Review of Construction Employer Case Studies of Safety and Health Equipment Interventions

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Abstract: This paper presents a review of 153 case studies of equipment interventions to improve safety and health of construction businesses in Ohio in 2003–2016. These represent $6.46 million (2016 USD) in purchases incentivized through the Ohio Bureau of Workers' Compensation (OHBWC) Safety Intervention Grant (SIG) program. The source data in the review were extracted from employer grant applications and final reports of the case studies. Results were aggregated by type of construction equipment and included the reduction in safety and ergonomic hazards (risk factors for work-related musculoskeletal disorders), and an assessment of the quality of the case studies as determined through criteria established by the authors. Equipment associated with greatest reduction in risk factors and with case studies of higher quality were electrical cable feeding/pulling systems, concrete sawing equipment, skid steer attachments for concrete breaking, and manlifts (boom lifts). This review illustrates challenges in demonstrating efficacy of equipment interventions to improve construction safety/health—even from case studies within a structured health/safety program. The authors are aware of no other systematic review of case studies reporting on experiences with health/safety intervention equipment specific to the construction industry. **DOI:** 10.1061/(ASCE)CO.1943-7862.0001782.

Introduction

Construction work is hazardous, and this is reflected in workplace injury and illness statistics for the industry. In 2015, the rate of nonfatal injuries requiring days away from work in the construction sector was 134.8 per 10,000 full-time equivalents, which was 44% higher than the average rate of 93.9 for all industries (CPWR 2018). Although rates of fatal injuries in the US construction industry have been generally declining, the construction sector still accounted for 20% of all fatal workplace injuries in 2015 (CPWR 2018), although the sector consisted of only 4.5% of US workers.

Occupational safety and health (OSH) and insurer risk-control programs have recognized the need to address sources of workplace hazards to improve safety and health outcomes. Overexertion in lifting, being struck by an object, and falls to lower level are the leading causes of nonfatal injury costs (Liberty Mutual Research Institute 2018). Accordingly, OSH agencies and insurers have interest in identifying effective prevention approaches to address these leading causes of workplace injury/illness and to promote their adoption. In 2015, workers' compensation (WC) insurance covered 135 million US workers and covered $7.19 trillion in US wages, with private and state fund insurers paying $61.9 billion in benefits (McLaren et al. 2018). The Ohio Bureau of Workers' Compensation (OHBWC) Safety Intervention Grant (SIG) program is one of few insurer-sponsored programs that is administratively structured to incentivize employer acquisition of workplace equipment interventions to address safety and health hazards and that collects information about employer experiences with the equipment (Miller et al. 2017).

The OHBWC SIG program is an equipment-based grant program in which eligible Ohio employers who are awarded a grant receive matching funds as a multiple of 2:1, 3:1, or 4:1 (varying over the program years) for the purchase of equipment anticipated to positively affect safety/health. For the purposes of this paper, an employer is a construction contractor/business owner whose workers' compensation insurance is obtained from OHBWC, who is the awardee of the grant funds (through the SIG program), and who is responsible for implementing the purchased equipment on the worksite to improve safety of employees. A requirement of SIG program participation is that the successful applicant employer submit a 1-year final report (case study) describing the experience with the intervention. The SIG program provides an opportunity to assess employer safety and health experiences with equipment interventions through individually documented cases studies OHBWC (2019a). The OHBWC SIG case studies are a large information source that were believed to have potential to inform existing databases of effective intervention equipment in construction.

Outcomes related to health/safety among employer participants in the OHBWC SIG program have been explored to assess impacts in healthcare facilities and nursing homes (Fujishiro et al. 2005; Park et al. 2009) and, more recently, on workers' compensation claim costs across all industries (Wurzelbacher et al. 2014). Fujishiro et al. (2005) showed that equipment purchases through the Ohio BWC

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Note. This manuscript was submitted on April 8, 2019; approved on August 12, 2019; published online on January 20, 2020. Discussion period open until June 20, 2020; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Construction Engineering and Management***, © ASCE, ISSN 0733-9364.

program to specifically reduce employee exposure to bending, lifting, and carrying (e.g., adjustable beds, patient lifts, and transfer chairs) were associated with decreased musculoskeletal disorder injury rates (OSHA logs) throughout a 2-year follow-up period across 86 participating healthcare facilities. Park et al. (2009) showed reductions in back-injury claim costs attributable to multiple intervention components that included consulting hours received, training hours received, and ergonomics equipment purchases across 1,028 employers with nursing home payrolls over a 10-year period.

Wurzelbacher et al. (2014) analyzed the OHBWC accepted claims experience among 468 Ohio employers receiving grants across all industries through the SIG program in 2003–2009. SIG program participation was demonstrated to reduce injury claim rates and costs in most industries. Construction was one industry not associated with a reduced claims rate through SIG participation. Their analysis examined only the injury claims experience and was a study of the effect of program participation. The SIG case-study reports contain information beyond the WC claims experience.

Construction industry experiences with health/safety interventions were also of interest because the investigators have backgrounds and expertise in the assessment and communication of construction industry solutions to reduce workplace injuries, in particular musculoskeletal injury. An example of this is an industry-targeted publication to describe lower-cost solutions to a number of construction tasks such as work with masonry, drywall, sheet metal, and fastening tools, among others (Albers and Estill 2007). The investigators also have established partnerships in the construction sector to assist with translation of intervention research findings.

Evidence-based medicine holds the randomized controlled trial (RCT) as the gold standard for demonstrating efficacy, yet high-quality RCT study designs of workplace-equipment interventions are rare, with the exception of those in office environments, such as computer workstations, furniture, or input devices (Driessen et al. 2010; van Erd et al. 2016). High-quality study designs for evaluating intervention effectiveness are difficult to conduct on any workplace equipment, and there are few examples of RCTs or similar high-quality study designs for health/safety equipment interventions in the construction industry. RCT studies such as those by van der Molen et al. (2005) and Peters et al. (2018) have examined program interventions in construction workplaces in the form of participatory ergonomics and worksite health promotion.

