CODE OF PRACTICE

Safe mobile autonomous mining in Western Australia

MIAC

Government of **Western Australia**
Department of **Mines and Petroleum**
Resources Safety

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Further details of publications produced by Resources Safety can be obtained by contacting:

Resources Safety
Department of Mines and Petroleum
100 Plain Street
EAST PERTH WA 6004

Telephone: + 61 8 9358 8002 (general queries)
+ 61 8 9358 8154 (publication orders)

NRS: 13 36 77
Facsimile: + 61 8 9358 8000
Email: ResourcesSafety@dmp.wa.gov.au (general queries)

RSDComms@dmp.wa.gov.au (publication orders)

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In September 2014, the working group participated in a workshop jointly hosted with the International Organization for Standardization (ISO) Technical Committee 127 to share information on the intent and content of ISO Standard 17757 *Earth-moving machinery – Autonomous machine safety*, which is being developed. This collaboration promoted consistency between the documents.

Input was also received from industry and other Australian regulators during the public comment period.

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Foreword

Basis for code of practice

This code of practice is issued by Resources Safety under the *Mines Safety and Inspection Act 1994*, with the endorsement of the Mining Industry Advisory Committee (MIAC) and approval from the Minister for Mines and Petroleum.

A code of practice is a practical guide to achieving the standards of occupational safety and health required under legislation. It applies to anyone who has a duty of care in the circumstances described in the code. In most cases, following a code of practice would achieve compliance with the duties in the legislation in relation to the subject matter of the code. However, like regulations, codes of practice deal with particular issues and do not cover all hazards or risks that may arise. Duty holders need to consider all risks associated with work, not only those for which regulations and codes of practice exist.

Codes of practice are admissible in court proceedings. Courts may regard a code of practice as evidence of what is known about a hazard, risk or control and may rely on the code in determining what is reasonably practicable in the circumstances to which the code relates. However, compliance with the legislation may be achieved by following another method, such as a technical or an industry standard, if it provides an equivalent or higher standard of work health and safety than the code.

An inspector may refer to an approved code of practice when issuing an improvement or prohibition notice.

Scope and application

This code of practice will assist those involved with mobile autonomous mining in Western Australia to meet their legislative obligations for work health and safety under the *Mines Safety and Inspection Act 1994*.

It is designed to provide guidance on:

- mobile autonomous and semi-autonomous systems used in surface and underground mines and quarries
- developing and evaluating safe work procedures for such systems.

It focuses on:

- the control of autonomous loaders, trucks and other mobile equipment such as drills and dozers at mine sites
- the identification of the unique risk profiles in relation to new or existing mobile autonomous mining systems.

The provisions of this code of practice apply to all mines as defined in section 4(1) of the Act, except those extracting coal by underground mining.

The code of practice does not apply to:

- remote operations centres
- unmanned aerial vehicles (UAVs)
- remote controlled systems, but parts could be relevant to mobile tele-remote systems if they incorporate additional functionality that takes autonomous control of machines
- autonomous functionality of a process or machine that moves on
  - fixed infrastructure such as rail (e.g. trains, stackers, reclaimers)
  - a fixed base (e.g. laboratory robots).

Who should use this code of practice?

You should use this code of practice if you have functions and responsibilities for planning, designing, implementing and maintaining mobile autonomous mining systems. The code of practice may also be useful for supervisors, operations personnel, and safety and health representatives who need to understand the hazards associated with mobile autonomous mining systems.

How to use this code of practice

The code of practice includes references to both mandatory and non-mandatory actions.

The words “must” or “requires” indicate that legal requirements exist, which must be complied with. The word “should” indicates a recommended course of action.


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PART 1
RISK MANAGEMENT APPROACH

1 Introduction

1.1 Aims

Mobile autonomous mining, like any large-scale mining activity, is hazardous with many inherent risks. When integrated with a manned mining operation, additional risks may be present beyond those recognised for conventional mining techniques.

The aims of this code of practice are to describe:

- a set of desired safety outcomes for mobile autonomous mining to meet the approval requirements of the project management plan (PMP) under the *Mines Safety and Inspection Act 1994* and Mines Safety and Inspections Regulations 1995
- the variables to be considered to demonstrate that a mobile autonomous mining system is safe and performing as designed
- the role of the competent person in the hazard management process for mobile autonomous mining
- the broader occupational health and safety requirements for operating in accordance with the *Mines Safety and Inspection Act 1994* and Mines Safety and Inspection Regulations 1995.

The code of practice promotes a proactive approach to the introduction and operation of mobile autonomous mining systems to ensure the safe use of mobile autonomous (and semi-autonomous) technology. It also promotes continuing communication and consultation between system and component suppliers and the mining operation as the end user.

The general duty of care applies to all stakeholders from systems design, construction of mobile equipment and control centres, mine planning to accommodate mobile autonomous fleet, commissioning of systems, implementation, operation and maintenance, to achieve the desired safety outcomes for both surface and underground operations.

Note: The term "autonomous" is used in this code of practice to cover both autonomous and semi-autonomous mining system. It does not apply to remote controlled systems, but parts of the code of practice could be relevant to tele-remote systems if they incorporate additional functionality that takes autonomous control of machines.

1.2 Structure of this code of practice

Chapter 2 describes the risk-based approach to managing safety.

Chapter 3 summarises the requirements for information, instruction, training and supervision to ensure the safe operation of the mobile autonomous mining system.

Chapter 4 describes the requirements for general hazard control management. These themes are then developed further for mine planning and design (Chapter 5), system planning and design (Chapter 6) commissioning (Chapter 7), operational hazard control (Chapter 8) and maintenance (Chapter 9).

Chapter 10 covers emergency management requirements.

Appendix 1 lists the legislative provisions that apply to mining activities in general.

Appendix 2 lists examples of Australian and International Standards and other guidance that may apply to mobile autonomous mining system.

Appendix 3 provides a glossary of terms used in this code of practice.

Appendix 4 contains detailed information on PMP requirements for mobile autonomous mining projects.

