HEALTH HAZARDS IN CONSTRUCTION

An Evidence-Based Approa

By Babak Memarian, Sara B. Brooks and Chris Trahan Cain

DESPITE EFFORTS TO CREATE SAFER and healthier workplaces, construction workers in the U.S. still experience a noticeably high rate of fatal and nonfatal injuries and illnesses. The construction industry has experienced a fatality rate of 10.2 per 100,000 full-time employees, approximately three times higher than all other industries' average (CPWR, 2018). These fatalities are, to a large extent, attributed to acute safety incidents or exposure to hazardous substances and materials on construction jobsites. However, approximately 95,000 workers died in 2017 from chronic occupational diseases (AFL-CIO, 2019), and up to 50% of occupational cancer deaths are attributed to exposures in the construction industry (Hutchings & Rushton, 2012). National Occupational Research Agenda (NORA) Construction Sector Council (2018) has identified silica, welding fumes, noise and lead as research priorities in the construction industry.

Silica causes a number of chronic illnesses and fatalities among construction workers. OSHA (2019) reported that about two million construction workers are exposed to hazardous levels of silica dust every year. OSHA promulgated a comprehensive silica standard in 2016 in an effort to reduce construction worker exposure to hazardous levels of silica dust.

Lead is a persistent health hazard in construction. To reduce construction worker exposure to lead, OSHA released a comprehensive standard in 1993. However, NIOSH has reported that about 32 of 100,000 construction workers still have elevated levels of lead in their blood, defined as 10 µg/dL or higher (CPWR, 2018). This concerning fact calls for more robust preventive solutions.

Noise and welding fumes are also responsible for a significant number of work-related injuries and illnesses in the construction industry. CDC (2015) reports that about 20% of construction workers complain about some level of hearing loss. The only industry with a higher prevalence of hearing loss is mining (CPWR, 2018). Based on a report by National Center for O*NET Development (2015), about 52% of welders are also exposed to hazardous conditions caused by welding fumes at work.

Without conducting personal exposure monitoring, determining worker exposure to airborne hazards and noise is difficult, and construction employers will have little information on how to effectively control health hazards. Engineering controls are one of the most effective means of reducing worker exposures to these hazards. However, the variability of construction tasks and the dynamic nature of construction work sites can complicate the process of selecting and implementing the most appropriate engineering controls at the outset of a project. As a potential solution, a database of exposure measurements associated with specific variables such as task, material and available controls has been suggested as the basis for reasonable working assumptions to implement protective procedures (Susi & Schneider, 1995). Despite its importance, the construction industry has lacked such a system for many years.

Construction safety and health scholars have developed large exposure data sets for selected hazards over the past 20 years, but these data sets are mainly for the purpose of statistical and epidemiological analyses (Beaudry, Lavoué, Sauvé, et al., 2013; Burstyn, Kromhout, Cruise, et al., 2000; Lehnert, Hoffmeyer, Gawrych, et al., 2015). These data sets are of limited utility to construction practitioners, as the data are either not readily available, limited to one hazard, or in a format that is difficult and time-consuming to interpret and apply. In response to these limitations, some groups have developed databases to make their data more accessible by incorporating search interfaces. Nonetheless, reducing usage of such databases has been limited to either specific workplaces or geographic regions, designated as member-only, or restricted by a paywall (Construction Employers Association, 2016; Ng & Davies, 2016; Van Dyke, LaMontagne, Martyny, et al., 2001).

These factors highlight the need for a more comprehensive, intuitive and publicly available system to estimate the probable exposure levels to common health hazards so practitioners can select and use the most effective measures to protect workers. Benefits of such a system would be significant for small and mid-sized contractors that have limited resources for employing full-time safety and health personnel. Approximately 91%

KEY TAKEAWAYS
- **Engineering controls are one of the most effective means of reducing construction worker exposure to health hazards. However, given the variability of construction tasks and the dynamic nature of construction work sites, assessing worker exposure and selecting the most appropriate controls at the outset of a project is challenging.**
- **This article discusses the development, functionality and application of the Exposure Control Database, an evidence-based solution that estimates construction worker exposure to four common health hazards: silica, welding fumes, noise and lead.**
- **It also highlights the limitations and lack of consistency in air sampling procedures and outlines a new approach to standardize and continuously improve data collection and data sharing processes.**

ach to Estimating Exposure

of all construction employers in the U.S. employ fewer than 20 workers, but experience fatalities at a disproportionately high rate (CPWR, 2018). To bridge this gap, CPWR—The Center for Construction Research and Training developed the Exposure Control Database (ECD) for four priority health hazards: silica, welding fumes, noise and lead. This article describes the ECD's development, functionality and utility.

