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BC GUIDELINE
for Safe Mobile Autonomous Mining

Health, Safety and Reclamation Code for Mines in British Columbia

BRITISH COLUMBIA
Ministry of
Energy, Mines and
Low Carbon Innovation

Acknowledgements

The ***BC Guideline for Safe Autonomous Mining*** is an adaptation of the Code of Practice, Safe Mobile Autonomous Mining in Western Australia by the Department of Mines, Industry Regulation and Safety and the Mining Industry Advisory Committee for Western Australia, and is used by permission. The BC Ministry of Energy, Mines and Low Carbon Innovation gratefully thank the Department of Mines, Industry Regulation and Safety in Western Australia for use of this material.

Foreword

Who should use this Guideline?

This Guideline is for qualified professionals and those who have functions and responsibilities related to the planning, designing, implementing, and ongoing maintenance of mobile autonomous mining systems. The Guideline 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.

Use

The *BC Guideline for Safe Mobile Autonomous Mining* (Guideline) has been prepared by the Emerging Technology and Autonomation Sub-Committee on behalf the Code Review Committee.

The purpose of this Guideline is to provide information and a practical resource to qualified professionals, individuals and proponents preparing an Autonomous Mining Project Management Plan (AMPMP) required under section 6.18.3 of the *Health, Safety and Reclamation Code for Mines in British Columbia* (the Code) for submission to the Ministry of Energy, Mines and Low Carbon Innovation. **It is not intended to replace the regulatory requirements within the Code.**

The Guideline is intended to provide information on the expectations of the submission requirements for the AMPMP.

The Guideline also includes general information on the implementation of autonomous and semi-autonomous mining including:

- Risk management,
- General hazard controls,
- Emergency response, and
- Potential mobile autonomous mining risks.

Please note, this Guideline deals with particular issues and does not cover all hazards or risks that may arise. Mine managers need to consider risks associated with the work.

Scope and application

This Guidance was developed to assist proponents to meet the submission requirements for an AMPMP under section 6.18.3 of the Code (For further detail on section 6.18.3 requirements please see Appendix 1).

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, haulage trucks, light vehicles, crew transport and other mobile equipment such as drills, excavators, and dozers at mine sites
- the identification of the unique risk profiles in relation to new or existing mobile autonomous mining systems

The Guideline 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)

Contents

PART 1: Risk Management Approach

Chapter 1: Introduction

1.1 Aims

Mobile autonomous mining, like any large-scale mining activity, has inherent risks. When integrated with a conventional mining operations (with human operated production equipment), additional risks may be present beyond those recognised for conventional mining techniques.

The aims of the Guideline is to describe:

- a set of desired safety outcomes for mobile autonomous mining to meet the acceptance requirements of the AMPMP required by section 6.18.3 of the Code
- the variables to be considered to demonstrate that a mobile autonomous mining system is safe and performing as designed
- the role of the qualified professional in the hazard identification and risk management process for mobile autonomous mining
- the broader occupational health and safety requirements for operating in accordance with the Mines Act and the Code

This Guideline 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 responsibility for the safe use of autonomous technology 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 Guideline to cover both autonomous and semi-autonomous mining systems. It does not apply to remote controlled systems, but parts of the Guideline could be relevant to tele-remote systems if they incorporate additional functionality that takes autonomous control of machines.

1.2 Structure of this Guideline

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 provides guidance on regulatory provisions that apply specifically to autonomous mining operations and to mining activities in general.

Appendix 2 lists examples of other guidance that may apply to mobile autonomous mining systems.

Appendix 3 provides a glossary of terms used in this Guideline.

Appendix 4 contains detailed information on AMPMP 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.

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, and
- 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 Heath and Safety Program
- 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
- incorporating information from system builders into the site's Health and Safety Program
- 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 unique 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 Office of the Chief Inspector of Mines regarding submission of the AMPMP for the site (Appendix 4)

Chapter 2: Safety and risk management process

2.1 Introduction

The operation of autonomous equipment can introduce hazards not normally encountered on a conventional mine site with human operated equipment.

The effective management of the hazards and 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 practical 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 hazards risks are listed in Appendix 5 and Appendix 6.

