# ASSET RISK MANAGEMENT OF BULK MATERIALS HANDLING EQUIPMENT

*by Richard Morgan*[1]


## ABSTRACT

*Modern bulk materials terminals are heavily reliant on achieving high productivity through the use of large, high capacity rail-mounted equipment such as shiploaders, ship unloaders, stackers, reclaimers, etc. These are large moving structures with relatively onerous load conditions and have shown failure rates that are much higher than standard building structures. Under workplace health and safety legislation, owners and operators of such equipment have significant responsibilities for safe operation. Traditionally, engineers check that their designs confirm with relevant codes of practice and statutory regulations. However this approach only provides a minimum acceptable standard for design. Other factors may include operations, maintenance and human error. In addition, protective or load-limiting devices in the electrical, control, mechanical and hydraulic systems are very important in determining the load imposed on a machine. This is an area which requires close attention both in the design phase and on site to ensure that the installed devices perform the correct function.*


## 1. INTRODUCTION

Large materials handling machines such as stackers, reclaimers and shiploaders are typically of welded steel construction balanced by a large counterweight. They are normally capable of long travelling, slewing and luffing motions and must withstand repetitive dynamic loads. Historically, such machines have experienced higher failure rates than other types of structures. The main risks are typically machine collisions, corrosion and structural fatigue cracking. The structural integrity of a machine is dependent on the structural, mechanical, electrical, and control systems operating correctly. The distinguishing feature of mobile equipment for continuous handling of bulk materials is the inherent high level of risk and the very large cost of addressing the failure consequences. This difference justifies specific processes to manage this risk.

## 2. BACKGROUND

### 2.1. Machine Types

A description of some of the more common types of machines used in ports follows below.

#### 2.1.1. Shiploaders

a) Bridge type shiploaders

Bridge type shiploaders have a large travelling bridge spanning from the seaward rail to a second rail or pivot point located on the land or some distance behind the berth on a structure where the berth is at sea. A shuttling trolley system, which supports the boom, tower, and luffing winch system travels along the bridge. This shuttle can fully retract behind the quay line to allow ships to berth or de-berth.

The machine may have a telescopic chute at the end of the boom to control the flow of material into the ship's hold. Chutes can operate in free flow or deflector mode where a trimmer is installed at the bottom of the chute.

Bridge shiploaders may be long travelling, radial or linear types. These shiploaders tend to be large and relatively heavy compared to portal gantry and portal slewing types. Metal fatigue in the bridge girder and at the boom head due to chute rotations is a common issue with this type of shiploader. For the long travelling bridge type, skew control is very important to avoid derailment or other major damage.

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**Figure 1: Long travelling bridge type shiploader**

b) Portal gantry type shiploader

This type of shiploader has a portal structure spanning the rails and a fixed boom gantry set at 90 degrees to the rail track. The shiploading chute shuttles in and out to load the hatches and due to geometry, there are limitations on the length of inboard travel of the shuttle. The shuttle mechanism may vary the length of the boom as in Figure 2 or the boom may be of fixed length with the shuttle within the boom. The main issue with this type of shiploader is the accumulation of fatigue cycles due to shuttling and due to spout rotations for trimming.

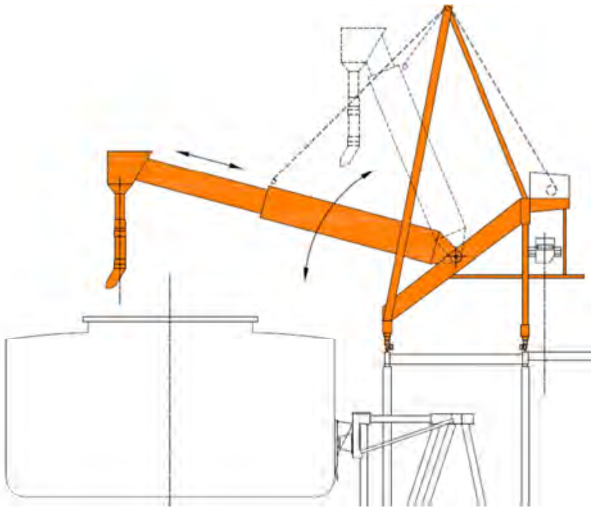

**Figure 2: Long travelling portal gantry shiploader with extending boom**

c) Portal slewing type shiploader

The portal slewing type shiploader is suitable for ships without masts and cargo gear. Trimming of hatches is accomplished by a combination of slewing and long travel motions. The portal slewing and shuttling type shiploader allows for greater flexibility in loading different ship types than the portal slewing type.

**Figure 3: Portal slewing and shuttling shiploader**

### 2.1.2. Stacker Reclaimers

Figure 4 shows the components on an older style of stacker reclaimer. The machine has a long travel motion along tracks propelled by driven wheels on the bogie system. In the stacking mode bulk material is fed onto the machine from the yard belt via a tripper which discharges onto the elevator. Material travels on a conveyor up the elevator and discharges through a chute onto the boom conveyor. The bulk material discharges onto the stockpile from the end of the boom.

In reclaiming mode, the boom conveyor reverses direction. Bulk material is reclaimed from the stockpile by the bucketwheel. This component rotates via a driven shaft. The buckets dig material from the stockpile and discharge it onto the boom conveyor. The boom conveyor discharges material through a central chute onto the yard conveyor.

The boom can pivot in a vertical plane about a central bearing to follow the stockpile terrain. This motion is driven by hydraulic cylinders and is termed "luffing". The boom can also rotate in the horizontal plane about a circular bearing. This motion is driven by a gear system and is termed "slewing".

Machines of this type are sensitive to changes in balance about the luffing pivot. Changes in weight and weight distribution need to be carefully monitored and controlled. The repetitive loading due to the bucketwheel motion requires consideration for metal fatigue of the structure and slew bearing. A "C" frame configuration as shown in Figure 5 can slew to both sides of the rail tracks without the need to extend the tripper and elevator.

