Protecting Human Capital through the Intersection of Architecture, Engineering and Worker Safety

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Prevention through Design (PtD) is intended to protect workers by eliminating hazards at work. Capital Project Planning is a process that businesses follow to improve facilities. Human capital is protected when safety management is given co-equal consideration with architecture and engineering throughout the capital planning process.

Keywords: Workers safety, Prevention through Design, occupational safety and health .

1 Introduction

The mission of the Prevention through Design (PtD) initiative is to protect workers at all stages of their career by designing out hazards and thereby reducing risks of injury, illness, and death. The Capital Project process presents a unique opportunity to fulfill this mission. The PtD initiative arose from discussions among industry, academic and government leaders about preventable deaths in the construction sector attributed to carelessness. The futility of blaming the victim was readily apparent. What could designers through the design process do to eliminate the root cause of these fatalities?

Administration of the initiative fell to the National Institute for Occupational Safety and Health (NIOSH), a division of the Centers for Disease Control and Prevention (CDC), which is part of the Department of Health and Human Services (HHS) in the United States. At the end of the seventh year of the initiative, almost 700 collaborators have published more than 3000 peer-reviewed journal articles, books and related safety materials.

In 2010, I joined the PtD team at NIOSH tasked with the development of safety training modules for undergraduate engineers. Thus began an extensive review of the safety literature, including risk management strategies, government regulations, and management philosophy. Working with experienced NIOSH industrial hygienists, I focused on understanding how PtD could influence the Capital Project Process. I became the interim PtD Coordinator in 2013 and served until the end of my appointment.

2 Including Occupational Safety and Health (OSH) in Design

PtD addresses occupational safety and health (OSH) issues by eliminating hazards and minimizing risks throughout the life cycle of work premises, tools, equipment, machinery, substances, and work processes, including their construction, manufacture, use, maintenance, and ultimate disposal or re-use. PtD involves including OSH considerations at each step of the design, re-design, and retrofit processes, including on-going operations and maintenance and ultimately, re-purposing or recycling. The earlier PtD concepts are introduced into the capital project process, the greater the protection of human capital, workers, through hazard elimination.

What is Capital Project Planning? This is a nine stage process that business entities follow to spend money on improvements to the business. The ten steps are: Project Initiation, Conceptual Design, Detail Design, Final Design, Procurement, Construction, Start-up & Commissioning, Project Close-out, Operations & Maintenance, and Decommissioning. A brief description of each of the steps follows:

Project Initiation — The process begins with a concept to satisfy a need. The customer/owner forms a team and invites them to a kick-off meeting. In this meeting, the budget and timeline are established and the project scope is defined. For facilities, the team consists of the owner, a financial expert, an architect, a project manager, one or more engineers and a safety and health (S&H) professional. The team identifies overarching policies such as PtD. They evaluate alternate locations for the facility, including zoning and environmental restrictions. The owner may have specific material preferences (steel, titanium, concrete, wood, glass, etc.) and these should be discussed.

Conceptual Design — The existing applicable literature, problems and successes associated with existing solutions, costs, and marketplace needs are evaluated during a feasibility assessment. Legal requirements including permits and regulations are identified for each design option. The conceptual design phase is principally concerned with the generation, evaluation and presentation of ideas for the Project Design Specification (PDS). Concept generation involves the development of whole product or sub-system concepts. These are normally presented in the form of sketches, layout drawings, or diagrams. The design team considers a broad range of concepts. The goal of the conceptual design phase is to identify the very general type of solution that will be pursued. By the end of the phase, a single concept will be proposed for further development. This chosen solution will be feasible and in keeping with the PDS.

During conceptual design, hazards are identified and goals are set to reduce worker exposures to noise; radiation; hot/cold stress; and chemical, biological, and/or ergonomic hazards. Operations and emergency procedures, fire safety, electrical demand, water usage, machinery, chemicals and chemical processes, animals and biological processes, instrumentation, maintenance, and security must all be considered. Permits are filed. An industrial engineer may recommend a specific workflow to reduce risk of ergonomic injuries or improve plant productivity. Geographic location, geologic composition, access to infrastructure, and other factors may influence facility siting. Applicable standards are identified.

