

Final Report: Machine Guarding: Translation into practice

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Table of contents

List of terms and abbreviations	page iii
Abstract	page 1
Section 1	page 2
Section 2	page 4
Background for the project	page 4
Specific aims	page 5
Methodology	page 6
Results	page 15
Discussion	page 32
Conclusions	page 35
Publications	page 37
Inclusion enrollment report	page 38
Materials available for other investigators	page 39
References cited	page 41

List of terms and abbreviations

Analysis of variance (ANOVA)

Collision Autobody Repair Safety Study (CARSS)

Computer numerically controlled (CNC)

Electrical discharge machinery (EDM)

Full-time equivalents (FTEs)

Full-time equivalent per year (FTE-yr)

Institutional review board (IRB)

Job hazard analysis (JHA)

Lockout/tagout (LOTO)

Machine Guarding Application (MGA)

Machine Guarding Data (MGD)

Maine Employers' Mutual Insurance Company (MEMIC)

Minnesota Machine Guarding Study (MN-MGS)

Musculoskeletal disorders (MSDs)

National Machine Guarding Program (NMGP)

North American Industry Classification System (NAICS)

Occupational health and safety (OHS)

Occupational Safety and Health Administration (OSHA)

Park Nicollet Institute (PNI)

Part of body (POB)

Quality assurance (QA)

Reach, Effectiveness - Adoption, Implementation, Maintenance (RE-AIM)

Research-to-practice (R2P)

Slips/trips/falls (STFs)

Standard deviation (SD)

Washington Employers (WA-EMP)

Workers' compensation (WC)

Abstract

Background:

Metal fabrication workers experience high rates of traumatic occupational injuries. Machine operators in particular face high risks, often stemming from an absence or improper use of machine safeguarding or the failure to implement lockout/tagout (LOTO) procedures. Small manufacturing businesses often lack access to occupational safety and health (OSH) expertise. Development of effective OSH interventions widely applicable to smaller firms remains a persistent challenge. The National Machine Guarding Program was a research initiative to address these issues among small (3 - 150 employees) metal fabrication businesses. This study assesses the impact of a nation-wide intervention to improve machine safety and LOTO in small metal fabrication businesses.

Methods:

The National Machine Guarding Program (NMGP) was a translational research initiative implemented in partnership with two workers' compensation (WC) insurers. Insurers enrolled metal fabrication businesses in an intervention designed to comprehensively improve machine safety. Technical checklists were developed for assessment of safeguarding equipment for 26 different types of metal fabrication machinery. An additional checklist was used to assess business-wide safety management practices such as safety committee activities, lockout/tagout (control of hazardous energy), and job hazard analyses (JHAs). Insurance safety consultants were trained to collect data on-site and deliver the intervention. Each participating business received four on-site visits from insurance safety consultants trained in study protocols: a baseline safety evaluation; intervention delivery visits at 3 months and 6 months; and a follow-up safety evaluation at 12 months. After the one-year on-site intervention was completed, the research team developed and tested an additional checklist that businesses could use to independently self-audit their LOTO practices.

Results:

Among the 160 businesses that completed the intervention, the mean safety management audit score improved from 43% to 59% ($p < 0.0001$) and the mean machine safeguarding score increased from 73% to 79% ($p < 0.0001$). Businesses that added a joint management-labor safety committee during the intervention made the greatest improvements (44% to 68% for safety management, $p < 0.0001$; 74% to 84% for machine safeguarding, $p < 0.0001$), with particularly strong performance in lockout/tagout (increase from a mean of 54% to 87%; $p < 0.0001$). Developed based on those improvements in LOTO, the LOTO self-audit checklist was tested at ten businesses and found to have excellent inter-rater reliability and accuracy.

Conclusions:

The National Machine Guarding Program represents a new translational research model for widespread outreach to small industrial firms. Insurance safety consultants were highly effective at data collection and intervention delivery. Establishment of a joint management-labor safety committee was an important factor in improving safety programs even in the smallest businesses (3 - 10 employees), demonstrating the central role of joint worker-management cooperation. Insurance safety consultants proved effective at disseminating a machine safety and LOTO intervention via management-employee safety committees. Future research should further evaluate tools such as the LOTO self-audit checklist, as a reliable self-audit instrument removes the need for external auditors to visit worksites, thereby expanding capacity for outreach and intervention while minimizing costs of on-site audits.

Section 1

Significant or Key Findings

Baseline inspection of machine-related hazards in 221 businesses demonstrated a need for improvement in many aspects of machine safety and lockout/tagout (LOTO) in small metal fabrication businesses. Safeguards were frequently absent or inadequate for hazardous areas of machines such as the point of operation and other moving parts. Older machines were both widely used and less likely than newer machines to be properly guarded. Elements of critical machine safety programs such as LOTO were also found lacking.

At baseline, critical safety management programs were frequently absent. A safety committee appears to be a more important factor than business size in accounting for differences in outcome measures. NMGP data show that a safety committee is correlated with better safety management program scores even in the smallest shops.

The NMGP intervention was completed by 160 businesses. Adding a safety committee was associated with a 10-percentage point increase in business-level machine scores ($p < 0.0001$) and a 33-percentage point increase in LOTO program scores ($p < 0.0001$).

Insurance safety consultants proved effective at disseminating a machine safety and LOTO intervention via management-employee safety committees. Businesses with a safety committee had the highest baseline and follow-up summary scores. Business that added a safety committee improved summary scores substantially more than those that started and ended without one. Regardless of size, adding a safety committee was likely to result in substantially more improvement than not doing so.

The NMGP highlights the need for a nationwide effort to improve many aspects of machine safety within small industrial firms. Sustainable improvements would substantially reduce risk for serious workplace trauma and work-related fatalities. The NMGP provides a framework for comprehensively auditing and improving risk management practices and demonstrates the central role of worker participation and representation.

Translation of Findings

The National Machine Guarding Program was a research-to-practice (R2P) intervention targeted to small metal fabrication businesses. To our knowledge this is the first R2P intervention implemented nationwide in U.S. manufacturing industry. Machine safety audit methods developed in the MN-MGS were modified into an intervention program that was widely distributed by two community partners. This included audit checklists, software, and program templates that could be used to establish and maintain safety management efforts. Results demonstrate that the NMGP represents an important step in translating the findings of a controlled trial carried out in a small region to a widely applicable intervention program that can be integrated into the routine work of intermediary organizations and small businesses.

As a translation research initiative, the NMGP provides a new model for outreach to small businesses. The NMGP intervention prioritized establishment of a safety leadership structure as a basis for implementing sustainable, cost-effective programs in LOTO and machine safety. Business safety assessments and intervention delivery were conducted on-site at each business, and pre-post analysis indicates this was an effective means of improving safety management. The success in improving LOTO demonstrates the potential for insurance safety consultants to effectively work with small businesses to improve worker health and safety. Insurance risk consultants were able to provide simple technical guidance to businesses to help improve safety practices. Businesses were also provided guidance on how to establish and run a safety committee.

NMGP data indicate the need for a nationwide effort to improve the management and performance of LOTO within small industrial firms. Toward this objective, a LOTO self-audit checklist was developed for businesses to use independent of outside assistance. Field-testing

of the LOTO self-audit at ten manufacturing firms demonstrated high inter-rater reliability, indicating that it would be useful in employers' efforts to regularly assess and improve their LOTO programs. Business self-auditors attained a high level of accuracy in identifying items that were not compliant with the OSHA LOTO standard. By removing the need for costly on-site visits from external auditors, this audit instrument can help overcome barriers of geography and cost in assessing LOTO practices at large numbers of manufacturing businesses.

Research Outcomes/Impact

Potential outcomes: Establishment of a safety committee is an important first step for metal fabrication businesses in improving safety management programs. Maintaining compliant programs in areas such as lockout/tagout (LOTO) and conducting regular inspections of machine guarding in order to identify and correct hazards are likely to reduce risk for serious injuries in these workplaces. Machine guarding checklists and other materials developed, tested, and used in the NMGP would help businesses improve machine safety.

The results of this study are likely to be applicable to a broad range of businesses such as plastic molding, food processing, woodworking, and other industries where large machinery is used. OSHA citations, serious traumatic injuries, and fatalities related to LOTO within these industries are common place and indicative of a widespread problem.

To our knowledge, the current pilot study is the first to evaluate inter-rater reliability of a self-audit instrument targeted specifically to hazards and safety programs in manufacturing workplaces. Results indicate that the LOTO self-audit checklist would be useful in manufacturing firms' efforts to assess and improve their LOTO programs. In addition, a reliable self-audit instrument removes the need for external auditors to visit worksites, thereby expanding capacity for outreach and intervention while minimizing costs.

Intermediate outcomes: Findings from the NMGP were used to develop and test software to assess LOTO. Software and business self-audit were tested in 10 establishments. The high level of success provided data that support self-audit as a viable means of intervention. Using these data, four intermediary organizations were recruited to jointly develop a new grant proposal and initiative specifically focused on LOTO in manufacturing. The prospective project would be conducted with two state safety councils, a university manufacturing extension program, and a workers' compensation insurer. The objective is to implement findings from the NMGP in assisting businesses with establishing and maintaining LOTO programs and procedures, while using a computerized LOTO self-audit and intervention training modules in order to minimize the need for on-site visits by field staff.

Section 2

I. Background for the project

Approximately 2.5 million U.S. workers are employed in metal manufacturing [Census 2013], of whom 1.3 million are employed in fabricated metal product manufacturing businesses (North American Industry Classification System NAICS 332). In related industrial sectors, more than 900,000 are employed in machinery manufacturing (NAICS 333) and approximately 350,000 in primary metal manufacturing (NAICS 331) [Census 2013]. Metalworking machinery is also used in a wide range of industries for tool and die making as well as the fabrication and repair of parts.

In 2014, the rate of injuries involving lost workdays (125.1 per 10,000 workers) in metal fabrication was considerably higher than the overall rate for private manufacturing (97.8 per 10,000) as were the rates for amputations (2.7 vs 0.5 for private manufacturing overall), injuries to the eye (9.1 vs. 2.2), and hand (34.5 vs. 12.8) [BLS, 2016]. The large size of the workforce engaged in metal fabrication, in combination with the high rates of both injuries and OSHA citations for machine guarding and lockout/tagout (LOTO) [BLS 2016; OSHA 2015a], highlights the importance of hazards and the potential benefits of injury prevention programs. In addition, the majority of U.S. metal-manufacturing establishments have fewer than 50 employees [Census 2010] a size range that is often lacking occupational health and safety (OHS) expertise and comprehensive safety management programs. [NIOSH 1988; Champoux and Brun 2003; Eakin et al., 2010; Lentz et al., 2001; Leviton and Sheehy, 1996; Parker et al., 2012]

Metal-working machines such as power presses, press brakes, and lathes are frequently noted in U.S. Occupational Safety and Health Administration (OSHA) investigation reports of fatalities and catastrophic injuries [OSHA, 2015b]. A Michigan surveillance program reported that metal fabrication was the industrial sub-sector with the highest average annual number of amputations for the period 2006-2012, and the third highest average incidence rate behind wood products and paper manufacturing [Largo and Rosenman, 2015]. State-level surveillance in Minnesota found that lack of machine guards was a contributing factor in a high proportion (61%) of amputation cases during 1994-1995 [Boyle et al., 2000]. Although risk from specific types of machines has not been well characterized, surveillance data indicate that metal fabrication machinery such as power presses, shears, and powered saws are particularly hazardous, [Boyle et al., 2000; Stanbury et al., 2003; Largo and Rosenman, 2013a] with power presses alone accounting for as many as 12% of workplace amputations [Stanbury et al., 2003].

The Occupational Safety and Health Administration (OSHA) has several standards related to machine safety. These include requirements for machine guarding, [OSHA 2016a] lockout/tagout (LOTO), [OSHA 2014a] control of mechanical power transmission hazards, [OSHA 2016] and for specific machines such as power presses [OSHA 2016c] and abrasive wheels. [OSHA 2016d] The absence or incomplete use of machine guarding or failure to implement a LOTO program may result in serious traumatic injuries including amputations and fatalities. [Boyle et al., 2000; Largo and Rosenman, 2013; Bulzacchelli et al., 2008; OSHA 2015b]. LOTO consistently ranks as one of the most frequently cited OSHA standards in manufacturing (NAICS 31, 32, 33). [OSHA 2015a] In 2014, LOTO comprised 9% (2,040/22,789) of Federal OSHA citations for small-and medium-sized manufacturing businesses (1 to 249 employees). Of all LOTO citations, metal manufacturing subsectors NAICS 331, 332, and 333, accounted for 7%, 26%, and 8%, respectively.

Surveillance and case study data demonstrate that a failure to follow LOTO practices is an ongoing cause of occupational fatalities and serious traumatic injuries. A narrative text analysis of 592 OSHA fatality investigation reports from 1984 to 1997 involving the control of hazardous energy showed that in only 6% of cases was lockout known to have been attempted; 5% failed because of human error and 1% was attributed to mechanical failure. [Bulzacchelli

2006; 2008] No lockout attempt was made in 59% of cases and was probably not attempted in an additional 9%. The use of LOTO was indeterminate in 26% of cases. From 2003-2013, 16% of non-fatal, catastrophic injuries and 9% of fatalities in manufacturing (NAICS 31, 32, 33) recorded in the OSHA Fatality and Catastrophe Investigation Summaries database were lockout-related. [OSHA 2015b]

Several studies have shown that employees in small workplaces have an increased risk of injury and fatality when compared with workers in large establishments [Oleinick et al., 1995; Leviton and Sheehy, 1996; DOL, 2004; Mendeloff et al., 2006]. However, the nature and causes of increased risk are not well understood. Contributory factors are thought to include a lack of safety personnel, the failure of regulatory agencies to affect a sufficient number of enterprises, the absence of readily available and easy-to-use information, and employer and employee time constraints [MacEachen et al., 2010; Lentz, 2001; Okun et al., 2001; Leviton and Sheehy, 2006; Parker et al., 2012].

These problems are compounded by an absence of data on the structure of health and safety in small enterprises with the exception of limited information from focus groups and key informant interviews [Eakin, 1992; Hasle et al., 2011; Parker et al., 2012]. Data are lacking on the presence of safety committees, injury investigations, and worker training, all of which are thought to be important to worker safety and health. Data are also absent on how health and safety practices change as the business size increases from extremely small (e.g., < 10 employees) to small (11-49) to moderate-size (50-150) establishments.

The Minnesota Machine Guarding Study (MN-MGS) tested the effectiveness of an intervention conducted during 2002-2007 in 40 small (5-100 employees) metal fabrication firms in the Minneapolis-St. Paul metropolitan region. At baseline, machines frequently lacked point of operation and other critical safeguards. [Parker et al., 2009; Samant et al., 2006] Participants received on-site training and a report with detailed recommendations for improving machine guarding and related programs such as LOTO. One-year follow-up assessments found improvements of 7.5 percentage points (from 58.5% to 66.0% in the half of the businesses with lowest baseline scores) in machine guarding and 12.0 percentage points (52.3% to 64.3%) in safety programs. [Parker et al., 2009].

In the MN-MGS, enterprises with a safety committee had better safety practices compared to those without. Businesses that lacked a safety committee at the outset but added one during the intervention made greater improvements in machine safety practices than other shops. However, the study was constrained by a small sample size. [Munshi et al., 2005; Samant et al., 2007; Parker et al., 2009]

The National Machine Guarding Program (NMGP) was designed to help fill a gap in translational research by disseminating the MN-MGS to a broader set of businesses across the United States [Yamin et al., 2014]. This was done in partnership with two workers' compensation insurers. Data were collected as part of a national intervention, the objectives of which were to assist businesses with establishing a safety leadership structure as a basis for improving machine safety and related programs such as lockout/tagout (LOTO), and thereby reduce employee risk for injury.

II. Specific Aims

Specific aims of the study as stated in the original proposal:

Aim 1. *Revise and expand the Minnesota Machine Guarding Program for dissemination via a community partner.*

Aim 2. *Implement a randomized, controlled study to evaluate effectiveness of a machine guarding intervention with a community partner.*

Aim 3. *Measure the outcome of a randomized, controlled intervention on machine guarding by (a) evaluating a change in the incidence and cost of machine-related injuries; and (b) evaluating improvements in machine guarding and related safety programs.*

Aim 4. *Evaluate factors that will lead to a sustained adoption of this intervention by other sources (e.g., other insurance companies and business associations).*

III. Methodology

Methods used to accomplish each aim are summarized in this section. Additional detail is available in the peer-reviewed publications referenced herein.

Aim 1.

Evaluate insurer work practices: The National Machine Guarding Program (NMGP) intervention design team consisted of Dr. David Parker (PI), Lisa Brosseau (Co-investigator), Samuel Yamin (Research Program Manager), and Boyd Wissbroecker (Federated Insurance). A central activity of the intervention design team during years one and two was to evaluate in detail the practices of Federated safety consultants, with the objective of developing a standardized set of activities that could be executed by trained safety consultants during the course of this study. The baseline evaluation, intervention protocol, and other activities described below were all developed and refined through this process.

The Park Nicollet Institute (PNI; now merged into HealthPartners Institute) worked with three additional insurers -- Maine Employers' Mutual Insurance Company (MEMIC), Washington Employers (WA-EMP), and CNA -- to establish partnerships and determine how their safety consultants could carry out the data collection and intervention delivery components of this study. While Federated remained the key partner, the PI established additional partnerships in order to increase the reach of the intervention and the final number of businesses enrolled in the intervention.

