



Construction Industry Institute®

Strategies for Improving Hazard Recognition

Matthew R. Hallowell

Alex Albert

University of Colorado Boulder

Brian Kleiner

Virginia Polytechnic Institute and State University

Construction Industry Institute

Abbott	AMEC
Air Products and Chemicals	AZCO
Ameren Corporation	Aecon Group
American Transmission Company	Affiliated Construction Services
Anglo American	Alstom Power
Anheuser-Busch InBev	Audubon Engineering Company
Aramco Services Company	Baker Concrete Construction
ArcelorMittal	Barton Malow Company
Architect of the Capitol	Bechtel Group
BP America	Bentley Systems
Cameco Corporation	Bilfinger Industrial Services
Cargill	Black & Veatch
Chevron	Burns & McDonnell
ConocoPhillips	CB&I
Consolidated Edison Company of New York	CCC Group
DTE Energy	CDI Engineering Solutions
The Dow Chemical Company	CH2M HILL
DuPont	CSA Central
Eastman Chemical Company	Cannon Design
Ecopetrol	Coreworx
Eskom Holdings SOC	Day & Zimmermann
ExxonMobil Corporation	Dresser-Rand Company
General Electric Company	eProject Management
General Motors Corporation	Emerson Process Management
GlaxoSmithKline	Faithful+Gould
Global Infrastructure Partners	Fluor Corporation
Huntsman Corporation	Foster Wheeler USA Corporation
Intel Corporation	GS Engineering & Construction Corporation
International Paper	Gross Mechanical Contractors
Irving Oil Limited	Hargrove Engineers + Constructors
Kaiser Permanente	Hatch
Koch Industries	Hilti Corporation
Eli Lilly and Company	Honeywell International
Linde North America	IHI E&C International Corporation
LyondellBasell	IHS
Marathon Petroleum Corporation	International Rivers Consulting
National Aeronautics & Space Administration	JMJ Associates
NOVA Chemicals Corporation	JV Driver Projects
Occidental Petroleum Corporation	Jacobs
Ontario Power Generation	KBR
Petroleo Brasileiro S/A - Petrobras	Kiewit Corporation
Petroleos Mexicanos	Kvaerner North American Construction
Petrolia Nacional Berhad	Lauren Engineers & Constructors
Phillips 66	Leidos Constructors
Pioneer Natural Resources	Matrix Service Company
Praxair	McCarthy Building Companies
The Procter & Gamble Company	McDermott International
Public Service Electric & Gas Company	Midwest Steel
Reliance Industries Limited (RIL)	Parsons
SABIC - Saudi Basic Industries Corporation	Pathfinder
Sasol Technology	POWER Engineers
Shell Global Solutions US	Quality Execution
Smithsonian Institution	Richard Industrial Group
Southern Company	The Robins & Morton Group
Statoil ASA	S&B Engineers and Constructors
SunCoke Energy	SBM Offshore
Teck Resources Limited	SNC-Lavalin
Tennessee Valley Authority	Skanska USA
TransCanada Corporation	Technip
U.S. Army Corps of Engineers	Tenova
U.S. Department of Commerce/NIST/ Engineering Laboratory	TOYO-SETAL Engenharia
U.S. Department of Defense/Tricare Management Activity	URS Corporation
U.S. Department of Energy	Victaulic Company
U.S. Department of Health & Human Services	WESCO International, Inc.
U.S. Department of State	Walbridge
U.S. Department of Veterans Affairs	Wanzek Construction
U.S. General Services Administration	Wilhelm Construction
Vale	Willbros United States Holdings
The Williams Companies	Wood Group Mustang
	WorleyParsons
	Yates Construction
	Zachry Holdings
	Zurich

STRATEGIES FOR IMPROVING HAZARD RECOGNITION

by

Matthew R. Hallowell
Alex Albert
University of Colorado Boulder

Brian Kleiner
Virginia Polytechnic Institute and State University

A Report to
Construction Industry Institute
The University of Texas at Austin

Under the Guidance of
CII Research Team 293
Strategies for HSE Hazard Recognition

CII Research Report 293-11
April 2014

© 2014 Construction Industry Institute®

The University of Texas at Austin.

