Defining Requirements for Implementing Autonomous Systems Underground Workshops Summary of Input

The list below compiles all the output from the three "Defining Requirements for Implementing Autonomous Systems Underground" held August 9, 16, and 24. The workshops covered the whole guideline but focused most on the operational readiness and deployment section because it was the section with the most specific detail.

Note that Section numbering is from v1 and has been adapted in v2. Notes to be added to the working draft for forthcoming content generation workshops.

The key themes that emerged from these workshops are:

- There will be specific infrastructure and design differences that will affect many aspects of implementation (e.g., size of equipment).
- Communications infrastructure is a key consideration for underground.
- Underground may require some different implementation approaches.
- There are additional regulations to consider for underground mining.
- Recoverability of equipment in the case of a breakdown is a key challenge with autonomous systems underground.
- There are different kinds of environmental conditions to consider underground.
- Human monitoring needs need to be augmented/considered

Recurring themes are in bold text.

6. COMMON TERMS OF REFERENCE

(*based on comments on TOC from Aug 24)*

- Consider scope definition: whole of mine (AHS) vs restricted isolated section
- Terminology around autonomous area, consider changing to work area

7. CHANGE MANAGEMENT

(*based on comments on TOC from Aug 24)*

- Might be harder to manage UG with many types of vendors and equipment.
- There may be some specific UG critical success factors.
- Change management for the system of the mine, but also from the OEM - not always captured by the mine. There needs to be an overarching process.

8. BUSINESS CASE

(*based on comments on TOC from Aug 24)*

- **UG-specific infrastructure considerations - maybe in cost or value drivers.**
- Would you design differently if not putting humans in?
- Interoperability, kind of equipment, various OEMs
- Longer term options in equipment purchase impacted by interoperability

9. HEALTH AND SAFETY

(*Aug 9 review of content and Aug 24 TOC review)*

- **Elaboration on the monitoring**
- More risks but the process would be the same
- Altitude an environmental health and safety consideration
- Stakeholder list: add communications/software stakeholders (e.g., manufacturers/distributors, service providers, system integrators, comms/software)
- Risk analysis: consideration of operational design domain
- Documentation: Nuances re. locations of autonomous/work areas
- Emergency Management Planning: should we have the option on what sort of infrastructure required to support it?

10. REGULATIONS

(*Aug 9 review of content and Aug 24 TOC review)*

- Examples would be useful on maturity in different jurisdictions
- Surface regulations tend to be more advanced than UG
- **Additional regulations or different/nuanced regulations may be required for UG**
    - Underground drone operation may not need aviation approvals based on country
    - May or may not need different radio frequency usage approvals
- Australia state regulators guidelines on functional safety, very superficial (note functional safety is out of scope of the guideline)
- Be mindful of regulations that are not typically mining related (GDPR, data handling, transport etc.)
- In situations of no regulations available, work with regulatory bodies to have a guidelines
- Check WA DMIRS regulation reference as it is currently being reviewed.

11. COMMUNITY AND SOCIAL IMPACT

(*Aug 9 review of content and Aug 24 TOC review)*

- Risk - sense of culture of working in UG might decrease
- Evolving workforce requirements: seek underground-specific case studies from those with known experience in this.
- Education: further detail or examples.

12. OPERATIONAL READINESS AND DEPLOYMENT

(*Content reviewed in all workshops)*

- Introduction
    - **Additional UG nuances re. implementation approach**
    - Additional UG nuances related to list of factors to determine upfront (cross referencing other sections)
    - Site automation/technology maturity level in relation to change management and cultural acceptance & adoption.
    - Skillsets & support resources required after implementation.
    - Add a bullet point to call out mining operational context as surface or underground.
    - Different requirements to address depending on isolated piece of equipment vs broad. Depending on scale, different considerations.
- Physical mine design:

  - Environmental conditions such as rock properties and their affect on communications
  - Underground-specific layout considerations such as tunnel size.
  - Need to include flexibility for unexpected findings with geology and/or metallurgy.
  - Mine geometry should include consideration for the equipment choice dimensions.
  - Ventilation requirements could include commentary around ventilation direction away from tip point to avoid driving through dust generated from bogging.
  - Design for barrier placement to segregate zones within an automation zone
  - Potentially amend "fuel" to energy source – for alternate "green/decarbonization" methods.
  - What optimizations can be considered when "using autonomy" - I.e., a traditional mine design may need to accommodate an environment fit for people which is a constrain which may be released.
  - Interoperability – evaluation of requirements, based on scale, mix of equipment required
- System infrastructure:
  - **Communications infrastructure: Consideration on how remote operations are dependent on communications infrastructure, additional nuances on redundancy, scalability, and compatibility. Communications, localization schemes and strategies.** Also Reference UG comms guidelines
    - Technology used for localization – no real standard. Can have types of infrastructure required for localization – cameras, markers, etc.
  - Mitigation plan/fall-back plan in case infrastructure goes down
  - IT infrastructure, further detail re. open data
  - Cybersecurity might have some specific UG nuances - Automation network integrity considerations – refer to cybersecurity guidelines.
  - Placement of antennas and clearance from equipment.
  - Check-in/out procedure to introduce equipment in & out of an automation zone.
  - Need to add more about Reliability, Availability, Maintainability, Survivability.
  - Determine what data, what we have a right to access, data ownership and access or shared concept. Could include data considerations and understanding of down-stream requirements
- Process planning:
  - **Human monitoring needs need to be augmented/considered**
  - All items might have some specific differences related to Underground Mining, considerations listed are far from complete. If there ends up being too much, some could be included in appendices
  - Automated equipment can operate during a blast without requiring a clearance of the blast zone.
  - Maintenance considerations
  - Illustrative examples of process planning recommended
  - Implementation strategies
  - Process of optimization - needs optimization of the automation system to get overall process improvement. Measurement, analysis and tweaking.
- Engineering design management:
  - **What to do in event of a breakdown – recoverability of equipment in unsupported area**
  - **Differences underground in terms of how design incorporates limitations imposed by environmental conditions.**

