INGAA FOUNDATION

Pipeline Construction High Energy Hazards and Controls Inventory

July 2024

THIS PAGE LEFT INTENTIONALLY BLANK

PURPOSE

Recent safety research underscores Serious Injuries and Fatalities (SIF) are best prevented through the identification and targeted control of High Energy (HE) hazards. High-energy hazards are those "with more than 1,500 joules of physical energy and are most likely to cause a serious injury or fatality" (Hallowell et al., 2017) and "…that every high-energy hazard should have a corresponding control that ensures that a SIF is no longer reasonably probable." (see Appendix C: "Moving beyond TRIR: Measuring and monitoring safety performance with high-energy control assessments." for more background). This paper leverages insights gained from this body of research to develop a comprehensive inventory of common high-energy safety hazards and controls associated with pipeline construction activities. The utility of this inventory is that it can be used to revise current construction safety planning and execution tools (e.g. Job Safety Analyses (JSAs), Project-Specific Safety Plans (PSSP's), training & orientation, inspection and observation approaches, etc.) all in the service of an integrated approach to SIF Prevention.

INTRODUCTION

The INGAA Foundation is at the forefront of enhancing safety performance in pipeline construction, advocating for a strategic shift from traditional metrics like Total Recordable Injury Rates (TRIR) towards incident prevention by leveraging a deeper understanding of high consequence, low frequency safety incidents, known as Serious Injuries and Fatalities (SIFs). This evolution in safety is driven by the necessity to address the most severe risks effectively and improve overall safety outcomes. Research by the Construction Safety Research Alliance at the University of Colorado - Boulder has cast a critical light on the limitations of TRIR, demonstrating its lack of predictive power for future SIFs and underlining the need for a more nuanced and effective safety management approach. In response, the INGAA Foundation is emphasizing the significance of understanding high-energy hazards, typically those with energies of 1500 Joules or more, which pose the greatest risk for SIFs.

Research in high-energy hazards and what is known as High Energy Control Assessments (HECA) has been instrumental in informing a shifting safety paradigm towards SIF Prevention. This research underscores that SIF Prevention is best affected through the identification and control of high-energy hazards. The concept of direct controls is introduced as *safeguards that dramatically reduce the probability of SIFs because they are specifically targeted at high-energy hazards, effective in eliminating or reducing energy releases to below 1500 Joules, and not prone to human error*. HECA is the proportion of high-energy hazards with a corresponding direct control. For more background, refer to Appendix C "Moving beyond TRIR: Measuring and monitoring safety performance with high-energy control assessments.".

This paper leverages these insights gained from HECA research to develop a comprehensive inventory of common high-energy safety hazards and controls associated with pipeline construction activities. The utility of this inventory is that it can be used to improve the effectiveness of current safety planning tools such as Job Safety Analyses (JSAs), Project-Specific Safety Plans (PSSP's), training & orientation, inspection and observation approaches. This is in the service of an integrated approach to SIF Prevention. It is hoped that this inventory will serve as a critical resource for pipeline construction safety. While this is not an exhaustive catalog, it includes most of the common and impactful hazards encountered during pipeline construction and details effective control measures. With this information, the industry can better focus on the proactive implementation of controls and strategies that significantly reduce the risk of SIFs.

APPROACH AND METHODOLOGY

The INGAA Foundation Task Team for this paper used a collaborative approach, involving several Foundation member companies and subject matter experts (SMEs) in the development of a working inventory of high-energy hazards and conventional controls. This initiative sought to catalogue the most common phases of pipeline construction and associate these with identified high-energy hazards and their respective controls, based on the latest research and collective expertise.

Formation of a Collaborative Committee

A Task Team comprising representatives from various INGAA Foundation member companies and SMEs trained in the latest high-energy hazards and controls research was formed (see Appendix A). This committee was responsible for steering the project, facilitating discussions, and synthesizing the information gathered.

Identification of Common Pipeline Construction Phases

The Team identified and defined the most common phases of pipeline construction, primarily sourced from Pipeline Construction Inspection, API Recommended Practice 1169 2nd Edition, March 2020. This included phases such as clearing, grading, stringing, welding, among others. The aim was to establish a common framework for discussing and categorizing high energy (HE) hazards and controls.

Training and Education Workshops

To become SMEs, Task Team members were delivered an all-day workshop (June 2023) by Dr. Elif Erkal and Dr. Matt Hallowell, technical advisors to the project. This was to ensure all participants and contributors had a uniform understanding of the latest HE hazards and controls research, providing a foundation for identifying and discussing hazards and controls accurately and effectively.

Iterative Identification of Hazards and Controls

Task Team participants were assigned 1-2 construction phases to discuss and document within their respective companies' typical high-energy hazards and controls (either Direct or Other). Iterations of this work were circulated and reviewed prior to arriving at a consensus work product. This body of work can be seen in Appendix B, in the form the Construction phase-specific High Energy Hazards and Controls Inventory: the construction phase activity breakdown, high-energy hazards, Direct Controls (if applicable), or "Other Controls" if typical Direct Controls could not be cited by the team.

Two Independent Validation Exercises

Mirroring the basic methodology of Task Team, the **March 2024 INGAA Foundation Pipeline Construction Safety Roundtable (PCSR)** workshop in Houston began with a one-hour orientation of all attendees to Energy-based safety, high-energy hazards, and Direct Controls before being broken up into tables assigned the same construction phases as described in Appendix B. Each table of 8-12 participants brainstormed, with the assistance of a facilitator (also a Task Team member, if possible), on pipeline construction phase specific high-energy hazards and controls. The results of this work were combined with the work of the Task Team and incorporated into the High Energy Hazards and Controls Inventory in Appendix B.

During the Spring of 2024, graduate students primarily with engineering backgrounds, as well as senior-level undergraduate students from the University of Colorado, Boulder, collaborated with a subject matter expert/mentor from the pipeline industry. The students were organized into groups, with each group focusing on a different pipeline construction phase detailed in Appendix B. Together, they meticulously compiled an inventory of potential high-energy hazards and corresponding controls for their assigned phases. After breaking down each construction phase into manageable task steps, the students identified the specific high-energy hazards, direct controls, and other safeguards typically required for each task step. Their collective efforts culminated in a comprehensive catalog detailing hazardous energy sources, along with the corresponding controls, for every major construction step, aligning with established standard definitions.

Taken together, these two (2) wholly independent validations greatly improved the quality and depth of the final High Energy Hazards and Controls Inventory described in Appendix B.

Note that the collected data should be considered a working inventory that was not built to a standard of consensus or perfection. Instead, it establishes a common and useful working inventory based on collective expert knowledge and current practices. This inventory should be subject to regular updates to ensure it reflects the latest research, industry practices, and safety control innovations.

The authors of this report declare that in the writing process of this work, no generative artificial intelligence (AI) or AI-assisted technologies were used to generate content, ideas, or theories. AI was used solely for the purpose of enhancing readability and refining language. This use was under strict human oversight and control. After the application of AI technologies, the authors carefully reviewed and edited the report to ensure its accuracy and coherence. The authors understand the potential of AI to generate content that may sound authoritative yet might be incorrect, incomplete, or biased. Considering this, the authors ensured that the report was thoroughly revised by human eyes and judgment

APPLICATION

The High Energy Hazards and Controls Inventory in Appendix B will assist all safety performance stakeholders involved in pipeline construction – from project managers and safety professionals to field workers – with key knowledge for SIF Prevention strategies. It can facilitate informed decision-making and promote a shared understanding and commitment to eliminating the most severe safety threats.

Below are just a few examples of anticipated application:

1. Job Safety Analyses (JSAs): The inventory provides detailed information on high-energy hazards and controls specific to each phase of pipeline construction. This information can be integrated into JSAs to ensure they address the most critical risks and apply the most effective controls. By focusing on the high-energy hazards that have the greatest potential for SIFs, JSAs become more targeted and effective.

2. Project-Specific Safety Plans (PSSP's): PSSPs can be enhanced by incorporating the inventory's insights into the planning stage of a project. The inventory aids in identifying potential high-energy hazards early on and prioritizing the necessary controls, resources, and training needed to mitigate these risks throughout the project lifecycle.

3. Training & Orientation: The inventory acts as a foundational document for developing SIF-sensitive training materials and orientation programs. By understanding the common high-energy hazards and controls, trainers can emphasize these areas, ensuring that workers are well-informed about the risks they may encounter and the measures they can take to protect themselves and their colleagues from SIFs. This targeted training approach reinforces the importance of SIF Prevention and equips workers with the knowledge they need to operate more safely.

4. Inspection and Observation Approaches: Inspectors and observers can use the inventory as a checklist or reference guide when conducting SIF-differentiated safety inspections and observations. By being aware of the most likely high-energy hazards and the expected controls, they can more effectively identify gaps in safety practices and areas where additional preventive measures are required. This proactive approach helps in early detection and correction of potential SIF precursors.

5. Integrated Approach to SIF Prevention & Risk Assessment and Management: The inventory provides a systematic understanding of high-energy hazards and controls, which is essential for comprehensive risk assessment and management. By focusing on the hazards with the highest potential for severe consequences, efforts can be prioritized to where they can have the most significant impact on SIF Prevention.

6. Continuous Improvement: As a living document, the inventory supports the continuous improvement in SIF Prevention. Feedback mechanisms and periodic reviews ensure the inventory stays up to date with the latest research, Best Practices, and Lessons Learned, continuously enhancing the industry's approach to SIF Prevention.

7. A Foundation for High Energy Control Assessments (HECA): By providing a comprehensive and detailed list of the most prevalent high-energy hazards and their corresponding controls in pipeline construction, this inventory directly informs a path forward for adopting HECA as a next-generation safety performance metric (See Appendix C). With a clear understanding of what constitutes a high-energy hazard, and the conventional controls typically applied, safety professionals can more accurately and systematically evaluate whether appropriate direct controls are in place and functioning effectively during HECA's. This not only enhances the precision and reliability of the HECA as a performance measurement tool but further shifts the

focus of safety metrics from reactive counting of incidents to proactive assurance of critical control effectiveness. As a result, the inventory not only supports a more nuanced and targeted approach to safety performance measurement but also aligns with contemporary safety management principles that emphasize prevention through control of high-hazard scenarios.

In summary, the working inventory of High Energy Hazards and Controls is a versatile and valuable tool for enhancing SIF Prevention strategies in pipeline construction. Its integration into safety planning tools, training programs, inspection practices, and the broader safety management system holds the promise of more focused, informed, and proactive approaches to eliminating or mitigating the hazards that have the potential for the most severe safety outcomes.

DEFINITIONS

High Energy Control Assessment (HECA) - a safety performance score specifically designed to evaluate the presence and effectiveness of safeguards for high-energy hazards in a workplace environment.

High Energy (HE) Hazards – Hazards associated with an element of work that involves more than 1500 Joules or approximately 500 ft-lb of physical energy.

Direct Controls - A barrier that is specifically targeted to the high-energy source; effectively mitigates exposure to the high-energy source when installed, verified, and used properly; and is effective even if there is unintentional human error during work that is unrelated to the installation of the control.

Serious Injury and Fatality (SIF) - A work-related injury or illness that was life-threatening, life-altering, or fatal. SIF focuses on acute injury exposure only and does not include chronic injury exposure, e.g., Muscular-Skeletal Disorders (MSDs) of ergonomic origin, hearing loss, etc.

REFERENCES

INGAA Foundation Guidance CS-G-09 "Guidance for Serious Injury and Fatality Prevention"

Hallowell, M. R., Alexander, D., & Gambatese, J. A. (2017). Energy-based safety risk assessment: Does magnitude and intensity of energy predict injury severity? Construction management and economics, 35(1-2), 64-77.

Erkal, E. D. O., & Hallowell, M. (2023). Moving beyond TRIR: Measuring & monitoring safety performance with high-energy control assessments. Professional Safety, 68(05), 26-35.

Hallowell, M., Quashne, M., Salas, R., MacLean, B., & Quinn, E. (2021). The statistical invalidity of TRIR as a measure of safety performance. Professional Safety, 66(04), 28-34.

Oguz Erkal, E. D., Hallowell, M. R., Ghriss, A., & Bhandari, S. (2024). Predicting Serious Injury and Fatality Exposure Using Machine Learning in Construction Projects. Journal of Construction Engineering and Management, 150(3), 04023169.

APPENDIX A:

TASK TEAM MEMBERSHIP

Task Team participants and their company affiliations are listed below.

Co-Lead - Brad MacLean – Wolfcreek

Co-Lead - Victor Flores – TC Energy

Aaron Madsen – Enbridge*, later replaced by Ernesto Perez – Enbridge

Derek Szymoniak – Henkels*

Randy Richmond – US Pipeline

Nate Healy – Michels

Steve Reynolds – JL Allen

Dave Maxey – TC Energy*

Todd Martin – PE Ben

Kim Kontz – Charps

Seth Washington – Cheniere

Cliff Dugas – Sunland

Kirby Kunka – Williams

Chris Davis – National Fuel

Mark Meade – Tellurian

Coordinator – Ramsey Robertson – Triad

Technical Advisors

- Dr Matt Hallowell (Construction Safety Research Alliance) and
- Dr Elif Erkal (Exponent)
- Arnaldo Bayona (PhD candidate U of Colorado, Boulder)

Additional support & input from Andy Reimer (Enbridge), David Collins (US Pipeline), Michael Istre (INGAA Foundation), James Upton Jr (Urbint), Mitchell Tackett (MPG), Bert Loftin (Audubon), Vince Chappa (Primoris), and Robert Duda (Safety Science).