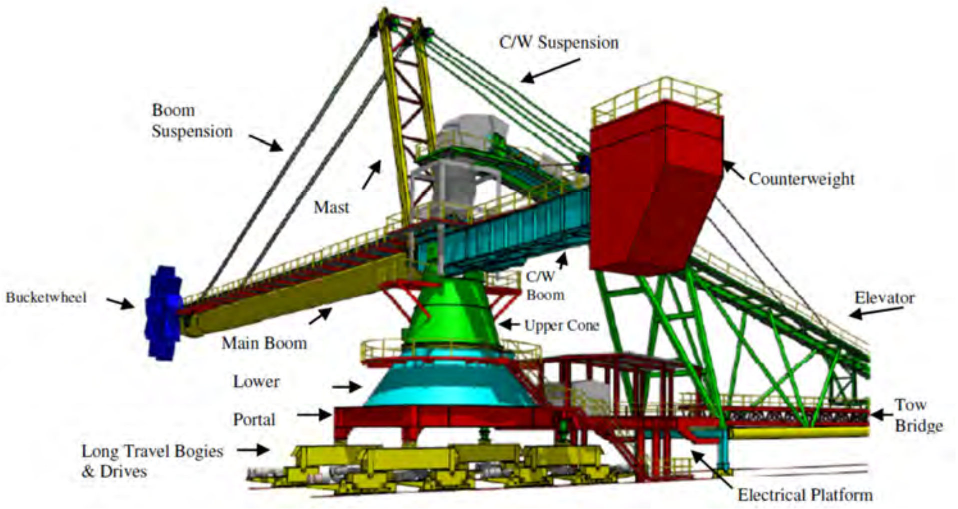


**Figure 4: Stacker reclaimer**

**Figure 5: "C" frame stacker reclaimer**

### 2.1.3. Stackers

Stackers predominately long travel with limited slewing motions in order to lay the stockpiles for subsequent reclaiming by a slewing or bridge type reclaimer. Figure 6 shows an older stacker, which is luffed by means of a winch system. Currently most luffing is carried out by means of hydraulic cylinders. Stackers with longer spans are often articulated to provide less variation in load during the luffing motion.

**Figure 6: Stacker with luffing winch**

### 2.1.4. Reclaimers

Figure 7 shows a bridge reclaimer of the bucketwheel type used for reclaiming on the face of a blended stockpile. Note the “rakes” which are used to loosen material on the active face. Bucketwheel boom type reclaimers are similar to a bucketwheel stacker reclaimer (see Figures 4 and 5) but without the stacking function so do not include a tripper and elevator.

**Figure 7: Bridge reclaimer**

## 2.2. Machine failures

As a result of several serious machine failures in the iron ore industry in Western Australia in the 1990s, much greater awareness of the risk associated with continued use of this type of equipment now exists in Australia. On one of the failures which resulted in a fatality, the Western Australian coroner, CULLEN, F. (1994), made recommendations regarding the following:

- Need for a strict Australian Standard regarding reclaimers and balanced machines of all types, particularly with respect to bucket wheel shafts
- Consideration to having reclaimers and balanced machines subject to an independent audit on design as is the case in Germany.
- The need for documents relating to the design and structure of mine machinery to be stored at

a central point within mining premises and that there should be a Codes of Practice as to the history of such machinery.

Australian Standard AS4324.1:1995 - Mobile Equipment for Continuous Handling of Bulk Materials, STANDARDS AUSTRALIA (1995), was issued in 1995 largely in response to these machine failures.

The author and colleague, MORGAN, R. and GATTO, F. (2002) collected information on 53 machine failures in Australia from 1977 to 1997. This has been updated in 2013 with a further 15 failures. These machines include stackers, reclaimers, stacker/reclaimers, shiploaders, ship-unloaders and in-pit systems. Figure 8 shows the number of failures per year over the past 36 years.

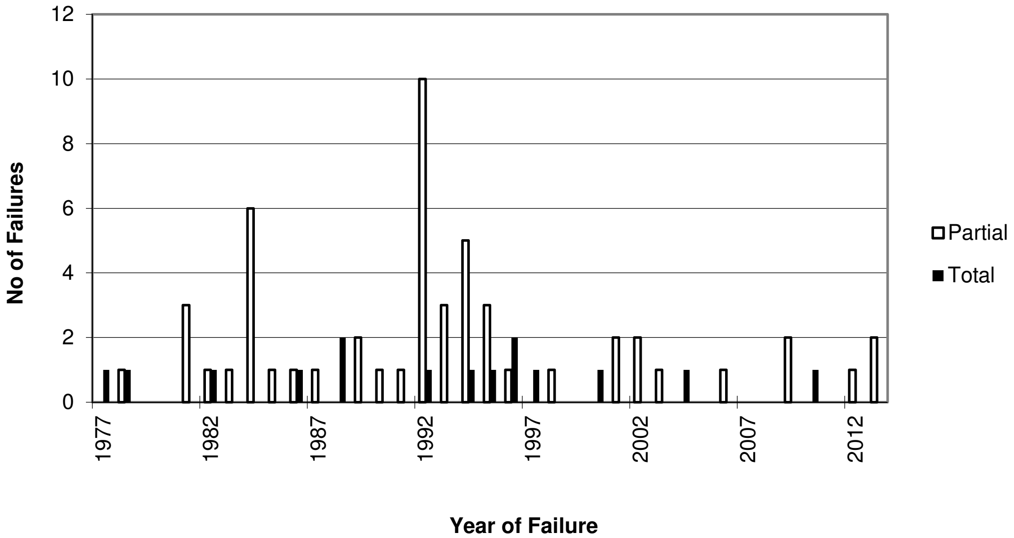


**Figure 8: Number of machine failures**

Partial failures are defined as failures which require major repairs outside of normal maintenance. Total failure involves the total collapse of the machine with the machine being beyond repair. As can be seen from Figure 8, the number of failures was increasing with time up until the introduction of Australian Standard AS4324.1 Since that time the number of failures has noticeably decreased and the total failures have all been on machines which were not designed to AS 4324.1.

Figure 9 shows the number of machine failures versus the age of the machine at failure. It can be seen that a significant number of failures have occurred during the construction and commissioning phases and early life of the machine. Further failures then tend to occur during the mid to late life of the machine.

