

NATIONAL MACHINE GUARDING PROGRAM: DESIGN OF A MACHINE SAFETY INTERVENTION

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ABSTRACT

Background: Incidence rates for lost-time injuries (133.1 per 10,000) and amputations (2.6 per 10,000) are elevated among metal fabrication workers compared to U.S. private industry as a whole (105.2 and 0.6 per 10,000, respectively), indicating a need for improved safety practices. Objective: This manuscript describes the development of an intervention to help small metal fabrication businesses (< 150 employees) establish and maintain machine safety programs, implement applicable standards, and conduct regular safety audits. Methods: A business-research partnership was formed to update audit methods utilized previously and translate our prior findings into a standardized intervention to be delivered nationwide. The RE-AIM model was applied to frame research questions that can be quantitatively evaluated. Conclusions: This translation research initiative provides a new model for outreach to small businesses. Cost-effective intervention measures will enable businesses to build sustainable machine safety programs. If effective, this research would form the basis for new, widely-applicable practice guidelines.

Keywords: Injury Prevention; Intervention Study; Machine Guarding; Occupational Safety; Risk Management; Small Business; Translation Research; Worksite Intervention

BACKGROUND

Despite downward trends in recent years, incidence rates for lost-time injuries remain elevated among metal fabrication workers. In 2011, there were 133.1 lost-time injuries per 10,000 employees of fabricated metal product manufacturing firms (North American Industry Classification System [NAICS] code 332) compared to 105.2 per 10,000 for U.S. private industry as a whole [1]. Incidence rates for specific types of injuries were also elevated among metal fabrication workers. Amputations occurred at a higher rate in metal fabrication than in general industry (2.6 per 10,000 versus 0.6 per 10,000), as did eye injuries (8.8 per 10,000 versus 2.4 per 10,000) and injuries of the upper extremities (59.0 per 10,000 versus 33.1 per 10,000) [1]. These disparate figures indicate a need for improved safety practices.

A study of workers' compensation claims in Kentucky identified "machine operators and assemblers" as the occupational category at highest risk for amputation [2]. Surveillance programs in Minnesota and Michigan

have found that cutting machinery and presses, both common in metal-working industries, cause a larger proportion of amputations than other types of machines used in manufacturing [3,4].

Injured workers interviewed by the Minnesota Sentinel Event Notification System for Occupational Risks (MN SENSOR) cited absent or ineffective machine safeguards, inadvertent activation of equipment, and shifting work materials as contributing factors in the majority of amputations [3]. These findings point to the potential to prevent a large proportion of amputations and other injuries through proper machine safeguarding and related programs such as lockout/tagout (LO/TO; the control of hazardous energy during maintenance and service).

The large number of workers potentially at risk for machine-related injuries underscores the importance of prevention programs. As of 2010, there were over 84,000 metal and metal products manufacturing establishments in the U.S., employing approximately 2.5 million people [5]. The majority of these are small businesses: 94% have fewer than 100 employees; 87% have fewer than 50 [5]. Smaller businesses are generally under-served in terms of occupational safety and health (OSH) expertise [6-11]. Higher incidence rates of injury have been reported for small to mid-size firms as compared to larger establishments [12-15], a pattern reflected within the fabricated metal product manufacturing sector [16].

This paper describes the development of the National Machine Guarding Program, a research-to-practice (R2P) intervention targeted to small metal fabrication businesses. As described by the National Institute for Occupational Safety and Health (NIOSH), the purpose of R2P is to translate research findings, information, and technologies into prevention practices applied in the workplace [17]. To our knowledge this is the first R2P intervention implemented nationwide in U.S. manufacturing industry. Although this intervention will be conducted among U.S. firms only, the risk reduction framework presented here has international applicability.

PREVIOUS WORK

The current program builds on the Minnesota Machine Guarding Study (Minnesota Study), a technical and educational intervention implemented in 40 small metal fabrication shops in the Minneapolis-St. Paul metropolitan region [18-23]. In the Minnesota Study, two principal audit measures were used to evaluate each business:

Machine safety score— 25 machines in each business were randomly selected and evaluated using a set of 23 machine scorecards.

Shop safety score—Safety programs such as LO/TO, employee training, and other programs were evaluated using a 25-question shop safety audit.

Methods for developing those audit measures are described elsewhere [23].

