Functional Specification

TITLE:	Oyu Tolgoi Tracking Device Functional Specification	DOC. NO.: TBA	REV. A

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1 INTRODUCTION

Oyu Tolgoi plans to procure tracking devices which are compatible with planned Vehicle Interaction Management systems.

The purpose of this Functional Specification is to define the requirements for the devices, in order to obtain capability, costing and general information required to procure them.

2 DELIVERABLES

2.1 Design

1. Concept design for a Tracking Tag and supporting System that satisfies the requirements outlined in this document;
2. Infrastructure and environmental requirements, tolerances and dependencies;
3. Information regarding dependencies, to ensure compatibility and integration with existing systems to ensure feature availability. (i.e. minimum versions and releases of existing equipment/systems);
4. List of all electrical and environmental standards that the equipment is compliant with;
5. List of applications available and what partners have been integrated with the solution;
6. Notes on stability, reliability, scalability and security of the solution;
7. Proprietary elements required or recommended for optimisation of the system;
8. Product information including datasheets and technical manuals for all proposed components, equipment and applications;
9. Details on any functional requirements criteria outlined in this document which are not satisfied;
10. A technology vision and road map indicating future development goals, including product life cycle;

3 TRACKING DEVICE

3.1 General Use Cases

Oyu Tolgoi wishes to use a range of tracking devices to improve safety and productivity of its underground mining operations. The following are the general use case uses.

1. Detection of the range to personnel and vehicles from a vehicle fitted with a suitable detector.
2. Detection of the location of personnel and vehicles relative to a vehicle fitted with a suitable detector.
3. Detection of the absolute location of personnel and vehicles relative to fixed infrastructure installed in the underground mine, using the fixed infrastructure.
4. Detection of the location of vehicles relative to fixed infrastructure installed in the underground mine, using on-board vehicle infrastructure.
5. Detection and monitoring of the status of personnel and vehicles via input to the tracking device, including buttons and sensors.

3.2 Common Requirements

The features and requirements in this section may be delivered within multiple devices in order to avoid single point of failure risk scenarios. Oyu Tolgoi currently utilizes a cap lamp including WIFI, V2X and BLE functionality, but seeks to evaluate whether all technologies should be combined in one device or whether multiple devices provides better redundancy, performance and flexibility.

3.2.1 Technology Requirements

1. Tracking devices must provide compatibility with all of the following technologies, but these may be delivered by a set of devices rather than a single device. Acceptable combinations are defined in section 3.3.
    a. Wireless LAN (802.11a/g/n/ac), for communication and low-accuracy location using Cisco wireless network infrastructure.
    b. V2X DSRC (802.11p), for peer-to-peer communication and medium-accuracy long-range location using V2X Road Side Unit (RSU) infrastructure.
    c. Bluetooth Low Energy (BLE), for communication and short-range location using BLE beacon infrastructure.
    d. IEEE 802.15.4 UWB, for high-accuracy medium-range location.
    e. EPC C1 Gen2v2 / ISO18000-63 RFID, either embedded in device or able to be flexibly attached (i.e. OPPIOT model OPPF5015 flexible label).
2. Tracking devices must provide access to low-level device functionality, data and events through open protocols or well documented APIs, as it is anticipated that the tags will be integrated to existing systems, corporate applications and third party infrastructure.

3. Tracking devices must not rely solely on third party cloud-based services, as the tracking system must be capable of operating standalone and within an isolated network.
4. Management, support and upgrade functions may be delivered as cloud-based services if they are not required during normal operation.

3.2.2 Location and Ranging Requirements

1. Tracking devices shall store the unique device ID in on-board persistent storage.
2. Tracking devices shall make the unique device ID and assigned personnel or equipment ID available to detectors via location and communication protocols.
3. Tracking devices shall support the storage of the unique device IDs of paired tracking devices, if used as part of a redundant set.
4. Tracking devices shall alarm if other paired tracking devices are not in proximity or malfunctioning (i.e. lost or damaged).
5. Tracking devices shall transmit the IDs of paired devices to detectors for validation.
6. Tracking devices shall support the detection of BLE beacons in close proximity, along with the transmission of beacon IDs to detectors. These may be used to indicate safe or muting zone occupancy, or to trigger a specific behaviour in the tracking device.
7. Tracking devices shall be detectable at a range of not less than 60m from the detecting vehicle in a straight or curving tunnel with line-of-sight between tracking device and detector.
8. Tracking devices shall be detectable to better than 5m accuracy by detecting vehicles at a range of not less than 30m around a 30°, 60°, 90°, 120° and 150° intersection.
9. Tracking devices shall be accurately detectable to better than 1m accuracy when within 20m of a detecting vehicle.

3.2.3 Physical and Environmental Requirements

1. Tracking devices shall be physically labelled with a unique device ID (typically MAC address).
2. Tracking devices shall be suitable for use in a metalliferous underground mining environment:
    a. Tracking devices shall be sealed to Ingress Protection rating of IP67 (EN 60529).
    b. Connectors and charging interfaces shall tolerate dust, dirt and contamination.
    c. Devices shall tolerate shock and vibration (IEC 60068-2-27, IEC 60068-2-6).
    a. Devices shall operate in ambient temperatures of -20°C to 50°C.
3. Where possible, tracking devices should be designed for use in explosive atmospheres (IEC 60079-35-1, IEC 60079-35-2, and IEC 80079-34).

