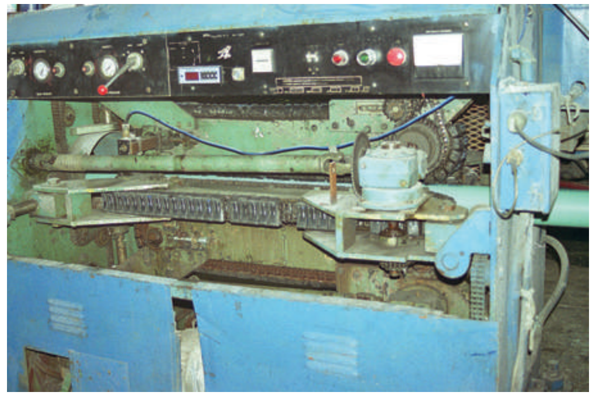
# Machine safety – a risk-based approach informed by standards

Simply adding guards to machines may not be enough. Risks may still exist because they were not identified as part of a thorough risk assessment. In this article Chris Peace shows how the risk assessment process set out in the joint standard AS/NZS ISO 31000:2009 Risk management – Principles and guidelines can be applied to machinery safety.



*In operation at the time, this machine posed trapping, impact, entanglement, ejection and health hazards*

## The problem

Machinery has been maiming and killing people ever since it was first built, causing pain and suffering for the injured, their families and workmates. Internationally, the death toll and number of injuries have been reducing for many years but horrific accidents still happen. Reducing this toll has become harder as production and other machinery has become more complex or forms part of larger, integrated production systems.

Some machines may release dust or hazardous substances, leading to delayed harm sometimes months or years later. While this is important (many people die every year because of earlier exposure to hazardous substances released during machinery operations), this article focuses on more immediate harm.

Guarding some machines can seem very simple. A fixed guard, held in place by suitable fixings, will stop access. But what happens when the guard is removed for cleaning or maintenance? Will the guard be replaced correctly – or at all? Do the operators get frustrated by frequent jamming and resort to permanently removing the guard for easier access? Do guards slow production to the detriment of wages and order completion?

Such questions should be asked (and answered) as part of a thorough risk assessment before any injury occurs. Where to start? And what exactly are we talking about?

## Risk, hazard, risk assessments, controls and actions

We should start by clarifying what we mean by hazard, risk and risk assessment.

A hazard is something with the potential to cause harm. The Health and Safety in Employment Act 1992 gives a much longer definition but that's what it boils down to. Hazard is all about negative consequences for people.

Typically, a machine takes energy and converts it into mechanical motion to help change something. If that energy is not properly separated from people it may cause harm. The greater the energy, the greater the harm may be.

For example, a power press has a flywheel that stores energy to enable the press to punch through metal. The stored energy can 'escape' when not expected and harm the operator. The 'punch' motion of a power press may also generate impact noise that can cause hearing damage.

Understanding risk means we understand how uncertainty might affect the achievement of our objectives. Objectives should include the safety and occupational health of workers as well as productivity and related issues.

### How are people harmed?

**Trapping** causes injuries when the body or limbs are trapped between closing or moving parts of machines, including in-running nips.

**Impact** injuries happen when a person is struck by moving parts of a machine or by the machine.

**Contact** injuries result from hot, sharp or abrasive surfaces or from contact with electrical components.

**Entanglement** of clothing, hair or rings can result in dragging into machinery (especially rotating machinery).

**Ejection** of small or large parts of the material being worked on can cause immediate harm (eg, a part breaking up hits a person or burns are caused by hot metal splashes or sparks) or delayed harm (eg, hazardous dust or noise).

These are the "business-as-usual" causes of harm but many injuries happen during maintenance. While the immediate causes may be the same, the root causes may be different and are often found in a failure to understand the change in operational environment.

Risk is not only about negative consequences. For safety-related risks, positive risk objectives might include a happy, healthy and productive workforce, willing to go the extra mile because they know management cares about them.

A risk assessment is carried out to help understand risks and decide if the situation is acceptable 'as is'. It is not just about how we might eliminate or reduce a risk.

