GLOBAL MINING GUIDELINES GROUP

GMG

GUIDELINE FOR THE IMPLEMENTATION OF AUTONOMOUS SYSTEMS IN MINING

VERSION 2 - PUBLISHED 2024

AUTONOMOUS MINING WORKING GROUP

ABOUT GMG

The Global Mining Guidelines Group (GMG) is a network of representatives from mining companies, original equipment manufacturers (OEMs), original technology manufacturers (OTMs), research organizations and academics, consultants, regulators, and industry associations around the world who collaborate to tackle challenges facing our industry. GMG aims to accelerate the improvement of mining performance, safety, and sustainability by enabling the mining industry to collaborate and share expertise and lessons learned that result in the creation of guidelines, such as this one, that address common industry challenges.

Interested in participating or have feedback to share? GMG is an open platform, and everyone with interest and expertise in the subject matter covered can participate. Participants from GMG member companies have the opportunity to assume leadership roles. Please contact GMG at info@gmggroup.org for more information about participating or to provide feedback on this guideline.

GMG was formed out of the Surface Mining Association for Research and Technology (SMART) group as part of the Canadian Institute of Mining, Metallurgy and Petroleum (CIM) and with the support of other Global Mineral Professionals Alliance (GMPA) members.

GMG is an independent, industry-led organization.

ABOUT GMG GUIDELINES

GMG guidelines are peer-reviewed documents that describe good practices, advise on the implementation and adoption of new technologies, and/or develop industry alignment. They are the product of industry-wide collaboration based on experience and lessons learned. The guidance aims to help readers identify key considerations, good practices, and questions to ask on the topic covered and enable operational improvements for safe, sustainable, and productive mines.

Once the guideline is reviewed and accepted by the project group steering committee, working group members peer review and GMG members within the working group vote to approve draft documents prior to their approval by the GMG Board of Directors.

GMG guidelines are intended to provide general guidance only, recognizing that every situation will be different. Use of these guidelines is entirely voluntary and how they are applied is the responsibility of the user. These guidelines do not replace or alter standards or any other national, state, or local governmental statutes, laws, regulations, ordinances, or appropriate technical expertise and other requirements. While the guidelines are developed and reviewed by participants across the mining industry, they do not necessarily represent the views of all of the participating organizations and their accuracy and completeness are not guaranteed. See the disclaimer on p. ii for further detail.

RELATED GMG DOCUMENTS

While guidelines are the primary output of GMG Working Groups, GMG also produces documents that supplement guidelines. These include:

- White papers: Educational or foundational documents that provide broad knowledge and identify further reading on a topic that is new to or not well-understood in the industry. These documents are reviewed throughout development and editing but do not undergo the working group review and voting process as guidelines do. These projects can lead to guideline development.
- Reports: Outcomes of outreach, industry research, and events can be presented in reports and can inform the priorities for developing industry guidance.
- Landscapes: Reviews of ongoing related work by other organizations on a key topic. These aim to provide the industry with an idea of what exists and prevent duplication of effort.
- Case studies/other examples and tools: These documents aim to share knowledge and provide examples for the benefit of the broader industry and supplement GMG guidelines.

RELATIONSHIP TO STANDARDS

GMG guidelines are not standards and should not be treated as such. The guidelines can be used to assist the mining community with practices to improve their operations and/or implement new technologies. They aim to supplement, not replace, existing standards, regulations, and company policies. Guidelines can also be a first step in identifying common and successful practices and feed into standardization efforts. GMG does not develop standards but does participate in standardization efforts through partnerships.

CREDITS

The following organizations and individuals were involved in the preparation of these guidelines at various stages including content definition, content generation, and review. Please note that the guidelines do not necessarily represent the views of the organizations listed below.

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Implementation of Autonomous Systems V2

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DISCLAIMER

EXECUTIVE SUMMARY

GUIDELINE PURPOSE

The intent of this guideline is to provide high-level guidance, structured around the key areas of consideration, to various stakeholders to assist with the path forward for implementing autonomous systems in mining.

DEVELOPING A BUSINESS CASE

Implementation of autonomous systems requires a well-defined business case that addresses potential issues and opportunities. Key recommendations for the business case should include:

- Safety and risk considerations
- Value drivers
- Costs
- Strategy
- Business risk and potential problems

CHANGE MANAGEMENT CONSIDERATIONS

The implementation of autonomous systems often results in cultural challenges and changes. Change management needs can vary depending on brownfield or greenfield mines; however, there are similarities and best practices for both when managing the plan (i.e., reviewing and adjusting the plan throughout the process). The change management section of the guideline provides visuals for critical success factors and change management progression.

SAFETY AND RISK MANAGEMENT

Increasing levels of automation in mining can improve control and visibility to the mining process. Safety and risk management considerations should include:

- Risk identification and analysis
- Controls of the risks and hazards
- Monitoring and reviewing

Additionally, it is recommended that emergency response plans are created and include accident investigation and root cause analysis procedures as well as recovery methods after an emergency. This section provides a visual of hierarchical controls for autonomous systems in mining.

OPERATIONAL READINESS OF PEOPLE, PROCESSES, AND TECHNOLOGY

This section of the guideline provides guidance and best practices (i.e., for scheduling, monitoring, unplanned events) when planning for new processes while also reviewing and modifying those that already exist. While processes are a major aspect of implementation, the implementation of autonomous systems requires end users to install supporting technologies, which should be identified and included in the operational readiness planning and deployment processes.

DEPLOYMENT

This stage of the implementation process includes considerations around the installation, testing, and the transition period to the operations side. Since technologies have different maturity levels, there is a requirement to understand the increased level of integration, testing, and de-bugging during deployment.

TABLE OF CONTENTS

1. INTRODUCTION

1.1 PURPOSE

This guideline provides information on implementing autonomous systems in mining using current industry practices, common terms of reference, and guidance on justifying, planning, preparing, testing, and executing autonomous mining projects.

This implementation guideline provides high-level guidance to mining companies, OPSs, OTMs, third-party solution providers, system integrators, regulators, and other stakeholders, along with some recommendations and considerations that can help them to move forward with autonomous systems.

As different levels of autonomous system maturity exist across mining operations and requirements vary depending on the type of operation, this guideline aims to be broad enough to apply to a variety of situations while remaining useful as technologies advance. It serves as a first step and aims to assist companies implementing autonomous mining projects ranging from single autonomous machines and hybrid fleets to fully autonomous fleets.

Overall, this guideline aims to:

- Provide considerations for implementation
- Outline some of the risks and benefits of autonomous mining
- Offer a global and unified understanding of good practices for key stakeholders
- Enable future autonomous mining innovation with the aid of common practices
- Communicate that implementation can be facilitated through cooperation between involved parties, including mining companies, OPSs, OTMs, and system integrators

1.2 SCOPE

This guideline includes details on the application of autonomous and semi-autonomous systems across a broad spectrum of mining and quarry operations, including greenfield and brownfield operations, surface, and underground operations. These operations range from those dealing with in situ material, mining activities that contribute to material extraction, and more. Though this guideline is specific to mobile equipment operation, much of the guidance can be applied to fixed plant automation which is typically mature compared to mining equipment automation.

The scope of this guideline is intentionally broad so that it can apply to a variety of situations, business models, and processes while remaining relevant as the industry matures. As autonomous technologies are rapidly changing, this document will be frequently reviewed and updated.

1.2.1 Out of scope

The following is out of scope for this document:

- How to design an autonomous system
- Detailed guidance on interoperability
- Detailed guidance on specific technologies
- Detailed guidance on different jurisdictional requirements

1.2.2 Principles of Scope

This guideline does not replace safety requirements, regulations, or duty of care. It acknowledges that regulatory bodies and standards already exist and that they can influence the processes at various stages of the mine cycle. This guideline should be taken in the context of integration into the overall mining cycle value chain.

1.3 STAKEHOLDERS

As a document intended to provide a broad overview with some specific guidance based on industry experience, this guideline is intended for all stakeholders in projects implementing autonomous systems in mining. While each project will require a clear stakeholder mapping process, and this guideline does not replace the advice and support of qualified professionals, a non-exhaustive list of stakeholders to consider includes:

- Mining companies
- Management
- Information technology (IT)/Operational technology (OT)
- Operations and maintenance
- Engineering
- Corporate affairs
- Support services (e.g., safety and emergency response, human resources, risk management)
- OPSs and OTMs
- Internal and external subject matter experts (SMEs)
- Legal representatives
- Regulators
- Financial representatives
- Unions
- Neighbouring communities
- Educational facilities
- Governments
- Environmental approvals and compliance departments and agencies
- System integrators and consultants

1.4 SUMMARY OF CONTENTS

This guideline is structured around the key areas of consideration for those implementing autonomous systems. These topics are presented in sections covering:

- Development a business case
- Change management considerations
- Heath, safety, and risk management
- Regulatory engagement
- Operational readiness of people processes, and technology
- Deployment

Though arranged in broadly chronological order, many of these considerations will likely happen simultaneously and inform each other. The appendices provide additional contextual information, checklists, considerations, and examples.

1.5 INDUSTRY CONTEXT AND NEED

The mining industry is increasingly embracing automation as a safety and productivity enabler and as a critical factor in making future mining methods sustainable. Successfully implementing autonomous systems can improve safety, increase production efficiency, and lower maintenance costs. Implementing autonomous systems also presents new challenges, such as security and safety risks and workforce and workflow changes.

Since the first edition of this guideline was published in 2019, new innovations and options are making autonomous technologies increasingly available to a broader range of mining operations. While innovation and broader adoption can help make the industry safer and more sustainable, they also make the associated challenges more diverse.

While there are existing safety standards, such as ISO 17757 and the Western Australia Code of Practice for Safe Autonomous Mining (Government of Western Australia Department of Mines and Petroleum, Resources Safety, 2015; some sections in this guideline are adapted, with permission, from this source), mining stakeholders have identified a need for a global guideline that covers autonomous mining implementation more broadly. This guideline not only assists those implementing autonomous systems with maximizing the value of autonomous system implementation but also provides a framework for mitigating risks and managing change.

1.6 GMG CONTEXT

GMG's working groups have several complimentary projects underway and completed, including:

Guideline for Applying Functional Safety to Autonomous Systems in Mining

This guideline provides a common approach to applying functional safety to autonomous systems and references international standards within the context of the mining industry and its current maturity. It also describes clear expectations for the communication requirements to support change management and effective application.

System Safety for Autonomous Mining White Paper

This white paper provides a comprehensive view of the need for a system safety approach for those deploying and using autonomous systems in the mining industry. It aims to increase awareness of system safety and its benefits in delivering and maintaining safe and efficient autonomous systems.

Guideline for Applying System Safety in Autonomous Mining

This guideline provides guidance on applying system safety practices to autonomous systems in mining. It acts as both an informative document on system safety and a reference for reviewing end-user internal processes against industry best practices.

2. IMPLEMENTATION MATURITY AND APPROACHES

This section outlines a maturity model for autonomous mining and defines broad implementation approaches.

2.1 MATURITY MODEL

This subsection provides a high-level maturity model (Figure 1) for autonomous mining along with a description of each maturity level. The model assigns levels of autonomous system implementation and stages of maturity that reflect the overall operation's level of autonomy.

The levels assigned to mining equipment are based on those outlined in the SAE International (2018) taxonomy of driving automation terms and adapted to apply to mining automation using standard terminology from ISO 17757 (International Organization for Standardization, 2017a).

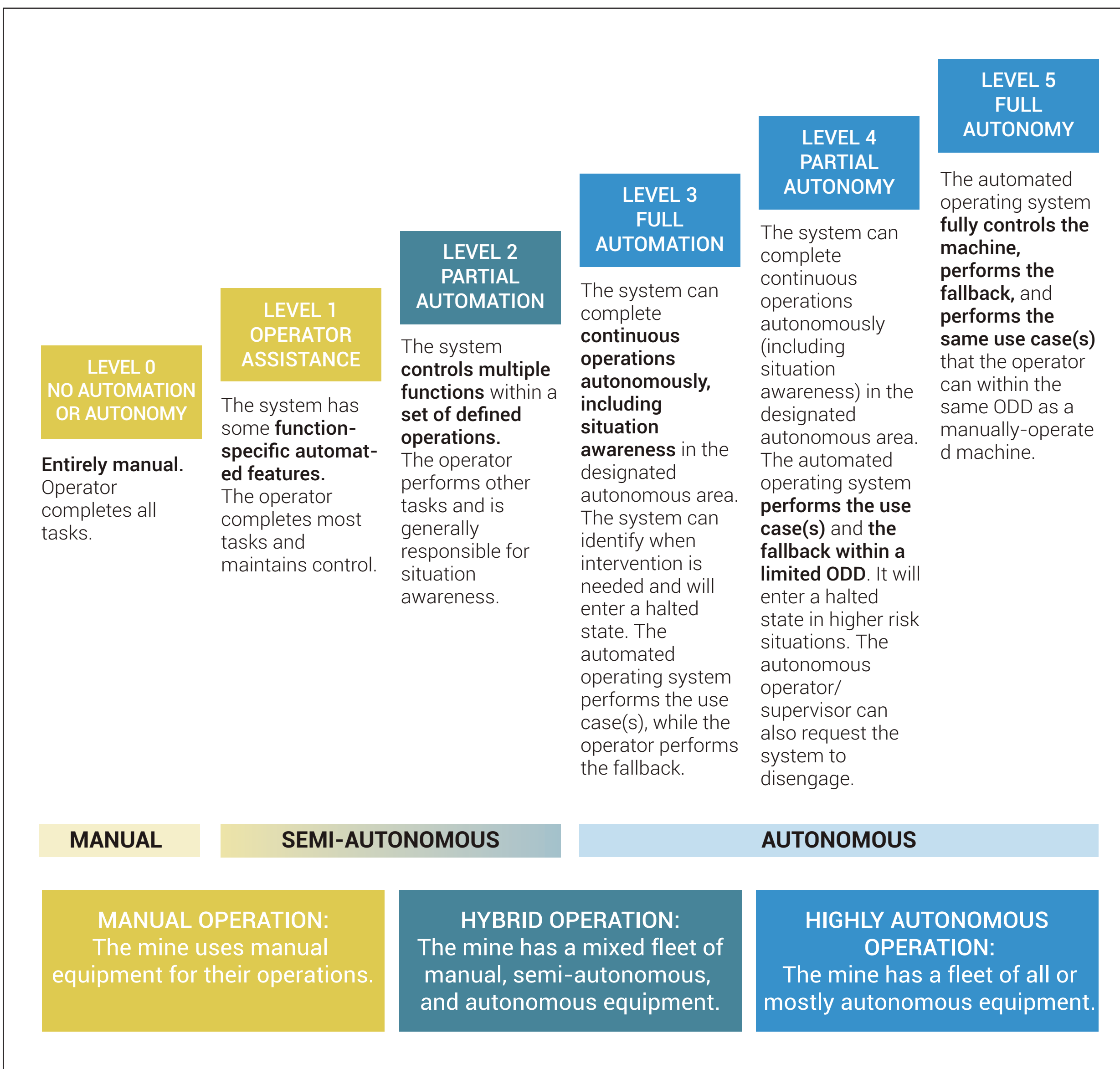

Figure 1: Mining Automation Maturity Model

The level at which a mining organization starts the implementation varies. For example, in existing traditional mines, it can be more difficult to jump levels, while for new projects, it is possible to choose the starting level and move forward from it.