Study designs considered weaker in evidence quality include case series (Howick et al. 2011), in which a group is followed prospectively over time before and after an intervention but where no comparative (untreated) group is referenced. An individual case study is considered weaker evidence than an experimental design study, but case studies are more feasible to conduct. Targoutzidis et al. (2014) reviewed 91 existing case studies of health/safety interventions, only one of which was in the construction industry. These authors then presented 13 new case studies, of which six were in the construction industry. These included a variety of interventions, including program/administrative practices (exercises, sessions with physiotherapists, and rest break reminders) as well as engineering control/equipment interventions (hoists and lifts for handling materials). Payback periods reported for the construction intervention case studies ranged from less than 1 year to a maximum of 3.2 years.

Goggins et al. (2008) reported one of the largest reviews of workplace intervention case studies, identifying 250 ergonomic interventions through a variety of sources and searches, including general World Wide Web searches. Case studies included in the Goggins et al. (2008) study spanned multiple diverse industries and lacked a standardized format for reporting. A number of measures were reported to represent cost-benefit effectiveness, as percentage changes due to the intervention, and at a broad level of equipment/industry aggregation that emphasized office and healthcare interventions.

The purpose of the present study was to systematically evaluate the results of OHBWC SIG experiences (case studies) involving construction equipment purchases. This paper will operationalize a case study as the documentation of the grant awardee's original application and the 1- and/or 2-year final report describing the intervention equipment experience. The evaluation assessed each case study against criteria believed to be important to demonstrating that the equipment was effective. Results were aggregated by type of construction equipment to identify which types of equipment awarded through the program were associated with case studies with more compelling evidence of equipment effectiveness. An advantage of the present review of case studies is that the size of the OHBWC SIG program allows for a review focus on a single industry, in this case construction, and inclusion of a large number of case studies. Additionally, case studies and source data are drawn from a common program, with standardized reporting requirements and generally consistent risk-assessment metrics. The analysis assessed the quality of evaluative aspects of employers' self-reported experience with the equipment including how the intervention equipment demonstrated reductions in risk factors, employee and management acceptance/adoption of the intervention, and impact of the intervention equipment on productivity. The authors are not aware of existing systematic reviews of employer case studies reporting on experiences with health/safety intervention equipment, aggregated by equipment type, in the construction industry.

Methods

Source Documentation

As part of the SIG program, OHBWC consultants work with employers to identify potential interventions, assist with submission of applications for program funds, and, following successful award for a proposal, verify that the intervention is implemented and reduces risk factors. OHBWC grant funds are awarded based on how strongly the employer's application conveys the following: severity of the problem to be addressed, potential impact of the intervention in eliminating hazards, anticipated positive effects on productivity, expected cost effectiveness, and how well the program needs will be served.

Employer-submitted grant applications and associated final reporting documentation (case studies) for SIGs awarded between 2003 and 2016 were compiled in March 2017. Case-study documentation was organized and keyed by an anonymous application ID number that served as the linkage between the original application, final reporting documentation, and background information about the grant award and awardee (employer category size, warrant amount for grant funding match, and occupational classification code). NCCI (2017) four-digit code describing the nature of the business operations and occupations for collective actuarial risk and rate administration of the affected work group was used to crosswalk to an established construction industry trade/specialty. This was defined by the employer in their grant application.

At the time the source documentation was compiled, there had been 368 SIG awards for the purchase of intervention equipment by employers classified as construction subindustries. However, over a third of those grants were awarded in 2015 and 2016 alone, and many of those did not yet have final reports submitted by employers. The present review included 224 construction SIG awards for which reporting materials had been received from the grant recipient employer. Of these, 52 grant awards with the following characteristics were excluded because they were not deemed to involve equipment used on a construction worksite:

- Shop-based equipment/machinery purchased for use in fabrication of installations.
- Equipment purchased for lifting vehicles and heavy equipment for the purpose of maintenance.
- Equipment purchased for the purpose of appliance delivery (including HVAC systems).
- Equipment purchased for certain landscaping work that was not considered construction.
- Sewer jetting system equipment. These processes were not considered to be construction-related.

Further, 19 of the 224 SIGs were excluded because of significantly incomplete reporting with full sections missing. In total, the final review included 153 SIG experiences.

Data Extraction

A data extraction form was developed and subjected to review by three subject-matter experts with background in OSH intervention evaluation, specifically in the construction industry. The three subject matter experts were recognized leaders in the area of construction safety and ergonomics. Two were university faculty (Professor level) in occupational health programs, both with over 25 years of experience in addressing OSH issues in the construction sector. The third was an individual with expertise in communications of best practices and solutions for construction industry processes. Reviewers commented on the proposed assessment criteria and revisions to the data extraction instrument were made. The criteria (Fig. 1) include whether the employer experienced a WC claim injury among the affected employee group during the baseline period and the plausibility of the intervention equipment affecting risk factors relevant to those injuries.

Other criteria included the use of a systematic approach to assessment of risk-factor reduction (between preintervention and postintervention periods), indication that employees received training with the equipment, indicators of employee acceptance of the intervention, and effects of the equipment on productivity and work quality. Reduction in risk factors was given the greatest emphasis (Fig. 1), which is consistent with the approach by which grant award determinations are made by OHBWC. Criteria for quantifying existing risk factors are given three times the weight as quantifying actual loss (WC claims) experience in the grant award process, and the anticipated impact on risk-factor mitigation is given twice the weight as anticipated impact on productivity/quality. A single analyst reviewed grant applications, final reports, and any supporting materials to extract data items according to the defined criteria.