CII members may reproduce and distribute this work internally in any medium at no cost to internal recipients. CII members are permitted to revise and adapt this work for their internal use, provided an informational copy is furnished to CII.

Available to non-members by purchase; however, no copies may be made or distributed and no modifications made without prior written permission from CII. Contact CII at <http://construction-institute.org/catalog.htm> to purchase copies. Volume discounts may be available.

All CII members, current students, and faculty at a college or university are eligible to purchase CII products at member prices. Faculty and students at a college or university may reproduce and distribute this work without modification for educational use.

Printed in the United States of America.

Executive Summary

Construction Safety management involves recognizing and managing safety hazards in the work environment. Hazards that remain unidentified can potentially expose workers to unanticipated risk that can result in catastrophic injuries and illnesses. To improve hazard recognition, the industry has practiced record-keeping and post-accident analysis to identify hazard patterns that are then incorporate as lessons learned in training programs. Other prevalent methods include Checklists, Safety Audits, and Job Hazard Analysis (JHA). Despite the adoption and benefits of these traditional hazard recognition methods, recent research indicates that workers are unable to predict, identify, and respond to significant hazards in dynamic and rapidly changing environments (Carter and Smith 2006; Haslam et al. 2005). Construction Safety professionals believe that an improvement in hazard recognition can significantly reduce injury and accident rates. The goal of the RT293 research team, in response to this critical issue, was to develop transformative strategies and hands-on tools to equip construction workers to effectively improve hazard recognition and communication.

In the first phase, a comprehensive list of promising hazard recognition methods used in diverse industries including aerospace, military, manufacturing, mining, and construction were catalogued from industry reports and literature. Over 100 hazard recognition techniques were identified that were either new to construction or not used specifically as a hazard recognition improvement tool. The three with the greatest potential for step-change improvement were selected using the Nominal Group Technique, a research technique that capitalizes on the expertise of the research team. The three strategies include: (1) *a system for augmented virtuality safety (SAVES)* that immerses workers in a hyper-realistic augmented environment for training; (2) *a pre-job safety meeting quality measurement (SMQM) maturity model* that facilitates continuous improvement of the pre-job hazard identification and communication process; and (3) *a visual cue-based hazard identification and transmission board (HIT board)* that records hazards during task evaluation and real-time as the job progresses.

In the second phase, because these strategies were new to construction and were completely conceptual, the research team developed prototype versions of each tool for proper field implementation. After development, in the third phase, the impact of the strategies as interventions was empirically and experimentally field tested with active work crews from

diverse projects. The multiple-baseline testing (MBT) approach was used because of its ability to establish causal relationships between the strategies and hazard recognition performance.

The results of the field tests indicated that workers were able to identify less than half of hazards in their immediate work environment before work begins. In other words, more than half of the hazards were not adequately identified and discussed prior to work. Fortunately, the experimental field tests reveal that the *SMQM* model, *SAVES* system, and *HIT* Board caused a net weighted overall improvement in hazard recognition skill of 27%, 31%, and 30%, respectively. The findings imply that the adoption of the developed and tested strategies can drastically improve hazard recognition skill of the workforce, and potentially reduce injury and accident rates. The research report discusses the relevant background for this study, the development of the key strategies, the specific testing protocol, and the results. Relevant conclusions are drawn and recommended future research is presented.