The PI and Research Program Manager also trained safety consultants from WA-EMP and CNA and provided the full range of program and technical support to their safety consultants, however, both of those partners left the study, citing a lack of significant success in recruiting client shops for participation. Therefore, the remainder of intervention activities were conducted with Federated and MEMIC.

Form an advisory board: An advisory board of machine safety experts was formed to help the research team review the safety audit checklists from the Minnesota Machine Guarding Study (MN-MGS) and update those checklists for use in the current study. The research team consulted frequently with members of the advisory board, and convened three formal meetings of the entire advisory board in 2011. One of the meetings was held at a technical college with a large metal fabrication shop so the advisory board could discuss and refine the checklists while viewing machinery.

Revise intervention protocol: The intervention design team revised our prior protocols. This entailed multiple steps which are summarized as follows:

1. *Update machine safety checklists* – The intervention design team revised and re-organized the machine safety checklists used in the Minnesota Machine Guarding Study (MN-MGS). Many questions were added to allow evaluators to collect data at each machine workstation related to the presence or absence of guards and hazards as well as key safety program elements such as lockout/tagout (LOTO) and safe work practices (e.g., eyewear, safe attire, not bypassing safeguards).

Several new checklists were developed for machines not previously included in the MN-MGS, based on trade association recommendations and investigator observations. These included screw machines, computer numerically controlled (CNC) machines, turret punch press, electrical discharge machinery (EDM), and laser-cutting equipment.

Some checklists were consolidated (e.g., vertical and horizontal milling machines were combined into one checklist) to arrive at a set of 26 checklists distributed across the following classes of machinery:

- Milling, drilling, and boring machines
- Cutting, shearing, and sawing machines
- Presses
- Sanding and grinding machines
- CNC/screw machines
- Other metal-forming machines

The advisory panel of machine safety experts was convened to review all of the checklists in detail and reach consensus on content and format. An example checklist can be found as a figure within one of our publications. [Parker et al., 2015a].

Five items on LOTO procedures were added to all 26 machine checklists. With those plus the two items on lockable disconnects carried forward (in modified form) from the MN-MGS checklists, up to seven LOTO items were completed for each machine, if applicable.

2. *Update supporting documentation for machine safety audit* – Supporting documentation in the form of a guidebook was updated to provide standards interpretation and best practices information corresponding to all items addressed in the machine safety checklists.
3. *Update safety management checklist* – An audit of business-wide safety programs and policies was developed by revising an audit originally used in the MN-MGS, to complement data collected at the machine workstations. Many new questions were added on written programs and policies, injury and “near miss” investigations, and employee training. Several questions were removed from the checklist used in the MN-MGS because they were a) peripheral to machine safety, b) state-specific to MN, or, c) too subjective to ensure inter-rater reliability. Other items were moved to the machine safety checklists because they could be more suitably evaluated at the machine workstation. MN-specific items were removed because the intervention was delivered to businesses in 31 states.

The final safety management audit consisted of 33 questions addressing 4 areas:

- Safety leadership: 12 questions assessed the safety management structure, written safety programs, and workplace safety policies.
- Job hazard analysis (JHA): 8 questions determined the presence and completeness of a program for conducting JHAs and integration of findings from JHAs into regular work practices.
- Machine maintenance: 8 questions assessed the documentation of periodic inspection to assure machines were effectively guarded on an ongoing basis.
- Lockout/tagout (LOTO): 5 questions assessed key elements of a LOTO program and related employee training and record-keeping.

The full checklist can be found as a figure within [Parker et al., 2015b].

4. *Random machine selection* – The project statistician designed a method for randomly selecting machines for evaluation in each participating business. Numbered tags were placed on each machine, then the total number of machines was entered into a random

number generator on the evaluator's laptop computer. Machine tag numbers were randomized into clusters of three to minimize time spent walking around the shop floor. A sample of 12 machines was selected. Study protocol dictated that no more than 3 of any machine type could be included, in order to maintain a sample that contained a variety of machines. Pilot testing confirmed that this ensured a sample representative of safety conditions for both production and support machinery.

5. *Safety climate survey* – The safety climate survey from the PI's Collision Autobody Repair Safety Study (CARSS) was revised and tested, and used in the field. The survey was a 2-sided, machine-readable form. All shop personnel, including shop owners, completed the same survey form. Both the survey and the employee assent document were made available in English and Spanish.
6. *Software development* – A contractor worked with the intervention design team to create project-specific software called the Machine Guarding Application (MGA). This software was used for random machine selection, checklist data entry, generating a site-specific report for the baseline and follow-up evaluation of each participating business, tracking intervention activities, and transmitting data on all site visits. The MGA allowed for easy data entry on a laptop computer. Safety consultants evaluated machines using paper copies of the checklists, then entered the data using their laptops. We worked to ensure that the software was both user-friendly and thorough in terms of capturing all the data collected at baseline and follow-up. The software was extensively tested by PNI and Federated personnel. The contractor and Research Program Manager provided software support by phone and email to safety consultants in the field.
7. *Update reporting to businesses* – As noted, the MGA generated a site-specific report for each participating business. This report was concise yet informative, containing a summary of scores from the baseline evaluation. Output included a template to be used by the safety consultant for creating an action plan in cooperation with the shop owner or safety committee. For each participating business, results from the baseline evaluation were used to formulate a shop-specific action plan to work on intervention programs.

Machine guarding recommendations were provided to businesses as part of the shop-specific action plan. Because each machine safety checklist contained between 25 and 35 technical questions, machine audit results were organized by machine type and by the categories listed below, rather than as a list of point-by-point recommendations. If requested, shops were also provided with a copy of all checklists scored during the evaluation as a supplement to the audit report.

Machine safety audit results were organized into these topics:

- Equipment safeguards
 - Point of operation safeguards
 - Safeguards for other mechanical hazards
 - Power transmission guards
 - Workpiece control
 - Operational controls and emergency stops
 - Lockable disconnects
- LOTO procedures
- Electrical

- Work environment

8. *Intervention design* -- The intervention design team developed methods for helping businesses prevent machine-related injuries through: 1) establishing and maintaining safety programs; 2) implementing applicable standards and guidelines, and, 3) self-auditing to identify and control hazards.

The intervention was implemented in two on-site visits following the baseline evaluation. The intervention was framed as follows:

- I. Safety leadership program
- II. Machine maintenance program
- III. Machine-specific guarding equipment
- IV. Job hazard analysis (JHA) program
- V. Lockout/tagout (LOTO) program

The checklist data collection tools used at baseline were carefully refined to provide quantified output to guide a standardized process for selecting priorities from among these four topics to build a shop-specific action plan. Action plans were used by the shop owner and safety consultant to create a concise document outlining key intervention goals, target dates, and persons responsible.

Safety leadership was the foundation for implementing the other three intervention programs. The first priority in the safety leadership area was to ensure that a safety committee or safety leadership team comprised of both employees and management was established and that it had been assigned the responsibility and authority to carry out safety programs. From this starting point, the safety leadership team was to manage the implementation of the other three intervention programs. The safety consultant provided guidance and assistance to the safety leadership team as they worked to complete the action plans developed at baseline.

The intervention design team wrote program templates and examples that safety consultants provided to shops as tools to help them establish or enhance their own programs. Machine safety checklists were also provided to shops to use as a self-auditing tool.

Develop insurer training: Extensive insurer training was developed. Safety consultants completed a two-day training course before conducting safety evaluations or intervention delivery visits on-site. The training course was conducted at technical colleges and split between classroom instruction and time spent in the machine shop learning how to evaluate machine safeguards on metal-working machinery using the study checklists.

The updated machine safety checklists, supporting documentation, safety culture surveys and consent documents, and other materials were integrated into this training along with project-specific instruction on study protocols and intervention implementation. Other aspects of the training course included:

- a. *Protocols for selecting machines within each business* – Safety consultants were trained in the random machine selection scheme developed for this study.
- b. *Protocols for development of shop-specific recommendations and action plans* – Safety consultants were trained in a standardized method for guiding development of shop-specific action plans based on quantitative results of the baseline evaluation.
- c. *Intervention implementation practices* – Safety consultants were trained to assist businesses with skill-building in project-specific intervention areas.

Pilot testing: The Research Program Manager, consulting engineer, and software developer pre-tested the random machine selection scheme, checklists, and data collection software at three metal fabrication businesses in the Minneapolis-St. Paul metropolitan area. At each test site, a meeting was held with safety directors and plant managers to gather feedback on the methodology and on the usefulness of the report output. Federated safety consultants pilot-tested the entire baseline evaluation at four additional businesses. After the pilot, the intervention design team met with these safety consultants to discuss their experience and further refine study methods.

Aim 2.

Train safety consultants: Over 60 consultants from four insurers were trained in the use of software, machine evaluation, and intervention delivery. The training courses were held at technical colleges that have metal fabrication labs. This provided the opportunity to supplement classroom learning with hours spent in the lab inspecting various metal-working machines, and receiving technical training from instructors with expertise in machine safety evaluation. Use of a lab also allowed us to train the consultants in random selection of machines in a realistic shop environment.

Three groups of Federated safety consultants completed the training course. The first group was trained in January 2012; a second group in March 2012; and a third group in August 2012. Two of these training courses were conducted at Hennepin Technical College in Minnesota, and the third course was held at Anoka Technical College, also in Minnesota. Safety consultants in each training group represented different regions of the United States where Federated had significant numbers of client businesses. Safety consultants were trained in separate groups in order to maintain a maximum class size of 15, and to stagger the timing of the study launch in each region.

A group of 12 MEMIC consultants was trained in December 2012, at the University of Southern Maine. In March 2013, six consultants from Washington Employers were trained at Green River Community College in Washington. A final group consisting of 13 consultants from CNA was trained at Anoka Technical College in Minnesota in March 2013.

Recruitment and eligibility: Addition of MEMIC as a study partner allowed for expansion of the sample frame. MEMIC conducted field work in areas of the northeastern U.S. where Federated had little or no presence.

Due to a June 2012 restructuring of how Federated conducts its business nationwide, shops were no longer selected by state, rather businesses were selected by service region and how businesses are categorized by Federated. All businesses in the service region of a participating safety consultant were eligible for participation, if study criteria (listed below) were met. Safety consultants from MEMIC recruited businesses in a similar manner. To be eligible, a business had to meet all of the following criteria:

- The primary production activity was metal product manufacturing. The majority (> 90%) of the eligible pool fell within North American Industry Classification System (NAICS) sub-sector codes 332 (fabricated metal products manufacturing), 333 (machinery manufacturing), or 331 (primary metal manufacturing), but firms within other NAICS sub-sectors also met this criterion if their primary source of revenue (75% or more) was metal fabrication.
- The business had at least three but no more than 150 employees.
- For a business with multiple locations, only one location could participate.
- The business purchased workers' compensation insurance from one of the partner insurance companies.

Machine safety audit and on-site data collection:

At baseline and follow-up, consultants randomly selected a unique sample of 12 machines for a standardized assessment of machine safeguarding. Evaluation was performed at each of the selected machine workstations using technical checklists developed and tested in the MN-MGS.

At each participating business, a safety consultant placed numbered tags on all machines. The range of tag numbers (e.g., 100–135) was entered into the study software, which randomly selected 12 machines for evaluation. To ensure that a variety of machines was evaluated at each shop, no more than three machines could be selected from any one of the 26 machine types. Businesses with as few as six machines were allowed to participate (two shops had nine machines; one shop had ten). Assessments were performed only on machines that were in use, set up for operation, or temporarily idled. All checklist responses were entered into the study software, to generate a summary inspection report and action plan for the business. Machines were not included if they were permanently out of service.

The safety management audit was completed during an interview with the owner, manager, or safety director. Responses were verified by auditing documentation for 13 out of 33 questions. The total number of employees, the number of employees working in the shop, and years in business were also recorded.

Implement intervention:

The basis for implementing sustainable shop-wide programs was safety leadership: A safety committee or safety leadership team comprised of both employees and management was designated as responsible for carrying out safety programs. From this starting point, the safety leadership component of the intervention was designed to incorporate other leadership practices linked to reduced risk of injury. These included demonstrating management commitment to safety; writing and communicating shop policies and programs; encouraging employee participation; and providing sufficient resources [Simonds and Shafai-Sahrai, 1977; Smith et al., 1978; Habeck et al., 1991; Shannon et al., 1997; Gilkey et al., 2003].

When the intervention was launched at participating businesses, safety leadership team members managed implementation of programs in LO/TO, JHAs, and machine safeguarding. These components of the intervention were designed to provide technical guidance specific to each topic area. In addition, each program incorporates practices associated with lower injury rates such as regular safety auditing, employee training, and record-keeping [Simonds et al., 1977; Smith et al., 1978; Habeck et al., 1991; Shannon et al., 1997].

Three months after the baseline evaluation, the safety consultant returned to the shop to conduct the first intervention visit. A second intervention visit was conducted approximately six months after baseline. The purpose of these visits was for safety consultants to assist shop safety leaders with skill-building and guide the implementation of intervention programs. Safety consultants demonstrated intervention activities such as machine safety checklist audits, job hazard analyses (JHAs), and development of written lockout/tagout (LOTO) procedures. Due to the importance of safety leadership in the intervention design, a top priority at the first intervention visit was to ensure that there was an active safety leadership team at the shop. Safety consultants recorded their on-site activities conducted at all study visits using study software, and transmitted data electronically to PNI.

Twelve months after the baseline assessment, the safety consultant returned to the shop to conduct a follow-up evaluation. A new random sample of 12 machines was selected and evaluated, and the safety management audit checklist was completed again. Data were entered into the MGA software to produce a follow-up business report to help the owner with making a comparison with baseline results. Safety consultants met with shop safety leaders to

review progress and discuss plans to continue intervention programs beyond the study participation period.

Aim 3.

Develop database infrastructure: Database infrastructure was created and tested for management and analysis of data collected at the baseline, intervention, and follow-up site visits. Safety climate surveys were scanned into a separate database at PNI. All data sets were analyzed using SAS. A second study software application called Machine Guarding Data (MGD) was developed, tested, and used at PNI for importing and managing study data. The MGD program was also used for generating reports to provide the research team and study partners with information on intervention progress and emerging trends in the data. The safety climate survey database was programmed so that summary reports of pooled responses within each shop could be extracted. This was done in response to a request from Federated Insurance that participating businesses be provided with an overview of key indicators of safety climate and perspectives among their workforce. PNI and Federated built additional capacity in order to manage and analyze workers' compensation data.

Audit scores:

The machine safety checklists were used to create two summary scores:

- Business-level machine score: The number of "yes" responses for all machines was divided by the number of "yes" plus "no" responses on the 12 machine safety checklists completed at each shop to compute a single score.
- Machine-level score: The number of "yes" responses was divided by the number of "yes" plus "no" responses for individual machine checklists.

In addition, four subcategory scores were calculated for each machine. Scores were calculated as the number of items present divided by the total number of items x 100:

- Equipment safeguards: Depending on the type of machine, different numbers of items were used to assess point of operation safeguards, safeguards for other mechanical hazards, power transmission guards, workpiece control, operational controls and emergency stops, and the presence of lockable disconnects. Percentage scores were calculated for each of these sub-groups of checklist items.
- LOTO procedures: Five items addressed the presence and completeness of LOTO procedures.
- Electrical hazards: Six items addressed the condition and configuration of electrical wiring.
- Work environment: Between six and eight items addressed conditions of the work area and employee work practices such as wearing proper safety eyewear. Work practices were only assessed if a worker was present at the workstation at the time a machine was evaluated.

An overall safety management audit score was created using the 33 questions from the safety management audit as well as separate measures. Scores were calculated as the number of items present divided by the total number of items x 100.

- Safety leadership: Twelve questions assessed the safety management structure, written safety programs, and workplace safety policies. Safety leadership was defined as a formal, organized structure within which employees and management cooperatively identify, evaluate, and remediate hazards.
- Job hazard analysis (JHA): Eight questions determined the presence and completeness of a program for conducting JHAs and integration of findings from JHAs into regular work

practices. JHA was defined as a systematic means of assessing hazards associated with each job and devising means of remediating the hazards

- Machine maintenance program: Eight questions assessed the documentation of periodic inspection of machines to ensure they were effectively guarded. Machine maintenance was defined as inspecting machines on a routine basis to ensure safe operation.
- LOTO program: Five questions assessed key elements of a LOTO program and related employee training and record keeping. LOTO was defined as compliance with OSHA standard 1910.147 to ensure safe control of hazardous energy. OSHA requires that each business have a comprehensive written LOTO program. A LOTO procedure is a series of steps to safely shut down and restart machines.

Example questions within each score category can be found in our publications. [Parker et al., 2015a; 2015b; Parker et al., 2016a]

Measures of safety climate:

Insurer A requested that the survey be limited to two pages to assure completion and ease of use. Safety climate was measured using an abbreviated version of a survey developed by the British Health and Safety Executive and comprehensively described by Cheyne et al. [1999]. The survey had 9 constructs with two questions per construct. Questions were answered on a scale of 1 (strongly disagree) to 5 (strongly agree). Demographic data included age, gender, education, language preference, and primary job activity. The initial survey was written in English and subsequently translated into Spanish and reviewed for accuracy and back translation. Additional details are found in Parker et al., 2017 [Appendix 1].

Survey distribution and data collection

An encrypted identification number unique to each business was embedded into a barcode on the surveys. Surveys were then printed on a machine-readable form and provided to the business by the insurer. The owner or manager was responsible for having shop employees complete the survey. After completion, owners returned surveys to the safety consultant in-person or via US mail. The insurer then mailed the surveys to research staff. After inspection for errors or damage, surveys were optically scanned.

