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Reducing Risk on Machinery: A Field Evaluation Pilot Study of Risk Assessment

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A pilot evaluation of the ANSI B11-TR3 Machinery Risk Assessment/Risk Reduction (RA/RR) Guideline was conducted. The TR3 guideline was introduced into five companies on one machinery system in each company with a second machine system serving as a control. A pre-post investigation was performed with safety conditions measured pre and post in both treatment and control and with risk reduction score measured only in the treatment machine system. NIOSH provided a commercially available risk assessment software to facilitate the process. Evaluation measures included avoided injuries, reduced exposure to machinery hazards, pretest and posttest knowledge demonstration, assessment of group processes following training, correct implementation of the guidelines, and degree to which risk reduction recommendations were implemented. The qualitative results of this pilot effort appear to be the best indicators for the way ahead in industrial machine risk assessment. All companies indicated that they derived value in participating in this study and in conducting risk assessments. Quantitative study results suggest that: (1) as measured by the knowledge of the participants before and after the TR3 training, the guidelines can be effective at enhancing employee knowledge of safe machine operations and (2) although the injury reduction trends appear successful, the small sample size in the study size should be considered in interpreting these early results.

KEY WORDS: Evaluation; machine risk; risk assessment; standards

1. INTRODUCTION

In 1995, an American National Standards Institute (ANSI) subcommittee, ANSI B11 TR3, was formed under the auspices of the ANSI B11 Machine Tool Safety Standards Committee. The TR3 subcommittee had labor, machine builder, machine user, government, and safety consulting representatives. Their purpose was to develop a Technical Report (TR) document to help bring machine tool risk assessment practice in the United States up to or above the level indicated by the then European standard EN 1050, now an international standard ISO 14121 "Safety of Machinery: Risk Assessment."[1] The international standard sets forth a process for ensuring that safety measures are appropriate to the risks in machine operation and servicing tasks.[2,3] The ANSI B11 TR3 document[4] became available for general use in November 2000. Several sources give detailed background on machine risk assessment.[5–9]

Because machine-related fatalities have been the third leading source of occupational death in the United States,[10,11] an intervention evaluation of the new TR3 machinery risk assessment for risk reduction (RA/RR) guideline was initiated by the National Institute for Occupational Safety and Health (NIOSH). Evaluation measures included injury rates, reduced

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exposure to machinery hazards, pretest and posttest knowledge demonstration, assessment of group processes following training, correct implementation of the guidelines, and degree to which risk reduction recommendations are implemented. How well technical information was conveyed to both safety and health professionals and line workers who made up a RA/RR team was also evaluated. Corollary measures of improved quality and reduced production errors were also collected and analyzed.

1.1. The TR3 Process That is Being Evaluated

The TR3 process prompts the use of the hazard control hierarchy to: (1) eliminate the hazard by design; (2) apply safeguards and protective devices; and (3) apply administrative controls and other protective measures (e.g., warn, train, use personal protective equipment). The hierarchy needs to be applied until an acceptable level of risk is reached. The general approach is: task and hazard identification; risk estimation; risk reduction determination; safeguard selection; verification of risk reduction; and documentation. The aim of risk assessment on new machinery is to see that hazards are mitigated before they are introduced into the workplace. Employed judiciously, TR3 can help to locate critical elements in a design, identify associated hazards, evaluate their risks, and prompt decisions to reduce risks to acceptable levels. In the TR3 method, the risk for a task depends on a two-way relationship between the potential severity of harm (catastrophic, serious, moderate, or minor) and probability of occurrence of harm (very likely, likely, unlikely, and remote). These factors are entered on a risk estimation matrix (Table I is one example) and a risk level is determined. A risk rating of serious severity and likely probability does not necessarily equate to there being prior injuries for that task hazard. The TR3 approach recognizes that prior injury history is only one factor in assigning risk. The method recognizes that an absence of prior injury is not an indicator of low risk. Acceptable risk must meet minimum levels of local, regional, and national regulatory compliance requirements. Qualified personnel are particularly important in decision making about acceptable risk.