* Departed project prior to completion.

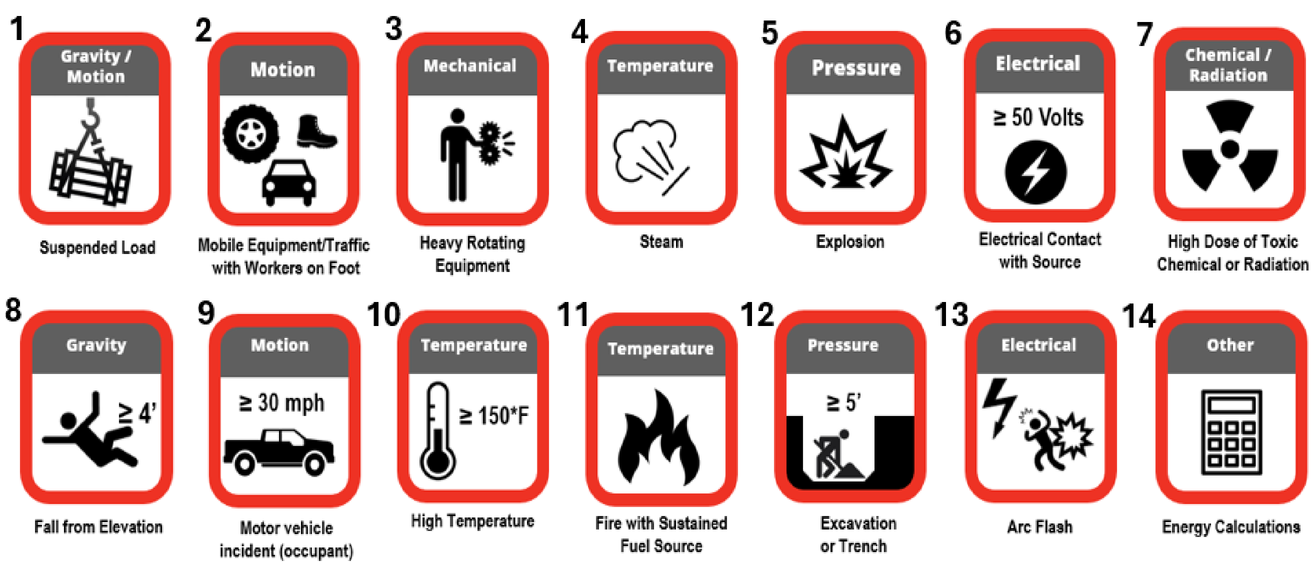
APPENDIX B:

HIGH ENERGY HAZARDS AND CONTROLS INVENTORY

The following High Energy Hazards and Controls inventory details the most common high-energy hazards and controls by construction phase. Pipeline construction phase definitions draw from Pipeline Construction Inspection, API Recommended Practice 1169 2nd Edition, March 2020.

The following legend applies to all the worksheets:

Common High Energy Hazards



Clearing

Clearing is the phase of pipeline construction after surveying, where the pipeline ROW is prepared for the upcoming pipeline installation activities. Key steps of the clearing process typically include:

- clearing (cutting and removal all trees, brush, undergrowth, and debris from the pipeline ROW, including disposal);

- timber salvage (recovery and temporary storage of useful, merchantable timber from the ROW);

- unsalvageable timber disposal (removal or elimination onsite of nonmerchantable timber and brush by chipping, or mulching); and

For the purpose of our hazards inventory, timber/brush burning and fencing related activities are excluded.

High Energy Hazards and Controls Inventory – Clearing

Task Steps	High-Energy Hazard Description	High-Energy Hazard Number	Direct Control(s)	Other Controls		Notes
Felling trees using feller bunchers	*Suspended load (falling trees)*	*1*	*Cab protection (Reinforced cabin, brush guards, rollover protection, seatbelt restraint)*	*Exclusion zone*		*Specialized attachment for lifting typically attached to excavator. Ground conditions and weight/stability can cause equipment to tip.*
	Electrical contact with source (>50 Volts) possible overhead powerline	*6*	*De-energization (uncommon for transmission lines), Power line lifting*	*Spotter*	*Exclusion with barriers*	
	Heavy mobile equipment tipping	*14*	*Cab protection (Reinforced cabin, brush guards, rollover protection, seatbelt restraint)*	*Exclusion zone*		
Felling trees with chainsaw	*Suspended load (falling trees and limbs/canopy debris)*	*1*	*None*	*Exclusion zone*		*Hazards from tree being cut and other trees the falling tree impacts.*
	Electrical contact with source (>50 Volts) possible overhead powerline	*6*	*De-energization (uncommon for transmission lines), Power line lifting*	*Spotter*	*Exclusion with barriers*	
	Heavy rotating equipment (chainsaw)	*3*	*Cutting pants, chain break, kill and lock-out switches, rear handguard, chain catcher.*	*Exclusion zone*		*Chainsaw operation procedure.*
Pioneering (travel lane construction)	*Heavy mobile equipment roll-over / tip-over when skidding*	*14*	*Cab protection (Reinforced cabin, brush guards, rollover protection, seatbelt restraint)*			
Processing/bucking/delimbing	*Lateral skidder tail movement*	*1*	*None*	*Exclusion zone*		
Skidding	*Suspended load*	*1*	*Cab protection (Reinforced cabin, brush guards, rollover protection, seatbelt restraint)*			*Terrain conditions can introduce stability issues with suspended loads.*
	Heavy equipment moving with workers nearby on foot	*2*	*None*			
	Lateral swinging load (timber)	*1*	*None*	*Exclusion zone*		
	Heavy mobile equipment (excavators) tipping	*1*	*Cab protection (Reinforced cabin, brush guards, rollover protection, seatbelt restraint)*			

High Energy Hazards and Controls Inventory – Clearing (continued)

Task Steps	High-Energy Hazard Description	High-Energy Hazard Number	Direct Control(s)	Other Controls		Notes
Loading	*Heavy equipment moving with workers nearby on foot*	*2*	*None*			
	Heavy mobile equipment (skid steer) with workers on foot	*2*	*None*	*Exclusion zone*		
	Log movement	*2*	*None*			*Procedure for loading logs onto trucks.*
	Heavy mobile equipment (skid steer) tipping	*1*	*Cab protection (Reinforced cabin, brush guards, rollover protection, seatbelt restraint)*			*Terrain can cause stability hazards.*
Chipping / Grinding	*Projectiles (tree/brush material, and broken chipping knives)*	*14*	*Guard body on the barrel placement (when done by hand), Cab protection (reinforced cabin, brush guards, rollover protection, seatbelt restraint)*	*Exclusion zone*		*Loading trees into chipping and grinding equipment can present line of fire hazards.*
Pre-grading Clean-up	*Heavy mobile equipment roll-over when transporting mats*	*1*	*Cab protection (Reinforced cabin, brush guards, rollover protection, seatbelt restraint)*			
	Heavy mobile equipment tip-over when lifting and seated outside cab	*1*	*Operating equipment with outriggers and within engineered limits*			

Note: Additional High Energy Hazards and Controls can be found on the worksheet “Common to All Phases”

Grading and Clean-up

Grading is the flattening, sloping, benching, or other excavation to modify the terrain along the pipeline ROW to make it safe and accessible for construction. Grading is immediately preceded by grubbing or the removal and disposal of tree stumps and large roots from specific areas of the ROW and the stripping and storage of topsoil (for later redistribution after the pipe has been backfilled). In some cases, grade rock blasting, excavation, and removal may be required (excluded for the purpose of our hazards inventory). Bridging, matting, and erosion-control measures are also installed during this phase of construction (also excluded for the purposes of our hazards inventory).

Construction site clean-up is the final cleaning and removal of construction materials left over from the pipeline ROW and surrounding area after the following stages of construction are complete. All materials not native to the site are removed. Restoration returns the construction site to its former (i.e. prior to construction) condition, including the establishment of a vegetative cover and the original grade of the ROW

High Energy Hazards and Controls Inventory – Grading and Cleanup

Task Steps	High-Energy Hazard Description	High-Energy Hazard Number	Direct Control(s)	Other Controls		Notes
Grading (includes stripping and piling of topsoil) and Return to Grade	*Swinging excavator bucket*	*2*	*None*	*Spotter*		*During rough grading the motion of the excavator bucket poses a hazard if workers are in the swing path*
	Heavy equipment moving with workers nearby on foot	*2*	*None*	*Spotter*	*Cameras, Reverse alarms*	*This occurs mainly during rough grading when the surface is extremely uneven.*
	Electrical contact with source (> 50 Volts) possible overhead powerline	*6*	*De-energization (uncommon for transmission lines), Power line lifting, Insulated boom*	*Spotter*	*Exclusion with barriers*	*This covers excavators or dumps with the beds up when transiting*
	Fall from Elevation from entering/exiting equipment cab	*8*	*Railing/Enclosure*	*3 points of contact rule*		*This is for Entering and Exiting the Equipment at heights*
	Motor vehicle incident (occupant) e.g. crew trucks	*9*	*Rollover frame, seatbelt restraint, airbag*			*While there should not be any transit on right-of-way exceeding 30mph, travel to and from the right-of-way would include this type of travel*
Surveying/Grade Checking	*Struck by excavator bucket*	*2*	*None*	*Spotter*	*Cameras, Reverse alarms*	
	Heavy equipment moving with workers nearby on foot	*2*	*None*	*Spotter*	*Cameras, Reverse alarms*	*Eye contact with operator when moving around equipment*
Spoils Disposal (utilization of excavators/loaders to load non usable soil/rock into dump trucks for hauling away from site)	*Electrical contact with source (> 50 Volts) possible overhead powerline*	*6*	*De-energization (uncommon for transmission lines), Power line lifting*	*Spotter*	*Exclusion with barriers*	*This covers excavators or dumps with the beds up when transiting*
	Fall from Elevation from entering/exiting equipment cab	*8*	*Railing/Enclosure*	*3 points of contact rule*		*This is for Entering and Exiting the Equipment at heights*

Note: Additional High Energy Hazards and Controls can be found on the worksheet "Common to All Phases"

Stockpiling and Stringing

For projects of significant size, materials are received at a marshalling yard or stockpiling site, typically located away from the ROW, for temporary storage. Stringing involves placing pipe joints end to end along the pipeline ROW, including strategically placing pipe section supports (e.g. wooden skids or plastic tubs) next to the proposed pipeline ditch (in some cases trench may already be dug). This includes laying out material for specific crossings (e.g. water, road, railroad, horizontal directional drills (HDD), sidebends, etc.)

High Energy Hazards and Controls Inventory – Stockpiling & Stringing

Task Steps	High-Energy Hazard Description	High-Energy Hazard Number	Direct Control(s)	Other Controls		Notes
Loading and Unloading of Pipe on Trucks/Pipe Carriers	*Suspended Load*	*1*	*Rigging for Vertical movement, Vacuum System for both Vertical and Lateral Movement*	*Spotter*	*Taglines*	*Rigging standards. Safe Vacuum unit procedures. Safe loading and unloading procedure to protect coatings and pipe from damage.*
	Struck by pipe placed on supports (rolling, movement)	*1*	*Cribbing, Blocking*			*Placement of pipe on cribbing. Safe location for stockpiling.*
Transport of Pipe via Pipe Carriers	*Pipe movement during transport*	*2*	*Supporting, blocking and strapping*			*Strapping the pipe while being piled properly on the trailer. Safe driving procedures. Load configuration. Manufacturers requirements for strapping and safe working loads.*
	Motor vehicle incident	*9*	*Rollover frame, seatbelt restraint, airbag*			*Safe driving procedures*
	Struck by oversize loads	*2*	*None*			*Safe driving procedures. Pilot car.*
Pipe stringing by Rigging, Vacuum	*Suspended load*	*1*	*Rigging for Vertical movement, Vacuum System for both Vertical and Lateral Movement*	*Spotter*	*Taglines*	*Rigging standards. Safe Vacuum unit procedures. Safe loading and unloading procedure to protect coatings and pipe from damage. No lifting over hazards (existing pipeline crossings and powerlines).*
	Stuck by pipe placed on supports (rolling, movement)	*1*	*Cribbing, Blocking*			*Placement of pipe on cribbing. No dropping of pipe. Secured to prevent damage.*

Note: Additional High Energy Hazards and Controls can be found on the worksheet “Common to All Phases”

Field Bending

Field bending refers to the set of activities associated with bending the pipe in the field so that it fits the shape of the right-of-way (ROW) and trench. Field bending is also known as “cold” bending since the pipe is not heated before the operation.