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

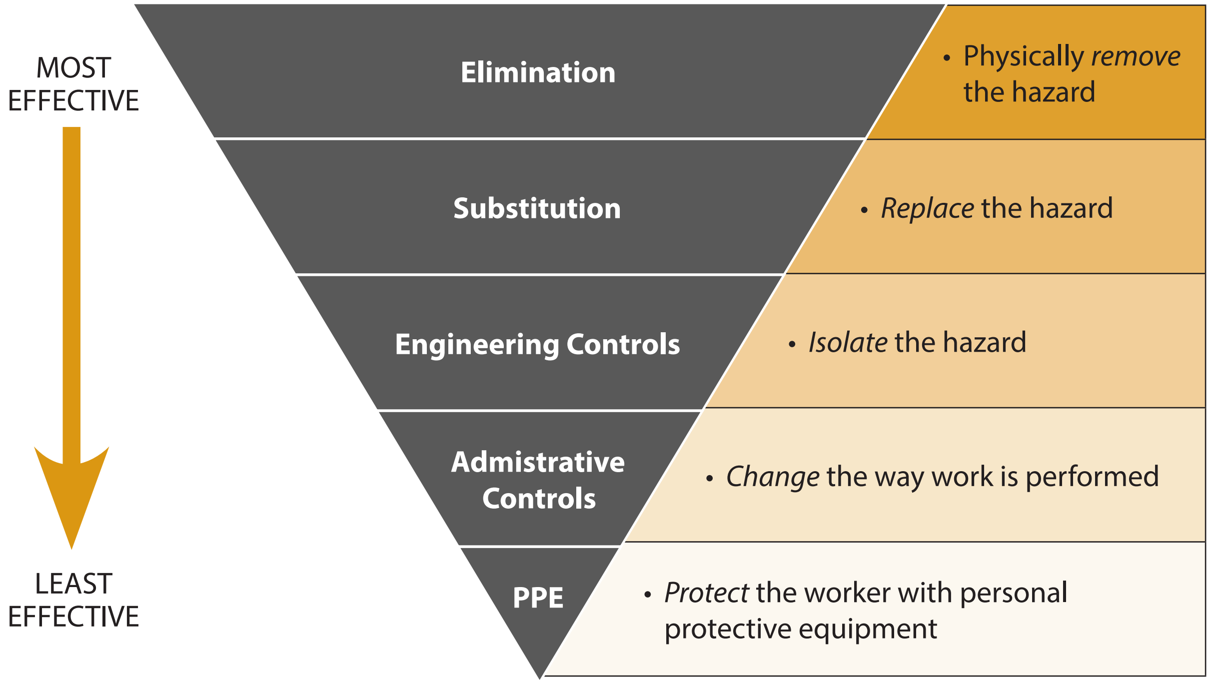
It is important that those undertaking a risk assessment have the necessary information, training, knowledge, and experience of the:

- 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 controls. Higher-order control measures eliminate or reduce the risk more effectively than administrative controls or personal protective equipment.

FIGURE 1: HIERARCHY OF CONTROLS



For mobile autonomous mining, it is advisable to implement:

- primary controls that:
  - avoid the risk by deciding to modify, not to start, or to continue with the activity (e.g., decrease speed or 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 human operated fleets 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 practical minimum
- monitoring and review outcomes and actions

The documentation of this information forms the basis of the health and safety program for mobile autonomous mining systems (*see section 1.6.9 (1) (c.1) of the Code*).

Chapter 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, regulation, 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 procedures (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.

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, equipment, plants are introduced or changed, there should be a plan to ensure affected personnel are consulted, retrained as necessary and reassessed.

For regulatory requirements for training, please refer to sections 1.11 and 6.18.3 (2) (k) of the Code.

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 general safety rules or SWPs to management for further instructions
- communicating learnings from incidents

Note: For regulatory requirements for supervision, please refer to section 26 of the Mines Act, and section 1.12 of the Code.

PART 2: General Hazard Controls

Chapter 4: Introduction to general hazard controls

The use of mobile autonomous mining technologies, whether at the surface or underground, can introduce unique hazards that are not associated with a conventional 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 other controls or factors as identified that are not included in the list above

Chapter 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, parking areas, load and dump locations, access controls for exclusion and interface areas)
- area segregation (e.g., separation of autonomous equipment from personnel and human operated equipment for parking areas, go-lines, and specific work areas)

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

5.6 Change management

Mine management, 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

Note: Mine designers and planners must also follow mine design and operation Code requirements. See Part 6 of the Code for more information.

Chapter 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 requirements 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)

Chapter 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 builder's 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

Chapter 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
  - qualifications of qualified persons, qualified professionals, and supervisors
  - 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 manual operating modes are managed, documented, and communicated
  - traffic management and associated procedures to govern interactions between autonomous equipment, human operated 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, human operated, 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.