Background

Several exposure databases have been developed in response to the construction industry's need for health hazard characterization. These databases aim to help practitioners select and implement effective protections for workers.

CPWR developed a database that contains exposure measurements from welding operations and uses major categories of variables including project type, trade, process, materials, task and environment to characterize exposure (Susi, Goldberg, Barnes, et al., 2000). It was developed based on the task-based exposure assessment model (T-BEAM), which emphasizes task as a key predictor of exposure in the construction industry (Susi & Schneider, 1995). Following a similar approach, other scholars developed exposure databases for additional hazards in the construction industry. For example, Flanagan, Seixas, Becker, et al. (2006), created a database for silica using multiple data sources including CPWR, regulatory agencies, universities and the private sector. Scarselli, Corfiati and Di Marzio (2016) analyzed hexavalent chromium data from the Italian Information System on Occupational Exposure to Carcinogens (SIREP), a database populated by employer exposure data reported to the Italian national workers' compensation authority. Beaudry, et al. (2013), developed a database of silica exposures, which was the first to provide broad public access. However, none of these databases are equipped with a mechanism to enable users to search or filter data for a given working condition. This may limit their utility for contractors or practitioners who want to characterize specific work environments for the purpose of selecting the most effective respirator or engineering control. This issue has been addressed in recent years by incorporating features into the databases that enable users to sort and filter measurements by task, tool and other relevant determinants of exposure. Unfortunately, these systems are only available to policyholders or members (Construction Employers Association, 2016; Ng & Davies, 2016).

Although all of the aforementioned databases have limitations to use and availability, they have laid the foundation for building a more comprehensive system.

> These factors highlight the need for a more comprehensive, intuitive and publicly available system to estimate the probable exposure levels to common health hazards so practitioners can select and use the most effective measures to protect workers.

ALEMASCHE72/ISTOCK/GETTY IMAGES PLUS

Methods

Industry Advisory Group

An industry advisory group was convened to review the structure, design and functionality of the ECD at various development stages and provide feedback through an iterative process. This advisory group, known as the Engineering Controls Workgroup, comprises 25 subject-matter experts in industrial hygiene, safety and engineering. It was originally established in 1993 by NIOSH and CPWR to identify, implement and evaluate engineering controls in construction.

Exposure Predictors

In existing occupational exposure databases, measurements are most useful when accompanied by a set of predictors of exposure (Beaudry, et al., 2013; Swuste & Hale, 1994). To determine the most relevant predictors for the hazards in the ECD, three steps were taken: 1) a literature review; 2) a balloting process; and 3) an iterative review process by the advisory group. A literature review was performed for each hazard, which identified a preliminary list of predictors. Advisory group members ranked the importance of these predictors through a balloting process. Three face-to-face meetings and two conference calls were held with the panel to finalize predictors for each hazard:

- silica: task, tool/equipment, material, control method, environment and project type;
- welding fumes: type of hot work, consumable (if applicable), base metal, control method and environment;