Appendix 5 provides general guidance about matters to consider when introducing mobile autonomous systems to mining operations.

Appendix 6 provides examples of potential mobile autonomous mining risks.

Appendix 7 lists examples of autonomous-specific incidents that result from system malfunctions or operator errors, and the reporting requirements under the *Mines Safety and Inspection Act 1994*.

1.3 Roles and responsibilities

There are two main groups involved in the introduction of an autonomous mining system:

- system builders — those who design, manufacture, import, supply and commission or install the system
- system operators — those who use the system, including operators, contractors and maintainers.

The first group may comprise multiple parties, including original equipment manufacturers (OEMs), or the system may be built in-house by the principal employer, or by a third party developer.

Communication and cooperation are keys to a successful autonomous operation. The roles and responsibilities of those involved should be defined and agreed upon by all parties. While some roles and responsibilities have been assigned to certain stakeholders, it is noted that many are dependent on information supplied by another party. Circumstances, unique to each operation may result in assignment of some of these roles and responsibilities differing from those outlined below.

System builders

The responsibilities of system builders should include:

- assessing the proponent's proposal and determining the suitability and compatibility of system components
- participating in the initial site risk assessment to determine the suitability of the proposed autonomous mining approach
- establishing the standards to which the machine and system will comply
- determining requirements for mine supplied componentry including functional safety to allow the system operator to ensure the integrity of final system (e.g. communications infrastructure)
- establishing performance specifications
- sharing residual risk information with the system operator for inclusion in the operator's safety management plan
- supplying functional safety information for maintaining the system's integrity over its life cycle
- providing information and instructions on use of the system, with regard to
  - operation, maintenance and servicing
  - calibrating test procedures
  - commissioning information
  - trouble shooting test procedures
  - performance parameters (e.g. system response for use in safety plans)
- providing information and instructions on how tailored or bespoke systems may affect or be affected by other components and systems
- providing assurance of certification-type testing of the system and components (e.g. electromagnetic compatibility, EMC; functional safety; base machine performance)
- establishing communication security and making recommendations regarding cyber security.

System operators

The responsibilities of system operators should include:

- developing the proposal and requirements for the introduction of autonomous mining
- conducting an initial site risk assessment to determine the suitability of the proposed autonomous mining approach
- understanding the risks associated with the system, including any residual risks
- using the system in accordance with the specifications, and seeking advice if design specifications or system components are modified after commissioning
- preparing a business case for the introduction of autonomous mining
- incorporating information from system builders into the site's safety management plan
- developing safe work procedures to integrate the autonomous operation into the mine
- establishing change management processes
- consulting with workers on autonomy implementation and hazards
- training mine personnel in relation to autonomous operations, including
  - operation of equipment
  - processes and procedures for work in autonomous areas
- developing and implementing general awareness training for all personnel on site to make them aware of the hazards associated with autonomous mining
- auditing any site-supplied componentry (e.g. computers, servers, radios, positioning system, Wi-Fi, telecommunications) to confirm its compatibility with systems security, and that builder requirements for safety integrity are met
- liaising with the Department of Mines and Petroleum regarding submission of the PMP for the site (Appendix 4)
- recording, reporting, investigating incidents and taking action to prevent further incidents, in consultation with the system builder and Department of Mines and Petroleum (Appendix 7).

2 Safety and risk management process

2.1 Introduction

The operation of autonomous equipment can introduce hazardous situations not normally encountered on a conventional manned mine site.

The effective management of the risks associated with operating a mobile autonomous mining system requires input from diverse operational groups, ranging from researchers, design engineers, project managers, team leaders and control room operators to safety and health representatives and other workers involved in the tasks, as well as emergency response personnel.

The risk management process should address the following questions.

- What are the potential scenarios for mobile autonomous mining incidents? (see Appendix 6 for examples)
- What are their potential consequences in terms of safety and health?
- What controls are available and how effective are they?

Note: Effective risk assessment for mobile autonomous mining may also require input from other subject matter experts (e.g. system builder, designers, engineers).

2.2 Communication and consultation

Communication and consultation are fundamental for ensuring the most effective risk management. In particular, it is essential that those with knowledge of the design, engineering, commissioning, operation and maintenance of the autonomous mining systems are involved in assessing and minimising associated risks during the operational life cycle.

2.3 Information for risk management

Mining operations should be able to demonstrate that the hazards associated with mobile autonomous mining are being controlled so far as is reasonably practicable by considering issues such as:

- any previous events or information (e.g. incident and injury reports, data from similar technology applications)
- reliability, maturity and available safety features of autonomous equipment and systems
- provision and frequency of validation processes (e.g. trials, functionality testing)
- suitability of established work procedures (e.g. separation, inspection and maintenance processes)
- whether established emergency procedures are sufficient
- the provision and competency of operational and support personnel (e.g. assessment of knowledge and training needs)
- identification of specific risks and provision for regular reviews of controls.

2.4 Risk identification

The use of autonomous technology in an operating mine environment will change established safety systems. It is important to identify these changes and the associated risks.

Hazard identification systems that can be implemented to ensure mobile autonomous mining risks are identified include:

- a hazard and operability study (HAZOP)
- layers of protection analysis (LOPA)
- functional safety analysis
- change management
- employee hazard identification and reporting procedures
- workplace inspections
- monitoring the working environment
- incident investigations (e.g. ICAM, Taproot)
- monitoring OEM and service company bulletins, recommendations and specifications
- regulator safety alerts.

Some potential mobile autonomous mining risks are listed in Appendicies 4 and 5.

2.5 Risk analysis

At the risk analysis stage, the nature of the risk is assessed and the risk level is determined. Factors to consider include:

- likelihood of an incident
- potential severity of any injury or damage.

It is important that those undertaking a risk assessment have the necessary information, training, knowledge and experience of the:

- operational environment (e.g. scale, complexity and physical environment of mining activities)
- operational processes (e.g. maintenance systems, work practices, interaction, separation)
- autonomous systems (e.g. functionality, safety features).