Chapter 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

Note: Code requirements for mobile equipment must also be followed. See Part 4 of the Code for more information.

PART 3: Emergency Preparedness

Chapter 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 plan (see section 3.7.1 of the Code) 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, and
- 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 and working in or around autonomous operations, 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 must be tested annually to ensure their effectiveness. Both "desk-top" tests and emergency response drills involving onsite personnel should be carried out. The drills can be used to evaluate how people respond.

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

Note: For regulatory requirements for mine emergency response please refer to section 3.7.1 of the Code.

APPENDIX 1: Regulatory Guidance

Autonomous Mining Project Management Plan (AMPMP)

Section 6.18.3 of the Code requires the development and submission of a AMPMP prior to the implementation of autonomous or semi-autonomous mining systems:

Autonomous and semi-autonomous machines

6.18.3

1. *Prior to the use of autonomous or semi-autonomous tracked or rubber-tired mobile equipment, the manager must submit to the chief inspector an Autonomous Mining Project Management Plan prepared by a qualified professional.*
2. *The plan must contain the following elements, as described in the BC Guideline for Safe Mobile Autonomous Mining:*
   a. *a detailed risk assessment for the purpose of identifying, assessing and managing hazards;*
   b. *a summary of the health and safety plan that includes general safety rules and safe working procedures for autonomy as required in section 1.6.9 of this code;*
   c. *a summary of the project plan, project milestones and scope;*
   d. *details on location, access, infrastructure, and equipment;*
   e. *a summary of key roles and responsibilities associated with the project;*
   f. *a summary of system functionality, redundancy, limitations and safety features;*
   g. *an autonomous or semi-autonomous mine and operations plan;*
   h. *an interaction plan for human operated equipment and personnel;*
   i. *a commissioning plan;*
   j. *maintenance and inspection plan;*
   k. *training program and competence assessment for working with and around autonomous and semi-autonomous machine systems as required in section 1.11.1 and 1.11.2 of this code;*
   l. *the process for investigating failures;*
   m. *a Mine Emergency Response Plan as required by section 3.7.1 of this code;*
   n. *an assessment of this code to identify any variances or additional project specific considerations that may be required;*
   o. *a summary of critical controls as identified in the risk assessment.*
3. *The OHSC must be provided with an opportunity to review and provide comments relating to worker health and safety within the plan and risk assessment, and associated updates as required in subsection (5), prior to submission to the chief inspector.*

4. *The manager must implement and adhere to the plan once the chief inspector confirms that it meets the requirements of this code and is appropriate for the site.*

5. *If the manager wants to change the operational use of autonomous or semi-autonomous tracked or rubber-tired mobile equipment set out in the Autonomous Mining Project Management Plan, the manager*

    a. *must have an update of the plan prepared by a qualified professional and submit the updated plan to the chief inspector, and*

    b. *must not make operational changes until the chief inspector confirms that the updated plan meets the requirements of this code.*

The AMPMP must contain the information outlined in section 6.18.3 (2) (for further information please see Appendix 4).

The Occupational Health and Safety Committee (OHSC) must be given the opportunity to review the AMPMP, or AMPMP update, prior to submission to the Chief Inspector. It is noted that portions of the AMPMP may be considered proprietary, but the OHSC must be given the opportunity to review and comment on the parts of the AMPMP that are specific to worker health and safety.

If there are to be material changes to the operational use of autonomous or semi-autonomous tracked or rubber tired mobile equipment, the AMPMP must be updated.

An operational change is considered a material change if it introduces new hazards that are not addressed in the original risk registry and critical control list.

Changes to the operational use that are considered material include but are not limited to:

- Addition of new autonomous and semi-autonomous technologies
    - I.e., adding autonomous drilling to a site that already has autonomous haulage
- Change of system builder or system
- Changing from a segregated autonomous operating area to co-mingling autonomous and manually operated operations

Other changes, such as expansion of fleet size and operating area may not trigger an update, if the associated hazards, risks and controls are addressed in the original submission.

The Office of the Chief Inspector is the lead for the review and consideration for the implementation of Autonomous Mining Project Management Plans (AMPMP) on mines in British Columbia. Proponents must provide the information as required under section 6.18.3 in the Code and as described within this Guideline.