2.2 IMPLEMENTATION APPROACHES

There are many methods mines can use to implement autonomous systems along with variations within these approaches based on each mine's situation. Possible implementation approaches for mines replacing old systems include:

Slow implementation: A lower risk but higher cost approach where implementation is extended over a long time with multiple checkpoints (e.g., proof of concept, trials, and multiple releases). This approach allows the mine to incorporate research and development efforts.

Phased implementation: A medium risk and medium cost approach where implementation is completed in paced stages with two or three checkpoints. This approach often involves implementing a mix of mature and agile solutions.

Fast implementation: A higher risk but lower cost approach where the new system completely replaces the old one. This approach often involves implementing mature commercial solutions.

The choice of approach depends on several factors. Figure 2 represents the level of regulatory advocacy, risk tolerance, autonomous operational maturity, cost pressure, schedule pressure, and how business stakeholder support can be used to determine the appropriate approach. As with any new process or system implementation, there could be a productivity dip during the implementation phase.

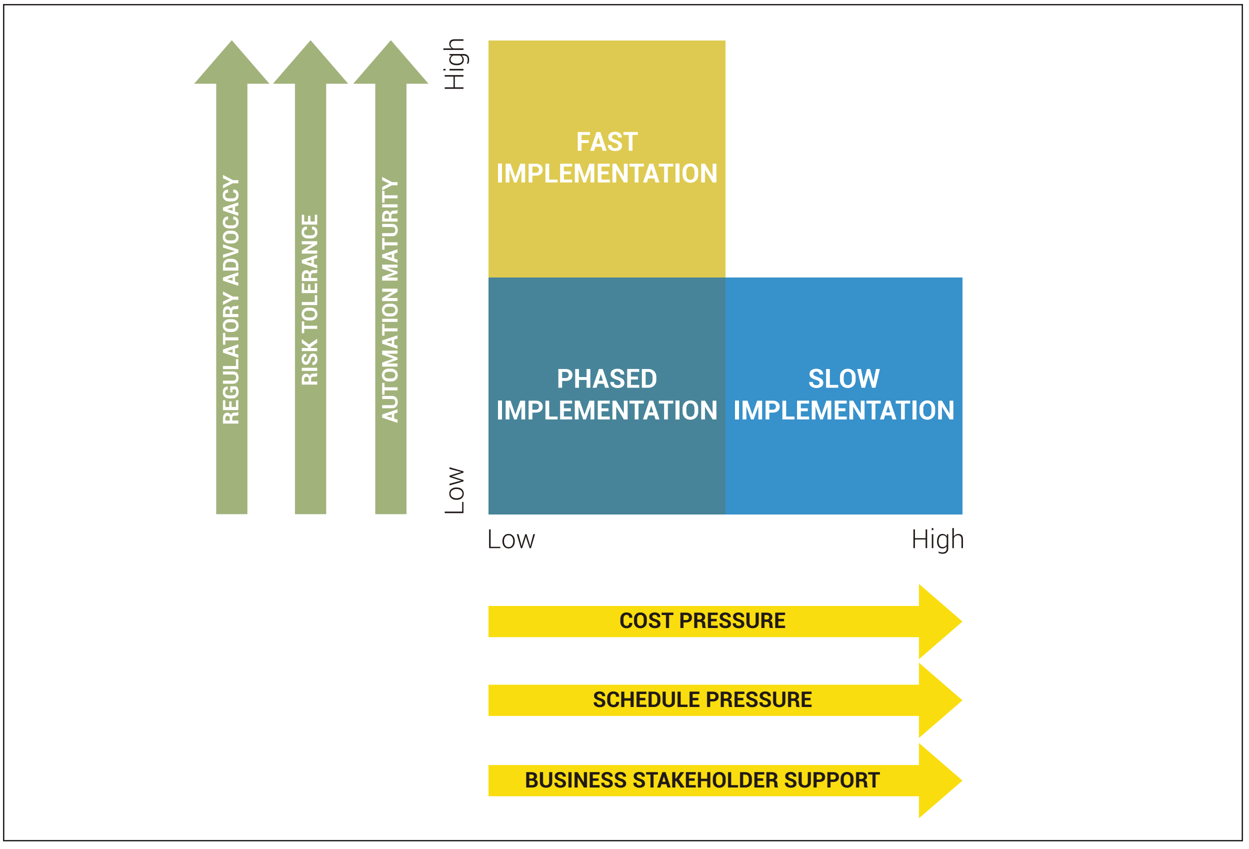

Figure 2: Factors Influencing the Choice of Implementation Approach

3. BUSINESS CASE

Before implementing autonomous systems, it is recommended to prepare a well-defined business case that addresses potential issues and opportunities that can affect desired outcomes. This section provides considerations to help produce accurate and complete business cases applicable to a company's situation.

A comparison between the current state, including constraints and issues, and the future state, including new capabilities and enablers, is the basis of the business case. The business case should address the following:

- Why automation is desirable
- What level of maturity to implement, including:
  - What components/processes/tasks to automate for hybrid operations
  - What components/processes/tasks will be more highly automated (e.g., equipment maturity levels four and five versus level three)
- How to approach implementation (slow implementation, phased implementation, and fast imeplementation, see Section 2.2)
- How long the transition will take (a realistic timeline between initial implementation and steady state operations)

The business case should also define financial, operational, and safety risks associated with automation, including the positive and negative externalities (i.e., the costs or benefits to third-parties). It should also define key performance indicators (KPIs) used to evaluate and measure success (see Section 11 on Benchmarking Performance and Value Realization). The business case aims to demonstrate net present value, demonstrating that the cost, questions, risks, and challenges warrant the benefits of the project. The business case should be developed according to company-specific financial evaluation requirements (ROI, NPV, IRR, etc.) and include a sensitivity analysis of key autonomous performance assumptions.

It is important to understand the business case's audience to achieve acceptance and gain operational ownership. Stakeholder participation is essential. During the business case development process, identify and include key stakeholders at all levels of the business, including operations, maintenance, health and safety executives, human resources, legal, supply, and technology. The introduction of an autonomous system should be promoted as a collective decision by all stakeholders. It is important to inform all stakeholders about their current problems, and how the solutions will enhance their overall efficiency and safety.

3.1 SAFETY AND RISK CONSIDERATIONS FOR THE BUSINESS CASE

Although autonomous systems can frequently benefit safety, they can also present new safety risks. While the business case typically considers all types of risks associated with the project, it is important to consider both the safety benefits and risks of automation.

The business case should address both safety benefits and hazards of the project and how they impact the organization and the implementation timelines.

Companies should allocate sufficient time and resources to confirm autonomous operations can start up safely and meet production expectations. See Section 5 for more specifics about health, safety, and risk management of autonomous systems.

3.2 VALUE DRIVERS

The business case should communicate the project's value drivers. For technology implementation projects, value drivers refer to the increased value that the new technology brings. Some value drivers can be easily measured (e.g., reduced downtime) or refer to a specific cost reduction (e.g., lower insurance rates), while others are more difficult to measure (e.g., improved safety).

Value drivers vary depending on many factors and co-dependent processes in mining operations. Companies considering the implementation of autonomous technology should consider the upside and downside risks, including the likelihood of realizing benefits indicated by the business case, by including a sensitivity analysis of the baseline assumptions as part of the evaluation.

See Section 3.3.3 on Potential Benefits, Value Drivers, and Costs for a list of key drivers for implementing autonomous systems.

3.3 COSTS

Implementing autonomous systems comes with both upfront and ongoing costs that should be included in the business case. The following subsections provide some key examples of costs and cost categories to consider.

It is also important to determine the appropriate balance between capital and operating expenses, consider the return on investment, and consider financial opportunities, such as tax deductions or grants.

3.3.1 Implementation Costs

The business case should consider the costs associated with autonomous system implementation. These costs include, but are not limited to:

New technology and equipment: Costs associated with purchasing and implementing autonomous systems. For example, equipment and parts, monitoring systems, and integration of systems. There might also be different costs associated with different types of systems implemented simultaneously, or if choosing between adopting new systems and adding to an existing one.

Supporting infrastructure: Costs to adapt the infrastructure to support the new systems. For example, changes in road structure, site improvements, and new or adapted supporting infrastructure such as IT and communications infrastructure.

Personnel: Upfront costs to hire and train new personnel. For example, training courses on- or off-site, recruitment of experts, and costs of consultants. This can include costs for training tools, such as simulators. During the time it takes to ramp-up production, costs for additional operational staff should be considered.

Loss in productivity during ramp-up and deployment: Loss in productivity during ramp-up and deployment can greatly impact a business, and understanding these impacts plays a crucial role in achieving the estimated production levels.

3.3.2 Full Lifecycle Costs

Implementing autonomous systems involves ongoing, full lifecycle costs that should also be considered as part of the business case. Choices made before implementation can have a significant impact on costs throughout the life of the mine.

Factors that can influence decision-making on the models and approaches to these costs include the life of the mine, size of the operation, type of implementation, and whether the mine is a greenfield or brownfield. The economic viability of the mine should also be considered as uncertainties in performance assumptions can impact the viability.

3.3.2.1 Selection of solutions and ownership models

The selection of solutions and models should consider the following factors:

Ownership and maturity: By purchasing a system, the operator is committing to a technological partnership with the vendor and deprecation pathway that will involve significant sustaining capital over the system lifespan.

Commercial models: Emerging commercial models offer opportunities and challenges, such as lease or subscription models that typically include software maintenance and updates. Each OPS will have a different model or offer different options. Partnership-based models could help with the transition and addressing ownership challenges; however these models could also result in long-term dependencies.

Training models: Consider the holistic costs associated with an effective and sustainable training model that not only covers initial and ongoing training to continually optimize skills including keeping up with the regular version updates.

Technology licensing: Different licensing frameworks will have different benefits and risks affecting total cost of ownership.

Emerging technological solutions: Some technical solutions such as automation as a service are emerging from other industries. While these solutions can be helpful and innovative, they might not be developed with the mine environment in mind.

Interoperability: Consider how long-term equipment and purchase options might be affected by interoperability challenges.

3.3.2.2 Expected ongoing post-implementation costs

Full lifecycle costs of autonomous systems include costs that occur after implementation. These post-implementation costs can include the following:

Local sourcing and support: This includes ongoing training, recruitment, and consulting costs.

Ongoing upgrades and technical advancement: Obsolescence through technological advancement can be rapid, especially early in the process. The hard costs (e.g., reduction in production due to updates), support costs (e.g., new technologies and configurations) and training costs associated with improvements and changes in technology over time can be difficult to estimate. New features and upgrades can require additional training, process, and hardware changes.

Maintenance and replacement strategies: Retrofitting can cost less than replacement. Changes in maintenance processes should also be considered. In some cases, these changes can be positive, for example if the new equipment requires less maintenance than existing equipment.

Outages: Costs of lost production in case of outages.

3.3.3 Potential Benefits, Value Drivers, and Costs

Table 1 describes the potential benefits, value drivers, and costs that should be considered in the business case. It can also serve as a starting point for financial analysis and communications considerations.

This list is not exhaustive and does not apply to every situation. Benefits and value drivers are often interdependent. For example, insufficient data analytics have the potential to reduce situation awareness with autonomous systems because the technologies that improve situation awareness (e.g., predictive maintenance) depend on their environment.