High Energy Hazards and Controls Inventory – Bending

Task Steps	High-Energy Hazard Description	High-Energy Hazard Number	Direct Control(s)	Other Controls		Notes
Movement of the Pipe from Stockpile to Bending Location	*Suspended Load, Pipe*	*1*	*Proper rigging, secondary braking*	*Spotter*	*Taglines*	*Rigging procedures and safe lift procedures.*
	Heavy equipment moving with workers nearby on foot	*2*	*None*	*Spotter*	*Reverse alarms*	
	Electrical contact with source (> 50 Volts) possible overhead powerline	*6*	*De-energization (uncommon for transmission lines), Power line lifting*	*Spotter*	*Exclusion with barriers*	*This covers excavators or dumps with the beds up when transiting*
	Hydraulic Press, Piston Movement	*3*	*Caging*			*Identify limitations and requirements for field bending.*
	Mandrel - Mechanical	*3*	*None*	*Spotters*		
Placement of the pipe into the bend, and moving the bender through the machine	*High Pressure Hose Connections*	*5*	*Whip checks*			
	Bender Electrical Box	*6*	*De-energization, Lock-out-tag-out*			
	Fall from heights	*8*	*Railing on bender and ladder*	*3 points of contact rule*		
Movement of pipe out of machine and laying it on cribbing after the bending	*Suspended Load, Pipe*	*1*	*Proper rigging, secondary braking*	*Spotter*	*Taglines*	*Ensure no damage to pipe after bending (coating).*
	Suspended Load, Pipe on Cribbing	*1*	*Cribbing, Blocking*	*Rigging, Spotter*	*Taglines*	*Placement of pipe on cribbing. Safe location for stockpiling.*

Note: Additional High Energy Hazards and Controls can be found on the worksheet "Common to All Phases"

Welding (stick and mechanized)

Welding during pipeline construction is performed to join lengths of pipe together as the construction crew moves along the ROW. Welding is a process for joining materials together to become a manufactured or fabricated item. The welding process is used to join pipe to pipe, and pipe to components.

High Energy Hazards and Controls Inventory – Welding

Task Steps	High-Energy Hazard Description	High-Energy Hazard Number	Direct Control(s)	Other Controls		Notes
Pipe Facing **33–35-degree bevel for weld**	*High temperatures from pipe facing equipment*	*10*	*Welding Blanket, Fire retardant clothing and Thermal Insulated Gloves*	*Caution signs with hazard label*	*Exclusion with barriers*	*Sparks from cutting and grinding*
	Heavy rotating pipe facing equipment	*3*	*Machine Guarding*	*Caution signs with hazard label*	*Exclusion with barriers*	*Pipe Facing Machine*
Pipe Positioning for Welding	*Suspended load*	*1*	*Proper rigging, secondary braking*	*Spotter*	*Taglines*	*Suspended piping and equipment*
Preheat pipe to minimize cracking	*High temperatures from preheating equipment*	*10*	*Thermal Insulated Gloves*	*Caution signs with hazard label*	*Heat shields or barriers around the preheating equipment, Flame-retardant clothing*	*Open flame*
	Explosion from pressurized propane tanks	*5,11*	*Tank cradle, straps, and valve cap*	*Tank hazard label*	*Protective Bollards*	*Propane tank*
	UV Radiation from welding flash	*7*	*Welding Curtain, Welding helmet*	*Caution tape and signs with hazard label*		
	Fire from sparks	*11*	*Remove combustibles*	*Fire Watch*	*Flame-retardant clothing*	
Passes: Root pass (Initial weld to close gap), Hot pass (Joins the root weld to both groove faces), Filler pass (Multiple passes made to the fill the weld)	*Electric Shock from Welding Power Source*	*6*	*Equipment grounding*			*Electric Shock from Welding Power Source*
	High temperatures and Spatter from Weld	*10*	*Gloves, Chaps, Welding Jacket, Welding Helmet*	*Exclusion zone with signage*		*Heat and Spatter from Weld*
	Moving Mechanical Equipment, Welder	*2*	*Proper rigging*	*Spotter*	*Taglines*	*Moving Mechanical Equipment, Welder*
Buffing & grinding to Clean Weld/slag from weld	*Heavy rotating equipment from grinder wheel*	*3*	*Machine Guarding*	*Exclusion zone with signage*		*Grinder wheel*
	High temperature from grinder and slag	*10*	*Welding Blanket*	*Exclusion zone with signage*		*Sparks for cutting and grinding*

Note: Additional High Energy Hazards and Controls can be found on the worksheet “Common to All Phases”

Non-Destructive Testing (NDT) (out of trench and in trench)

Non-destructive testing (NDT) is a technique used to inspect and analyze pipelines without damaging them. It is used to evaluate the properties of pipelines for discontinuities like surface corrosion, mechanical damage, and cracks.

High Energy Hazards and Controls Inventory – NDT (Out of Trench)

Task Steps	High-Energy Hazard Description	High-Energy Hazard Number	Direct Control(s)	Other Controls		Notes
Check equipment (safeguards, set safety zone, etc.)	*Faulty equipment safeguard (Gamma)*	*7*	*Equipment specific direct controls are built into all radiography equipment (lead shielding, mechanical failsafe's, etc.)*	*Signage*	*Additional testing/verification of radiation levels when approaching, handling, or in the vicinity of radiation producing equipment/material*	*Gamma sources constantly emit radiation. Direct controls built into equipment should safeguard but common practice and safety rules require checking radiation levels with separate Radiac prior to handling.*
	Suspended Load	*1*	*Proper rigging, secondary braking*	*Spotter*	*Taglines*	*Pipe is elevated in a cradle. Due to overall weight this is a high energy hazard if not secured well*
Secondary mobilization - Film exposure and Film related hazards	*Suspended load*	*1*	*Proper rigging, secondary braking*	*Spotter*	*Taglines*	*Pipe is elevated in a cradle. Due to overall weight this is a high energy hazard if not secured well*
	Electrical hazard of 2 generators in truck and high voltage cable to Xray equipment on pipeline weld	*6*	*Insulated cable. De-energized until Xray being taken*	*Signage noting high voltage line*	*Exclusion zone with cones*	*X-ray equipment uses high voltage lines and 2 generators in the back of a truck to power the Xray equipment and capture images.*
Secondary mobilization - digital exposure	*X-ray radiation exposure*	*7*	*Equipment specific direct controls are built into all radiography equipment (lead shielding, mechanical failsafe's, etc.)*	*Signage*	*Exclusion zone with cones*	*Exposure to x-rays from incorrect distancing (ignoring warning/marked off area) or equipment malfunction (ex: crawler fails to turn off and continues to generate x-rays until battery is depleted)*
	Gamma radiation exposure	*7*	*Equipment specific direct controls are built into all radiography equipment (lead shielding, mechanical failsafe's, etc.)*	*Signage*	*Exclusion zone with cones*	*Exposure to gamma radiation from incorrect distancing (ignoring warning/marked off area) or equipment malfunction (source material does not retract)*

Note: Additional High Energy Hazards and Controls can be found on the worksheet "Common to All Phases"

High Energy Hazards and Controls Inventory – NDT (In Trench)

Task Steps	High-Energy Hazard Description	High-Energy Hazard Number	Direct Control(s)	Other Controls		Notes
Mobilization onto site with NDT Equipment - X-ray double wall in trench and Gamma IR - 192	*Falls from height into trench*	*8*	*None*			*Falls at approximately 4ft on a sloped surface but often while carrying equipment of ~70lbs*
	Working in trench	*12*	*Benching/sloping/trench box*	*Ladder or other for egress*		
	Driving vehicle close to trench	*9*	*Rollover frame, seatbelt restraint*			*Not above 30mph, but truck falling into a trench is above the energy threshold*
	Heavy equipment moving with workers nearby on foot	*2*	*None*	*Spotter*	*Cameras, Reverse alarms*	*This may not be feasible, given the mobile nature of work conditions*
	Electrical contact with source (> 50 Volts)	*6*	*Insulated cable. De-energized until x-ray being taken*	*Signage High Voltage*	*Exclusion zone with cones*	
	Faulty equipment safeguard (Gamma)	*7*	*Equipment specific direct controls are built into all radiography equipment (lead shielding, mechanical failsafe's, etc.)*	*Signage noting radiography/radiation danger*		*Gamma sources constantly emit radiation. Direct controls built into equipment should safeguard but common practice and safety rules require checking radiation levels with separate Radiac prior to handling.*
Establish Safety parameters (Check equipment safeguards; set safety zone, etc.)	*Falls from height into trench*	*8*	*None*			*Falls at approximately 4ft on a sloped surface but often while carrying equipment of ~70lbs*
	Working in trench	*12*	*Benching/sloping/trench box*	*Ladder or other for egress*		
	Handling of hazardous and non-hazardous chemicals	*7*	*None*	*All chemicals and waste appropriately labeled*		*Developing film is conducted onsite with somewhat hazardous chemicals*

High Energy Hazards and Controls Inventory – NDT (In Trench) (continued)

Task Steps	High-Energy Hazard Description	High-Energy Hazard Number	Direct Control(s)	Other Controls		Notes
Secondary mobilization - Film exposure and Film related hazards	*Falls from height into trench*	*8*	*None*			*Falls at approximately 4ft on a sloped surface but often while carrying equipment of ~70lbs*
	Working in trench	*12*	*Benching/sloping/trench box*	*Ladder or other for egress*		
	Electrical hazard of 2 generators in truck and high voltage cable to X-ray equipment on pipeline weld	*6*	*Insulated cable. De-energized until x-ray being taken*	*Signage noting high voltage line*	*Exclusion zone with cones*	*X-ray equipment uses high voltage lines and 2 generators in the back of a truck to power the X-ray equipment and capture images.*
	Suspended load (lowering equipment into trench)	*1*	*Proper rigging, secondary braking*	*Spotter*	*Taglines*	*In areas with limited lateral space, a deeper trench with trench box is used and equipment is lowered via mobile equipment*
Secondary mobilization - digital exposure	*X-ray radiation exposure*	*7*	*Equipment specific direct controls are built into all radiography equipment (lead shielding, mechanical failsafe's, etc.)*	*Signage*	*Exclusion zone with cones*	*Exposure to x-rays from incorrect distancing (ignoring warning/marked off area) or equipment malfunction (ex: crawler fails to turn off and continues to generate x-rays until battery is depleted)*
	Gamma radiation exposure	*7*	*Equipment specific direct controls are built into all radiography equipment (lead shielding, mechanical failsafe's, etc.)*	*Signage*	*Exclusion zone with cones*	*Exposure to gamma radiation from incorrect distancing (ignoring warning/marked off area) or equipment malfunction (source material does not retract)*

Note: Additional High Energy Hazards and Controls can be found on the worksheet "Common to All Phases"

Ditching, Excavation, Backfill

Ditching and excavation typically involve digging a trench in the ROW for pipe installation. Commonly, the ditching operations are after stringing, bending, welding, nondestructive testing (NDT), and coating due to the risk of having an open trench. There are exceptions, including where rock is encountered, when the trench may be blasted and excavated prior to stringing and in urban areas or other areas where numerous underground utilities and obstructions may exist. A mechanical wheel ditcher/trencher or backhoe with a trencher is generally used to create a trench of uniform depth and width; more specialized techniques and equipment may be required based on the type of soil and pipe. For example:

- backhoes or traditional excavators may be used for points of intersection,
  wet areas where buoyancy control of the pipe requires an extra wide trench (to accommodate placing weights over the pipe),
- road, highway, railroad, Third-Party pipelines, and river crossings,
- at all tie-in locations where extra width and depth are required for welders to work in the trench,
- areas with unsuitable/unstable soil conditions where trench sides need to be sloped (e.g. sandy soil),
- mountainous/steep slope and rocky soil/rock conditions, and
- short sections of pipe and/or areas where moving equipment around is not practical.

Backfilling refers to refilling the trench with the excavated or new fill subsoil once the pipe section has been lowered into the trench. As backfilling operations begin, the soil is returned to the trench in reverse order, with the subsoil put back first followed by the topsoil, returning the topsoil to its original position.