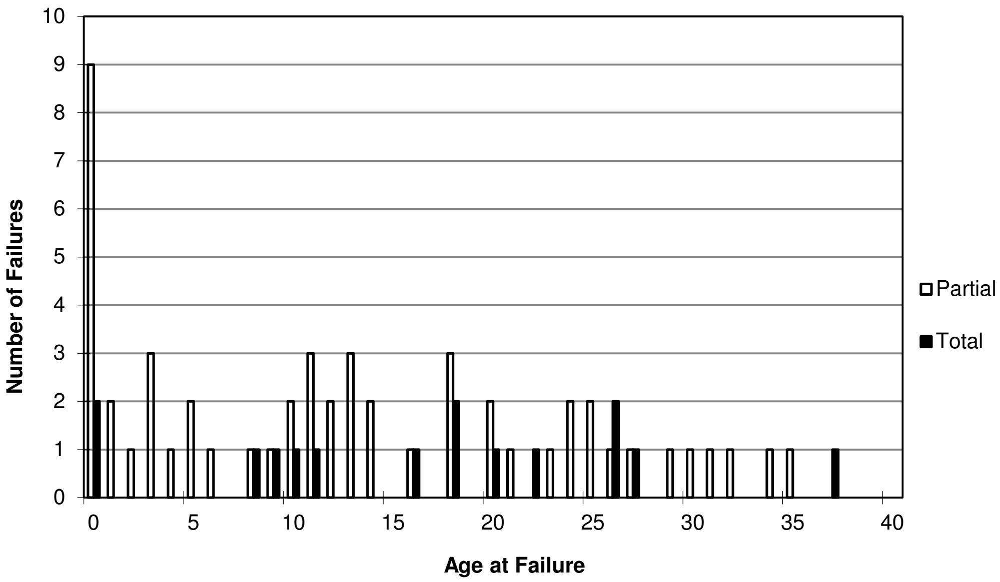


**Figure 9: Number of machine failures versus age of machine at failure**

Earlier work by the author and colleague, MORGAN, R. and GATTO, F. (1998) for Australian machine failures between 1977 and 1997 showed that the major causes of failure could be divided into four major categories:

- Human factors
- Extreme factors
- Operational factors
- Deterioration

When the analysis of failures was compared with the load combinations in AS4324.1-1995 as per Table 1 below, it was found that the effect of other causes than that covered by the design standard was significant and that this should be taken into account using a risk management approach. It should be noted that in addition to the design of machines to the AS4324.1 standard, much more emphasis has been placed by owners and operators in Australia on risk management of rail-mounted machines since the mid 1990s and this could also account for the lower failure rates even though the population of machines has increased significantly.

| | Failure Analysis | AS4324.1 |
|---|---|---|
| Human Factors | 6% | 0% |
| Extreme | 13% | 20% |
| Operational | 56% | 74% |
| Deterioration | 25% | 6% |

**Table 1: Comparison of failure analysis causes with AS4324.1 load cases**

### 2.3. Legislation and Standards

Workplace Health and Safety (WHS) legislation in Australia, SAFE WORK AUSTRALIA (2011), requires that a person conducting a business must ensure the provision and maintenance of safe plant and structures. Also, there is a requirement that a person with management or control of a plant has to identify reasonably foreseeable hazards that could give rise to risks to health and safety and eliminate risks to health and safety so far as is reasonably practicable.

Coal mining safety and health legislation requires that systems be put in place to reduce risks to acceptable levels, including systems to identify, analyse and assess risk and to maintain the place of work and plant in a safe state with risk to persons from coal mining operations at an acceptable level. Regulations require that a safety and health management system must provide for reporting all defects in the plant, structures, and procedures.

Australian Standard AS4324.1:1995 - Mobile Equipment for Continuous Handling of Bulk Materials was issued in 1995. This standard was written to specifically address these safety issues, to ensure machines are designed from the outset to survive accidental and overload situations over their operational lives. Under “duty of care” the design of pre-1995 machines should be reviewed, non-compliance with AS4324.1 identified, the risk evaluated and appropriate risk treatment actions be put in place. Post-1995 machines should comply with AS4324.1:1995. AS4324.1 is currently being revised and AS4324.2 for mechanical equipment is currently under preparation, MORGAN, R. (2013).

Where the machine relies on protective devices to protect against collisions and other hazards, these devices and associated systems need to be designed to an appropriate standard such as AS4024 – Safety of machinery, STANDARDS AUSTRALIA (2006). This is a default standard for control and protection for the type of machines within the scope being considered. Alternative standards including IEC61508, EUROPEAN ELECTROTECHNICAL COMMISSION (2010) and ISO13849, INTERNATIONAL ORGANISATION for STANDARDISATION (2006), can also be used for these purposes. Similarly, under “duty of care” the design of such machines should be reviewed, non-compliance with AS4024 identified, the risk evaluated and appropriate risk treatment actions be put in place. Modern machines should comply with AS4024 or an equivalent standard.

# 3. RISK MANAGEMENT

## 3.1. General

The methodology described below has been developed for asset risk management of rail-mounted machines. It follows the risk management process described in ISO 31000-2009, INTERNATIONAL ORGANISATION FOR STANDARDISATION (2009). An overall description of this process is presented below.

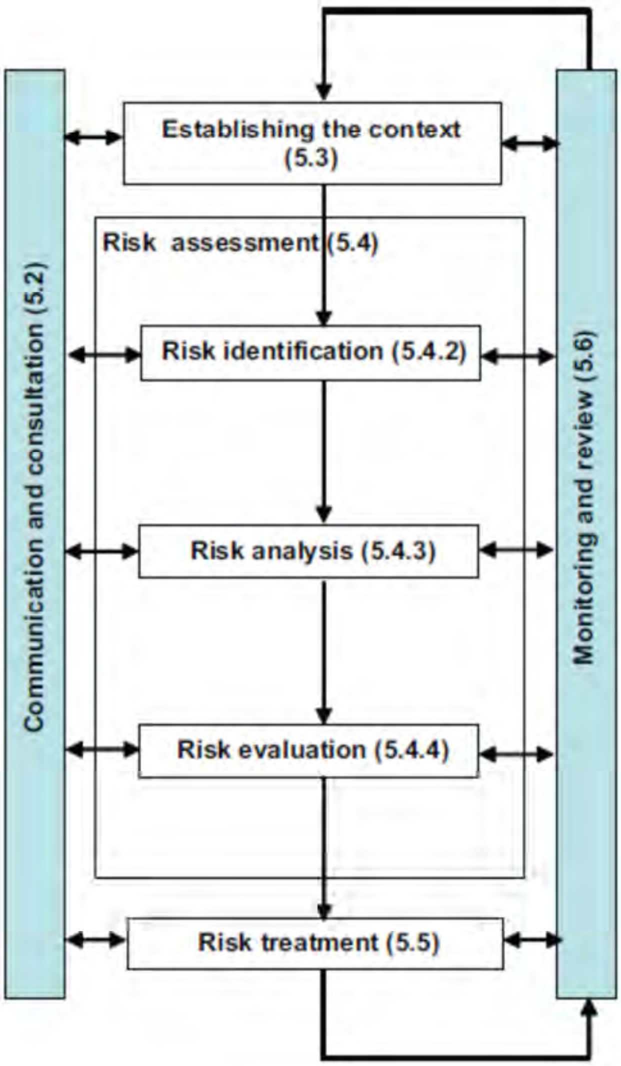


**Figure 10: Risk management process**

### 3.1.1. Establish the Context

Some of the items that need to be established are:

- Stakeholders – the people who have an interest in the results.
- Desired outcome – for example, ccompliance with regulations, the avoidance of catastrophic failures, maintaining minimal interruption to business, maintaining the value of the asset, maintaining business reputation and understanding the best way to manage risk for this particular asset.