The process for review and confirmation of the AMPMP is as follows:

- The proponent informs the Office of the Chief Inspector of their intent to implement autonomous mining. At this time, EMLI will provide further guidance on the review process, including the requirement to submit an AMPMP.
- Once submitted, the Office of the Chief Inspector will review each AMPMP application for accuracy, relevance and adherence to the Code requirements including site appropriateness.
- Each application must address all section information as required in the Code. Incomplete applications will be returned to the proponent with an explanation of missing information or sections. This guideline provides explanation for each of the sections and what the expectation is for information within the AMPMP submission (see Content).
- The Office of the Chief Inspector will designate a project manager who will lead the reviewing process. This work will be performed by an Advisory Committee (AC) composed by different specialists within EMLI.
- The AC may ask for additional information to clarify sections of the AMPMP application.
- Timing for responses from the AC will depend on the scope and complexity of the AMPMP application, however, it is in the interest of the proponent to provide additional information as soon as possible as delays can affect review timelines.
- The average time for application review and response will vary. Once the AMPMP application is received, the reviewing office will work out a schedule for review timelines with the proponent.
- The proponent will receive a formal response letter from the Chief Inspector of Mines with their decision.

Autonomous and Semi- Autonomous Code Provisions

The table below lists provisions of the *Health, Safety and Reclamation Code for Mines in British Columbia* that are specific to autonomous mining systems.

Section	Header	Provisions	Guidance
1.6.9	Health and Safety Program	The manager shall develop a Mine Health and Safety Program which includes the following sections (c) safe working procedures on a departmental basis (c.1) if autonomous or semi-autonomous mobile tracked or rubber-tired equipment is in use at the mine, safe working procedures for the equipment**	If mobile autonomous or semi-autonomous mobile equipment are used, safe work procedures (SWPs) must be developed. The SWPs required will depend on the site, system and application, but examples include: Access to autonomous operating areas Procedures for working within an autonomous operating area Clearing of autonomous operating areas, and restarting autonomous operations Switching mobile equipment between autonomous and manual mode Recovering a failed/stopped mobile equipment This list is not considered to be exhaustive.

Section	Header	Provisions	Guidance
4.6.1	Unattended Vehicles	(6) Subject to subsection (7), when the operator leaves a piece of diesel-powered equipment the master switch must be turned off. (7) If autonomous or semi-autonomous tracked or rubber-tired mobile equipment is parked in a designated parking area and the engine or power source is turned off, the master switch may be left on.**	Section 4.6.1 is applicable to mobile equipment in underground mines. There may not be an operator present in the work area to turn off the master switch for autonomous and semi-autonomous mobile equipment. Designated parking areas should be designed to prevent vehicle runaway and rollover.
6.4.1	Examination of Workings	(2) All persons working underground shall have their work areas inspected by a shiftboss or supervisor at least twice per shift. (3) Subject to subsection (4), work areas containing underground autonomous or semi-autonomous tracked or rubber-tired mobile equipment must be inspected by the shiftboss or supervisor prior to employees entering the work area, or at least once per shift. (4) In an underground coal mine, the fireboss must conduct the workplace inspections required by subsection (3). **	Where mobile autonomous and semi-autonomous machines are used underground, operators may not be present in the same work area as the equipment. Work areas are still entered periodically by other workers (maintenance, technical services etc.). The workplace must be examined for hazards by the shiftboss or supervisor to ascertain they are in safe working condition prior to employees entering the area, or at least once per shift. In underground coal mines this inspection must be conducted by a certified fireboss.
6.19.1	Operator's Responsibility	(2) A person who enters commands or inputs information into an autonomous or semi-autonomous system that governs the behavior of tracked or rubber-tired mobile equipment, must do so in a manner that ensures the safe operation of the equipment and that the system can maintain full control of the mobile equipment.**	Autonomous mobile equipment is controlled differently than conventional equipment. Conventional equipment has an operator behind the steering wheel who is responsible for maintaining control of the equipment (section 6.19.1 (1)). For an autonomous system, there can be a variety of people who are responsible for control of the system, including, but not limited to, individuals who survey the working area, restart stopped equipment, design the digital environment, assign tasks, or input commands to the system. Any individuals who enter commands or input information into the system have a responsibility to ensure the system can maintain control of the equipment.