Table 1: Potential Benefits, Value Drivers, and Costs Associated with Implementing Autonomous Systems

Potential Benefits	Value Drivers	Costs
Workforce Automation can change the size and shape of the workforce and alter specific roles, responsibilities, and skill requirements		
• More flexible locations possible with remote operation • Improved work/life balance • Improved diversity and inclusion (e.g., opportunity to hire people with disabilities or to implement more family-oriented strategies) • Larger resource pool (new worker demographics might be interested in mining if jobs require less exposure to environmental elements)	• Reduced personnel support costs for fly-in, fly-out/first-in, first-out operations (accommodations, travel) • Reduced employee turnover (related to improved conditions, more flexible locations, and improved work/life balance) • Minimize the costs/effects of absenteeism • Reduced overtime	• Recruiting and offering incentives to attract and retain skilled labour (because of the current skill gap) • Labour displacement, retraining and upskilling current employees, and training new recruits • Change management (e.g., consultants, engagement) • Government, regulator, or self-imposed community commitments • Increased employee turnover when autonomous systems are announced
Health and Safety Automation introduces health and safety challenges and hazards, but it also reduces many of those associated with manned operations		
• Distancing operator from operation can lower exposure to health and operational hazards • Better overall quality of life for workers • Cleaner, less dangerous operating conditions (physical and mental health benefits)	• Lower health and safety costs (e.g., those associated with work-related incidents) • Lower fatigue management costs • Lower lost time hours (from health and safety concerns) • Lower accident repair costs • Lower health- and safety-related insurance rates (lower human involvement and lower variability in machine operation)	• Implementing new health and safety management procedures • New physical infrastructure for physical separation, identifying autonomous areas, access points, and control rooms • Implementing new hazard controls • Implementing layers of protection
Processes and Technology Overall, autonomous systems change how mines operate. They can facilitate optimized mine design and consistent processes and can help minimize waste and improve overall planning processes These changes can translate directly and indirectly to increased OEE and productivity, reduced process variability, and long-term savings. All changes need to be identified and developed in a timely manner to maximize the success of introducing automation.		
• More efficient mine design and processes (e.g., more efficient scheduling and traffic management) • Consistent performance, leading to standardization and repeatability of operating practices • New kinds of mining methods and equipment • Preventive or predictive maintenance can lead to longer machine and component life	• Long-term savings on mine design and structure • Reduced productivity loss from process variability • Decreased planned operator and equipment downtime (e.g., shift time delay, mealtime) • Reduced inter- and intra-cycle idle time • Reduced non-value-added but necessary time (e.g., refueling and maintenance stops)	• New communications and digital infrastructure (e.g., for remote operations) • Time and resources for implementing design, scheduling, and safety management changes • Required improvements to foundational technologies (e.g., radio, Wi-Fi®, LTE® network positioning) and geospatial technologies

Table 1: Potential Benefits, Value Drivers, and Costs Associated with Implementing Autonomous Systems (continued)

• Increased measurement and control are often possible, increasing situation awareness • Increased system integration • Mining process will become closer to a continuous one • Better coordination with downstream processes	• Reduced costs associated with equipment abuse/misuse and human-caused damage • Optimized processes and increased communications capability can reduce wasted/inefficient time or unplanned downtime (e.g., shovel hang time, bunching, traffic conflicts, misdirected loads) • Defer capital investment (by moving more material with the same equipment and extending the life of the equipment from autonomous operation versus manned operation. Improved efficiencies can also reduce the need to extend fleet size.) • Lower machine maintenance costs (condition-based or predictive maintenance through instrumentation and monitoring versus a scheduled maintenance regime) • Increase end-of-life asset (asset management to specification and through-life asset history capture will increase disposal value)	• Constructing the physical environment for autonomy (roads, stockpile spaces, bypass and overpass roads, control rooms) • Digital infrastructure and facilities (hardware, cloud provisioning, configuration, and commissioning) • Technology development and maintenance • Required incremental network improvements • Required improvements to upstream and downstream equipment and processes • Hardware or retrofit costs per machine • Cost of handover • Loss in productivity during ramp-up and deployment • Equipment insurance • Upfront and ongoing licence costs • IT infrastructure and/or cloud platform maintenance and support, other technical support • Ongoing subscriptions to usage-based service contracts • Sensor changeouts • Maintaining the physical infrastructure • Obsolescence • Adjustments to standard operating systems • Road maintenance

3.4 STRATEGIC FIT

It is important to ask whether autonomous mining is an explicit corporate strategic goal. The lack of a strategic fit can derail the business case from the corporate standpoint. The organization's leaders should understand the current state to assess whether the organizational change and the costs associated with adopting the systems align with their goals and is strategically viable. There are operations where autonomous systems are not viable at all or where a fully automated operation is not viable, and a hybrid implementation is preferable.

Table 2 provides examples of situations where there can be a strong strategic fit and where the strategic fit might need more consideration. The operation's current scope and autonomous operational maturity and the organization's current capacity and capability are principal factors. For example, automation can compound poor reliability and poor availability if it is not handled correctly.

Individual mines should make decisions concerning technologies and components based on the appropriateness to their specific operation. Autonomous technologies and components vary in maturity (Section 2.2) and applications. The strategic fit discerns which maturity level(s), implementation approach, and specific applications are most appropriate.

Table 2: Examples of Considerations for Assessing Strategic Fit for Automation

Strong Strategic Fit	Strategic Fit May Need More Consideration
• Long life and large scale • Labour constraints, high turnover • Highly efficient operation • New automation-ready equipment • Remote, challenging logistics • High altitude, difficult environment • Greenfield projects • Highly variable commodities • Mature health and safety • High change acceptance • High-cost labour market • Sustainable communications infrastructure (e.g., good capacity and supportability)	• Short life, small, intermittent • Social license requires employment • Factors that can affect efficiency • Old equipment with short remaining mine life • Low-quality planning • Constraints in upstream or downstream processes • Immature project delivery capability • Local community with high capability in existing technologies • Low-cost labour market • Requirement of many communications infrastructure improvements • New environments

The outcome of the strategy can also inform the development of new business models. New models can require new plans, such as lease versus buy or mining as a service—where a third-party to the OPS and mining company offers autonomous mining as a service to the mining company by assembling a full system offering composed of elements that OPSs provide. Some understanding can be gleaned from other industries and generic packages makes or models.

3.5 BUSINESS RISKS AND POTENTIAL PROBLEMS

The business case should also include the risks of the organization not being able to achieve the change. Potential risks to equipment include equipment and/or sensor damage, production impacts during hardware and software upgrades, obsolescence, and long-term OPS commitments. There are also risks that operations can have delays related to growing pains, workforce acceptance, and changes to mine plans, increasing decision risk for future capital investments.

Implementation challenges, cybersecurity, integration and dependency issues between platforms, and ongoing support from technology partners, suppliers and the workforce are risks that should also be considered.

3.6 OTHER CONSIDERATIONS

In addition to the above sections of the business case, there are other areas of consideration. These include identifying realistic and specific scenarios that the mining company assumes will happen, determining the estimated timeline for implementing autonomous systems and following a proper stage gate evaluation process, and analyzing strengths and weaknesses of the business/trade environment.

It is also important to identify alternatives to autonomous systems and alternative ways of implementing autonomous systems. For example, if the business case is for a highly autonomous operations, an alternate scenario can be included for hybrid operations,

4. CHANGE MANAGEMENT

Implementing autonomous systems is an organizational and cultural change that should be a primary consideration throughout the process. Change management aims to achieve a situation where stakeholders trust that the change is beneficial, support the implementation process, and understand the benefits and risks of the new system.

Change management processes vary and depend on:

- Whether it is a greenfield or brownfield site
- The type of activity
- The planned level of autonomous maturity
- The components to be automated
- The implementation approach
- The internal capabilities of the organization

Change management processes also differ for underground mining, with alternate vendors and types of equipment to consider. Processes need to consider the system of the mine, as well as the OPS. This section covers the topic of change management broadly and provides some suggestions for how to approach it based on industry experience. While this guideline focuses on implementation, change management is done throughout the whole lifecycle.

4.1 CHANGE MANAGEMENT PLAN

For the implementation project to realize the benefits associated with automation, it is recommended that a change management plan is executed as part of the implementation process. It should also be reviewed and adjusted regularly throughout implementation to incorporate unexpected situations or changes.

Some recommendations for developing a change management plan for implementing autonomous systems are listed below in Sections 4.1.1 and 4.1.2. These considerations are based on what has worked for some operations and the approach will vary for each situation. Established methodologies for change management can help guide the approach.

When undergoing change management from a people-perspective, it is recommended to clearly articulate the vision and purpose of implementing autonomous operations and involve employees early in the process to foster ownership and early acceptance of the autonomous operations. Having a clear project charter aligned with this vision, along with defined implementation responsibilities and clear measurements of success can help manage expectations and keep projects on course.

4.1.1 Considerations for Greenfield and Brownfield Operations

Figure 3 highlights some considerations for what should be included in a change management plan, regardless of a greenfield or brownfield operation. Additional considerations that only apply to brownfield operations are listed in the following section.

Establish a Clear Vision and Strategy

- A clearly defined vision and goals of the main changes required to implement autonomous systems.
- A comprehensive strategy that aligns with the organization's long-term objectives and incorporates the benefits of autonomous technologies.
- The risks and benefits.
- Contingency plans for managing changes that don't match the expected outcome.
- Legal or jurisdictional constraints and requirements.

Stakeholder Engagement and Communication

- Stakeholder engagement plans from the early stages.
- Methods for identifying how stakeholders are affected by the planned changes and incorporate their feedback into the plan.
- Communication channels to provide updates, address concerns, and gather feedback.
- People and teams responsible for analyzing data, ideas, and interpretations brought forward from multiple champions at different organizational levels.
- Tailored communication to different stakeholder groups, highlighting the advantages, risks, and mitigation measures associated with autonomous systems.
- Communication channels (e.g., email, engagement sessions, social media, and posters).
- Pathways for those affected to make positive contributions

Workforce Planning and Skill Development

- Assessment of the required workforce capabilities and plan for the necessary skills required for operating and maintaining autonomous systems.
- A workforce plan that includes recruitment, training, and upskilling strategies.
- Tailored role-based training programs to equip employees with the skills required to operate, maintain, and troubleshoot the systems.
- Opportunities for upskilling and career development.

Change Leadership and Culture

- Change leaders who can champion the implementation and provide clear direction.
- Mechanisms for knowledge sharing and learning among employees to foster acceptance and readiness for change.

Infrastructure and Resource Planning

- Infrastructure requirements for the deployment of autonomous systems.
- Confirmation of adequate resources, such as power supply, connectivity, and maintenance facilities, are planned and implemented accordingly.

Foster Continuous Improvement

- Mechanisms for ongoing monitoring, evaluation, and improvement of the implemented changes.
- Engagement with employees and stakeholders to gather feedback and make necessary adjustments.
- Continuous learning and improvement strategies to confirm the sustained success of autonomous systems.

Figure 3: Change Management Considerations for Mine Operations

4.1.2 Additional Considerations for Brownfield Operations

In addition to the considerations for change management in Figure 3, there are additional considerations that only apply to brownfield operations, highlighted in Figure 4.

Assess Current State and Readiness	- A comprehensive assessment of the existing operations, processes, and workforce capabilities. - Identification of areas where autonomous systems can be integrated and understand the potential impact on the workforce. - Evaluation of the readiness and openness of employees to embrace change.
Employee Engagement and Empowerment	- Establishment of employees to be champions for the change to foster a sense of ownership and empowerment. Champions should not only include those who tend to be open to new technology, but also those who might not typically champion new technologies or processes. - Communications highlighting the reasons for implementing autonomous systems and how they can enhance safety, productivity, and job satisfaction. - Mechanisms for employee feedback, suggestions, and participation in pilot programs to drive acceptance and adoption.
Pilots and Demonstrations	- Plans for pilot programs or demonstrations of autonomous systems in specific areas of the brownfield site. - Plans for allowing employees to observe the benefits firsthand, gain confidence in the new technologies, and provide valuable feedback. - Success stories and lessons learned from. - For phased implementations, achievements required to advance to the next phase of implementation and transition plans.
Readiness	- Existing issues that autonomous systems could exacerbate. For example, an inefficient communications infrastructure to support the technology. - The implementation timeframe and approach and any risks associated. For example, a staged approach could require different procedures for autonomous and manual operations. - A training approach, including keeping up with ongoing changes made by OTM to evolve the autonomous systems.
On-site Engagement	- Stakeholder analysis that includes all affected groups. - Pathways for those affected to make positive contributions.
Communications	- A clear and consistent message covering what the changes are, why they are important for the business, when they will happen, who they will affect, and how they will be implemented. - Communication strategy for messaging stakeholders at the appropriate time, explaining why the change is important for them, and manage their expectations. - Methods for addressing questions and concerns from front-line staff and supervisors. - Highlight that change management is dynamic and continuous.

Figure 4: Change Management Considerations for Brownfield Operations

4.2 CRITICAL SUCCESS FACTORS

The change management plan should identify critical success factors (the areas of the project that are essential for success). These should be measured and monitored throughout the process. Table 3 includes critical success factors and how they can be measured.

Table 3: Critical Success Factors for Change Management

Critical Success Factors	What to Measure	Examples of How to Measure
Stakeholder Satisfaction	Measure the level of satisfaction and support among stakeholders, including employees, local communities, regulators, and project partners.	Conduct surveys, interviews, or focus groups to gather feedback and assess stakeholder perception of the changes.
Adoption and Acceptance	Evaluate the degree to which employees have embraced and adopted the autonomous systems.	Track the usage rates of the new technologies using the data coming from the systems. For example, monitor and track the login/logout details to understand the extent to which employees are incorporating the systems into their daily work.
Safety Performance	Measure key safety indicators such as accident rates, near-miss incidents, and compliance with safety protocols before and after the implementation of autonomous technologies.	Through monitoring safety protocols via safety management systems used on-site, risk registers, hazard identification/controls, incident/near-misses reporting, injury-rates, safety inspections and audits, benchmarking against industry benchmarks for safety statistics, incident rates etc. as defined within the business case value drivers and associated KPIs.
Productivity and Efficiency	Measure the impact of autonomous systems on productivity and operational efficiency by comparing performance indicators before and after the implementation to determine the effectiveness of the changes.	Tracking metrics such as production output, equipment uptime, equipment availability, cycle times, and overall equipment effectiveness (OEE) etc. as defined within the business case value drivers and associated KPIs.
Cost Reduction (if applicable)	Measure the financial impact of autonomous systems in terms of cost reduction (if applicable). Compare these costs with the pre-implementation baseline to quantify the benefits of the changes.	Track savings in operational costs, maintenance expenses, fuel consumption, labor costs, etc. as defined in the business case.
Employee Skills and Competencies	Assess the development and enhancement of employee skills and competencies resulting from the change management process	Monitor the progress of training programs, track employee certifications/skills, and evaluate the acquisition of new skills relevant to autonomous systems. Monitor the variability of workforce performance at the beginning phase and post-implementation phase to measure improvements.
Continuous Improvement and Innovation	Evaluate the organization's ability to foster continuous improvement and innovation in the context of autonomous mining.	Measure the number of employee suggestions, process improvements, or technological advancements that have emerged because of the change management process.

4.3 CHANGE MANAGEMENT PROGRESSION

Change management considerations typically evolve as the project progresses through project preparation, implementation, and steady state (Figure 5). Three major aspects of change need to be considered at all stages; people, processes, and technology. This progression will typically happen in coordination with operational readiness assessments and planning, risk management, project controls, and management reporting. These considerations are discussed in more detail in other sections of this guideline.