### 3.1.2. Risk Identification

The following table lists some of the common hazards that apply to materials handling machines.

| HAZARD | CAUSE |
|---|---|
| ***Human factors*** | |
| Unknown nature of the machine condition/status | • Insufficient manufacturers data<br>• Structural or mechanical changes to machine since commissioning<br>• Electrical/control changes to machine since commissioning<br>• Deterioration due to normal wear or corrosion<br>• Damage/overstress due to collision or other incident<br>• Modifications resulting in changes to mass and/or balance<br>• Non-conformances to new standards i.e. old design does not consider all possible load cases<br>• Changes to the duty of the machine<br>• Changes to the interfacing fixed plant or other machine proximity |
| Structural damage due to modification | • Improper structural/mechanical modification<br>• Improper PLC program or protective device modification<br>• Unauthorised welding to the machine<br>• Uncontrolled operating or maintenance procedure changes |
| ***Extreme*** | |
| Damage by Cyclone or high wind | • Damaged or deteriorated cyclone tie-downs<br>• Inadequate tie-down or high wind procedures<br>• Inadequate tie-down provisions<br>• Wind speed exceeds tie-down capacity |
| Failure of rail/track support system | • Excessive rail wear or fastener deterioration<br>• Deterioration of the footings/beams or supporting structure<br>• Overload of the supporting structure |
| Fire | • Major fire leading to loss of structural integrity<br>• Transformer oil fire<br>• Switch room fire |
| Collision | • Impact with other machines, material stockpiles, vessel superstructure |
| Earthquake | • Loss of rail gauge and alignment<br>• Structural damage<br>• Toppling of machine |
| ***Operational*** | |
| Failure/damage due to improper operation of the machine | • Operating hazards not understood<br>• Insufficient training<br>• Inadequate written procedures<br>• Inadequate protective systems |
| Failure due to exceeding the capacity of the machine | • Design capacity of machine not known or understood<br>• Protective device failure<br>• No limiting device or ineffective |
| Damage during maintenance | • Lack of maintenance procedures<br>• Suitable maintenance procedure not identified<br>• Maintenance procedure not followed<br>• Inadequate identification of specialised conditions (e.g. high grade steels, high strength fasteners) |
| Power supply failure | • Emergency supply available and reliable in the event of loss of power in inopportune scenario<br>• Failure of major electrical components such as transformer or switchboard |

| ***Deterioration*** | |
|---|---|
| Failure of critical component | • Lack of lubrication<br>• Fatigue<br>• Mechanical capacity exceeded<br>• Normal wear<br>• Excessive corrosion<br>• Inadequate maintenance strategy or execution<br>• Improper adjustment |
| Failure of a protective function | • Electrical switch or wiring faulty<br>• Mechanical component or activation-device faulty or modified<br>• Control system fault prevents operation |
| Fatigue failure | • Machine exceeds design life<br>• Component exceeds fatigue limit<br>• Upgrade or change of duty without recognition of impact on components<br>• Welding or cutting of fatigue prone structural elements<br>• Poor original design or fabrication detail/workmanship |
| Deterioration of rail system | • Rail movement<br>• Rail wear<br>• Clip damage/wear<br>• Rail damage due to machine impact<br>• Inadequacy of end buffers<br>• Wear mal/adjustment of rail clamps<br>• Damage to storm tie down |

**Table 2: Common hazards and causes**

#### 3.1.3. Risk Analysis

A risk rating is obtained by considering the likelihood of the hazard occurring and the consequence of damage due to that hazard. The likelihood (or frequency of occurrence) of each failure event identified at the hazard identification stage is obtained using expert judgement and historical knowledge of the workshop team using the HAZOP process, KLETZ, T. (1999).

The definitions of likelihood and consequence will be based on the client's risk system.

The consequence of occurrence is a measure of the likely impact should the event occur. Consequences consider injury and disease (includes workers and community), environmental effects, social/cultural heritage, operational impact, legal and business cost. Consequences are divided into categories.

In undertaking the risk analysis and arriving at a risk rating, assessment of existing controls is also taken into account.

#### 3.1.4. Risk Evaluation

The purpose of risk evaluation is to make decisions, based on the outcomes of risk analysis, about which risks need treatment and treatment priorities. Risk evaluation involves comparing the level of risk found during the analysis process with risk criteria established when the context was considered.

#### 3.1.5. Risk Treatment and Actions

The types of actions can include:

- Elimination of the hazard
- Substitution
- Engineering design controls
- Administrative controls
- Behavioural controls

### 3.2 Machine Protection Functions

The industry standard in Australia for machine protection and safety is AS4024 – Safety of Machinery. Other standards that can be used in lieu of this include AS61508 and ISO13849. The approach to implementing these standards is a risk management process with some variation in how this process is implemented. As the overall machine integrity procedure requires a risk management process, once the hazards are identified and assessed, the category for the protection function can be applied as per AS4024. The inspection frequencies can then be assigned depending on the category of function.

# 4. BASELINE AUDIT

## 4.1 General

A baseline audit is required when a new machine is acquired or where an existing machine is being addressed for the first time. This establishes the machine's compliance with the machine standard AS4324.1-1995 and other relevant standards and specifications.

## 4.2 New Machines

Where a new machine is purchased, the baseline audit is undertaken by an independent design audit engineer. The structural audit is carried out in accordance with Appendix K of AS4324.1. Mechanical components and systems are audited in accordance with the purchase specification in conjunction with recognised standards. Electrical components and systems are audited in accordance with the purchase specification and recognised standards.

## 4.3 Old Machines

A very significant risk category, particularly for older machines, is the "unknown" status and physical condition of these machines. The knowledge may exist but is inaccessible by the site people or the information does not exist at all and must be created. The primary mechanism for doing this is a baseline audit.

The review objective is to:

- Establish the current status of the machine in terms of its condition, capability, safety and conformance to the latest recognised standards and current industry practice
- Assign a projected working life to the machine

The baseline audit includes a technical review. If not available, a comprehensive structural model is developed using a suitable computer program and a structural check performed to determine conformance with relevant standards. This check includes strength, stability (centre of gravity), serviceability (fatigue), wheel loads, cylinder loads, etc, for all appropriate load cases. All non-conforming structural and mechanical elements are clearly identified and remedial actions recommended. Non-conformances are risk-assessed, prioritised and a treatment action plan put in place.