High Energy Hazards and Controls Inventory – Ditching, Excavation, Backfill

Task Steps	High-Energy Hazard Description	High-Energy Hazard Number	Direct Control(s)	Other Controls		Notes
Excavation Operations: any man-made cut, cavity, trench, or depression in the earth's surface formed by earth removal; typically conducted by an excavator	*Working in trench*	*12*	*Benching/sloping/trench box*	*Ladder or other for egress*		
	Falls from height into trench	*8*	*None*	*Exclusion zone with caution tape*		*Direct control typically used for working in pedestrian and traffic areas*
	Heavy equipment moving with workers nearby on foot	*2*	*None*	*Spotter*	*Cameras, Reverse alarms*	
	Damaging existing pipelines - Ground Disturbance (contain toxic/flammable gas/other)	*5,7,11*	*Schedule and verify implementation of utility outage/ De-pressurize pipes*	*Daylighting, Locates, hydro-vac, exposing, potholing*	*Flame-retardant clothing*	*Also make sure to check utility plans and As-Builts*
	Electrical contact with source (> 50 Volts) possible overhead powerline	*6*	*De-energization (uncommon for transmission lines), Power line lifting*	*Spotter*	*Exclusion with barriers*	
Trenching Operations: a narrow excavation with a depth greater than its width but is no wider than 15 feet; work typically conducted by an excavator or trencher	*Falls from height into trench*	*8*	*None*	*Exclusion zone with caution tape*		*Direct control typically used for working in pedestrian and traffic areas*
	Damaging existing pipelines - Ground Disturbance (contain toxic/flammable gas/other)	*5,7,11*	*Schedule and verify implementation of utility outage/ De-pressurize pipes*	*Daylighting, Locates, hydro-vac, exposing, potholing*	*Flame-retardant clothing*	*Also make sure to check utility plans and As-Builts*
	Contacting existing electrical lines (below ground)	*6*	*De-energization/ schedule & verify utility outage*	*Daylighting, Locates, hydro-vac, exposing, potholing*		*Sometimes a concrete pipe/sleeve is used to protect underground electrical lines. checking existing utility plans*
	Heavy equipment moving with workers nearby on foot	*2*	*None*	*Spotter*	*Cameras, Reverse alarms*	
	Electrical contact with source (> 50 Volts) possible overhead powerline	*6*	*De-energization (uncommon for transmission lines), Power line lifting*	*Spotter*	*Exclusion with barriers*	
	Damaging existing pipelines - Ground Disturbance (contain toxic/flammable gas/other)	*5,7,11*	*Schedule and verify implementation of utility outage/ De-pressurize pipes*	*Daylighting, Locates, hydro-vac, exposing, potholing*	*Flame-retardant clothing*	*Also make sure to check utility plans and As-Builts*
	Falls from height into trench	*8*	*None*	*Exclusion zone with caution tape*		*Direct control typically used for working in pedestrian and traffic areas*

Note: Additional High Energy Hazards and Controls can be found on the worksheet “Common to All Phases”

Coating

Coating of the pipeline provides a protective barrier against damage to the pipe (e.g. corrosion, scrapes). Most of the coating operation occurs in a centralized plant but since individual pipe joints are welded together during the construction process, the (girth) weld area requires coating in the field.

High Energy Hazards and Controls Inventory – Coating

Task Steps	High-Energy Hazard Description	High-Energy Hazard Number	Direct Control(s)	Other Controls		Notes
Surface Preparation (Sandblasting of weld where two pipeline sections have been joined)	*Blasting stream (pressurized air and blast media)*	14	*Kill switch, supplied air, ventilation hood, leathers*	*Exclusion zone, barrier around air compressor tank safety zone*	*Signage of denoting pressurized tanks*	
	Pressure from air compressor sand blasting equipment (explosion)	14	*Whip checks*	*Hearing protection*		
	Chemical Inhale from sand blasting particles	7	*Wearing Respirator Mask/Ventilation*			
	Blasting hose connection failure	14	*Whip check connected with safety pins and tie wire*			*Hose and connection must be regularly inspected (approx. 120+ psi with media)*
	Open flame from tiger torch	11	*Supply switch (Supply switch that controls fuel flow to the torch)*			*Pre-heating is not done by a small handheld torch. It is typically a weed burner that is used with a valve.*
Preheating (by hand)	*Pressure from gas cylinder for preheat torch*	5	*Cylinder valve*			
	Hot joint/weld	10	*None*			
Preheating (by induction coil)	*Induction heating coil*	14	*None*	*Spotter*	*Tag lines, Danger tape with cones*	
	Suspended load of heating ring	1	*Automatic brake on lifting equipment, additional securing line*	*Spotter*		
	Heavy equipment moving with workers nearby on foot	2	*None*	*Spotter*	*Cameras, Reverse alarms*	
	Electrical contact with heating ring	6	*Insulating guard*	*Spotter*		
	Hot joint/weld	10	*None*			

High Energy Hazards and Controls Inventory – Coating (continued)

Task Steps	High-Energy Hazard Description	High-Energy Hazard Number	Direct Control(s)	Other Controls		Notes
Mixing and Application (spray)	Heavy equipment moving with workers nearby on foot	2	None	Spotter	Cameras, Reverse alarms	
	Mechanical motion from spinning coating ring	3	Machine guard around spinning ring			
Machine coating ring of preheated pipeline joint	Suspended load of coating ring	1	Automated brakes on lifting equipment, additional securing line	Spotter		
	Electrical contact with coating ring	6	Insulating guard around shock hazard	Spotter		

Note: Additional High Energy Hazards and Controls can be found on the worksheet “Common to All Phases”

Padding and Lowering-In

Padding and lowering-in refers to preparing the trench base (if required, due to presence of rock or stones), picking the pipe up from its temporary supports off the ROW and placing it into an excavated trench after welding, nondestructive testing (NDT), coating of pipe joints, and completing any associated coating repairs.

High Energy Hazards and Controls Inventory – Padding and Lowering-In

Task Steps	High-Energy Hazard Description	High-Energy Hazard Number	Direct Control(s)	Other Controls		Notes
Workers pad the excavation (with heavy padding machinery) to provide a layer of soft and fine soil, to prevent pipe damage from rocks and uneven surfaces.	*Heavy equipment moving with workers nearby on foot*	*2*	*None*	*Spotter*	*Cameras, Reverse alarms*	*Terrain can represent hazards while using heavy equipment.*
	Falls from height into trench	*8*	*None*			
Workers secure assembled pipe on several side booms' roller cradles.	*Pinch point between side boom's rollers and pipe*	*3*	*None*	*Spotter*		*Pipe movement can introduce hazards.*
	Electrical contact with source (> 50 Volts) possible overhead powerline	*6*	*De-energization (uncommon for transmission lines), Power line lifting*	*Spotter*	*Exclusion with barriers*	
	Assembled pipe roll/fall off cribbing	*1*	*Proper rigging, secondary braking*	*Spotter*		
Side booms travel along excavation at a slow and steady pace, laying the pipe assembly into the excavation.	*Pipe assembly suspended by several side booms*	*1*	*Proper rigging, secondary braking*	*Spotter*		
	Pinch point between side boom's rollers and pipe	*3*	*None*	*Spotter*		
	Electrical contact with source (> 50 Volts) possible overhead powerline	*6*	*De-energization (uncommon for transmission lines), Power line lifting*	*Spotter*	*Exclusion with barriers*	
	Heavy equipment moving with workers nearby on foot	*2*	*None*	*Spotter*	*Cameras, Reverse alarms*	*Terrain and limited walking areas can represent hazard around moving heavy equipment.*
	Tipping of side boom	*1*	*Cab protection (Rollover protection, Seatbelt restraint)*			

Note: Additional High Energy Hazards and Controls can be found on the worksheet "Common to All Phases"

Horizontal Directional Drills (HDD)

HDD involves creating a hole underneath obstacles, along a specially designed drill path (based on existing underground infrastructure and subsurface conditions), in order to pull the pipe back through the hole. HDD consists of the following three basic steps: drilling the pilot hole to establish the drill path for the crossing, reaming (or enlarging) the pilot hole, and pulling the carrier pipe back through the reamed hole.

A road bore involves installing pipeline using construction methods that do not disturb the road surface. Typical approach for road bore involves a machine being lowered to the bottom of the bore pit to tunnel using a cutting head mounted on an auger. The auger rotates through a bore tube, both of which are pushed forward as the hole is cut. The pipeline is then installed through the bored hole and welded to the adjacent pipeline.

High Energy Hazards and Controls Inventory – HDD

Task Steps	High-Energy Hazard Description	High-Energy Hazard Number	Direct Control(s)	Other Controls		Notes
Mobilization of Equipment on both entrance and receiving end, Staging and material mobilization	*Heavy equipment moving with workers nearby on foot*	2	*None*	*Spotter*	*Cameras, Reverse alarms*	*Traffic control devices: Dependent on the project location*
	Suspended load	*1*	*Proper rigging*	*Spotter*	*Taglines*	
	Electrical contact with source (> 50 Volts) possible overhead powerline	*6*	*De-energization (uncommon for transmission lines), Power line lifting*	*Spotter*	*Exclusion with barriers*	
Reamer runs through length of future pipeline and bentonite is pumped in to keep the hole open	*Damaging existing pipelines - Ground Disturbance (contain toxic/flammable gas/other)*	*5,7,11*	*Schedule and verify implementation of utility outage/ De-pressurize pipes*	*Daylighting, Locates, hydro-vac, exposing, potholing*	*Flame-retardant clothing*	*Also make sure to check utility plans and As-Builts*
	Reamer rotating above ground	*3*	*Torque limiter device, Emergency stop function*	*Alarm sensors*	*Spotter*	
Side Boom lifts pipe and loads into rig	*Suspended load*	*1*	*Proper rigging, secondary braking*	*Spotter*	*Taglines*	
	Heavy equipment moving with workers nearby on foot	*2*	*None*	*Spotter*	*Cameras, Reverse alarms*	
	Drill rig threading pipe	*3*	*Emergency stop function reamer*	*Spotter*		
Pipe elevated by Side boom using Cradles (with rollers)	*Suspended load*	*1*	*Proper rigging, secondary braking*	*Spotter*	*Taglines*	
	Heavy equipment moving with workers nearby on foot	*2*	*None*	*Spotter*	*Cameras, Reverse alarms*	
Pipe continuously fed until the entire pipeline has been laid in the hole (continuous process)	*Threading of pipes in drill rig*	*3*	*Drilling guards/emergency stopper*	*Signage*		
	Damaging existing pipelines - Ground Disturbance (contain toxic/flammable gas/other)	*5,7,11*	*Schedule and verify implementation of utility outage/ De-pressurize pipes*	*Daylighting, Locates, hydro-vac, exposing, potholing*	*Flame-retardant clothing*	*Also make sure to check utility plans and As-Builts*

Note: Additional High Energy Hazards and Controls can be found on the worksheet "Common to All Phases"

High Energy Hazards and Controls Inventory – Road Bores

Task Steps	High-Energy Hazard Description	High-Energy Hazard Number	Direct Control(s)	Other Controls		Notes
Mobilization of Equipment on both entrance and receiving end	*Heavy equipment moving with workers nearby on foot*	*2*	*None*	*Spotter*	*Cameras, Reverse alarms*	*Traffic control devices: Dependent on the project location*
	Damaging existing pipelines - Ground Disturbance (contain toxic/flammable gas/other)	*5,7,11*	*Schedule and verify implementation of utility outage/ De-pressurize pipes*	*Daylighting, Locates, hydro-vac, exposing, potholing*	*Flame-retardant clothing*	*Also make sure to check utility plans and As-Builts*
Trench on either side of roadway	*Working in bell hole*	*12*	*Benching/sloping/trench box*	*Ladder or other for egress*		
	Heavy equipment moving with workers nearby on foot	*2*	*None*	*Spotter*	*Cameras, Reverse alarms*	
	Falls from height into trench	*8*	*Physical Barriers*			
Auger rotates and dummy pipe is pulled through	*Auger rotation*	*3*	*Emergency stop function*	*Spotter*	*Signage*	
	Pipe assembly suspended by side boom(s)	*1*	*Proper rigging, secondary braking*	*Spotter*		
Useful pipe is welded on and pulled through hole	*Useful pipe is welded on and pulled through hole*	*Refer to Welding task worksheet*	*Refer to Welding task worksheet*	*Refer to Welding task worksheet*	*Refer to Welding task worksheet*	*Refer to Welding task worksheet*

Note: Additional High Energy Hazards and Controls can be found on the worksheet "Common to All Phases"

Hydrostatic Testing

A hydrostatic test is a form of pressure testing used to confirm that the pipeline has acceptable strength and will not leak under operating conditions. Hydrostatic testing uses water under pressurized conditions to perform the test.

High Energy Hazards and Controls Inventory – Hydrostatic Testing

Task Steps	**High-Energy Hazard Description**	**High-Energy Hazard Number**	**Direct Control(s)**	**Other Controls**		**Notes**
Installation of pig launcher and receiver	*Refer to welding worksheet*	*Refer to welding worksheet*	*Refer to welding worksheet*	*Refer to welding worksheet*	*Refer to welding worksheet*	*Refer to welding worksheet*
	Pressure (Valve/Pipe)	*14*	*Whip Checks / Steel lines in a controlled environment*	*Exclusion zone with barriers*		
Filling pipe with water. Filling pipe with water will create high pressure hazard in the pipe and the hoses.	*Pressure (Pipe)*	*14*	*None*	*Exclusion zone with barriers*		*The pressure test can be conducted remotely from a distance to minimize risk.*
Performing the Test on the Pipe	*Detachment of Hose*	*14*	*Whip Checks*			
Dewatering of the pipe: Upon completion of the test, water should be drained from the pipe. Additionally, pipe should be dried out completely.	*Pressure (Pipe/Valves/Nipples and Ts)*	*14*	*Properly rated pipes, valves, nipples and Ts. Launcher/receiver doors properly secured.*	*Exclusion zone with barriers*		
	Suspended load	*1*	*Proper rigging, secondary braking*	*Spotter*	*Taglines*	

Note: Additional High Energy Hazards and Controls can be found on the worksheet "Common to All Phases"

An additional High Energy Hazards and Controls Inventory is included below that catalogues high-energy hazards and controls that are very common across all phases of pipeline construction. This avoids repeating these hazards and controls on each construction phase-specific High Energy Hazards and Controls Inventory.