2.6 Risk evaluation and management

All hazards related to mobile autonomous mining need to be identified and controlled. This is best done by applying the hierarchy of control. Higher-order control measures eliminate or reduce the risk more effectively than administrative controls or personal protective equipment.

For mobile autonomous mining, it is advisable to implement:

- primary controls that
  - avoid the risk by deciding not to start or continue with the activity (e.g. cease operations during adverse weather)
  - remove the source of the risk (e.g. isolate or provide alternative access for personnel not directly involved with the autonomous activity)
  - change the likelihood (e.g. restrict specific functions to authorised personnel)
  - change the consequence (e.g. modify route, decrease speed)
- contingency controls that minimise the effects if there is an incident (e.g. layers of protection, systems that fail to the safe state).

Prevention and management controls should be based on established processes and relevant standards, including:

- safe design, construction and installation (according to specifications and design parameters)
- separation of the autonomous fleet from manned operations where possible
- effective change management processes
- operational and maintenance safe work procedures (SWPs)
- competency-based training and assessment of workers
- supervision and management oversight.

2.7 Monitoring and review

To ensure the effectiveness of controls is maintained at the site, a monitoring and review program should be implemented that includes control audits, verification and validation.

As part of the site's validation process, responsibilities and accountabilities should be clearly defined and assigned, and may include independent auditing. The findings should be used to:

- confirm that the recommendations of previous reviews have been actioned
- confirm that appropriate responses have been made to any incidents or issues arising
- verify compliance with specifications (e.g. inspection, monitoring, quality control)
- recommend any necessary operational or system design modifications, which are documented and managed through a formal change management process.

2.8 Documentation

The results of the risk assessment need to be formally documented in the operation's risk register, detailing the:

- locations of autonomous areas
- size and complexity of operations
- types of potential incidents
- consequences and likelihood of each incident
- controls used to mitigate each risk to a practicable minimum
- monitoring and review outcomes and actions.

The documentation of this information forms the basis of the site's safety management plan for mobile autonomous mining systems.

3 Information, instruction, training and supervision

3.1 Introduction

The provision of information, instruction, training and supervision is an essential component of any safe system of work.

3.2 Information

Personnel must have the information necessary to complete tasks safely. Such information may include:

- manuals, specifications and operating instructions provided by the system builder
- the operation's policies, procedures and plans
- applicable legislation, Australian and International Standards, and other guidance material.

3.3 Instruction

Personnel must be instructed about system functionality and specific tasks to be undertaken, including the hazards and risks, the controls to be applied, and the job steps necessary to complete the tasks safely and correctly.

Instructional tools such as safe work instructions or procedures (SWIs or SWPs) and standard operating procedures (SOPs) may be used to document the process, but should be reviewed and amended if there are any changes (e.g. equipment, conditions).

If there is to be a deviation from the SWPs, a job safety or hazard analyses (JSAs or JHAs) should be undertaken to capture the hazards for the task and ensure controls are implemented.

Such instructional tools must be formally approved by the supervisor or management.

3.4 Training

Personnel must be competent in the tasks they are assigned. This means they must have the knowledge and skills necessary to perform the task safely and correctly. Competency is gained through training and experience while being supervised or mentored.

The risk management training provided must be appropriate to the assigned roles and responsibilities, and provide information on:

- the risk management process
- task-specific safe work methods, including the safe use of equipment and safe systems of work.

All personnel should understand the effects that their activities may have during commissioning, operation and maintenance of the mobile autonomous mining system. They should also understand:

- what to expect if environmental or operational conditions change
- site requirements for monitoring of machine performance
- how to recognise when machines are not operating as intended
- how to report incidents.

Assessment of competency should be evidence based and verified before work commences. Competency may be verified by:

- recognition of prior learning
- on-site recognition or validation of current competency
- using the operation's training and development program.

Verifications of competency must include a documented assessment.

Whenever systems of work or plant and equipment change, or new systems of work or plant and equipment are introduced, there must be a system to ensure affected personnel are consulted, retrained as necessary and reassessed.

3.5 Supervision

Supervision is a fundamental safety function that complements the provision of information, instruction and training. Effective supervision sets and maintains high standards of performance.

Supervisors within an autonomous mining operation help achieve the operation's safety and health goals in a variety of ways, including:

- leading and managing their team using their understanding of the key principles and safety features of the autonomous technology
- ensuring work is carried out in accordance with system builder documentation
- confirming workers (including contractors) are trained and assessed as competent to perform their duties
- communicating regularly with those affected by work
- confirming fit-for-purpose equipment is available and used
- monitoring the workplace, and identifying and controlling hazards in accordance with site rules
- confirming the operation's risk register reflects the risk analysis of jobs and critical tasks
- reporting and recording performance issues (e.g. equipment failures, variances to approved operating parameters)
- referring new and changed circumstances not covered in site rules to management for further instructions
- communicating learnings from incidents.

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PART 2
GENERAL HAZARD CONTROLS

4 Introduction to general hazard controls

The use of mobile autonomous mining technologies, whether at the surface or underground, can add hazards beyond those associated with a conventional manned mining operation. These additional hazards require detailed consideration and risk assessment to ensure they are effectively managed.

The controls in place for an autonomous operation should provide an equivalent or better safety performance than what could reasonably be expected from a non-autonomous operation, even in the event of loss of system communications (e.g. with the primary control system).

To understand and adequately assess inherent or residual risks and implement appropriate controls, matters to be considered should include:

- suitability and design of operational environment
- identification of any limitations of the autonomous technologies
  - safety functionality
  - multiple autonomous systems operating in close proximity
  - use of mixed, hybrid and after-market technologies
- identification of any limitations of operational processes
- competency of operational and support personnel
- records management
  - risk register
  - monitoring and maintenance of controls (e.g. systems security)
  - system incidents and actions to prevent further incidents
  - system performance monitoring over the life (e.g. system functionality)
- change management
  - communication and consultation
  - change control and traceability
- any “new” factors.