	PEOPLE	PROCESSES	TECHNOLOGY	ONGOING PROCESSES
PROJECT PREPARATION *Design*	- Skill inventory and gap assessment - Communicate impact of change to workers - Develop skills pipeline - Involve employee "champions" - Assign responsibility - Stakeholder identification, including formal and informal stakeholders - Engage using a community plan or strategy - Engage with regulators	- Consider "as-is" and "to-be" states - Identify what is to happen - Develop/Update documentation and standards Systemic Withdrawl Plans (SWP) and Standard Operating Procedures (SOP) - Develop an effective training program with a focus on minimizing impact to production - Frame metrics and key performance indicators (KPIs) - Develop the supply chain - Process impact analysis	- OTM support - Blended Learning Technologies to be used for training (such as digital, simulation-based technologies)	- Operational readiness assessment and planning - Risk assessments - Risk planning - Project controls - Management reporting - Workforce management
IMPLEMENTATION / EARLY OPERATION *Implement*	- Workforce selection - Implement training / upskilling pipeline - Keep front-line decision-makers onboard during the implementation period - Listen to stakeholders' concerns and respond transparently - Manage skills - Maintain strong senior management - Communicate value for stakeholders and senior management	- Establish process discipline - Deliver on KPIs - Plan-Do-Check-Act - Deliver on business drivers - Process planning - Training to address skills decay and to keep up with ongoing changes to the system	- Manage transition from OTM to in-house setup - Maintenance planning - Keep up with ongoing changes to the systems	
MATURE / STEADY STATE *Sustain*	- Mature training plan and competency - Competency assessment - Progression plans for workforce - Optimize workforce skills	- Manage continuing change, new steady state - Carry out commitments - Standard reports by exception - Benchmarking against global best practices - Continuous Improvement	- Software / system interface - In-house expertise running the systems - Target product enhancements with OTM to better address new operational opportunities	

Move into continuous improvement lifecycle, adapt to ongoing change
Repeat stages as more systems are added on the journey from hybrid to fully autonomous
May have multiple phases ongoing at once for different implementations

Figure 5: Change Management Progression

5. SAFETY AND RISK MANAGEMENT

Increasing the level of automation in mines can bring more control and visibility to the overall mining process. Autonomous equipment and systems can reduce requirements for extensive human presence in hazardous operational areas, enhancing working conditions for various personnel. From a health and safety perspective, autonomous systems can mitigate or even remove some of the hazards related to traditional manual operations.

However, even in autonomous operations, humans remain an essential part of operations. This means that implementing autonomous equipment can introduce new failure modes and hazards that are not yet fully understood. The integration of advanced software-driven functionalities increases the complexity of the equipment. Machines are not just standalone entities; they form interconnected systems, potentially involving multiple suppliers. As a result, human work in the mines requires a special focus on health and safety management when implementing autonomous.

This section provides general guidance on developing health and safety management plans in an autonomous mining environment. Safety should be considered a standalone part of the implementation plan to provide it with the necessary focus and included in other plans as necessary. It should also be integrated with other parts of the implementation to ensure effective ownership by all stakeholders. Those planning to implement autonomous systems should address all safety requirements as early as possible in the deployment lifecycle and establish a safety culture applicable to autonomous mining.

Safety requirements for autonomous systems vary. Broadly, they can be considered in the following categories:

- Environmental health and safety (e.g., weather, heat, ventilation, altitude)
- Infrastructure (e.g., buildings, roads, pipelines, electrical installations)
- Equipment and machinery
- System configuration and reliability
- People (e.g., workforce, site visitors) and the community
- Processes
- Cybersecurity and data privacy

System safety requirements for autonomous systems are described in more detail in the **GMG System Safety for Autonomous Mining (2021)** white paper, which provides a comprehensive view of the need for a system safety approach.

Because health and safety processes change over time, effective change management processes (Section 4) are necessary to ensure that the processes, workforce, and stakeholders are ready to meet new health and safety requirements.

Effectively managing the health and safety risks associated with implementing and operating autonomous systems requires input from diverse operational groups, including, but not limited to:

- Operations and mintenance personnel at the mine site (including mechanical and technical maintenance)
- Researchers and regulators
- Design engineers and mine planners
- Project managers, site managers, mine managers, and team leaders
- IT and infrastructure personnel
- Health and safety representatives, and emergency response personnel
- Manufacturers, distributors, service providers, and system integrators

Those implementing autonomous systems need to delineate how roles and responsibilities change from the previous system. It is recommended to create a responsibility assignment matrix (such as RACI "responsible, accountable, consulted, informed"). These should specify the owner of the information for implementing the autonomous solution of choice and what that provider is expected to submit. This matrix would include OPSs, operators, consultants, third-party technology providers, and regulators.

The system should comply with all relevant regulations and safety standards. The new system should also gain approval from authorities at all stages, ideally undergoing a peer-review process. It is recommended a list of established standards be compiled and classified, based on ownership, purpose, and applicability. The list should include site and region specific nuances. See Section 12.1 for a list of relevant international standards.

Verification that the autonomous system meets functional safety requirements and operational design domain requirements is necessary. All controls should be verified and audited, emergency response plans in place, and the mine site equipped with the information needed to use the systems safely.

5.1 RISK MANAGEMENT

The health and safety risk management process involves identifying the system's functional safety requirements and identifying and planning to manage potential risks and hazards. It is recommended to create a risk evaluation matrix that covers incident management, human factors, and change management planning. Deployment scheduling, site preparation, communications, contingency, vendor partner selection, execution, support and handover, and business continuity should have separate plans that are part of the implementation. Plans will vary to accommodate different mine types and operational and equipment maturity.

Those with knowledge of autonomous system design, the mine site and plans, engineering, commissioning, operation, and maintenance should be involved in assessing and minimizing associated risks during the operational lifecycle.

5.1.1 Risk Identification

It is important to identify how using autonomous technology changes established safety systems and any risks and hazards associated with those changes (see Appendix B.1 for a list of hazard identification systems and processes). This process might involve identifying safety functionality and operational process limitations of the autonomous system. When identifying autonomous mining health and safety risks, people, equipment, environment, and cybersecurity should all be considered.

5.1.2 Risk Analysis

At the risk analysis stage, mine sites should determine the nature of the hazard and the risk level, considering the likelihood of an incident, potential severity of injury or damage, and ability to identify an incident. Those assessing the risk should have the necessary information, training, knowledge, and experience of the following:

- Operational environment (e.g., scale, complexity, physical environment of mining activities)
- Operational processes (e.g., maintenance systems, work practices, interaction, separation)
- Maintenance risks
- Autonomous systems (e.g., functionality, functional safety requirements, safety features)
- Site continuity plan
- Corporate risk guidelines

5.1.3 Controls for Risk and Hazard Management

Once health and safety risks and hazards have been identified and analyzed, it is important to put appropriate controls in place to prevent and/or reduce their risk and minimize potential consequences (see Appendix B.2 for specific examples). Controls should be prioritized per the Hierarchy of Controls (Figure 6), with a preference for the most effective controls, only employing less effective controls where more effective ones are not possible.

When determining how to implement various controls, mine sites should confirm that they provide sufficient information for decision-making. Though the systems are autonomous, human decisions are still required to overcome exception states for systems at all maturity levels. The system should be designed such that alerts and alarms are prioritized with humans in mind, considering urgency, and avoiding alarm fatigue from excessive notifications.

MOST EFFECTIVE

ELIMINATION:
Controls that eliminate or remove the hazard

- Safe design, construction, and installation (according to specifications and design parameters, in compliance with safety regulations)
- Procedures for ceasing operations to avoid risk (e.g., adverse weather)
- Definition of safe states and failure modes incorporated into the design
- Digital infrastructure design incorporates cybersecurity measures, layers of protection
- Use systems and equipment that fail to a safe state and that have been sufficiently tested and validated

SUBSTITUTION:
Controls that replace or provide alternatives to the hazard

- Plans for changing processes/equipment used to accommodate environmental factors: modified routes, modified speeds, alternate activities, alternate equipment, etc.
- Digital, network and communications redundancy, layers of protection

ENGINEERING CONTROLS:
Controls that isolate people from hazards

- Separating autonomous fleet and systems from manned operations wherever possible, or providing sufficient barriers
- Set up a clearly isolated autonomous area
- Provide alternative access for personnel not directly involved in autonomous activity
- Management for human and machine interaction when necessary (recovery options, refueling)

ADMINISTRATIVE CONTROLS:
Controls for work practices preventing hazards

- Certain functions restricted to authorized personnel (includes password protection for electronic security)
- Competency-based training and assessment of workers
- Supervision and management oversight
- Operational and maintenance safe work practices and safety training for all personnel
- Plans for training, access control, and inductions for occasional mine visitors
- Reporting and communication tools and policies for potential hazardous conditions/situations

LEAST EFFECTIVE

Figure 6: Hierarchy of Controls for Autonomous Systems in Mining (examples are non-exhaustive)

5.1.4 Monitoring and Review

A monitoring and review program should be implemented that includes control audits, verification, and validation to confirm that controls are in place and effectively maintained. Responsibilities and accountabilities should be clearly defined and assigned as part of the mine site's validation process and may include independent auditing, in cooperation with the OPS, OTM, or other suppliers.

The findings should be used to confirm that recommendations from previous reviews have been actioned and that any incidents or issues have had appropriate responses. They should also confirm recommendations for continuous improvement and recommend any necessary operational or system design modifications, which are documented and managed through a formal change management process.

Mine sites should also consider that autonomous systems can create a greater dependency on instrumentation to report equipment health and incidents. Monitoring and reviews should therefore consider how to balance information (e.g., machine health data, KPIs) and physical observation (e.g., observing environmental conditions, observing the health of the machine during maintenance). Monitoring, review, and auditing should also consider that the autonomous system and supporting systems are being implemented as designed.

Health and safety management processes to respond to accidents and incidents should be reviewed and updated as required to ensure that where an incident relates to automation, the appropriate technical resources are involved. This includes both capturing and interpreting any data logged by the systems, and the correct application and response of safety related functions by the system.

5.2 EMERGENCY MANAGEMENT PLANNING

Emergency management involves understanding the likelihood and potential consequences of an emergency event and being prepared to respond effectively in order to minimize effects and recover promptly. Effective emergency management identifies all foreseeable emergency scenarios and develops emergency response plans for each so that there is a comprehensive and coordinated response if they occur. These plans should also consider that safe access and effective communication can be difficult to establish and maintain in an emergency. While autonomous systems have some unique emergency response considerations, emergency response planning for autonomous operations should be integrated with the overall emergency response planning for the mine.

The mine site should establish the following:

- An emergency response plan
- Accident investigation and root cause analysis procedures
- Recovery methods after an emergency

All emergency response personnel should understand their responsibilities before entering autonomous areas, including an appreciation of functional control basis and points of accountability for on-site autonomous control systems. Emergency response access to autonomous areas can be supported by an autonomous mining team escort or positive confirmation that all autonomous equipment has been remotely stopped.

Emergency response plans should be regularly tested as per local regulatory requirements to confirm that they are effective with both simulated tests and emergency response drills involving all on-site personnel. The drills can be used to evaluate how people respond, and debriefs should be conducted after an emergency or drill to help identify potential improvements to the emergency response plan for the mine and surrounding areas.

6. REGULATIONS

Regulatory frameworks can lag the implementation of autonomous and semi-autonomous systems on the mine site. Existing regulatory and legislative frameworks might not address autonomous and semi-autonomous systems, although most rely on comprehensive risk management systems or the mine operator having a safe system of work, based on the following:

- Fit-for-purpose equipment
- Equipment being operated within OPS parameters
- Equipment maintained based on OPS recommendations
- Trained and competent workers

Additionally, existing health and safety requirements written for manually operated equipment can be inconsistent with the functionality of autonomous systems, and can have an unintended impact on how those systems can be used. Engagement with the appropriate regulatory bodies and evaluation of the regulatory environment should be done early to understand requirements or gaps in the regulatory framework and establish a plan for the project.

To accommodate autonomous systems, mines should try to work with regulators to explore exemptions or modernization of the regulatory framework. If change is not possible, mines might find solutions within the existing regulatory framework. Additional or different regulations might apply to underground mines than to surface mines.

Those implementing autonomous systems should be prepared to discuss with regulators how the project fits into the existing regulatory framework. Though many current regulations were written without consideration for autonomous systems, a person or team should be able to grasp the sense of an existing regulation by considering what it intends to accomplish and seeking to meet or exceed that expectation. Project leads should also be cognizant of any regulatory requirements not specific to mining that may be applicable to the project. For example, radio frequency approvals or data protection requirements (e.g., Europe's General Data Protection Regulation).

The jurisdiction's regulatory approach (e.g., risk-based regulation, outcome-based regulation, and prescriptive regulation) can influence project compliance. For example, a prescriptive approach can specify actions that should be taken, whereas an outcome-based approach focuses on a desired result, which allows parties to choose the best way to meet the requirement. It is important to know who the responsible parties are, and if applicable, where the duty of case lies, in context of the regulatory program (owners, operators, mine managers, OPSs, etc.).

Regulatory awareness and appreciation of risks related to autonomous mining systems should be considered and incorporated into the shareholder engagement journey, especially where a risk-based approach to regulation exists. For example, risks for manually operated machines are well understood and defined, whereas risks associated with autonomous and semi-autonomous machines may vary between systems and maturity stages. Whether the use of the equipment is sufficiently covered by existing health and safety and duty of care requirements should be verified as regulations that refer to drivers may not apply.

6.1 ENGAGING REGULATORS

When approaching regulators, consider when to begin the engagement process, what material needs to be shared with regulators, and for which milestones follow-up discussions are needed.

Once applicable regulations and legal liability related to operating autonomous systems are identified, conduct a gap analysis of standards, regulations, and norms to identify challenges and what needs to change. Based on the gap analysis, determine the level and type of engagement required with regulators. Adjustments to existing requirements are often simpler than developing entirely new regulations or addressing current regulations that are prohibitive and incompatible with autonomy. It is not always in the mining operation's abilities to ask the regulator to make regulatory changes and it might require lobbying with associations. The time it takes to get regulatory approvals should also be considered.

Organizations can do the following to facilitate engagement with regulators:

- Bring in a subject matter expert when meeting regulators who has knowledge of how the autonomous system works to maintain credibility.
- Understand the differences between autonomous systems at different maturity levels (see Section 2).
- Share project management plans outlining how the autonomous systems are intended to be deployed and controlled to achieve equivalent or higher level of protection for workers, environment, and property (see Section 7).
- Share risk assessments that offer deeper details on how failure modes and consequences would be mitigated and handled (see Section 5).