2. RESEARCH QUESTIONS

This study sought to begin answering the general question, "Is the TR3 method effective in reducing machinery risk?" by using qualitative and quantitative methods. Qualitative data relative to this question were collected on ease of implementation of risk assessment, productivity, and management support. Quantitative questions were: (1) How effective are the TR3 guidelines to the team in evaluating the risks associated with the machines as measured by teams' number of completed risk reduction actions? (2) How effective are the TR3 guidelines in enhancing employees' knowledge of safe machine operations as measured by risk knowledge scores of the participants before and after the TR3 training? and (3) Are there significant differences between the rate of injuries before and after TR3 application as measured by changes in injury rates?

Table I. Risk Estimation Matrix

Probability of Occurrence of Harm	Severity of Harm			
	Catastrophic	Serious	Moderate	Minor
Very likely	High	High	High	Medium
Likely	High	High	Medium	Low
Unlikely	Medium	Medium	Low	Negligible
Remote	Low	Low	Negligible	Negligible

3. METHOD

This study introduced the TR3 risk assessment method into five workplaces, on one machine system in each workplace. A machine system was defined as two or more production machines that may be linked by transfer machines. Two or more workers would normally be assigned to perform operation, maintenance, and/or servicing on the machine system. A second, comparable machine system served as a control. In general, the study sequence was: identify the set of companies to receive training; conduct a training workshop on the use of team-based TR3 method; collect reports from the sample group on completed RA/RR actions; perform a one-year follow-up to measure changes in machinery safety conditions; and document the results of the evaluation. The training conducted had a "train-the-trainer" emphasis to enhance the plant champions' ability to train their in-plant team members. The effectiveness measured in this study started with what companies already had as their machine safety component in an overall safety program and this study evaluated marginal change from applying TR3.

3.1. Study Design

Robson *et al.*[12] highly recommend including a control group in evaluation studies. In this study

design, the control group was the second, comparable machine system. A pre-post investigation was performed with safety conditions measured pre and post in both treatment and control and with risk reduction score measured only in the treatment machine system. Safety measures were collected during the first site visit on both the machine system targeted for TR3 application and the second system that was the control. At the end of one year, data were collected on the target system and the control system. Multiple outcomes consisting of injury rate, safety conditions score, and risk awareness score were measured. The study design was quasi-experimental, in that a control group was used, but was chosen in a nonrandomized manner from closely matched systems in the workplace.

Advantages of this design are control of several major threats to the validity of the study; a quicker result; lower likelihood that major changes at the company would interfere with the study; the design permits expansion to a staggered design; and the ability to accommodate smaller sample sizes; so much was gained by adding the control set. Disadvantages included fewer data being collected than with a more complex design and the practical limitation that a purely randomized control group could not be obtained.

3.1.1. Evaluation Measures

Table II contains a description of the dependent variables measured and analyzed subsequent to the independent variable (use of the TR3 methodology) being applied. The injury case definition includes only injuries that the TR3 risk assessment has some hope of preventing. For example, if the machine operator is exiting the plant cafeteria and struck by a forklift, then the TR3 risk assessment would have no bearing on this injury. Company workers' compensation records and OSHA 300 logs were used to identify injuries.[13]

Table II. Dependent Variables

Dependent Variable	Metric
Injury rate	Injuries/number of hours worked
Safety conditions rating	4-point ratings on 28 machine safety factors by 2 researchers
Knowledge of risk control	Pre- and posttraining score on 38-question quiz
TR3 conformance	Number of task-hazard pairs identified and risk reductions planned
Implementation of risk reduction recommendations	Descriptive postintervention changes observed by researchers
Production effects	Qualitative descriptions provided by champions one year after TR3 application
Safety attitude change	
Safety teamwork change	

The safety conditions ratings were performed by two members of the NIOSH research team. Individual opinions were given about the state of each of the 28 generic safety-related features of the machine systems. These generic safety features were based on checklists used by OSHA and in the insurance industry. Such a rating approach does not assume that there is a fixed value that raters should converge on. The criteria for making the ratings were that the raters were to assess each of the 28 conditions in light of their similar knowledge of machine safety factors. All raters were selected because of their experience as senior safety professionals. Interrater reliability was not a factor, given that the standard for the rating is set by the individual rater and not the feature being rated. The researchers discussed their ratings after the site visit and came to a consensus on the rating, or stated their reasons for differences.