5 Mine planning and design for hazard control

5.1 Introduction

The following fundamental principles need to be built into mine design and planning processes early in the project:

- risk management (see Chapter 2)
- designing and planning for autonomy
- managing and minimising interactions
- autonomous infrastructure.

5.2 Designing and planning for autonomy

Mine designers and planners should understand the limitations of any autonomous mining technology being used, including:

- application of engineering and system controls to safety process and practices
- modification of established planning and operational processes
- life cycle planning (e.g. fleet replacement)
- verification of system data (e.g. surveys) to validate mine designs and plans
- knowledge and competency of planning and operational personnel.

5.3 Managing interactions

Mine designers and planners should ensure work area design and construction are suitable for autonomy and minimise interaction with personnel and non-autonomous equipment, taking into account:

- system builder recommendations
- access controls and processes for exclusion and interface areas
- traffic management (e.g. road network, intersections, park-ups, load and dump locations)
- placement of infrastructure within the autonomous area such as
  - fuel facilities
  - crushers or ore passes
  - stockpiles
  - workshops and service areas
  - crib rooms
  - calibration and commissioning areas
  - services (e.g. electrical reticulation, dewatering bores).

5.4 Autonomous infrastructure

The design, location and integration of autonomous infrastructure should consider:

- the scalability and capability of the autonomous system and associated infrastructure
- equipment specifications, fleet size and operating capabilities (e.g. turning circle, road network layout, gradient)
- communication systems (e.g. wireless, fixed)
- area access (e.g. location and control of area entry and exit points, provision of perimeter protection and signage)
- monitoring system health (e.g. wireless, positioning systems).

5.5 Operating environment

Mine designers and planners should ensure work areas are suitable for autonomy, taking into account:

- work area, road design and construction are in line with the system builder requirements (e.g. road surface, gradients, potentially harsh conditions)
- traffic management (e.g. intersections, park-ups, load and dump locations, access controls for exclusion and interface areas)
- area segregation (e.g. separation of autonomous equipment from personnel and manned equipment for park-ups, go-lines and specific work areas).

To minimise interactions, consideration should be given to having separate roads for manned light vehicles.

5.6 Change management

Mine designers and planners should ensure a comprehensive change management system is employed for mine planning and design changes that are introduced through the use of autonomous mining technology, including:

- operational and maintenance practices
- design specifications
- system changes (e.g. updates, upgrades) that affect mine design
- data collection and integration.

6 System planning and design for hazard control and functional safety

System builders and users are required to identify, assess and control the hazards associated with autonomous operations. Functional safety provides assurance that the safety-related elements of the autonomous system and operational controls provide suitable risk reduction to achieve the safe operation of the autonomous systems. The safety functionality of autonomous control systems should be designed:

- in accordance with relevant standards (see Appendix 2)
- to meet statutory obligations (e.g. communication network licences).

The criticality of the safety functions, and the performance levels required of them, should be determined by the hazard identification and risk assessment process, including:

- roles and responsibilities of system operators and system builders
  - agreed, defined and documented to reflect the operating model
  - controls and authority levels are established to ensure changes do not increase the risk due to modified performance
- system design
  - layers of protection and redundancies in the safety systems (e.g. perception and collision avoidance systems, underground area separation)
  - configuration management and security to prevent unauthorised modification of settings, parameters and base guidance
  - approval through change management process before design or configuration changes are implemented
  - process to initiate post-change review and acceptance testing
- fail-to-safe state
  - if elements of the system fail then the system is designed to fail (shutdown) to a safe condition
  - assessment of human interactions with the autonomous systems (e.g. operational and maintenance personnel in autonomous areas)
  - the impact of human interactions and behaviours on autonomous system performance (e.g. level of intervention actions for alarms and warnings)
- review and audit processes
  - periodic reviews of the system performance and parameters in accordance with design parameters to confirm operational management requirement are met and there are no uncontrolled or unauthorised changes
  - the review frequency is determined by the operating model, scope of system changes, and the risk management process
- change logs
  - records kept of changes to the autonomous control system, operating practices or parameters
- systems security
  - controls that prevent unauthorised changes
  - approval process to authorise system changes
  - access control to manage implementation of changes (e.g. who, when).

7 Commissioning hazard controls

To achieve the desired safety outcomes, commissioning activities for autonomous equipment should adequately address matters such as:

- roles and responsibilities of system operators and system builders
  - boundaries agreed, defined and documented
  - commissioning tasks assigned to competent persons
  - formal commissioning and hand-over process
- risk management process
  - technology and specific functionalities are understood
  - identify hazards specific to the commissioning phase (e.g. safety critical tests)
  - ensure appropriate controls are in place
- formal approvals processes
  - system builders
  - system operators
  - regulators
  - other stakeholders as required
- commissioning planning
  - communications and reporting plan
  - commissioning project plan and timeline
  - selection and survey of suitable commissioning area (e.g. segregated, isolated)
  - checklists for installation, assembly and commissioning
  - change management plan
- commissioning test plan
  - based on the recommended test procedures from the system builder
  - safety systems tests
  - operational performance tests
  - system integration tests
  - documented test procedures
- functional and user acceptance testing
  - tests conducted in line with documented test procedures
  - testing should be traceable to the system version or type to confirm systems meet the system builders' and operational requirements
  - compliance with relevant standards
  - test results are documented (e.g. pass, fail, defects, issues)
- systems acceptance
  - formal process for managing unresolved defects and issues
  - user acceptance based on system builder specifications
  - training and assessment of competency for the various roles.