It can also be helpful to share use cases where applicable and appropriate. New jurisdiction mining companies can find it useful to create a project plan based on the Western Australia Code of Practice - Safe mobile autonomous mining in Western Australia (Government of Western Australia Department of Mines and Petroleum, Resources Safety, 2015).

7. PEOPLE

Introducing automation affects the workforce and other stakeholders. In this context, the workforce includes all employees of the mine, from operations to management. Changing operational processes and requirements can influence the size and shape of the workforce (e.g., there might be more options for remote work), including new skills becoming part of organizational structures.

The future state for people involves cultural change, where the new way of doing things becomes habitual and where people are open to ongoing change. A critical part of implementing autonomous systems is having the acceptance of the workforce. This section covers many of these changes, and how to assess and address them.

7.1 ENGAGEMENT PLANS

For brownfield operations, the bulk of the engagement should focus on the changing work landscape, impact of automation on the existing workforce, and identifying opportunities for upskilling and reskilling.

For greenfield operations, engagement strategies should focus on exploring the social benefits of automation for workforce and the community. This can include identifying opportunities to create jobs, improving working conditions and safety, and promoting economic growth and sustainability.

It is important to understand specific workforce requirements as they apply to the mine type (surface or underground operations), as skills and resources can vary. Understanding these requirements is important for developing strategies to recruit and retain a skilled workforce to ensure safety and productivity of mining operations

The engagement plan should include the following:

- **Communicate a clear and consistent message** regarding changes in employment, workplace health and safety, knowledge and skills, local mining communities, local supply chain, and regional legislation.
- **Define the planned future state** to serve as a roadmap for the project, outlining the steps required to achieve the desired outcomes.
- **Develop a personnel plan** that facilitates the transition from employees' current responsibilities to their new ones. This can include identifying key roles and positions that could be affected by the transition to autonomous equipment, defining new job responsibilities to have a clear description of the role, the skills and experience required, and assessing current employee skills to identify any supplementary training might be needed.
- **Include a gap analysis** of key roles after a set period of operations to gain a detailed insight into areas of role compliance, and areas of skillset that need focus.

7.2 STAKEHOLDER ENGAGEMENT

Autonomous technology has impacts beyond the workforce, including communities, regulators, and other stakeholders. Engagement should include two-way communication that encourages stakeholders to provide feedback and share their perspectives on the transition, address concerns, and identify opportunities for collaboration.

It can be helpful to collect supporting case studies on the successes or failures of autonomous deployments in various environments to guide engagement.

7.3 COMMUNICATIONS STRATEGY

Communicating the overall benefits of automation can help to engage the workforce and community. There should be a detailed communications plan for each stakeholder group, aligned to their specific needs. A robust monitoring and evaluation framework is essential to ensure the ongoing effectiveness of the communication strategy and adapt it as required.

7.4 ROLE REDESIGN AND WORKFORCE REQUIREMENTS

Proactively address role redesign within the workforce and establish career development pathways for workers who can be affected. As the level of autonomous capability increases, the organization's structure and processes need to evolve to support new operating models. Changing workforce requirements include:

- Upskilling
- Employee relocation
- Job loss
- Cross-skilling and collaboration with other industries

To define resourcing and upskilling requirements, complete staff assessments that identify the current skillsets, abilities, and adaptability of the workforce. Identify the new skills required, where they might to come from, and any training required.

7.5 ONGOING TRAINING AND UPSKILLING

Adequate training and upskilling opportunities for the workforce to adapt to the new technology and ensure they are comfortable with new processes should be provided throughout the implementation process.

Training should be done in stages, starting with basic concepts and gradually increasing complexity to maximize knowledge retention.

Training should be designed alongside the operation phase out in order to reduce gaps during the implementation process and should be done in an environment where operational risks can be effectively controlled. Ongoing training should be done at regular intervals, and could include simulators, hands-on-tools, and other training tactics to help personnel understand different scenarios, and build confidence.

It is also important to foster a collaborative environment that encourages knowledge sharing between workers and subject matter experts (SMEs) of autonomous or remote technology OPSs. OPSs should provide specific system training, while mine operators should provide site specific training. Additionally, OPSs should provide documentation for maintenance, daily operations and/or other best practices. It can be useful to create platforms or forums for SMEs to share their expertise and insights with the operational teams. This collaboration can help identify new ways to enhance the performance of the technology and address any potential gaps.

8. PROCESSES

The implementation of autonomous systems can result in a change to mining processes. It can be beneficial to plan new processes while also reviewing and modifying existing ones. This section describes considerations for some of these processes.

8.1 ACTIVITIES AND SCHEDULING

The sequence of activities in mining processes can change as new mining processes are introduced and adjustments to the mining rate change. It is important to account for all activities that interface with the autonomous system to make the most of or minimize the impact of it. Often, autonomous mines can required daily scheduling to realize full performance benefits.

Shift management changes and changeover should be considered, as a benefit of autonomous systems is being able to operate over a longer period and being able to adjust operations such as implementing drilling during shift changes, hot swapping excavator operations to minimize standby times of haulage equipment, and more. However, there are also other scheduling considerations to account for, including wait periods following a blast before humans can enter work areas, and changes in maintenance planning and inspections.

For underground mines, there are additional considerations, including ground support, infrastructure installation (electrical, piping, communications, etc.), and rehabilitation. This means that there may be differences in scheduling processes. Different areas of the underground mine should plan their activities to minimize interventions in the autonomous areas to be able to get the most out of the systems.

8.2 MONITORING

Implementing autonomous systems in mining operations involves a complex interplay of various rules and regulations that must be carefully monitored to ensure safety, efficiency, and compliance. Four key aspects that should be monitored include the following:

Machine/Infrastructure Rules: Autonomous mining machines operate within a defined infrastructure, which includes roads, tunnels, and work zones. Monitoring and adherence to machine/infrastructure rules are crucial for the safe and efficient operation of autonomous systems.

Machine/Machine Rules: Autonomous/autonomous and autonomous/manned machine protocols are important to assure consistent and safe interactions in the mine environment (rules of the road, right of way, etc.) because both are mobile, which can create added risk.

Machine/People Rules: Safety is paramount when implementing autonomous systems in mining operations. Monitoring machine-to-people interactions and enforcing rules in this aspect is critical.

Machine and People/Interface Rules: The interface between people, operators, autonomous systems, and control centers should be monitored for efficient operations.

Overall, the successful implementation of autonomous systems in mining operations requires continuous monitoring and strict adherence to the above rules. The use of INS, LIDAR, GIS, and GNSS technologies should be used for maintaining safety, optimizing efficiency, and ensuring compliance with regulatory requirements.

8.3 UNPLANNED EVENTS

Unplanned and unforeseen events can occur in any operation and in an autonomous operation, when a system is down, a site is down. Consider creating criteria for resiliency of the system, including response strategies for outages and design requirements to ensure high availability. These events can include system faults or unforeseen disasters. A disaster recovery plan should be incorporated into any process design.

8.4 ENGINEERING DESIGN MANAGEMENT FRAMEWORK

When implementing autonomous systems, adopting a structured design framework is recommended. This framework enhances overall equipment effectiveness and ensures safe production. It achieves this by allowing for remote operation, reducing safety risks and minimizing delays, maximizing asset availability while minimizing failures, streamlining maintenance operations, and ensuring equipment meets production targets. The framework encompasses specific design considerations such as technology assessments, standards, requirements, safety, and maintainability.

A structured design framework also addresses broader contexts, including communication, human/system integration, environmental factors, and decision-making. Safety remains a central focus throughout the entire process.

8.4.1 Key Challenges

Challenges can lie in balancing new and existing systems, particularly in brownfield operations. In such scenarios, it is important to identify interoperability requirements between incorporating new systems and validating the compatibility of existing ones. Upgrades and enhancements may be necessary for downstream and upstream systems to successfully interface with the new design. There may need to be trade-offs between design changes and the use of manual and autonomous fleets for special operations.

Operational safety, authority, and control are another significant challenge in autonomous systems. It is important to define and maintain the appropriate level of control or authority, especially when incidents occur, or override situations arise. Failing to do so can result in consequences, such as collisions or incidents. Appendix D.3 provides further details on addressing these challenges.

Autonomous systems typically require many components working together to accomplish a goal, from mechanical parts to software. Each component should be in a known state for the system to function correctly.

8.4.2 Design Management Plan

Developing a design management plan with agreement from all stakeholders, including the autonomous system suppliers, is recommended. Considerations for the design management plan include defining acceptance and performance criteria and agreeing on how the design will be verified and approved. It is also important to consider risk assessment approaches (see Section 5) and version management approaches for system updates and upgrades. Appendix D.4 provides a document deliverables list with both internal and external stakeholders.

8.4.3 Configuration Management Plan

It is essential to develop a configuration management plan for the safe operation of autonomous systems. The following are key considerations for managing change of configuration:

- Define configuration items for operations. It is important to consider it from a system maintenance viewpoint and how it translates into maintenance management platform.
- Set a configuration baseline during the commissioning phase.
- Update configuration details as and when required and conduct regular audits for compliance to configuration requirements.

For more information, see the configuration management standards in ISO10007 – Configuration Management and PAS 1881&1883 – Guidance on change control and configuration management, road vehicles.

8.4.4 Management of Engineering Design Changes

Having a different approach for operational systems and development systems is key to understanding where the boundaries between those systems lie. It is important to have a proper change control process in place and establish strong partnerships with OPSs and for OPSs to communication and coordinate with operators.

It is important to consider that with cumulative changes, for example with systems that are new developments, making many minor changes can result in an accumulation of change that can happen without consideration for the consequences of each change. Without adequate assessment, there can be changes in system functionality. Understand that both long-term and short-term changes can affect systems and that external technology can also influence the system.

8.5 MINE PLANNING AND DESIGN

Mine management and mine designers and planners should understand the limitations, opportunities, and benefits of the autonomous system they will use and the differences between manual and autonomous operations (see Appendix D.2). Autonomous systems often introduce higher levels of technology dependency. These differences influence designs and plans on multiple levels. Understanding that planning for autonomy instead of making autonomy fit the plan helps drive an efficient transition when going from manual to autonomous.

The physical mine should accommodate new characteristics of autonomous systems that require new approaches to excavation and material movement design. Ultimately, the mine design should be suitable for autonomous equipment and potential combinations of autonomous, semi-autonomous, and manual equipment. Conventional designs for one or the other might not be sufficient and the design should accommodate limitations and ambiguities associated with the systems in the mine.

In greenfield projects or complete redesigns, the whole design can facilitate autonomous systems. In brownfield projects, current designs and operational processes require adjustment or redesign. Designing for an efficient autonomous system may also require a hybrid approach, where a brownfield mine is extended and some parts of it are new. This kind of approach may include the opportunities and challenges associated with both greenfield and brownfield mines. The greater the complexity of change, the more the mining environment must consider human factor risks.

All mine design and planning should incorporate safety by design. From the earliest stages, controls should aim to minimize the start-up risks with the systems (e.g., start simple and small and gradually build capacity) and create an area where the autonomous system is isolated or interactions with manually operated systems are minimized (e.g., consider the implication in mine design, plans, zones in different stages of maturity, workforce training, and schedules). Activity sequencing for isolation can smooth the process of transferring to autonomous systems and enable activities without creating additional work. Emergency management planning is also part of this process and is described in Section 5.

8.5.1 Layout and Road Networks

Mine geometry (e.g., pit shape, haul road width, tunnel profile) should be considered for autonomous systems when being designed. In addition, the areas of the mine should also be considered, including dumping and loading areas, and areas with potentially hazardous conditions (e.g., calibration zones, crusher pads).

Road networks should be designed and constructed in line with the system builder requirements (e.g., road surface, gradients). Road quality and the potential for road maintenance should also be considered, along with traffic management and intersection design. In a dynamic environment, road network changes should be considered. Additionally, equipment specifications, fleet size, and operating capabilities (e.g., turning circle, road network layout, gradient) should also be considered in the layout.

These considerations are the same for greenfield and brownfield operations, but how requirements are integrated can differ. For underground mines, it is important to also consider the following:

- Access and egress differences (e.g., ladder ways, shaft level, declines)
- Considerations of infrastructure size and specific bottlenecks
- Production vs. development areas
- Ventilation requirements
- Design that accommodates autonomous mining activity other than transport (e.g., drilling, loading, unloading, blasting)

8.5.2 Separation, Boundaries, and Safety Interfaces

When planning mines for autonomous systems, it is important to consider access controls for exclusion and interface areas, as well as barrier placement (e.g., location and control of area entry and exit points, provision of perimeter protection and signage). Infrastructure placement within the autonomous area (e.g., fuel facilities, crushers or ore passes, stockpiles, workshops and maintenance facilities) should also be considered (including heavy physical barriers as well as electronic barriers).

Additionally, the infrastructure placement should also consider clear delineation of geographic boundaries (exclusion or inclusion zones) and should be implemented with a phased approach that can include smaller fleets, shorter haul distances, and roadway systems that increase as maturity increases. Having separate roads for manned operations, when possible, can help reduce interaction and human factors.

For underground mines, it is important to also consider that separation is typically required and there may be more stringent requirements. There is also a difference in infrastructure placement within the autonomous area (e.g., water, electrical services should be accessible).

8.5.3 Other Considerations

When planning and designing a mine for autonomous systems, it is also important to consider how changes integrate with non-mining infrastructure, including the urban environment and processing plants.

Managing electrical load and balancing demand should also be considered in mine planning and design. Uninterruptible power supply arrays and back-up generators for critical infrastructure should be included in the mine design.

9. TECHNOLOGY

Implementing autonomous equipment requires end users to install supporting technologies, such as sophisticated and robust wireless communications networks, and data collection and dissemination technologies. These should be identified and be part of the operational readiness planning and deployment processes.

9.1 ARCHITECTURE

Architecture refers to the structure, components, and design principles of a system and the relationships between them (see International Organization for Standardization, 2011: The Open Group, 2018). There are several ways of categorizing architecture. Appendix D.1 describes architecture in the context of autonomous systems as they fall into the following subsets: business, application, data, and technology.

Overall, the architecture for autonomous systems is an integrated information technology (IT) and operational technology (OT) system. IT systems used for data-centric computing are integrated with the OT systems used to monitor processes and control devices. Experience has shown that an aligned IT/OT capability is advantageous as most autonomous systems require a heavy reliance on both disciplines. Considerations around availability, redundancy, resiliency, and cybersecurity should be addressed at every level of the architecture.