In fact, a thorough risk assessment starts with even bigger questions about the business and operating environments a given machine is operating in. Understanding these environments requires input from management if a full picture is to be built up. Such an understanding may change the question from "how do we guard this machine" to "how do we improve the process, to the safety and satisfaction of workers, customers and regulators?". This different question will help gain an understanding of the risks associated with the machine.

Part of this understanding will include researching the numbers and nature of injuries and near hits associated with the machine in question. It may also be necessary to ask a trade body or the Department of Labour for such information to help build up a bigger picture.

***The photoelectric beam had been deactivated to allow occasional jams to be removed quickly. The operator no longer had to stop and reset the robots but could have been crushed as the robot cannot distinguish between a work-piece and a human being***

## How badly might people be harmed?

The level of possible harm might be analysed using the labels and descriptions set out in figure 5, the machine risk analysis matrix.

## The risk assessment

Once we understand the business and operating environment, we may have some ideas about how injuries might happen.

It may seem obvious, but we first need to identify risks before they can be analysed and then evaluated. Identifying risks involves asking questions. Some simple techniques can help build a picture. For example, using the Structured What If Technique (SWIFT) as part of a brainstorming exercise with management, machine operators and others will often unearth previously unknown risk factors. It has the side benefit of building trust between the various parties – provided it is done constructively and sensitively.

To help identify risks using SWIFT, we might apply the words of Rudyard Kipling:

*"I keep six honest serving-men*
*(they taught me all I knew);*
*Their names are What and Why and When*
*And How and Where and Who."*

Ask questions such as the following (and others) about the machine.

- **What** exactly is it for? What does it do? What does it use (energy, raw materials)? What does it make? What cleaning is re-

*Figure 1*

## The effectiveness of controls

A single administrative control is almost certainly not reliable. For example, allowing access to moving parts that could cause a serious crush injury after asking permission from an office-based supervisor will be unacceptable.

On the other hand, several independent engineering controls backed by permit-to-work and audit systems would be quite acceptable if the worst foreseeable injury was negligible. But you must be certain the controls are reliable and do work effectively under all circumstances.

One way of evaluating controls is shown in the Table below. This can be used if a machine has two or more controls for the same risk.

### Controls effectiveness evaluation

| *Control effectiveness description* | *Meaning* |
|---|---|
| Effective | Nothing more to be done except review and monitor the existing controls. Controls are well designed for the risk, modify the root causes and management believes they are effective and reliable at all times |
| Partially effective | Most controls are designed correctly and are in place and effective. Some more work to be done to improve operating effectiveness or management has doubts about operational effectiveness and reliability |
| Ineffective | While the design of controls may be largely correct in that they modify most of the root causes of the risk, they are not currently very effective<br>OR<br>Some of the controls do not seem correctly designed in that they do not modify root causes; those that are correctly designed are operating effectively |
| Totally ineffective | Significant control gaps. Either controls do not modify root causes or they do not operate at all effectively |
| None | Virtually no credible control. Management has no confidence that any degree of control is being achieved due to poor control design and/or very limited operational effectiveness |

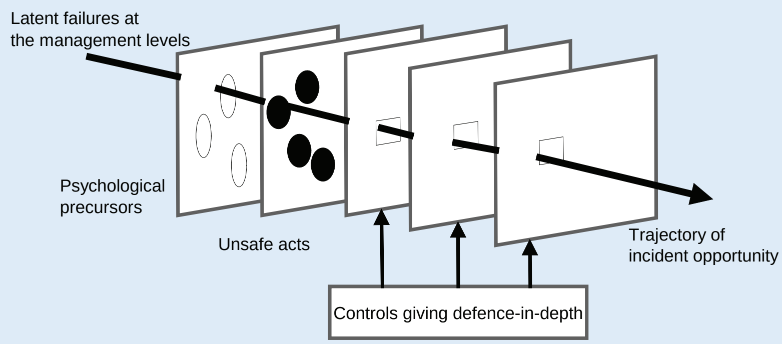
## Swiss cheese model

*Figure 2*

In a well-managed organisation, all controls would always work as intended and risks would be effectively managed to an acceptable level. However, organisations are not always well-managed and errors occur, sometimes with disastrous consequences. The potential for controls to fail can be identified using several techniques including layers of protection analysis (lines of defence) and bow-tie analysis to show how several complementary controls could be compromised.