8 Operational hazard controls

To achieve the desired safety outcomes, the design and function of operational practices should adequately address matters such as:

- management and supervision, including support functions
- technical and system knowledge within operating teams
- roles and accountabilities
  - job descriptions
  - appointments under section 44 of the *Mines Safety and Inspection Act 1994*
  - changes introduced by autonomy
- competency validation (e.g. supervision, technical support, operators, maintainers)
- change management such as
  - system updates and upgrades
  - changes to operational practices, documentation and training requirements
  - sharing safety learnings
- interaction rules
  - how changes between autonomous and manned operating modes are managed, documented and communicated
  - traffic management and associated procedures to govern interactions between autonomous equipment, manned equipment and pedestrians
- human factors (e.g. response to system information or warnings, adherence to exclusion zones)
- performance monitoring of continuous improvement and change management (e.g. equipment, systems, personnel)
- area security and control
  - access control for autonomous, manned and mixed fleet areas
  - area or hazard inspections that incorporate checks for area security and control
- tools and processes
  - risk management (SWPs, JSAs, risk assessments, risk register)
  - communication protocols and considerations (e.g. radio network)
  - monitoring
  - incident reporting
  - emergency response
- technical support provision.

Note: Restricted operational modes may be appropriate to consider following certain non-critical system events.

9 Maintenance hazard controls

To achieve the desired safety outcomes, maintenance activities for autonomous equipment should adequately address matters such as:

- safety-related parts of control systems and functional safety considerations for system maintenance
- scheduled maintenance and inspections processes
- in situ inspection and servicing
- base platform
  - autonomous components
  - system (e.g. database management and maintenance)
- recovery procedures in autonomous areas
- area and activity isolation
  - physical and virtual demarcation to provide safe area of work
- condition monitoring and diagnostics
  - understanding criticality of autonomous components
  - alarm and error reporting analyses to indicate system behaviour
- calibration and testing (including designated testing areas)
  - after repairs and scheduled maintenance
  - as indicated by system reporting tools
  - following a component upgrade, system change or return to autonomous service
- other equipment considerations.

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PART 3 EMERGENCY PREPAREDNESS

10 Emergency management

The potentially hazardous nature of autonomous mining operations, and often remote locations where they are carried out, mean that being prepared is critical to the health and safety of personnel. Emergency management involves understanding the likelihood of an emergency situation and its potential consequence, and being prepared to mitigate its effects, respond effectively, and recovering afterwards. Effective emergency management means that there are plans in place for all foreseeable emergency scenarios so the response is comprehensive and coordinated.

Emergency response planning for autonomous operations should be undertaken as part of the mine emergency response planning to ensure the integration of responses where necessary. It should be noted that safe access and effective communication during an emergency can be difficult to establish and maintain.

The mobile autonomous safety system should include emergency response procedures to:

- isolate all, or part of, the autonomous area
- shut down the mobile equipment.

The critical element of preparedness is the development of emergency response plans for identified emergency scenarios. All personnel should be familiar with the emergency response strategy before entering the site, to ensure they understand their responsibilities and what to do in an emergency.

In particular, the emergency response team should have an understanding of how the system works and controls required before entering an autonomous area. A member of the autonomous mining team should brief the team and may be required to escort them to the location.

Emergency response plans should be regularly tested to ensure their effectiveness. Both "desk-top" tests and emergency response drills involving all onsite personnel should be carried out. The drills can be used to evaluate how people respond.

Debriefings conducted as soon as practicable after an emergency or drill will help identify potential improvements to the emergency response plan.

APPENDICES

Appendix 1 Legislative provisions

The parts of the *Mines Safety and Inspection Act 1994* and Mines Safety and Inspection Regulations 1995 that are directly applicable to this guideline are listed below.

Mines Safety and Inspection Act 1994

Part 1 – Preliminary

s. 4	Terms used

Part 2, Division 2 – General duties

s. 9	Employers, duties of
s. 10	Employees, duties of
s. 11	Duty to report some occurrences and situations
s. 11A	Mine manager's duties when s. 11 report received
s. 12	Employers and self-employed persons, duties of
s. 14	Plant designers etc., duties of

Part 7, Division 2 – Accidents and occurrences

s. 78	Some occurrences at mines to be notified and recorded
s. 79	Some potentially serious occurrences to be notified

Mines Safety and Inspection Regulations 1995

Part 3	**Management of mines**
Part 4	**General safety**
Part 6	**Safety in using certain types of plant in mines**
Part 10	**Specific requirements for underground mines**
Part 13	**Surface mining operations**

Note: The only authorised versions of the Act and regulations are those available from the State Law Publisher (www. slp.wa.gov.au), the official publisher of Western Australian legislation and statutory information.

Appendix 2 Selected standards

Examples of Australian and International Standards and other guidance that may apply to mobile autonomous mining systems are listed below.

Note: This list is not exhaustive but gives an indication of the many aspects to be considered.

Safety lifecycle (risk assessment)

AS/NZS ISO 31000	*Risk Management – Principles and guideline*
AS/NZS 3100	*Approval and test specification – General requirements for electrical equipment*
ISO 12100	*Safety of machinery – General principles for design – Risk assessment and risk reduction*
AS/IEC 61508.1	*Functional safety of electrical/electronic/programmable electronic safety-related systems – General requirements*

Design

ISO 5006	*Earth-moving machinery – Operator's field of view – Test method and performance criteria*
ISO 13849	*Safety of machinery – Safety-related parts of control systems*
ISO 16001	*Earth-moving machinery – Hazard detection systems and visual aids – Performance requirements and tests*
ISO 17757	*Earth-moving machinery – Autonomous machine safety* [under development]
ISO 20474	*Earth-moving machinery – Safety*
IEC 61508.2	*Functional safety of electrical/electronic/programmable electronic safety-related systems – Requirements for electrical/electronic/programmable electronic safety-related systems*
IEC 61508.3	*Functional safety of electrical/electronic/programmable electronic safety-related systems – Software requirements*
AS/NZS 60529	*Degrees of protection provided by enclosures (IP Code)*

For "smart" tele-remote

AS 4240	*Remote control systems for mining equipment – Design, construction, testing, installation and commissioning*

Appendix 3 Glossary

In order to reduce confusion and ambiguity, it is recommended that standard terminology is applied. For the purposes of this document, the following terms are defined.