Data analysis: Audit results and intervention activity records were transmitted electronically from field sites to the research team and analyzed using statistical software SAS v9.4 [2016]. Power was computed using business-level machine safety scores from the MN-MGS while accounting for variance within and between shops. A sample size of 150 provides a power of over 0.8 to detect a 10% improvement in machine safety score.

A score for each of the nine safety climate constructs was determined by adding responses for both questions within that construct. Each pair of questions had a minimum score of 2 and a maximum score of 10. Scores were summed within shops and then averaged for the number of respondents. Internal consistency of the safety climate constructs was evaluated using Cronbach's alpha.

Analyses of NMGP data included descriptive statistics such as mean and standard deviations for continuous variables, and frequencies and percentages for categorical variables. Bivariate analyses such as chi-square test of a two-way contingency table, t-test or nonparametric Mann-Whitney test between two groups, analysis of variance (ANOVA) between multiple groups, and Pearson correlation coefficients were computed to explore the relationship between percentage of missing items on machine safety checklists and business demographics. Linear and logistic regression models were used to examine the relationship between different

aspects of machine safety and the presence of administrative programs such as a safety committee and written policies related to safety and health.

Baseline analysis of injury and cost data: Workers' compensation (WC) loss history data provided by Federated were used to assess the baseline relationship between incidence rates and costs of injuries and on-site measures of machine guarding and safety management. MEMIC declined to provide workers' compensation data, citing management concerns associated with a prior data breach unrelated to the study.

The dataset consisted of 4,283 claims from 576 metal fabrication businesses that carried workers' compensation insurance between January 2010 and February 2014. Data included codes for part of body, nature and cause of injury, and a brief (one or two sentence) narrative description of the event extracted from the employer's first report of injury. Identifiers such as personal names and business names were removed from the data before transmittal to PNI. Cost data were included for 3,849 claims that were closed (i.e., no future costs) by February 2014. No information was provided on number of lost or restricted work days.

The number of employees at a business was included in the WC data set if the following criteria were met: a) at least one claim had occurred during the time frame noted above, and, b) Federated had conducted a premium audit of the business. For businesses assessed as part of the NMGP, an estimate of the total number of employees was collected on-site during the machine safety audit. When the number of employees was known, incidence rates were derived based on 100 full-time equivalents (FTEs) per year. To determine FTE for a business, we used the number of employees recorded in the Federated workers' compensation database as an estimate of FTEs. The number of months that the business held a policy with Federated before enrolling in the study was used to approximate years. For example, if a business had 25 employees, and was a policy holder from January 1, 2010 onward, then joined the study on July 1, 2012, they contributed to the analysis $25 \text{ FTE} \times 1.5 \text{ yr} = 37.5 \text{ person-years or FTEs- per year}$.

Characterization of machine-related injuries: Research staff developed a multi-level classification scheme to systematically characterize each claim [Bertke et al., 2012]. The purpose was to examine the strengths and limitations of workers' compensation claims data as a surveillance tool in understanding the etiology and cost of machine-related injuries occurring in metal fabrication businesses.

First, a keyword auto-coding program was used to assign all injury claims to one of three mutually exclusive categories: musculoskeletal disorders (MSDs), slips/trips/falls (STFs), or all other injuries. Research staff then classified all claims grouped as "all other injuries", and reviewed each claim narrative to determine the work task most directly involved in the injury. A detailed description of this methodology can be found in Yamin et al., 2016.

Quality assurance (QA):

Reproducibility of machine safety audit results was evaluated by comparing data recorded by pairs of safety consultants simultaneously assessing machines at three MEMIC client businesses. Safety consultants conducted these assessments on the same day, without discussing observations or sharing notes. Due to travel costs, logistical considerations, and additional time spent away from regular loss control work, Federated declined to have any safety consultants involved, and MEMIC determined it was too costly to have more than a few safety consultants participate in this side-by-side machine evaluation.

A second quality assurance (QA) exercise was conducted among 25 Federated safety consultants. Photographs of five different machines were used to develop a web-based test of evaluators' ability to correctly identify hazards. The test consisted of 50 items selected from the corresponding machine safety checklists. While this simulation is likely to have been a less

rigorous method than paired evaluators on-site, this allowed for looking at consistency of responses across a larger group of safety consultants.

The kappa statistic was derived for data collected at sites evaluated by paired safety consultants for quality assurance testing. Established benchmarks for interpreting strength of agreement for categorical data were then applied [Landis and Koch, 1977]. The kappa statistic was also used to evaluate results of the web-based quality assurance test taken by safety consultants.

Aim 4.

Process evaluation: Qualitative assessment of work with intermediary organizations

The research team gathered qualitative feedback on an ongoing basis from insurance company managers and field staff, and from metal fabrication businesses. This enabled us to assess whether or not intervention programs and materials were useful only within the Federated Insurance corporate framework, or if other insurers or other organizations could successfully apply the same methodology. Having the unexpected opportunity to work with three additional insurance companies provided an opportunity to test study protocols and materials with additional intermediary organizations in addition to the primary study partner Federated. Many lessons were learned not only about working with insurance safety consultants but also much useful information was gathered on the broader potential for researchers to effectively work with intermediary organizations with ability to conduct outreach to large numbers of small businesses.

Develop and test a LOTO self-audit checklist for use by businesses

The widespread absence of LOTO programs and procedures found in the NMGP (described under Results for Aim 3, below) highlight the need for a comprehensive instrument for the assessment of LOTO. As described in Yamin et al., 2017 [Appendix 2], we developed and tested a LOTO self-audit instrument for manufacturing workplaces. If found sufficiently reliable, a self-audit of LOTO would allow for assessment of large numbers of businesses across wide geographic areas without the cost of sending trained evaluators to each site. This would be an important component of future outreach efforts to reduce the impact of LOTO incidents on a national scale.

IV. Results

Results are from Aims 3 and 4 only. Additional detail is available in the peer-reviewed publications referenced herein.

Results for Aim 3.

Baseline evaluations were conducted by Federated and MEMIC between January 2012 and August 2013 at 221 businesses located in 31 states. A breakdown of enrollment by region and business size is provided as a table within Parker et al., 2015a. The majority (67%) of participating businesses were located in seven states, with the greatest numbers in Wisconsin (33) and Minnesota (28).

At baseline, Federated evaluated 198 businesses, and MEMIC evaluated 23. Of these, 160 (72%) completed the entire program including the follow-up assessment: 146 from Federated and 14 from MEMIC. Changing insurer (37/61; 61% of dropouts) was the primary

reason given for not completing the study. Fifteen businesses left the study citing a lack of time and/or interest. Nine Federated clients were lost to follow-up because corporate restructuring made it impossible for safety consultants to complete intervention visits on schedule.

Combining on-site safety data from the two insurers:

There was no significant difference in mean baseline *business-level machine score* for participants from Federated and MEMIC (74% vs. 71%; $p = 0.26$), although the difference was significant when adjusted for business size (74% vs. 69%; $p = 0.02$). The difference between insurers in mean baseline *safety management audit score* was not significant (42% versus 48%; $p = 0.22$) and remained non-significant after adjusting for business size (43% versus 39%; $p = 0.37$).

Data from the two insurers were subsequently combined and analyzed as one group. After merging data, there were no significant differences between shops that did and did not complete the study with regard to mean shop size ($p = 0.32$), baseline *business-level machine score* ($p = 0.89$), or *safety management audit score* ($p = 0.79$). Among clients of Federated, 192 were nonunionized, 1 was unionized, and union status was unknown for 5. For MEMIC, none of the 23 businesses were unionized.

Baseline analysis of injury and cost data:

In comparing the loss history of Federated study participants versus eligible non-participants the injury rate was 2.4 / 100 FTEs- per year (FTE-yr) for participants and 5.3 / 100 FTE-yr for non-participants ($p < 0.0001$). Mean claim cost (total) was \$7896 / 100 FTE per year for participants and \$18,053 / 100 FTE per year for non-participants ($p < 0.0001$). These differences could potentially indicate that shops with better safety programs were more likely to enroll in the study, but this cannot be determined with certainty, in part due to limitations of the database, but also because Federated did not track response rate during recruitment (nor did MEMIC), so it is not known how many of the eligible non-participants were invited to participate. In addition, the range in baseline audit scores was very wide (43% to 97% for business-level machine score; 3% to 96% for safety management score), so self-selection bias on the basis of prior performance appears unlikely.

Among study participants, there were no significant differences in loss history between Federated client businesses who completed the intervention versus those that left the study before completion. Injury rate for completers was 2.5 / 100 FTE-yr for completers versus 2.0 / 100 FTE-yr for dropouts ($p = 0.7$); mean claim costs were \$7826 / 100 FTE-yr for completers versus \$8092 / 100 FTE-yr for dropouts ($p = 0.61$).

Initial data analysis did not find significantly better history of injury incidence rates or claims costs for businesses scoring better on the baseline safety evaluation conducted under the NMGP. It is possible that the size of the Federated data set may not be large enough to adequately assess the relationship between safety measures and rates of injuries that are relatively rare. Further, no data were included for eligible non-participants if those businesses did not experience a claim during the time period of the data run, which further reduced the amount of person-years in the analysis. An additional consideration is that the amount of time involved (38 months or less, depending on when a business became a Federated client) may not be sufficient to detect differences, in combination with the relatively small data set. Lastly, without data on lost workdays the data were lacking a key indicator of injury severity, thus it was impossible to perform analysis using rates of lost-time injuries.

An additional limitation initially was that the cause of injury and nature of injury codes assigned by Federated were not sufficient to make a confident determination of whether or not an injury was machine-related, or to derive useful information about the circumstances leading to the injury. Therefore, in January 2014, the PI requested that Federated add the narrative text portion

of each claim to the data pull. Federated agreed to this request and provided the narrative text as an additional column within the data set.

Research staff used the narrative text to re-characterize injuries that were likely machine-related. Although the narrative text was not standardized and often unclear and fragmentary, in many instances those data allowed for more accurate classification of claims and re-analysis of relationships between rates and costs of relevant injuries and baseline measures of safety performance. In the re-evaluation using narrative text, many injuries coded by the insurer as machine-related were re-classified for our analysis, because those injuries were not machine-related but simply occurred in the vicinity of a machine, or actually involved a hand-held power tool or other machine such as a lawnmower or motor vehicle rather than a stationary metal-working machine such as those investigated in the NMGP. Similarly, a large number of injuries simply coded as “eye”, “caught in, under, or between”, “caught, punctured, scraped”, etc., were determined to be machine-related based on narrative text analysis.

In this analysis, two separate rates were derived: one for injuries that were identified as “machine-related”, and one for all injuries combined, the latter of which included machine-related injuries as well as non-machine injuries and those which could have been in either group but were not classifiable due to poor data quality.

Table 1 shows the proportion of shops in the study that experienced at least one claim. Nearly 60% of baseline participants experienced no claims at all, and 74% had no claims categorized as machine-related. (For eligible non-participants, data were only available if the business experienced at least one claim during the time period of the data pull.)

Table 1. Proportion of Federated study participants experiencing at least one claim (n = 198)

All injuries		N
	Shops with non-zero incidence	81 (41%)
	Shops with zero incidence	117 (59%)
Machine related injuries		
	Shops with non-zero incidence	52 (26%)
	Shops with zero incidence	146 (74%)

Table 2 (next page) shows injury incidence and mean costs for the 198 baseline business participants insured by Federated, in comparison to baseline measures of their safety performance. Table 3 contains data for the same measures but only for the 81 participating businesses with at least one claim at baseline. In neither table did businesses with higher audit scores have significantly lower injury rates or costs. Businesses with a safety committee had higher rates of injury, as did larger businesses, but it is likely that this reflects the small size and poor quality of the data rather than any real factors. For these tables, costs were capped at \$100,000 per claim, in order to avoid skewing within categories.

Eye injuries could be classified with more confidence than most other types of injuries due to the fact that they were assigned the part of body code indicating “eye”. Therefore we assessed the rate of eye injuries among participating businesses who had a policy requiring safety eyewear

for all persons entering the shop, versus those who did not have such a policy at baseline. Those shops with an eyewear policy had a lower rate of eye injuries (0.38 versus 0.51 per 100 FTE/yr), but the difference was not significant ($p = 0.53$), possibly due to the high proportion (85%) of businesses who had a safety eyewear policy in place at baseline.

Claims for amputations were also readily identifiable as they were given the nature of injury code indicating amputation. However, the data set was not large enough to perform comparative analysis of rate data for relatively rare events such as amputations. Eight amputations (0.03 per 100 FTE/yr) were recorded among participating businesses, with an additional 44 among non-participants (0.08 per 100 FTE/yr).

As a whole, and within all of the sub-categories of the analysis described here, it was not possible to detect any significant positive relationships between baseline measures of safety and injury rates or costs. Therefore, it is not possible to meaningfully compare changes in pre/post measures of safety performance with any changes in insurance loss history which may have occurred during the same time frame. As noted above, this may be attributable to the limited size and time frame, and a lack of standardization within the data set. More broadly, an additional factor is that WC data are typically gathered for legal and business rather than research purposes. Nevertheless, the narrative text analysis performed by research staff allowed for a separate investigation of circumstances involved in machine-related injuries, described in the next section.

(continued, next page)

Table 2. Injury rates and mean costs for Federated study participants at baseline

		n	Incidence rate (per 100 FTE / year)		Total cost (\$ per 100 FTE / year)	
			All injuries	Machine-related	All injuries	Machine-related
All study participants		198	2.18	0.59	7616	1761
Safety committee	present	67	4.10	1.12	17284	4549
	absent	131	1.20	0.31	2595	345
	p-value		0.001	0.004	0.0003	0.03
Safety management audit score	<28%	50	1.18	0.42	2927	917
	28-38%	50	1.58	0.44	3004	275
	39-54%	49	3.65	0.82	12966	142
	55%+	49	2.35	0.67	11566	4534
	p-value		0.06	0.22	0.006	0.05
Business-level machine score	<69%	48	1.02	0.25	2478	489
	69-73%	46	1.83	0.54	6446	1690
	74-78%	57	3.53	0.98	13090	4079
	79%+	47	2.09	0.49	7153	24
	p-value		0.09	0.19	0.1	0.7
Business size (# of employees)	≤ 10	58	0.24	0.09	194	69
	11 - 29	83	1.23	0.34	5231	1416
	30 - 49	29	3.23	0.80	7395	1471
	50 - 150	29	7.43	2.00	28220	6143
	p-value		<0.0001	<0.0001	<0.0001	0.008

(continued, next page)

Table 3. Injury rates and mean costs for Federated study participants with ≥ 1 claim at baseline

		n	Incidence rate (per 100 FTE / year)		Total cost (\$ per 100 FTE / year)	
			All injuries	Machine-related	All injuries	Machine-related
All study participants		81	5.33	1.43	18896	4471
Safety committee	present	39	7.05	1.92	29692	7991
	absent	42	3.74	0.98	8369	1132
	p-value		0.02	0.03	0.001	0.053
Safety management audit score	<28%	12	4.92	1.75	14050	4086
	28-38%	22	3.59	1.00	6827	641
	39-54%	25	7.16	1.60	25413	2847
	55%+	22	5.23	1.50	25761	10654
	p-value		0.42	0.85	0.04	0.1
Business-level machine score	<69%	18	2.72	0.67	7123	1353
	69-73%	17	4.94	1.47	17442	4573
	74-78%	25	8.04	2.24	29844	9518
	79%+	21	4.67	1.10	16008	592
	p-value		0.16	0.31	0.22	0.8
Business size (# of employees)	≤ 10	9	1.56	0.56	1382	491
	11 - 29	35	2.80	0.77	12154	3290
	30 - 49	18	5.39	1.33	12325	2648
	50 - 150	19	11.74	3.16	44558	9700
	p-value		<0.0001	<0.0001	<0.0001	0.1

Characterization of machine-related injuries:

The number of injuries associated with various machine-related work tasks is shown in Figure 1. Eye(s), finger(s) other than thumb, thumb, and hand were the most commonly injured body parts and accounted for 81% of machine-related injuries. As seen in Table 4, eye(s) were the most frequently injured body part during both removing chips (57% of total) and machine operation (39%). Finger(s) were the part most often injured during setup/adjustment and workpiece handling (47% and 48%, respectively). Claims assigned various other part of body (POB) codes each accounted for fewer than 5% of the total.

Cost data were available for 86% of machine-related claims. These claims had a cumulative cost just over \$2.3 million. Amputations were the most costly events with a median total cost per claim of almost \$12,000 and the lowest percentage of claims with medical-only expenses (14%). Claims with total costs of at least \$10,000 accounted for 6% (53/902) of machine-related injuries, including 14 lacerations, 13 amputations, and 10 fractures. Additional results can be found in Yamin et al., 2016.

Based on narrative text analysis, there appear to be a large number of preventable injuries among metal fabrication workers. For example, the large number of eye injuries related to a foreign body may reflect a need for businesses to provide all workers with proper safety eyewear and enact other preventive measures such as strictly limiting the use of compressed air for removing chips from machines or parts. Similarly, the large number of finger, hand, and thumb lacerations may indicate the need for better machine guards during machine operation and use of tools rather than hands for tasks such as removing scrap or jammed parts from machines.