The "Swiss cheese" model below shows how a latent failure in a management system can allow an initiating event to cause an event. If controls are less than perfect they may line up to allow the failure to run through the defences-in-depth resulting in harm to a person.

The model confirms the need for defences-in-depth when lives are at risk.




quired (if in the food industry, this is a very important question)?

- **Why** do we do or use or make that?
- **When** do we do or use or make that? Summer or winter? Day or night? Once a year or every weekday?
- **How** do we use or make that? Batch, continuous or intermittent process? Manual or automatic feed? How much energy does the machine store (hint: how long does it take to stop after being turned off)?
- **Where** do we use or make that? Main production floor or remote corner of the site? On our own site or in a customer's site?
- **Who** (age, experience, training) delivers raw materials to the machine? Who operates the machine? Who takes away the finished goods? Who cleans the machine and the area around the machine (which leads to another 'when' question)?

Getting answers to these and other ques-

tions will gather a lot of information about the exposure to hazards from a machine.

### Current or controlled risks

We also need to know how risks from a given machine are currently controlled so we can decide if that level of control is acceptable.

A 'control' is something that is modifying a risk. It might be a device (such as a guard), an administrative policy, an operating procedure or practice, training or competence certification or some other action that modifies risk.

We often talk about reducing risks but in reality 'controls' modify risk. Sometimes controls have no effect on the risk itself, but modify the business or operational environment where the risk is found and so change a machine-related risk to an acceptable risk. If the level of risk is acceptable there may be no need to add to or change the controls.

Asking questions about how the machine is operated, and by whom; and how the energy is contained and so on will help identify the controls.

***The double saws in this plant sliced building boards into strips. They jammed regularly and the machine guard could be opened without deactivating the whole process. A jam cleared unexpectedly on one operator and his hand was sawn off above the wrist. The emergency trip wire could be pulled only in one direction, adding to the problem***

While the best controls are often said to be design-based, they do not always achieve the best production results and may be defeated by operators, sometimes with the seeming approval of line managers. This can especially be a problem when pay is linked with production and guards are seen to reduce output.

Similar problems can occur with administrative controls. For example, a permit-to-work system for machine maintenance workers (including contractors) is highly dependent on all parties knowing and following the permit system.

In short, controls do not always exert the intended or assumed modifying effect – another good reason for a collaborative workshop to discover why this might be. The workshop should also evaluate controls for their effectiveness (see figure 1).

Control weaknesses can occur in the best designed systems. The higher the risk, the greater the defences-in-depth should be. However, sometimes, control weaknesses can coincide resulting in the "Swiss cheese" model (see figure 2).

*Figure 3*

## Options for modifying unacceptable risks

Risk treatment has a wide-ranging definition in the standard, summarised in the left-hand column of the table below. Using that definition, the examples shown in the right-hand column have been developed.

### Options for modifying unacceptable risks

| *Risk treatment option* | *Examples* |
|---|---|
| Avoiding the risk by deciding not to start or continue with the activity that gives rise to the risk | A new machine poses unacceptable risks and is not purchased<br>An existing machine poses unacceptable risks and is taken out of service until it can be upgraded or is used for spares for less risky machines<br>An existing machine poses unacceptable risks and is replaced with a modern machine |
| Seeking an opportunity by deciding to start or continue with an activity likely to create or enhance the risk | This is not usually an acceptable solution but might arise under some circumstances |
| Removing the source of the risk | Similar to isolation but may include:<br>• moving the machine to a locked off area<br>• some forms of guarding |
| Changing the nature and magnitude of likelihood | Guarding that keeps people away from the hazardous areas of the machine |
| Changing the consequences | Guarding that slows or stops the machine before people can enter the hazardous area<br>Providing personal protective equipment |
| Sharing the risk with another party or parties | Contracting out work to an organisation appropriately equipped to keep the risk to an acceptable level |
| Retaining the risk by choice | Low levels of risk may be tolerated provided they are informed by a competent risk assessment and controls are effective and monitored by managers and specialists |