The team considers ways to eliminate hazards; substitute less hazardous agents/processes; establish risk minimization targets for remaining hazards; assess risk; and develop risk control alternatives. For example, a goal may be to limit noise exposure below a specific level to avoid the cost of providing hearing protection for workers. The PM works with the team to narrow design choices. The architect may construct models of the various design alternatives. Preliminary drawings are issued. The public may be asked to comment. The PM may solicit bids or otherwise identify subcontractors for the design of the structure, the building envelope, HVAC systems, site access and parking during construction.

PtD Activities during Conceptual Design —During conceptual design, occupational hazards that may be associated with building the project, installing or operating project-related equipment, and operating and maintaining the products of the project are anticipated. Occupational safety and health (OSH) goals should be established and provided to the design team to address these hazards. Many organizations have an established S&H policy statement. Specific S&H goals ensure that hazard elimination and substitution are considered and that risks from remaining hazards will be assessed and minimized as part of the design process. Examples of project goals include: reduce reliance on personal protective equipment to non-routine tasks, control exposures to noise to <85 dBA, minimize of the risk of falls from heights, achievability, and minimization of financial burden. OSH personnel can then formulate plans to accomplish the prioritized objectives.

Detail Design — At this stage of the project, the preferred concept has been identified and work can begin on the details. Drawings, diagrams and computer models are updated with locations, dimensions, elevations and other specific information required to manufacture the product or to build the facility. Specifications are written for purchased equipment and materials. Prototypes may be tested and evaluated. Every member of the design team has an assigned role. The S&H professional conducts process hazard reviews and recommends design interventions to eliminate chemical, biological or ergonomic hazards. Specific engineering and administrative controls are selected to reduce residual risks encountered during operations and under emergency conditions. Team members develop project specifications, including design life, facility dimensions, maintenance provisions, operating parameters and reliability requirements. The architect generates a set of drawings and specifications for each subcontractor. The PM monitors costs and tracks progress. Structural engineers, civil engineers, mechanical engineers, chemical engineers, and electrical engineers may all be involved at this stage. Depending on project complexity, each engineering firm may have several employees developing specifications and construction drawings for the project. Experienced trade contractors and others may be asked to review the detailed design for constructability, but this is not common in the United States.

PtD activities during Detailed Design —During this stage, risks should be eliminated by changing the design or by and avoiding processes that create hazards such as fumes, dust, vapors, vibration and noise. A risk analysis is conducted on hazards that cannot be designed or substituted out of the system. A variety of risk assessment methodologies are available from the American Industrial Hygiene Association (ANSI/AIHA Z10-2012) and the American Society of Safety Engineers (ANSI/ASSE Z590.3 – 2011). They include both a hazard analysis and a failure mode and effects analyses (Manuele 2013).

Minimal risk targets for remaining hazards are established and risk control alternatives are developed. During the preliminary design stage, environmental release permits and other regulatory documents are developed. Additionally, planning begins for the quantitative risk assessment that will occur during the final design phase.(http://www.fhwa.dot.gov/everydaycounts/projects/toolkit/design.cfm)

Final Design — The owner reviews all design decisions to date. Internal quality assurance checks are performed. During a final engineering review, the S&H professional may be required to justify specific risk control interventions. The S&H professional develops "checks and tests" for factory acceptance testing and commissioning. Final design documents are let for bid. The PM monitors costs, schedules, and progress. The Architect develops a traffic control and site access plan.

PtD activities during Detailed Design —During the final design stage, control systems are selected for use in mitigating hazards that could not be designed out in previous design stages. Consideration needs to be given to the type of work that will occur at the facility and what will happen in the event of an emergency. Equipment such as eyewash and emergency showers must be integrated into the project designs. A final hazard review and risk assessment ensures that mitigation strategies are addressed (Manuele 2008). Tests to ensure that equipment and processes meets the design specifications are developed.

Identified hazards or risks that were not eliminated in previous design stages are addressed through appropriate control systems. A maintenance and repair review should be completed. This review should examine the architectural and structural design to determine the risks associated with the design and select techniques to mitigate these risks. (Workplace Safety and Health Council)

Procurement — Procurement often occurs and overlaps multiple stages. Procurement describes the merging of activities undertaken by the client to develop the project. Procurement activities should be developed in the early stages of a project. During procurement, all design decisions are reviewed and internal quality assurance checks are performed. Checks and tests for factory acceptance testing and commissioning are developed.