High Energy Hazards and Controls Inventory – Hazards Common to All Phases

High-Energy Hazard Description	High-Energy Hazard Number	Direct Control(s)	Other Controls		Notes
Heavy equipment moving with workers nearby on foot	*2*	*None*	*Spotter*	*Cameras, Reverse alarms*	
Electrical contact with source (> 50 Volts) possible overhead powerline	*6*	*De-energization (uncommon for transmission lines), Power line lifting*	*Spotter*	*Exclusion with barriers*	
Motor vehicle incident (occupant) over 30 mph	*9*	*Rollover frame, seatbelt restraint, airbag*	*Posted Speed limits*		
On-ROW vehicular accidents (e.g. ATV's) under 30 mph	*9*	*Rollover frame, seatbelt restraint*	*Posted Speed limits*		
Working on foot near bell holes	*8*	*None*	*Exclusion zone with caution tape*		*Direct control typically used for working in pedestrian and traffic areas*
Damaging existing pipelines - Ground Disturbance (contain toxic/flammable gas/other)	*5,7,11*	*Schedule and verify implementation of utility outage/ De-pressurize pipes*	*Daylighting, Locates, hydro-vac, exposing, potholing*	*Flame-retardant clothing*	*Also make sure to check utility plans and As-Builts*
Contacting existing electrical lines (below ground)	*6*	*De-energization/ schedule & verify utility outage*	*Daylighting, Locates, hydro-vac, exposing, potholing*		*Sometimes a concrete pipe/sleeve is used to protect underground electrical lines. checking existing utility plans*
Fire with sustained fuel source	*11*	*Vehicle and equipment bonding, Automatic fire suppression system & Fire detection and alarm systems*	*Portable fire extinguishers, Emergency response plans and training, Fire-resistant clothing*		

Note: Additional High Energy Hazards and Controls can be found on the worksheet "Common to All Phases"

FOOTNOTES

1) The pipeline construction phases used in the High Energy and Control Inventory have been simplified for practical use, therefore do not include more complex scenarios such as steep slope or marshland construction.
2) There are many pipeline construction hazards that don't meet the 1500 Joule threshold or are more suitable for an industrial hygiene assessment and are therefore NOT considered high-energy. Examples include noise, small tools, ambient temperature and UV radiation, etc. Many are wholly legitimate hazards that require operations discipline in their identification, assessment, and control but because their energy releases fall below 1500 Joules are considered out of scope for this High Energy Hazards and Control Inventory. In some cases, e.g. UV from welding or fumes from coating operations, hazards may warrant an industrial hygiene evaluation to determine if Permissible Exposure Limits (PELs) are being exceeded.
3) The Direct Controls icons encompass approximately 90% of HE Hazards on a construction site. The "Calculator" icon represents circumstances in the remaining 10% that require a mathematical analysis to confirm hazards are High Energy, i.e. 1500 Joules or above.
4) "Other" Controls in the High Energy Hazards and Controls Inventory are common controls used for a given hazard but do not meet the standard of a Direct Control.
5) It is not uncommon for many construction activities to have not practical Direct Controls, making the use of multiple Other Controls the operational norm.
6) Many common safety activities such as training/orientation, observation programs, Pre-Job Meetings/Job Safety Analyses, etc. *facilitate or enable* the effective deployment and use of controls but do not meet the definition of Direct Controls or Other Controls and are therefore out of scope for this High Energy Hazard and Control Inventory.

For more detailed guidance on what constitutes high-energy hazards and insights on Controls, refer to Appendix C:

Oguz Erkal, E.D. & Hallowell, M.R. (2023, May). "Moving beyond TRIR: Measuring and monitoring safety performance with high-energy control assessments." <u>*Professional Safety*</u>*, 68(5), 26-35.*

APPENDIX C:

"MOVING BEYOND TRIR: MEASURING AND MONITORING SAFETY PERFORMANCE WITH HIGH-ENERGY CONTROL ASSESSMENTS."

Oguz Erkal, E.D. & Hallowell, M.R. (2023, May). "Moving beyond TRIR: Measuring and monitoring safety performance with high-energy control assessments." <u>*Professional Safety*</u>*, 68(5), 26-35.*

July 2024

MOVING BEYOND T
Measuring & Monitoring Sa With High-Energy Control

By Elif Deniz Oguz Erkal and Matthew R. Hallowell

ADVANCEMENT OF SAFETY requires a standardized method of measuring and communicating safety performance. A common safety metric enables professionals across industries to compare outcomes, assess trends and make strategic decisions. Although never explicitly intended as a comparative safety metric, total recordable incident rate (TRIR) has been the dominant indicator of safety performance for more than 50 years (Hallowell et al., 2021; U.S. Bureau of Labor Statistics, 2019). Defined simply as the rate at which a company experiences an OSHA-recordable incident scaled per 200,000 work hours, TRIR has been used to make important business decisions ranging from the prequalification of contractors to annual performance incentives (Karakhan, 2017; Lingard et al., 2017; Lofquist, 2010; Wilbanks, 2018). TRIR has become ubiquitous, in part because it is simple, standardized and easy to communicate. However, recent research has shown that TRIR has serious limitations that impede strategic decision-making and long-term improvement (Hallowell et al., 2021; Korman, 2022). This leaves the safety community and other business professionals asking, "If not TRIR, then what?"

KEY TAKEAWAYS
- The prevailing method of measuring safety performance, total recordable injury rate, is statistically and philosophically flawed.
- High-energy control assessment (HECA) is introduced as a new method to monitor the presence of safeguards against critical hazards (e.g., capacity).
- HECA is built on the philosophy that all life-threatening (high-energy) hazards should have an adequate safeguard (direct control).
- Methods to assess the energy magnitude and the presence of a direct control objectively and consistently are presented along with a case example.
- HECA is positioned as a performance monitoring method to continuously track and manage safety. HECA may generate sufficient volumes of data to inform reliable data-driven strategic decision-making.

A common answer to this question is leading indicators. However, despite their strengths, safety leading indicators have some limitations that prevent them from being a wholesale solution. First, safety professionals still do not agree on a single definition of a leading indicator, and the term is used so broadly that it can mean anything that is not injury rates (lagging indicators). Even with the more accepted academic definition (i.e., measures of the activities performed to prevent injuries), leading indicators are not yet benchmarkable because they are not consistently applied across the industry. That is, companies measure different aspects of the safety system in different ways, making the resultant numbers incomparable among companies. Although safety leading indicators are likely to be an important part of a future solution once standardized, safety professionals still need a method of safety assessment that 1. enables consistent and objective assessment of the safety related to working conditions at any point in time, and 2. statistically explains the relationships between leading indicator activities (inputs) and long-term injury rates (outputs).

In this article, high-energy control assessment (HECA) is introduced and explored as a new way of monitoring and measuring safety performance. By combining the latest science in high-energy controls with principles of human and organizational performance, HECA is underpinned by science, statistically valid, focused on serious injuries and fatalities (SIF), and representative of a modern understanding of safety as the presence of safeguards rather than the absence of injuries. The authors introduce HECA as an initial attempt to close the gap between modern safety science and principles (what we say), and current methods of measuring, monitoring and communicating safety (what we do).

Background

To illustrate the need for a new method of safety performance assessment, HECA is juxtaposed with the prevailing method of safety performance measurement: TRIR. Because TRIR is pervasive and ingrained within the industry, it is critical to explore its strengths and weaknesses before introducing alternative assessment strategies. The authors' position is that any alternative safety metric must capitalize on the strengths of TRIR while addressing its fundamental weaknesses.

The quality of any performance metric (safety or otherwise) can be judged against the six primary criteria in Table 1. These criteria include those based on direct evidence (objective, valid and predictive) and on judgment and values (clear, important and actionable). To provide an honest and holistic assessment of TRIR, the authors evaluate it empirically and logically against each of the six criteria. Although the focus is on TRIR because it is the most dominant safety performance metric, most assessments in this article apply similarly to any lagging indicator that is based on injury rates.

1. Objective: TRIR is objective because it is based on direct observation. TRIR is based simply on a count of recordable injuries over time. Although there are well-documented issues

July 2024

TRIR
afety Performance Assessments

with underreporting, case management and data manipulation (Pedersen et al., 2012), there is typically only one definition of what makes an incident recordable in a geographical region (e.g., OSHA-recordable injury in the U.S.).

2. Valid: TRIR is not valid because it is not statistically stable. Although never mandated by OSHA for business use, TRIR is often used to make direct comparisons among businesses, projects and teams often over a relatively short time. When applied in this way, TRIR loses statistical validity. A metric is statistically valid if it is based on sufficient volumes of consistent data within reasonable time frames to allow acceptable uncertainty estimations and statistical precision (Kotek et al., 2018; Oguz Erkal, 2022). An analysis of more than 3 trillion worker hours revealed that the occurrence of recordable injuries is almost entirely random and that more than hundreds of millions of worker hours are needed before TRIR carries statistical meaning (Hallowell et al., 2021). Therefore, in almost any practical scenario, it is statistically problematic to use TRIR to inform business decisions.

3. Predictive: TRIR is not predictive because TRIR of the past is not indicative of TRIR (or fatalities) in the future. In addition to statistical instability, TRIR of the past does not provide predictive information about TRIR of the future (Hallowell et al., 2021). Per this research, TRIR has no statistical relationship to SIFs, meaning that recordable injuries should not be used as a proxy or warning sign of something more serious to come.

4. Clear: TRIR is clear because it is easy to understand and communicate. Perhaps the greatest strength of TRIR is that it is easy to understand and communicate. Since OSHA-recordable injuries are based on a government mandated definition of a recordable injury, one consistent definition is used across companies, industries and geographies.

5. Actionable: TRIR is not actionable because it does not support proactive behavior or strategic decisions. Since TRIR only represents rare, random and historical incidents, it does not provide useful information about underlying patterns of why injuries occur or what contributes to success. At its best, a spike in TRIR motivates organizations to put more time and energy into the safety system without a targeted strategy.

6. Important: TRIR is not important because it is not aligned with emergent safety principles or a focus on SIF. Although not explicitly stated in the definition of TRIR, using injury rates to communicate safety performance is based on the implicit premise that safety is the absence of injuries. That is, TRIR is implicitly based on the idea that a worker hour

GUVENDEMIR/ISTOCK/GETTY IMAGES PLUS

TABLE 1
QUALITIES OF A STRONG METRIC

Criterion	Definition	Reference
Objective	The metric is based on observations that are minimally subject to cognitive biases.	Johansen and Rausand, 2014; Kotek et al., 2018; Leveson, 2015; Taaffe et al., 2014
Valid	The data required for the metric can be generated in sufficient volume to produce statistically significant trends.	Kotek et al., 2018; NORSOK, 2008
Predictive	The historical trends in the metric provide information on the probability of future trends.	Alexander et al., 2017; Esmaeili et al., 2015; Goh and Chua, 2013; Hallowell et al., 2017; Hinze et al., 2013; Salkind, 2010; Tixier et al., 2016
Clear	The metric is easy to understand and practical to communicate.	Johansen and Rausand, 2014; Kotek et al., 2018; Leveson, 2015; NORSOK, 2008; Taaffe et al., 2014
Actionable	The metric provides information that may prompt interventions and strategic planning.	Johansen and Rausand, 2014; Kotek et al., 2018; NORSOK, 2008; Taaffe et al., 2014
Important	The metric reports information related to an organization's strategic vision and goals.	Johansen and Rausand, 2014; Kotek et al., 2018; Leveson, 2015; Taaffe et al., 2014

FIGURE 1
HECA METRIC STRUCTURE

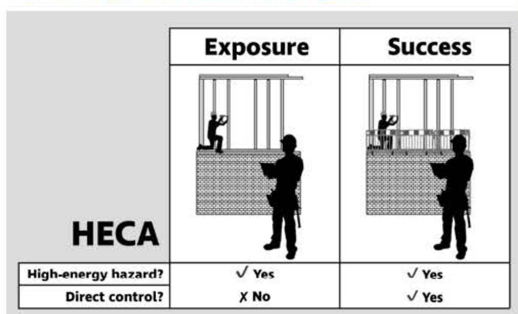
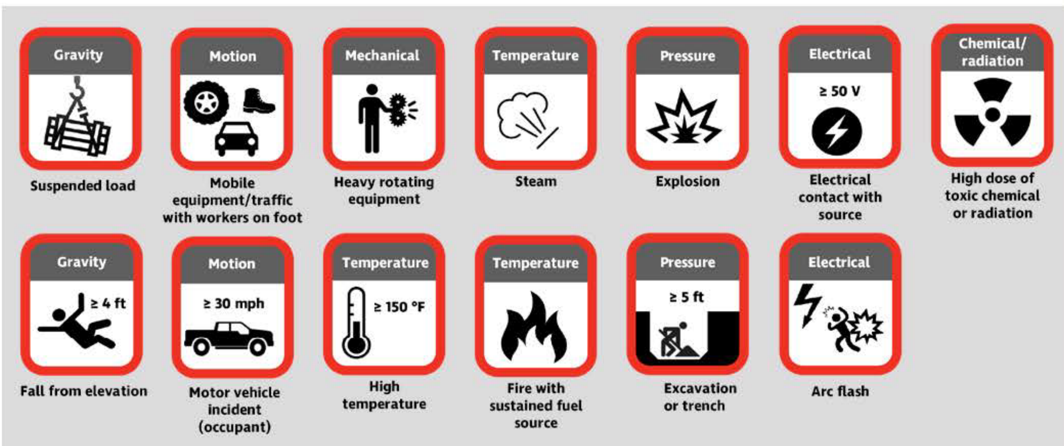


FIGURE 2
EXAMPLE HIGH-ENERGY HAZARDS



without a recordable injury was safe and a worker hour with a recordable injury is unsafe. However, not every worker hour without an injury involves safe work; sometimes work is performed unsafely, and the organization is simply lucky that an injury did not occur (Conklin, 2019). Instead, safety has been reimagined as the presence of safeguards (capacity), rather than the absence of injuries (Hollnagel et al., 2015; Lofquist, 2010). Thus, TRIR and other injury rates are antithetical to modern views of safety.