*The mesh cover allowed powder to be tipped out of a sack into a mixer where a large paddle stirred a slurry. The operator left the guard open as powder clogged on the mesh. He was found drowned and beaten an hour after going missing*

## Risk analysis and evaluation

A risk analysis can then be carried out using the information about the business and operating environment, the risk in business-as-usual circumstances and maintenance or other circumstances, the current controls (engineering and administrative) and the likelihood of each specified harm. This information can be combined to show the level of risk using a matrix such as that shown as figure 5.

This matrix is an incomplete example for the purposes of this article and not intended to provide reliable guidance. The business and operational environments are quite different between different organisations and the risk analysis questions may reveal unexpected issues.

The risk analysis may show there are risks that could cause harm, even significant harm, to machine operators or other workers (including contractors or other visitors). In such cases action will be needed and management will need to approve an action plan, including a budget.

## Options for further modifying the risk

Machine-related risks might be modified by changing, for example, either the materials to be processed, the overall production process, the finished goods, or how the product is packed or transported, as well as by improving the machine guarding.

To help improve machine guarding, safety practitioners (and the Health and Safety in Employment Act 1992) use the simple control hierarchy:

1. avoid or eliminate
2. isolate
3. minimise
4. provide personal protective equipment.

However, the risk treatment stage of risk management (the 'process of developing, selecting and implementing controls') suggests the options shown in figure 3.

From a management perspective, this wider approach opens up more cost-beneficial options while still leading to improved

### Some statistics

In 2010:

- 75 workers were killed at work
- 5,945 serious harm notifications were made, many involving machinery
- 89 employers or employees were successfully prosecuted for breaches of health and safety legislation.

safety (without necessarily reducing profitability).

The standard makes a further important point: treatment can create new risks or modify existing risks. In other words, a further risk assessment should be carried out on the preferred risk treatment option to help ensure new risks are not created or other risks unacceptably increased.

### Talk to people!

Experience shows the best risk assessments include open-minded consultation with people in the workplace about the machine risks and, in fact, the Health and Safety in Employment Act 1992 requires this. Effective consultation asks about the risks and seeks ideas for overall process improvement.

Good communication with machine operators and others will also be essential. This might include training operators how to safely operate a machine as well as telling others what they are or are not allowed to do on and near the machine.

*Figure 4*

## Machine guarding choices

The following are some common types of machine guarding in a generally accepted hierarchy of machine guarding effectiveness from most effective to less effective.

### Machine guarding choices and effectiveness

| ***If access to the dangerous areas is not needed during normal operation the following can be used*** |
| --- |
| Fixed guards – A fixed guard should be fit for purpose and only capable of being removed with special tools. It should not allow access to moving parts but some gaps may be needed to feed materials into the machine; these should be carefully set to prevent fingers or other parts of the body being harmed |
| Distance guards – A distance guard (eg, a fence or fixed barrier) prevents any part of the body reaching into a danger area |
| Trip devices – A trip device such as a trip wire or mat can be used to sense the presence of the machine operator and stop or reverse the machine before harm can occur |
| Control guards – If a machine can be stopped quickly fitting a control guard can help prevent starting when the guard is open and stop or reverse the machine if the guard is opened during a cycle |

| ***If access to the danger area is needed during normal operation the following can be used*** |
| --- |
| Interlocked guards – An interlock prevents the machine operating while the guard is open. They may lock the guard closed during a cycle. Interlocks can be overridden or fail in service |
| Automatic guards – These are typically used on slow-moving machines and physically remove the operator from danger or vice versa |
| Adjustable guards – Such guards are used where some access is needed, perhaps because of varying sizes of materials being fed into the machine. Correct adjustment and good supervision are essential |
| Self-adjusting guards – The workpiece opens a self-adjusting guard which closes when the workpiece has moved through (a circular saw guard is an example of a self-adjusting guard) |
| Two-hand controls – The operator must hold both handles (and typically press a button on each) for the machine to operate. Alone, such a guard provides no protection for anyone else in the vicinity |
| Overrun devices – If a machine has a long run-down time some form of rotation sensor or timing device is needed to prevent a guard from being opened |


***This machine was activated by either one of two foot pedals. It took little imagination to see how either worker could injure the other***

### Monitoring and review

Once decisions have been made to modify a machinery-related risk, progress with action must be monitored. Similarly, controls must be monitored by machine operators, line managers and any specialist safety practitioners. For high-importance controls, some independent audit may be needed.