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Figure 1. Classification of workers' compensation (WC) claims using narrative text

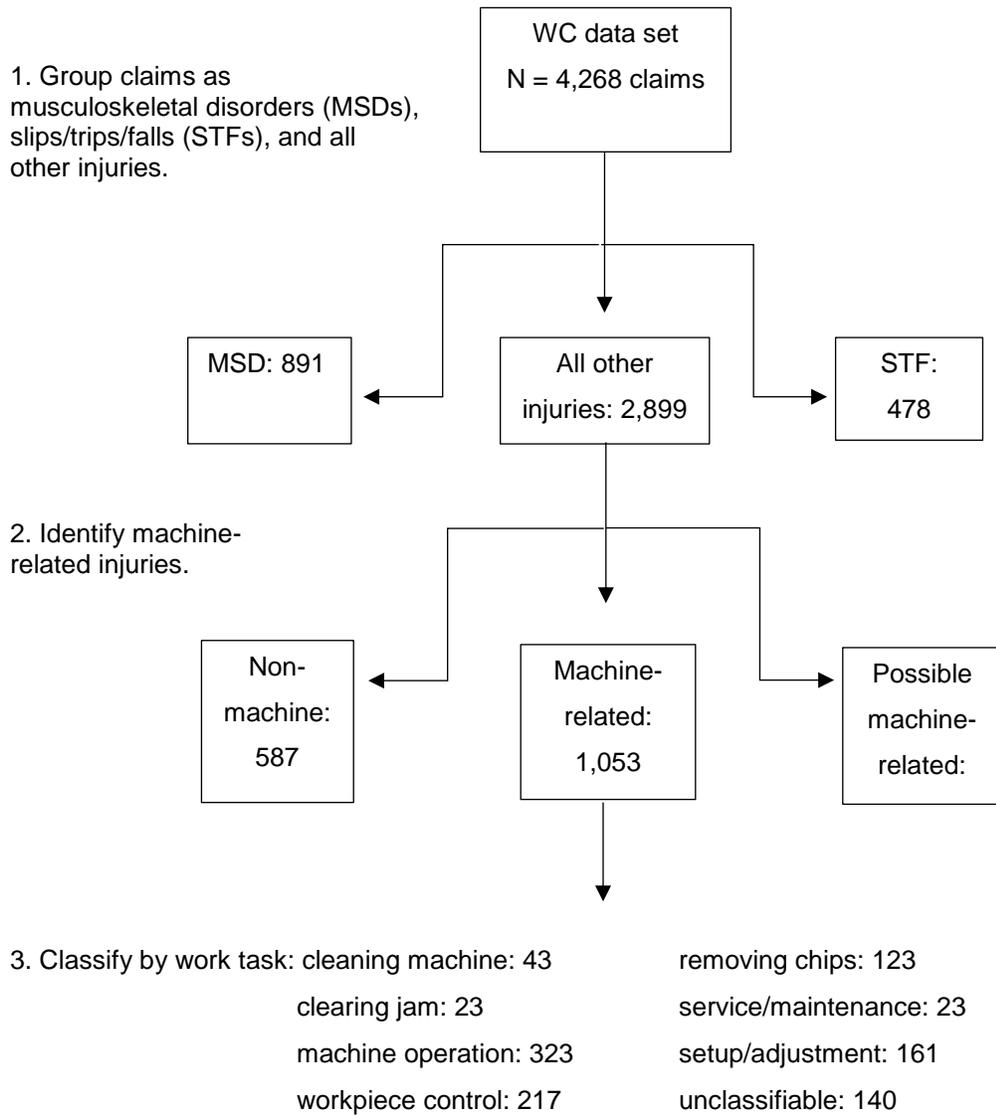


Table 4. Machine-related injuries: Common work tasks and body parts injured

Part of body (POB)	Work task									
	Removing chips		Machine operation		Setup / adjustment		Workpiece handling		Total, all machine-related	
	n	(%)	n	(%)	n	(%)	n	(%)	N	(%)
Eye(s)	70	(57)	125	(39)	3	(2)	2	(1)	211	(20)
Finger(s)	25	(20)	101	(31)	75	(47)	104	(48)	422	(40)
Hand	10	(8)	33	(10)	26	(16)	31	(14)	127	(12)
Thumb	10	(8)	26	(8)	15	(9)	24	(11)	92	(9)
All other POB	8	(7)	38	(12)	42	(26)	56	(26)	201	(19)
Total	123	(100)	323	(100)	161	(100)	217	(100)	1053	(100)

Percentages are subject to rounding error.

Findings from baseline machine safety analysis:

A total of 2,632 machines were evaluated at the 221 study sites, with the expected sample size of 12 machines assessed at 214 businesses. Average *business-level machine score* was 73% (SD = 9%; range = 43 to 97%), with mean scores of 80% or higher for each of the four assessment categories except *LOTO procedures* (mean = 9%) (Table 5, next page. Additional data tables can be found in Parker et al., 2015a). Mean scores for sub-categories within the *equipment safeguards* group were relatively high aside from *point of operation safeguards* (mean = 67%) and *safeguards for other mechanical hazards* (mean = 72%).

(continued next page)

Table 5. Business-level machine scores at baseline (n = 221)

Machine Function or Type of Hazard	Mean %	SD
Equipment safeguards	80	10
Point of operation safeguards	67	19
Safeguards for other mechanical hazards	72	16
Power transmission guards	92	11
Workpiece control	83	15
Operational controls and emergency stops	83	11
Lockable disconnects	88	19
LOTO procedures	9	24
Electrical	92	10
Work environment	89	9
Business-level machine score (total)	73	11

Business-level machine score was not significantly related to business size. Within the four scoring categories, no significant relationships with business size were observed except for *LOTO procedures* ($p = 0.006$). *Business-level machine scores* did not differ significantly based on geographical region (northeast, north central, southeast, southwest), years in business, or between participants under the jurisdiction of federal ($n=123$) or state-based ($n=98$) OSHA programs. Additional results from baseline analysis of machine guarding practices are found in Parker et al., 2015a.

Findings from baseline safety management analysis:

Mean *safety management score* improved with increasing shop size ($p = 0.0001$) (Table 6, next page). The trend was particularly strong for the *LOTO program score* where there was a 30% difference between the smallest and largest shops ($p < 0.0001$). For the *safety leadership program score*, the difference between the smallest and largest shops was 25% ($p < 0.0001$). Using simple linear regression to evaluate the relationship between the *safety leadership score* and shop size, for each additional employee in a shop, the safety leadership score increased by 0.3% ($p < 0.0001$). Few shops reported regularly conducting JHAs regardless of size.

(continued next page)

Table 6: Business size and baseline safety management audit scores (N =221)

	Business size by number of employees					
	All	3 - 10	11 - 29	30 - 49	50 - 150	
	Number of businesses					
	221	60	82	36	43	
Program	Mean % score in each program					P-value for trend
Safety leadership	59	48	57	66	73	<0.0001
Job hazard analysis (JHA)	9	6	6	16	13	0.04
Machine maintenance	42	34	42	46	48	0.008
Lockout/tagout (LOTO)	57	40	58	65	70	<0.0001
Overall safety management audit score	43	34	42	49	53	<0.0001

For all businesses, establishments with a safety committee scored 19% higher (55% v 36%) on *the safety management audit* (after removing safety committee as part of the measure) compared to those without ($p < 0.0001$). Those having a safety committee also scored significantly higher in three of the four programs comprising the safety management audit, with JHAs being the sole exception.

Shops with a safety committee had a significantly higher *safety management audit* score within each size range apart from the largest (50 -150, $p= 0.16$) when compared to shops without a safety committee. Scores for the overall audit and for each program component increased with increasing business size for shops without safety committees.

Business size was not an important factor for shops with safety committees. Shops with a safety committee did equally well regardless of size for safety leadership ($p =0.98$ for trend), job hazard analysis ($p= 0.35$ for trend), machine maintenance ($p=0.68$ for trend), and LOTO ($p = 0.85$ for trend). Further, the smallest (3-10 employees) shops with safety committees scored higher in the total audit and in each program area than the largest (5- 150 employees) shops without safety committees, although the difference in scores was statistically significant only for safety leadership program ($P = 0.001$).

Additional results from baseline analysis of safety management can be found in Parker et al., 2015b.

Findings from pre-post assessment of LOTO:

Three summary LOTO measures were calculated for each business. Cronbach's alpha was > 0.8 for items within each of the three LOTO categories: lockable disconnects, LOTO procedures, and LOTO program; indicating that these could be used as summary scores. Significant improvements were observed in each of the three summary LOTO measures (Table 7, next page) among the 160 shops that completed the intervention.

Table 7: Summary business-level lockout measures pre and -post intervention (N = 160)

	Mean % at baseline	Mean % at follow-up	Percentage point change	p-value	SD at baseline	SD at follow-up
Lockable disconnects score	88	92	4	<0.0001	18	17
LOTO procedures score	8	33	25	<0.0001	22	42
LOTO program score	55	76	21	<0.0001	37	33

In comparing businesses that added a safety committee during the study period with those who did not (Table 8), the former showed significantly greater improvements in LOTO procedures (44 vs. 14 percentage points improvement; $p=0.005$) and LOTO programs (33 vs. 18 percentage points; $p=0.06$). Four shops that began the study with a safety committee but finished without one were excluded from this part of the analysis.

Table 8. Safety committee effect on three summary LOTO scores pre and post intervention

Pre-to-post intervention safety committee status		Lockable disconnects			LOTO procedures			LOTO program		
		N	Baseline %	Follow-up %	p-value	Baseline %	Follow-up %	p-value	Baseline %	Follow-up %
Group A: yes-to-yes	51	92	94	0.0478	15	38	0.0005	72	89	<0.0001
Group B: no-to-yes	42	91	96	0.0074	6	50	<0.0001	54	87	<0.0001
Group C: no-to-no	63	82	88	0.0070	4	18	0.0008	41	59	0.0006
All shops	160	88	92	<0.0001	8	33	<0.0001	55	76	<0.0001
P-value for change; group B versus group C				0.95			0.0005			0.06

Multiple regression was used to evaluate the 105 shops that started without a safety committee. After controlling for baseline LOTO scores and safety committee status, business size had no effect ($p>0.10$) on pre-post intervention changes in LOTO scores in any of the three summary measures. Establishing a safety committee was associated with a 5% ($p=0.12$) greater improvement in the lockable disconnect score, 39% greater improvement in LOTO procedures score ($p<0.0001$), and a 25% greater increase in LOTO program score ($p=0.0006$) when compared within shops that started and ended without a safety committee. Additional results from the pre/post analysis of LOTO practices can be found in Parker et al., 2016a.

Machine age was obtained for 44% of machines at baseline and 37% of machines at follow-up. Machine age was stratified by year of manufacture ≤ 1989 or ≥ 1990 , the latter being the first full year after the OSHA LOTO standard went into effect. Machines manufactured during or after 1990 were 8% more likely at baseline to have all disconnects in place than older machines ($p = 0.0003$). The proportion of machines manufactured pre-1990 that were fully equipped or retrofitted with disconnects improved during the intervention period from 85% to 95% ($p=0.001$).

Analysis of overall pre-post data:

At the 160 shops that completed the entire one-year program, a total of 1,912 machines were evaluated at baseline and 1,913 were assessed at follow-up. The average business-level machine score increased from 73 to 79% ($p < 0.0001$) over the course of the intervention. Point of operation guarding increased from 67 to 72% ($p < 0.0001$) and the presence of lockable disconnects rose from 88 to 92% ($p < 0.0001$). LOTO procedures showed the largest improvement, from 8 to 33% ($p < 0.0001$).

From baseline to follow-up, there were improvements in the overall safety management score in all business size ranges ($p < 0.0001$ for all groups). Businesses in all size ranges also made improvements in safety leadership and LOTO. Machine maintenance program scores improved significantly for all but the largest shops ($p = 0.15$). At baseline, JHAs were infrequently conducted regardless of business size. There was an improvement of 15 percentage points in mean JHA score for all shops combined ($p < 0.0001$) and significant improvements within each business size range for all but the smallest (3-10 employee) shops.

As seen in Table 9, businesses that started and ended the intervention with a safety committee attained the highest scores on the overall safety management audit and its four component scores (with questions on safety committee removed from these outcome measures) at baseline and follow-up. Shops that added a safety committee made substantially greater gains in the overall safety management audit score than shops that did not (24 vs 9 percentage point improvement; $p = 0.0002$). As seen in Table 10, businesses that added a safety committee during the study also made substantially greater improvements in the business-level machine score when compared to businesses that did not have a safety committee throughout the study period (10 vs 2 percentage point improvement; $p = 0.0001$).

Regression analysis was used to compare shops that started without a safety committee ($n = 105$) and ended the intervention with ($n = 42$) or without ($n = 63$) one. Controlling for baseline safety management audit score and business size, shops that added a safety committee improved 21 percentage points more on the overall safety management audit score ($p < 0.0001$) and 9 percentage points on the business-level machine score ($p < 0.0001$) when compared to those that did not add a committee. Additional results are provided in Parker et al., 2016b.

(continued, next page)

Table 9. Baseline and follow-up safety management scores for shops that maintained (n = 51), established (n =42), or did not establish a safety committee (n = 63)*

Safety committee status at baseline and follow-up	Baseline		Follow-up		P-value for change in mean scores: baseline to follow-up	Percentage point change: baseline to follow-up (SD)	p-value:*** Comparison of baseline and follow-up: Groups B and C
	Mean %	SD	Mean %	SD			
Overall safety management audit**							
Maintained (A)	55	19	74	15	<0.0001		
Established (B)	44	19	68	19	<0.0001	24 (21)	0.0002
Did not establish (C)	33	18	42	20	<0.0001	9 (14)	
Safety leadership**							
Maintained (A)	78	16	91	10	<0.0001		
Established (B)	58	20	87	14	<0.0001	29 (21)	<0.0001
Did not establish (C)	48	21	53	21	0.0915	5 (21)	
Job hazard analyses (JHAs)							
Maintained (A)	15	30	41	44	<0.0001		
Established (B)	11	27	30	41	0.0096	19 (47)	0.06
Did not establish (C)	4	18	8	26	0.2461	4 (27)	
Machine maintenance							
Maintained (A)	49	30	69	23	0.0003		
Established (B)	51	28	64	30	0.0032	13 (32)	0.83
Did not establish (C)	33	23	45	28	0.0002	12 (23)	
LOTO							
Maintained (A)	72	28	89	18	<0.0001		
Established (B)	54	39	87	26	<0.0001	33 (39)	0.06
Did not establish (C)	41	38	59	39	0.0006	18 (41)	

* Excludes 4 shops that went from having to not having a safety committee

**Excludes checklist items concerning the presence of a safety committee.

*** Comparison of groups "no to yes" versus "no to no".

Table 10. Safety committee status and business-level machine score*

Safety committee status at baseline and follow-up	Business-level machine score							
	N	Baseline		Follow-up		p-value for difference in mean score: baseline to follow-up	Baseline to follow-up: percentage point change (SD)	p-value**
		Mean %	SD	Mean %	SD			
Yes to yes	51	75	9	81	10	<0.0001		
No to yes	42	74	7	84	11	<0.0001	10 (9)	0.0001
No to no	63	72	10	75	11	0.0367	3 (9)	
All shops completing the intervention	160	74	9	79	11	<0.0001		

* Number of shops "yes to no" is 4; data are not shown as a separate row in table.

** Comparison of groups "no to yes" versus "no to no."

Quality assurance (QA):

Reproducibility of machine safety audit results was evaluated by comparing data recorded by pairs of safety consultants simultaneously assessing machines at three MEMIC client businesses (details above, Methods section). Within the three shops evaluated by paired raters, the respective kappa values were 0.53 (modest agreement), 0.73 (high agreement), and 0.96 (excellent agreement). Kappa for combined total responses collected at all three shops was 0.74.

A web-based quality assurance (QA) exercise was conducted among 25 Federated safety consultants. Average score on the 50-item web-based evaluation was 92.6%. Kappa values for the 25 safety consultants who took the on-line quiz ranged from 0.65 to 1.00 (mean 0.87).

When all field work was completed in September 2014, research staff reviewed data transmitted from the field for baseline, intervention, and follow-up site visits. Data from two businesses that had completed the intervention were excluded from the analysis because they were determined to have more than 150 employees, the maximum number allowed for study eligibility. An additional two businesses were eliminated because the data indicated that the safety consultant who evaluated the shop did not follow study protocol which dictated that the evaluator randomly select a new sample of 12 machines at follow-up if there was a large enough number of machines at the business. Rather, that safety consultant simply evaluated the same 12 machines at baseline and again at follow-up.

Safety climate:

Safety climate surveys were returned by 132 (60% of the baseline group of 221 shops). There were no differences in the overall shop score, business-level machine score, the presence of LOTO programs or procedures, the presence of safety committees, number of years in business, or number of employees between business that did and did not participate in the safety climate survey ($p > 0.4$ for all measures).

For the 132 shops that returned surveys, both workers and at least one owner/manager completed surveys in 115 and only workers in 17. Analysis was done using these 115 shops. After eliminating 28 surveys that could not be identified as coming from an owner or employee, the final analysis was completed on 2,502 individuals including 2,161 employees (86%) and 341 owners or managers (14%). The response rate for workers was 59% (2164 out of 3646) for employees in the 115 shops. A response rate was not calculated for owners and managers as the denominator could not be obtained and only one survey was sought per business.

Tables and additional detail are provided in Parker et al., 2017 [Appendix 1]. Owners consistently rated their enterprises more favorably than did workers. As business size increased there was a consistent trend towards lower safety climate measures. A negative and statistically significant downward trend was seen for all constructs except involvement in safety. This trend was consistent across all size ranges. The largest difference was seen for management commitment which went from 8.8 in the smallest shops to 7.8 in the largest shops. The only construct that did show significant differences by size range was involvement.