In addition to misalignment with contemporary safety principles, TRIR is not focused on SIFs. Since TRIR, by definition, includes a large spectrum of incident severities, from a two-stitch cut on the finger to a fatality, it is reasonable to estimate that SIFs account for a small proportion of recordable incidents. Because TRIR does not include exclusive information about SIFs and is not predictive of future SIFs, it is logical to conclude that TRIR does not have much utility for preventing SIFs. Although it may be tempting to suggest using fatality rates to address this concern, note that fatality rates are even less statistically stable than TRIR because fatalities are equally random and even rarer than recordables.

Based on the severe limitations of TRIR, there is a need for a new method of assessing safety performance that is scientifically valid and aligned with modern safety philosophies and priorities. To this end, the authors introduce and explore HECA as an intentionally created method of safety performance monitoring that may complement other forms of safety performance assessment.

What Is HECA?

HECA is defined as the percentage of high-energy hazards with a corresponding direct control. HECA is built on the concept that safety performance is best measured as the control of high-energy hazards. Structurally, HECA is binary because every condition observation is modeled only as success (the high-energy hazard has a corresponding direct control) or exposure (the high-energy hazard does not have a corresponding direct control), as shown in Figure 1 (p. 27). The formula to calculate HECA is given here.

The total number of HECA observations:

$$Total = success + exposure$$

where success is the number of high-energy hazards with a corresponding direct control and exposure is the total number of high-energy hazards without a corresponding direct control.

Since the total number of high-energy hazards is equal to success plus exposure, HECA may be expressed as a ratio of success to total number of assessments.

HECA:

$$HECA = \frac{Success}{Total}$$

Although the computation of HECA is simple, the challenge in applying HECA is a consistent application of definitions of a high-energy hazard and direct controls.

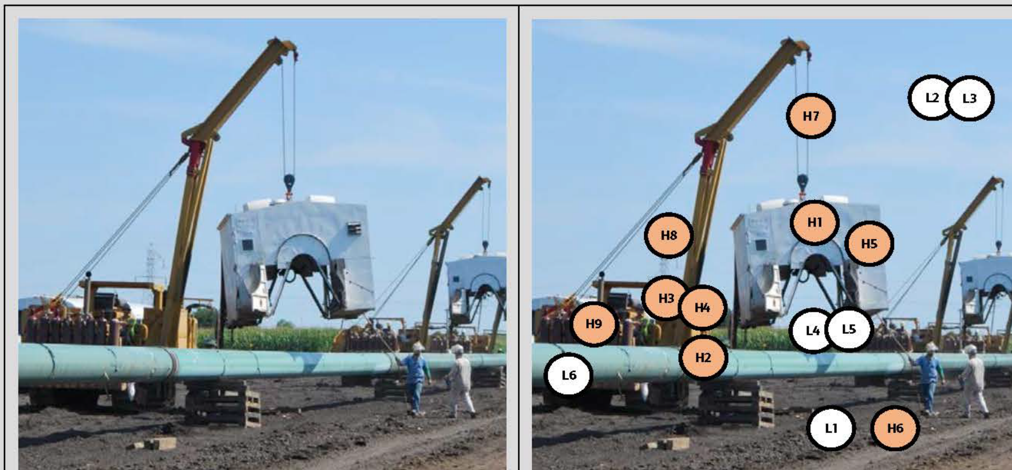
What Is a High-Energy Hazard?

The first step in HECA is to identify all high-energy hazards faced by a specific work crew at the time of observation. The term "high-energy" is based on research that shows that the severity of an injury is directly related to the magnitude of physical energy associated with a hazard (Alexander et al., 2017). For example, a heavier object higher off the ground has more potential for serious harm than a lighter object lower to the ground. Specifically, Hallowell et al. (2017) found that hazards with fewer than 500 joules of energy are most likely to cause a first aid injury; hazards with between 500 and 1,500 joules of energy are most likely to cause a medical case injury; and hazards with more than 1,500 joules of physical energy are most likely to cause a serious injury or fatality (Hallowell et al., 2017). Therefore, the term high-energy is used to describe hazards with more than 1,500 joules of physical energy because the most likely result of a contact between a human and this energy source is an SIF. Put simply, high-energy hazards are the life-threatening hazards.

High energy was selected as a key component of HECA to encourage a focus on SIF prevention and to ground the assessment in the latest scientific knowledge. Although practitioners have often focused on discussing the worst possible outcome

FIGURE 3
PIPE SHACK INSTALLATION CASE HAZARD IDENTIFICATION

This table includes all energy sources (hazards) identified by the observer. When the energy computations indicated that the energy magnitude associated with a hazard was less than 1500 joules, the hazard was marked as low energy.



Hazard ID	Hazard name	Energy source	High-energy?
H1	Suspended load (falling)	Gravity	Yes
H2	Elevated pipe	Gravity	Yes
H3	Side boom (tipping)	Gravity	Yes
H4	Side boom (tracking)	Motion	Yes
H5	Swinging load	Motion	Yes
H6	Vehicular traffic	Motion	Yes
H7	Cable and pulley	Mechanical	Yes
H8	Power lines	Electrical	Yes
H9	Compressed gas	Pressure	Yes
L1	Uneven ground	Gravity	No
L2	Construction noise	Sound	No
L3	Sun exposure	Radiation	No
L4	Insects	Biological	No
L5	Pesticides	Chemical	No
L6	Pipe surface temperature	Temperature	No

associated with a hazard, this can be counterproductive because an SIF is always remotely possible. Instead, it is more productive to discuss the most likely outcome associated with a hazard. Using the concept of high energy refocuses attention on hazards that are most likely to cause an SIF.

Although computing the magnitude of energy associated with an energy source is relatively simple for some energy types (e.g., gravity, motion), others are much more complex (e.g., mechanical, pressure). To enable field assessments, the 13 icons in Figure 2 were created by the Edison Electric Institute (Hallowell, 2020). These high-energy icons represent approximately 85% of all high-energy hazards documented in the literature as primary causes of SIFs (Hallowell et al., 2017). Although the high-energy icons enable a more practical analysis, not all high-energy hazards lend themselves to icons. For example, while some dropped tools may be high energy if the tool is high and heavy enough, many dropped tool scenarios are not high energy. Therefore, computations of energy magnitude may be required for some hazards to ensure a complete assessment. Such additional computations may be warranted due to various task- or context-based energy sources such as calculating the energy contained in equipment operations (e.g., side boom tracking and tipping) or consulting with an industrial hygienist for determining threshold exposures to toxic chemicals or radiation (Electric Power Research Institute, 2019). The high-energy icons in Figure 2 can be used to simplify the energy assessment process; however, if an icon does not apply, it is always reasonable to calculate the energy magnitude using the methods described in Hallowell et al. (2017).

What Is a Direct Control?

The second step in measuring HECA involves determining whether a direct control exists for each high-energy hazard observed. Aligning with the idea of safety as the presence of safeguards, HECA is built on the notion that every high-energy hazard should have a corresponding control that ensures that an SIF is no longer reasonably probable. Here, the term "direct control" is used to refer to a control that meets the minimum standards offered by the Edison Electric Institute (Hallowell, 2020). Although there are levels within the hierarchy of controls (i.e., elimination, substitution, engineering, administrative, PPE) and different types of controls documented in literature (i.e., absolute, mitigative, preventative), the authors intentionally use a definition for direct control that is binary (i.e., a control is or is not a direct control). One consistent definition promotes clarity, simplicity and practicality, and allows the community to move forward with a scientific definition, which is critical for the external validity.

Hallowell (2023) offers a precise and strategically designed definition of a direct control that aligns with both energy-based safety and human and organizational performance principles.

To qualify as a direct control, a control must meet all three of the following criteria:

1. Targeted to the high-energy hazard. The control must be specifically designed and intentionally used to address the high energy of concern. Examples of targeted controls include fall arrest systems for work at height, machine guards for rotating equipment and engineered excavation support systems.

2. Effectively mitigates to the high-energy hazard when installed, verified and used properly. A direct control must either eliminate the energy or mitigate the energy exposure to below the 1,500-joule threshold. An example of a direct control that eliminates the energy exposure is the de-energization, verification and lockout/tagout for electrical energy. An example of a control that reduces but does not eliminate the energy is a self-retracting fall arrest system.

A control is only considered present when it is installed, verified and used properly. If the control is not installed properly, inspected on schedule, maintained regularly or is misused, the control is considered absent. For example, a personal fall arrest system must be properly installed to an engineered anchor point, inspected, maintained on the prescribed schedule and worn properly on the body to be considered present.

3. Effective even if there is unintentional human error during the work (unrelated to the installation of the control). Controls are not considered adequate to protect against life-threatening hazards if they require workers to be perfect when using them. Given enough time, the probability that a worker will make an unintentional error is 100%. Thus, it is not *if* a worker will make a mistake, it is *when*. The controls against high-energy hazards must be functional even when someone makes a mistake during work. For example, situational awareness, signage and training are not considered direct controls because they are all vulnerable to human error. However, engineered barricades, de-energized electrical systems and some highly specialized PPE may be direct controls because they are effective even if a worker makes a mistake.

Importantly, all controls are vulnerable to human error during their installation. Therefore, criterion two includes the language "installed," "verified" and "used properly" and criterion three includes the language "unrelated to the installation of the control."

HECA Case Example

A case example is provided to illustrate HECA in a practical scenario. This case describes a pipe shack lifting operation being performed by one crew. The operation involves lifting and installing a pipe shack over a pipe supported by a temporary structure using a crane. The work takes place within a rural site on a sunny day that is approximately 60 °F. The work location is in proximity to a field or farm, power lines and a temporary site road.

Identification of Hazards

The energy sources (hazards) identified by the observer are shown in Figure 3 (p. 29). Nine high-energy hazards and six low-energy hazards were identified. Low-energy hazards included sun exposure (below 70 °F), insects and pesticide exposure from adjacent farms, noise exposure to typical machinery operations, uneven ground and pipe surface temperature. The high-energy hazards were further evaluated in the HECA assessment as shown in Table 2. When assessing whether a hazard is high energy, the 13 high-energy icons in Figure 2 (p. 28) were used. If the hazard was not represented by an icon, a formal energy computation was performed to determine whether the hazard was high energy (≥ 1,500 joules) or low energy (< 1,500 joules).

Assessment of Direct Controls

A control assessment was performed for each high-energy hazard to determine whether there was a corresponding direct control. For future data analysis and intelligence, the relevant controls (both present and absent) were recorded. The data only represented as-found conditions before any immediate intervention or corrective action was taken in response to the condition assessment. The assessment of each control is shown in Table 2. Note that for all direct controls missing in this example, the only feasible solution identified by the observer was a hard physical barricade, which was not installed in this case.

Although HECA is designed to assess the presence of direct controls only, the authors recognize that such controls might not always be possible or feasible in practice given the resource constraints or available technology. In such cases, controls other than direct controls (e.g., having spotters, specialized training to workers) play a role as a secondary line of defense to reduce the risk of exposure becoming an incident. These instances point to opportunities for innovation where the industry could collaborate to develop direct controls over time.

HECA Evaluation

If a high-energy hazard existed without a direct control, the observation was marked as "exposure." If a high-energy hazard had a corresponding direct control, the observation was marked as "success." The analysis was performed using the hazards as the units of analysis to enable more refined trending, analysis and modeling.