Periodically, the business and operating environment need review to find out if there have been changes. Sometimes, this shows new risks have emerged, or controls have become less effective.

### Official guidance

The Department of Labour guidance is now 16 years old and quotes even older standards and documents, many out of date, some withdrawn, others superseded – and omits some more recent standards. For example:

- BS 5304: 1988 Code of Practice for Safety of Machinery has now become PD 5304: 2005 Guidance on safe use of machinery
- all the UK Health and Safety Executive documents mentioned in the Department of Labour guidance have been withdrawn
- the multi-part Australian standard, AS 4024: 2006 Safety of Machinery, has become available and contains guidance based on European and International Organisation for Standardisation standards with some modifications for Australia.

The Australian standard sets out internationally accepted guidance on the safety of machinery (it is also accepted in the USA) and is important for any machine guard specifier, designer or advisor to have (at least the relevant parts). But the standard is expensive (a deterrent to purchase by machine purchasers) and may be due for update.

## Suppliers' duties

The Health and Safety in Employment Act 1992 sets duties on anyone who hires, loans, sells, supplies or leases 'plant' (ie, machines) to another person for use at work. The supplier must make sure the plant is designed and made and has been maintained so that it is safe for any known intended use, or any use of that plant that could reasonably be expected. Similar requirements apply if the supplier agrees to install the plant. These requirements do not apply to second-hand plant sold 'as is'.

These requirements are sensible, but they mean a supplier must make sure the person who hires, borrows, buys, receives or leases plant:

- has told the supplier what they will use the plant for and
- has been told by the supplier of any limitations the plant may have in use.

For example, it is possible a machine may require special guarding under some conditions of use. The supplier must ask what the machine is to be used for and must supply that guarding with and as part of the machine.

## The end point

The higher the machine-related risk to people who might come into contact with a given machine, the more the risk must be modified. This might require the help of a machine guarding specialist but readers should not overlook the opportunities for redesign of work flow or the whole process. ■

*– Chris Peace, is a director of Wellington-based Risk Management Ltd, wrote this article for ElectroLink on behalf of the NZ Society for Risk Management Inc*

## Machine risk analysis matrix

*Figure 5*

| | | | | | | |
|---|---|---|---|---|---|---|
| **Types of controls modifying the likelihood of harm (effectiveness increases going down)** | **Description of likelihood of harm** | | | High | High | Extreme |
| Single administrative control | Almost certain | | | High | High | Extreme |
| Redundant administrative controls | 4 | | | | High | Extreme |
| Single engineering control | 3 | | | | High | Extreme |
| Redundant engineering controls | 2 | | | | High | Extreme |
| Redundant engineering and administrative controls | Almost incredible | Negligible | | | | |
| | | **Trivial** | **Minor** | **Moderate** | **Serious** | **Catastrophic** |
| | **Description of possible harm** | Trivial cut or splinter at worst | First aid treatment | Temporary disability | Major harm, possibly permanent disability | Death of people at the machine or in the vicinity |
| | **Types of controls modifying the consequences of harm (effectiveness decreases from left to right)** | Redundant engineering and administrative controls | Redundant engineering controls | Single engineering control | Redundant administrative controls | Single administrative control |

The level of risk is shown inside the matrix (eg, extreme and high down to negligible). An extreme or high level of risk will require action to modify the operating environment or the machine or both.

This matrix is deliberately incomplete as it is very difficult to provide reliable guidance in a general article such as this. The business and operational environments are quite different between different organisations and the risk analysis questions may reveal unexpected issues.

Note: for simplicity, health-related hazards (eg, dust, hazardous substances and noise) are not covered here for simplicity.