There were slight differences in safety climate measures when stratified by the overall machine score for each shop. Management commitment, priority of safety, and safety discipline were all associated with a slight but statistically significant increase in summary measures ($p < 0.01$).

There were few differences in safety climate scores between businesses by quartile ranking for overall safety leadership score. The overall measure of safety climate was virtually the same for business in the highest and lowest quartiles ($p = 0.94$). When differences were seen, a positive and statistically significant trend was seen only for supportive environment ($p = 0.0003$). The presence or absence of a safety committee made minimal and contradictory differences in safety climate measures.

Multiple regression was used to assess the relative impact of the safety climate score and the presence or absence of a safety committee. A total of 47 out of 115 (41%) businesses had a safety committee. Using multiple regression with the overall safety audit score as the dependent variable, an increasing safety climate score showed no correlation with the overall safety audit score ($p = 0.29$) while controlling for both shop size and safety committee. However, the presence of a safety committee resulted in a 15% increase ($p < 0.0001$) in the overall safety audit score while controlling for the effect of shop size and overall safety climate score. Similarly, an increasing safety climate score did not affect the baseline LOTO score ($p = 0.65$); however, the presence of a safety committee was associated with a 21% ($p = 0.002$) increase in this measure. Neither the safety climate score nor the presence of a safety committee impacted measures of machine guarding.

Aim 4.

Process evaluation: Qualitative assessment of work with intermediary organizations

An important outcome of establishing partnerships with three additional insurers is that we had an opportunity to determine whether the intervention designed in partnership with Federated is adaptable by other insurers. Every indication is that the intervention, data collection methods, and MGA software are all readily adaptable by other insurance companies. This includes a smaller, regional insurer (MEMIC), another large nationwide insurer (CNA), and an insurer within a state-based plan system (WA-EMP). This is an encouraging indication that this intervention methodology is widely applicable.

This preliminary assessment appears to hold true despite CNA and WA-EMP having left the study, as described above. The reasons for those two insurers leaving the study had nothing to do with any shortcomings in the methodology or any failures on the part of the PI.

Nevertheless their departure has added to the insights gained on working with intermediaries that should be considered in design of any similar programs in the future.

A major problem for CNA and WA-EMP was overconfidence in their ability to recruit and enroll existing workers' compensation clients into the study. Despite repeated cautionary advice from the PI, these partners placed very little emphasis on plans and techniques for recruitment in advance of study launch. During the months after these partners were trained and began enrollment, the PI and Research Program Manager held several teleconferences with managers and safety consultants from both insurers and provided talking points and other materials to assist with recruiting. Nevertheless, these two partners were apparently not able to overcome the initial lag in enrollment, and they left the study. No problem with adapting our methods to their business models was noted by either partner; on the contrary, feedback on the methodology has been consistently positive both from safety consultants and (indirectly) participating businesses who were policyholders with all four insurers.

A similar overconfidence in ability to enroll clients was encountered with both Federated and MEMIC as well. However, with persistent effort by the PI, Research Program Manager, and our key contacts at each of those companies, we were able to successfully overcome the initial inability to enroll significant numbers of client businesses. Further, through strong collaboration we have overcome a variety of other unforeseen challenges such as the restructuring of Federated's business model in 2012, layoff of large numbers of Federated safety consultants during 2013, and the untimely passing of the manager of MEMIC's safety consultants in 2013.

Key lessons learned in implementing a sustainable intervention with insurance industry partners acting as intermediaries are as follows:

- Do not assume that eligible businesses will participate in a study simply because they are clients of the insurer – Prepare a rigorous recruitment/enrollment plan as in other types of outreach programs.
- Establish a reliable and consistent working relationship with a contact or “champion” [Sinclair et al., 2013] at each partner company, who has received and will continue to receive explicitly communicated backing of senior management to recruit businesses, as well as carry out and subsequently and sustain the intervention at a suitable number of participating sites.
- Verify that intervention activities are included in the job responsibilities of safety consultants, and are not viewed as extracurricular or optional.
- Understand the importance of training safety consultants employed by the intermediary organization as well as communicating study goals and findings at regular intervals to senior management at each partner company.
- Understand that skills and knowledge can vary widely among loss control consultants serving as safety consultants and be prepared to provide program and technical support to the partner organizations at every stage of the intervention.

Develop and test a LOTO self-audit checklist for use by businesses

Field-testing of the LOTO self-audit at ten manufacturing firms demonstrated high inter-rater reliability, indicating that it would be useful in employers' efforts to regularly assess and improve their LOTO programs. Business self-auditors attained a high level of accuracy in identifying items that were not compliant with the OSHA LOTO standard. Full results are presented in Yamin et al., 2017 [Appendix 2].

V. Discussion

The NMGP provides an important perspective on safety management within small enterprises. The large national sample, in combination with data on both hazards and management practices, permits stratification to determine the impact of business size on the presence and quality of safety programs. The NMGP demonstrated the importance of having or adding a safety committee in improving summary measures of machine safety. Businesses with a safety committee had the highest baseline and follow-up summary scores. Business that added a safety committee improved summary scores substantially more than those that started and ended without one. Regardless of size, adding a safety committee was likely to result in substantially more improvement than not doing so.

Safety management in small businesses

Several authors have developed frameworks for disseminating health and safety programs to small enterprises through intermediary organizations such as insurers. [Hasle and Limborg 2006; Sinclair et al., 2013; Cunningham et al., 2014; Cunningham and Sinclair, 2015] However, there is a lack of supporting data to test suggested best practices due to the difficulties and expense entailed in implementing a large-scale standardized intervention. The success of the NMGP in improving both machine guarding and LOTO demonstrates the potential for intermediaries such as insurance safety consultants to effectively work with small businesses to effect positive safety-related changes. Insurance personnel are able to provide technical information and consultative services in an unbiased fashion and without the need to promote commercial products. In addition, they are the most common source of safety information used by small businesses (74%), followed by state OSHA consultation (38%). [Morse et al., 2013]

Most studies related to human resource management have focused on large-scale enterprises. There is a tendency to assume that findings from large enterprises may be automatically applied to small enterprises [Wilkinson, 1999]. Management practices shown to increase business performance include, among others, the use of teams and opportunities for training and development. These same practices have also been shown to increase employee effort. However, it is not clear how—or if—findings from large enterprises ought to be applied to small business [Allen et al., 2013].

The lack of an infrastructure for human resource management is another important problem faced by small businesses [Fonteyn 1997; Wager 1998; Hornsby 2003]. Accounting, finance, production, and marketing take precedence over personnel-related issues and personnel policies – including those that address safety –are frequently lacking in firms with fewer than 50 employees [Wager 1998; Hornsby and Kuratko, 2003].

In small businesses, human resources management and business administration become more structured as business size increases [Barber et al., 1999; Kotey and Slade, 2005; Vaz Junior et al., 2012]. Small firms may lack the technical knowledge necessary to develop and implement formalized human resource practices [Allen et al., 2013; Vaz Junior et al., 2012]. Additionally, autonomous and self-directed work is seen as an important aspect of management commitment to employees of small firms [Allen et al., 2013]. Surprisingly, with regard to health and safety, focus groups indicate that workers prefer formal to informal work practices [Parker et al., 2012].

As firms grow, there are pressures to formalize human resource management practices [Storey et al., 2010]. From the vantage point of business development, formal human resources practices enhance employee perception of fairness and may lead to greater levels of employee commitment especially in enterprises where employee satisfaction may be low [Wilkinson, 1999; Eakin et al., 2003; Saridakis et al., 2013].

Numerous investigators have reported that small industrial firms lack occupational safety and health programs and infrequently engage the services of an occupational safety and health

professional [Leviton and Sheehy 1996; Bradshaw et al., 2001; Lentz 2001; Champoux and Brun, 2003; Eakin et al., 2010; Parker et al., 2012]. Data from the NMGP indicate that management practices within small firms may be an underlying impediment to the implementation and maintenance of best practices with regard to safety and health.

Importance of safety committees

While it is commonly supposed that lack of resources is one of the primary barriers to safety performance in small businesses, the true picture is considerably more complex. For example, Champoux and Brun [2003] found that a lack of resources is not likely the major obstacle to improving business health and safety in most small businesses. In the NMGP, larger businesses were more likely to have a safety committee at the start of the intervention or establish one over the course of the intervention. There was, however, no indication that the need for a safety management structure varied with business size. After controlling for the presence or absence of a safety committee, business size (range 3-150 employees) did not have an impact on any of our safety measures. In addition, although aging machinery was associated with lower safeguarding audit scores, there was no association between machine age and business size or years in business.

Coordinated worker and owner participation is crucial to the identification of hazards and subsequent selection and implementation of controls [Parker et al., 2012; Champoux and Brun 2003; Jeppesen 2003; Kogi 1998; 2002; Kidd et al., 2004; Walker and Tait, 2004]. A safety leadership structure centered on a safety committee, appeared to contribute to improvements in several critical workplace safety measures [Yamin et al., 2014; Parker et al., 2015b; 2016a; 2016b. This entails shared responsibility between workers and management and was central to the NMGP intervention. Although there is debate on the optimal characteristics of a safety committee, shared responsibility seems central to most [Morse et al., 2013]. Regardless, many shops with safety committees had substantial room for improvement in most summary measures, indicating the need for other elements of safety management beyond the presence of a safety committee.

Engaging owners and workers is particularly important for small businesses where owners are the gateway to shops, make decisions about the selection and purchase of controls and set and enforce rules and policies [Kazutaka, 2012; Huy, 2010; MacEachen et al., 2010]. In this study, after completion of a summary audit report, safety consultants encouraged the owner and safety committee to work together in selecting areas for improvement and developing a one-year business action plan.

Hasle and Limborg [2006] note the importance of the owner as central in small enterprises. Although the NMGP did not assess the roles of specific individuals, it is clear that if there is shared responsibility for safety leadership, numerous aspects of safety are likely to improve. Owners often rely on information obtained through informal relationships with individuals who they feel they can trust [Eakin and MacEachen, 1998; Parker et al., 2012]. These individuals may be vendors with a vested interest in a specific product that is inadequate to meet the needs of the employees and employers. However, it is often difficult for employers or employees to assess the quality of information provided, the efficacy of personal protective equipment, or whether consultative services adequately meet their needs [Hasle and Limborg 2006; Eakin and MacEachen, 1998; Hasle et al., 2012]. To address this problem, the NMGP intervention prioritized establishment of a safety leadership structure as a basis for implementing sustainable, cost-effective programs in LOTO and machine safety. Business safety assessments and intervention delivery were conducted on-site at each business, a consultative approach that has been described as an effective means of delivering prevention programs in occupational settings [Hasle and Limborg, 2006].

Lockout/tagout in the NMGP

Both the MN-MGS [Parker et al., 2009] and NMGP demonstrated the importance of adding a safety committee in improving summary measures of machine safety. NMGP data demonstrate that regardless of size, LOTO practices are consistently better in shops with a safety committee when compared to those without. Businesses with a safety committee had the highest baseline and follow-up LOTO program scores. Business that added a safety committee improved both their LOTO program and procedure scores substantially more than those that started and ended without a safety committee. Nonetheless, at the final evaluation, scores in businesses that added a safety committee were not quite high as those that started and ended with one.

The success of the NMGP in improving LOTO demonstrates the potential for insurance safety consultants to effectively work with small businesses to improve worker health and safety. Insurance risk consultants were able to provide simple technical guidance to businesses to help improve safety practices. Technical guidance consisted of providing businesses with sample LOTO procedures and administrative programs, both of which were frequently absent at baseline. Businesses were also provided guidance on how to establish and run a safety committee. The site visits, however, proved to be costly and could not be maintained beyond the intervention period [Parker et al., 2016b], a need that is bypassed with the development and testing of a reliable self-audit instrument, as described in Yamin et al., 2017 [Appendix 2].

Characterization of machine-related injuries using workers' compensation data

Findings from the analysis of workers' compensation (WC) insurance claims data performed as part of this study are twofold in nature. First is the extent to which analysis of WC data provides a better understanding of machine-related injuries and thereby aids in future prevention efforts. Second are insights into the strengths and limitations of WC data as a means of enhancing occupational injury surveillance.

This study evaluated a cross-section of machine-related injuries in metal fabrication businesses. Slightly over 30% of injuries occurred while the worker was operating a machine to produce or finish a part, with the remainder taking place during tasks such as removing chips, setup/adjustment, and workpiece handling. In comparison, an early study of metal-cutting lathe operators found that 17% of injuries occurred during machine operation, while the rest involved a variety of manual secondary tasks described as loading/unloading, deburring, and cleaning/clearing [Etherton et al., 1981].

From an occupational health surveillance perspective, several studies have investigated amputations within the metal fabrication trades [Largo and Rosenman, 2015; Boyle et al., 2000; Stanbury et al., 2003; Olson and Gerberich, 1986]. This study provides a broader perspective on the number and scope of injuries in metal fabrication, including many relatively minor (as indicated by low costs) but frequently occurring events such as lacerations and eye injuries. Although preventing amputations through point of operation guarding is critical, the finding that amputations and other serious, costly traumatic injuries such as fractures, crushes, and severe lacerations occurred during a variety of work tasks underscores a need to extend prevention efforts beyond the point of operation.

Based on this narrative text analysis, there appear to be a large number of preventable injuries among metal fabrication workers. For example, the large number of eye injuries related to a foreign body may reflect a need for businesses to provide all workers with properly-fitted, OSHA-compliant safety eyewear [OSHA 2016e] and enact other preventive measures such as strictly limiting the use of compressed air for removing chips from machines or parts. Similarly, the large number of finger, hand, and thumb lacerations may indicate the need for better machine guards during machine operation and use of tools rather than hands for tasks such as removing scrap or jammed parts from machines.

Workers' compensation insurers collect data on occupational injuries in manufacturing and are well positioned to assist businesses with implementation of safety management

programs [Morse et al., 2013; Barbeau et al., 2004; Parker et al., 2016a; 2016b]. As such, data collection for purely administrative purposes represents a missed opportunity with regard to occupational injury surveillance. WC claims narratives often have insufficient detail to identify causal factors or to allow for precise coding of the nature of injury. Improving the quality of these narratives and integrating claims data with diagnostic coding would enhance the usefulness of WC data for occupational injury surveillance and prevention research.

Safety climate

An underlying question in small business research is if safety climate measures can be used to create safer work environments. [Parker et al., 2007] Safety climate measures collected from workers and owners in the NMGP were not predictive of workplace hazards or safety management practices such as safeguarding equipment, worker training, or written programs. Similarly, Neitzel et al, found an inverse relationship between compliance with safety regulations as measured by an outside observer and safety climate. [Neitzel et al., 2008] In a review of safety climate in the construction trades, Schwatka et al., [2016] concluded that safety climate was often correlated with subjective measures of safety behavior rather than measures of ill health or objective measures of safety. A notable exception was work from Gershon et al. [2000] found a strong relationship between self-reported work practices and measures on safety climate among hospital healthcare workers.

The findings from Neitzel et al. [2008], and Schwatka et al. [2016] in conjunction with those from the MN-MGS, CARSS and the NMGP point to problems using safety climate measures as a means of fostering improvements in worker safety. In contrast, the presence of a functioning safety committee appears to be a good proxy for safety management practices observed during an independent audit of small businesses. This finding is consistent with our previous work in the smaller, regional MN-MGS, in which the presence of a safety committee was found to be a stronger indicator of safety audit performance than safety climate constructs [Parker et al., 2007]. Similarly, our work in small auto collision repair shops in the CARS study revealed a discrepancy between owners' perceptions of safety performance and actual conditions documented in site audits.

From a practical perspective, the presence of a safety committee is easily assessed and provides a clear basis on which to make recommendations with regard to how it functions (e.g., frequency of meetings, membership), whereas measures of safety climate fail to provide actionable information. Although safety climate constructs are poorly correlated with empirical measures of safety, it is equally clear that organizational structure is associated with improved worksite safety and the presence of important safety programs such as lockout/tagout. Based on data from the NMGP, it is more important to assess the presence or absence of programs and policies than worker or owner perceptions of their effectiveness. For example, the presence of a functional safety committee can be assessed with a few simple questions related to the presence or absence of regulatory programs and worker training.

VI. Conclusions

The NMGP represents an important step in translating the findings of a controlled trial carried out in a small region to a widely applicable pragmatic intervention program that can be integrated into the routine work of intermediary organizations and small businesses. Future research should evaluate whether or not gains such as those achieved in the NMGP are independently sustained by small businesses with minimal ongoing assistance. Work also needs to be done on developing effective outreach programs that do not require time-consuming, costly on-site consultative services.

The NMGP highlights the need for a nationwide effort to improve many aspects of machine safety within small industrial firms. Sustainable improvements would substantially reduce risk for serious workplace trauma and work-related fatalities. The NMGP provides a

framework for comprehensively auditing and improving risk management practices and demonstrates the central role of worker participation and representation. An important first step is to improve or implement worker-management safety programs.

The NMGP demonstrated the importance of having or adding a safety committee in improving summary measures of machine safety. Businesses with a safety committee had the highest baseline and follow-up summary scores. Business that added a safety committee improved summary scores substantially more than those that started and ended without one. Regardless of size, adding a safety committee was likely to result in substantially more improvement than not doing so.

NMGP data indicate the need for a nationwide effort to improve the management and performance of LOTO within small industrial firms. Improving LOTO could substantially reduce serious workplace trauma and work-related fatalities. This intervention provides a framework for enacting improvements in LOTO practice, having demonstrated large and statistically significant improvements in a nationwide sample.

