properly. Dual lanyards, for example, are to be used to provide 100% fall protection. Many employees who have been oriented in the requirements of site specific safety requirements of 100% fall protection may commonly use only one lanyard. Misapplication of engineered systems or the premature removal of shoring or supports that may result in the collapse of a poured structure further illustrate the lack of comprehension or misuse of technology.

As a result of the developed approach, an example of HEAT is shown in Fig. 3 as it was used in on-site training sessions. The intent of using HEAT in the construction site environment is to educate personnel at any level to prevent error(s) that can occur on any level (organization management, front line supervisory, field employee). To illustrate the consequence that result from errors, such as events that lead to incidents, accidents, or even fatalities, acronyms are defined in the HEAT in such a way that allows personnel at all levels to easily remember key concepts in safety training and education. Furthermore, a simplistic approach like HEAT easily allows conveying the message of usually complex safety concepts by linking a few of the relevant factors that are present in the construction industry and typically lead to unsafe acts. Illustrated in Fig. 3, some examples are presented (following the errors in the diagram): "A good organizational safety CULTURE needs to be ACCEPTED to achieve its INTENT," "OPERATIONS need to be carefully PLANNED, to avoid FATIGUE and to stay FOCUSed," and "Proper RESOURCE MANAGEMENT requires LEADERSHIP to be ADEQUATE and according to PROCEDURES." To each acronym further details are provided. Examples of the acronyms are CORE, PAIN, FAIL, PROFIT, VIPER, STOP, DIE, SET, SLAC, MAP, SCAM, and STEP. Individual modules can be taught from each of these acronyms. Another significant contribution from the HEAT model not found in HFACS is the usage of acronyms that produce an encoding method that enhances retention of HEAT influences for use in field observations and job preplanning by operations and field personnel. Using these acronyms in various orders can help construction personnel understand and link previously complex safety concepts that a construction organization may have in place.

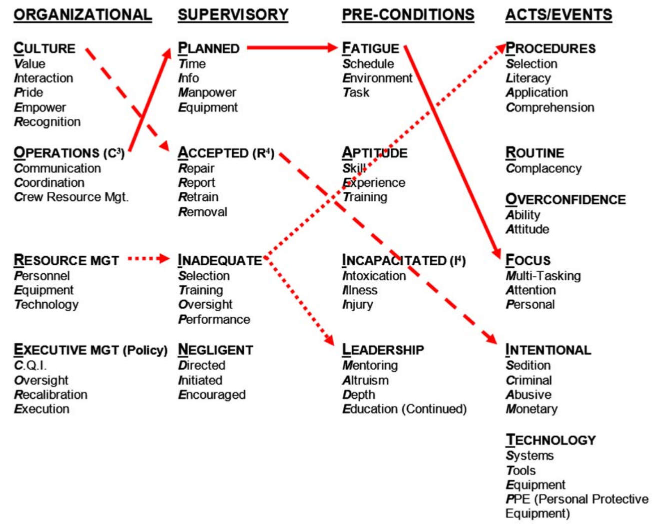

Fig. 3. Three examples of HEAT as it is practiced in the field

Path Forward

The diversity and scale of the construction industry is such that the ability to learn from accidents is dependent on the quality of communication arising out of a rapid investigation to establish the root cause of the accident. Experiences in other countries, like the United Kingdom, have shown that there are real benefits to be gained from a more rapid and accurate reporting of the causes of an accident or incident (Haste 2005). Leveraging technology, to capture timely and direct communication of near miss data, can assist construction operations in the field in which the incidents and accidents occur. In-depth human error investigation can enable better project preplanning, training for the future, and the communication of the core cause.

The consistency of the existing methods starts with collecting the data by the different interviewers. A number of such tools are available. For example, the critical event reporting tool (Von Thaden et al. 2006) which was developed for improving the type of information gained from aircraft incidents and accidents, or the behavioral sequence interview technique (Keating and Loftus 1984) when interviewing people after fire incidents.

However, the influence of attitudes and culture plays a critical

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role in good data collection (Muir and Thomas 2004). The overall safety culture of a company depends on near miss and accident investigations integrated with the science of human behavior, and the identification of specific contributing factors involved. The lack of real data, however, often prevents valid assessment of human error causes.

In advance of human factor investigators receiving training in the science of human behavior and before joining an investigating team, it might become essential for them to assist with the practices in place using the following methodologies:

1. Improve training, educational tools, and methods within a framework of human error principles;
2. Leveraging existing and emerging technologies as data collection tools, designed within a human error analysis process;
3. Develop organizational cultural analysis and corporate cultural sustainability programs; and
4. Utilize standardized methodology regarding key employee assessments to establish baseline capabilities of supervisor's behaviors and motivators, in addition to the cognitive skills in areas of critical thinking, leadership, and problem solving.

Conclusion

This paper proposed a new error analysis, educational, and classification tool for safety within the construction industry. The intent of this research study was to develop an intuitive field program regarding human error that educates executive, operations, and field employees in the identification of human error causation and the techniques of mitigation. Many reasons of unsafe behavior were discussed. An outlook was presented to validate the presented framework through data collection and data analysis to develop effective training and active safety tools.

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