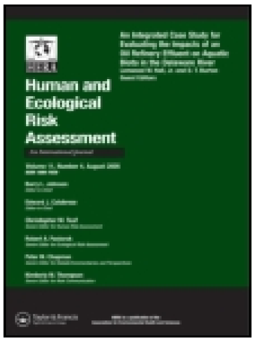

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Machinery Risk Assessment for Risk Reduction

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ABSTRACT

New avenues are reviewed and discussed for preventing industrial machine-related injury by means of realistic risk evaluation and reduction processes at the design and application stages of machinery development and use. U.S. guidelines and European standards on machinery risk assessment procedures are described. Applications of risk assessment for machine-related injury risk management and teaching machine-risk control are discussed.

Key Words: occupational injury, machinery, risk assessment, guidelines.

INTRODUCTION

In London subway stations, a gap often exists between the edge of the platform and the edge of the open door to a subway car. This gap is sometimes large enough that a person could step into it and be at risk of injury should the train then proceed forward. The transit authority's solution for this hazard has been an amplified voice, announcing at regular intervals throughout the station, "MIND THE GAP!" Presumably, the injury risk had been assessed and a risk reduction decision was made that the probability of injury could be sufficiently reduced by warning people to stay clear of the hazard. Undoubtedly, the thinking behind this solution was that it reduced the risk enough so that more expensive engineering alterations to the platform's design were not needed. Arriving at acceptable safety solutions for man-machine interfaces is a common objective in both public and industrial environments.

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In 1995, a Technical Report subcommittee (TR3) was formed under the auspices of the American National Standards Institute (ANSI) B11 Machine Tool Safety Standards Committee. The subcommittee has labor, machine builder, machine user, government and safety consulting representatives. Their purpose was to develop a technical guidance document to bring machine tool risk assessment practice in the United States up to or above the level now required by European standard EN 1050 "Safety of Machinery: Risk Assessment". The European standard mandates that a process be followed that ensures that safety measures are appropriate to the risks in machine operation and servicing tasks. The ANSI B11 TR3 (2000) document became available for general use in November 2000, adding the benefits of risk assessment to the array of methods already available for preventing injury at machine tools in the United States.

Machinery safety risk assessment (MSRA) is an analytical process that engineers and safety practitioners may use to define safe machinery design, procurement, and application requirements (Figure 1). The aim of risk assessment on new machinery is to see that hazards are mitigated before they are introduced into the workplace. Employed judiciously, MSRA can help to locate critical elements in a design, identify associated hazards, evaluate their risks, and prompt decisions to reduce risks to acceptable levels. This review will discuss occupational machine injury risk assessment with respect to the European perspective, developments in the United States, risk management and cost assessment, and machinery risk control training.

A NEW FORM OF RISK ASSESSMENT

Risk is often defined as the probability of adverse response. Risk assessment (RA) is a process for systematically guiding risk reduction/risk management activities (Webb 1996; Lewis 1990; NAS 1983; Rowe 1980). RA results are traditionally based on collecting and evaluating data on *severity* of an injury or health event and *probability of occurrence* of the event. But currently, formal RA methods are rarely applied for occupational machinery risk reduction.

The U. S. Department of Defense developed, and updates one of the most pervasive risk assessment approaches, MIL-STD-882D (2000) "Standard Practice for System Safety". The chemical industry has also been involved for many years (Center for Chemical Process Safety 1994). Aviation, medical devices, semi-conductor and robotics industries, along with the Occupational Safety and Health Administration (OSHA), have all adopted risk assessment for specific applications (Main 2000). There is no one "best" method. The really good news is that with all of the uncoordinated effort in risk assessment development and implementation, there is a good deal that is common among all of the methods.