The risk-factor reduction score was calculated for case studies that reported baseline (preintervention) and follow-up (1-year postintervention) assessments consistently. This was based on instruments for assessing work-related musculoskeletal disorders (WMSD) risk factors, safety hazards, or in one case, industrial hygiene exposures. In all but the earliest years, the WMSD risk factors were evaluated using a structured semiquantitative assessment of upper-extremity, back, and lower-extremity risk factors based on the 1995 OSHA Draft tool (Schneider 1995). It includes assessment of awkward postures, repetitive motion of the hand wrist, contact stress, vibration exposure, and manual materials handling. These assessments were generally conducted by OHBWC consultants as part of their service provision to these employers. Information on these instruments is available from OHBWC (2019b).

The SIG program reporting requirement include an employer self-reported cost-benefit analysis (CBA) using a standardized worksheet. CBA items were extracted from submitted CBA worksheet to describe the following costs and cost savings: intervention purchase cost, training costs, maintenance and other costs, claims costs—2 year baseline period claims costs—1 year follow-up period, less production time costs (savings), less rework costs (savings), less absenteeism costs (savings), and other cost savings.

Injury Claims Reduction Experience (20%)

- (10%) Was there one, or more, injury claims indicated for the baseline period? (Q1)
  No = 0; Yes = 10
- (10%) Was there one, or more, baseline claims that would be *plausibly prevented had the intervention equipment been in place?* (Q2)
  No = 0; Yes = 10

Risk Factor Abatement Experience (40%)

- Are *WMSD, Safety, or IH Risk Factor*s compared in a consistent manner (baseline <u>and</u> follow-up comparable) addressing exposure(s) affected by the intervention? (Q3)
  none = 0; qualitative description ONLY (in narrative) = 15; OHBWC instruments* (or other quantitative method) = 40

Acceptance/Adoption Experience (15%)

- Does the report contain any description of employees' acceptance/non-acceptance of the intervention? (Q4)
  No = 0; Yes = 15

Work Productivity Experience (15%)

- (10%) Are effects on productivity described? (Q5)
  none = 0; qualitatively ONLY = 5; quantitatively = 10
- (5%) Is an ROI calculation result reported (Cost Benefit Analysis form, or in report narrative)? (Q6)
  No = 0; Yes = 5

Work Quality Experience (5%)

- Are effects on work quality described? (Q7)
  none = 0; qualitatively ONLY = 3; quantitatively = 5

Training (5%)

- Was there evidence of training conducted? (Q8)
  no description of actual training conducted and no training costs incurred = 0 ; actual training described in narrative ONLY = 3; CBA form or report lists training costs incurred = 5

Fig. 1. Determination of case-study quality score from extracted items. A total of 100 points was possible.

J. Constr. Eng. Manage., 2020, 146(4): 04020012

Data Analysis

Primary outcomes were risk-factor reduction (WMSD and safety risk factors) and a case-study evaluative quality score, with the individual SIG (case studies) as the unit of analysis. Case studies were grouped according to whether they involved single equipment ($n = 105$) or multiequipment ($n = 48$). In single-equipment case studies, grant funds were used to purchase a single piece of equipment or an integrated system consisting of a primary piece of equipment and related attachments used in a singular task. Multiequipment SIGs were those in which the employer purchased multiple pieces of equipment that were not used as an integrated system in a single construction task. Even if complete information had been submitted for each of the multiple pieces of equipment, the ability to attribute outcomes to a specific piece of equipment would have been confounded by potential cointervention effect. In only 6 of the 48 multiequipment case studies did the risk assessments differentiate risk-factor reduction by tasks. In the single-equipment SIGs, a more clear association can be made between the single intervention equipment and changes in any outcome. Multiequipment grants were a combination of equipment types (categories) related to different tasks for a given trade. For example, walk-behind (powered) roof-cutting systems were typically purchased in combination with walk-behind (powered) hauling systems.

Subtraction of the follow-up score from the baseline score using these instruments yielded the change score (positive reduction in risk factors). Change scores in assessments of WMSD risk factors and safety hazards were calculated as postintervention minus preintervention scores. These scores were z-transformed such that percentiles allow comparisons between the two different scales (WMSD risk-factor instrument and safety assessment instrument). To report on equipment type in aggregate, the mean percentile for the equipment classification was calculated. The case-study quality scores for the SIG experiences were simply rank ordered, with ties being assigned the average of ranks. To report on equipment type in aggregate, the median score was calculated. Emphasis was on identifying types of intervention equipment associated with higher-quality case studies and larger reductions in risk factors.

Equipment purchase costs from the grant budget and financial documentation were adjusted to 2016 dollars using the *Producer Price Index for Other Heavy Machinery Rental and Leasing: Construction Equipment Rental and Leasing* (Federal Reserve Bank of St. Louis 2018). All other costs were inflation adjusted using the Consumer Price Index specific to Ohio. Intervention equipment cost per affected employee was based on the number of employees who perform the work with the equipment being implemented. This affected employee count was a determination made by the employer in the grant application.

Results

Classification of Equipment Purchases

The 153 case studies reviewed encompassed $6.5 million (in 2016 dollars) in construction equipment purchases supported through the SIG program (Table 1). Seventy percent of that total ($4.57 million) were single or integrated equipment purchases, and the remaining 30% were multiple equipment purchases. Forty-three percent of the $6.5 million was spent on equipment for work at heights or the handling of materials at heights (i.e., categories of: scissor lift, mast lift, manlift/boom lift, scaffolding, and nonman lift hoists, described subsequently). This equipment represented 45 of the 105 single-equipment grants, and another 13 multiequipment grants (of 48) included one of these types of equipment. The most common construction trades represented, based on North American Industry Classification (NAICS) were roofing ($n = 24$), power and communication line and related structures (24), masonry (16), framing (13), all other specialty trade contractors (13), and heating, ventilation, air conditioning, and refrigeration systems (8).