Architectures for autonomous systems should be incorporated into all design and planning processes. Early on, roles and responsibilities required to develop the architecture need to be specified to ensure the appropriate skills and capabilities are in place.

Architectures should also consider both the current and future state of the system. Reviewing emerging technologies is necessary to future-proof solutions and understand that new business value might arise in the future. Overall, the architecture should facilitate planning for future expansions and technology development, and confirm that systems can be upgraded and expanded.

9.2 INFORMATION AND DATA COLLECTION

With autonomous systems, managing operations and safety becomes much more data-driven, with new technologies providing more accurate information than a manual system. The use of mine-specific systems, where multi-users can collaborate to limit potential risks, assists in bringing in data quickly to set teams up for success.

A key consideration for companies is determining how to collect the information from various field devices installed across the mine site. Some devices can be fixed while others are mobile like wireless modems or routers installed in an autonomous machine. There are various options to manage these devices and collect data. One option is having a Graphic User Interface (GUI) that can visualize and present the data. Another option is to have a centralized Network Management Systems (NMS) managing all the components of the network. Centralizing the data can reduce the amount of reporting and allow for quicker decision making.

Whichever option is used to manage the flow of data, it is important to consider an option that is compatible with all systems but simple enough to avoid generating additional distraction. Data collection should run over time so that it can be used to validate business cases, expected results, and shed visibility on hidden operational inefficiencies. Security and safety of the data should be considered while planning the flow of information. Sensitive and critical data should be restricted by access controls within the system.

9.3 IT/OT INFRASTRUCTURE PLANNING AND DESIGN

Mines are a uniquely specialized and hazardous environment, therefore when it comes to IT/OT infrastructure planning, OT infrastructure design should be more robust, redundant, and secure, as compared to the IT data. Disruption in OT infrastructure can impact production and increase safety risks for people and assets. In addition, IT support infrastructure and staffing should be considered, as they can be different when implementing autonomous systems. Infrastructure planning should also include infrastructure status monitoring, data management and system upgrades.

9.3.1 Data Management

When setting up data management infrastructure, it is important to consider the choice of cloud systems or company servers, including understanding the difference between public and private cloud analytics systems. Cybersecurity, data ownership, and data sharing should be considered when making the decision between systems.

The speed of data transmission, as well as the data quality, filtering and cleaning, is important when implementing autonomous systems. Identifying what gets sent to the cloud or company servers can help determine processing needs. Additionally, the data storage and retention periods should be evaluated, as the split between company servers and cloud storage can impact the investment needed for the IT and OT environments. Establishing data access and ownership can also help understand downstream requirements. All data should also be auditable to allow for traceability and local legal requirements.

9.3.2 System Updates and Upgrades

OPS and OTM testing programs for autonomous system software and firmware updates, and a mine-specific test system to confirm the viability of system updates should be implemented. It is important to identify legal and operational requirements and consult with OPSs if using a third-party to add capabilities to existing equipment. A system update plan should be included to effectively and efficiently keep systems up to date.

9.4 COMMUNICATIONS AND NETWORK INFRASTRUCTURE

Key considerations for communications and network infrastructure include communications technologies, network design, redundancy and scalability, and monitoring and tracking systems. Network design should be considered for the life of the mine, including any transition to underground, traveling under overpasses or large infrastructure.

9.4.1 Communications Technologies and Network Design

Communication technologies and network design, including high-speed Wi-Fi, are important as delays can introduce risks. Having different channels (e.g., Wi-Fi or LTE 5G) for different applications can be considered to reduce latency. It is important to decide which platform is best suited for autonomous systems. Network limitations, GNSS, satellite, and crew size affect network design and reliability.

New types of transponders used for surface mining can help systems respond to mixed environments where regulations allow them. Heavy duty and robust communications equipment should also be considered in places where extreme weather is possible. For underground mines, communication requirements are more stringent, which can lead to reconfiguration and infrastructure challenges. Requirements for the network should be developed through collaboration with OPSs and communication protocols should drive network implementation.

9.4.2 Redundancy, Scalability, and Compatibility

Network redundancy ensures business continuity with backup network equipment and systems. Most organizations now rely on digital information, data, or procedures to carry out their routine business activities. Network redundancy ensures that mining companies can still access vital processes or information when network components malfunction.

There are many types of redundancy planning options including power, geographic and data redundancy, uptime, security, latency, and business continuity.

Scalability is the ability for the network to perform as normal when new users or network components are added to the system. Mining companies should factor in the growth they are expecting for at least the next few years while selecting the network. For example, an LTE network should be able to support tens of thousands of users without adding a new core network.

New technology should be backward compatible to minimize the cost of deployment. For example, a new IP network should be compatible with the existing IP network. Proper due diligence should be done before selecting any system to ensure that the new system is compatible with the existing system and that it also works coherently in the current ecosystem.

9.4.3 Monitoring and Tacking Systems

Monitoring and tracking systems, such as wireless positioning systems, are an important part of the system infrastructure. Comprehensive network health monitoring is vital to ensure systems are operational. Layers of control, including location and tracking of both humans and non-autonomous equipment and other object detection avoidance systems (both reactive and predictive) are needed to minimize risk. Currently, there is no defined standard for location services, especially in GNSS-denied scenarios.

Other monitoring systems should also be considered and installed, including machine health, monitoring and telemetry sensors, and cameras that are connected to the central control system to monitor equipment and surrounding areas.

9.5 CYBERSECURITY

Autonomous mining solutions are designed to meet high security demands. With the advent of cloud computing, mining companies have the option of storing data on their premises or on a remote cloud network. As technologies become more interconnected, the potential for cybersecurity incidents are growing. The impact of these incidents can be severe, resulting in production or revenue losses, harm to the environment, regulatory fines, reputational damage, constrained economic growth, the shutdown of critical infrastructure and injury to personnel. This can be further compounded by the emerging complexities and convergence between operational technology and information technology.

Mining companies should consider implementing the following non-exhaustive list of strategies to minimize security risks:

- Deploy modern authentication technology that integrates with legacy protocols and enable multi-factor authentication.
- Patching vulnerabilities in legacy OT/IT systems.
- Privileged access management system, with the capability to audit and track access.
- Partner with security organizations. If partnering with third-parties, considerations for NDAs and other agreements.
- Logical segregation of networks to minimize impact in case of attacks.
- Recognize the risks associated with multi-network modes of access to assets (LTE and Wi-Fi) where consistent line of sight across the mine site from one system may not be possible.

Implementing cybersecurity controls and protections requires time, effort and financial investment, however it is important to protect the data, the equipment, and the organization.

10. DEPLOYMENT

This section provides general considerations on the deployment and commissioning of autonomous systems, including testing and handover to operations.

10.1 INSTALLATION AND COMMISSIONING

It is important to understand technology when commissioning and deploying, as some of the technology will be more mature than others thereby requiring an increased level of integration, testing, and de-bugging.

Autonomous systems and associated risk classes can be differentiated by non-deterministic software (e.g., artificial intelligence, machine learning, etc.) and deterministic software (logic based). There can be different installation and commissioning requirements for different types of high-risk machinery. OPSs should provide documentation, including system level check lists to the mining company.

A systematic commissioning strategy should be developed that covers the commissioning process, timeline, risks, roles and responsibilities, and test plan, and meets formal approval and user acceptance. When commissioning, the project team can have the asset fleet at full operational readiness before deployment and handover to avoid going through a secondary commissioning period. Alternatively, a staged rollout, where only portion of the asset fleet is deployed first, can be done to determine that systems are working well before the entire fleet is commissioned and deployed. See Appendix D.5 for a more detailed list of some commissioning activities.

10.2 TESTING

Any autonomous system requires validation and testing following an earlier formulated acceptance and commissioning strategy with a clearly articulated vision of the future. Both the site and the OPS are responsible for different aspects of the testing, and it is important to identify who is responsible for which testing activities. For example, infrastructure testing is typically the site's responsibility while equipment verifications are typically the OPS's responsibility, but it varies depending on the situation and contractual agreement.

The **GMG Guideline for System Safety for Autonomous Mining** details a methodology for defining system requirements and conducting verification and validation activities. Mining operations can develop a core competency in testing autonomous systems which can be utilized at a number of points during its lifecycle. Types of testing which should be considered include proof of concept, pilot testing, early production deployment, system updates, and new machine introduction.

A project execution plan should be developed that covers responsibility, testing and acceptance criteria, staging and timing, detailed deployment plans, and equipment and personnel needs. This plan should be formed based on the planning and design considerations and the chosen implementation approach (see Section 2.3). Acceptance criteria for testing should be agreed upon at the onset between the mine operator and OPS. The OPS can develop testing plans and criteria, however the mine operator should review and approve them as well.

10.2.1 Pilot Tests

To test new technologies, mining operations should consider conducting pilot tests in accordance with the working design documentation developed, accounting for the development of mineral deposits, and the conclusion of a specialized design organization. Pilot tests should be carried out with a developed safety justification and approved by the relevant groups. The people responsible for conducting the pilot test should be appointed by the organization's general manager.

Pilot test programs should contain measures to implement industrial safety measures, and scientific and technical assessments of proposed tests. Tests should include the purpose and objectives of the tests, information about the responsible executors, conditions, the procedure for organizing the tests, and measures to control the tests.

The results of the pilot test should be reviewed by the operation and reflected in a report, which contains information on the pilot's progress, identified problems, and conclusions. Based on the results of the pilot test, the operation should, in accordance with the procedures established by legislation, make appropriate changes to the project documentation.

10.3 TRANSITION AND HANDOVER TO OPERATIONS

During the handover to operations, the responsibilities of designers, manufacturers, and suppliers should be documented, and safety related information should be provided to mine operators. It is important to reference appropriate standards and provide training and guidance to the operators and technical maintenance teams to allow them to develop a safe system of work. All processes, procedures, and training, particularly those involving safety and outages, should be in place before handover is done.

During handover, it is important to identify leaders in the workforce and demonstrate the readiness of the system to help manage change. This includes demonstrating to operators the efficiencies of the autonomous systems. The demonstrations should highlight benefits including better working conditions, addressing lack of resources, and more.

11. BENCHMARKING PERFORMANCE AND VALUE REALIZATION

As part of the implementation planning and deployment, the organization should benchmark existing manned operations to create a baseline from which they can measure the performance of the autonomous fleet. Identification of external benchmarks might not always be evident, by virtue of operating conditions, however breaking down the benchmarks into sub-sets can help clarify.

This subsection provides guidance around beneficial areas to measure, focusing on measuring how the autonomous system performs, and whether it is working as designed. It offers key considerations and questions to ask to accommodate the fact that different suppliers use different terminology to describe performance.

The performance of the autonomous systems should be benchmarked and analyzed against established KPIs including safety, productivity, and cost. Deployments should be benchmarked in phases to match typical deployments, for example deployments of tele-remote with semi-autonomous tramming.

Benchmarking and analysis should be reassessed regularly to confirm that it remains appropriate for current processes and goals.

11.1 PERFORMANCE AND METRICS

It is recommended to consider the KPIs that are already measured onsite, data that is already available, and how performance can be discretely measured for autonomous systems. For mixed fleets, looking at interaction points between manned and autonomous systems can be a useful starting point.

Companies should consider having clearly defined KPIs, keeping the success of an implementation and the success for the business separate.

Most key differences between autonomous and manned systems are the metrics for availability and utilization, particularly around overall equipment effectiveness.

Time usage models often provide the basis of productivity metrics. Accurate performance tracking relied on a standardized classification framework. Models should be adapted to meet site requirements. The initial time classification of machine events should be completed by the mine controller and automated where possible.

The interaction between the equipment and physical environment is also a key area of consideration when establishing metrics for autonomous system performance. For example, metrics around velocity and speed, brake temperatures, strut pressures, autonomous specific components, sensors, and life of overall mechanical components.

Data management is a key consideration in measuring and making improvements based on metrics. Autonomous systems will typically produce more data, and understanding the data, data sharing models, and documenting and prioritizing data are important considerations. OPSs typically provide performance standards, however alignment between operators and suppliers should also be facilitated. The types of data to prioritize and analyze will vary based on the type of mine.

When understanding performance and metrics, it is important to establish achievable targets based on the maturity of the autonomous system implementation. There can be a period of ramp-up while adjusting to systems before equipment performance can be measured in a way that reflects how it will be going forward. For underground mines especially, it is also important to standardize ways of measuring network performance.

A key challenge with benchmarking is that there is no universal time usage model and different definitions between vendors. Before making comparisons, it is important to confirm that data is comparable. The GMG **Time Classification Framework for Surface Mining** (2020) can be used as guidance for surface mining. Another option is using a pulse-based model, which draws from asset performance KPIs.

11.2 CONTINUOUS IMPROVEMENT

The implementation process should encompass a continuous loop that feeds back into the planning process. Keeping ongoing focus after commissioning is required for the system to allow for continuous improvement. A strategy should be developed and driven by leadership that includes guidelines for implementing improvements. This should incorporate data-driven decision making and include benchmarks and targets. As part of continuous improvement, processes should be reassessed to determine if they are aligned with current goals and that targets are reachable. Continuous improvement should be applied both to the technology and equipment, and the people side of operations.

12. RESOURCES, REFERENCES, AND RECOMMENDED READING

The following section outlines resources, references, and recommended readings.

12.1 RELEVANT STANDARDS

The following tables are not intended to be comprehensive, and not all standards listed will be applicable to all situations. It is the responsibility of the user to reference local regulations and implement the appropriate standard for their situation. The citations listed are for the latest version of the standard at the time of this guideline's publication. Please consult the most recent version of any standard referenced.