Automatic — term used for (part of a) process when a machine follows well defined rules

Automation — the technique, method or system of operating and controlling a process or machine by automatic means with minimal human intervention

Autonomous — a process or machine that is intended to accomplish its task(s) within a set of defined operations without human intervention or direct control

Autonomous area — area in which autonomous equipment operates

Collision — unintended contact between two or more objects

Mechanised — commonly used when a certain process is done with the aid of machines

Mobile autonomous mining — mobile equipment operated using an autonomous system

Mode indicator — means by which a process or machine shows its operating mode (e.g. autonomous, semi-autonomous, manual) or status (e.g. starting up, reversing)

Remote controlled — the functionality and operator interface are the same or similar on the machine, but the controller is separate to the machine and is under human supervision while the machine is operated in line-of-sight or tele-remote mode.

Safe state — equipment condition, whether the equipment is operating or shut down, such that a hazardous event is unlikely if autonomous activity continues

Semi-autonomous — a process or machine that is intended to accomplish a portion of its task(s) within a set of defined operations without human intervention or direct control

Appendix 4 Project management plan (PMP)

Requirements

A company proposing a new mine (including autonomy) must submit a PMP through the Department of Mines and Petroleum's online Safety Regulation System (SRS).

Note: The introduction of mobile autonomous mining to an existing operation is considered a substantial change to operating conditions and an addendum to the site's PMP should be submitted to the Department through SRS.

The introduction of mobile autonomous mining technologies to a mining operation, whether surface or underground, new or existing, can add hazards beyond those associated with a conventional manned mining operation. These additional hazards will require detailed consideration and risk assessment to ensure they are effectively managed.

Submission of the PMP for mobile autonomous mining should be seen not only as a legislative requirement, but an opportunity to demonstrate an understanding of the risks associated with implementing autonomous technology. The PMP is an important tool in the development of a site-specific occupational health and safety management system.

Content

The following headings cover the PMP content for mobile autonomous mining projects. The plan should set out clear objectives, stating what will be done, how it will be done, and the proposed schedule for doing it.

Section 1 Introduction

1.1	Proposed autonomous project	☐
1.2	Make-up of autonomous system	☐
1.3	Communications and reporting process	☐
1.4	Implementation process	☐
1.5	Risk management strategy	☐
1.6	Limitations of system	☐

Section 2 Project overview

2.1	Location	☐
2.2	Access	☐
2.3	Equipment	☐
2.4	Plan and timeline	☐
2.5	Organisation	☐
2.6	Key roles	☐
2.7	Skills and knowledge of implementation team	☐

Section 3 Functionality of the system

3.1	Autonomous equipment	☐
3.2	Manual vehicles	☐
3.3	Autonomous and non-autonomous areas	☐
3.4	Autonomous/manual interface (operation/ maintenance)	☐
3.5	Central control room	☐
3.6	Navigation systems	☐
3.7	Safety systems and control systems flowcharts	☐
3.8	Other functionalities	☐
3.9	System redundancy	☐
3.10	Safety integrity level / failing to safe	☐
3.11	Compliance with relevant Australian / International Standards	☐
3.12	Interactions and tasks within the autonomous area	☐

Section 4 Equipment control system

4.1	Layers of protection	☐
4.2	Communication	☐
4.3	Controller integration	☐
4.4	Controller recording	☐

Section 5 Autonomous mine and operations plan

5.1	Key principles	☐
5.2	Facilities within the autonomous area	☐
5.3	Mine design principles	☐
5.4	Drill and blast	☐
5.5	Supervision	☐
5.6	Contract management	☐
5.7	Other requirements (e.g. survey, geology)	☐

Section 6 Commissioning, maintenance and inspections

6.1	Commissioning process	☐
6.2	Maintenance and inspection strategy	☐
6.3	Maintenance and inspection of ancillary equipment	☐
6.4	Maintenance and inspection of light vehicles	☐
6.5	Maintenance and inspection of control system	☐

Section 7 General safety plan

7.1	Safety management plan	☐
7.2	Risk management applied to the project	☐
7.3	Other major risks (normal PMP hazards/ controls)	☐
7.4	Autonomous equipment system risk management strategy	☐
7.5	Change management strategy	☐
7.6	Process monitoring	☐
7.7	Review and auditing	☐

Section 8 Training and competence assessment

8.1	Training program	☐
8.2	Ramp-up plan	☐

Section 9 Means of investigating failures

Appendices

Appendix A – Plans	☐
Appendix B – Detailed risk assessment	☐
Appendix C – Emergency response plan	☐
Appendix D – Inspection protocols	☐
Appendix E – Protocol testing	☐

Appendix 5 Introducing mobile autonomous systems to mining operations

Mobile autonomous applications

Autonomy can be used to move a variety of plant and equipment used in mining and exploration. Examples include:

- haul trucks
- drill rigs
- loaders
- underground load-haul-dump (LHD) units (e.g. boggers)
- dozers
- continuous miners feeding trucks or conveyor systems
- mobile crushing and screening plants
- light vehicles
- haulage trains in loading and unloading applications.

Decision to automate

The decision to automate parts or all of a mining operation is a commercial decision based on perceived future gains in productivity, efficiency and safety performance. Many large mining companies and equipment suppliers have been involved with pilot projects in Western Australia for a number of years and are introducing autonomous and semi-autonomous mining equipment such as loaders, trucks, drills and dozers into production activities in surface and underground operations. While the decision to automate particular aspects of mining activities depends on the project's financial and logistical viability, companies are also required to demonstrate to the regulator, through a project management plan, that they can effectively accommodate this new mining approach in their safety management system and manage the change.

The addition of autonomous mobile equipment can introduce hazardous situations not normally encountered on a conventional manned mining operation. It is important that these safety challenges are addressed early in the planning cycle to maximise opportunities for solutions high in the hierarchy of control (i.e. elimination, substitution, engineering).

Companies considering introducing autonomous mobile mining systems into their operations should consider the following to achieve a safe and successful outcome:

- undertake a comprehensive mine site risk assessment prior to making the decision to introduce autonomous mining
- have a well-documented change management process, including
  - roles and responsibilities
  - development of strategies
- integrate autonomy into mine design and planning as early as possible.