Section	Header	Provisions	Guidance
6.19.3	Examination of Equipment	(2) In the case of autonomous or semi-autonomous tracked or rubber-tired mobile equipment, the manager must (a) when the unit is serviced, or at a minimum of every 24 operating hours, ensure that a qualified person examines and checks the equipment and reads the logbook, and (b) if an unsafe condition is discovered, ensure that the equipment is not put into operation until (i) repairs have been made, or (ii) a qualified person has assured the manager that the equipment is safe to put into operation and noted the reason in the logbook. **	It is understood that autonomous mobile equipment can run through shift changes, unlike conventional equipment. Examinations of autonomous mobile equipment must be conducted when the unit is stopped for service (maintenance, fueling, etc.) or at a minimum of every 24-hour period when the equipment is continuously running. If an autonomous machine is to be manually operated, the operator must conduct an examination prior to putting it to use (section 6.19.3 (1)). The risk assessment should consider when an examination of autonomous equipment is required due to an interruption of use within 24-hour cycle. For example, if a truck is parked for six hours for a shovel down. The examination must be conducted by a qualified person. The person must be trained to approach the equipment safety (i.e., perform mode change) and examine components of the autonomous system on the truck as set out in the maintenance and inspection plan required in section 6.18.3(2)(j). This may include physical/functionality checks of critical autonomous safety devices such as the Perception/Object Detection Sensors and Emergency Stop Buttons. The requirements for repair of unsafe conditions and what must be recorded in the logbook are the same for human operated and autonomous mobile equipment. For more information see sections 6.19.2 and 6.19.4 of the Code.

** This provision is not quoted in its entirety, please see the Health, Safety and Reclamation Code for Mines in British Columbia for the full requirement.

Other provisions

Although autonomous and semi-autonomous machine systems are not explicitly referenced, there are additional sections of the *Health, Safety and Reclamation Code for Mines in British Columbia* that must be considered in an autonomous mining operation:

Section	Header	Provisions	Guidance
4.9.4	Vehicle Requirements	(1) All rubber tired mobile equipment over 7000 kg gross vehicle weight shall have a minimum of two wheel chocks which shall be used whenever necessary.	For manually operated equipment, where equipment has an in-cab operator, "whenever necessary" has been interpreted as whenever the operator leaves the cab. For mobile autonomous vehicles, there may not be an operator in the cab to place wheel chocks when the vehicle is parked. The risk register and critical controls list in the AMPMP must address wheel chocks and determine when wheel chocks are required based on the risk, system, and application. Mobile equipment over 7000 kg are still required to carry a minimum of two wheel chocks.
4.9.10	Braking and Steering Modifications	Every truck, loader or other rubber tired vehicle having a manufacturer's gross vehicle weight in excess of 45,000 kg shall have any modification affecting the braking, steering or resulting in an increase to the gross vehicle weight be approved by the chief inspector.	This provision applies when physical modifications are made to the electrical and mechanical aspects of the braking and steering systems. If physical modifications to the steering or braking system are required to convert a piece of mobile equipment to autonomous or semi-autonomous use, an approval from the Chief Inspector is required under section 4.9.10. This provision does not require system logic (software programming, computer algorithms, etc.) that dictates the use of braking and steering systems to be approved by the Chief Inspector.
6.8.3	Traffic Control	The manager shall prepare traffic control procedures, showing the maximum allowable speeds for the vehicles in use, rules for passing, "stop" and "yield rules," priority rules for various vehicles, rules for night operation, maximum operating grades, emergency run-off protection, shoulder barriers, and any other information that may be required to ensure the safe operation of all types of vehicles on the mine site.	The requirement for traffic control procedures is applicable to autonomous mining operations. The procedures should consider: Rules for interactions between conventional and autonomous equipment; Autonomous operating area access and exclusion zones; Road, dumping and loading area design requirements and system limitations from manufacturer; and Priority rules.