The results of this study are likely to be applicable to a broad range of manufacturing businesses such as plastic molding, food processing, woodworking, and other industries where large machinery is used. OSHA citations, serious traumatic injuries, and fatalities related to LOTO within these industries are commonplace and indicative of a widespread problem [OSHA 2015a; 2015b].

With regard to occupational safety and health research in small-scale enterprises, there is a need to fund long-term pragmatic intervention studies. The NMGP represents an important step in translating the findings of a controlled trial carried out in a small region to a widely applicable intervention program that can be integrated into the routine work of intermediary organizations and small businesses. Future research should evaluate whether or not gains such as those achieved in the NMGP are independently sustained by small businesses with minimal ongoing assistance. Work also needs to be done on developing effective outreach programs that do not require in-person time-intensive consultative services. A first step on this work was the development and testing of a LOTO self-audit at ten manufacturing firms as a part of this study. By removing the need for costly on-site visits from external auditors, this audit instrument can help overcome barriers of geography and cost in assessing LOTO practices at large numbers of manufacturing businesses.

Publications

Parker DL, Yamin SC, Xi M, Stanley R, Most I. [2017] Findings from the National Machine Guarding Program: Safety climate, hazard assessment, and safety leadership in small metal fabrication businesses. Under review at J Occup Environ Med. 2017. [Appendix 1]

Yamin SC, Parker DL, Xi M, Stanley R. [2017] Self-audit of lockout/tagout in manufacturing workplaces: A pilot study. Am J Ind Med. 2017;9999:1–6. <https://doi.org/10.1002/ajim.22715> [Appendix 2]

Parker DL, Yamin SC, Xi M, Brosseau LM, Gordon R, Most IG, Stanley R. [2016] Findings From the National Machine Guarding Program-A Small Business Intervention: Machine Safety. J Occup Environ Med. 2016 Sep; 58(9): 885-91.

Yamin SC, Bejan A, Parker DL, Xi M, Brosseau LM. Analysis of workers' compensation claims data for machine-related injuries in metal fabrication businesses. [2016] Am J Ind Med. 2016 Aug; 59(8): 656-64.

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Parker DL, Yamin SC, Brosseau LM, Xi M, Gordon B, Most I, Stanley R. [2015] National Machine Guarding Program – Part 1: Machine safeguarding practices in small metal fabrication businesses. Am J Ind Med. 2015 Nov; 58(11): 1174-83.

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Yamin S, Parker D, Brosseau L, Gordon B, Xi M. National Machine Guarding Program: Design of a machine safety intervention. [2014] Safety Science Monitor [Sweden]. 2014, 18(1) <http://ssmon.chb.kth.se/index.php/volume-18/issue-1>

[View Burden Statement](#)

PHS Inclusion Enrollment Report

OMB Number: 0925-0001 and 0925-0002

This report format should NOT be used for collecting data from study participants.

Expiration Date: 10/31/2018

*Study Title (must be unique):

* Delayed Onset Study? Yes No

If study is not delayed onset, the following selections are required:

- Enrollment Type Planned Cumulative (Actual)
- Using an Existing Dataset or Resource Yes No
- Enrollment Location Domestic Foreign
- Clinical Trial Yes No
- NIH-Defined Phase III Clinical Trial Yes No

Comments:

Racial Categories	Ethnic Categories									
	Not Hispanic or Latino			Hispanic or Latino			Unknown/Not Reported Ethnicity			Total
	Female	Male	Unknown/Not Reported	Female	Male	Unknown/Not Reported	Female	Male	Unknown/Not Reported	
American Indian/ Alaska Native	5	16	0	0	0	0	0	0	0	21
Asian	16	95	0	0	1	0	0	0	0	112
Native Hawaiian or Other Pacific Islander	0	2	0	0	0	0	0	0	0	2
Black or African American	14	63	0	0	0	0	0	0	0	77
White	367	2,680	5	1	7	0	0	0	0	3,060
More than One Race	11	74	0	1	5	0	0	0	0	91
Unknown or Not Reported	5	61	0	49	127	0	1	20	99	362
Total	418	2,991	5	51	140	0	1	20	99	3,725

Report 1 of 1

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Materials available for other investigators

The following data collection instruments described in this report can be obtained by contacting the PI:

- 1) Safety management audit checklist
- 2) Safety climate survey in English or Spanish
- 3) LOTO self-audit checklist
- 4) Machine safeguarding checklists for specific metal-working machines:

Milling/drilling/boring machines

Drill press

Lathe -- horizontal

Mill -- vertical or horizontal

Cutting/shearing/sawing machines

Bandsaw -- vertical

Bandsaw -- horizontal

Ironworker

Metal shear

Presses

Hydraulic power press -- manual feed

Hydraulic power press -- automatic feed

Mechanical power press -- manual feed:

 full revolution clutch press

 partial revolution clutch press

Mechanical power press -- automatic feed

Turret punch press

Sanding/grinding machines

Precision honing machine

Belt sander

Disc sander

Pedestal grinder

Surface grinder

Screw machines

Screw machine

Computer numerically controlled (CNC) lathe

CNC mill

Other Metal-Forming Machines

Roll forming machine

Hydraulic press brake

Mechanical press brake

Laser cutting machine

Electrical discharge machinery (EDM)

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Findings from the National Machine Guarding Program: Safety climate, hazard assessment, and safety leadership in small metal fabrication businesses
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Abstract:	<p>Objectives: The National Machine Guarding Program (NMGP) was an intervention designed to improve machine safety in small metal-fabrication businesses.</p> <p>Methods: Baseline safety climate surveys were completed by 2161 employees and 341 owners or managers at 115 businesses. A separate onsite audit of safety management practices and machine guarding equipment was conducted at each business.</p> <p>Results: Safety climate measures were not correlated with machine guarding or safety management practices. The presence of a safety committee was correlated with higher scores on the safety management audit when contrasted with those without one.</p> <p>Conclusions: The presence of a safety committee is easily assessed and provides a basis on which to make recommendations with regard to how it functions. Measures of safety climate fail to provide actionable information. Future research on small manufacturing firms should emphasize the presence of an employee-management safety committee.</p>

Abstract

Objectives: The National Machine Guarding Program (NMGP) was an intervention designed to improve machine safety in small metal-fabrication businesses.

Methods: Baseline safety climate surveys were completed by 2161 employees and 341 owners or managers at 115 businesses. A separate onsite audit of safety management practices and machine guarding equipment was conducted at each business.

Results: Safety climate measures were not correlated with machine guarding or safety management practices. The presence of a safety committee was correlated with higher scores on the safety management audit when contrasted with those without one.

Conclusions: The presence of a safety committee is easily assessed and provides a basis on which to make recommendations with regard to how it functions. Measures of safety climate fail to provide actionable information. Future research on small manufacturing firms should emphasize the presence of an employee-management safety committee.

Introduction

Numerous studies discuss the importance of measuring safety climate in order to improve workplace safety.¹⁻⁵ Safety climate has been defined as workers' shared perceptions of safety policies, procedures, and practices as well as the overall importance attributed to safety by an organization.^{4,6} Factors influencing safety climate may include management's commitment to safety, return-to-work policies, post-injury administration, and safety training.

Data are needed to clearly describe the nature of safety practices within small-scale enterprises and how they are reflected in the knowledge and beliefs of both employees and owners.⁷ Data from large corporations indicate that, as worker perceptions of health and safety increase, they are correlated with lower injury rates.⁸ However, it is unclear if and how findings from large companies are applicable to small enterprises.⁹ In addition, we can find few studies that assess safety climate within small enterprises.¹⁰ Rather, most studies have focused on the qualitative assessment of small businesses using focus groups or key informant interviews.^{11,12}

Our previous work showed that small businesses with safety committees performed better on an independent assessment of hazard control on a wide range of metal fabrication machines than businesses without one.^{10,13} We also demonstrated that even modest investment of resources on the part of businesses facilitated the improvement of machine-related hazards and substantially improved lockout and tagout (LOTO).^{10,14} Neitzel et al found that measures of safety climate were at times negatively correlated with safe work practices; however, their work was conducted in large manufacturing facilities.¹⁵

This manuscript examines the relationship between safety climate as reported by workers and owners and an independent business safety assessment conducted by insurance safety risk consultants. Our null hypothesis was that, after accounting for the presence of a safety

committee, safety climate measures would not be correlated with business safety practices. Findings utilized baseline data obtained as part of the NMGP, a National Institute for Occupational Safety and Health (NIOSH)-sponsored R01 grant initiative.

Methods

The institutional review board (IRB) of the Park Nicollet Institute approved all study methods and materials. Informed consent was obtained from each business owner before enrollment. The IRBs exempted the safety climate survey from signed consent because identifying information was not obtained. An information sheet was included with each survey advising employees of their right to decline participation.

Eligibility and recruitment

Safety consultants employed by 2 insurance companies recruited businesses from their workers' compensation client base. Businesses were eligible to participate if they had 3 to 150 employees, earned at least 75% of revenue through metal fabrication, and maintained a workers' compensation policy with a participating insurer. Once enrolled in the machine guarding intervention, owners were given the choice of having their company participate or not participate in the safety climate survey.

Measures of safety climate

Insurer A requested that the survey be limited to 2 pages to ensure completion and ease of use. Safety climate was measured using an abbreviated version of a survey developed by the British Health and Safety Executive and comprehensively described by Cheyne et al.^{16,17} The

survey had 9 constructs, with 2 questions per construct (Table 1). Questions were answered on a scale of 1 (strongly disagree) to 5 (strongly agree). Demographic data included age, gender, education, language preference, and primary job activity. The initial survey was written in English, subsequently translated into Spanish, and reviewed for accuracy and back translation.

Survey distribution and data collection

An encrypted identification number unique to each business was embedded into a barcode on the surveys. Surveys were then printed on a machine-readable form and provided to the business by the insurer a week before, and returned no more than 2 weeks after, the baseline visit. The owner or manager was responsible for having shop employees complete the survey and place their individual surveys in a sealed envelope. Surveys were returned by employers to the safety consultant in person or via US mail. The insurer then mailed the surveys to research staff. After inspection for errors or damage, surveys were optically scanned.

Onsite business safety audit

At baseline, 12 machines were randomly selected for a standardized onsite assessment of machine safeguarding.^{8,9} Checklists assessed 4 types of hazards: equipment safeguards, LOTO procedures, electrical, and work environment. Checklists varied by machine type and contained 25 to 35 questions, depending on the complexity of the machine.⁸⁻¹² All checklists had been validated for inter-rater reliability.^{13,18}

A separate safety management audit checklist was completed during an interview with the owner or the owner's representative (Figure 1). The safety management audit addressed safety leadership, machine maintenance, and LOTO. For all checklist items, a "yes" response

meant that the presence of a safeguard, policy, or written document was verified by the evaluator. Results from the machine and safety management audits were transmitted electronically from field sites to the research team.

Data analysis

Data collected using the machine safety checklists were used to calculate a business-level machine score. The number of “yes” responses was divided by the number of “yes” plus “no” responses for each machine and scaled to 100%. Next, a business-level machine score was calculated by adding the scores for each machine and dividing by 12 — the number inspected in each business.

An overall safety management audit score was created using 25 questions from the safety management audit. In addition, sub-scores were created for safety leadership, machine maintenance, and LOTO. Scores were calculated as the number of items present divided by the total number of items multiplied by 100.

- Safety leadership and risk management: Twelve questions assessed safety leadership practices, programs, and policies. These were defined as a formal, organized structure within which employees and management cooperatively identify, evaluate, and remediate hazards.
- Machine maintenance programs and policies: Eight questions assessed the documentation of periodic inspection of machines to ensure they were effectively guarded for safe operation.
- LOTO program: Five questions assessed compliance with Occupational Safety and Health Administration (OSHA) standard 1910.147 to ensure safe control of hazardous

energy, commonly known as the LOTO standard. OSHA requires that each business have a comprehensive written LOTO program. A LOTO procedure is a series of steps to safely shut down and restart machines.

Internal consistency of the safety climate constructs was evaluated using Cronbach's alpha. A score for each of the 9 safety climate constructs was determined by adding responses for both questions within that construct. Each pair of questions had a minimum score of 2 and a maximum score of 10. Scores were summed within shops and then averaged for the number of respondents. Separate analyses were conducted for employees and owner/managers within each shop. Analysis included the computation of means, standard deviations, t-tests, and Chi-squares. Simple multiple regression was used to assess the impact of safety climate scores, the presence or absence of a safety committee, and the overall safety leadership as well as the overall machine guarding scores.

Results

A total of 221 businesses agreed to participate in the baseline assessment. Safety climate surveys were returned by 132 (60%). There were no differences in the overall shop score, business-level machine score, the presence of LOTO programs or procedures, the presence of safety committees, number of years in business, or number of employees between businesses that did and did not participate in the safety climate survey ($P > 0.4$ for all measures).

For the 132 shops that returned surveys, both workers and at least 1 owner/manager completed surveys in 115 and only workers in 17. Analysis was done using these 115 shops. A total of 47 of 115 (41%) shops had a safety committee. As the number of employees increased from 2-10, 11-29, 30-49, and 50-150, the presence of a safety committee went from 4 of 22

(18%), 12 of 43 (28%), 12 of 23 (52%) to 19 of 27 (68%) (P -trend < 0.001) businesses, respectively.

After eliminating 28 surveys that could not be identified as coming from an owner or employee, the final analysis was completed on 2502 individuals, including 2161 employees (86%) and 341 owners or managers (14%). The response rate for workers was 59% (2164 of 3646) for employees in the 115 shops. A response rate was not calculated for owners and managers, as the denominator could not be obtained, and only 1 survey was sought per business. The intra-class correlation coefficient (ICC) was 0.1 for workers and 0.21 for owners, indicating substantial differences in individual responses within shops. The ICC did not change appreciably between shops with fewer than 10 and 10 or more employees.

As seen in Table 1, for employees, Cronbach's alpha ranged from a high of 0.84 for management commitment and priority of safety to a low of 0.29 for safety training. For owners/managers, it ranged from 0.84 for management commitment to 0.28 for safety training.

Table 2 shows the demographic characteristics for shop workers (N=2161) and owners/managers (N=341) who completed safety climate surveys. Safety climate measures in Table 2 are averaged at the individual level. Sixty-two percent of employees classified themselves as machinists, and most workers and owners had completed high school. For workers, 36% completed at least some college, and 27% graduated from technical school, compared with 46% and 22%, respectively, for owners. For workers, there was no difference in safety climate measures based on level of education. Spanish surveys were completed by 26 workers, most of whom were men (58%) and machinists (81%). Most Hispanic workers had completed high school (15 [58%]), and 2 (8%) had graduated from technical college (data not shown in table).

Owners with less than a high school education had lower safety climate scores than those with more education. However, significance was not calculated due to low numbers (N=7). For both owners and workers, there was no difference in safety climate measures based on age. Further analysis of workers was confined to the 1977 individuals who worked in the shop, the original target population for the safety climate survey. For workers, scores declined from a high of 88% to 84%, 84%, and 83% for those working at the company <1, 1-4, 5-9, and ≥ 10 years, respectively (P -trend < 0.0001). A minimal but reverse trend was seen for owners whose scores for these same 4 categories were 87%, 88%, 87%, and 90% (P -trend = 0.0003).

Safety climate measures in Tables 3 to 7 were averaged at the shop level, accounting for the small differences in the overall safety climate score in Tables 2 and 3. Table 3 contrasts the safety climate constructs for owners/managers and employees. Owners consistently rated their enterprises more favorably than did workers.

Table 4 shows safety climate scores by business size. As size increased, there was a consistent trend towards lower safety climate measures. A negative and statistically significant downward trend was seen for all constructs except involvement in safety. This trend was consistent across all size ranges. The largest difference was seen for management commitment, which went from 8.8 in the smallest shops to 7.8 in the largest shops. Involvement was the construct that did show significant differences by business size range.

As shown in Table 5, there were slight differences in safety climate measures when stratified by the overall machine score for each shop. Management commitment, priority of safety, and safety discipline were all associated with a slight but statistically significant increase in summary measures ($P < 0.01$).

Table 6 shows the overall safety climate score stratified by quartile of the overall safety management audit, safety leadership, machine maintenance, and LOTO program scores. There were minimal differences in safety climate measures between businesses in the lowest and highest quartiles (P -trend > 0.5 for all measures). As seen in Table 7, the presence or absence of a safety committee made minimal and contradictory differences in safety climate measures.

Multiple regression was used to assess the relationship between the summary safety climate score and summary measures for safety leadership, machine maintenance programs, and LOTO programs. When controlling for shop size and safety committee, an increasing safety climate score was not correlated with the safety leadership score ($P = 0.48$), machine maintenance program score ($P = 0.43$), or LOTO program score ($P = 0.74$).

Next, based on our a priori hypothesis that the presence of a safety committee was associated with an improvement in shop safety, multiple regression was used to assess the impact of the overall safety climate score and the presence or absence of a safety committee.

A total of 47 of 115 (41%) businesses had a safety committee. Using multiple regression with the overall safety audit score as the dependent variable, an increasing safety climate score showed no correlation with the overall safety audit score ($P = 0.47$) while controlling for both shop size and safety committee. However, the presence of a safety committee resulted in a 16% increase ($P = 0.0003$) in the overall safety audit score while controlling for the effect of shop size and overall safety climate score as well as 21% ($P < 0.0001$) percentage point increases in safety leadership, 4% ($P = 0.51$) in machine maintenance program score, and 22% ($P = 0.004$) in LOTO program score.