Likewise a review of the electrical and protection systems is included. This would nominally include reviewing the systems to bring them in line with AS4024 or an approved equivalent standard. This review would need to follow through to verify that protection functions are designed to meet the required categories assigned to the function. This will include drawings, functional specification and software.

## 4.4 Assessment for Continued Use

This should be carried out at the end of the nominated design life which if not known should be taken as a maximum of 25 years for structural components and 10 years for mechanical items.

The key objectives in this continued use assessment are:

- Achieve a future operating life for the machine.
- Understand the availability of the machine by addressing known maintenance, reliability and operability issues.
- Identify and address issues with design compliance to relevant current Australian and International standards.
- Identify and address issues with the condition of the machine (structural, mechanical and electrical).
- Identify and address issues with obsolescence of major components.
- Minimise impact on operations due to major works.

## 5. MACHINE MONITORING

Equipment data monitoring from the onboard monitoring system is an effective way of ensuring that the machine is operating within its design parameters thus minimising the risk of overloading and fatigue damage. Data is normally obtained for a minimum of one month of operation. The key items to measure include throughput capacity (boom conveyor weightometers), drive powers and motor currents, hydraulic pressures of luff cylinders, machine speeds (long travel, slew and luff), bucketwheel speed and drive pressures, etc. However, the data requires some mathematical processing and formatting to determine the actual loadings and load cycles. An example graph showing data for a boom conveyor weightometer result is presented in Figure 11. Figure 12 shows the bucketwheel speed versus time.

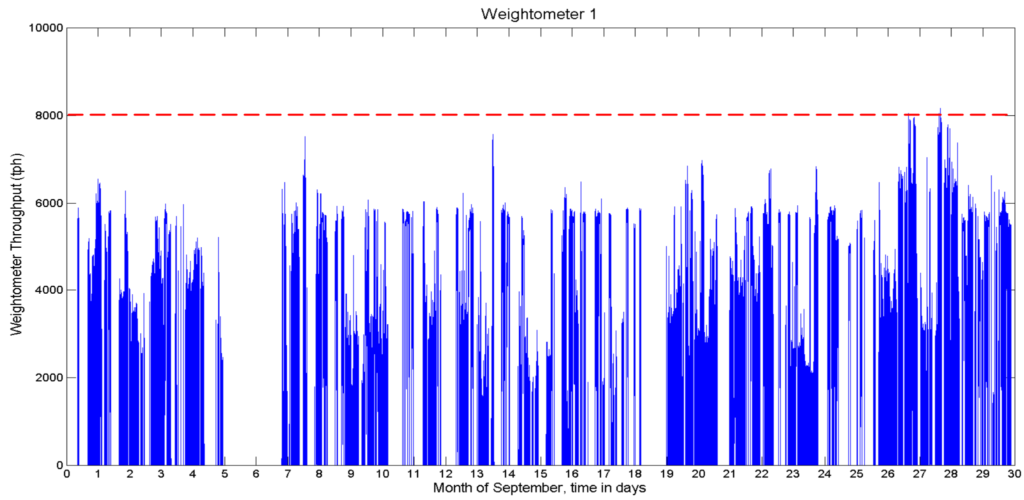


**Figure 11: Example graph of data for a weightometer evaluated against peak design throughput**

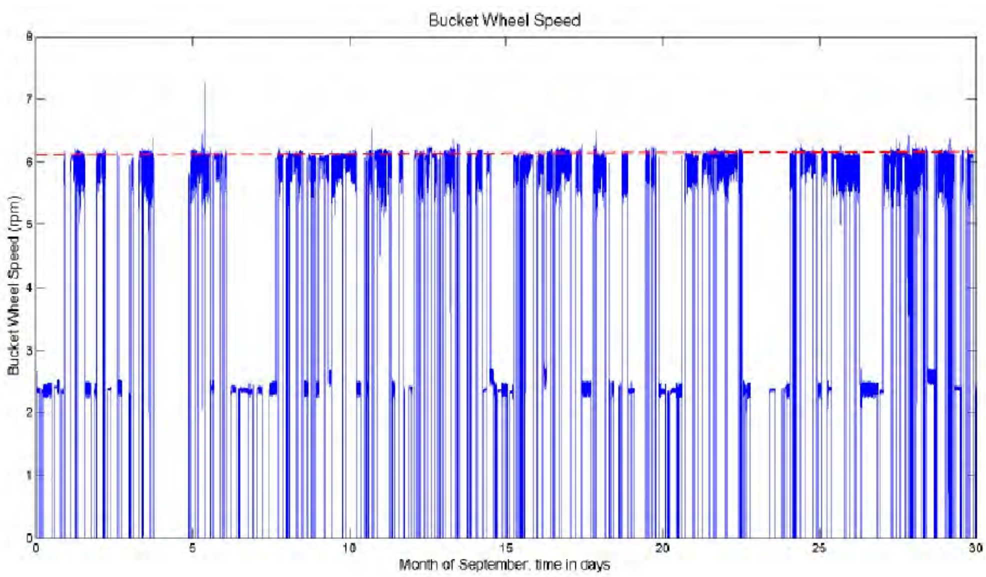


**Figure 12: Example graph of data for bucketwheel speed versus time**

Most bucketwheel reclaimers these days operate automatically and have protection settings to limit the torque on the bucketwheel without causing excessive trip outs which will affect the machine throughput. In this case the protection is based on the exceedance of set current values for a time period. Once the secondary protection is exceeded, the bucketwheel drive trips out. Where there is a high variability in the material resistance during digging, care needs to be taken to set the bucketwheel protection at an appropriate value so as not to cause excessive trips but also remain within the structural load envelope for the machine. The plot in Figure 13 is useful for estimating how often different settings would be exceeded based on the throughput set point.