- Might be some nuances around safety system calibration and system uplifts.
- Secondary braking – autonomous zone ie. block cave mining, requirements at a draw point, can cause issues at adjacent draw points
- A detailed example of machine life expectancy to technology would be helpful.
- **Needs rework on key challenges for further explanation and clarity – there are specific challenges underground**
    - Communications and positioning
    - Lack of supervision underground
    - Equipment infrastructure and space constraints
    - Skilled personnel for maintaining and monitoring systems
    - Safety and productivity details – need to take a risk-based system safety approach
- Design management plan should reference System Safety
- Look at FMECDAs Failure Mode Effect, Criticality, and Detectability Analysis (re. the framework).
- Configuration management:
    - Essentially this is a focus on all configuration items (CIs) and should be under change control.
    - Development of a configuration management plan is advised.
    - Need to allow for broken communications. Vehicle configuration both directions. Configurations for bringing data collection back up
    - Interoperability between various systems from equipment to systems ie ventilation, etc
    - Radio frequency control

- Architecture (note: this section was slated for some restructure so most of these points have been noted in other sections of the guideline)
    - Decarbonization benefit (driver) – consider in business case, unsure if it will stay in this section for v2
    - Deeper mines bring additional challenges associated with people
    - Communication requirements more stringent in underground (consider in new comms infrastructure section)
        - Reconfiguration challenges
        - Ongoing bandwidth requirements
        - Infrastructure challenges
    - Location services (consider in new comms infrastructure section instead)
        - No defined standard – need to define a standard
        - GPS Denied Scenarios
    - Power distribution challenges
    - Unique environment
    - Future work: Localization systems
- Metrics and KPIs
    - Consider new ISO discussion?
    - Infrastructure utilisation – delays need to be incorporated into TUM (e.g. network latency)
    - Standardised way of measuring network performance
    - Consider options for trial deployment locations / site (not under production pressure)
    - Define safety KPIs

- Deployment and Commissioning
    - Ongoing operations and support
    - Change Management (culture)
    - Management of Change (process, procedures)
    - Guidance on realistic expectations on commissioning time
    - Optimization part of the commissioning process
- Other
    - Include safety use cases

Overarching Priorities

From group on August 24

- Kind of equipment. Definitions and specifications.
- Progression of autonomy and phases we need to go through. Addressing safety, interoperability, etc
- Getting info locked down and built into our roadmaps
- Useful to hear various perspectives. Going deeper into it will make it more useful. Interoperability!
- Safety, interoperability and data sides
- Interop – standard API or language to bring different OEM equipment together, new pieces of equipment into cycle without interrupting
- Mine planning and mine design for autonomy. Seen investigations because of mine design impacts
- Useful to understand the requirements
- Overarching change management is crticial – how to define internally, externally and jointly. How conversations flow, and what's the end game.
- Maturity piece – considering different maturity levels of different solutions coming together at a single operation. How to handle that.

Future work/parking lot:

- **How does electrification complement autonomous implementation?**
- Perhaps evolve "systems thinking" into a broader systems-based approach
- Physical Mine Design
    - Autonomous battery swap / storage for battery electric vehicles
    - Infrastructure for trolley assist
    - This physical mine design section generated further discussion on macro-categories of mining automation, four levels were discussed i) Not automated ii) automation and manned (separated) iii) automated and manned co-op iv) full automation – monitoring and control from the surface.
- Process: Dynamic dispatching to different draw points to optimize feed, not suitable to manual operations.
- Re. Deployment and Commissioning: Mine design changes to suit autonomous operations (LoM, Planning, Simulation, etc)
- TUM between surface and underground needs to be standardised
- ISO standard – consensus on what interoperability looks like. Multiple vehicle types within one barrier system. What that looks like.

- Infrastructure required around surface to underground transition ie trucks running from UG to surface – how the transition works and infrastructure required