Discussion

In the NMGP, safety climate for workers and owners was poorly correlated with workplace hazards or safety management practices such as safeguarding equipment, worker training, or written programs. In contrast, the presence of a functioning safety committee appears to be a good proxy for safety management practices observed during an independent audit of small businesses. This finding is consistent with data from the MN-MGS, in which the presence of a safety committee was a stronger indicator of safety audit performance than safety climate.²⁰ Similarly, our work in small auto collision repair shops revealed a discrepancy between owners' and workers' perceptions of safety performance and actual conditions documented in site audits.¹⁰

Few studies have simultaneously measured safety practices and safety climate. Neitzel et al found an inverse relationship between compliance with safety regulations as measured by an outside observer and safety climate.¹⁵ In a review of safety climate in the construction trades, Schwatka et al concluded that safety climate was related to subjective measures of safety behavior rather than measures of ill health or objective safety and health outcomes.^{19,20} A notable exception was work from Gershon et al, who found a strong relationship between self-reported work practices and measures of safety climate among hospital healthcare workers.¹⁹

The difference in the utility of safety climate measures between small and large businesses may, in part, be accounted for by the human resource management practices that facilitate the creation and maintenance of a safe work environment. These practices become more structured as business size increases.²¹⁻²³ Survey and focus group data show that many small businesses lack a defined structure for managing health and safety, which parallels — or, in fact, may simply reflect — the lack of technical knowledge necessary to develop and implement formal human resource practices.^{9,23-25} Health and safety problems related to a lack of

human resources capacity are compounded by a lack of access to good information, as well as unawareness of the scope of regulations with which a business must comply.^{14,26}

As firms grow, there is an increasing need to formalize human resource management practices.²⁷ From the vantage point of business development, formal human resources practices enhance employee perception of fairness and may lead to greater levels of employee commitment, especially in enterprises in which employee satisfaction may be low.^{28,29}

Focus groups indicate that owners believe it is their responsibility to ensure they are doing all they can to create a safe work environment.²⁴ This belief is supported by safety climate data in which owners consistently rate their safety performance quite highly. However, in the NMGP, only 28 of 88 (32%) businesses with < 50 employees had a safety committee. In a Canadian survey of business with ≤ 50 employees (N = 223), only 5% had a safety committee.⁹ The contrast between what is reported by owners in focus groups and safety climate surveys and what is taking place within businesses may arise because owners often downplay the distinctions between themselves and their employees.¹¹ This may lead owners to see their commitment to safety in a more favorable light than do employees.

Seen another way, small companies usually have a flat organizational structure in which workers feel some personal responsibility for the success or failure of the business as a whole.³⁰ A flat organizational structure is likely to diminish as companies grow, with the concomitant result of lower worker perception of safety climate as seen in the NMGP (Table 4). It may be impossible to disentangle the interaction between social relations at work and perceptions of health and safety in small enterprises. If this is the case, while hypothetical, the higher safety climate scores seen in the smallest enterprises in the NMGP when contrasted with their larger

peers are more a reflection of interpersonal relationships than they are of health and safety practices.³¹

This paper has several limitations. First, this was not a random sample of businesses. Most owners see receiving a benefit as prerequisite to participation in a study. If there is no perceived benefit, they decline participation. Ethically, we believe it is necessary to provide baseline results to owners and employees, along with materials to help remediate serious hazards. In our previous work, we showed that even a minimal intervention may result in change.³²

Second, the wide geographic reach in the NMGP necessitated that owners distribute safety climate surveys to employees. It is unknown if this may have impacted employee responses; however, the names of individuals and businesses were not collected, and respondents were provided an envelope in which to place and seal their surveys. Third, there was a low Cronbach's alpha for 3 and a moderate Cronbach's alpha for 2 of 9 constructs. This may stem from having only 2 questions per construct. Regardless, these values draw into question the internal validity of several measures.

Last, our previous work showed a relationship between improving self-reported work practices and improving scores for the safety climate construct for rules and procedures. However, no relationship was found between overall safety climate measures and self-reported work practices.¹⁰ We were unable to measure self-reported work practices in the NMGP because one of our partners felt a survey that exceeded 2 pages would be poorly received by employers.

Conclusions

Based on data from the NMGP, it is more important to assess the presence or absence of programs and policies than worker or owner perceptions of their effectiveness. From a practical perspective, the presence of a safety committee is easily assessed and provides a clear basis on which to make recommendations with regard to how it functions (e.g., frequency of meetings, membership), whereas measures of safety climate fail to provide actionable information. Safety, much like productivity, improves with employee participation. For example, regular employee meetings, self-management teams, profit sharing, and skill development have been shown to increase productivity.³³

To our knowledge, the NMGP is the single largest assessment of safety climate in small businesses. We were able to stratify findings over businesses ranging from 3 to 150 employees. The failure to find useful relationships between safety climate and more robust measures of safety leads us to conclude that safety climate assessment is unlikely to provide small business researchers with helpful information and/or a framework with which to guide research and/or intervention efforts. Future research should emphasize the presence of a well-functioning safety committee — a practical intervention point that is readily assessed.

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Figure 1: Safety Management Audit Form

Figure 1: Safety Management Audit

Business Name: _____ Today's Date: _____

Yes	No	N/A	
Safety leadership practices			
			Is one employee or manager designated as responsible for safety issues?
			Is there a formal committee that discusses safety?
<i>If "yes", answer the next 2 questions:</i>			
			Does this committee meet at least quarterly?
			Are minutes from committee meetings posted? (Verify by seeing documentation.)
			Are safety issues discussed at least quarterly at meetings that include all employees?
			Is there a formal method for obtaining employee input on safety?
Risk management programs and policies			
			Is there a written policy stating the consequences of failing to follow safety procedures? (Verify.)
			Is there a designated employee to whom injuries are reported?
			Is there a written policy requiring that employees promptly report all injuries?
			Is a written investigation conducted for each injury?
			Is a written investigation conducted for near-misses?
			Is there a policy requiring that everyone wear safety eyewear in the shop?
Machine safeguarding programs and policies			
			Are machine safety audits conducted at least annually? (Verify by seeing documentation.)
			Are machine maintenance inspections conducted at least every 60 days?
			Is power outage (anti-restart) protection in place for each machine?
			Are records kept showing that emergency stops are regularly inspected and tested? (Verify.)
			Does the shop have written machine guarding policies/procedures? (Verify.)
			Is there a brief audit checklist for setup of each machine? (Verify.)
			Are light curtains or other presence-sensing devices used anywhere in the shop for machine safeguarding?
<i>If "yes", answer the next question:</i>			
			Is there documentation that blanking is compliant with OSHA table 0-10, or that stop-time analyses are performed, or both? (Verify.)
Lockout/tagout (LO/TO) program			
			Does the shop have a written LO/TO program? (Verify.)
			Does the LO/TO program designate "authorized" employees? (Verify.)
			For each lock issued to an "authorized" employee, is there just one key that opens that lock? (Verify.)
			Are there records verifying that all employees are trained in LO/TO? (Verify.)
			Are there records of annual audits verifying the effectiveness of written LO/TO procedures for each machine? (Verify.)

Table 1: Cronbach's alpha for nine safety climate constructs

Construct	Definition	Cronbach's alpha		
		All respondents (n=2502)	Workers (n=2164)	Owners (n=338)
Management commitment	Perceptions of management's commitment to addressing health and safety issues.	0.84	0.84	0.81
Communication	Perception about how well safety information is communicated within a business.	0.75	0.75	0.66
Priority of safety	The importance of health and safety issues within the business.	0.83	0.83	0.86
Safety rules and procedures	Views on the efficacy and necessity of rules and procedures.	0.61	0.62	0.58
Work environment	Perceptions of the nature of the physical environment.	0.74	0.74	0.73
Supportive environment	The nature of the social environment at work and the support derived from it.	0.64	0.64	0.44
Safety training	Employee understanding of personal risks and responsibilities.	0.29	0.28	0.30
Safety discipline	Employee understanding of expectations and rules for safety.	0.56	0.56	0.50
Involvement	The extent to which safety is a focus for everyone, and all are involved.	0.51	0.52	0.34

Table 2: Demographic characteristics and average safety climate measures for all respondents

Characteristic		All Employees			Owner/manager		
		Number	%	Summary safety climate score (SD)	Number	%	Summary safety climate score (SD)
All workers		2164		84.6 (11.9)	338		89.2 (9.4)
Gender	Male	1834	86.6	84.3 (11.9)	304	92.1	89.2 (9.5)
	Female	284	13.4	86.5 (11.0)	26	7.9	88.6 (9.5)
Job title	Machinist	1346	62.2	84.1 (12.2)			
	Engineer/electrician	97	4.5	87.0 (11.5)			
	Other shop duties	534	24.7	84.6 (11.4)			
	Does not work in shop	187	8.6	87.2 (10.5)			
	Owner	---		---	145	42.9	90.7 (8.7)
	Manager	---		---	193	57.1	88.1 (9.8)
Education	< High school	122	5.7	85.3 (11.6)	7	2.1	80.6 (9.0)
	High school	1252	58.2	84.4 (11.9)	167	49.6	89.2 (9.8)
	At least some college	777	36.1	84.6 (11.9)	163	48.4	89.7 (8.9)
Technical education	No technical school	1133	52.7	84.6 (11.7)	145	42.9	88.9 (9.6)
	Some technical school	435	20.3	84.9 (11.8)	73	21.6	89.1 (8.3)
	Technical graduate	580	27.0	84.2 (12.2)	120	35.5	89.7 (9.9)
Age (years)	< 25	227	10.7	85.8 (10.7)	5	1.5	86.2 (9.1)

	25-40	678	32.0	84.3 (12.4)	89	26.9	88.4 (9.9)
	41-54	798	37.7	84.2 (12.0)	166	50.2	89.0 (9.4)
	≥ 55	414	19.6	85.6 (10.7)	71	21.5	91.0 (7.9)

Table 3: Comparison of average shop-level of safety climate measures between workers and owners/managers

Safety climate constructs	Mean safety climate score		P-value, difference between groups
	Workers mean (SD)	Owner/managers mean (SD)	
Overall score	86.8 (5.3)	89.5 (7.4)	<0.0001
Management commitment	8.6 (0.9)	8.7 (1.3)	0.053
Communication	8.8 (0.7)	9.0 (1.0)	0.006
Priority of safety	8.6 (0.9)	8.9 (1.3)	0.0005
Safety rules and procedures	7.5 (1.0)	7.5 (1.8)	0.55
Work environment	8.7 (0.8)	8.9 (1.2)	0.001
Supportive environment	8.6 (0.7)	9.3 (0.8)	<0.0001
Safety training [Personal appreciation of risk]	8.6 (0.6)	8.9 (1.0)	<0.0001
Safety discipline	9.4 (0.4)	9.6 (0.6)	<0.0001
Involvement [Personal priorities and need for safety]	9.6 (0.3)	9.8 (0.4)	<0.0001

Table 4: Average shop-level worker safety climate scores by business size

Safety climate constructs	Business size				
	2-10	11-29	30-49	50-150	
	Safety Climate Score				
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	<i>P</i> -trend
Overall score	89.3 (5.9)	87.4 (5.1)	87.3 (2.7)	82.4 (4.3)	<0.0001
Management commitment	9 (1)	8.7 (0.8)	8.6 (0.5)	7.7 (0.6)	<0.0001
Communication	9.3 (0.7)	8.8 (0.7)	8.8 (0.4)	8.1 (0.6)	<0.0001
Priority of safety	9.1 (1)	8.7 (0.8)	8.6 (0.5)	7.9 (0.7)	<0.0001
Safety rules and procedures	7.2 (1.4)	7.7 (0.8)	7.6 (0.6)	7.2 (0.6)	0.70
Work environment	9.2 (0.8)	8.7 (0.7)	8.7 (0.5)	8 (0.7)	<0.0001
Supportive environment	8.8 (1)	8.6 (0.7)	8.8 (0.3)	8.3 (0.5)	0.06
Safety training [Personal appreciation of risk]	8.8 (0.7)	8.6 (0.6)	8.5 (0.4)	8.3 (0.5)	0.002
Safety discipline	9.5 (0.6)	9.5 (0.4)	9.4 (0.3)	9.2 (0.3)	0.04
Involvement [Personal priorities and need for safety]	9.5 (0.4)	9.6 (0.3)	9.7 (0.2)	9.5 (0.1)	0.78

Table 5

Table 5: Average shop-level worker safety climate scores and quartile of business-level machine score

Safety climate constructs	Safety climate scores by quartile of business-level machine score				
	1st (45%-69%)	2nd (70%-74%)	3rd (75%-78%)	4th (79%-97%)	P- trend
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	
Overall score	85.9 (5.4)	87.2 (5.6)	86.7 (4.6)	87.9 (5.6)	0.23
Management commitment	8.4 (1)	8.7 (0.9)	8.6 (0.9)	8.8 (0.8)	0.19
Communication	8.7 (0.6)	8.9 (0.8)	8.8 (0.7)	8.8 (0.8)	0.83
Priority of safety	8.4 (0.9)	8.7 (0.8)	8.7 (0.9)	8.7 (0.8)	0.26
Safety rules and procedures	7.6 (0.6)	7.3 (1)	7.1 (1.2)	7.9 (0.9)	0.64
Work environment	8.7 (0.7)	8.7 (0.9)	8.7 (0.9)	8.6 (0.7)	0.74
Supportive environment	8.5 (0.7)	8.6 (0.6)	8.8 (0.6)	8.7 (0.8)	0.29
Safety training [Personal appreciation of risk]	8.5 (0.6)	8.5 (0.6)	8.6 (0.6)	8.6 (0.6)	0.67
Safety discipline	9.3 (0.6)	9.4 (0.4)	9.5 (0.3)	9.4 (0.4)	0.49
Involvement [Personal priorities and need for safety]	9.5 (0.3)	9.6 (0.3)	9.6 (0.2)	9.6 (0.4)	0.28

Table 6

Table 6: Average shop-level worker safety climate scores by quartile for the overall safety management score and each of its 3 component parts.

Component of the Safety Management Audit Checklist	Quartile for the Overall and Components of the Safety Management Audit Checklist*				
	1st	2nd	3rd	4th	P-trend
	Overall Safety Climate Score				
Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)		
Overall safety management audit score	86.7 (5.4)	87.3 (5.4)	85.0 (5.3)	88.1 (4.2)	0.87
Safety leadership score	87.6 (5.7)	85.9 (3.7)	85.9 (4.9)	87.6 (5.9)	0.94
Machine maintenance program score	86.1 (6.7)	88.1 (4.2)	85.5 (5.2)	87.0 (5.6)	0.69
LOTO program score	87.4 (3.8)	85.8 (4.3)	84.8 (6.1)	87.3 (4.5)	0.51

*The quartile ranges changes slightly for each of the four measures.

Table 7: Average shop-level worker safety climate scores by safety committee status at baseline

Safety climate construct	Safety committee status at baseline		
	Absent (n = 68)	Present (n = 47)	<i>P</i> -value
	Mean (SD)	Mean (SD)	
Overall score	87.3 (5.4)	86.1 (5)	0.25
Management commitment	8.7 (0.9)	8.5 (0.8)	0.34
Communication	8.9 (0.7)	8.6 (0.7)	0.07
Priority of safety	8.7 (0.9)	8.5 (0.8)	0.25
Safety rules and procedures	7.5 (1.1)	7.4 (0.8)	0.65
Work environment	8.8 (0.7)	8.5 (0.8)	0.14
Supportive environment	8.6 (0.8)	8.7 (0.5)	0.86
Safety training [Personal appreciation of risk]	8.6 (0.6)	8.5 (0.6)	0.48
Safety discipline	9.4 (0.5)	9.4 (0.4)	0.57
Involvement [Personal priorities and need for safety]	9.6 (0.3)	9.6 (0.3)	0.66

The National Machine Guarding Program provides safety climate data on small businesses. The effect of safety climate on measures of safety management practices and machine guarding is compared with the effect of a safety committee on those same outcomes. A safety committee is a better predictor of workplace hazards and safety programs.

Self-audit of lockout/tagout in manufacturing workplaces: A pilot study

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Background: Occupational health and safety (OHS) self-auditing is a common practice in industrial workplaces. However, few audit instruments have been tested for inter-rater reliability and accuracy.

Methods: A lockout/tagout (LOTO) self-audit checklist was developed for use in manufacturing enterprises. It was tested for inter-rater reliability and accuracy using responses of business self-auditors and external auditors.

Results: Inter-rater reliability at ten businesses was excellent ($\kappa = 0.84$). Business self-auditors had high (100%) accuracy in identifying elements of LOTO practice that were present as well those that were absent (81% accuracy). Reliability and accuracy increased further when problematic checklist questions were removed from the analysis.

Conclusions: Results indicate that the LOTO self-audit checklist would be useful in manufacturing firms' efforts to assess and improve their LOTO programs. In addition, a reliable self-audit instrument removes the need for external auditors to visit worksites, thereby expanding capacity for outreach and intervention while minimizing costs.