PtD Activities during Procurement —During the procurement process, equipment purchase orders are reviewed to ensure that the purchased equipment is compliant with the S&H specifications for the facility. PtD activities can include the choice to specify quieter construction equipment as specified in NASA's "Buy Quiet" initiative (ANSI/AIHA 2012). Every piece of equipment is tested to ensure that the equipment meets the S&H specifications. A construction safety plan is developed, approved, and continually reevaluated. Additional construction and environmental permits are obtained as needed.

The practice of prequalifying bidders protects project integrity, promotes overall efficiency in the conduct of work, and ensures a helpful and safe working environment (AIHA 2001). Prospective bidders are required to submit financial and OSH performance history. These are reviewed. Only qualified contractors are allowed to submit bids.

Construction — The owner retains financial control of the project and may approve or deny proposed changes to the design. Employers are responsible for construction crew safety. The construction superintendent is responsible for site safety, although a subcontractor may be hired to enforce the traffic control and site access plan. Various engineers inspect the work in progress and note "as-built" deviations from their drawings. The PM monitors costs, schedules equipment and crews, and tracks progress.

PtD Activities during Construction —The overall health and safety of persons on the site is the objective. All contractors should have an approved S&H plan. The standards established in the S&H plan should be followed (ANSI/AIHA 2012). The Construction Superintendent informs all contractors of site-specific risks and hazards. Specific work processes can influence erection times. Parts of the structure can be prefabricated on the ground and then lifted into to place to reduce the amount of time workers are working at heights (AIA 2007). As a last resort, the use of safety equipment such as Personal Protective Equipment, harnesses, guardrails and procedures such as securing ladders and inspecting scaffolding can curtail the risk of occupational injuries in the construction industry.

Start-up & Commissioning — Commissioning is a systematic process of quality control and assurance, and is required for all capital projects. It is a formal process which is used to verify and document that the systems are designed and constructed in accordance with design specifications. The main function of this stage is to confirm, through functional testing, that the interactive operation of processes and systems comply with the capital projects design criteria. Preceding operation start-up, the pre-start-up OSH review is completed. Unacceptable items are resolved.

Final project acceptance and documentation of all design details and equipment files occurs in this stage. A project critique is held, closeout report prepared, and learning shared within and beyond the project team. Feedback is solicited from project team members as to standards and requirements for which changes are needed

The owner conducts a walk-through to identify incomplete items or omissions. The engineer prepares a punch list of items to resolve before final payment is made. The S&H professional and others conduct tests on equipment and processes to demonstrate compliance with design intent and specifications. PtD Activities during Startup & Commissioning

During the startup and commissioning stage, preliminary industrial hygiene monitoring is conducted. A comparison of residual risks versus risk targets is made. A walkthrough and industrial monitoring occurs to ensure that hazard control measures have been installed and operating effectively. This includes pre-start up safety reviews and the development of standard operation procedures (SOPs). Acceptance testing of equipment is conducted along with any retrofits that are necessary. The S&H professional consults with project team members regarding standards and requirements when changes are needed.

Project Close-out — The owner takes possession of the facility/product. The architect may be hired to perform a post-occupancy inspection to confirm that the facility meets design intent. A set of as-built drawings may be created. The PM resolves any outstanding invoices and change orders. The S&H professional completes all OSH-related documentation, including the development of checklists for operations & maintenance.

Operations & Maintenance — The facility is open for business. The Facility Manager (FM) oversees all operations and conducts periodic inspections. Production and productivity goals are established. The FM manages both the operation of the facility and the staff required to run it. The Maintenance Crew attends to routine maintenance and makes repairs as needed. Extraordinary repairs may be contracted out. Environment, Health and Safety (EHS) staff conduct training for new and existing personnel. They prepare reports as required by permit, such as an emissions inventory. They document all accidents and incidents.

PtD Activities during Operations & Maintenance — From time to time, accidents happen. All incidents are examined in depth to establish root cause of the failures that affect the design or operation of the facility (ANSI/AIHA 2012, Manuele 2013,Manuele 2008). Training on safety equipment, processes, and policies should be conducted to enhance employee awareness and encourage safer behavior (Manuele 2008). The formation of a facility safety team is recommended. This team should consist of individuals at all levels of responsibility, including hourly employees and management, to encourage ownership of solutions. Approximately six months after close-out, a post-occupancy evaluation can be conducted to compare design intention with space utilization and to identify obvious opportunities to design out hazards.