References to configuration management standards:

- ISO 10007 – Configuration Management
- PAS 1881 & 1883 – Guidance on change control and configuration management, road vehicles
- ISO 23725:2023 - Autonomous System and Fleet Management System Interoperability

Table 4: Relevant standards

Standard number	Title	Citation
General Standards		
ANSI/ISA-95.00.03	Enterprise-Control System Integration – Part 3: Activity Models of Manufacturing Operations Management	International Society for Automation, 2013a
ANSI/ISA-95.00.04	Enterprise-Control System Integration – Part 4: Object and attributes for manufacturing operations management integration	International Society for Automation, 2012
ANSI/ISA-95.00.05	Enterprise-Control System Integration – Part 5: Business-to-Manufacturing Transactions	International Society for Automation, 2013b
IEC 60204-1	Safety of machinery –Electrical equipment of machines – Part 1: General guidelines	International Electrotechnical Commission, 2016
IEC 61508-1	Functional safety of electrical/electronic/programmable electronic safety-related systems – Part 1: General requirements	International Electrotechnical Commission, 2010
IEC TS 62443-1-1	Industrial communication networks–Network and system security–Part 1-1: Terminology, concepts and models	International Electrotechnical Commission, 2009
ISO 13849-1	Safety-related parts of control systems – Part 1: General principles for design	International Organization for Standardization, 2015a
ISO 12100	Safety of machinery –General principles for design –Risk assessment and risk reduction	International Organization for Standardization, 2010
Autonomous Specific		
ANSI/ISA-95.00.01	Enterprise-Control System Integration – Part 1: Models and Terminology	International Society for Automation, 2010a
ANSI/ISA-95.00.02	Enterprise-Control System Integration – Part 2: Object Model Attributes	International Society for Automation, 2018
IEC 60073:2002	Basic and safety principles for man-machine interface, marking and identification – Coding principles for indicators and actuators	International Electrotechnical Commission, 2002
ISO 13850:2015	Safety of machinery - Emergency stop function - Principles for design	International Organization for Standardization, 2015

Table 4: Relevant standards (continued)

ISO 13849-2	Safety-related parts of control systems – Part 2: Validation	International Organization for Standardization, 2012
ISO 31000	Risk management –Guidelines	International Organization for Standardization, 2018c
ISO 20474-1	Earth-moving machinery –Safety –Part 1: General requirements	International Organization for Standardization, 2017b
ISO 19296	Mining – Mobile machines working underground –Machine safety	International Organization for Standardization, 2018a
ISO 17757	Earth-moving machinery and mining –Autonomous and semi-autonomous machine system safety	International Organization for Standardization, 2017a
ISO 45001	Occupational health and safety management systems – Requirements with guidance for use	International Organization for Standardization, 2018b
ISO 10218:2011 (parts 1 & 2)	Robots and robotic devices - Safety requirements for industrial robots	International Organization for Standardization, 2011
ISO 15817:2012	Earth-moving machinery - Safety requirements for remote operator control systems.	International Organization for Standardization, 2012
ISO 7010	Graphical symbols – Safety colours & safety symbols – Registered safety signs	International Organization for Standardization, 2019
ISO/IEC/IEEE 42010	Systems and Software Engineering –Architecture description	International Organization for Standardization, 2022
ISO/IEC/IEEE 15288	Systems and Software Engineering – System life cycle processes	International Organization for Standardization, 2023
SAE J3016	Taxonomy of Terms Related to Driving Automation Systems	SAE International, 2018

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APPENDIX A. TERMINOLOGY, DEFINITIONS, AND ABBREVIATIONS

Because this guideline deals with concepts and operational processes where specific terms often vary depending on the mine and region, the following tables identify terms this guideline applies to describe these concepts and disambiguates terms that are often used interchangeably. Definitions are informed by standard language in ISO 17757 and the Western Australia Code of Practice for Safe Autonomous Mining (Government of Western Australia Department of Mines and Petroleum, Resources Safety, 2015).

Table 5: Terminology and definitions

Term	Definition
Automatic	A process or 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 task(s) within a set of defined operations without human intervention or direct control.
Autonomous area	The area in which autonomous equipment operates.
Autonomous operator	The person who operates an autonomous process or machine and takes control when necessary.
Autonomous machine:	Same definition as ASAM as defined in ISO 17757:2019
Autonomous supervisor	The person who supervises one or several autonomous processes or machines at high levels of equipment maturity and intervenes when necessary. This role overlaps with that of the autonomous operator.
Autonomous system	A system that can perform desired tasks in unstructured environments without continuous human guidance.
Availability	The amount of time in a defined period during which an asset is available to provide the needed function.
Change management	The processes and steps associated with managing changes to people and processes.
Component	A part of a larger whole. In this guideline, component refers to components of individual machines and components of integrated systems.
Control room	A facility from which dispersed operations, systems, and equipment can be monitored and controlled; often also called an operations centre.
Geofence	Virtual spatial boundary that initiates a programed software response. These boundaries are how all autonomous systems illicit machine behaviour.
Implementation plan	The high-level plan developed for implementing autonomous systems in mines.
Management of change	Management of changes made to the system that affect how the system functions.
Manned operation	An operation where a human is at the location and operating the equipment.
Manual operation	An operation where a human is in control of the equipment. This can be either manned or remote control.
Mobile autonomous mining	Mobile equipment operated using an autonomous system.
Operational readiness	The capability to operate a new system, technology, or piece of equipment. This involves having people, processes, controls, and infrastructure in place.
Redundancy	Duplication of components or functions to create a backup or fail-safe mode in which to operate after a disruption.

Table 5: Terminology and definitions (continued)

Reliability	A measure of the dependability of a system to perform at a defined quality.
Remote controlled	A type of operation where the functionality and operator interface are the same or similar on the machine, but the controller is separate from the machine and is under human supervision while the machine is operated in line-of-sight or tele-remote mode.
Safe state	Operating or shutdown equipment condition whereby a hazardous event is unlikely if autonomous activity continues.
Semi-autonomous	A process or machine that is intended to accomplish a portion of assigned task(s) within a set of defined operations without human intervention or direct control.
Situation awareness	The ability to perceive environmental elements and comprehend their meaning and, in some cases, project the future status.
Teleremote	Distinct to ASAM. ASAM equipment are commonly used in a teleremote control capacity, however teleremote equipment may lack technology layer to support autonomous operations.

Table 6: Abbrevations

AI	Artificial Intelligence
CHAZOP	Control Hazard and Operability Study
FMEA	Failure Modes and Effects Analysis
GIS	Geographic Information Systems
GNSS	Global Navigation Satellite System
HAZOP	Hazard and Operability Analysis
INS	Inertial Navigation System
IP	Internet Protocol
ISO	International Organization for Standardization
IT	Information Technology
KPI	Key Performance Indicator
LOPA	Layers of Protection Analysis
OEE	Overall Equipment Effectiveness
OEM	Original Equipment Manufacturer
OMF	Open Mining Format
OPS	Original Product Supplier
OT	Operational Technology
OTM	Original Technology Manufacturer
RACI	Responsibility assignment matrix (Responsible, Accountable, Consulted, Informed)

APPENDIX B. SAFETY AND HAZARDS

B.1 HAZARD IDENTIFICATION AND VERIFICATION LIST

Hazard identification and verification systems can be implemented to describe, understand and analyze autonomous mining risks. Some examples include:

- A hazard and operability study (HAZOP) or control hazard and operability study (CHAZOP)
- Layers of protection analysis (LOPA)
- Functional safety analysis
- Bowtie analysis
- Task-based risk assessment
- Failure modes and effects analysis (FMEA)
- Employee hazard identification and reporting procedures and tools
- Workplace inspections
- Monitoring the working environment
- Change management
- Incident investigations
- Monitoring OPS and service company bulletins, recommendations and specifications
- Regulator safety alerts

B.2 MAINTENANCE HAZARD CONTROLS

Maintenance hazard controls are especially important for autonomous equipment. To achieve the desired safety outcomes, maintenance activities for autonomous equipment should address:

- Safety-related parts of control systems and functional safety considerations for system maintenance (autonomous systems will not function without operational safety systems)
- Scheduled maintenance and inspections processes
- In situ inspection and servicing (e.g., consider ventilation for human traffic in autonomous areas during in situ work)
- Base platform autonomous components
- Recovery procedures in autonomous areas
- Identifying correct configurations of hardware and software
- Procedures for updating software and hardware
- Maintenance area and activity isolation
- Condition monitoring and diagnostics
- Calibration and testing (including designated testing areas)

B.3 PREPARING PERSONNEL FOR SAFE WORK

B.3.1 Information

Personnel need to be informed so they are prepared to work safely and respond to any issues. This preparation includes providing the information necessary to complete tasks safely. Such information includes:

- Manuals, specifications, and operating instructions provided by the system builder
- The operation's policies, procedures, and plans
- Applicable legislation, standards, and other guidance material
- Identified hazards and their associated risks
- Implemented controls and their relevance
- Historical incidents, near misses, and their documented resolutions

- Emergency shutdown procedures for autonomous equipment
- Training materials including OPS training for specific systems
- Ongoing identification of autonomous boundaries

Tools such as safe work instructions or procedures and standard operating procedures may be used to document the process but should be reviewed and amended if there are any changes (e.g., to equipment or conditions). Any deviation to the safe work procedures would require a job safety or hazard analyses to capture any additional or changed hazard and confirm associated controls are implemented and operational. Supervisory or management personnel should formally approve instructional tools. Establishing safe work practices is an administrative control. These are a secondary line of defense after higher level controls such as designing out hazards.

B.3.2 Training

It is important for personnel to be competent in the tasks to which they are assigned, including having the knowledge and skills necessary to perform the task safely and correctly. Competency is gained through training and experience while being supervised or mentored. Competency assessments should be based on evidence and verified before work commences. Competency verification also typically includes a documented assessment. Competency can be verified by:

- Recognition of prior learning
- On-site recognition or validation of current competency
- Using the operation's training and development program

The risk management training provided should be appropriate to the assigned roles and responsibilities, and provide information on the risk management process and 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 system. They should also understand:

- What to expect if environmental or operational conditions change
- Site requirements for monitoring of machine performance
- How to recognize when machines are not operating as intended
- How to report incidents

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

B.3.3 Supervision

The system should be monitored for changes in behaviour and performance to identify any potential issues in the autonomous system, procedures and/or human factors. Supervisors within an autonomous mining operation help achieve the operation's health and safety 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 following system builder documentation
- Confirming workers (including contractors) are trained and verified 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 following 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 lessons from incidents

APPENDIX C. WORKFORCE AND SOCIAL IMPACT

C.1 DETAILED STEPS FOR COMPLETING A SOCIAL AND ECONOMIC IMPACT ASSESSMENT

This appendix lists considerations for completing a social and economic impact assessment. It provides a step-by-step approach as an example.

The social and economic impact assessment determines the engagement strategy to take with the community. The following is an example of what to consider when completing this assessment.

Consider demographics and how they can influence the implementation project:
- **Population:** Size, trends (growing or diminishing, long-term residents or newer residents)
- **Age:** Distribution, generational gaps
- **Cultural values:** Education, remuneration, quality of life, mobility, and family.
- **Economic situation:** Employment rates, gross revenue, investment in the community, education and skills development, new startups
- **Education level:** Skills (soft and technical), literacy, languages
- **Diversity policies:** For example, those concerning ethnic groups and gender diversity (case studies can help guide this process)
- **The importance of the mine to local suppliers and towns:** Both in the current state and future state.

Develop a community profile to determine how changing roles can be managed in specific situations. It can also help to determine what benefits the new technology can have for the community (e.g., it may attract new suppliers or attract visitors to the demonstration site). The current community situation needs to be compared with the feasibility study of the operation. The following details can be used to build a community profile:
- **Location:** Remoteness, accessibility (transportation, presence of community)
- **Community history:** Industry presence, evolution
- **Industry sectors and employers in the community:** Both those depending on the mining operation (e.g., suppliers) and other industries
- **Infrastructure:** Schools, colleges, utilities, hospitals, accessibility
- **Strategic community plans:** Growth, population, sustainability, urban planning
- **Academic institutions:** Strategic collaboration between academia and industry to stimulate simultaneous technological development and regional economic development and education
- **Unions:** In the context of the local governmental rules and labour laws
- **Employment statistics:** Including diversity (e.g., the status of women in the workforce), age, and education levels
- **Training strategies:** Training opportunities available to enhance the skills and employability of local communities
- **Career opportunities:** Having access to new technological approaches allows the community to have more career opportunities through learning new practices

Assess the outcome by asking the following questions:
- What is the community's level of dependency on the mining operation, and how will it be affected by the introduction of automation?
- Will there be a significant impact and for how long?
- How can the introduction of the technology improve the community situation (e.g., mine life or new suppliers)?

C.2 REQUIRED SKILL SETS

Potential future skills needed include, but are not limited to, the following:

- Data analytics and data statistics/data science: To interpret and analyze the data being collected from the systems.
- Technology design, engineering, and maintenance: Autonomous systems are more advanced and require higher technical knowledge.
- Machine learning: Skills in machine learning to be able to train autonomous systems on tasks.
- Model based control: Skills required for creating a model of a system or process and using that model to understand, analyze, and predict its behaviour.
- Artificial Intelligence: Autonomous systems can have an AI component to them that requires specialized knowledge.
- Networking: Transmission control protocol/internet protocol systems are part of autonomous systems.
- Wireless propagation and antenna theory (especially in an underground context)
- Cybersecurity: Autonomous systems are interconnected technologies that are dependent on programs that are vulnerable to cyber-attacks.
- Other languages: For a more global industry.
- Business information systems: Business information tools are needed for operations and analysis with data.
- Advanced systems development: Skills and integration to manage autonomous systems and shipping platforms.

APPENDIX D. OPERATIONAL READINESS

D.1 ARCHITECTURE SUBSETS APPLIED TO AUTONOMOUS SYSTEMS

The following table describes architecture in the context of autonomous systems as they fall into the following subsets, as defined by the The Open Group Architecture Framework (TOGAF) standard (The Open Group, 2018): business, application, data, and technology.