KEYWORDS

audit, lockout/tagout, machine safety, manufacturing, occupational health, safety management

1 | INTRODUCTION

An occupational safety and health (OHS) self-audit is an assessment of workplace hazards, controls, programs, and documents performed by a business owner or employee. OHS self-auditing has been promoted as an effective means for businesses to improve, track, and maintain workplace safety and minimize hazards independent of external assistance.^{1,2} A 1999 survey of U.S. industrial and construction firms conducted by the Occupational Safety and Health Administration (OSHA) found that 85% reported performing at least an annual evaluation or audit of safety practices.¹ OSHA recommends that employers regularly conduct workplace inspections and compliance audits, and use the results to guide safety and health programs.²

Despite their widespread use in industrial firms, there is little research available on the inter-rater reliability of OHS audit tools.³⁻⁵ An audit instrument with good inter-rater reliability yields consistent results when used at the same workplace by two or more knowledgeable users. Among

comprehensive OHS management audits tested, inter-rater reliability is often low^{4,6-8} casting doubt on their usefulness.

Several self-audit tools have been developed to target specific occupational settings. These include automobile collision repair shops,⁹ residential construction sites,¹⁰ and farm tractor cabs.¹¹ These trade-specific audit tools have provided better results with regard to inter-rater reliability^{10,11} than broader audits assessing a wide range of hazards. However, problems remain with regard to accuracy,⁹ that is, workers' ability to correctly identify hazards and controls with the audit tool.

In our prior work,^{12,13} we assessed inter-rater reliability of instruments designed to allow trained research and field staff to evaluate machine safety, including compliance with OSHA standard 1910.147 for control of hazardous energy, commonly known as the lockout/tagout (LOTO) standard.¹⁴ However, employee ability to self-audit was not assessed, leaving a gap related to providing both employers and workers a tool with which to assess hazards independent of outside expertise.

LOTO is a set of practices for preventing injury through systematic control of hazardous energy during maintenance and repair of machinery. The standard is applicable whenever inadvertent startup or other energization of a machine is a risk to employees performing machine maintenance or repair. The OSHA LOTO standard¹⁴ provides employers with a framework for a LOTO management program including employee training, designation of employees authorized to perform LOTO, development and auditing of machine-specific procedures, and proper LOTO equipment.

The failure to properly perform LOTO during machine maintenance and repair is an ongoing and serious risk to workers. Nationally, LOTO ranks among the most frequently cited OSHA standards.¹⁵ In manufacturing, the failure to implement LOTO contributed to 8% of fatalities and 15% of non-fatal catastrophic injuries investigated by OSHA for the period 2005-2014.¹⁶ Analysis of OSHA incident reports on 592 fatalities involving hazardous energy between 1984 and 1997 found that LOTO was attempted in only 6% of cases.¹⁷

In the National Machine Guarding Program (NMGP), a study of machine safety in metal fabrication firms, businesses had, on average, only 55% of core elements of a LOTO program in place at baseline and complete step-by-step LOTO procedures were available at fewer than 10% of machine workstations.¹⁸ The widespread absence of LOTO programs and procedures highlighted the need for a comprehensive instrument for the assessment of LOTO. This paper describes development and testing of a LOTO self-audit instrument for manufacturing workplaces. If found sufficiently reliable, a self-audit of LOTO would allow for assessment of large numbers of businesses across wide geographic areas without the cost of sending trained evaluators to each site. This would be an important component of future outreach efforts to reduce the impact of LOTO incidents on a national scale.

2 | MATERIALS AND METHODS

The Institutional Review Board (IRB) of Park Nicollet Institute approved all materials and methods. Consent to participate was obtained from each business owner or a representative.

2.1 | LOTO self-audit checklist development

Findings from the NMGP served as the starting point for developing a LOTO self-audit checklist. Questions from the NMGP machine safety audit covering LOTO programs and procedures^{13,18,19} were modified or expanded. Items on the shop safety committee were included based on our previous findings that the presence or addition of a safety committee was an important factor in improving LOTO practices at many businesses.¹⁸ Input was collected from machine safety experts, business owners, and employees authorized to perform LOTO. Additional questions were added in order to fully assess worksite compliance with the OSHA LOTO standard.¹⁴ The final checklist allowed owners and employers to conduct a comprehensive assessment of LOTO programs, LOTO procedures, and the safety committee.

After the LOTO self-audit checklist was developed, it was assessed for content validity, that is, how completely results reflected a business's implementation of the requirements of the OSHA LOTO standard. This was a two-step process consisting of review by a machine safety engineer and pre-testing at a technical college and a business. At each test site, research staff collected feedback from shop personnel on usefulness and applicability of checklist content, question format, and clarity of language.

The final LOTO self-audit checklist consisted of four sections (supplemental file 1):

- **Business demographics:** Ten questions covered basic demographic data such as the role of the employee completing the LOTO self-audit checklist, total number of employees at the business, type of business and North American Industry Classification System (NAICS) code, and union status.
- **LOTO programs:** Eight questions covered the presence and content of written LOTO programs including employee training and designation of employees authorized to perform LOTO.
- **LOTO procedures:** Eighteen questions covered the availability, content, and annual re-evaluation of machine-specific LOTO procedures, as well as equipment necessary to execute LOTO procedures such as locks, tags, and lockable disconnect switches.
- **Safety leadership:** Six questions covered the presence, composition, and activities of a safety committee.

2.2 | Business recruitment

Businesses were recruited in partnership with a workers' compensation insurance company and contacted by either the principal investigator (DP) or an insurance representative. Participation was not restricted by business size as defined by the number of employees, or by industrial sector, as long as the establishment was a private firm with stationary machinery covered by the OSHA LOTO standard.

2.3 | LOTO audit

At each business the self-auditor (the employee who completed the LOTO self-audit checklist) was provided with brief written instructions on performing the audit. A "yes" response to a question indicated that the specified LOTO document or equipment was both present and compliant with the OSHA LOTO standard. A "no" or "unsure" response meant that the item was missing, non-compliant, out-of-date, or not verifiable. For example, one shop manager stated that employees were trained in LOTO but could not locate a training sign-in log. Two items could be marked "not applicable" as they covered specific machines or equipment configurations not present at all sites.

An external auditor who was either a machine safety expert from the research team or a safety consultant from the insurer visited each participating business. Each business was given the option of completing the LOTO self-audit checklist in advance or on the day of the site visit. Within each business, the external auditor independently completed the audit and verified the presence of written programs by having a business representative retrieve documents such as written

programs, training records, and procedures. External auditors inspected production areas to assess LOTO equipment.

2.4 | Data analysis

Demographic variables were summarized using univariate statistics. For the LOTO audit, three category scores and an overall audit score were calculated for each business, based on the responses of self-auditors and external auditors. The overall score was based on 30 to 32 items per business. Scores were calculated as follows:

2.4.1 | LOTO program score

Number of "yes" responses ÷ total number of items (eight per business) × 100.

2.4.2 | LOTO procedure score

Number of "yes" responses ÷ total number of items (16 to 18 per business) × 100.

2.4.3 | Safety leadership score

Number of "yes" responses ÷ total number of items (six per business) × 100.

2.4.4 | Overall audit score

Number of "yes" responses ÷ total number of items (30 to 32 per business) × 100.

Basic descriptive statistics were used to compare percentage scores between business self-auditors and external auditors.²⁰ The kappa statistic was used to assess inter-rater reliability and the extent of random error. Kappa values were compared to accepted benchmarks for interpreting strength of agreement; a value of 0.80-1.00 indicates excellent agreement, 0.61-0.80 substantial agreement, and 0.41-0.60 moderate agreement.²¹

Accuracy was assessed by determining the ability of the business self-auditor to correctly identify items that were present and in compliance, and, separately, those that were absent or out of compliance with regulatory requirements. External evaluators' responses were used as the standard for accuracy. For items marked "no" by the external auditor, the self-auditor's accuracy was calculated as:

$$\left[\frac{\text{Number of "no" responses by self-auditor}}{\text{Number of "no" responses by external auditor}} \right] \times 100.$$

Similarly, for items marked "yes" by the external auditor, the self-auditor's accuracy was calculated as:

$$\left[\frac{\text{Number of "yes" responses by self-auditor}}{\text{Number of "yes" responses by external auditor}} \right] \times 100.$$

These measures were calculated for the overall audit, the three scoring categories (LOTO programs, LOTO procedures, and safety leadership), and for individual questions.

2.5 | Re-analysis

During the study, additional qualitative feedback on the LOTO self-audit checklist was collected in unstructured format from business self-auditors in order to identify problems with usability or content

validity. Six checklist items were identified as problematic and reviewed by the research team. Data were subsequently re-analyzed with those six items removed. Items removed prior to the re-analysis are indicated within the full 32-item checklist (supplemental file 1). Among the 26 items in the re-analysis one could be marked "not applicable."

3 | RESULTS

Ten businesses participated in the pilot study between April and September 2016. Five were enrolled in Minnesota by the research team, and five in Maine by the insurer. There were two external auditors in Minnesota and two in Maine. A range of individuals conducted the business self-audits: four were owners or senior managers, two were shop supervisors, and four were safety directors.

Six businesses specialized in metal products, two in wood products, and one each in sign and boat manufacturing. None of the businesses were unionized. Five (50%) had a safety committee that had convened at least once during the 4 months preceding the visit by the external auditor. Four participants had 3-24 employees, three had 25-99, and three had 100-250. Businesses with 25 or more employees received higher overall audit scores from the external evaluators (mean of 83% vs 26%; $P < 0.0001$).

Table 1 shows inter-rater reliability and accuracy of the LOTO self-audit. Both the self- and external auditors independently assessed 312 items in ten shops. The kappa value for the overall audit was 0.84, indicating excellent reliability. Similarly, kappa was at least 0.79 within each of the three categories: LOTO programs, LOTO procedures, and safety leadership. With regard to accuracy, self-auditors correctly identified 100% of items that were present and in compliance with the LOTO standard. Self-auditors correctly identified 81% of non-compliant items on the overall audit, and at least 75% within each category.

After omission of problematic questions, 255 paired observations were re-analyzed. The kappa value for the overall audit increased from 0.84 to 0.92 (Table 1). LOTO procedures was the area of greatest change, with the kappa value for that category increasing from 0.79 to 0.91. The proportion of missing or non-compliant items correctly identified by self-auditors increased from 81% to 90% on the overall audit and from 75% to 88% for LOTO procedures.

Table 2 shows business-level results for all participants. In general, self-auditors gave their shops higher overall scores than external auditors. Business-level kappa values for the overall audit ranged from 0.56 (moderate level of agreement) to 1.00 (perfect agreement). The proportion of non-compliant items correctly identified by self-auditors ranged from 59% to 100%.

In the re-analysis, inter-rater reliability improved in four businesses at which external auditors found at least 50% of LOTO items missing or non-compliant (Table 2). Initial business-level kappa values at those four sites were 0.56, 0.63, 0.65, and 0.71; these values improved to over 0.80 at each business. Accuracy also improved at these four sites with the self-auditors' ability to correctly identify

TABLE 1 Inter-rater reliability and accuracy of the lockout/tagout (LOTO) self-audit at ten businesses

Audit category	Analysis based on the 32-item checklist					Re-analysis using 26 items				
	Total number of applicable items ^a	Mean percentage of "yes" responses ^b by self-auditors	Mean percentage of "yes" responses by external auditors	Kappa value for agreement between auditors	Percentage of non-compliant items correctly identified by all self-auditors combined	Total number of applicable items ^c	Mean percentage of "yes" responses by self-auditors	Mean percentage of "yes" responses by external auditors	Kappa value for agreement between auditors	Percentage of non-compliant items correctly identified by all self-auditors combined
LOTO program	80	68	60	0.84	81	60	78	73	0.86	82
LOTO procedures	172	72	62	0.79	75	135	72	68	0.91	88
Safety leadership	60	57	55	0.97	96	60	57	55	0.97	96
Total audit	312	68	60	0.84	81	255	70	66	0.92	90

^aResponse "not applicable" was allowed for two items, therefore contribution to denominator could be 30, 31, or 32 items per business.

^bA "yes" response indicated an item was present and in compliance with regulatory requirements.

^cResponse "not applicable" was allowed for one item, therefore, contribution to denominator could be 25 or 26 items per business.

TABLE 2 Business-level results of the lockout/tagout (LOTO) self-audit

Business site	Analysis based on the 32-item checklist					Re-analysis using 26 items				
	Percentage "yes" responses ^a by self-auditor	Percentage "yes" responses by external auditor	Kappa value for agreement between auditors	Percentage of non-compliant items correctly identified by self-auditor	Percentage of non-compliant items correctly identified by self-auditor	Percentage "yes" responses by self-auditor	Percentage "yes" responses by external auditor	Kappa value for agreement between auditors	Percentage of non-compliant items correctly identified by self-auditor	
01	87	81	0.76	67	100	96	89	0.47	33	
02	75	75	1.00	100	100	85	85	1.00	100	
03	94	94	1.00	100	100	100	100	n/a ^b	100	
04	84	84	1.00	100	100	81	81	1.00	100	
05	90	90	1.00	100	100	92	92	1.00	100	
06	13	10	0.84	96	100	12	12	1.00	100	
07	84	75	0.71	63	100	89	85	0.84	75	
08	39	23	0.63	79	100	36	28	0.82	89	
09	68	45	0.56	59	100	64	56	0.83	82	
10	42	26	0.65	78	100	40	32	0.83	88	
All sites	68	60	0.84	81	100	70	66	0.92	90	

^aA "yes" response indicated an item was present and in compliance with regulatory requirements.

^bSite-level kappa statistic was not applicable because both external and self-auditor responded "yes" to all items.

non-compliant items increased by 10 to 23 percentage points. For six sites with high percentage of items in compliance, inter-rater reliability and accuracy remained high except at one business.

4 | DISCUSSION

To our knowledge, the current pilot study is the first to evaluate inter-rater reliability of a self-audit instrument targeted specifically to hazards and safety programs in manufacturing workplaces. Dyjack et al⁶ tested an OHS management audit described as a universal assessment instrument (UAI) using paired evaluators at four sites, three of which were manufacturing establishments. Kappa values were below 0.30 at all sites, indicating low reliability even among trained auditors from the same research team.⁶ In addition, there was not an employee self-audit component to that study.

Inter-rater reliability of the LOTO self-audit checklist compares favorably with that of OHS self-audit instruments designed for other economic sectors.^{10,11} Kaskutas et al¹⁰ developed an audit of fall prevention practices for use by workers at residential construction sites. Two evaluators simultaneously completed the audit at sixteen sites, with excellent agreement (kappa 0.93). Kelso et al¹¹ developed and evaluated a self-assessment checklist for hazards associated with tractors modified for disabled operators. Their checklist had moderate reliability (kappa 0.427) when comparing results of six evaluators to each other, and to those of an expert rater (kappa 0.555).

In testing a self-audit for safety in auto-body shops, Bejan et al⁹ found a high percentage agreement between shop owners' and outside evaluators' responses in 11 shops. However, shop owners were found deficient in identifying items that were missing or out of regulatory compliance. Owners correctly identified only 22% of non-compliant items compared with 95% of compliant items. The authors concluded that studies of self-audit reliability should include assessment of the self-auditors' accuracy in order to ensure the usefulness of the audit instrument.⁹ In the present study, self-auditors' accuracy in identifying non-compliant items was 81% on initial analysis of the 32-item checklist, and 90% on re-analysis using 26 items, indicating that the concerns with accuracy noted by Bejan et al⁹ have been addressed for the LOTO self-audit.

A reliable OHS self-audit instrument has the potential to be an important component of intervention research by eliminating the need for costly site assessment visits by external auditors. For example, in the National Machine Guarding Program (NMGP), insurance safety consultants conducted machine safety audits and entered the data into laptop computers in order to provide immediate feedback to businesses.^{13,19,22} This demonstrated the usefulness of computerized algorithms to provide business-specific recommendations for hazard remediation and safety management. The site visits, however, proved to be costly and could not be maintained beyond the intervention period,²³ a need that is bypassed with a reliable self-audit instrument.

4.1 | Limitations

The primary limitation to this pilot study was that participants were a non-random sample of businesses selected on the basis of convenience.

Therefore it is possible that high-performing shops may have been more willing to participate than poor performers. However, the sample represents both high- and low-performing businesses, as four out of ten study sites had poor audit scores (<50% of items present).

4.2 | Conclusions

Field-testing of the LOTO self-audit at ten manufacturing firms demonstrated high inter-rater reliability, indicating that it would be useful in employers' efforts to regularly assess and improve their LOTO programs. Business self-auditors attained a high level of accuracy in identifying items that were not compliant with the OSHA LOTO standard. By removing the need for costly on-site visits from external auditors, this audit instrument can help overcome barriers of geography and cost in assessing LOTO practices at large numbers of manufacturing businesses.

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AUTHORS' CONTRIBUTIONS

Mr. Yamin was responsible for overall management of the research study, data collection and analysis, and drafting the manuscript. Dr. Parker served as the principal investigator and was responsible for the design, overall integrity and accuracy of the research, and drafting the manuscript. Dr. Xi was lead statistician and data analyst, and reviewed and approved the manuscript. Mr. Stanley managed data collection at several study sites, and reviewed and approved the manuscript.

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ETHICS APPROVAL AND INFORMED CONSENT

The Institutional Review Board (IRB) of HealthPartners Institute – Park Nicollet Institute approved all materials and methods. Consent to participate was obtained from each business owner or a representative, in the form of verbal consent and a written information sheet provided to the participant. Although verbal consent was obtained, a signature was not required because the study posed no risks to individuals or businesses participating and no health data or other data on individuals were collected.

DISCLOSURE (AUTHORS)

The authors report no conflicts of interest.

DISCLOSURE BY AJIM EDITOR OF RECORD

Steven B Markowitz declares that he has no conflict of interest in the review and publication decision regarding this article.

DISCLAIMER

None.

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

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