CONTENTS

EXECUTIVE SUMMARY	iii
LIST OF FIGURES	vi
LIST OF TABLES	vii
1. BACKGROUND	1
2. RESEARCH OBJECTIVES	3
3. BACKGROUND KNOWLEDGE	4
3.1 Hazard identification and evaluation	4
3.2 Classes of hazard recognition methods	5
3.3 Role of hazard recognition in accident causation	6
3.4 Safety training programs in construction	8
4. RESEARCH APPROACH	9
5. SELECTION OF CANDIDATE STRATEGIES	10
5.1 Exploratory research studies to identify hazard recognition program elements	10
5.2 Short-listing of potential hazard reception program elements	11
5.3 Nominal group technique (NGT) results	13
5.4 Overarching strategy: Energy-Based Cognitive Mnemonics	16
6. PHASE 2: DEVELOPMENT OF KEY STRATEGIES	18
6.1 Training Strategy: System for Augmented Virtuality Environment Safety (SAVES)	18
6.2 Planning strategy: Safety Meeting Quality Measurement (SMQM)	21
6.3 Workforce Execution Strategy: Hazard Identification and Transmission (HIT) Board	22
7. PHASE 3 – FIELD EXPERIMENTS WITH MULTIPLE BASELINE TESTING AND INTERRUPTED TIME SERIES REGRESSION MODELS	25
7.1 Measuring hazard recognition performance by shadowing work crews	26
7.2 Multiple baseline testing protocol and analysis	27
7.3 Potential limitations and methods used to improve validity and reliability	30
7.4 Independent validation using image analysis	31
7.5 Multiple baseline field study results	32
Training Strategy: System for Augmented Virtuality Environment Safety (SAVES)	33
Planning Strategy: Safety Meeting Quality Measurement (SMQM)	38
Workforce Execution Strategy: Hazard Identification and Transmission (HIT) Board	43
8. CONCLUSIONS AND RECOMMENDATIONS	48
8.1 Recommended Future Research	49
9. REFERENCES	50
Appendix– Pre-job safety meeting quality measurement (SMQM) maturity model	58

List of Figures

Figure 1. Selection of hazard recognition elements.....	10
Figure 2: Development of SAVES	19
Figure 3: Conceptual framework of SAVES	20
Figure 4: Hazard Identification and Transmission (HIT Board)	23
Figure 5: Mathematical model selection flowchart for analysis.....	29
Figure 6: Results of Case 1- Multiple baseline study on oil and gas facility.....	35
Figure 7: Results of Case 2- Multiple baseline study on fluff pulp processing facility.....	37
Figure 8: Results of Case 3- Multiple baseline study on modular construction project	40
Figure 9: Results of Study 4- Multiple baseline study on power plant project.....	42
Figure 10: Results of Case 5- Multiple baseline study on food processing facility	44
Figure 11: Results of Case 6- Multiple baseline study on manufacturing plant.....	47

List of Tables

Table 1: Emerging hazard recognition programs with application to construction.....	12
Table 2: Decision Criterion for down-selection process.....	13
Table 3: Results of rating process.....	15
Table 4: Energy sources for hazard identification process.....	17
Table 5: Interrupted time series regression models.....	28
Table 6: Project Characteristics.....	32
Table 7: Results of Case 1- Multiple baseline study on oil and gas facility.....	35
Table 8: Results of Case 2- Multiple baseline study on fluff pulp processing facility.....	37
Table 9: Results of Case 3- Multiple baseline study on modular construction project.....	40
Table 10: Results of Study 4- Multiple baseline study on power plant project.....	42
Table 11: Results of Case 5- Multiple baseline study on food processing facility.....	44
Table 12: Results of Case 6- Multiple baseline study on manufacturing plant.....	47

1. BACKGROUND

The construction industry continues to account for a disproportionate occupational injury rate. In the last decade, despite continual safety efforts, the construction sector has decelerated in terms of improvement in injury rates. According to the Bureau of Labor statistics (2012), the US construction sector has been responsible for more than a thousand fatal injuries every year between 1995 and 2008. In 2011, construction workers accounted for one out of every five (20%) work-related deaths (BLS 2011). These injury statistics clearly show that construction workers are more likely to be injured than workers in most other industries. Alarming, in 2013 the fatality rate in construction increased for the first time in over 40 years (*Engineering News-Record* 2013).