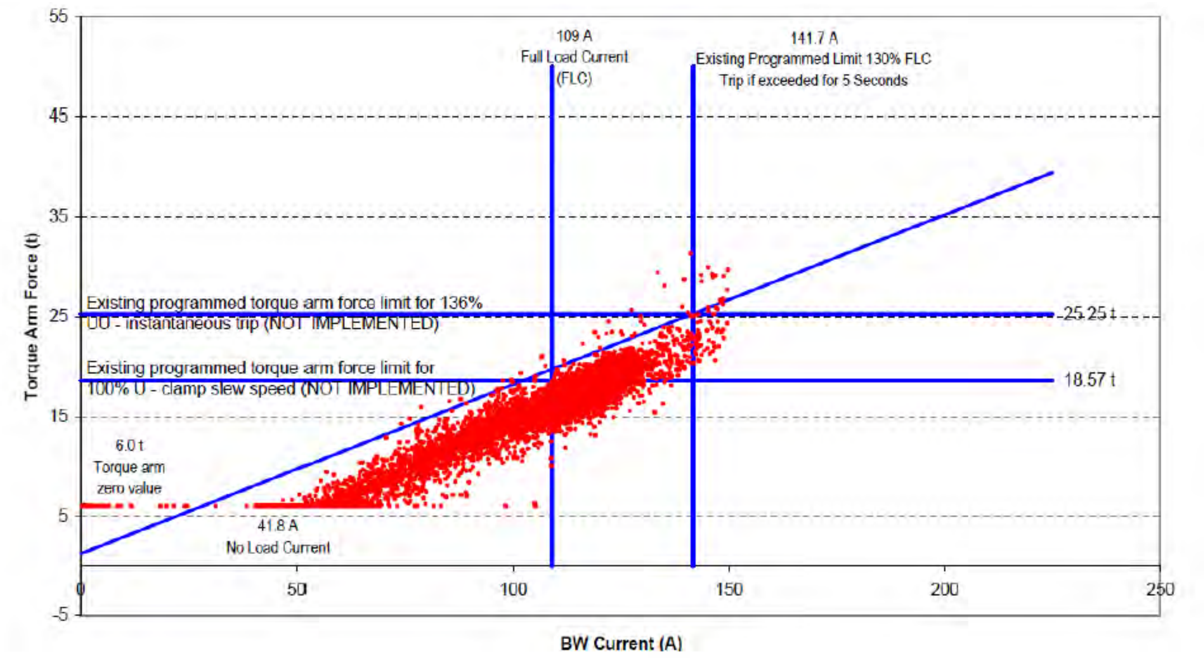


**Figure 13: Example plot of data for bucketwheel torque arm force versus current**

## 6. INSPECTIONS AND AUDITS

### 6.1. General

Many owners and operators have inspection practices that have evolved over time, and it is rare that the subject is approached holistically. Inspection types and interval often exist due to a mix of what has been done in the past, looking at what other sites do, specific problems that have been experienced at a particular site and perceptions regarding the requirements of Australian Standards, legislation or government authorities. However it needs to be realised that inspections are a control against a particular risk. Some to the key issues that should be addressed when determining an appropriate inspection regime are:

- What is the inspection for?
- How can the inspection be done most effectively with minimal impact to operations?
- How frequently do inspections need to be carried out?

The main types of structural integrity risks are:

- Impact damage, which can occur at any time, and therefore requires a relatively short inspection interval
- Corrosion which is mostly related to time and environment
- Fatigue damage which is related to the load and accumulation of load cycles which is closely correlated to throughput rates and cumulative tonnes.

Risk is often not adequately considered in the inspection process, nor when it comes to prioritising repairs. Failure to consider risk may lead to higher inspection costs and funds not being allocated to right areas or the wrong repair strategies being adopted. Many systems are based heavily on rating the physical appearance of a defect rather than the effect the defect has to the integrity of the structure. This may lead to misdirected or over expenditure or expenditure at the wrong time in the assets life cycle which will lead to increased costs over the life of the asset.

It is important to review the frequency of inspections to reflect the criticality of the structure or component. The scheduling of the inspections should also be reviewed so that they provide the required information to align with the business planning process and maintenance outages.

Some of the common types of inspections and audits and factors that need to be considered are described below.

### 6.2. Engineering Inspections

An engineering inspection is executed to confirm that the machine's structural and mechanical condition complies with the applicable standards, it is structurally and mechanically sound, and it can continue to operate safely and reliably. The engineering inspection is particularly focused on operational and impact damage so needs to be carried out at an appropriate frequency. The engineering inspection is undertaken from the walkways on the machine as well as by the use of an elevated work platform (EWP) and or a man cage to examine areas not visible from the walkways. The machine may need to be isolated and out of operation. It will be executed by a competent inspector with an expert experienced with this type of equipment reviewing the findings.

Engineering inspections may require exclusive control of the machine. In this case other works (maintenance etc) may not take place without prior agreement from the job owner and inspector to ensure that a full inspection can be performed and completed safely.

### 6.3. Protective Coating Inspections

Protective coatings need to be inspected regularly to ensure minor coating and corrosion defects are addressed and repaired before they become major issues resulting in unacceptable levels of risk and requiring expensive remedial works. To maximise the life span of the structure, preventative works should be undertaken when the coating system has reached its practical life (typically when >5% coating breakdown occurs and active rusting of the substrate initiates.)

In situations where the paint system has been assessed as totally ineffective, the effects of section loss due to corrosion need to be assessed. This should be carried out regardless of whether or not the member has been painted as part of the corrosion protection preventative maintenance program.

### 6.4. Fatigue Inspections

Fatigue inspections should be considered separately to inspections for damage and corrosion, although this is not typically done. Machines that are operated within their design load envelope should exhibit minimal cracking within their design life (typically 25 years). Fatigue cracks will eventually occur, but it is not as common as corrosion damage.

Fatigue cracks are the most difficult form of damage to detect, and are less likely to occur when the machines are "young" and increasingly likely to occur as the load cycles accumulate, for example after the first 10 years of operation. Machines that are more highly loaded and operate for more hours per year will be more likely to have fatigue issues earlier than machines that have low utilisation. In other words, fatigue is more closely correlated with throughput rate and cumulative tonnes handled than with time.

Fatigue cracks can be difficult to detect because:

- They can be very fine and may not show through the paint.
- They are difficult to see if the machine is not completely clean.
- A proper fatigue inspection is meticulous and requires removal of paint at the welds and NDT techniques (e.g. magnetic particle). This is time consuming to do properly.
- Close access is required to complete NDT inspections that are different to visual inspections from walkways.

Figure 14 shows a typical fatigue crack. Once this type of cracking occurs it is generally time to look at replacing the machine or at least the sub assembly on the machine where the fatigue cracking is occurring. An intensive inspection regime should be in place to monitor such cracks while the machine replacement is being arranged. Unfortunately an intensive inspection regime is fairly intrusive on operations and will reduce production. Hence as machine replacement can take several years to implement it is advisable to plan for this well in advance. The use of finite element analysis to determine stress ranges in the structure and fracture mechanics to determine crack propagation rates allows appropriate inspection intervals to be determined so that the machine can continue to operate safely.