The investigators established groupings of equipment type based on equipment function and, in some cases, grouping on identical equipment make/model. This included all equipment purchased with grant program funds in the 153 grants included in the review. After grouping by equipment type, 13 broad types of construction equipment were identified: scissor lifts, articulating and telescoping boom lifts, scaffolding/work platforms, skid steer attachments, walk/ride-behind powered equipment, powered hand tools, lift gates/trailers/restraints, bulk material transfer/dispensing, conduit bending, concrete sawing, cable feeding/pulling systems, fall protection systems, and vacuum and/or hydroexcavation systems. An additional group to account for other equipment reflects 11% of equipment purchase costs in both the single-equipment and multiple-equipment SIGs. More specific subclassification of the skid steer attachments and walk/ride-behind powered equipment resulted in 24 types of equipment (Table 1) in addition to an Other category. The Other category is populated by equipment that did not fit within the 13 broader categories and that was more specialized equipment and dissimilar to other equipment purchases.

As described previously, multiequipment SIGs were not evaluated according to equipment classification to report on outcomes. In some multiequipment intervention grants, there were as many as 18 distinct types of equipment among those purchased with grant funds. Thus, the row totals by equipment type count for multiequipment SIGs in Table 1 do not sum to the multiequipment SIG count of 48.

Equipment Effect on Hazards and Risk Factors

The effect of the intervention on WMSD risk factors was characterized, quantitatively or qualitatively, in 115 (75.2%) SIGs. Qualitative descriptions of WMSD risk factors indicated improvement (reduction in risk factors) in all cases. In 66% of the 115 case studies, preintervention and postintervention WMSD risk-factor assessment scores were reported; in 69.6% of cases studies, it was through qualitative description in the narrative. In 41% of case studies, this was reported using both the WMSD risk-factor assessment scores and by qualitative description. WMSD risk-factor assessment scores showed one case with equal preintervention/postintervention scores, and all others with reduction in risk-factor score. The intervention effect on safety was characterized in 86 (56.2%) SIGs. In 39.5% of case studies, this was through preintervention and postintervention safety assessment instrument scores; in 81.4% through qualitative description in the narrative, and in 20.9% through both safety assessment scores and qualitative description.

Case Studies: Quality of Evaluation

There were 17 case studies with a quality score exceeding 70 and that were above the 50th percentile for risk-factor reduction (Fig. 2) (complete descriptions are also contained in the Appendix). Three of those 17 case studies were grants with purchases of cable feeding/pulling equipment. Cable feed/pulling systems tended to be associated with stronger-quality case studies and with large reduction in WMSD risk factors. This equipment appears to be worthy of recommendation as an equipment intervention in applicable electrical trades. Table 1 aggregates case studies for single-equipment SIGs by equipment type, sorted by median case-study quality score. Other equipment types ranking highly include concrete sawing equipment, skid steer attachments for concrete breaking, and manlifts.

Table 1. Summary of case studies by equipment classification category ranked by median of case-study quality scores

	Single equipment						Multi equipment	
Equipment classification	Sum equipment cost (2016 USD)	Number of single-equipment case studies	Mean equipment cost per employee[a] (2016 USD)	Median case-study quality score	Mean percentile WMSD risk reduction	Mean percentile safety risk reduction	Sum equipment cost (2016 USD)	Number of multiequipment SIGs associated
Skid steer attachment—other	100,067	1	5,559	85	28.3	—	47,851	3
Skid steer attachment—augering	90,408	2	3,749	83	34.2	—	31,132	1
Cable feed/pulling systems	174,780	5	800	83	71	—	55,698	3
Concrete sawing (not hand tools)	258,521	5	3,068	78	54.8	34.1	24,686	3
Skid steer attachment—rotary grinding	12,647	1	1,405	75	40.4	—	0	0
Powered hand tools	136,170	4	1,138	70.5	27.1	83.1	760,179	26
Vacuum and or hydro excavation	135,403	2	5,043	65.5	46.9	75.3	0	0
Skid steer attachment—concrete breaking	82,057	4	998	65	62.3	83.1	22,548	2
Trailers	67,457	2	5,092	65	84	—	65,544	4
Manlift (boom lift)	995,977	14	5,766	63	59.5	60.9	32,460	1
Conduit bending	29,860	1	459	60	14.2	—	70,685	5
Liftgates	38,763	4	222	59	24.1	—	3,151	1
Bulk material transfer/dispensing (tar and adhesive applications)	139,337	4	2,651	58	31.3	21.9	23,415	2
Other	511,337	13	2,468	58	45.1	11.4	218,362	20
Scissor lift/mast lift	700,945	16	2,648	57	58.7	26.4	169,971	4
Trailer restraints	8,225	1	191	55	—	—	0	0
Scaffolding/platform	632,305	12	2,945	49	37.5	58.9	69,005	4
Fall protection systems (carts, etc.)	58,308	4	489	49	—	64	104,280	7
Walk/ride behind (powered)—trenching	6,736	1	192	48	89.3	32.8	0	0
Walk/ride behind (powered)—screeding	186,316	3	3,047	48	79.7	—	0	0
Cranes/hoists (other than manlifts)	162,802	3	6,103	45	18.3	—	51,620	4
Skid steer attachment—asphalt cold planer, tiller, brooms, etc.	32,225	2	1,710	44	63.1	—	0	0
Walk/ride behind (powered)—cutting/removal of roof material	7,657	1	219	30	—	—	136,355	10
Walk/ride behind (powered)—hauling	—	0	0	—	—	—	76,853	7
Walk/ride behind (powered)—other	—	0	0	—	—	—	17,161	3
Total	4,568,303	105		—			1,886,943	48[b]

[a]Mean cost per employee is the mean equipment cost per SIG divided by the affected employee count documented in the SIG application.
[b]The column total shown does not reflect the sum of rows because a given ME SIG had a variable number of equipment classifications associated.