Section	Header	Provisions	Guidance
6.20.3	Dumping Over Bank	No person shall drive or operate a haulage vehicle, in such a manner as to dump material from the vehicle over a bank that is more than 3 m high, or dump within 3 m of the dump berm crest when the bank is more than 3 m high, except as described in section 6.10.1(4), unless a dump person is directing vehicles to the dumping position and a dump berm is in place.	Section 6.20.3 is applicable to conventional mining operations, and no person shall drive a haulage vehicle as described. The intent of section 6.20.3 is to prevent haulage vehicles from backing over the crest of a dump, and therefore mitigate the risk of fatality or injury, environment impacts, and hazards associated with asset recovery. Although there is no operator in the cab, environmental impacts and asset recovery are still applicable to an autonomous mining operation in the event of an overturned vehicle. Every autonomous mining system manages dumping and reversing movements differently, and typically risks are mitigated by a combination of engineering system controls and administrative controls. The risk register and critical controls list in the AMPMP must identify and mitigate hazards associated with dumping operations.
6.20.4	Reverse when Dumping	The driver of a haulage truck shall not (1) where the bank is more than 3 m high and the dumping position is within 3 m of the dump berm crest, move the vehicle backward to the dumping position or begin dumping until he/she has received directions from the dump person, (2) operate the vehicle in reverse for a distance greater than 4 truck lengths on a dump other than a bin, raise, or other opening referred to in section 6.10.1 (4), or (3) operate the vehicle in reverse for a distance greater than 4 truck lengths, on a stockpile, ramp, road, or a ramp or road that is under construction, unless the ramp or road has a positive gradient of more than 5% or the procedure is accepted as part of a permit application or work system approval.	Section 6.20.4 applies to conventional mining operations, and no driver shall operate a haulage truck in the way prescribed. The intent of section 6.20.4 is to prevent vehicles overturn and collisions in situations where a haulage vehicle is reversing. In an autonomous mining operation, there is still the hazard of overturn, asset recovery and collision. Every autonomous mining system manages dumping and reversing movements differently, and typically risks are mitigated by a combination of engineering system controls and administrative controls. The risk register and critical controls list in the AMPMP must identify and mitigate hazards associated with: Reversing for dumping operations; Reversing for distances greater than 4 truck lengths; and Reversing for ramp and road construction.

Section	Header	Provisions	Guidance
6.20.5	Dump Person	A dump person who is responsible for directing vehicles at a dump point shall (1) continually inspect the condition of the dump site and if abnormal or hazardous conditions are observed take corrective action to alleviate any danger to workers assigned to the dump, and (2) communicate immediately any abnormal or hazardous conditions found to the open pit shiftboss or, in the case of a mine with fewer than 6 employees, the supervisor.	In conventional mining operations, a dump person physically directs the haulage vehicle to the dump point, if it is dumping within 3 m of the dump berm crest. Typically, this is the dozer operator. Autonomous mining systems do not require a real-time spotter for dumping tasks. Section 6.20.5 still applies to individuals who have responsibility for releasing surveys and dump locations to the system. The requirements for dump inspections under section 6.5.2 are also still required.

Please note that these provisions are not an exhaustive list; each mine is unique and all regulatory requirements that are applicable to the operation must be considered. The mine manager must take all reasonable measures to ensure compliance with the Mines Act, the regulations, the Code, and the mine permit.

APPENDIX 2: Selected Standards

Examples of 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.

Standards in the Code

ISO 3471 - Earthmoving Machinery Rollover Protective Structures –Laboratory Tests and Performance Requirements

CSA B352.095 – Rollover Protective Structures (ROPS) for Agricultural, Construction, Earthmoving, Forestry, Industrial, and Mining Machines

SAE J/ISO3450 JAN 98, Earthmoving Machinery – Braking Systems of Rubber-Tired Machines – Systems and Performance Requirements and Test Procedures

SAE J1026 APR 90, Braking Performance – Crawler Tractors and Crawler Loaders

SAE J151 1 ISO5010 FEB 94, Steering For Off-Road, Rubber-Tired Machines

CAN/CSA-M424. 1-88 – Flame-Proof Non-Rail Bound Diesel-Powered Machine for Use in Gassy Underground Coal Mines

CAN/CSA-M424.2-90 – Non Rail Bound Diesel- Powered Machines for use in Non Gassy Underground Mines

CAN/CSA-M424.3-90 – Braking Performance – Rubber Tired, Self-Propelled Underground Mining Machines

CSA B51-14 – Boiler, Pressure Vessel and Pressure Piping Code

CSA M421 – Use of Electricity in Mines

Safety lifecycle (risk assessment)

ISO 31000 – Risk Management – Guidelines

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

IEC 61508-1 – Functional safety of electrical/ electronic/programmable electronic safety-related systems – Part 1: 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 – Object detection systems and visibility aids – Performance requirements and tests

ISO 17757 – Earth-moving machinery and mining – Autonomous and semi-autonomous machine system safety

ISO 20474 – Earth-moving machinery – Safety

IEC 61508-2 – Functional safety of electrical/ electronic/programmable electronic safety-related systems – Part 2: Requirements for electrical/electronic/programmable electronic safety-related systems

IEC 61508.3 – Functional safety of electrical/electronic/ programmable electronic safety-related systems – Part 3: Software requirements

AS/NZS 60529 – Degrees of protection provided by enclosures (IP Code)

ISA/IEC 62443 – Security for industrial automation and control systems

For "smart" tele-remote

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

Guidelines

Implementation of Autonomous Systems Guideline, 2019. The Global Mining Guidelines Group (GMG)

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.