Traditionally, the construction industry has taken a reactive approach to safety. Accordingly, problems associated with an organization's safety program are only apparent after injuries occur. With increased financial implications associated with occupational injuries and the emerging pursuit of zero incident projects, construction professionals are exploring the implementation of innovative safety strategies that can be introduced early in the project development process (Goetsch, 1996; Holt, 2001).

The objective of a construction safety program is to control hazards before they are encountered (Goetsch and Goetsch 1996; Holt and Lampl 2006). The ability of individual and groups of workers to identify and communicate hazards is the fundamental aspect of any safety activity. Those who are unable to perceive active, emerging or latent hazards in the environment may be exposed to uncontrolled risks (Laurence 2005; Sneddon et al. 2004). Unfortunately, according to studies conducted by Carter and Smith (2006), and the Center for Disease Control and Prevention (CDC 2012), workers are traditionally poor at identifying hazards before construction because of the diverse, fragmented, and dynamic nature of the industry. In fact, 42% of accidents involve inadequate hazard identification and appraisal skills of workers (Haslam et al. 2005a). This connection between hazard recognition and safety performance is logical because, as Wilson (1989) shows, workers who do not recognize hazardous conditions are not able to behave safely. This problem is compounded by the lack of safety knowledge transfer channels within organizations and among work crews (Alsamadani et al. 2012; Hallowell 2012).

In order to enhance hazard recognition skill, employers in most industries process workers through formal hazard recognition programs. Through these programs, workers are trained to actively gather and process the sensory cues that are pre-cursors to incidents. Workers are then able to mentally relate current observations with knowledge and experience received from the past. When training programs are implemented effectively, workers' ability to identify, process, and respond to hazards is greatly improved. The methods used to promote hazard recognition skills in construction tend to be different from those used in other traditional industries because work processes and environments tend to change rapidly and, thus, may be more akin to battlefield scenarios and training methods.

2. RESEARCH OBJECTIVES

The objective of this research study was to develop and test new, potentially transformative hazard recognition strategies for step-change improvement in safety performance. We aimed to develop techniques that incorporated industry best practices and relevant theories from psychology and behavioral sciences. We conducted research in three segregated but interrelated phases that address current weaknesses in safety training, planning, and execution. In the first phase a comprehensive list of hazard recognition strategies was identified and three were selected for further development and testing using the Nominal Group Technique. In the second phase the three strategies were developed and refined for use in the construction industry since the methods identified were new to construction. In the third and final phase the three strategies were field tested to determine their impacts on hazard recognition skill. The overall aim of this research was to experimentally test the hypothesis that a given strategy causes a measurable increase in the proportion of hazards identified and communicated before work begins.

3. BACKGROUND KNOWLEDGE

3.1 Hazard identification and evaluation

Hazard identification has become a critical element of an effective safety program. According to the National Safety Council (NSC as cited in Mitropoulos et al. 2005, p. 817), a hazard is, “an unsafe condition or activity that, if left uncontrolled, can contribute to an accident.” To prevent injuries hazard recognition methods are introduced to identify work-place hazards and mitigate risk associated with these hazards through the use of procedural or physical barriers. Hazards that are not identified during the evaluation process may not have adequate controls in place, which may pose severe threat to both safety of workers and to the environment. Thus, it is critical to execute an organized effort to identify and evaluate processes and activities for potential hazards. Such informal and formal methods provide valuable information to improve safety and manage operational risks.

Potential hazards are identified based on the knowledge of operations and past experience with similar work-tasks. This usually involves brainstorming-type sessions among team members having familiarity with operational activities (Campbell, 2008). Several formal analytical hazard identification and evaluation tools are being used in the manufacturing and chemical industries. For example, the Hazard and Operability (HAZOP) analysis systematically uses key guide-words to identify hazards that may result from deviations from planned operations (Mushtaq and Chung, 2000). Additionally, fault tree analysis is a graphical array of logic gates that illustrate the series of faults that lead to an undesirable event (Brooke and Paige, 2003) and Failure mode and Effect Analyses (FEMA) helps managers to identify hazards related to potential failure modes (Stamatis, 2003). Although such formalized hazard recognition methods are commonly employed in other industries (Abdelgawad and Faye, 2012), they are generally unsuitable for construction because of the lack of standardization of work-tasks and the inherent dynamic nature of construction projects.