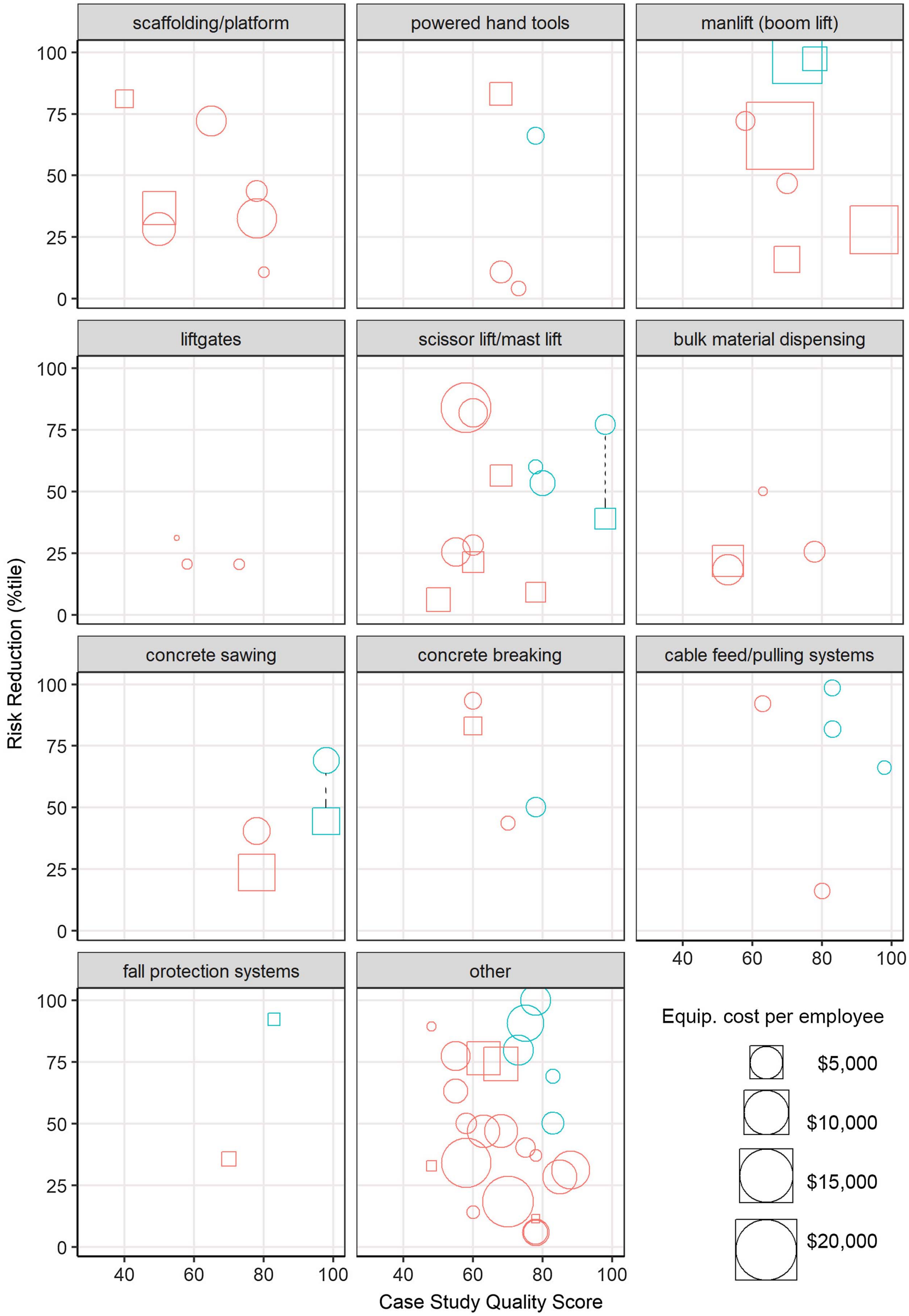

Fig. 2. Risk reductions and quality of case studies aggregated by equipment type. Risk reduction percentile based on z-score for the reduction in safety hazards (squares) and WMSD risk factors (circles). Point sizes are scaled to the initial equipment purchase cost per affected employee. The cases studies that rank highly in risk reduction and quality score are described in the Appendix.

Other Cost-Benefit Considerations

Table 1 also lists average cost per affected employee for single equipment SIGs by equipment type. This measure does not indicate the number of units of the equipment purchased within the grant. For example, the equipment category skid steer attachment–rotary grinding shows one case study with equipment costs of $12,647. This employer purchased two attachment units, and the number of affected employees identified by the employer was nine, resulting in a cost of $1,405 per employee.

CBA information self-reported by employers could be assessed for 101 SIG case studies. Those excluded were 31 grants awarded

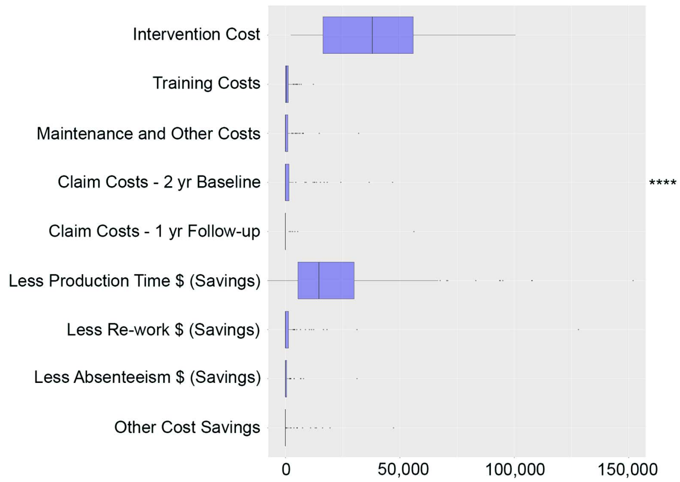

Fig. 3. Boxplot summarizing costs and cost savings as documented by employers in $n = 101$ case studies with complete CBA forms. Four SIG case studies reported high cost claims in the baseline period totaling $2,537,469. These cannot be shown with linear axis scaling.