Decommissioning — Decommissioning is the planned shut-down or retirement of a facility, system or process in a manner that does not endanger personnel or harm the environment. It entails planning waste, management security and protecting the worker and the public. It may also entail razing structures and dismantling building components and equipment. If buildings are left in place, decommissioning may involve converting them for alternate uses.

Planning is an important factor in decommissioning. Ideally, planning for decommissioning should begin during the design sages. During the design stage a cost/benefit evaluation should be used to determine the best strategy for decommissioning. This early planning will allow timely allocation of funding and infrastructure.

The purpose of decommissioning planning is to identify the resources that will be needed when they will be needed. The decommissioning plan should include at least a rough of cost estimate, a schedule of activities and a waste estimate by type and volume (Reisenweaver 2010).

The following information should be included in the decommissioning plan:

- Facility Information
- Administrative Details
- Detailed Cost Estimate
- Radiological Details
- Waste Management Plan
- Safety/Risk Assessment
- Environmental Assessment
- S&H Plan
- Quality Assurance
- Emergency Plan
- Physical Security & Safeguards

PtD Activities during Decommissioning —PtD activities during decommissioning are similar to those of the Construction phase. The decommissioning plan organizes the work to reduce the risk to the employees doing the work. Quieter construction equipment may be ordered, per NASA's "Buy Quiet" initiative (ANSI/AIHA 2012). It may be advantageous to disconnect and lower sections of the structure to the ground for disassembly to reduce the amount of time workers are working at heights (AIA 2007). As always, safety equipment, guardrails and standard operating safety procedures can reduce the risk of worker injuries. Health and safety on the site is essential to completing a project on time and under budget. All contractors should have a health and safety plan that covers routine and emergency situations. The standards established in the health and safety plan should be followed (ANSI/AIHA 2012).

3 Conclusion

Workers are human capital. The costs to train and protect skilled workers are minimal compared to the costs of replacing them. Accidents occur either when people are unaware of danger or when systems or equipment fail. The first step is to identify which hazards are present. Are they always present or are they the result of circumstances? Can the hazards be eliminated? Whenever an incident occurs, determine the root cause and document the solution. Keep a log. When the opportunity presents itself, perhaps through the acquisition of a new facility, be proactive to eliminate the hazard. Manage risks by controlling exposures. New equipment may be required. Employees must be trained. Consider "what if" scenarios and plan for each contingency. Develop an emergency plan and practice emergency procedures. Companies that protect their human capital save money. Keeping workers safe is a good business decision.

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About the Author

Pamela Heckel, Ph.D., P.E. is the former Project Officer for the Prevention through Design Initiative at the National Institute for Occupational Safety and Health. She earned the doctorate in environmental engineering in 2007 from the University of Cincinnati. Her doctoral research used a terrestrial insect as a surrogate for human, occupational exposure to ambient mercury. She developed a novel, complex air pollutant dispersion model to predict ambient concentrations along roadsides. She conducted epidemiological research studies and modeled occupational exposures to mercury during a post-doctoral fellowship in the College of Medicine. In addition to the doctorate in engineering, she has undergraduate engineering degrees from Vanderbilt and Purdue, a Master's in Architecture and is a registered engineer in Ohio.

Prior to NIOSH, Dr. Heckel's work experience includes design and manufacturing of nuclear reactors and construction of nuclear containment facilities. She designed a laminar drill platform used to manufacture the stainless steel internal structure of a nuclear reactor. She worked as a field engineer on the Trans-Alaska Pipeline where she managed the steel yard and supervised a union crew of Boilermakers, Teamsters and Operators. She was a pioneer in developing computerized inventory-control systems at Boeing and later worked on the Customer Engineering Sales Support team for the 737. At General Electric, she performed life cycle analysis on the CFM56 engines that power the 737 aircraft and wrote the LM1600 engine test manual. She supervised the contract employees from Essig Research. This year, she joined the Board of the international Air & Waste Management Association. Dr. Heckel applied for patents on two Type II medical devices: an ergonomic grip and a device to treat hammertoes. In addition to journal publications and conference presentations, she has published a play (Uncle Doc), two textbooks (Putting People First the Theory of Universal Design and Environmental Mercury Exposure of Terrestrial Life Forms), and musical scores for Psalms 1 & 2. She is the President and CEO of the Five Minute Church, Inc. a web-based ministry. Dr. Heckel and her husband Walter recently celebrated their Silver Wedding Anniversary. They have four adult children.