Results from the Minnesota Study indicate that inadequate machine guarding programs and practices are a widespread problem in smaller (< 100 employees) metal fabrication businesses [18,21]. Critical safety equipment such as emergency stops and barrier guards were often absent, as were safety program components such as written LO/TO procedures [21]. At baseline no machines were found to be in full compliance with existing standards and guidelines [21,23].

Relatively simple, low-cost interventions led to significant improvements on both machine and shop safety scores (increases of 13% and 23%, respectively) [18]. Establishment of a joint management-labor safety committee was found to be a critical factor in enabling businesses to reduce machine-related hazards and assure safe work practices [18,19,22].

INTERVENTION DEVELOPMENT

Research partnership

To develop the current intervention, a research partnership was formed between Park Nicollet Institute (PNI), the University of Minnesota (UMN), and a private workers' compensation insurer with clients throughout the U.S. Roles and responsibilities of each study partner are shown in Figure 1. The over-arching objective of the partnership has been to devise effective 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.

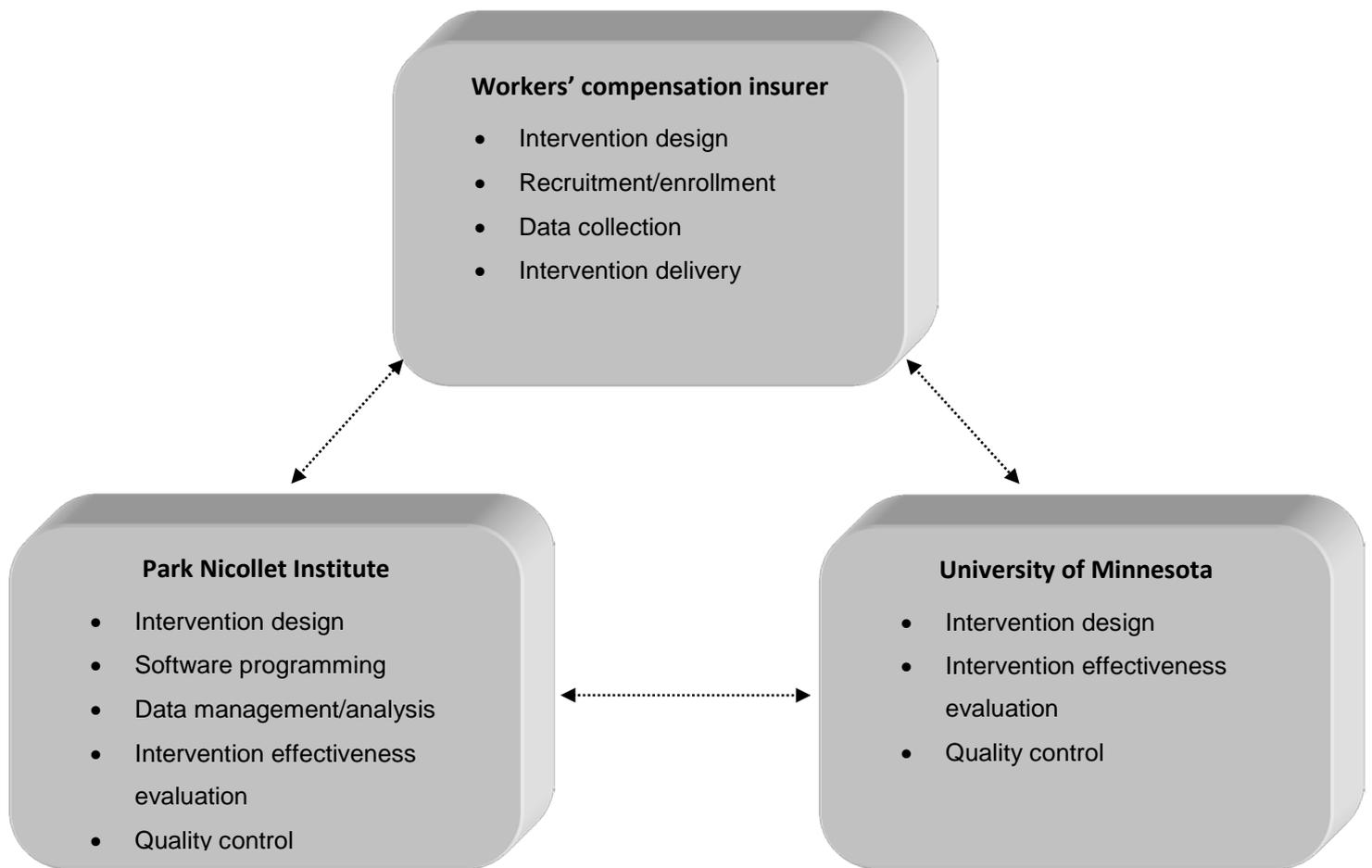


Figure 1. National Machine Guarding Program – Research partnership roles and responsibilities