In the case image (Figure 3, p. 29), nine high-energy hazards were identified, five of which had corresponding direct controls. As a result, using the given formula, HECA was calculated to be 5/9, or 56%. This percentage indicates that 56% of the high-energy hazards were controlled by direct controls while 44% were not.

HECA Is Neither Leading nor Lagging; It Is a Method of Monitoring

Safety performance assessments are often categorized as lagging or leading with nothing in between. Typically, measures of injury prevention activities (e.g., frequency of safety observations) are considered input metrics and are categorized as leading indicators. Alternatively, injury rates (e.g., TRIR) are considered outputs of the system and categorized as lagging indicators. Both leading and lagging indicators generally involve measurement where the experiences and observations over an extended time are reduced to a single number. Leading indicators typically involve the total number of times a safety activity was performed, and lagging indicators are represented by the number of injuries, illnesses or other incidents.

HECA is different. It is not a leading indicator because it is not a measure of a safety activity and is a direct consequence of the safety system in place. Also, despite being an output metric, it is also not a lagging indicator because it is not an incident rate. Since HECA is intended to be collected during active work, it represents a consequence of the safety system, but precedes the occurrence of a serious safety incident. Thus, instead of attempting to characterize HECA as leading or lagging, HECA is positioned in the middle from a timeline perspective as a monitoring variable that may moderate or explain the relationship between leading and lagging variables.

In contrast to measuring, monitoring is a method of nearly real-time surveillance to assess and act upon underlying trends over relatively short periods. As an analogy, traffic engineers may measure the success of a transportation system as the number of people moved through the system in a year or decade, but real-time traffic monitoring helps citizens to select the best possible route in a morning commute. Although both measurement and monitoring are important; measurement is summative and reflective, and monitoring is ongoing and supports proactive decision-making. In safety, safety measurement (long-term trends) has largely been explored rather than monitoring (short-term trends).

Monitoring safety conditions may enable regular learning, real-time trending, strategic discussions and mobilization of resources before serious incidents occur. That is, a monitoring variable such as HECA allows an organization to control safety rather than react to historical trends. Like leading and lagging variables, HECA may also be reduced to a meaningful number when aggregated over enough time. However, as will be discussed, observation and analysis of trends in HECA are likely to be more insightful than a single HECA number.

The relationship between leading, monitoring and lagging variables is illustrated in Figure 4.

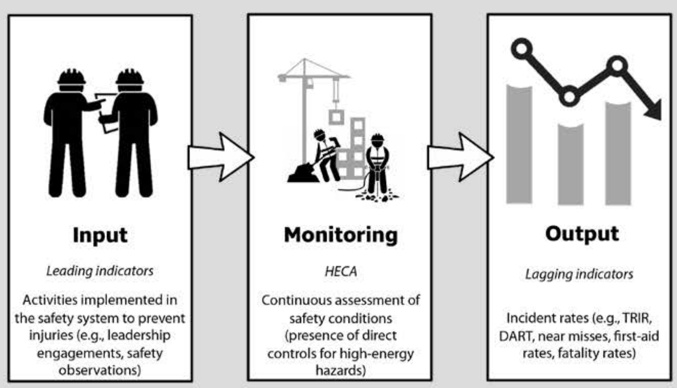
Operationalizing HECA

Because HECA is based on conditions rather than incidents, HECA may be assessed any time work is performed. To

TABLE 2
HECA ASSESSMENT FOR HIGH-ENERGY HAZARDS

Hazard ID	Hazard name	High energy?	Energy assessment	Direct control?	Direct control assessment	HECA evaluation
H1	Suspended load	Yes	Suspended load	No	No energy mitigation, and operation was vulnerable to human error.	Exposure
H2	Supported Pipe	Yes	Suspended load	Yes	Cribbing was engineered and installed properly.	Success
H3	Side boom (tipping)	Yes	Computation of energy magnitude	Yes	Operations were within acceptable equipment limits.	Success
H4	Side boom (tracking)	Yes	Heavy mobile equipment with workers on foot	No	No energy mitigation, and operation was vulnerable to human error.	Exposure
H5	Swinging load	Yes	Computation of energy magnitude	No	No energy mitigation, and operation was vulnerable to human error.	Exposure
H6	Vehicular traffic	Yes	Heavy mobile equipment with workers on foot	No	No energy mitigation, and operation was vulnerable to human error.	Exposure
H7	Cable and pulley	Yes	Computation of energy magnitude	Yes	Cables/rigging were engineered, inspected and used properly.	Success
H8	Power lines	Yes	Electrical energy more than 50V	Yes	The line was de-energized when work was near power lines.	Success
H9	Compressed gas	Yes	Explosion	Yes	Cylinders were engineered, inspected and used properly.	Success

FIGURE 4
HECA TIMELINE



align with a typical safety observation program, HECA was designed to be a short-term assessment of active work. HECA should be measured by a knowledgeable professional during a site visit where the primary purpose is to observe work and determine whether high-energy hazards are adequately controlled. HECA recordkeeping is critical to extracting useful intelligence. Although it may be efficient to record HECA as one number (e.g., the proportion of high-energy hazards with corresponding direct controls), recording the specific observations per high-energy classes enables meaningful trending and strategic decisions. When performing a HECA observation, the following fields are suggested:

•List of high-energy hazards observed (e.g., suspended load, work over 4 ft of height, computation of energy magnitude)

•For each high-energy hazard, was a corresponding direct control observed (yes or no for each high-energy hazard)?

•For each hazard with a direct control, which control was observed (e.g., engineered rigging, fall protection)?

•For each high-energy hazard without a direct control, what control was missing?

For most safety observation programs, collecting these data should not be a large departure from current activities. Although there is more to an effective observation than a controls assessment (e.g., meaningful engagements should be performed with workers), controls for serious hazards should be an integral component. Thus, it should be possible to integrate HECA into traditional safety observation programs once training is provided.

Although some initial thoughts are provided on the operationalization of HECA, much work is yet to be done. The purpose of this article is to simply introduce the concept of HECA for the first time. Future work is planned to better understand HECA in practice and create robust data collection strategies to ensure objective and high-quality data intake.

FIGURE 5
LONG-TERM TRENDING OF HECA FOR HYPOTHETICAL COMPANY A

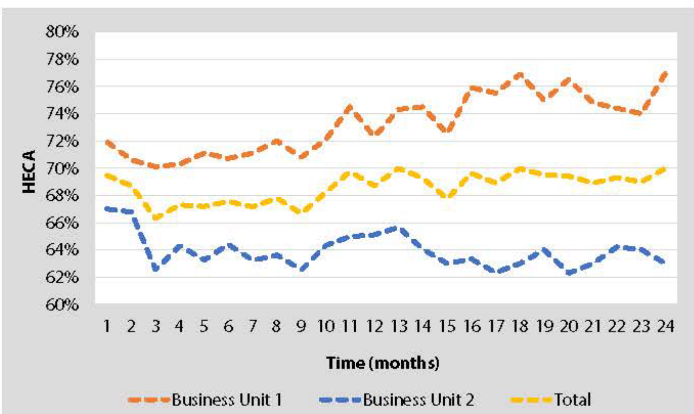
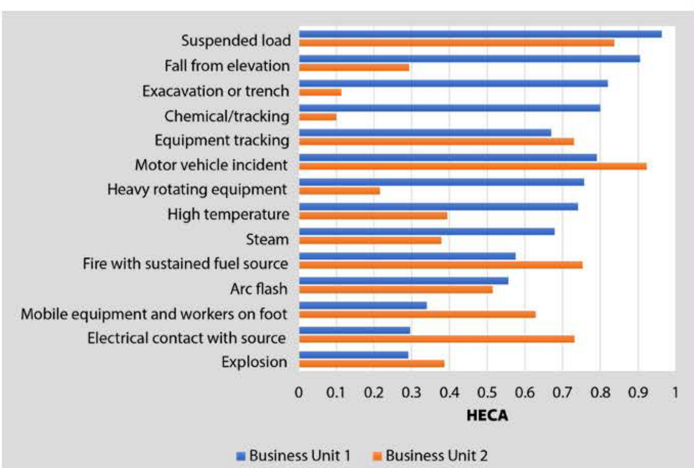


FIGURE 6
EXAMPLE HECA REPORT COMPARING TWO BUSINESS UNITS

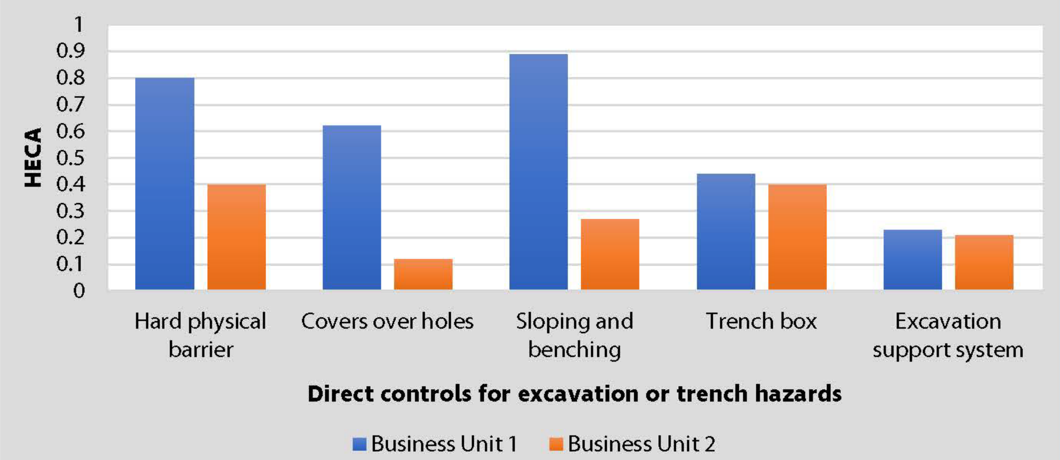


Example Intelligence From HECA

A safety performance assessment is only as useful as the intelligence it provides. Since HECA is based on the actual conditions around a work environment, it supports both tactical response and long-term strategic planning. For example, observing an inadequately controlled high-energy hazard may spur immediate coaching and problem-solving on site that will itself improve the real-time safety performance. Additionally, long-term trends in high-energy hazards and controls may instigate organizational learning, inform research and development activities, and motivate the mobilization of additional resources. Although most safety metrics are only summative in nature, HECA may also support formative assessments that enable continuous improvement.

In the simplest form, HECA may be tracked over time as the proportion of high-energy hazards with corresponding direct controls as monitored in regular condition assessments. Since HECA can be reduced to one single number, it could be used to summarize historical safety performance as a metric that tracks the percentage of high-energy hazards that have corresponding direct controls. The benefit of such information is that it provides insight on the long-term achievement of the primary goal of high-energy control. Figure 5 provides example HECA

FIGURE 7
DIRECT CONTROL COMPARISON OF TWO BUSINESS UNITS



data over a 2-year period for a hypothetical company, Company A, where each monthly HECA value represents the average HECA score for all observed crews of that week in aggregation and for two business units separately. For large companies, a weekly or monthly HECA value collected over sufficient sample size represents the aggregate of hundreds or thousands of crew observations. Such metrics are less vulnerable to random variability, making them more likely to carry statistical stability and predictive power.

When organizations collect data such as the specific high-energy hazards observed and the presence or absence of corresponding controls (see Figure 6 and 7), HECA may be analyzed to answer important questions, define opportunities for learning, and identify needs for targeted safety investments. For any period, HECA data may help to answer questions such as:

- Which high-energy hazards are relatively well controlled, and which are not?
- Which controls are typically present, and which are most commonly missing?
- How do projects or business units compare with respect to controlling specific high-energy hazards?
- To what extent have targeted interventions correlated with improvement in the control of high-energy hazards?
- To what extent do HECA trends predict future performance?

Associated with some of these questions, several graphics were produced for hypothetical Company A with two of its business units to illustrate the potential benefits of using HECA data. These include trends in the control of different high-energy hazards (Figure 6), and the analysis of the presence of specific direct controls (Figure 7) along with comparisons among business units. These analyses reveal important intelligence: Figure 6 shows that Business Unit 1 (BU1) is doing a considerably better job in implementing the direct controls to prevent the exposure to excavation- or trench-related high-energy hazards in comparison to Business Unit 2 (BU2). With this information, Company A could recognize an opportunity for interorganizational learning and shift some of its personnel with such know-how from BU1 to BU2 to advise and improve.

Taking the analysis further, Figure 7 shows the performance of direct controls against high-energy hazards related to excavation or trenches. While BU1 and BU2 have equal performance in implementing trench boxes and excavation support systems, BU1 has a much better performance in ensuring the installation of hard physical barriers, covers over holes and sloping. Company A could decide to effectively focus its efforts toward improving these direct controls.

These are simply a few examples of the types of intelligence one may produce from HECA recordkeeping and analysis. HECA data could yield many other iterations of visualizations and intelligence to show trending over time with high energy and direct control categorical breakdowns, combined with location or work-task-specific parsing as desired.