prior to 2009, which preceded the requirement to submit standardized CBA information, and another 21 deemed incomplete due to lacking a valid payback period calculation per the worksheet formulas. Cost valuation inputs extracted from CBA worksheets are summarized in Fig. 3. Only 29 (28.7%) of the CBA forms reported nonzero costs for WC claims in the 2-year baseline period preceding the intervention. The average of these claim costs per case study was highly skewed by four individual employer CBA reports, each of which had 2-year baseline claim costs exceeding $240,000. These four case studies accounted for over 90% of the total baseline period claim costs ($2.53 million of $2.79 million, in 2016 USD) for all 101 CBA worksheet cost valuations. Two individual claims in the baseline periods, an electrocution fatality and a permanently disabling ladder fall, accounted for 72% of the total. The 2-year baseline period average total claims costs per SIG of $27,646 was extremely skewed by those two claims. With those two claims removed, the average was $7,878.

As an exploratory analysis, total claim costs paid to date in the OHBWC claims database for the 76 injury claims documented in the 2-year baseline periods were compared with the employer-documented total in the CBA forms. The sum of the actual most recent claim costs paid (Wurzelbacher et al. 2013), calculated from the centralized OHBWC claims database for those 76 claims, was $3.37 million, which is 21% higher than the $2.79 million reported by employers. The final true cost for these claims will be even higher because 73 of the 76 had reserves for future anticipated payments. This means that the employers' cost-benefit reporting in case-study reports underestimated the true monetary costs of these injuries to the WC system.

Employer estimates of productivity cost savings averaged $24,462 (2016 USD) per case study, and productivity savings was documented as positive (nonzero) in 96% of case studies. Average cost savings (per case study) due to less rework was $2,931 and that due to reduced absenteeism was $859.

Discussion

This study has several limitations that affect interpretation of the findings. A key limitation is that the requirements of the SIG program experienced some changes and were not consistent over the 2003–2016 time period studied. Related to the reporting of injury claims, prior to July 2009 grants, were only awarded to address hazards for which an employer had experienced at least one compensable injury claim in the defined affected employee group. After 2009, as the program was significantly expanded, eligibility requirements changed so that grants could be awarded to address identified risk factors more proactively, even in the absence of injury outcomes. A second program change was that prior to 2007, the application required employers to document all injury claims occurring in the affected employee group, regardless of injury mechanism and causation. In the review of applications from that time period, some injury claim descriptions in baseline periods were noted for which the subsequent equipment intervention did not seem to have a plausible mechanism of prevention. These changes in requirements for the preintervention claims experience influenced the investigators' decision to place greater emphasis on the risk-factor reduction experience and less on the injury claim experience.

The completeness of quantitative risk-factor assessment information was also affected by changes in program requirements. Prior to 2007 only 1 of the 14 SIG case studies in the review had a complete quantitative (comparable preintervention/postintervention) WMSD risk-factor assessment, and none had a complete safety assessment. The absence of the quantitative risk-factor assessments in the earlier program years is another limitation. However, because of the expansion of the SIG program in 2009, the early program years account for less than 10% of all construction case studies in the review.

Cost-benefit analysis reporting was given less emphasis in the quality evaluation framework; however, incompleteness of information affects interpretation of the evaluative quality of the case studies. The CBA worksheet was not a program requirement prior to 2009, which explains the absence of this information from earlier grants but does not fully account for the missing/incomplete CBA in one-third of the case studies in the review. Additionally, there were some case studies with discrepancies between report narrative and monetary valuation in the CBA form. Some final reports described productivity increases in the text narrative while not assigning any monetary value to this in the CBA worksheet. Some case studies described injury claims in the application and did not account for these claim costs in the final report CBA reporting. Three case studies presented hypothetical scenarios of claim cost avoidance (what claim cost reductions could have been) when the application documented no actual claim costs in the baseline period.

The standardized CBA worksheet allowed the inputs to employer cost-benefit calculations to be summarized across case studies. This represents a large (>100) sample of case studies reported with a consistent framework. In the present review, the case-study reports had higher percentages reporting production time savings, absenteeism savings, and savings due to rework (scrap/errors) than the Goggins et al. (2008) review as a result of these being specific entries in the standardized OHBWC worksheet. However, injury claim costs and resulting cost savings were reported in a lower percentage of the present investigation's case studies than by Goggins et al. (2008). Goggins et al. (2008) reported a number of cost-benefit effectiveness measures as percentage changes due to the intervention at a broad level of industry/occupation aggregation (grouping by office interventions and healthcare interventions). Due to incompleteness and concerns about consistency of reporting cost valuations in the present review, the decision was made not to aggregate cost-benefit calculations within the industry studied (construction) by specific type of equipment.

A simple measure of intervention, equipment purchase cost per affected employee, may be useful to consider in combination with reduction in risk factors and evaluative quality of the case studies. The cable pulling/feeding equipment interventions were associated with low equipment cost per affected employee ($800). Concrete sawing equipment was also associated with high-quality case studies and above-average WMSD risk reduction, but the equipment cost per affected employee was nearly four times that of cable pulling/feeding systems. Manlifts (boom lifts) were associated with, on average, nine times the cost per affected employee. A caveat with this measure is that defining the affected employee group is not as straightforward as simply the operator or direct user of the equipment. With equipment such as powered hand tools, the beneficial effect is likely limited to the individual users/operators of the equipment. However, equipment interventions that fundamentally alter a construction process, such as the adoption of a single-operator walk-behind machine for trenching versus the need for multiple employees hand digging, may reduce ergonomic and WMSD risk factors for numerous employees in addition to the single operator of the equipment. Equipment intervention cost per affected employee was highly related (inversely) to employer size because larger employers tended to report having more employees in the affected employee group. Relatedly, employers often documented affected employee hours as the affected employee group's collective work hours, which does not necessarily equate to collective employee time exposed to the specific tasks and hazards that were mitigated by the intervention.