**Figure 14: Fatigue cracking**

### 6.5. Power supply audit

Certain operating situations can occur such that loss of power can cause significant risk to machine integrity. These include telescopic chute within ship or storm approaching and the need to get the machine to a safe tie down position. The ability to respond to such situations through back up supplies or such measures is important to both operations and also the integrity of the machine. Inspections and reviews to ascertain that such risks are minimised are required and this will include:

- Reliable operation of back up supply
- Reliable operation of switchgear that prevents a fault crippling electrical systems

### 6.6. Electrical fire

Potential sources of fire on machines include transformers and switch rooms. It is possible for such fires to cause risks to structural integrity of machines as well as extensive damage and down time. Inspections and reviews are required to provide some assurance that systems are sufficiently protected and inspected so that risks are minimised.

### 6.7. Protective function audit

The objective of the protective function audit is to check that all the machine protective functions are operating correctly, and that the mechanical condition of the associated trip plates or devices is sound. The inspections may require exclusive control of the machine. In this case, no other works (maintenance, etc) can take place without prior agreement from the job owner and inspector to ensure a full inspection can be performed and completed.

### 6.8. Anti-Collision Testing

Anti-collision testing consists of testing the following subsystems:

- Primary Machine to Machine Anti-collision system (ACS) Testing
- Fixed Objects Anti-collision
- Back up ACS Testing

### 6.9. Control System Audits

The objective of the control system software audits is to confirm that there have been no unauthorised or authorised changes made to the machine programmable logic controller (PLC) that could be putting the machine at risk of structural failure. The audit compares the current version of the control system software on the machine with the current site master and the version from the previous audit. The authenticity of each change and/or bridge that has been made over that period is audited against the site control system change register. Note that this process will check also that any changes have been reflected in the machine functional specifications.

### 6.10. Specialist Inspections

The following specialist inspections should also be carried out:

#### 6.10.1. Rail Inspections

Rails need to be inspected regularly for corrosion damage and wear. The rail mountings are critical items and are often problematic as shown in figure 15. A typical problem, which may occur, is that after the rail is installed on the pads, the space under the rails between the pads is connected or grouted. Because there is no steel plate to spread the load, the filler material is overstressed and cracks on application of load. The overall rail footing may also be subject to uneven settlement of soil movement so it is necessary to carry out regular surveys for horizontal and vertical alignment and compare these to the specified tolerances that the machine can sustain.


**Figure 15: Damaged rail system**

#### 6.10.2. Stay or Strap Inspection

Mechanical damage can be seen and can be due to careless handling, slapping against obstructions and collisions and impacts. Also “birdcaging” effects as shown in Figure 16 can be due to the sudden release of a heavy loading. On heavy strands, the end terminations are generally made from heavy steel sockets to enable load transmittal between the structure and the cable. The load is carried through the socket to the rope by adhesion between the rope wires and the material used in the socket. Typically the material used in the socket is epoxy resin or zinc metal. Test results show that even for the same type of end termination, cable fatigue life is very dependent on the workmanship for the termination and secondary effects due to restrained bending and corrosion.

Fatigue appears to be a major cause of failure in steel strands. Historically, the majority of failures for strands appears to occur near the end terminations and can be attributed to bending fatigue, possibly accentuated by corrosion.

Dynamic effects such as oscillations due to wind and digging loads on reclaimers are a common source of stress fluctuations in stays. These dynamic effects can lead to secondary bending stresses at the end terminations as well as fretting fatigue between individual wires. Wire breakages can occur at the internal wires because the contact stresses at the internal wires can be higher than the stresses at the outer wires.

**Figure 16: Damaged stays**

#### 6.10.3. Bucketwheel Shaft NDT Inspection

The recommended inspection interval that will reduce the risk as low as possible will allow at least two opportunities to detect a crack before failure, as well as some time to execute corrective actions (e.g. replacing the shaft). The bucketwheel shaft can be ultrasonically tested using two different techniques:

- Looking axially from the accessible end of the shaft
- Looking radially outwards from the bore of the shaft using a phased array probe

The phased array technique is generally more accurate in detecting small flaws.

#### 6.10.4. Structural Pin NDT Inspection

Structural pivots, pins and shafts where rotation occurs under load may be subject to moment friction in combination with their static loading and should be tested by ultrasonic techniques.

#### 6.10.5. Working Rope Inspection

Rope is a little more flexible axially than strand but very much more flexible in bending. This bending flexibility is why wire rope is widely used as a tractive element over pulleys and winch drums. Failures in wire ropes can occur due to internal or external wire breakages or failure at end terminations. Internal wire failures are not common in areas away from the end terminations; however appropriate testing methods are required to detect these internal defects. The grounds for discarding wire ropes are varied depending on the application, the degree of risk if the rope breaks in service, environmental conditions and the extent of inspection. Some commonly used criteria include:

- A maximum number of broken or cracked outer wires.
- A maximum percentage of allowable wear on the outer wires.

Internal wire failures are common in areas away from the end terminations and appropriate testing methods are required to detect these internal defects. Employment of an NDT system is recommended as a supplement to visual inspection to monitor internal degradation.

#### 6.10.6. Slew Bearing Height Measurement and Bolt Tension Check

Premature failures of large, precision slew bearings are quite prevalent in the materials handling industry. The failures tend to be associated with bucketwheel reclaimers and stacker reclaimers which experience a large number of cycles of rotation during the reclaiming process. The types of failures that are most common are failure of the slew bearing bolts and failure by excessive wear on the rollers and race. Bolt failures tend to be associated with overload or fatigue or a combination of both. Excessive wear can be due to long-term overloading or incorrect selection of the bearing at the design stage. Checks normally carried out include:

- Axial reduction wear measurement
- Raceway grease sample analysis
- Visual inspection of labyrinth and/or seal arrangement
- Check of lubrication system operation