FIGURE 1

ECD SEARCH PROCESS

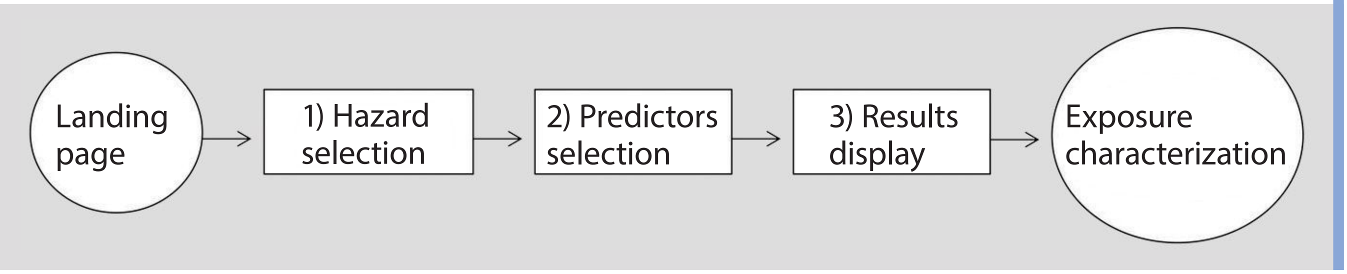
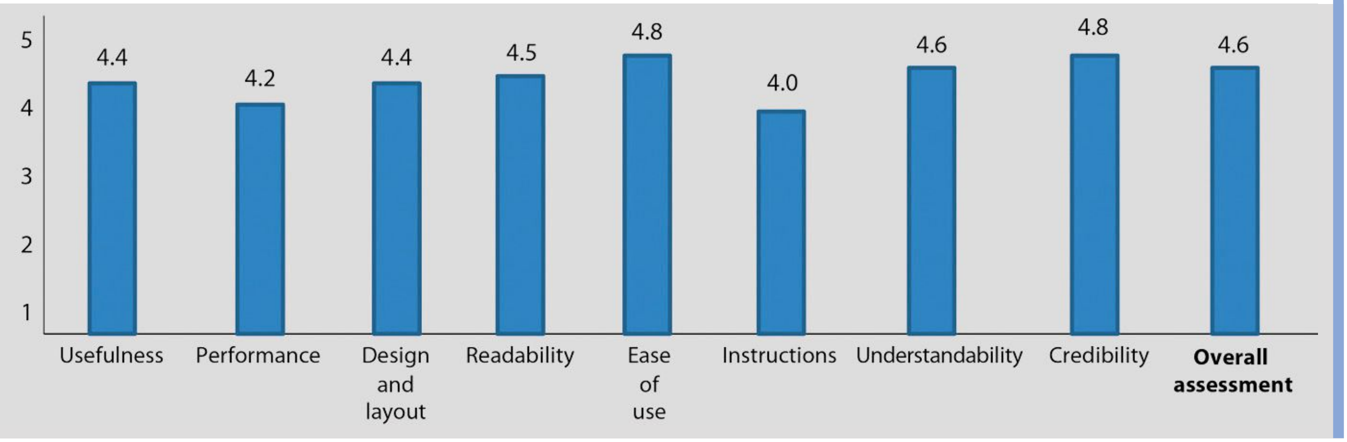


FIGURE 2

USABILITY TESTING RESULTS



- noise: tool, manufacturer, model, material and task duration;
- lead: task, tool, environment, project type and control method.

Finalizing the list of predictors for silica also involved consideration of OSHA's Table 1, a compliance option in the new silica standard in construction (OSHA, 2019). Predictors for noise were also informed by NIOSH's Buy Quiet initiative, which encourages contractors to focus on hearing loss prevention by investing in quieter tool models (Beamer, McCleery & Hayden, 2016).

Data Properties & Sources

To provide a closer representation of real-world working conditions, all exposure measurements entered into the ECD were collected on active jobsites, except for noise. Due to the specificity of noise variables (e.g., manufacturer, model) and data availability, all noise measurements were taken in a lab setting. No industrial hygiene sampling was conducted by the authors, and all measurements included in the ECD were pulled from peer-reviewed literature, government reports or received directly from partners in industry. Data sources were considered if they were published in 1990 or later to avoid describing historical exposures (Beaudry, et al., 2013).

To be considered for inclusion in the ECD, all predictors listed above had to be specified for each measurement. Additionally, samples had to be collected and analyzed according to validated NIOSH or OSHA methods, taken in the personal breathing zone, and recorded as time-weighted averages (TWA) for time sampled. No assumptions were made about exposure during un-sampled periods to calculate an 8-hour TWA. Measurements were entirely task-based and were excluded if more than one tool, control method or other variable was used during the sampling period (Susi & Schneider, 1995; Susi, et al., 2000). Measurements explicitly described as "worst case" were also excluded. Worst-case measurements are defined as measurements taken under special conditions where exposure is expected to be much higher than usual (Greim, 2002).

When measurements were small enough to fall below the analytical limit of detection (LOD), a procedure described by Hornung and Reed (1990) was used to impute a numeric value. This procedure defines the imputed value as the product of LOD/2, or LOD/$\sqrt{2}$, depending on the geometric standard deviation and percentage of measurements below the LOD. When measurements fell below the limit of quantitation, the same procedure was used.