In construction potential hazards are typically identified using less sophisticated and more informal techniques. Most site-based hazards are recognized by workers based on their experience and knowledge of operations through brainstorming-type sessions. Most advanced approaches, like the Job Hazard Analysis (JHA), generally involve reviewing the project scope, defining construction tasks, identifying potential hazards relevant to the defined task, and assessing risk, and designing a safe work plan. Although this method is highly useful, there are

several limitations, including: (1) hazards imposed by adjacent tasks are ignored (Rozenfeld et al. 2010); (2) workers are often unable to predict how tasks will be performed in the planning phase (Borys 2012); and workers are not fully competent in recognizing hazards the plethora of possible hazards.

In addition to the JHA, other common hazard recognition methods include lessons-learned and the use of safety checklists (Behm and Schneller 2012; Fleming 2009; Zou and Zhang 2009). These techniques gather valuable information for future improvement from past injury records, which is disseminated through safety training programs. Unfortunately, these methods have several significant inherent limitations. First, the underlying databases are often not complete because they do not include near-misses and unreported injuries (Gyi et al. 1999). Second, injury records only reflect only a small subset of hazardous work scenarios that resulted in injuries and information from past incidents is not generalizable across diverse and dynamic different settings (Rozenfeld et al. 2010). Third, these methods require that an enormous amount of information is effectively transferred through instructional methods. Finally, the cognitive demands of predicting hazards are substantially high and often inefficient because of the difference that exists between tasks as they are imagined and tasks as they are performed (Borys 2012).

3.2 Classes of hazard recognition methods

Existing hazard recognition methods can be classified in two categories: predictive and retrospective. Predictive hazard recognition methods, like the Job Safety Analysis (JSA), involve scenario-building where workers mentally visualize construction tasks to identify relevant hazards (Rozenfeld et al. 2010). Examples of other predictive methods include task-demand assessments and task-planning safety sessions (Mitropoulos and Namboodiri 2011). Although useful, such methods often fail to include hazards associated with adjacent work and changes in scope, methods, or conditions; assume that workers can correctly predict the sequence in workflow and associated hazards in dynamic and often unpredictable environments; and assume that workers already possess the required skill-sets to accurately detect hazardous stimuli. Alternatively, retrospective methods rely on past experiences and injuries in similar work-settings to identify hazards. Methods like lessons learned and safety checklists fall under this category. Like predictive methods, reactive hazard recognition methods have several

weaknesses, namely: near misses and past incidents are often not reported in sufficient detail for future learning and improvement; injury records and incident reports only represent a small subset of potential scenarios that unfortunately resulted in injuries; and it is often invalid to generalize accidents across different settings in dynamic environments (Dong et al. 2011; Williamsen 2013).

3.3 Role of hazard recognition in accident causation

Poor construction safety performance has prompted many researchers to model accident causation specifically for the construction industry to identify proactive hazard management measures. These models descriptively decode hazardous attributes of construction environments and associate them with incidents. Early accident causation models focused primarily on modeling behavior and personal characteristics of workers as the primary causes of injuries. For example, accident proneness theories suggest that certain individuals are more likely to be involved in accidents as a result of “their innate propensity for accidents” (Shaw and Sichel, 1971 p. 14). Kerr (1950; 1957) corroborates this theory by claiming that accidents are caused by workers who are unable to adjust to dynamic work environments. In a related accident causation model, the Domino Theory (Heinrich, 1950; Manuele, 2003) suggests that occupational injuries are caused when unsafe conditions are combined with unsafe actions that originate from the faults of individuals.