Core programs

As in the previous study, a key component of the current intervention is to assist businesses with interpretation and implementation of applicable standards and guidelines to prevent machine-related injuries. Beyond this fundamental objective, intervention development centered on devising methods to help businesses establish programs and policies within four topic areas: safety leadership, LO/TO, job hazard analysis (JHA), and machine safeguarding.

The basis for implementing sustainable shop-wide programs is safety leadership: A safety committee or safety leadership team comprised of both employees and management is 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 include demonstrating management commitment to safety; writing and communicating shop policies and programs; encouraging employee participation; and providing sufficient resources [24-28].

When the intervention is launched at participating businesses, safety leadership team members will manage the 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 [24-27].

After the basic intervention framework is put in place, regular internal audit activities are a key aspect of maintaining these programs and ensuring their effectiveness. JHAs inform enhancements to machine safeguarding and LO/TO practices. Similarly, results from routine audits of machine safety and programmatic activities such as LO/TO procedures will enable the safety leadership team to measure progress and target areas for improvement on an ongoing basis.

Application of the RE-AIM model

The RE-AIM model (Reach, Efficacy/Effectiveness - Adoption, Implementation, Maintenance) was used as a framework for generating research questions to evaluate intervention effectiveness [29,30]. Dimensions of the RE-AIM model as applied in the design of the current study are: 1) Reach – the proportion of program recommendations that safety leaders at each business agree to implement; 2) Effectiveness – the impact of the program on key outcomes (e.g., presence of machine guards); 3) Adoption – the proportion of eligible businesses that participate in the intervention; 4) Implementation – the extent to which the intervention is executed as intended; and, 5) Maintenance – the extent to which the program becomes part of ongoing shop practice and policy. Table 1 provides examples of how the RE-AIM model was applied.

Table 1. Application of the RE-AIM framework for evaluating intervention effectiveness

Research questions	Data sources
Reach	
What proportion of program recommendations did shop safety leaders agree to implement at the baseline evaluation visit?	Action plan
Effectiveness	
Did machine safety scores change?	Machine safety evaluation
Did shop safety scores change?	Shop evaluation
Did incidence rates of specific injury types change?	Workers' compensation data
Adoption	
What proportion of eligible shops enrolled?	Insurer records
Implementation	
Have businesses implemented action plan recommendations?	Action plan; intervention activity tracking forms; 12-month follow-up evaluation
Did participating businesses complete the program?	12-month follow-up evaluation
Maintenance	
Was the shop safety leadership team active one year after the study period?	Shop records
Is the shop safety leadership team conducting machine safety evaluations and other self-audit activities?	12-month follow-up evaluation; shop records

Data collection tools

An important aspect of developing the current intervention was to revise the shop evaluation checklist used in the previous study [19,23]. New questions were added to the shop evaluation checklist on subjects such as JHAs, LO/TO programs, injury and “near miss” investigations, and risk management policies. Items were removed that were either a) peripheral to machine safeguarding, b) better suited for assessment at the machine workstation, or, c) too subjective to ensure inter-rater reliability. The shop evaluation checklist now consists of 33 questions covering the four intervention program areas. This checklist can be found on-line as Appendix I.

Machine safety checklists from the previous study were also revised and re-organized. Several new checklists were developed for machines not previously included, based on trade association recommendations and investigator observations. Examples of new checklists include computer numerically controlled (CNC) machines and electrical discharge machinery (EDM). Checklists were consolidated where appropriate (e.g., vertical and horizontal milling machines were combined into one checklist) to arrive at a set of 26 checklists for assessment of machines listed in Table 2. Each machine safety checklist contains between 25 and 35 questions. Audit results

¹ The shop safety audit and machine scorecards adapted from the Minnesota Study [23] are hereafter referred to as the shop evaluation checklist and machine safety checklists, respectively.

will be summarized both by machine type and by technical category (e.g., safeguards at the point of operation; operational controls and emergency stops; LO/TO procedures) rather than as a long list of point-by-point recommendations. An example machine safety checklist can be found on-line as Appendix II.