The reported risk reductions measure was on total number of actions at the site that were listed as risk reductions on the final software reports to NIOSH. These reports were generated using a commercially available risk assessment software provided by NIOSH. These were the total of risk changes from high-to-moderate; high-to-low; high-to-negligible; moderate-to-low; etc. that each site reported. The TR3 concept of risk reduction is somewhat subjective. Although quantitative data are used in risk estimation as much as possible, a certain amount of the calculation is based on qualitative judgments of the local risk assessors, given their own experience and value judgments. Risk assessment team members were selected based on their being qualified to make decisions about acceptable risk.

The knowledge change about risk measure was on increase in knowledge of risk as a result of the training workshop. This was the average change in test scores for each site from before training to after training.

3.1.2. Statistical Methods

A nonparametric test was performed to see if the rank ordering between the safety conditions rating, risk knowledge, and risk reduction characteristics were related. Spearman's rank correlation coefficients (r_s) were computed for each of the three paired

categories.[14,15,16] The coefficient r_s is a measure of the strength of association between characteristics.

Because some sites were further along with their risk control and understanding of risk than other sites, the best way to make comparisons was by rank ordering the five sites from 1 to 5 on the three measures. In other words, the site with the fewest safety concerns was ordered 1; with the second fewest was 2; third fewest 3; fourth fewest 4; and the most 5. For reported risk reductions 1 = fewest reported risk reductions and 5 = most reported risk reductions. For knowledge change about risk 1 = lowest gain in knowledge of risk (indicates already fairly knowledgeable) and 5 = greatest gain in knowledge of risk. Adequate power considerations were based on a table of critical values of Spearman's r_s for small sample size.[17] Table values indicate that at the 10% significance level for a sample size of 5, the critical value for r_s is 0.900. The small sample size for this study places it in the category of being a pilot effort.

3.2. Test Sites

A mix of five large and small machine-using companies from the automotive, industrial, and consumer products industries was recruited for the study. A selection criterion was that the company had an interest in improving machine safety. Two sites provided only a single champion. The other four sites provided one management and one labor person who normally performed the company's machine safety review functions as champions. The sites made their own selection of the machine systems that served as the target and the control.

3.3. Sequence of Steps in the Study

3.3.1. Collect Preintervention Data

Measurement instruments of preintervention safety conditions (see Fig. 1) were administered on both the target machine system and the control machine system at the workplaces. Two members of the NIOSH research team collected these data at each site. These observers compared their individual scores and arrived at a joint score by consensus. The data collection instruments were compliance-based, focusing on specific machine components and environmental factors. The responses were the rated opinions of the evaluator as to the adequacy of the observed condition for preventing harm.

3.3.2. Training Workshop

NIOSH and its partners organized and conducted a training workshop on the TR3 guideline for all of the champions in the study. The workshop

Observed overall rating for this factor 1 = Poor 4 = Excellent	Component observed or procedural information requested. The overall system is considered.	The requirement for the highest rating (4).
1 2 3 4	Control panels	Clear, unambiguous labels All lights give a clear indication All controls work properly
1 2 3 4	Mechanical power transmission safeguarding	Guarding is in place on potential nip points formed by rotating belts, pulleys, chains, gears, shaft ends, nonsmooth shafts and couplings, etc. (within 7 feet from the floor or from the work platform, if higher).
1 2 3 4	Point of operation safeguarding	Guards are firmly secured and not easily removable. The safeguards permit safe, comfortable, and relatively easy operation of the machine. There is no evidence that the safeguards have been tampered with or removed.