Fortunately, accident causation models evolved as the understanding of the complexity of injuries causation improved. For example, Reason’s multi-causality approach (1990) delineated the accident development process beginning with latent failures at the managerial levels to local trigger events at the workplace. To explain the complex nature of a worker’s interaction with their work environment, Hinze (1996) developed the Distraction Theory, which suggests that productivity demands and difficulty reduce a worker’s focus on hazards, increasing the probability of accidents. According to Abdelhamid and Everett (2000), occupational accidents occur due to one or more of the following causes: (1) Failing to identify an unsafe condition that existed before an activity was started or that developed after an activity was started; (2) deciding to proceed with a work activity after the worker identifies an existing unsafe condition; or (3) deciding to act unsafe regardless of initial conditions of the work environment. The constraint-response model proposed by Suraji et al. (2001) suggested that environmental constraints and

management actions may result in inappropriate conditions or work operations at the site which increases accident risk. According to the 'Systems model of construction accident causation' (Mitropoulos, 2005), task characteristics and unpredictability create hazardous situations in the work-place, and the exposure to these hazards creates the potential for accidents. Accidents occur under exposure when hazards are released as a result of errors or loss of control in the work-place. Haslam et al. (2005), in explaining the hierarchy of causal influences illustrated that accidents occur as a result of the poor interaction between workers or work-team (e.g. worker behavior); workplace (e.g. poor housekeeping); and materials/equipment (personal protective equipment); which originate due to deficits in the Construction design and process; project management; risk management; Client and economic influences or Safety education and training.

These accident causation models were developed to explain contributory factors that lead to accidents with the ultimate goal of implementing timely and prudent accident prevention strategies. In a study examining contributory factors associated with 100 construction accidents (Haslam et al., 2005), 70% of accidents were estimated to have involved failure associated with human error (e.g. behavior and capability). These failures included worker's disregard for safety over other project priorities; inadequate hazard awareness and appraisal; and workers' propensity towards least efforts to accomplish defined project goals. The study attributed other accidents to workplace constraints, conditions, and local hazards (49%); the use of improper equipment (56%); and incidents involving the use of unsuitable materials (27%). Thus, a critical element to improve site-safety performance is to have a competent work-force capable of recognizing hazard causal factors in the work-environment along with a good understanding of the relationship between job-tasks, tools and work-place conditions.

According to Wilson (1989), workers are usually placed under risk either because of their ignorance of hazards in the work-place due to limited experience and knowledge or failure to behave safely which may be associated with the workers attitude towards safety (Abdelhamid and Everett, 2000) or the underestimation of perceived risk (Bailey, 1997; Choudhry and Fang, 2008). Also, inexperienced workers who are unable to recognize hazardous conditions will be unable to behave safely because of the lack in ability to recognize situations with the potential to cause injury. On the other hand, experienced workers who perform similar tasks repeatedly may be conditioned to work in an unsafe manner due to their reliance on prior success. Thus, the construction industry needs to take active steps to enhance worker skills for hazard recognition.

3.4 Safety training programs in construction

Although regulations require employers to provide safety education and training, research indicates that workers still lack essential safety knowledge (Haslam et al. 2005b). This is often because safety training programs are poorly designed and do not incorporate effective instructional methods (Haslam et al. 2005b). Additionally, most hazard recognition training programs focus on transferring explicit knowledge that is easily verbalized, documented, and presented. However, hazard recognition skills are mainly tacit knowledge (Watanuki and Kojima 2007) that is generally based on an individual's experiences and developed skill-sets (Cavusgil et al. 2003).

In addition to poor execution, the transient nature of the work-force has significantly impeded the adoption of innovative and effective training methods (Holte and Kjestveit 2012). Specific barriers to adopting improved methods include time constraints in schedule intensive projects, lack of interest and commitment among workers, and difficulty in quantifying benefits (Wang et al. 2010). Nevertheless, with the surging cost of construction injuries and the recent focus on delivering zero-incident projects, Hinze and Wilson (2000) and Waehrer et al. (2007) demonstrate the clear need for broad implementation of innovate, time-efficient, and cost-effective training programs. Therefore, it is necessary to develop novel learner-centric training programs that are sensitive to learning styles of the trainees, capture and transfer tacit knowledge, and can be delivered in a cost-effective manner (Cavusgil et al. 2003; Wilkins 2011).