Database Design & Structure

The goal of this project was to develop an intuitive system so that users with varying levels of computer literacy and technical expertise could use and understand the results. After the advisory group performed multiple iterations and reviews, a three-step, linear process was designed that allows the user to select the hazard of interest and predictors, then view results (Figure 1).

After choosing a hazard, the user can select each predictor in a drop-down menu. Menus are dynamic rather than prepopulated, pulling entries directly from the database in real time. This ensures that only predictors associated with available data are selected. The user is then navigated to the results page, which displays the requested data alongside metrics identified as most meaningful to practitioners. For silica, welding fumes and lead measurements, these metrics include 1) geometric mean; 2) existing occupational exposure limits (OELs); 3) range (minimum to maximum); and 4) number and distribution of measurements for each working condition. Geometric mean was selected over arithmetic mean because it is robust to outliers and represents the middle-most value in sets of occupational exposure measurements, which tend to follow a lognormal distribution (Flynn, 2004; Jin, Hein, Dedden, et al., 2011; U.S. EPA, 1994). Because geometric mean alone does not illustrate the range of data, the ability to view the data distribution and possible outliers lend additional confidence in the results. Research suggests that summary statistics of occupational exposure measurements are not meaningful unless there are a minimum of six data points (Hawkins, Norwood & Rock, 1991; Patty, 1981). Thus, when a search yields five measurements or fewer, the measurements are displayed individually and geometric mean is not presented.

Construction contractors in the U.S. have a legal obligation to keep exposures below the OSHA permissible exposure limit (PEL) and enact certain protections when exposures reach the OSHA action level (AL) or PEL. For that reason, these two OELs are displayed as the most relevant reference points, and the estimated exposure is plotted against these values. However, PELs and ALs are not available for every hazard, and they are not always comparable to a TWA. For example, there is no OSHA PEL for welding fumes total particulate, and the PEL for manganese is only available as a ceiling limit. Thus, in similar conditions, the American Conference of Governmental Industrial Hygienists threshold limit value, the NIOSH recommended exposure limit and the California OSHA PEL were substituted. The "ECD Use Case Example" sidebar demonstrates how the ECD can be used in a practical application.

Development Process

The structure, functionalities and initial design of the ECD interface were reviewed by the advisory group through three iterations, and necessary refinements were made accordingly. Once the final design was approved, the functional specifications and requirements of the database were drafted and the programming phase was initiated.

Usability Testing & Public Release

Before the public release of the database, usability testing was conducted to evaluate and refine its design and functionality from the perspective of potential users. Two scenario-based questionnaires were developed to enable participants to examine the database on four major categories:

- functionality: usefulness and system performance;
- user interface: page design and layout, readability, and ease of use;
- content: instruction, understandability and credibility;
- overall assessment: whether the database is recommended for use in the construction industry.

Participants were recruited through industry partners and five representatives from construction contractors volunteered to perform the test. The questionnaires were sent to participants, who were instructed to read through the testing scenarios, use the database to solve the problem, then score each factor using a 1 to 5 Likert scale and provide their feedback. Figure 2 illustrates the mean score of each testing factor, even though the goal of this usability testing was to obtain feedback and not to draw any statistical inferences. After implementing recommended improvements into the system, the ECD (**http://ecd.cpwrconstructionsolutions.org**) was officially released to the public on Aug. 30, 2018.

Discussion & Conclusion

The ECD was developed in response to the demand in the construction industry for a system to estimate the probable exposure levels to health hazards so practitioners can select and implement the most effective controls to protect workers. Unlike other existing databases that are typically for a single hazard, the ECD addresses four major hazards on a single platform. More importantly, this intuitive, interactive system is available to the public free of charge. This should be of significant benefit to small- and mid-sized contractors with limited resources to employ full-time safety and health personnel.

The ECD currently contains a total of 1,013 measurements: 550 for silica, 182 for welding fumes, 203 for noise and 78 for lead. Since its public release, users from a wide variety of organizations such as contractors, universities, nonprofits, labor unions and government agencies have accessed the ECD, and an average of 148 users have visited the website each month. Of the 3,241 inquiries run by users to date, approximately 68% are related to silica. This usage pattern, to a large extent, can be attributed to the concurrent release of the ECD and OSHA's updated silica standard for construction, which offers contractors an additional option to comply by using objective data to assess worker exposure. However, note that the ECD was not developed for compliance purposes.