Fig. 1. Sample factors from the 28 machine safety conditions rating instrument.

provided 12 hours of training in the TR3 risk assessment methodology and eight hours of hands-on exercises. The workshop also provided insights on safety team-building. A multiple-choice knowledge test and Likert scale questionnaire were administered to the trainees before and after training.

NIOSH provided champions with a commercially available risk assessment software tool. The software incorporated the TR3 approach in a systematic method for conducting task-based risk assessment. The software was selected as a convenient way for combining the many considerations in risk assessment into reports. The software was used only as a tool for this study and was not itself being evaluated.

3.3.3. Champions Return to the Workplace to Use TR3

After training, the champions returned to their workplaces, formed their teams, and carried out the assigned TR3 RA/RR process. Team composition varied from site to site according to the leadership style of the champions. Team size ranged from one to five, with the additional team members coming from among supervisory and line workers associated with the target machine. The completion of posttraining activities depended on how long it took sites to complete their risk assessments, select appropriate protective measures, and purchase and install risk reduction measures. An intervention was complete when a risk assessment had been completed on the target machine system and all modifications had been performed and the machine system was operational. Workplaces were contacted by phone to facilitate and review the progress of the intervention. The quality of the intervention delivery and areas for improvement were assessed by the research team. Progress reports were evaluated by NIOSH and project partners, and feedback provided to each workplace team.

3.3.4. Postintervention Data Collection

Return site visits to five workplaces were conducted by the NIOSH partner group approximately one year after the target intervention was complete. Effectiveness measures on both the target machine system and the control machine system were collected using the safety conditions rating instruments developed for the study (Fig. 1). The same two persons who collected the preintervention data collected postintervention data at each site. Differences in ratings were thoroughly discussed and a final, consensus rating was recorded. The champions were also asked questions about how well technical information was comprehended by both safety and health professionals and line workers who made up RA/RR teams. Questions about improved quality and reduced production errors were also asked.

4. RESULTS

4.1. General Case Results

In general, the risk assessment reports generated by each test site were tailored by the champions to blend with the risk reduction processes already in place at their location. Some sites had previously used checklists, while others had used informal safety coordination among the safety department, manufacturing engineers, and workers. Generally, management at each site supported a risk assessment reporting program with reassessments performed as needed.

4.1.1. Safety Conditions Ratings

The safety conditions at the facility before and after the study are one measure of TR3 risk assessment performance. Table III shows the percentage increase in 28 safety conditions that were rated as excellent (the highest level) both before and one year after the teams implemented the TR3 method. Interrater reliability was good for all 4 rating levels, in that raters agreed on 85.7% of all of their ratings. The target machine system had TR3 applied and the control machine system did not. The trend shows that TR3 resulted in better safety conditions for nearly all facilities.

Table III. Safety Conditions Percentage Improvement Observed for the Target and for the Control Machine Systems; the Table is a Comparison of the Percentage Increase in 28 Safety Conditions That Were Rated at the Excellent Level Before and One Year After TR3 Application

	Percentage Increase in Safety Conditions Rated Excellent (4)	
Site	Target (TR3 applied)	Control (TR3 not applied)
1	46%	46%
2	8	4
3	18	9
4	8	4
5	0	0
Avg	16%	12.2%

One of the key principles of the TR3 approach is the concept of tolerable or acceptable risk.[18–20] TR3 defines the term as follows:

Tolerable risk: Risk which is accepted for a given task and hazard combination [hazardous situation].

Note that this concept excludes the idea of zero risk. That zero risk is not achievable and that some risk will always remain is a belief of many in the safety community.[21]

The risk reduction teams applied the concept of acceptable risk as indicated by their tolerance of safety conditions about which OSHA regulations may not provide sufficient guidance. Examples included: machine frames that were not fixed to the floor but that were otherwise stable; slow moving pinch points not covered; irregularly scheduled safety inspections; and guards not fastened tightly. The teams viewed these risks as tolerable and not requiring further risk reduction, based on the concepts of TR3.