MSRA is a relatively new process that differs from substance-derived illness risk assessment (SIRA). The former is countermeasure-focused, dealing with multiple, known hazards with known severity of harm; while the latter focuses on actually determining severity of harm from varied doses of a suspected, or partially evaluated, substance (chemical, air contaminant, or biological material for example). In the ecology of the workplace, MSRA focuses on human exposure to multiple hazards within an industrial man-machine system in a specific workplace; whereas SIRA focuses on human exposure to a single substance in a global context.

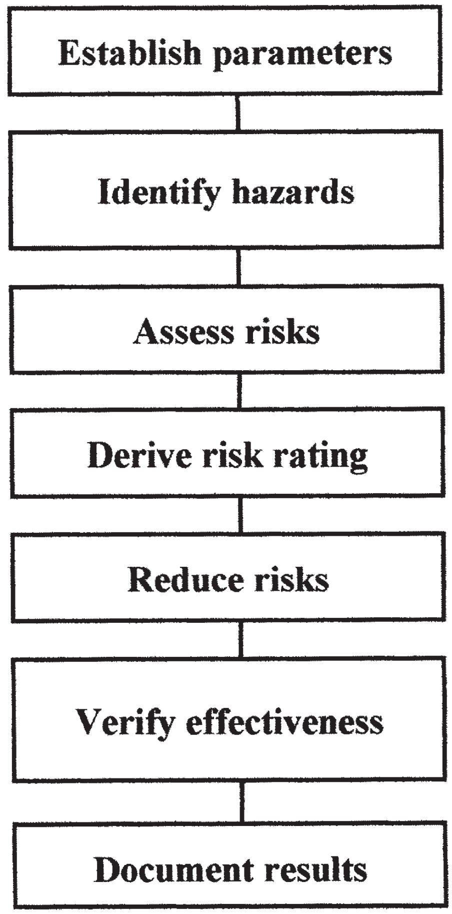

Figure 1. The steps in machinery safety risk assessment for risk reduction

Substance-derived illness risk assessment (SIRA) is a public health or regulatory guidance activity whose most common purpose is describing the effects on working populations of different dose levels of substances such as cadmium (NIOSH 1976), tungsten (NIOSH 1977), and metalworking fluids (NIOSH 1998). Typically large populations are involved, exposed to a single substance, that has unknown or ill-defined health consequences. The severity of illness response among individuals may vary widely, independent of dosage. Biostatistical methods are used in modeling population response to levels of exposure. Health epidemiology methods are used to measure exposure and consequence rates and to make rate comparisons.

The purpose of (MSRA) is to rationalistically guide machinery risk reduction choices across a wide array of protective measures options. Risk is reduced when a protective measure (change of design, use of safeguard, and/or implementation of safe procedure) is implemented that meaningfully reduces severity of injury or probability of occurrence of harm. This focus on discrete protective measure selection means that iterative assessments are the norm in MSRA. Engineers, managers, and workers use consensus methods to classify the risk of task-hazard pairs identified in the first stage of the MSRA process. For machinery systems, the severity consequences of hazardous energy transfers (mechanical, electrical, or thermal transfers for example) do not vary among individuals. The amount of energy transferable in typical industrial machinery processes (the dose) is well above levels that humans can tolerate. For this form of RA, injury epidemiology is useful for determining severity and probability of injury for task-hazard pairs for which adequate data has been collected. However, probability-of-injury determinations also take advantage of information on safeguard reliability and human factors.

Machinery Risks

Between 1996 and 1998 there were 464 occupational fatalities (an average of 155 per year) reported to the U.S. Department of Labor's Bureau of Labor Statistics resulting from being caught-in-running-machinery (BLS 1999). For the 1995 to 1997 period, there were 92,932 cases of nonfatal injury of this type involving lost workdays (SOII 1999). The majority of these (65%) were in the manufacturing industry. The 1996 total incidence rate (cases involving days-away-from-work per 10,000 full-time workers) for the manufacturing industry was 238.3 compared to 212.3 for all private industry. The rate for machinery injury in manufacturing was 27.7 (11% of the manufacturing rate.) Using National Safety Council (NSC 1996) estimates, the caught-in-running-machinery deaths alone cost the nation $122 million. Design safety experts in the United States and Europe agree that machine-related injury rates are high because protective measures that are only appropriate for low-level risks are being applied in situations where the risk involves frequent exposures to hazards that may lead to fatality or serious traumatic injury (Adams 1997). Also, inadequate attention is given to mitigating the hazards that arise when performing maintenance.