Table 2. Machine safety evaluation checklists

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)

Data from the checklists will be entered into the Machine Guarding Application (MGA), a software program developed for this study. The MGA generates output in the form of a concise report containing a summary of audit scores and an action plan template for improving areas with lower scores. Audit data will be transmitted electronically to PNI for analysis. Identifiers such as business name and address are automatically removed from the data files before transmittal.

Pilot study

Data collection methods were tested at three businesses in the Minneapolis-St. Paul, Minnesota metropolitan area. At each test site, a meeting was held with production managers and safety directors to gather feedback on the methodology and the usefulness of the results. After further refinements, a panel of machine safety experts was convened to review all of the checklists in detail. Part of this panel review was conducted at a technical college with a large metal fabrication shop so the panel could discuss the checklists while viewing machinery. After the checklists were finalized, study methods were pilot-tested at four additional Minnesota businesses.

INTERVENTION DESIGN

Epidemiological framework

The National Machine Guarding Program is designed as a randomized controlled trial using pre- and post-testing to evaluate intervention effectiveness. Changes in three outcomes will be evaluated: 1) machine safeguarding practices and related safety programs; 2) rates of injuries among intervention businesses versus controls (non-participating clients of the insurer); and, 3) implementation of program recommendations agreed upon at the baseline evaluation visit to each business. A roughly equivalent number of businesses will be randomly assigned either to intervention year one (early intervention group) or year two (delayed-intervention group). The delayed-intervention structure allows for assessment of the possible effect of time, while random selection ensures that other characteristics of the two enrollment groups do not differ significantly.

Field staff

Insurance risk consultants will serve as study field staff. They will conduct audits and deliver the intervention on-site. Each participating business will receive a series of four visits over a 12-month period following enrollment. Intervention activities are highly standardized to maximize consistency among 36 risk consultants operating in various regions of the U.S. Risk consultant training consists of a two-day machine guarding course followed by another two-day training course focused specifically on intervention activities.

Eligibility, recruitment, and enrollment

The research objective is to complete the full suite of program activities at 150 businesses nationwide. At least 165 workers' compensation clients will be enrolled in order to account for those businesses who withdraw from the study for various reasons (e.g., no longer insured). Risk consultants will recruit businesses from their existing client base. To be eligible, a business must meet all of the following criteria:

- Primary business is metal product manufacturing. The vast majority of eligible clients are classified within NAICS code 332 (fabricated metal product manufacturing), however firms within NAICS codes 331 (primary metal manufacturing) or 333 (machinery manufacturing) may be eligible if their primary source of revenue is metal fabrication.
- There are at least five but no more than 150 employees at the participating site.
- If the business has multiple locations, only one location can participate.

Participation is entirely voluntary and does not affect the client's business relationship with the insurer. A participating business may withdraw at any time. As part of recruitment/enrollment, the business owner is provided an informed consent document and the opportunity to ask questions about participation in the study. All study methods and materials have been approved by the Institutional Review Boards (IRBs) of both PNI and UMN.

Baseline evaluation

The baseline evaluation begins with a meeting between the risk consultant and the business owner or designated safety leader. The risk consultant reviews the purpose of the visit and interviews the owner or safety leader in order to complete the shop evaluation checklist. Answers to each question are verified if necessary, e.g., the risk consultant may ask to view materials such as a written LO/TO program or a policy requiring safety eyewear.

The risk consultant then proceeds to the shop floor to perform machine safety evaluations. 12 machines are randomly selected using a tagging system and a random number generator. A paper checklist is then completed for each of the 12 machines. The sample is comprised of no more than three machines from any of the 26 different machine types, to ensure that the sample consists of a variety of machines and is representative of both production and non-production machinery.

A sample of 12 machines was determined to be an optimal size based on re-analysis of data from the Minnesota Study. Simulations were performed to calculate power ratios for different numbers of participating shops, i.e., power obtained from a partial sample of machines in each shop compared to an assessment of all machines. As shown in Figure 2, with 120 shops participating, power is optimized at 10 machines per shop. A slightly higher sample size of 12 was chosen to assure statistical power.