4.1.2. Knowledge About Risk

Gains were achieved in knowledge of risk reduction concepts for this pilot sample ($n = 11$). The mean percentage of correct responses increased from 65% (95% CI: 62.28 to 67.72) in the pretest to 74% (95% CI: 72.35 to 75.65) in the posttest.

On the training tests, three risk attitude questions were posed in addition to the 38 questions about risk knowledge. Pre- and posttraining results revealed a favorable increase in the conceptual understanding of tolerable risk (Fig. 2). Perhaps more importantly, the strength of the responses after training suggests that the participants' confidence in their knowledge increased dramatically. This confidence is necessary to effectively train others in the TR3 approach.

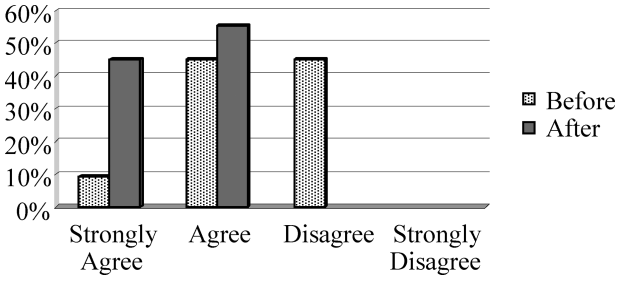

Fig. 2. Pre- and posttraining responses to the statement, "I understand the concept of tolerable risk."

Table IV. Risk Reductions Scheduled for Each Site's Target Machine System

Site	Risk Reductions
1	6
2	6
3	20
4	22
5	4
Total	58

Upon completion of the workshop, participants were able to explain key terms and concepts used in risk assessment, conduct a risk assessment using the software, and understand maintenance risk assessment applications. The numerous positive responses of attendees indicated that the training session was very successful and bode well for this pilot and future evaluation studies.

4.1.3. Reported Risk Reductions

Following the TR3 method, the five intervention teams identified a total of 58 hazards, the risks associated with which were reduced from either high or medium to a lower level. Sites 1 through 4 completed their TR3-based risk reduction process. Risk reduction actions were verified during the site visits after TR3 had been used for a year. The risk reduction process used by Site 5 changed during the course of the study. In Table IV, the four risk reductions for Site 5 were only documented in their first quarterly report. In their final report they chose not to specify reduced risks.

4.1.4. Comparative Associations Among Safety Conditions, Knowledge, and Risk Reduction

The rank order of the sites matched exactly when comparing the risk knowledge gained with the number of risk reductions. Rank order varied in only one rank when comparing the safety conditions score with number of risk reductions. Rank order also varied in only one rank when comparing the safety conditions score with risk knowledge gained. In general, this pilot study indicated that the less the teams initially knew about risk, the more they learned about risk assessment by participating in the study and the more they

were able to reduce risks on their machinery. More specifically, the results indicate that:

- The more a site learned about risk, the more risk reductions that it acted on. The nonparametric Spearman rank correlation relationship between knowledge change about risk and reported risk reductions was: $r_s = 1.0$ ($p = 0.0$).
- The more the pilot study target machine system needed its safety conditions improved, the more the TR3-trained team was able to reduce risks. The nonparametric correlation relationship between safety conditions before and reported risk reductions was: $r_s = 0.46$ ($p = 0.43$, statistically insignificant).
- The less that a pilot study workplace was providing good safety conditions on the target machine system before the study, the more knowledge about risk reductions the team gained in training. The nonparametric correlation relationship between safety conditions before and knowledge change about risk was: $r_s = 0.46$ ($p = 0.43$, statistically insignificant).

4.2. Case Description Results

Qualitative results for one of the five facilities that completed the study are in this section. This site was randomly chosen in the interest of efficiency in reporting results.

4.2.1. Case Description for Site 1

4.2.1.1. General features

The target machine system: A special-purpose machine for high volume medical products assembly involving three personnel per day.