Code Defined Terms:

Autonomous means designed to perform the full job cycle without operator interaction or direct control by a person

Semi-autonomous means designed to perform a subset of tasks within the full job cycle without operator interaction or direct control by a person

Risk assessment means a systematic process of evaluating the potential risks that may be involved in a projected activity or undertaking

Other Terms:

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 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

APPENDIX 4: Autonomous Mining Project Management Plan (AMPMP)

Requirements

A proponent proposing mobile autonomous mining at a new or existing mine must submit a AMPMP to the Chief Inspector of Mines.

The introduction of mobile autonomous mining technologies to a mining operation, whether surface or underground, new or existing, can introduce unique hazards that are not associated with a conventional mining operation with human operated equipment. These additional hazards will require detailed consideration and risk assessment to ensure they are effectively managed.

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

Content

The AMPMP must contain the information required in section 6.18.3 of the Code. The following headings cover the AMPMP 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.

The type of system, implementation, and level of complexity will determine the information and level of detail required in the following sections. The AMPMP is scalable with the size and complexity of the project.

AMPMP Section	Explanation
Section 1: Introduction	It is recommended to provide an introduction, to provide context for specific sections of the AMPMP. Information to consider including: • Introduction to the proposed autonomous project • Overview of the selected autonomous system • Overview of implementation process • Overview of risk management strategy
Section 2: Project Overview	This section covers information required by section 6.18.3 (2)(c) *a summary of the project plan, project milestones and scope*, and (e) *a summary of key roles and responsibilities associated with the project*," and serves as a project overview.
2.1 Scope	Information on the scope of the project, and any specifics that will or will not be considered as a part of the project and implementation.

AMPMP Section	Explanation
2.2 Project Plan	Information on location, access and access control, equipment, fleet size, and infrastructure for the project.
2.3 Milestones	Information for implementation and key milestones, including construction, commissioning, and production stages. If applicable, information on planned and staged project expansions.
2.4 Key Roles and Responsibilities	Information on the reporting structure for the project, including commissioning and production stages, and responsibilities and qualifications of personnel in key roles. This will often include a combination of system operator and system builder personnel, including technical, operations, supervision, and maintenance subject matter experts.
Section 3: System Functionality	This section covers information required by section 6.18.3 (2)(f) *a summary of system functionality, redundancy, limitations and safety features*," and explains how the system operates safely.
3.1 Mobile Equipment Information	Information on manually operated and (semi) autonomous equipment, including descriptions of hardware and functionality for essential systems (e.g., navigation, positioning and orientation, and perception). If applicable, information on how the system manages interactions with other production equipment (e.g., loaders, shovels dozers, graders).
3.2 Communication	Information on the basic infrastructure and communication systems being utilized.
3.3 Autonomous and Non-Autonomous Areas	Information on functionality and management of autonomous areas, manual interface areas (i.e., fueling areas), exclusion zones within autonomous operating area, and non-autonomous areas. Information on system requirements for entry to autonomous areas, and physical access restrictions. Layouts and location of autonomous operating areas should be included in Section 2, and do not need to be repeated in this section. Physical access restrictions can be covered in either Section 3 or Section 2, and do not need to be duplicated.
3.4 Layers of Protection and Safety Features	Information on layers of protection, safety systems, and control systems. Including but not limited to: • Situational awareness • Mode indicators • Interaction controls • Remote and system stops • Onboard shutdowns • Obstacle detection and response • Fire suppression • Fail to safe scenarios • Loss of communication system response(s) • Loss of navigation system response(s) • Loss of position system response(s) • Loss of physical position response (i.e., slip events)
3.5 System Redundancies	Information on redundancies built into the design, such as back up power sources.