Populating the ECD with a large number of high-quality measurements is an ongoing process that is critical to enhancing its predictive power. However, identifying reliable sources of data has been one of the major challenges throughout the development process. The investigators have been heavily reliant on published sources including peer-reviewed articles and government reports, which limits the

ECD USE CASE EXAMPLE

To renovate the columns of a concrete bridge, a contractor plans to perform wet abrasive blasting with silica sand to remove a deteriorated coating. To ensure that wet blasting is sufficient to prevent exposure to hazardous levels of silica, the contractor uses the ECD to estimate the probable exposure level. Selecting the ECD's silica tab from the home page, the user then selects the following entries for each predictor from the drop-down menus:

Task: abrasive blasting with silica sand
Tool/equipment: abrasive blasting equipment
Material: concrete
Control method: wet method
Environment: outdoor
Project type: renovation

The database has 16 measurements matching this condition, which yields an estimated exposure of 161 µg/m³. This is about three times the current PEL of 50 µg/m³ and requires implementing additional protective measures.

size of the database. In addition, out of 351 total published sources examined at this stage, only 22% contained usable measurements that met the defined criteria for inclusion in the database. This was largely due to 1) the practice of reporting summary statistics instead of individual measurements; 2) lack of sufficient information on one or more required predictors; or 3) multiple tasks, tools or control methods used during the sampling period.

Lack of consistency in air sampling procedures and reporting is another major issue that limits the usability of existing measurements. To standardize data reporting practices and streamline the data sharing process, two forms were initially developed for silica and noise, and made available to the public through the ECD. A small number of industry partners have used these forms and shared data with the authors. However, only 45% of the measurements provided by partners met all of the requirements for inclusion in the ECD. This emphasizes the need for a greater number of construction industry stakeholders to contribute data in a standardized format to continuously improve the process. This will help the construction industry more effectively reduce worker exposure to these debilitating and deadly health hazards. **PSJ**

References

American Federation of Labor and Congress of Industrial Organizations (AFL-CIO). (2019). Death on the job: The toll of neglect, a national and state-by-state profile of worker safety and health in the U.S. Retrieved from https://aflcio.org/sites/default/files/2019-05/DOTJ2019Fnb_1.pdf

Beamer, B., McCleery, T. & Hayden, C. (2015). Buy Quiet initiative in the USA. *Acoustics Australia, 44*(1), 51-54.

Beaudry, C., Lavoué, J., Sauvé, J., et al. (2013). Occupational exposure to silica in construction workers: A literature-based exposure database. *Journal of Occupational and Environmental Hygiene, 10*(2), 71-77.

Burstyn, I., Kromhout, H., Cruise, P., et al. (2000). Designing an international industrial hygiene database of exposures among workers in the asphalt industry. *Annals of Occupational Hygiene, 44*(1), 57-66.

CDC. (2015). National health interview survey. Retrieved from www.cdc.gov/nchs/nhis/index.htm

Construction Employers Association. (2016). Silica sampling and objective data program. Retrieved from www.ceacisp.org/safety/silica-sampling-objective-data-program

CPWR—The Center for Construction Research and Training. (2018). *The construction chart book*. Retrieved from www.cpwr.com/sites/default/files/publications/The_6th_Edition_Construction_eChart_Book.pdf

Flanagan, M., Seixas, N., Becker, P., et al. (2006). Silica exposure on construction sites: Results of an exposure monitoring data compilation project. *Journal of Occupational and Environmental Hygiene, 3*(3), 144-152.

Flynn, M. (2004). The 4-parameter lognormal (SB) model of human exposure. *Annals of Work Exposures and Health, 48*(7), 617-622.

Greim, H. (2002). The MAK-Collection for occupational health and safety. Weinheim, Germany: Wiley-VCH Verlag GmbH & Co. KGaA.

Hawkins, N., Norwood, S. & Rock, J. (Eds.). (1991). *A strategy for occupational exposure assessments*. Akron, OH: American Industrial Hygiene Association.