Existing safety program: The Corporate Safety and Health Program provides safety oversight, but there is not a designated safety person at the facility. Safety representatives assess areas monthly. The corporation is implementing a risk assessment policy on new machinery.

Champion: The champion was a senior engineer who had developed the special-purpose machine.

Operating environment: The target machine system has been reproduced several times as production has significantly increased at this site. This site employs approximately 700 people.

4.2.1.2. A typical risk reduction

Personnel at risk: The personnel involved consist of the operator, setup and engineering technician.

Typical task and hazard: Oven operation, setup and cleaning of the machine are typical tasks. A mechanical hazard involved in these tasks is pinch points at the end of the conveyor belt and uncovered drive roller.

Initial assessment: In relation to the above hazard, the results of the initial assessment were of serious severity and likely probability of producing a high-risk level.

Risk reduction method selected: The selected risk reduction method was to cover the ends of the conveyor.

Final assessment: Although the level of severity remained serious, by covering the ends of the conveyer the probability of occurrence was considered remote and the level of risk was reduced to low.

4.2.1.3. Productivity change. One action taken in conjunction with the TR3 risk assessment was designing a new control system. The new control system provided quicker, safer, more reliable operation of the machine and permitted faster and more efficient troubleshooting when such conditions arose.

4.2.1.4. Comprehensive comments of the champion about using the TR3 method (in many instances repeating the exact phrasing of the champion). A risk assessment approach to injury prevention had not yet become a specific operating practice in Workplace 1. In the future, the champion perceived a need to work more closely with safety representatives on risk reduction. In new specifications for vendors, a risk assessment following TR3 principles will be required. Adding software to the TR3 document was seen as making it a complete package. Because of information technology department restrictions, getting off-the-shelf software onto the company network was seen as problematic. Specific comments included:

> The software made using TR3 much more powerful. Software optimization should be investigated. The software was used for in-house training and it was well-understood. The software was a great mind-stimulator for identifying task hazards. Risk assessment has strong applications for custom-designed equipment.

Table V. Injury Counts and Incidence Rates (IR) on the Target and the Control Machines Before and After Application of TR3. IR per 100 Full-Time Workers = Number of Injuries × 200,000/Hours Worked at That Machine System per Year (BLS Method)

		3-Year Average Before Intervention (2000–2002)				The Year After Intervention (2004)			
		OSHA Injury	IR	First Aid	IR	OSHA Injury	IR	First Aid	IR
Company 1	Target	0	0	0	0	0	0	0	0
	Control	0	0	0	0	0	0	0	0
Company 2	Target	n/a	0	n/a	0	0	0	0	0
	Control	n/a	0	n/a	0	0	0	1	73.8
Company 3	Target	2.67	46.87	5.33	84	0	0	2	20.04
	Control	2.67	39.2	4	34.84	1	14.16	0	0
Company 4	Target	18.33	11.63	24.33	17.63	1	6.79	0	0
	Control	18.33	11.63	24.33	17.63	0	0	0	0
Company 5	Target	0.33	7.56	0.33	7.56	0	0	0	0
	Control	0	0	0	0	0	0	0	0

n/a = not available.

4.3. Injury Rate

Table V shows the injury experience for both the target and the control machine systems before and after application of TR3. The sample is small, so no attempt is made to draw statistical inferences from these results. Sites 1, 2, and 5 had elected to perform the study on machine systems that had good injury experience. That is not to say that they previously had a good record company-wide. These three sites extended their good injury records with the application of TR3. Sites 3 and 4 saw improvements in their injury experience during the test period. At Site 3, the OSHA recordable injury rate per 100 full-time workers (number of injuries × 200,000/hours worked at that machine system) for the targeted blow mold press was reduced from 46 to 0. The first-aid incidence rate for this machine system fell from 84 to 20. At Site 4, the OSHA recordable injury rate for the targeted riveting machine line was reduced from 11 to 6. The first-aid incidence rate for this machine system fell from 17 to 0. The injury record for all machines at the five sites was not generally available, although we do know that some sites chose to be in the study because they had targeted the need to reduce machine-related injuries.