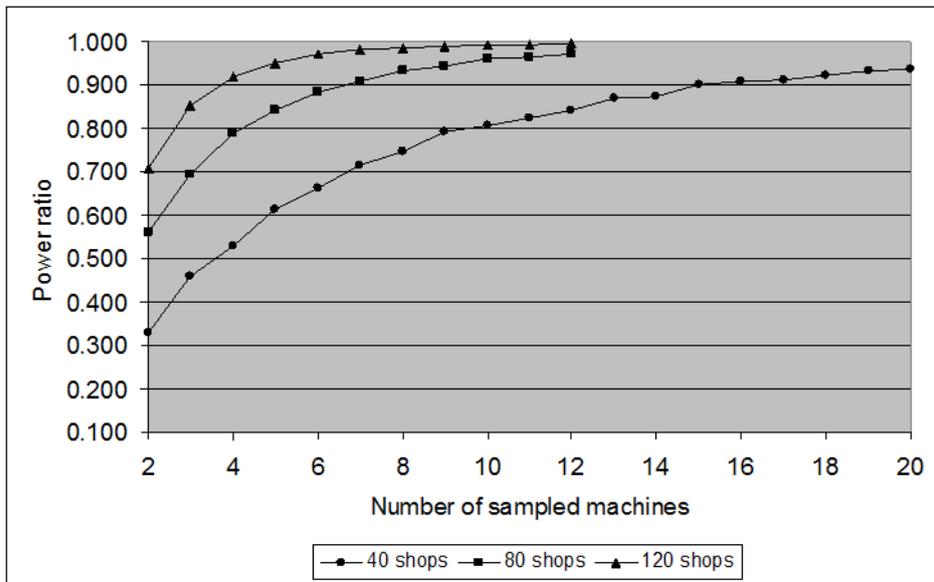


Figure 2. Power graph for determining optimal machine sample size

While still on-site, the risk consultant enters audit data into the MGA software. The MGA compiles category scores from all checklist responses into a comprehensive safety report that is provided to the shop owner and/or safety committee. The report also contains a brief list of action plan recommendations based on deficiencies identified in the checklist evaluations. The risk consultant and shop owner review this material to develop an action plan to guide intervention activities for the duration of the study period. A target date and person responsible are assigned for each action plan item. Audit results for each machine are included in the report as percentage scores; the MGA software separately generates full copies of scored checklists for each machine that can be provided to the business in order to track hazard controls for a specific machine.

The checklist audit is designed as an efficient means of collecting and quantifying machine safety data that are comparable across widely dispersed businesses. Previous work and pilot testing have validated the checklist audit methodology as a means of assessing risk, yet there are limitations to this approach. Checklist audit data are essentially a “snapshot” of safety in a business, as hazards and controls are observed during a brief inspection rather than over an entire production or maintenance process. Machine guarding scores reflect conditions at the machine workstations, so person-years of exposure are assumed to be spread equally across all machine shop personnel rather than measured for each employee individually.

Intervention visits

Each business will receive two intervention visits: One visit three months after the baseline evaluation and another at six months. At these visits, the risk consultant will meet with the safety leadership team to review progress and provide guidance. Risk consultants are trained to tailor intervention programs to shop-specific needs. A readily adaptable set of written guidelines and templates for programs in safety leadership, JHAs, LO/TO, and machine safeguarding has been developed to support on-site intervention activities.

Safety leadership is the critical element for putting intervention programs into practice. Therefore, the risk consultant’s initial priorities are to: 1) secure a management commitment to intervention program goals, and, 2) help the business establish an active safety leadership team if one does not exist or has minimal responsibilities.

After safety leadership roles and responsibilities are delineated, the risk consultant’s role is to assist with skill-building by modeling core program components on-site. The risk consultant will demonstrate machine safety auditing and instruct safety leaders in the use of machine safety checklists. The risk consultant will also demonstrate how JHAs are conducted and describe how specific findings from JHAs can be used to improve machine safeguarding and LO/TO practices.

Program activities performed by the risk consultant at each intervention visit are tracked using a standardized electronic form. This form also serves as a reference to help ensure continuity throughout the series of visits to each shop.

Follow-up evaluation

12 months after the baseline evaluation, a follow-up evaluation is conducted. A new random sample of 12 machines is selected for checklist assessment and the shop evaluation checklist is completed. A new business report will be generated with safety category scores for comparison with baseline results. The risk consultant will meet with the shop safety leadership team to review progress and discuss plans to continue intervention programs beyond the study participation period.

Quality control

Quality control (QC) measures have been built into the various data collection tools and intervention activities. The MGA software used for data collection contains numerous QC flags that are raised when data are invalid. A second software program has been developed for importing and processing study data. One feature of this program is to generate QC monitoring reports based on the electronic flags embedded in the MGA. The action plans and intervention tracking forms provide additional electronic documentation that can be monitored to assure that intervention activities are being carried out consistently and thoroughly at each site. The insurer also conducts conference calls and web-based meetings for study field staff during which methodological issues and concerns are addressed.