Hornung, R. & Reed, L. (1990). Estimation of average concentration in the presence of nondetectable values. *Applied Occupational and Environmental Hygiene, 5*(1), 46-51.

Hutchings, S. & Rushton, L. (2012). Occupational cancer in Britain: Industry sector results. *British Journal of Cancer, 107*(1), S92-S103.

Jin, Y., Hein, M., Deddens, J., et al. (2011). Analysis of lognormally distributed exposure data with repeated measures and values below the limit of detection using SAS. *Annals of Work Exposures and Health, 55*(1), 97-112.

Lehnert, M., Hoffmeyer, F., Gawrych, K., et al. (2015). Effects of exposure to welding fume on lung function: Results from the German WELDOX study. *Advances in Experimental Medicine and Biology, 834,* 1-13.

National Center for O*NET Development. (2015). O*NET Online. Retrieved from www.onetonline.org

Ng, M.G. & Davies, H. (2016). P126: A task-based silica exposure modelling tool for construction companies. *Occupational and Environmental Medicine, 73,* A161-A162.

National Occupational Research Agenda (NORA) Construction Sector Council. (2018). National occupational research agenda for construction. Retrieved from www.cdc.gov/nora/councils/const/pdfs/National_Occupational_Research_Agenda_for_Construction_June_2018_508.pdf

OSHA. (2019). Occupational exposure to respirable crystalline silica (29 CFR 1926.1153). Retrieved from www.osha.gov/laws-regs/regulations/standardnumber/1926/1926.1153.

Patty, F. (1981). *Patty's Industrial Hygiene and Toxicology, 3rd Edition*. New York, NY: John Wiley & Sons.

Scarselli, A., Corfiati, M. & Di Marzio, D. (2016). Occupational exposure in the removal and disposal of asbestos-containing materials in Italy. *International Archives of Occupational and Environmental Health, 89*(5), 857-865.

Susi, P., Goldberg, M., Barnes, P., et al. (2000). The use of a task-based exposure assessment model (T-BEAM) for assessment of metal fume exposures during welding and thermal cutting. *Applied Occupational and Environmental Hygiene, 15*(1), 26-38.

Susi, P. & Schneider, S. (1995). Database needs for a task-based exposure assessment model for construction. *Applied Occupational and Environmental Hygiene, 10*(4), 394-399.

Swuste, P. & Hale, A. (1994). Databases on measures to prevent occupational exposure to toxic substances. *Applied Occupational and Environmental Hygiene, 9*(1), 57-61.

U.S. Environmental Protection Agency (EPA). (1994). Guidelines for statistical analysis of occupational exposure data. Retrieved from www.epa.gov/sites/production/files/2015-09/documents/stat_guide_occ.pdf

Van Dyke, M., LaMontagne, A., Martyny, J., et al. (2001). Development of an exposure database and surveillance system for use by practicing OSH professionals. *Applied Occupational and Environmental Hygiene, 16*(2), 135-143.

Babak Memarian, Ph.D., is director of exposure control technologies Research at CPWR—The Center for Construction Research and Training and the cochair of the NIOSH/CPWR Engineering Controls Workgroup. He holds a Ph.D. in Construction Management from Arizona State University and an M.S. in Civil Engineering with a concentration in Construction Engineering and Project Management from Oklahoma State University. His research interest involves high-reliability construction work systems with a focus on safety, productivity and error management.

Sara B. Brooks, M.P.H., is an industrial hygienist at CPWR. She holds an M.P.H. with a concentration in Public Health with a concentration in Environmental and Occupational Health from University of Pittsburgh and a B.A. in Spanish from Carnegie Mellon University. She is also certified in environmental health risk assessment.

Chris Trahan Cain, CIH, is executive director of CPWR. She leads the organization's construction research, training, service programs and staff in finding synergies among departments to capitalize on programs funded by different federal grants. Cain has been working in construction safety and health for more than 20 years and holds a B.S. in Industrial Hygiene from Clarkson University.

Acknowledgments

This study was funded by NIOSH grant U60OH009762. The authors thank the members of the Engineering Controls Workgroup for their constructive feedback, Ohio Bureau of Workers' Compensation for sharing silica exposure measurements, and the anonymous construction practitioners who participated in usability testing and provided feedback to improve the ECD.