4.4. Management Support and Stress

Management support was seen to be a critical factor for the success of the risk assessment process. Stress on the champions who applied TR3 in this study was not measured, but its appearance was noted. The level of undesirable stress on the champions appeared to be associated with the level of management support for machine risk assessment. At Site 3, management initially supported the TR3 study and the staff participating in the training. Management also provided overtime pay for hourly personnel to participate in the risk assessments. However, the risk assessment effort was treated as an added activity not an integral part of doing business. Overtime payment increases costs and cannot be supported indefinitely. Without management support and commitment, results are not likely to be as successful as turned out to be the case at this site.

The management support at Site 4 was remarkable. This site experienced several frustrating challenges that occur in manufacturing from time to time that led to rework. Due to situations unrelated to this study (hard drive failure, file erasures), this team had to conduct the risk assessment three times. Although line personnel were resistant to the rework, eventually the team was instructed to "just do it." This instruction came from the management. In this case, adequate management support yielded positive risk assessment results. Management support was important for the entire risk assessment process from hazard identification to risk evaluation to risk reduction to maintenance of risk reduction measures.

5. DISCUSSION

Sites 1 and 5 derived sufficient value from applying the risk assessment principles of this study that they now require new specifications for vendors that include a risk assessment following TR3 principles. The value of risk assessment is indicated in this change of company policy. Encouraging results

were seen in the injury rate reductions observed at Sites 3 and 4. However, the small number and unknown variance of injuries that had occurred before the intervention (eight OSHA recordable injuries for Site 3 and 55 for Site 4) precluded making statistical inferences about the significance of the reductions. Future intervention effectiveness research on this topic that begins with a sample having a high number of pretest injuries is needed to be able to make more meaningful statements about statistical significance of results. Such large-sample occupational risk reduction research has focused on eye injury prevention,[22] backbelts,[23] and needlestick injuries in healthcare.[24]

Although a control machine system was designed into this pilot study, the control was only marginally useful for the results. However, the feasibility of using a control was demonstrated and controls should be considered in larger studies of machine risk assessment. The design of the study included four quantitatively dependent variables and four qualitative measures (see Table II). Two of the quantitative measures were safety conditions rating and TR3 conformance. These two separate measures were intended to draw the distinction between standard-based safety, represented by safety conditions rating, and risk-based safety, represented by TR3 conformance. The standard-focused approach was represented by the 28 safety conditions that experts evaluated before and after the intervention (Table III). The test sites were tasked to do their work based on the TR3 risk reduction guidelines rather than on just standards compliance. TR3 gives teams the flexibility to follow a risk-based approach in addition to a standard-directed approach. The test teams essentially began at zero for the number of risk assessments that they had previously completed.

Some companies participating in this study saw productivity increases, an unintended benefit from focusing on safety issues. Often, safety problems are also productivity problems. The risk assessment process identified specific areas (tasks and hazards) for improvement, resulting in risk reduction improvements with benefits to safety and often productivity.

Stress experienced by personnel performing the TR3 risk assessments is an issue that was not well documented in this study and the question of whether using TR3 was worth it from this perspective should be investigated through further study. Having dedicated risk assessment facilitators (either from within or outside the organization) would be a factor to be evaluated in determining the least stressful way to conduct TR3 risk assessments.

An early indication of the criterion validity of this pilot design can be seen in that its results, on the surface, appear to emanate from a potentially predictive set of measured variables. Future, larger studies should include near-miss data. However, the preliminary result is certainly a good indication that, in this pilot study, TR3 was a success.