New Machinery Technology

The mass introduction of new technologies into industrial production systems (more automation, more information technology) has increased the performance of these systems in terms of quality, productivity, flexibility, and availability. However, it has introduced a number of difficulties. These include safety problems with installation, maintenance, repair of breakdowns, and difficulty for the designer to take account of all these factors. Analysis of industrial situations often uncovers large differences between the predicted performance of systems and observed practice (particularly the management of deviations, constraints on production, extending the life of equipment, evolution of production systems, process variability, control circuit reliability). This gap is currently one of the main causes not only of poor performance, but also of risk-taking by operators. These situations have not been sufficiently considered in the design phase (Fadier *et al.* 1999).

Most design work relates to practical experience and has limited theoretical support (Wagner 1988). Although different researchers have tackled a very diverse range of problems, there are not many who have tackled the problem of integrating health and safety into the way the design process is managed. Many works have reviewed and analyzed the various tools, methods and approaches to design, or have offered new research or design methods (Fadier *et al.* 1999). Machinery system designers face the following problems in trying to achieve a safe design:

- lack of adequate hazard data during innovation and creative design (and even in routine design)

- inability to foresee differing needs for human intervention (clearing jams, maintenance, and repair for example) and the hazards associated with each activity

- identification of intended use and foreseeable misuse by machine users, particularly in tasks relating to maintenance and fault finding

- design conflicts between mechanical, pneumatic, electrical power, and control systems

THE EUROPEAN PERSPECTIVE

In the European Union (EU) machine-related occupational injuries are frequent and serious. Contact with machinery at work is the fourth most-common type of fatality (ESAW 1994). In the UK, machine operators had a non-fatal injury rate of 3250 per 100,000 workers while the rate for all occupations was just 1510 per 100,000 workers (LFS 1999). The number and regularity of machinery accidents show how difficult it is for machines and systems to operate safely. This problem is compounded because companies modernize in phases, which means that technologies of different generations co-exist at different levels of sophistication. Work activities are diverse and varying and the demands for operators to be multi-functional have increased.

The EU introduced a New Approach to Technical Harmonization and Standards aimed at integrating safety at the design stage. The Machinery Safety Directive (1993) sets out Essential Health and Safety Requirements (EHSR's), which must be met before machinery is placed on the market anywhere within the EU. EHSR's are expressed in general terms. Each member country develops European Harmonized Standards that provide machinery designers and suppliers with clear guidance on how to achieve conformity with the Directive and integrate safety at the design stage. This has fundamentally changed the approach to preventing machinery accidents in the workplace. In the place of reactive and prescriptive legislation and standards, the EU Directives represent a remarkable breakthrough in risk-based approaches to machinery and work equipment safety. However, research (Raafat and Nicholas 1999) has shown that the majority of machinery suppliers into the United Kingdom market have failed to demonstrate compliance with the risk-based approach.

Not every hazard and hazardous event warrants risk reduction measures. It is only when the risk of serious injury is significant that the designer would consider a hierarchy of risk reduction options. There are a number of tools based on semiquantitative methods for the evaluation of risks, that may be suited for the task of selecting the most appropriate category or safety integrity level, *e.g.,* a risk matrix

(ANSI 2000) and the risk calculator (Raafat 1996). Evaluation of risks, using the approach adopted by EN 1050 (1997), is based on the hazards identified for the machine. However, the approach to performing risk evaluation is unclear. The task-based approach adopted by ANSI (2000) may be more suited to the evaluation of risks associated with foreseeable modes of intervention. The task-based approach begins by actually determining what workers do as they operate and maintain machinery and the hazards are then connected to human exposure.