The approach to classification of equipment within only single-equipment case studies limits conclusions that can be drawn about some types of equipment. The powered hand tools equipment category was particularly affected in this way. Powered hand tools were commonly purchased in multiequipment case studies, with 84.8% of the total monetary expenditures on powered hand tools in the multiequipment case studies. Powered hand tools were purchased in only four single-equipment grants, but were acquired in 25 of 47 multiequipment grants, representing 41% of the equipment purchase costs in those SIGs. This category was diverse in terms of the variety of specific tools purchased (including roofing insulation attachment tools, angle grinders, reciprocating saws, screw-guns, hammer drills, and hand saws, among others) and SIGs involving powered hand tools almost always included other new equipment. Therefore, the nature of the typical SIG purchases of powered hand tools does not facilitate direct conclusions about the efficacy of specific powered hand tools relative to the original work methods and equipment those employers used.

Employers purchasing multiple equipment interventions did not report sufficiently to discern the contribution of individual equipment to the mitigation of identified risk factors. This created a co-intervention effect which confounds the interpretation of efficacy of individual equipment. For example, in one multiequipment grant, the employer acquired a mounted chipping hammer for concrete breaking and an electric powered walk-behind wheel barrow for hauling. These equipment items are used in different tasks, and the assessment of risk factors were reported for the analysis of a broad singular task of breaking up existing structures of concrete using pneumatic tools with compressors. An assessment of overall grant participation effectiveness (Wurzelbacher et al. 2014) would not be concerned with cointervention from multiple types of new equipment. However, the cointervention effect is a threat to conclusions drawn about specific equipment effectiveness.

Employers, with assistance from OHBWC program consultants, were asked in the grant application to describe anticipated new risks the intervention equipment might introduce. This was not specifically followed up in the final reporting with a question about actual experiences of new risks. Although few of the final report narratives described new risks introduced by the equipment, eight case-study reports specifically stated that no new hazards had been introduced. With many of these types of equipment, it is conceivable that new risks were introduced (e.g., battery-powered hand tools and heavier motorized equipment that might be more difficult to lift, carry, or maneuver) and a transference of risk is likely underreported. For example, one case-study report described a serious accident during the transport of newly acquired hydromobile scaffolding. It is suggested that employers critically appraise how new hazards might be introduced by new equipment with characteristics that differ from the current equipment or process. Final reporting might encourage the description of any new risks, anticipated or otherwise, that were encountered and how these risks were managed.

Potential reporting biases toward positive outcomes and selection biases due to nonrandom assignment of the interventions to employers must also be considered (Goggins et al. 2008). Excluding recipients of SIGs in the 2015 and 2016 award cycles, some of whom were still in the reporting period at the time of this review, 10.3% (24 of 234) of grant recipients did not submit any final reporting materials and 19 others submitted incomplete documentation. It is possible that a positive reporting bias might be introduced if those unreported experiences were less likely to reflect success with the equipment. It was not possible to fully characterize equipment types for the nonreporting grantees due to the missing documentation.

Future work is suggested to improve the understanding of construction employers' and business owners' abilities to prepare case-study reports that are useful for evaluative research on health/safety interventions. Completeness and consistency of employer documentation in case-study reports are crucial to interpreting how the equipment implementation affected risk-factor/hazard mitigation, work quality, productivity, and employee acceptance. Future work should also consider the feasibility and additional value of applying other risk-factor assessment methods, both semiquantitative (e.g., musculoskeletal risk surveys) and quantitative (e.g., wearable biomechanical sensors). Musculoskeletal symptom surveys of employees completed before and during the case-study period could provide additional data beneficial to demonstrating reductions in risk factors and improvements in health/safety.

Conclusion

This review evaluated the case-study experiences of construction-industry employers who implemented construction equipment through a dedicated safety intervention grant program. Case studies reporting on the health/safety experience with similar equipment provide more compelling evidence of effectiveness when summarized in aggregate compared to individual case studies. From this aggregate review of case studies, it was concluded that electrical cable pulling equipment, skid steer attachments for concrete breaking (hydraulic breakers), concrete sawing equipment, man lifts (boom lifts), and trailers with hydraulic tilting/ramps were associated with higher reductions in risk factors and higher-quality case studies. This review also highlights challenges in demonstrating safety and health efficacy of construction equipment interventions, even from case-study experiences within a program established specifically to improve health/safety outcomes.

Appendix: Case Studies With High Quality Scores and High Risk Factor Reduction Scores

Individual case studies with quality score exceeding 70 and risk-factor reduction scores above the 50th percentile tile are ranked by sum of quality score plus risk-factor reduction. Q1–Q8 refer to corresponding items in Fig. 1.