Evaluation of HECA

As the authors argued, the quality of any metric should be evaluated against the six primary criteria. In the following list, the authors summarize the perceived strengths and weaknesses of HECA and compare it against TRIR, which remains the most prevalent safety metric to date.

1. **Objective: HECA is objective based on empirical observation and guided by strict definitions.** Definitions and the instructions associated with HECA have little room for cognitive biases when high-energy guidelines are used for the assessment of energy magnitude and the definition of direct control is strictly and concisely applied. HECA simply targets to record the existence of high-energy hazards and associated direct controls. However, initial applications are likely to be based on the judgment of the observer and inevitable assumptions that must be made regarding the conditions on site. Therefore, although HECA has the potential to become an objective metric, it is likely to involve some subjectivity during initial implementation.

2. Valid: HECA is valid because it may be collected at sufficient volume to be statistically stable and precise. HECA could be continuously monitored and measured in great volume, especially if aligned with existing safety observation programs. For example, a company that performs 100 safety observations per month could yield more than 1,000 HECA assessments per year. Thus, in stark contrast to injury rates such as TRIR, HECA can be measured in large volumes making it highly statistically stable.

3. Predictive: It is unclear whether HECA is predictive of future performance because it has yet to be empirically tested. Although it is clear from recent research that TRIR is not predictive, research has yet to be conducted to determine whether HECA has predictive power. Thus, no conclusion can be drawn regarding the predictive nature of HECA.

4. Clear: HECA is moderately easy to understand but will require training to be consistently applied. Because HECA can be simply distilled into one number (i.e., the percentage of high-energy hazards with a corresponding direct control), it can be used as a simple metric. However, it is categorized as only moderately simple because training is required on high-energy and direct controls to ensure that the assessments are performed as designed. If these terms were to be institutionalized to the same extent as the term "recordable," the authors believe that HECA and TRIR would be equally simple.

HECA offers a new, intentionally designed method of assessing safety performance that is aligned with current safety principles and may enable continuous monitoring and strategic decision-making.

5. Important: HECA is important because it is aligned with emergent safety principles and a focus on SIF. Perhaps the greatest strength of HECA is its alignment with contemporary safety thinking. Most modern safety professionals have transitioned away from the notion that safety is the absence of injuries to an understanding that safety is uninterrupted presence of safeguards (capacity). The community is also aligning on the notion that serious injuries and fatality prevention deserve a disproportionately high level of attention (Oguz Erkal et al., 2021). Since HECA directly measures the presence or absence of controls against high-energy hazards that have the likely potential to cause SIF, it is aligned with both a contemporary understanding of safety and the prioritization of SIF. Moreover, HECA supports human performance principles by directly measuring the presence or absence of safeguards (i.e., measuring capacity). Although there may be other forms of capacity that could be assessed, HECA offers a relatively objective method that relies on empirical data. Thus, the authors believe that HECA is a far more important metric than TRIR.

6. Actionable: HECA is actionable because it supports proactive decisions based on continuous data. As a monitoring variable that can be measured in high volume, HECA has the potential to reveal real-time trends that can enable robust learning and proactive decision-making. Specifically, trends in the control of high-energy hazards may highlight resource demands that may otherwise be hidden until serious incidents occur. The ethos of HECA encourages investment in building capacity and resiliency.

In summary, a transition to HECA would involve a trade-off between challenges in objectivity and clarity and improvements in statistical validity, importance and actionability. The authors believe that widespread use of HECA would help to address issues in objectivity and clarity, whereas lagging indicators such as TRIR have little room for improvement.

Conclusions & Recommendations

This article presents a new method for regular monitoring of safety performance, serving as a long-awaited departure from traditional safety performance assessment methods. HECA is strategically positioned as a learning and monitoring metric to complement and improve existing forms of safety performance measurement. Moving forward, the success or failure of HECA will depend on the way it is operationalized, communicated, and to the extent with which it is curated and consistently applied by the industry and research. The next steps in developing HECA for implementation should aim to enhance the rigor and validity of the method, and to provide guidance on how organizations use HECA in business practices. The initial conclusions and recommendations in these areas are provided for consideration.

•**It is critically important to maintain one definition of HECA.** One reason that TRIR has been so pervasive is that there is only one government-mandated definition of a recordable injury. This strength must be replicated by creating and maintaining one definition of HECA. If organizations begin adapting HECA to meet their individual desires, HECA loses much of its utility for shared learning. Shared learning is critical for SIF elimination because no single company will figure out how to eliminate fatalities on its own. Instead, we must learn and advance together, which requires a shared vocabulary and assessment structure. Importantly, a shared vocabulary is also the underpinning of any emerging scientific field.

•**HECA should be used for learning and improving rather than measuring and comparing.** Any metric used to compare businesses, business units, projects, teams and so forth has the potential to directly or indirectly be incentivized. HECA is no exception. When incentivized, any metric can encourage poor behavior such as underreporting, misreporting, case management and other forms of data manipulation. The problem is not with the structure of the metric, but with the incentives created by the organization and external stakeholders such as investors. To ensure that HECA has the greatest positive impact, it should be used for continuous safety monitoring, learning and strategic allocation of resources.

•**HECA should be strategically operationalized to ensure long-term success.** The purpose of this article is to describe the initial concept of HECA and the strict definitions of high energy and direct control. Future work is needed to operationalize HECA and create guidance on sampling methods required to have a representative data set, methods to collegiate HECA to various stakeholders, methods to analyze and report HECA, opportunities for shared learning across communities, and approaches to independent validation.

•**The relationship among leading, lagging and monitoring variables (e.g., HECA) should be empirically explored.** Metrics are only useful if they tell a story that enables better discussions that yield more effective decisions. By understanding the potential relationships among leading indicators (inputs), HECA (system monitoring) and lagging indicators (outputs), there may be a future where collective metrics suggest what to change and by how much, what will be seen in the field, and what to expect for long-term outcomes. As a system monitoring variable, HECA would play an important role in regular surveillance and control and may be predictive in nature.

•**Although HECA still needs work, it is an important step toward a future where safety metrics are aligned with safety principles.** The safety community has made strides through concepts of human and organizational performance, but primary safety metrics (e.g., TRIR) remain antithetical and antiquated. HECA offers a new, intentionally designed method of assessing safety performance that is aligned with current safety principles and may enable continuous monitoring and strategic decision-making. More work is needed to understand HECA in practice, such as sampling frequency, independent validation and prevention of manipulation. PSJ

References

Alexander, D., Hallowell, M. & Gambatese, J. (2017). Precursors of construction fatalities. II: Predictive modeling and empirical validation. *Journal of Construction Engineering and Management, 143*(7), 1-12. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001297

Conklin, T. (2019). *The 5 principles of human performance: A contemporary update of the building blocks of human performance for the new view of safety.* PreAccident Media.

Electric Power Research Institute. (2019). Job-site hazard assessment: Identifying precursors of serious injuries and fatalities—Energy hazards (Technical report). https://bit.ly/3GM6Y6Y

Esmaeili, B., Hallowell, M.R. & Rajagopalan, B. (2015). Attribute-based safety risk assessment. II: Predicting safety outcomes using generalized linear models. *Journal of Construction Engineering and Management, 141*(8). https://doi.org/10.1061/(ASCE)CO.1943-7862.0000981

Goh, Y.M. & Chua, D. (2013). Neural network analysis of construction safety management systems: A case study in Singapore. *Construction Management and Economics, 31*(5), 460-470. https://doi.org/10.1080/01446193.2013.797095

Hallowell, M. (2023). Safety classification and learning (SCL) model (White paper). Edison Electric Institute. https://bit.ly/3mFRw5C

Hallowell, M.R., Alexander, D. & Gambatese, J.A. (2017). Energy-based safety risk assessment: Does magnitude and intensity of energy predict injury severity? *Construction Management and Economics, 35*(1-2), 64-77. https://doi.org/10.1080/01446193.2016.1274418

Hallowell, M., Quashne, M., Salas, R., Jones, M., MacLean, B. & Quinn, E. (2021, April). The statistical invalidity of TRIR as a measure of safety performance. *Professional Safety, 66*(4), 28-34.

Hinze, J., Thurman, S. & Wehle, A. (2013). Leading indicators of construction safety performance. *Safety Science, 51*(1), 23-28. https://doi.org/10.1016/j.ssci.2012.05.016

Hollnagel, E., Wears, R.L. & Braithwaite, J. (2015). From Safety-I to Safety-II: A white paper. The Resilient Health Care Net. https://bit.ly/43GqyLW

Johansen, I.L. & Rausand, M. (2014). Foundations and choice of risk metrics. *Safety Science, 62*, 386-399. https://doi.org/10.1016/j.ssci.2013.09.011

Karakhan, A. (2017, June). Six sigma and construction safety: Using the DMAIC cycle to improve incident investigations. *Professional Safety, 62*(6), 38-40.

Korman, R. (2022, April 13). Statistics that mislead: Is the obsession with recordable injury rates a deadly safety distraction? *Engineering News-Record*. https://bit.ly/3AnWSWx

Kotek, L., Nosek, A. & Bartos, V. (2018). Safety metrics of performance for small and medium-sized enterprises: Case study. *MM Science Journal*. https://doi.org/10.17973/MMSJ.2018_03_2017118

Leveson, N. (2015). A systems approach to risk management through leading safety indicators. *Reliability Engineering and System Safety, 136*, 17-34. https://doi.org/10.1016/j.ress.2014.10.008

Lingard, H., Hallowell, M., Salas, R. & Pirzadeh, P. (2017). Leading or lagging? Temporal analysis of safety indicators on a large infrastructure construction project. *Safety Science, 91*, 206-220. https://doi.org/10.1016/j.ssci.2016.08.020

Lofquist, E.A. (2010). The art of measuring nothing: The paradox of measuring safety in a changing civil aviation industry using traditional safety metrics. *Safety Science, 48*(10), 1510-1529. https://doi.org/10.1016/j.ssci.2010.05.006

NORSOK. (2008). Technical safety (NORSOK S-001:2008). Standards Norway.

Oguz Erkal, E.D. (2022). *Predicting serious injury and fatality exposure in construction industry* (Publication No. 29260661) [Doctoral dissertation, University of Colorado Boulder]. ProQuest Dissertations and Theses. https://libraries.colorado.edu/record=b12869717

Oguz Erkal, E.D., Hallowell, M.R. & Bhandari, S. (2021). Practical assessment of potential predictors of serious injuries and fatalities in construction. *Journal of Construction Engineering and Management, 147*(10), 04021229. https://doi.org/10.1061/(asce)co.1943-7862.0002146

Pedersen, L.M., Nielsen, K.J. & Kines, P. (2012). Realistic evaluation as a new way to design and evaluate occupational safety interventions. *Safety Science, 50*(1), 48-54. https://doi.org/10.1016/j.ssci.2011.06.010

Salkind, N.J. (2010). Encyclopedia of research design. *Sage*. https://doi.org/10.4135/9781412961288

Taaffe, K.M., Allen, R.W. & Grigg, L. (2014). Performance metrics analysis for aircraft maintenance process control. *Journal of Quality in Maintenance Engineering, 20*(2), 122-134. https://doi.org/10.1108/JQME-07-2012-0022

Tixier, A.J.-P., Hallowell, M.R., Rajagopalan, B. & Bowman, D. (2016). Application of machine learning to construction injury prediction. *Automation in Construction, 69*, 102-114. https://doi.org/10.1016/j.autcon.2016.05.016

U.S. Bureau of Labor Statistics. (2019). How to compute a firm's incidence rate for safety management. https://bit.ly/3GPDVQ4

Wilbanks, D.W. (2018, July). Contractor safety prequalification: The reality of demanded written programs. *Professional Safety, 63*(7), 36-40.

Cite this article

Oguz Erkal, E.D. & Hallowell, M.R. (2023, May). Moving beyond TRIR: Measuring and monitoring safety performance with high-energy control assessments. *Professional Safety, 68*(5), 26-35.

Acknowledgments

The authors thank Siddharth Bhandari, Mike Court, Chad Lockhart, Brad MacLean, Ramsey Robertson and James Upton for their review and thoughtful contributions to this article. They also thank the Construction Safety Research Alliance for the funding that made this study possible.

Elif Deniz Oguz Erkal, Ph.D., recently graduated from University of Colorado Boulder with a Ph.D. in Construction and Engineering Management specializing in safety performance measurement and predictive analytics for serious injury and fatality prevention. Previously, she worked in the oil and gas construction industry as a contract manager and completed graduate work at Carnegie Mellon University with an emphasis on operational networks in construction. Oguz Erkal continues her professional career as a senior associate in the construction consulting practice at Exponent.

Matthew Hallowell is founder and executive director of the Construction Safety Research Alliance, a President's Teaching Scholar, and an endowed professor of construction engineering at the University of Colorado Boulder. Outside academia, Hallowell is the executive director at Safety Function, which specializes in research-based workshops, training and artificial intelligence solutions for worker safety. He also serves as a principal technical advisor to the Edison Electric Institute, the Interstate Natural Gas Association of America and private companies. Hallowell is a professional member of ASSP's Rocky Mountain Chapter.