Table 7: Architecture Subsets Applied to Autonomous Systems

Category	Definition		Further details
	General	For autonomous systems	
Business	Drivers and processes that generate business value	Social impact, safety and organizational and operational readiness Current and future state for roles and responsibilities and reporting structures based on system interdependencies	Business impact assessment should be completed early to confirm the design is structured to meet business requirements for both systems and data. See mining business reference model and exploration and mining business capability reference map (The Open Group, 2013, 2014).
Application	Application landscape, including functionality, data, and integration	Current and future state (i.e., transformation within an existing production environment or an insulated greenfield project) How all capabilities need to come together (systems-level focus) System orchestration map for understanding data, scheduling, and control considerations	Systems: • Fire suppression • Ventilation • Traffic control • Fleet management • Ground control • Power/electrical • Network protocols • Localization
Data	How the organization manages data	Required data baseline (plans for data capture, sensor data, measurement strategy) Scale (quantity) of data and data model (mapping where data are and need to go) Master data management and data quality management (including traceability of lineage) Alert monitoring (to quickly address issues with flow or quality) Data exchange considerations (often for large volumes at high speed/resolution) Data security, scalability, and validation Data standards (open/closed) Automated data surveys	Data streams to examine: • Operating physical data (operating logics) • Input operational data (commands and plans) • Technical services and design inputs • Optimization loops for production (localized and integrated optimization) • Equipment data (maintenance and operational) • Edge systems (safety, management, environment) • Localization and positioning information (to feed and from fleet management)

Table 7: Architecture Subsets Applied to Autonomous Systems(continued)

Technology	Software and hardware functionality, capability, and how they integrate with other processes	How existing technologies intersect with current data and application landscape Changes that will be necessary for meeting business needs with the new system Blocks of technology	Systems: • Basic input/output system • Solid communications network/fixed infrastructure (e.g., network link, network redundancies, consideration for protocols, considerations for latency), specific underground challenges • Onboard autonomy system (automation processors) • Onboard detection/object avoidance system • Onboard machine actuation systems • Redundant power • Security systems

D.2 MINE DESIGN COMPARISONS

The following table describes potential design differences between manual and autonomous operations.

Table 8: Mine Design Difference between Manual and Autonomous Operations

Feature	Manual	Autonomous
Design layout	Designed using conventional design packages Design layout conforms with site-established parameters such as clearances, speeds, ramp angles, exclusion zones, angle of repose, and safety requirements	• Can require separation of manually operated and autonomous operations • Typically requires the same road widths as manually operated operations, but road widths need to be accurate • The design and area at loading and dumping locations will be to autonomous OTM specifications (similar to manually operated operations but may have different design requirements) • Might prompt review of intersection designs, ramp angles, truck speeds, and traffic density • Requires consideration for the interface between manual and autonomous fleets/operations • Requires consideration for the maintenance interface • Requires consideration for fueling location and layout
Plans	Plans prepared at a functional level with the site supervisors/operators as the "customer"	• Plans prepared at an execution level with the autonomous machine as the "customer," the machines operate exactly to plan • Plans can be levelled and optimized in an autonomous environment
Planning	Planner prepares and delivers the plan of the day to the mine supervisors Supervisor executes plan using mining judgment and experience (supervisor can change loading/dumping locations and truck allocation)	• Mine plan is uploaded into the autonomous operating system and the autonomous machines execute according to plan • Planner requires feedback on plan effectiveness • Supervisor does not have the discretion to modify the plan • If there is a machine breakdown, the plan needs to be modified

Table 8: Mine Design Difference between Manual and Autonomous Operations (continued)

Supervising	Supervisor primarily schedules and manages people	• Supervisor primarily manages machines • Supervisor needs to understand the mine plan and machine operating parameters
Controlling	Mine controller manages logistics within the pit	• Mine controller oversees operations and manages the effectiveness of the operation • Mine controller monitors autonomous machine operations and manages unexpected or inefficient operations • Mine controller manages survey and dispatch changes

D.3 KEY ENGINEERING DESIGN CHALLENGES

D.3.1 Safety and Productivity

Achieving the appropriate levels of safety without compromising the productivity value driver is a key design challenge. Safety systems that are too conservative, oversensitive, or prone to false positives (especially those at maturity level 3 where operator intervention is required for even minimal risk situations; see Section 2.2) regularly fail at a safe level of operation, increasing task variation, reducing utilization, and negatively affecting production performance targets. A safety system that is not rigorous enough, however, exposes resources to safety breaches, incidents, and regulatory risks.

Achieving the right balance can be accomplished by:

- Assessing, interpreting, and applying corrective actions for equipment OPS failure modes (i.e., braking, accelerating, steering, engine, hydraulics). The design should fully describe how all failure modes will be handled and how these will be tested to confirm the design. The design should correlate the autonomous system back to the equipment's safe working parameters.
- Incorporating an effective alarm management approach, ensuring data collected from alarms, alerts, and events are rationalized and that systems, processes, and roles are assigned to assess, interpret, and action them.
- Assessing cybersecurity threats and system vulnerabilities upfront and balancing them with the functional and safety requirements of the solution.

D.3.2 Balancing New and Existing Systems

It is challenging to balance new systems with existing ones. Unless the mine site is a greenfield environment, the mining equipment typically has existing onboard systems that need to be incorporated and interfaced into the design (e.g., fleet management system, high-precision positioning system, asset health monitoring).

Upstream and downstream systems might also require uplift or improvements to interact with or support an autonomous system. These include:

- Assessing and ensuring a smooth interaction between manned and unmanned systems
- Improving communications network availability, reliability, throughput, bandwidth, latency, and coverage
- Identifying and removing single points of failure (i.e., components that, if they fail, halt the entire system) within the network
- Improving network routing, firewalls, and protocols
- Improving high-precision GNSS availability, reliability, accuracy, and coverage
- Improving data centre availability, redundancy, and capacity
- Improving computer and storage availability, reliability, and capacity

D.4 DOCUMENT LIST FOR THE DESIGN MANAGEMENT PLAN

This list includes documents that should be provided as part of the design management plan. This list is designed to be a starting point and specific documents will vary depending on the situation. Not all documents are required. Document deliverables:

Table 9: Document Deliverables

	Documents
Project Management	• Inspection and test plans • Audit schedules • Commissioning test procedures • Vendor technical specifications • Commissioning management plans and procedures • Construction and installation specifications • Manufacturing data sheets • Network requirements
Engineering	• Engineering and technical specifications • General arrangement drawings • Detailed engineering drawings (including electrical/wiring/cabling drawings) • Equipment listing (mechanical, electrical, instrumentation, controls) • System architecture drawings • Interface control document • Configuration and logic files • Human-machine interface • Performance testing and acceptance procedures • Network requirements
Risk Management	• Risk management plan and assessments (e.g., HAZOP, FMEA) • Root cause analysis
Operations Management	• Asset management plans • Quality management plan • KPIs • Installation, operation, and maintenance manuals • Material listing and certificates (including hazardous materials) • Stock and Spare Part management plan

D.5 COMMISSIONING ACTIVITIES LIST

To achieve the desired outcomes, some commissioning activities to consider (assuming the operational readiness study is complete) are described in the following table.

Table 10: Commissioning Activities

Activity	
System operator and system builder roles and responsibilities	• Boundaries agreed upon, defined, and documented • Commissioning tasks assigned to competent persons • Formal commissioning and handover process
Risk Management Process	• Understand technology and specific functionalities • Identify hazards specific to commissioning phase (e.g., safety critical lists) • Confirm appropriate controls are in place
Formal approvals process	• System builders • System operators • Regulators • Other stakeholders as required
Commissioning planning	• Communications and reporting plan • Commissioning project plan and timeline • Select and survey suitable commissioning area (e.g., segregated, isolated) • Checklists for installation, assembly, and commissioning • Change management plan • A shutdown plan
Commissioning test plan based on system builder recommended test procedures	• Safety systems tests • Operational performance tests • System integration tests • Documented test procedures
Functional and user acceptance testing conducted in line with documented test procedures	• Testing traceable to the system version or type to confirm systems meet system builders and operational requirements • Compliance with relevant standards • Test results are documented (e.g., pass, fail, defects, issues)
System acceptance formal process for managing unresolved defects and issues	• User acceptance based on system builder specifications • Training and competency assessment for various roles

APPENDIX E. LESSONS LEARNED AND CASE STUDIES

Below are examples of safety incidents that occurred at two mine sites, discussion of their root causes, and the lessons they learned.

For additional examples from Western Australia, see the following reports:

- Collision between an autonomous haul truck and manned water cart
- Autonomous truck significantly damaged by lightning strike
- Seeking safe mobile autonomous equipment systems

E.1 SITE A: AUTONOMOUS LOADER AND PERSONNEL INTERACTION

The incident occurred April 21st, 2018 in North America.

The control failure was a machine/pedestrian interaction underground. The mucking level was not properly cleared of personnel and the access barrier was not in place to prevent access to the level. Additionally, requirements for entering the loading area were not followed.

Safe operating procedures included lockout-tagout of barrier control panels when accessing levels, but it was unclear on specific uses in different situations.

The root cause was risk management, change management, and errors in procedure. Global fatal risk control standards do not currently consider autonomous equipment. Requirements for contacting the loader operator were also inconsistent.

The change management process for implementing new technology in existing operations was insufficient. Although the standard operating procedures and standard task procedures for autonomous operations were very specific, there were small discrepancies in the documents concerning testing the system within the exclusion zone.

Lessons Learned

- An essential-factors process was undertaken and showed we must continue to look to replace administrative (people-based/behavioural-dependent) controls with engineering controls.
- Administrative control risk mitigation for potential or known hazards requires frequent auditing for compliance and desired effect.
- There is currently no fatal risk management standard related specifically to autonomous operations.
- Accountability for personal behaviours must be consistent with policies and procedures.

E.2 SITE B: SEMI-AUTONOMOUS LOADER AND PERSONNEL INTERACTION

The incident occurred on June 27th, 2018, in Africa.

Remote loading operations were being conducted with a semi-autonomous loader. Operations started after fixing a problem with the laser barrier, which had tripped and caused the loader to shut down. Another trip-out occurred, requiring the operator to inspect the work area before resetting the barriers, but the operator could not ascertain the reason for the trip. Mucking operations continued. While reversing from the draw point, the operator observed reflections on the rear monitor. He stopped but could not identify the reflections. As the operator turned to tram to the stockpile, he observed two people some distance away with the front monitor. He shut the machine off to investigate and found two production drill operators in the exclusion zone. Figure 7 presents a visual of this event.

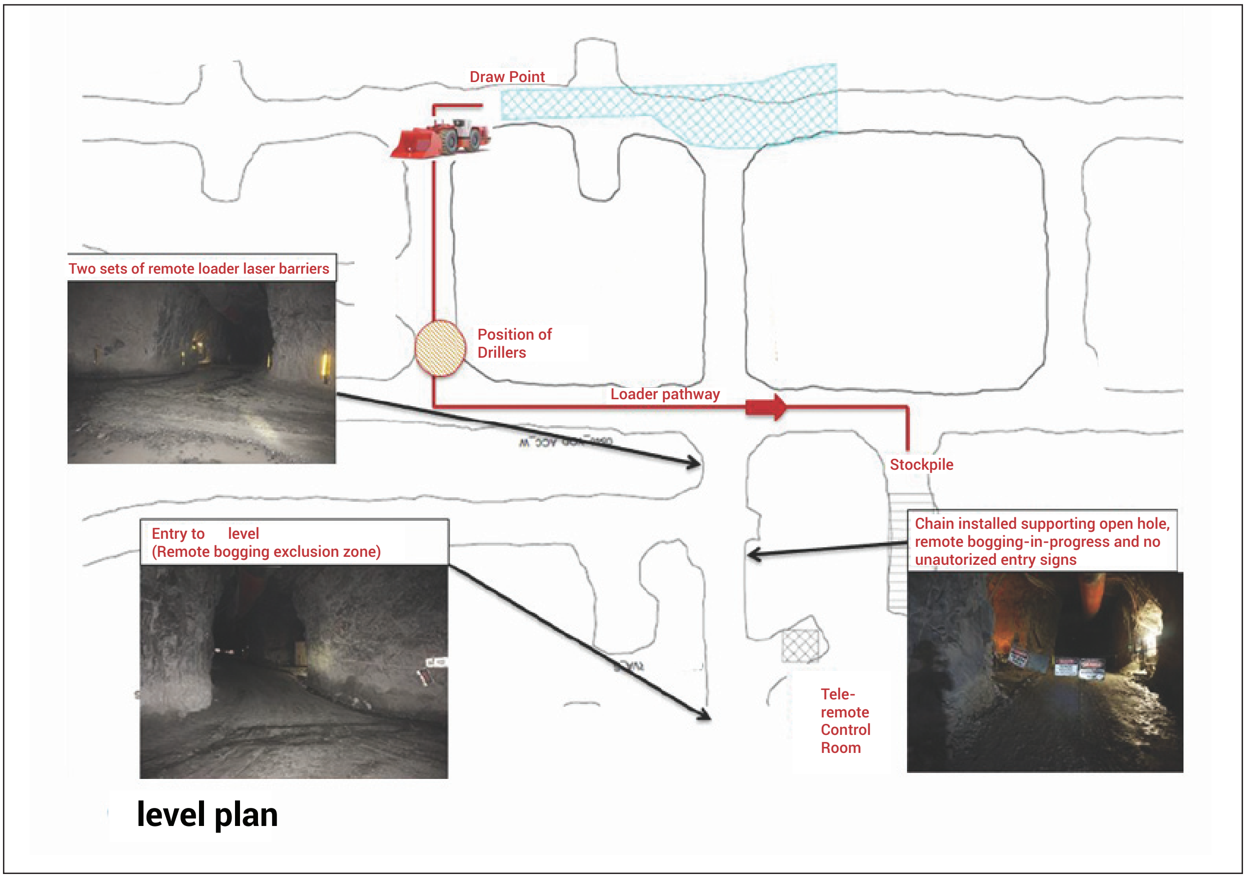

Figure 7: Visual of Semi-Autonomous Loader and Personnel Interaction (Provided by a GMG Contributor)

The control failure was a machine/pedestrian interaction underground. The laser barrier for the separation and exclusion zone was reset with personnel within the remote operation area. Personnel crossed the physical and electronic barriers while remote loading was in operation.

One cause was that the design and application of barriers allows them to be crossed for perceived authorized reasons. The standard operating procedures did not provide sufficient guidance on managing multiple laser trigger events. The laser system produced multiple false positives, diminishing the value of the control.

Lessons Learned

- Replace administrative controls with engineering controls to eliminate/reduce behavioural dependency.
- Standard operating procedures and training need to address all process changes, and personnel affected by that change need to be informed of how it could affect their work activities.
- The reliability of the laser detection technology needs improvement to minimize false positive trigger events. Processes also need to be in place for escalation when multiple trigger events occur and for clearing the area prior to resetting the laser barrier.
- Visual and audible alarms when the laser detection is triggered need improvement.