Equipment	Description of case study (equipment costs not inflation adjusted in the description)	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Quality score	Risk-factor reduction	Rank	Cost/ employee[a]
Cable feed/pulling systems	$34,046 received to purchase two cable feeders, four cable pullers, eight reel jacks, and four remote footswitches to potentially reduce the risk of injury to the wrist, neck, shoulders, hands, legs, and back related to repetition, hand force, awkward postures, contact stress, kneeling, and squatting. This intervention will improve the process of running/pulling wire.	10	10	40	15	5	0	3	0	83	97.4	1	$845
Scissor lift/mast lift	$26,888 received to purchase two scissor lifts to potentially reduce the risk of injury to the wrist, neck, shoulders, hands, legs, and back related to awkward posture, kneeling, twisting, bending, repetitive motion, contact stress, and fall from heights. This purpose of the intervention is to reduce the use of ladders while providing maintenance and repairs.	10	10	40	15	10	5	3	5	98	80.3	2	$1,513
Other (flex lancing system)	$40,000 received to purchase a flex lancing tool to potentially reduce the risk of injury to back, shoulders, and arms due to bending, pushing, pulling, and blowback associated with the use of high-pressure water. The purpose of the intervention is to reduce the manual handling of material and will remove the operator from the manual control of the flex lance hose.	0	0	40	15	10	5	3	5	78	98.7	3	$4,123
Fall protection systems (carts, for example)	$12,327 received to purchase a mobile fall protection device to reduce or eliminate the risk of injury related to falls from heights.	10	10	40	0	10	5	3	5	83	89.1	4	$345
Manlift	$40,000 received to purchase a boom lift with jib to reduce the risk of injury or strain to the upper and lower extremities related to repetitive motion, awkward postures, and fall from heights. This intervention will improve the roof, gutter and metal panel installation and steel erection processes.	0	0	40	15	10	5	3	5	78	93.8	5	$2,170
Manlift	$40,000 received to purchase an articulating boom lift to potentially reduce the risk of injury related to awkward postures, twisting, bending, repetitive motion, contact stress, and fall from heights. The purpose of the intervention is to reduce the need to use ladders while performing necessary maintenance and repairs.	0	0	40	15	10	5	3	0	73	96.9	6	$12,354
Concrete sawing (not hand tools)	$40,000 received to purchase a wall saw package to potentially reduce the risk of injury to the wrist, neck, shoulders, hands, legs, and back related to awkward posture, kneeling, twisting, bending, repetitive motion, lifting, contact stress, heavy load, and hand force.	10	10	40	15	10	5	3	5	98	71.7	7	$2,979
Cable feed/pulling systems	$18,693 received to purchase one cable puller, nine reel jacks, and one cable feeder to potentially reduce the risk of injury to back, shoulders, hands, fingers, and lower extremities due to repetitive bending, twisting, pulling, and awkward positions. The purpose of the intervention is to reduce the amount of heavy lifting and manual cable pulling that is required, thus increasing productivity and worker safety.	10	10	40	0	10	5	3	5	83	84.9	8	$907

Appendix: (*Continued.*)

Equipment	Description of case study (equipment costs not inflation adjusted in the description)	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Quality score	Risk-factor reduction	Rank	Cost/ employee[a]
cable feed/pulling systems	$34,200 received to purchase an electrical conductor reel set up to potentially reduce the risk of injury to the finger, shoulders, elbows, and lower extremities related to repetitive motion, hand force, heavy load, and awkward postures. This intervention was used to improve the hazards employees are repeatedly exposed to; heavy lifting and pulling for extended amounts of time while performing tasks.	10	10	40	15	10	5	3	5	98	69.1	9	$529
Trailers	$34,728 received for the purchase of a low-rise trailer and a sliding tilt trailer to reduce or eliminate the risk of injury when laying pipe and loading a backhoe.	10	10	40	0	10	0	5	0	75	90.8	10	$6,353
Walk/ride behind (powered)—screeding	$40,000 received to purchase a laser screed machine to reduce or eliminate the risk of injury associated with screeding and dragging concrete.	10	10	40	0	10	0	3	0	73	82.9	11	$4,045
Other (drywall cutting system)	$40,000 received to purchase two drywall cutting machines w/self-cleaning vacuum to reduce or eliminate the risk of injury related to work performed with awkward postures, repetitive motion, cuts/ lacerations, and exposure to dust.	10	10	40	0	10	5	5	3	83	71.7	12	$585
Powered hand tools	$2,887 received to purchase a rebar bender and cutter to reduce the risk of injury to fingers, wrist, elbows, shoulder, neck, arms, back, and legs due to hand force repetitive/static, awkward postures, contact stress, vibration, and push/pull heavy load. This intervention will improve the rebar installation into concrete process.	0	0	40	15	10	5	3	5	78	69.1	13	$978
Scissor lift/mast lift	$12,771 received to purchase one scissor lift to reduce the risk of injury related to awkward postures, twisting, slips, trips, bending, and fall from heights. The purpose of the intervention is to reduce the positioning, moving, and climbing of ladders while providing necessary maintenance and repairs.	0	0	40	15	10	5	3	5	78	64.5	14	$597
Scissor lift/mast lift	$33,781 received to purchase one scissor lift to potentially reduce the risk of injury to the wrist, neck, shoulders, hands, legs, and back related to awkward posture, kneeling, twisting, bending, repetitive motion, contact stress, and fall from heights. This purpose of the intervention is to reduce the use of ladders while providing maintenance and repairs.	10	10	40	15	0	5	0	0	80	61.8	15	$2,641
Other (wall forming system)	$40,000 received to purchase brick wall panel forms to reduce or eliminate risk factors that are associated with repetitive motion, awkward postures, manual material handling, and gripping of more than 4.5-kg (10-lb) loads.	10	10	40	0	10	5	3	5	83	57.9	16	$1,985
Skid steer attachment—concrete breaking	$5,663 received to purchase a mounted concrete and asphalt breaker to potentially reduce the risk of injury and strain to the back, neck, elbow, and shoulders related to heavy load, contact stress, and manual material handling. This intervention will improve the pavement demolition process.	0	0	40	15	10	5	3	5	78	57.9	17	$1,404

[a]Inflation adjusted to 2016 USD.

Data Availability Statement

Data generated or analyzed during the study are available from the corresponding author by request. Information about the *Journal*'s data-sharing policy can be found here: http://ascelibrary.org/doi/10.1061/(ASCE)CO.1943-7862.0001263.

Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention. Mention of any company or product does not constitute endorsement by the National Institute for Occupational Safety and Health (NIOSH) or the Ohio Bureau of Workers' Compensation. This project was supported in part by an appointment to the Research Participation Program at the Centers for Disease Control and Prevention administered by the Oak Ridge Institute for Science and Education through an interagency agreement between the US Department of Energy and the Centers for Disease Control and Prevention.

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