4. RESEARCH APPROACH

Throughout this research we relied on our panel of subject matter experts (i.e., our CII research team). Our research team consisted of fourteen highly experienced construction safety professionals with an average of over 25 years of safety management experience. Seven members were Certified Safety Professionals (CSP) and five were Certified Hazardous Materials Managers (CHMM). The team also included one or more members with the following licenses or certifications: Professional Engineers (PE), Occupational Health and Safety Technologists (OSHT), Compliance Safety and Health Officers (CSHO), Certified Industrial Hygienists (CIH). Further, several members were actively involved in various health and safety committees such as the American Society of Safety Engineers, National Safety Council, Accident prevention Association and other local safety counsels. Apart from experience and affiliations, the team was comprised of people with advanced degrees related to construction, safety or related fields. The group included five experts with master's degrees and six with bachelor's degree in occupational safety and health, construction engineering and management, civil engineering, or related field. In summary, the members qualified to participate as subject matter experts (SMEs) in this research study exceeded the recommendations provided in construction engineering literature (Hallowell and Gambatese 2009).

This research panel advised the conduct of this three-phase research. They also provided vital data during the identification and prioritization of candidate strategies. The three phases of this research project include: (1) identification and prioritization of innovative hazard recognition techniques; (2) development and adaptation of three high priority strategies, and (3) experimental field testing of the strategies. The details of these three phases are described in subsequent sections.

5. SELECTION OF CANDIDATE STRATEGIES

The research phase consisted of two distinct steps, designed to achieve several related objectives. In the first step, the objective was to identify high potential hazard recognition programs based on literature and data provided by construction organizations in the United States who have achieved exceptional safety performance. In the second step, the objective was to identify and refine the

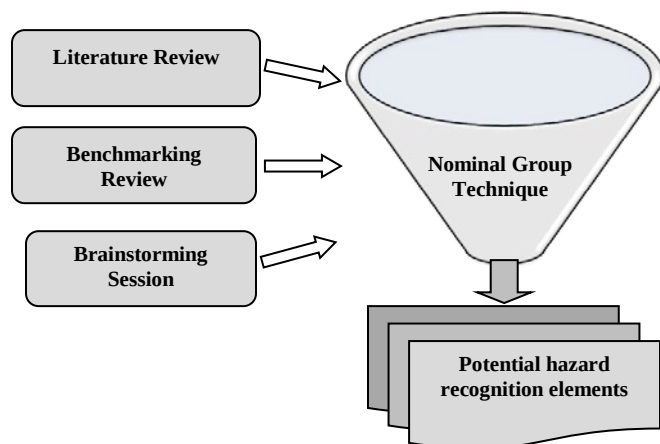


Figure 1. Selection of hazard recognition elements

three strategies that experts believe have the greatest potential to improve hazard recognition and, consequently, safety performance. Figure 1 summarizes this process.

5.1 Exploratory research studies to identify hazard recognition program elements

The research process began with an extensive literature search in an effort to identify hazard recognition program elements used in industries such as construction, mining, manufacturing, aviation chemical, and the military. Following this literature review, the expert panel and the research team met for a one-day face-to-face meeting that began with a brief orientation to the research study and a description of the literature review results. Following this introduction, the experts were encouraged to share hazard recognition strategies that were being implemented in their respective organizations. They were also encouraged to brainstorm additional methods that may be theoretically promising. To enhance efficiency, the team used a ‘round robin’ technique through which each member voiced his or her experience and opinion. After the first round of idea sharing, a second opportunity was provided to share ideas that may have generated while listening to the first round. All the ideas were recorded on a whiteboard by the meeting facilitator. Following the round-robin discussion the experts provided electronic and hard-copy forms of the strategies implemented in their organizations such as job hazard analyses, safety audit sheets, and leading indicators of safety performance. In total, twenty-one hazard reception program elements were identified or devised (Table 1).