AMPMP Section	Explanation
3.6 System Limitations	Information on system limitations, including operating, perception, and detection limitations.
3.7 Supervisory System/ Controller Integration	Information on the supervisory system's functionality, including task assignment, remote control, digital maps, and exception states. Information on human oversight, intervention, and interaction requirements for the system.
Section 4: Autonomous Mine and Operations Plan	This section covers information required by section 6.18.3 (2)(g) "*an autonomous or semi-autonomous mine and operations plan*," and (h) "*an interaction plan for human operated equipment and personnel*." It outlines mine design requirements for the system, and how the system will be managed operationally. This section is not intended to cover system functionality. Safety features and controls described in Section 3 are to be referenced as needed, but how the system "works" does not need to be explained in this section.
4.1 Mine Design Principles	Information on key operational principles (i.e., segregation), summary of traffic rules, and design requirements (e.g., haul roads, drift sizes, loading and dumping areas, width, grade etc.).
4.2 Facilities with the Autonomous Zone	Information on any required facilities not covered in other sections of the AMPMP and any associated design requirements. If facilities have been explained in other sections of the AMPMP a reference list is acceptable for this section.
4.3 Interaction Strategy	Information on interaction strategies and management, including pedestrians, manually operated vehicles, and mining and support activities (drill and blast, mine services, maintenance, survey, geology etc.).
Section 5: Commissioning Plan	This section covers information required by section 6.18.3 (2)(i) "*a commissioning plan*." Information on the commissioning process, including stages, testing requirements (installation checklists and user acceptance tests for construction and live commissioning), system builder responsibilities, system user responsibilities, and critical controls for hazards specific to commissioning.
Section 6: Maintenance and Inspection Strategies	This section covers information required by section 6.18.3 (2)(j) "*maintenance and inspection plan*." Maintenance and inspection plans must comply with the Code and should consider manufacturer recommendations. Information on maintenance and inspection requirements for autonomous mobile equipment, equipped manual vehicles, supervisory systems, system updates and autonomous hardware/ installations. If applicable, information on continuous machine health monitoring which informs the maintenance and inspection strategy.
Section 7: Health and Safety Program	This section covers information required by section 6.18.3 (2)(b) "*a summary of the health and safety plan that includes general safety rules and safe working procedures for autonomy as required in section 1.6.9 of this code*." The intent of this section is not to reproduce the Health and Safety Program, or safe work procedures in their entirety. The purpose is to provide an overview of the program specific to the autonomous mining operation.

AMPMP Section	Explanation
7.1 Safety Management Plan	Information on the Health and Safety program's framework, basic safety rules, a list of required safe work procedures, and provisions for safety tour inspections.
7.2 Risk Management Applied to the Program	Information on major hazards identified in the risk assessment, and the critical controls that have been incorporated in the Health and Safety Program.
7.3 Change Management Plan	Information on the change management strategy for implementation. The plan should address change associated with implementing autonomous mining systems at existing sites.
7.4 Review and Auditing	Information on the process for reviewing and auditing critical controls, safe work procedures and basic safety rules for performance and improvements.
Section 8: Training	This section covers information required by section 6.18.3(2)(k) "*training program and competence assessment for working with and around autonomous and semi-autonomous machine systems as required in section 1.11.1 and 1.11.2 of this code*."
8.1 Training Program	Information on the training program including roles and responsibilities, program components, hours of instruction and field time, competency assessment process, and delivery methods.
8.2 Ramp Up	Schedule information for workforce training.
Section 9: Means of Investigation Failures	This section covers information required by section 6.18.3 (2)(l) "*the process for investigating failures*." Information on the process and information available for investigation system failures.
Appendix A: Risk Assessment	This section covers information required by section 6.18.3 (2)(a) "*a detailed risk assessment for the purpose of identifying, assessing and managing hazards*." The project's risk assessment must be presented in this appendix.
Appendix B: Critical Controls Lists	This section covers information required by section 6.18.3 (2)(o) "*a summary of critical controls as identified in the risk assessment*." A summary list of critical controls identified in the risk assessment, including engineering and administrative controls and PPE, is required in this appendix.
Appendix C: Mine Emergency Response Plan	This section covers information required by section 6.18.3 (2)(m) "*a Mine Emergency Response Plan as required by section 3.7.1 of this code*." The intent is not to reproduce the MERP in its entirety, but provide a summary of how emergencies, and emergency response will be managed in the autonomous operating area.
Appendix D: HSRC Gap Analysis	This section covers information required by section 6.18.3 (2)(n) "*an assessment of this code to identify any variances or additional project specific considerations that may be required*." The purpose of this section is to examine the Code, and identify any regulatory gaps, provisions that require interpretation or variances requirements (see section 1.2 of the Code) for the project and implementation. Gaps and the need for interpretation or variances may arise when new technologies are introduced that the regulations do not account for.

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
- backhoes
- excavators
- 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. 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 unique hazards that are not associated with conventional 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 (e.g., 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 proponent should consider questions such as:

- What are the expected safety and organizational 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:

- organizational 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 with regards to training and skills development. Furthermore, roles and skill requirements will change — new skills will be part of new organizational 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.

Organizational 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, and 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
- health and safety 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" human operated 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. Autonomous systems 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 (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 consider 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, but are not limited to:

- 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, windows, 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