Risk assessment can prompt risk reduction in situations where hazards are well known. For example, Site 5 performed the TR3 risk assessment but did not express satisfaction with the results. It chose to return to its checklist specification approach. It indicated that the risk assessment approach did not help it identify hazards of which it was not already aware. Interestingly though, the risk assessment was cited as having value in convincing management to make changes to reduce risk. Although a grinding dust hazard was known before the TR3 risk assessment effort, the risk was tolerated and no further risk reduction was performed. Only after the TR3 risk assessment specifically identified the associated risks of the hazard were changes made to reduce the risks.

This study was conducted within the constraints of real-world manufacturing pressures. Site 3 experienced significant growth in operations, nearly doubling its capacity due to plant closings elsewhere. Champions' responsibilities and time demands increased accordingly and their time available to work on risk assessment was infringed. Site 4 faced the opposite situation, with operations shipped out of the facility and personnel being cut. Challenges of language and communication and flux of temporary workers are all a part of manufacturing today and risk assessment must be conducted in these settings. In spite of these upheavals, this study achieved success and indicates that risk assessment can be successfully applied in the real world of manufacturing.

One lesson learned in this study was that software greatly improves the speed and thoroughness of risk assessment activity. Another lesson was that companies with limited in-house safety professional resources may benefit from using a facilitated TR3 process in blending risk assessment with legacy methods for machine safety assessment. A third lesson was that it is absolutely essential that the TR3 process be conducted in a time-efficient manner. This means that users need to realize that they should focus first on high-risk items rather than getting caught up in the details of low-risk items. Out of fear of missing something, one team analyzed all of the hazards in

excruciating detail. As a result, their efforts bogged down and derailed. Risk assessment needs to focus on the higher-risk hazards and avoid tripping on low-risk details. This is a lesson that a TR3 facilitator at the worksite can emphasize. The TR3 task-based approach takes you to a much more granular level of analysis, but great detail may not be needed for all tasks/hazards.

6. CONCLUSIONS

The results of this study indicate that although TR3 was originally written for use in the machine tool industry, the principles and methods apply very broadly for many types of equipment, machinery, and manufacturing applications. The qualitative results of this pilot effort appear to be the best indicators for the way ahead in industrial machine risk assessment. Application of TR3 may result in productivity increases, an unintended benefit from focusing on safety issues. After using this risk assessment method companies may find that they want to require their suppliers/vendors to perform assessments on new equipment. Software use, in general, can greatly improve the speed and thoroughness of risk assessment activity. In companies with limited in-house safety professional resources, a facilitated TR3 process may help in blending risk assessment with legacy methods for machine safety assessment. It is essential that the TR3 process be conducted in a time-efficient manner. Having dedicated risk assessment facilitators (either from within or outside the organization) would be a factor to be evaluated in determining the least stressful way to conduct TR3 risk assessments. Quantitative study results suggest that: (1) the TR3 guidelines may be effective for teams, as indicated in this study by the teams' completion of numerous risk reductions; (2) as measured by the knowledge of the participants before and after the TR3 training, the guidelines can be effective at enhancing employees' knowledge of safe machine operations; and (3) although the injury trends appear successful, the small sample size in the study size yields inconclusive results on injury rates.

Consequently, these pilot results suggest that TR3 may be effective in reducing machinery risk. Generalized reduction in risk for machine-related injury may have other explanations requiring further study to test hypothetical relationships between risk assessment and injury by means of triangulation. The study was not intended to establish that TR3 is better than other methods such as ISO 14121, MIL-STD 882, or FMEA. The pilot evaluation does suggest that TR3 is better than no method.

This pilot application of TR3 has resulted in safer working conditions for a selected sample of U.S. workers. The companies that participated in this study benefited from the feedback they received on their risk reduction activities. The application of risk assessment should be considered by machinery designer/user teams to select protective measures appropriate to the risk. It could provide OSHA personnel with a more substantive basis for evaluating the sufficiency of machine safeguarding. In sum, because these pilot results suggest that TR3 may be effective in reducing machinery risk; machine users, voluntary standards developers, and regulators can more confidently begin exploiting the potential of TR3 guidance for meeting their machine-related injury prevention responsibilities.

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