A Recent MSRA Model From the UK

A new, easy-to-apply machinery risk assessment model has been developed in the UK that leads to accurate machinery safeguarding decisions. The model, based on work by Harani (1997), is a product model that capitalizes on existing knowledge. It has recourse to the principle of meta-modeling, *i.e.*, representing and grouping all the information defining the system in the same knowledge base, or organized information structure. This system model integrates the use of risk assessment to assist the designer in integrating health and safety into the machine/system design. The functional analysis in the proposed model considers: the mode of intervention of the operator on the system; the tasks carried out by the system and the operator; raw materials being processed; working environment; the work team; and both the tools and materials used to ensure correct operation of the system. The main concept of this model is to integrate health and safety during the machine design stage, using the risk-based approach and consideration of relevant EU product safety Directives and harmonized machinery safety standards.

The model was tested on a design of a mechanical 1200/800-ton press line used in a body shop of an automotive manufacturer. Five mechanical presses imported from the Far East did not comply with the EU machinery safety requirements. As the machine suppliers are not represented in the UK, the company undertook the design, construction and assembly of the automated tandem press line. As a result of the model's risk assessment, a design change was indicated to reduce risk during human access into a robot's work zone to perform fault finding on the gripper while the robot is powered and pneumatic power is on. As a result, the design was changed so that the robotic gripper can be changed automatically without the need for access into the danger zone for any of the robots. Table 1 lists the relevant EU machinery safety standards that were satisfied.

Significant improvements in productivity were also achieved. The average press stroke rate was increased to 8 strokes per minute. Average die changeover time was held to less than 3 minutes. Offline setup time averaged less than 30 minutes per setup. This productivity level not only meets safety standards but is regarded as world class performance by this global manufacturing organization's standards.

DEVELOPMENTS IN THE UNITED STATES

In 1995, the Machine Tool Safety Standards Committee commissioned a sub-committee to develop guidelines for risk assessment that could be integrated within the family of ANSI B11 general industry safety standards. The team completed a report entitled ANSI B11 Technical Report #3 (TR3) *Risk Assessment — A guideline to estimate, evaluate and reduce risks associated with machine tools*. The methodology

Table 1. EU safety standards complied with during model evaluation.

Machine Elements	Standard Number
Presses and their controls	EN 692 & EN 982
Safety controls	EN 954-1 & EN 60204-1
Software safety	IEC 61508
Interlocked gates	EN 1088
Photoelectric devices	EN 999 & EN 50100-1

within TR3 improves upon the existing EN 1050 methodology used in Europe because it requires both suppliers and users to identify the tasks that expose workers to hazards. Identifying task-hazard pairs has been proven to identify more hazards than the traditional approach. TR3 essentially sets forth a common risk assessment approach for integration into the B11 family of machine tool safety standards. Risk assessment is also tied into a risk reduction strategy that follows the hazard control hierarchy of: (1) eliminate the hazard, (2) engineering controls, (3) warn, (4) train, and (5) personal protective equipment (PPE).

TR3 may well become the benchmark for risk assessment in this country and the world because it harmonizes with Europe and builds on the best, proven methods in use today. The general approach is: task and hazard identification; risk estimation; risk reduction determination; safeguard selection; verification of risk reduction; and documentation.

ANSI B11 TR3 is especially important because it addresses tasks and hazards not previously identified, particularly those associated with maintenance. The historic focus has been the operator. But what happens when the operator or other employee cannot perform the work? Typically, employees bypass safeguards. They may also defeat interlocks, use “jumpers” across electrical interlocks, or corrupt control circuit logic. The argument is made that if only employees followed the rules there would be no injuries. However, in the opinion of many, industry would shut down within the hour and never run again, if such were the case. The benefits of risk reduction have associated costs. In real-life situations, the increased cost of improving safety will drive up prices and reduce sales in competitive world markets. High risk conditions may be condoned by labor unions and their members, who may prefer imperfect implementation of safety and health laws if it improves incomes and employment prospects (Maynard 1999).