DISCUSSION

As described by Goldenhar *et al.* [31], OSH intervention research should ideally proceed through several phases. Initially, researchers analyze surveillance data and seek to understand perspectives of a target population to guide development of effective interventions using behavioral and organizational theory. Subsequently, implementation processes are evaluated as the quality of the intervention is tested in a limited, controlled environment. Finally, during the intervention effectiveness research phase, health outcomes are evaluated as the intervention is put into practice under “real-world” conditions.

Surveillance data collected by the MN SENSOR program [3,32] informed the initial steps toward development of a machine safety intervention. During the Minnesota Machine Guarding Study, an intervention was developed and tested on a limited scale, under optimized conditions [18,20]. The National Machine Guarding Program is designed to evaluate intervention effectiveness by refining this methodology and disseminating it on a much broader scale.

In an extensive review of publications on preventive OSH activities in small businesses, Hasle and Limborg [15] identified three essential components of intervention research that have frequently been lacking: 1) application of findings from previous research in design of subsequent studies; 2) study design that accounts for characteristics of small enterprises; and, 3) evaluation of the effects of preventive activities.

The National Machine Guarding Program embodies all of these elements. Methods utilized in a previous study have been refined so that effectiveness of injury prevention measures can be evaluated. Conditions specific to smaller businesses (e.g., limited or no in-house OSH expertise) were considered in each stage of intervention development. Intervention activities make a wide range of complex standards readily accessible to small business owners and employees. Best practices for machine safety are often embedded within Occupational Safety and Health Administration (OSHA) and American National Standards Institute (ANSI) standards (e.g., 29 CFR 1910 Subpart O; ANSI B11) that require expertise to interpret and apply.

An important advantage of the current study is that insurance risk consultants will deliver the intervention on-site in a series of four visits to each participating business. Hasle and Limborg [15] observed that the most effective prevention programs are those that are “disseminated by personal contact.” In a survey of small industrial enterprises, Barbeau *et al.* [33] found that smaller firms typically rely on outside expertise to implement OHS programs, and suggested that technical assistance programs delivered by a trusted external agent such as an insurer can play a key role in improving shop safety.

During intervention development, it has been necessary to account for challenges presented by the transition from a regional study of 40 businesses to a nationwide program with a targeted enrollment of 150 businesses. Field staff receives extensive training in order to ensure consistent data collection and standardized intervention delivery. The use of software for data collection and transmittal has required a lengthy testing process. QC indicators have been built into the data collection tools. Differences in workers’ compensation practices (e.g., requirements for injury reporting) and the OSHA regulatory framework (state-based versus federal) from state-to-state will be controlled for within the analysis of insurance data on injuries.

Clear, concise objectives and a compact, standardized program structure are fundamental to ensuring the effectiveness of this intervention design under “real-world” conditions. Field staff will assess complex machinery and guide businesses through implementation of shop-specific safety programs; therefore it is critical that intervention goals can be communicated straightforwardly to shop personnel. Those goals are: 1) establish and maintain machine safety programs; 2) implement applicable standards and guidelines, and, 3) conduct regular safety audits to identify hazards and put preventive measures in place.

The basic intervention program framework presented here is designed to be easily understandable and readily adaptable, given the diversity of geographic regions, industrial processes, machinery, and other factors likely to be encountered. All hazard assessments and recommendations for preventive activities within this study are organized into four areas: safety leadership, LO/TO, JHAs, and machine safeguarding. Maintaining this four-fold program structure throughout all stages of a business’ participation in the study is intended to ensure continuity within each business and comparability with others.

CONCLUSIONS

The risk for injury is persistently elevated among workers in metal fabrication industries [1]. A large proportion of these injuries are likely preventable through proper machine safeguarding and implementation of related programs such as LO/TO [3]. Previous research found significant improvements in machine guarding and shop safety audit measures when relatively simple interventions were implemented [18]. The National Machine Guarding Program is a translation research initiative that provides a new model for outreach to smaller businesses that rarely have sufficient access to OSH expertise [6-11]. Cost-effective intervention measures delivered on-site will enable businesses to build sustainable machine safety programs. If effective, this intervention would form the basis for new, widely-applicable practice guidelines.

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