### 6.11. Frequency of Inspections and Audits

The following table sets out the typical inspection frequencies and actions for machines in general:

| Inspection/Action Type | Frequency | Comments |
|---|---|---|
| **Structural, Mechanical and General** | | |
| Baseline Audit | One off | On purchase of machine or implementation of risk management program |
| Engineering Integrity Inspections | 1 -2 yearly | The frequency will depend on the age, condition and exposure of the machine |
| Machine Performance Data Monitoring | 6-12 monthly | To check that the machine is operating within its design envelope |
| Fatigue Inspection | 5 yearly or as determined from machine performance data monitoring | Parameters set during baseline audit updated from monitoring |
| Assessment for Continued Use | 25 years for structural<br>10 years for mechanical | At end of nominal design life |
| **Electrical/Control Systems Audits** | | |
| Power systems and back-up supplies | 1yearly | |
| Electrical fire risk, transformers and switch room monitoring/protection | 1 yearly | |
| Protection functions | Typically 1 yearly | Protection functions determined by AS4024 assessment. |
| Control system audit | 6 monthly | |

| Specialist Inspections | | |
|---|---|---|
| Rail Inspection | Typically 2 yearly | |
| Stay or Strap Inspection | Typically 2 yearly | |
| BW shaft NDT Inspection | Typically 6 monthly | |
| Structural Pin NDT Inspection | Typically 2 yearly | |
| Working Rope Inspection | Typically 6 monthly | |
| Slew Bearing Height Measurement and Bolt Tension Check | Typically 2 yearly | |

**Table 3: Typical inspection and audit frequency**

# 7. RECORDS

## 7.1. Machine Book

As a result of the Western Australian coroner's findings mentioned in section 2.2, many owners and operators have instituted record systems referred to as Machine Books.

The Machine Book is a controlled, centralised source of key information relating to the machine. It provides information for operations, maintenance and engineering personnel. The Machine Book is typically maintained by a nominated custodian with the responsibilities of ensuring the correctness and completeness of the information and that a register is maintained. The Machine Book is updated whenever there is a significant change to the machine design, maintenance or operating procedures or if a significant incident occurs involving the machine.

Typically a Machine Book is maintained on a directory on a computer or network. An example of a Machine Book directory structure is presented in Figure 18. Note that any significant event or change will also trigger updates to the appropriate sections of the Machine Book.

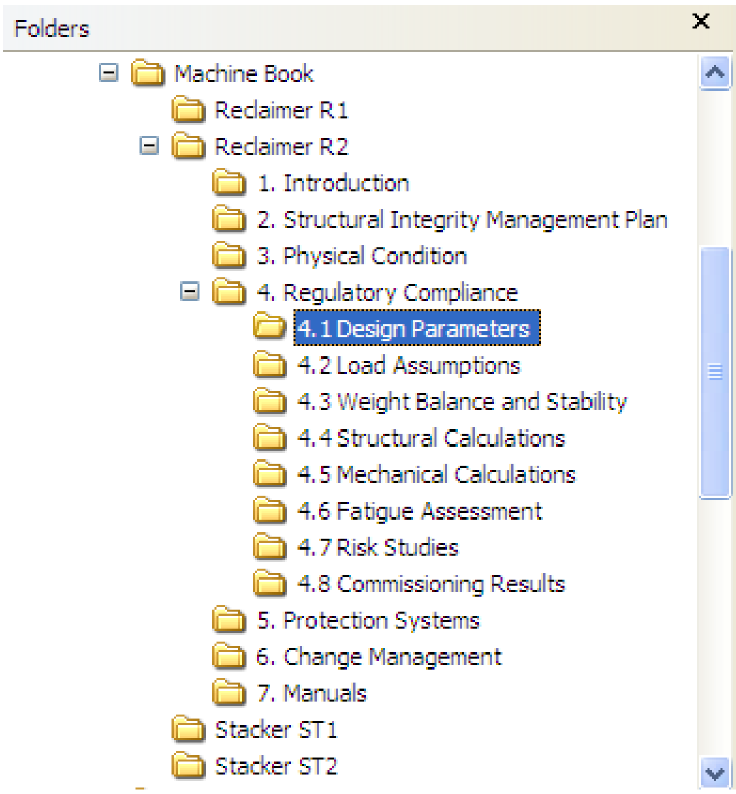


**Figure 18: Example of Machine Book directory structure**

In order to provide a level of standardisation, the following high level structure is recommended. Sub-headings can be set at the discretion of the site. The information relating to each of the headings in the Machine Book includes:

1. Introduction
    - Contains general Machine Book instructions, custodian details, update frequencies and record of audit history
2. Structural Integrity Management Plan (Machine Life Plan)
    - Timeline showing proposed engineering investigations, engineering design, inspections, audits and major maintenance item change outs
    - Budgets and planned expenditure, including contingency for critical items
    - Instructions for major maintenance works (e.g. slew bearing change, rope change)
3. Physical Condition
    - Inspection reports (e.g. electrical, mechanical, structural and hydraulics)
4. Regulatory Compliance
    - A list of statutory requirements and relevant design standards
    - OEM recommendations, relevant design and operating parameters
    - Complete set of drawings
    - Load calculation and design calculation documents including design audits
    - Measurement results such as strain gauging, weighing and machine performance data reviewing
    - Reports on risk assessments, hazards studies including assessments to AS4024 or equivalent
    - Commissioning results
5. Protection Systems
    - Functional specification
    - Description and settings for major protection devices (e.g. long travel, slew and winch brakes, rail clamps, collision detectors, load limiting devices and pressure relief valves) [May be included in functional specification]
    - Audit and test results
    - Procedures for operational shutdowns (e.g. storm wind event)
6. Change Management
    - Contains a record of significant issues, incidents and any changes made to the design, operation or maintenance of the machine and to its facilities.
7. Manuals
    - General operating, maintenance and training manuals for the various items of equipment used on the machine.

### 7.2. Change Management

A number of identified risks relate to poor control of change. Whilst many risk treatments create a safe machine at the time of implementation, they do not guarantee that the risk is managed for the future.

Management of change involves a systematic approach to decision making and implementation of workplace changes to ensure that adverse consequences are avoided. A Risk Management Plan typically stipulates that that all changes to a machine are subject to the management of change process.

Generally any changes to the machine structures, mechanical equipment, control system, operating capacity, maintenance procedures and operating procedures that may affect the structural integrity and safe operation of the machine will be subject to the change management process.

The management of change process requires the risk of any proposed change to be assessed. The risk assessment can be made by a competent person or, in the case of complex or large changes, by a formal hazard study. The machine hazard studies are to be referenced when considering changes.

The Machine Book describes the specific management of change procedures for each required area of control.

## 8. CONCLUSION

Rail mounted machines are high risk equipment items at ports. Robust risk management of such equipment requires a holistic approach including design to current standards, risk management throughout the asset life, a monitoring regime to ensure that the equipment operates within its design envelope and a formal record keeping system. Where changes and upgrades to a machine are contemplated a strict change management system should be in place.

Experience in Australia has shown that introduction of such an approach has reduced the level of machine failures being experienced.

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