A primary stumbling block to the consistent use of risk assessment has been concern about how exactly to perform risk estimation. TR3 does not specify a single model, but permits the use of any of the variety of risk assessment models that exist (ANSI/RIA 1999; Clemens 1993). After a model has been selected, additional questions may arise. Guidance is provided with respect to questions such as “Does injury frequency mean much if it is high potential severity?" and "How do you differentiate levels of injury severity?"

Overconcern with the legal ramifications of documenting both hazards and the reasoning behind countermeasure selection can be seen as shortsighted. Achieving risk reduction is more important than any of these concerns. Risk estimation should be viewed as a golden opportunity to proactively apply the hazard control hierarchy and qualitatively reduce risk. The model used is not critical. Companies can certainly be expected to take measures to protect confidentiality. Competitive advantage can be gained with the risk reduction skill-base that a company develops. And a well-justified MSRA can provide defense against liability action if an injury should occur. Good faith application of feasibility considerations in the selection of higher order hazard controls will be key. And risk assessment is of most value when it is done in design before a contract for a new machine is let.

The future will see more emphasis on risk assessment as companies become more and more global. Machinery suppliers are getting this message and responding. Training for engineers, safety personnel, and others concerned will be critical. There will be considerable discontent for lawyers, business leaders, safety engineers and others who don't want to face this reality. For those companies that do see the trend toward risk assessment for risk reduction, the future will see both improved safety and improved productivity.

RISK MANAGEMENT

Risk assessment can be a tool for managing against the risk of machine-related injuries to employees. Risk management requires:

- obtaining financial and technical information from specific sources
- tracking direct and indirect injury expenses
- calculating potential savings and rates on investments

Without adequate information, it is very difficult to set priorities for risk reduction. In other words, information is the basis for determining if equipment should be modified, replaced or remain as is. Information permits evaluation of the effectiveness of the safety program and the calculation of savings, rates of return and payback periods.

Insurance company records can provide specific company and industry data by injury type (amputation, crushing, *etc.*) as well as loss data and national trends. The US Bureau of Labor Statistics has national injury statistics by industry and the Census of Fatal Occupational Injuries. Internal company records are an excellent resource. NIOSH's National Traumatic Occupational Fatality surveillance system provides information on source of injury and type of event. Individual states and the National Council on Compensation Insurance have worker compensation injury data. The Consumer Products Safety Commission has emergency room injury data in its National Electronic Injury Surveillance System. Professional organizations (National Safety Council, Precision Metalforming Association, *etc.*) may also have injury data. For accessible data sources, injury case data can be downloaded, computer sorted and analyzed to identify trends when appropriate denominator data is available. Surveillance system improvements are needed to give current data systems the depth of detail that will satisfy a burgeoning interest in data for conducting MSRA's. Following is a general example of well-detailed injury case data:

> An injection molding set-up worker burned his right arm while replacing the mold into an injection molding machine. He worked in Dept. #3470 at Machine #64. The injury occurred on 8/14/2000 at 8:20AM. The worker had 6 months experience. He lost 15 days of work. Medical costs were $8,439; insurance totaled $40,000; and lost time costs equaled $3,752.

Costs

The pain, suffering, and remorse concomitant with injury are never to be ignored. Preventing the misery of injury is highly valuable work. In addition, monetary losses must also be considered (Bird and Davies 1996). Total accident costs are a combination of direct and indirect costs. Total injury cost can be illustrated with an example of an employee who crushes two fingers on his right hand in a power press die while removing scrap. For this example, direct costs are $42,000 and indirect costs are $168,000 (4 times the direct costs); resulting in total estimated costs of $210,000.