5.2 Short-listing of potential hazard reception program elements

The goal of the second step was to evaluate the twenty-one strategies and identify two to three with the greatest potential for transformative improvement in construction hazard recognition that would be refined by the expert team in later phases. To achieve this objective, a two-day face-to-face meeting was held. In this meeting the expert panel was divided into three subcommittees, each with at least four members. Each subcommittee was provided with three hours to brainstorm and choose three of the twenty-one strategies that they believed had the most potential. After this time, the subcommittees presented their strategies to the entire panel. During this session, the participants were also given an opportunity to ask question regarding the presented strategy in order to help comprehend the strategies' potential. Once each committee reported to the entire panel, they were asked to anonymously rate each presented strategy based on pre-established decision criteria shown in Table 2. A Likert scale was used where 1 meant 'strongly disagree'; 3 meant 'neutral'; and 5 meant 'strongly agree'.

This rating process was conducted efficiently using the Nominal Group Technique (NGT), which was facilitated by Groupputer, a group decision support software system donated by an expert panel member's organization. The NGT, unlike the Delphi procedure, is a highly structured and rapid decision-making method, while obtaining input from multiple group members (Forsyth, 2010). This was important since the short-listing process required the input from time-conscious working safety-professionals who constituted the expert panel in the study (Carney and Worth, 1996). The voting process was also led by two professional meeting facilitators who were not a part of the research team to improve the meeting process (Dennis and Wixom, 2002).

Table 1: Emerging hazard recognition programs with application to construction

Hazard reception program elements	Description
Pre-job safety meeting quality measurement tool	Tool that evaluates the crew's hazard identification capability and communication to create hazard awareness
Senior Leadership engagement in JSA process	A quantitative measure of the management's involvement in the JSA process through resource allocation and commitment
Augmented and Interactive reality training environment	Computer-based simulation tool that trains workers to identify hazards using a representative virtual environment
Safety situational-awareness training	A worker centric program in which various potential hazards are detailed to the work-crew prior to initiating work
JSA post-kick-off audit	Evaluation of JSA's after task completion to obtain feedback on unidentified hazards
Hazard identification Board	A water-proof board displayed at the work-site to communicate potential hazards as work progresses
Precursory Visual Cues	Using visual aids such as tapes, signals, signs and LEDs to communicate hazards to the work-force proactively
Physical area hazard simulation	An active exercise by the crew that simulates work to be done as a way of identifying associated hazards
Foreman One on One w/ Employee	A one-on-one walk through the work facility, where an experienced foreman points to hazards in the environment
Video/Photo Monitoring & Feedback	A continuous feedback process received through the review of previous work captured as videos or photographs
Job safety/hazard analysis	A formal technique that focuses on specific work tasks as a way of identifying hazards before work is initiated
Task demand assessment	An evaluative method in which task difficulty is assessed and better and efficient work practices are proposed
What-if analyses	Use of a systematic, but loosely structured form of brainstorming sessions guided by what-if questions
Action plan critique	A feedback mechanism involving the critiquing of established plans to improve implementation work plan
Recordkeeping and accident analyses	Creation of a database which records lessons learnt from past injuries and experiences to avoid recurrence of accidents.
Safety Checklists	Survey of work area or construction process to ensure conformance to certain established criterion
Method statement review /Work permitting	Audit of a written work plan elaborating on work tasks and conditions before a written permit to work is issued
Walk-through safety and health audit	A observational method to identify active hazardous conditions, unsafe behavior through walk-through sessions
Worker-to-worker observation program	A peer-to-peer safety observatory program to provide feedback on worker performance with respect to safety
Pro-active safety alert systems	Incorporation of detection technologies into equipment that sound an alarm, or is disabled when a hazard is detected
Pre-use analysis and planning	A formal study conducted prior to any process modification, or the use of new equipment, or chemicals in the job-site