Assessing suitability of operation for automation

Scoping the case

The introduction of autonomous mining is not a trivial matter as its impact will be felt in many areas of a mining operation. Although automation provides opportunities, it may not be suitable for some sites. The benefits of autonomous mobile mining are most obvious for bulk mining because of the continuity and scale of operations. However, the extraction of geologically complex orebodies may be challenging.

There needs to be a well-defined business case that addresses potential issues that may negatively impact desired outcomes.

The business case should address questions such as:

- What are the expected safety and organisational benefits?
- What are the hazards and limitations of the introduced technology?
- If there is an existing operation, what hazards may emerge that need to be considered and managed during integration?
- What is a realistic lead time for full implementation, given the need for verification and validation trials as part of the risk management process?

Companies should invest sufficient time and resources to ensure autonomous operations can start up safely and meet production expectations. Matters to be considered include:

- organisational readiness
- project management
- site-specific risks.

For a technology implementation project to be successful, attention is required in three key areas — people, processes and technology.

People

The workforce will be affected by the introduction of automation, particularly in regards to training and skills development. Furthermore, roles and skill requirements will change — new skills will be part of new organisational structures and some existing skills might no longer be applicable.

Potential changes need to be identified and managed carefully for the implementation of automation to be successful.

Processes

Automation will change the way in which the mine operates. It will impact many procedural aspects of mining such as:

- traffic management plans
- safety management plans
- safe work procedures
- work instructions.

These will need to be identified and developed in a timely manner to ensure the introduction of automation has the best chance of success.

The mine layout, mine design, mine plans and schedules will need to be tailored to accommodate autonomous mobile equipment and modifications need to be identified as early as possible to allow for sufficient time to incorporate any changes.

Technology

The implementation of mobile equipment automation requires the application of other technology such as sophisticated and robust wireless communications networks and control rooms. These will need to be identified and be part of the deployment process.

Organisational readiness

The ease with which automation can be introduced to a site will depend on the organisation's level of preparedness, at all levels, for the new technology. The greater the complexity of the proposed changes, the greater the importance of understanding whether there is a readiness for change and identifying the actions required to achieve the desired safety and performance outcomes.

Factors influencing organisational readiness include:

- robustness of safety culture
- commitment to effective change management
- responsiveness to change
- existing knowledge and understanding of autonomous mining, its risks and consequences
- human resourcing
  - identification of new roles, responsibilities and reporting relationships
  - recruiting to address skill gaps
- capacity of workforce to transition between mechanised and autonomous mining
  - ability to learn
  - adaptability of process and operation personnel
- awareness of the level of discipline required for autonomous mining.

The successful introduction of autonomous mobile mining requires:

- commitment from the board and senior management to ensure sufficient time and resources are allocated
- a clear vision of the project and outcomes
- defined responsibilities and accountabilities
- a collaborative approach so knowledge is shared, not only within the organisation but with equipment suppliers and service providers.
- workforce acceptance of the implementation strategy.

Change management

A well-constructed change management policy is critical to the introduction of autonomous mining. Successful change management will require the input and alignment of all parties involved in the process, including:

- principal employer
- project team
- mine management
- system designers, equipment suppliers and service providers
- workforce, including contractors
- safety and health representatives
- safety regulator.

The change management strategy may need to be different for each part of the site and type of mobile autonomous technology introduced.

Key aspects to be managed should include:

- procurement and installation
  - selection of autonomous system, including equipment specifications and associated technologies
  - commissioning of the autonomous system (both the "conventional" equipment as well as the on- and off-board control systems)
  - hand-over, including testing and monitoring requirements.
- mine planning
  - mine design — automation will have specific operating requirements (e.g. mine dimensions, layout of road network or underground development)

- mine plans and schedules — although automation systems are designed to be intrinsically safe, further reduction of risk is best accomplished by minimising interactions with autonomous equipment at the mine planning and scheduling phases.

- operational procedures
  - traffic management
  - access to and egress from an autonomous area
  - workplace inspections in an autonomous area
  - working near autonomous equipment
  - autonomous equipment inspection, servicing and maintenance
  - verification and validation to assess system integrity.
- personnel
  - organisational structure and control of safety — new roles and organisational structures may need to be considered
  - training and competency assessment in advance of system implementation is challenging prior to system implementation — equipment suppliers and service providers may have specialist skills and facilities that can be used
  - a system to ensure affected personnel are retrained and reassessed whenever systems of work or plant and equipment change, or new systems of work or plant and equipment are introduced.
- communication
  - implementation strategy
  - integration of autonomous systems into the operation
  - potential impact of changes on procurement, mine planning, operational procedures and personnel.

Integration of autonomy into mine planning process

The introduction of an autonomous system is typically a staged process that takes time to design and implement. Automation should not be simply seen as a "plug and play" system due to the complexity of the system and layers of safety that need to be built in.

Companies need to carefully evaluate why they wish to automate a site. They should evaluate their mine design and undertake a comprehensive risk assessment of the mining processes with support from site representatives and subject matter experts to satisfy the regulator that there are sufficient and robust controls. Controls should seek to:

- minimise the start-up risks with new plant (e.g. start simple and small and gradually build up capacity)
- create an area where the autonomous system is isolated or interactions with conventional, manned mining systems are managed (e.g. consider the implications in mine design, plans and schedules).

Supporting infrastructure and area requirements need to be identified early in the project, as automation systems may have specific needs (e.g. fuelling facilities, control rooms, communications network).

The following fundamental principles need to be built into mine design and planning processes:

- risk management
- designing and planning for autonomy
- managing and minimising interactions
- autonomous infrastructure.

Risk management

Issues that subject matter experts should considered when undertaking a risk assessment for mobile autonomous mining include:

- any previous events or information (e.g. incident and injury reports, data from similar technology applications)
- reliability, maturity and available safety features of autonomous equipment and systems
- provision and frequency of validation process (e.g. trials)
- suitability of established work procedures (e.g. inspection and maintenance processes)
- whether established emergency procedures are sufficient
- the provision and competency of operational and support personnel
- identification of specific risks and provision for regular reviews of controls.