Direct costs are medical benefits, lost time wages and insurance or self-insurance costs. Indirect costs (Table 2) can be 4 to 8 times the direct costs (Health and Safety Executive 1993). Insurance companies commonly use this ratio, basing it on injury claim reviews. Miller (1997) estimates lost productivity and workplace disruption costs using these assumptions:

- A quarter of the time wasted by deaths, disabling injuries, and injuries outside of work is supervisory time.

- A fatal injury costs 4 months of productivity (wages plus fringe benefits). Recruitment, retraining, and lost special skills are the major cost factors.

- A disabling injury serious enough to qualify for Workers' Compensation or require hospital admission costs 1 month of productivity for other employees.

- Other injuries on the job that cause work loss cost 2 days of supervisory time and 4 days of non-supervisory time.

If there are no actual injuries to evaluate at a specific company, estimated costs can be obtained from the insurer's claims department.

Savings and Benefits

Different formulas and computer programs are available for calculating potential savings, rates of return and payback periods. The benefits of implementing ergonomic principles are fewer injuries and illnesses; less stress and fatigue; improved productivity and quality; and higher job satisfaction. An example of savings with safeguard installation can be seen in an investment of $18,000 to provide light

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Table 2. Indirect cost categories with reasons for the cost.

Indirect Cost Category	Reason for Cost
Injured employee	Wages paid while receiving first aid
	Lost time if employee does not return to work that day
Machinery and equipment	Shutting down machines or processes
	Repairing/replacing damaged equipment
Managers, supervisors and safety committee	Seeing that injured employee receives prompt medical attention
	Investigating the accident
	Completing accident report
	Rearranging production schedule
	Transferring, hiring or training a substitute employee
Lost production, profits, customers and poor quality	Accident clean-up
	Time lost by other employees
	Overtime
	On-site first aid
	Possible liability claims

curtains for 6 press brakes. During a year of use, these light curtains prevent two injuries that would have cost $20,000 each. The company's desired rate of return is 10%. The inflation rate is 4%. Over 10 years, the company will save $462,240. This equates to a payback period of 5 months (direct costs only).

TRAINING FOR RISK REDUCTION

As the complexity of machine safeguarding grows, due in part to increased reliance on automated manufacturing systems, the need for training aids for understanding and maintaining the desired effectiveness of safeguarding becomes more important. Such training aids should address topics such as: safety related control circuit reliability, integration of different machine safeguarding technologies into a single manufacturing system, and proper set-up and use of machine safeguarding technologies. Training aids and "hands-on" laboratory activities can be particularly useful for teaching machine safeguarding technologies at the post secondary level.

The objectives of machine safeguarding training aids and curriculum materials are to familiarize safety decision makers with the capabilities and limitations of safety engineering controls. As examples, (a) a programmable logic controller can be used to construct a power press safeguarding simulator; (b) electrical relays can be utilized to teach safety related control circuits; (c) constructing a pneumatic energy system lockout simulator teaches machine-specific lockout procedures; and (d) a digital timing mechanism can be used to teach the concept of light curtain setback distances.

SUMMARY

Safe design processes that take advantage of risk assessment are not new, but are growing in sophistication. Adams (1997) enumerated one international corporation's three-phase safe design process for preventing injuries as:

1. Preparation of safety fitness-for-use criteria

2. Completion of an Engineering Design Safety Review

3. Completion of a walk-down or walk-through of installed equipment and processes prior to release to production.

That company used general design safety checklists as a key tool for its MSRA's. And, to ensure implementation of risk reduction measures, compliance procedures were developed and used.

To capitalize on the growing interest in MSRA methodologies for occupational injury prevention, future safety research will focus on effective MSRA training. Evaluations will be performed on how well risk reduction is achieved (injuries are prevented) after machinery risk assessment is performed. By establishing that MSRA methodologies are reliable, a safer workplace can be systematically assured.

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