Designing and planning for autonomy

Mine designers and planners should understand both the benefits and limitations of any technology being considered, including the:

- application of engineering and system controls to safety processes and practices
- modification of established planning and operational processes
- verification of system data (e.g. surveys) to validate mine designs and plans
- adaptability of planning and operational personnel
- application of positive outcomes to non-autonomous operations.

Managing and minimising interactions

Mine designers and planners should ensure work area design and construction are suitable for autonomy and minimise interaction with personnel and equipment, taking into account:

- access controls and processes for exclusion and interaction areas, such as
  - resupply of consumables (e.g. fuel, water)
  - breakdown and recovery of equipment
  - loading and unloading (e.g. excavated material, drill core)
- traffic management (e.g. road network, intersections, park-ups, load and dump locations, movement of mobile processing units for explosives)
- transitions between autonomous and other operating modes (e.g. procedures for checking, clearing and acknowledging the transition)
- placement of infrastructure within the autonomous area such as
  - fuel facilities
  - crushers or ore passes
  - stockpiles
  - workshops and service areas
  - crib rooms
  - services (e.g. electrical reticulation, dewatering bores).

Autonomous infrastructure

The design, location and integration of autonomous infrastructure should consider:

- equipment specifications, fleet size and system capabilities (e.g. turning circle, road network layout, gradient)
- communication systems (e.g. wireless, fixed), and matters such as
  - latency
  - bandwidth
  - spectrum allocation
  - packet loss
  - maintaining connectivity (e.g. wireless cell switch time)
  - redundancy
  - network monitoring
- autonomous signage and delineation.

Appendix 6 Potential mobile autonomous mining risks

Site-specific risks

If there are no existing operations, then planning for automation can be tailored from the start to address risks common to autonomous operations.

Risk factors to consider as part of a comprehensive risk management strategy include:

- capture of changes to work areas, especially before switching work areas between manual and autonomous
- loss or interference with communication systems for autonomous equipment
- loss of control of movement of autonomous equipment (sliding or skidding)
    - autonomous equipment deviating from its programmed path, leading to a fall to another level
- other human errors
- inadvertent access
- natural phenomena.

Introduction into an existing operation

Where there is an existing operation, a phased approach may be necessary to manage additional risks associated with integration and segregation, such as:

- infrastructure
- communication
- traffic management.

The following scenarios should be considered for inherent risks, as well as those hazards identified for manned operations:

- access into autonomous area by unauthorised personnel or equipment (surface or underground)
- human errors that may lead to autonomous equipment going into unauthorised areas or performing tasks that cause safety risks (e.g. human intervention, overriding an alarm condition, failure to update information such as survey plans)
- design speed of equipment failing to consider operating tolerances
- communications failure leading to lost, degraded, delayed, misdirected or hacked communications, on-board sensor or controller failures
- loss of control movement of autonomous equipment (e.g. sliding, skidding)
- autonomous equipment deviating from its programmed area
    - into the path of another vehicle (manned or autonomous)
    - leading to a fall to another level
- autonomous interactions in an autonomous environment and traffic management interactions (e.g. failure to convert virtual intersection to actual on the ground)
- failure to communicate changes (e.g. system updates, upgrades, changes to operational practices)
- manual interactions in an autonomous environment and traffic management interactions (including escorting of non-system equipment or non-system trained personnel)
- inadvertent switching between autonomous and other operating modes leading to loss of control
- interactions with pedestrians
- interactions with walls, windrows or other infrastructure
- passengers, observers and technicians aboard an operating autonomous vehicle
- remote re-starting of autonomous vehicle from a position without appropriate situational awareness
- fire
- accessing or checking autonomous equipment that has failed
- loss of competent persons on site (i.e. staff turnover), leading to loss of corporate knowledge.

Appendix 7 Incident reporting

Mobile autonomous mining should be as safe as or safer than conventional manned mining operations. An incident in an autonomous mining environment that could happen in a manned operation (e.g. rockfall, fire, blasting incident) has the same reporting requirements. However, there are some incidents unique to the autonomous environment and their suggested reporting treatment is listed in Table A1.

Table A7.1 Examples of autonomous-specific incidents that result from system malfunctions or operator errors, and the reporting requirements under the Mines Safety and Inspection Act 1994

Incident	Examples	Reporting requirement
Uncontrolled movement	• Breach of the designated area due to a system malfunction	Reportable under s. 78
Uncommanded movement	• Starting while "all clear" not in place	Reportable under s. 78
Failure to start moving when so commanded	• Failure to start • Stationary equipment fails to move when commanded by control room	Not reportable
Failure to stop when so commanded	• Moving equipment fails to stop when commanded by control room • Moving equipment fails to stop when commanded by on-board control system	Reportable under s. 78
Failure to change motion when so commanded	• Failure to change direction when commanded • Failure to change speed when commanded	Reportable under s. 78
"Near miss" with oncoming vehicle	• Various scenarios similar to "near miss" events for non-autonomous equipment	Potentially reportable under s. 79
Collision with property, equipment or personnel	• Various scenarios similar to "collision" or "struck by" events for non-autonomous equipment, including: – collision with other mobile equipment – worker struck by autonomous equipment	Reportable under s. 78
Other autonomous incident that could lead to injury, harm or damage in the manager's opinion	• Potentially serious incident involving autonomous system or component, including: – unexpected switching between autonomous and manual operating modes – non-standard response during testing	Potentially reportable under s. 79

Government of **Western Australia**
Department of **Mines and Petroleum**
Resources Safety

Department of Mines and Petroleum
100 Plain Street
EAST PERTH WA 6004

Resources Safety Division
Telephone: + 61 8 9358 8002
NRS: 13 36 77
Facsimile: + 61 8 9358 8000
Email: ResourcesSafety@dmp.wa.gov.au
Website: www.dmp.wa.gov.au/ResourcesSafety

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