4. Tracking devices should weigh under 200g if mounted on a helmet, clip or pouch, or under 500g if mounted on a belt.

3.2.4 Performance and Functional Requirements

3.2.4.1 Battery Requirements

1. Tracking devices shall operate continuously for a minimum of 16 hours, within the stated device operating life.
2. Tracking devices shall have an operating life of over 2 years before battery or other component replacement is required.
3. Tracking devices shall recharge fully in under 10 hours.
4. Tracking devices shall provide battery monitoring and management to extend life when transmission is not required.
5. Tracking devices shall have documented battery cycle service life curves in relation to depth of discharge, for estimation of device or battery refresh periods.
6. Tracking devices should provide the facility to replace batteries, if this can be achieved without compromising physical and environmental tolerance requirements.

3.2.4.2 Input and Notification Requirements

1. Tracking devices shall have at least on button for user input, which may trigger different functions depending on length or frequency of activation.
2. Tracking device shall have audible alert and alarm functions sufficient to be heard by the wearer over the background noise of operating vehicles and plant, which may be above 90dBm.
3. Tracking devices shall have a means of indication to the wearer that the tag remains healthy, which operates at a configurable interval not less than every 5 seconds.
4. Tracking devices should have a vibrate function, if feasible based on their form factor.
5. Tracking devices shall have a multi-colour indicator light which is obvious to the wearer in the underground environment.
6. It must not be possible to disable tracking device functions while in operational areas of the mine (or at all times when off the charger).
7. Tracking devices may have a display screen for messages, alerts and warnings, if feasible based on their form factor.
8. Systems and display devices must support English and Mongolian (Cyrillic alphabet).
9. Tracking device information display minimize the likelihood of the information becoming obscured through dust, dirt and scratches through normal activities of the mine workers.

3.2.5 Reliability and Usability Requirements

1. Tracking devices shall be robust enough to prevent accidental damage through the normal activities of mine workers.
2. Tracking devices will support safety critical activities such as evacuation and emergency response, and should be designed to be reliable and where possible fault tolerant.
3. Chipsets, firmware and software must be reliable and where possible fault tolerant.
4. Integration with other systems should be implemented in a redundant fashion where possible, and faults or degradation of device functionality should produce alerts.
5. Tracking devices may be included in Functional Safety assessments as a layer of protection, and as such should by designed with awareness of relevant standards such as IEC 61508 and ISO 21815 (currently in draft). Compliance is not yet mandatory, but supporting reliability data and documentation supporting the Functional Safety process is desirable.
6. The storage and display of any information via the tracking device shall support both English, French and Mongolian (using the Roman and Cyrillic alphabets).
7. Tracking devices shall be designed to be worn by personnel for the full duration of their 12 hour shift and shall be designed to securely mount to the person's body, belt, clothing or helmet.

3.2.6 Standards Compliance

Devices and supporting infrastructure should comply with Australian and Mongolian regulatory requirements, which may include:

- IEC/EN 60950: Information technology equipment - Safety – General requirements
- EN 61000-6-2: General standards – Immunity for industrial environments
- EN 61000-6-4: Generic standards – Emission standard for industrial environments
- EU LVD (Low Voltage Directive), EMC (Electromagnetic Compatibility Directive)

Tags fitted to mobile equipment shall conform to the relevant sections of the following standards:

- IEC/EN 60204-1: Safety of machinery - Electrical equipment of machines - General
- ISO 13766: Earth-moving machinery - Electromagnetic compatibility
- IEC 60068-2 series: environmental tests for shock, vibration and other required parameters, selected as appropriate to the type of equipment or mounting.

Tags shall comply with regulatory emissions limits and recommendations related to explosives and detonators. Generally, a limit of 1W EIRP is required for use in close proximity to explosives, but more specific standards may be applied.

3.2.7 Additional V2X Specifications

1. V2X chipset must comply with Cohda Wireless V2XLocate Specification v1.1 (CWD-P0005-RAD-SPEC-WW01-604-V2XLocate_802.11p_Tag_Ranging_Specification.pdf)
2. Devices should monitor V2X when no vehicles are in range, publishing defined packet at a configurable interval (i.e. 5s). If vehicles are detected in range, packet publishing rate should change rate to a more frequent configurable interval (i.e. 250ms).
3. Devices should monitor V2X when vehicles are in range, publishing defined packet at a configurable interval (i.e. 250ms). If no vehicles are detected in range for a configurable period, packet publishing rate should change to a less frequent configurable interval to conserve power.
4. If a specific device button combination is activated (i.e. 3s long-press), device should publish 'vehicle stop' in packet payload on V2X, indicating surrounding vehicles should stop all movement.
5. If a specific device button combination is activated (i.e. 3 fast presses), device should publish a 'user safe' in packet payload on V2X, indicating to surrounding vehicles that the user is in a safe location such as an Oyu Tolgoi 'safety bay'. In a caplamp device this function may be triggered by a switch to low-beam light mode.
6. If a safe zone beacon is detected within very close range (i.e. via BLE, V2X or UWB), device may publish 'user safe <location>' in packet payload on V2X, indicating that the user is in a defined safe location and vehicles may pass without risk.
7. If a risk to the user is detected via the device (i.e. man-down), device may publish 'user emergency' in packet payload on V2X, indicating that the user is in danger and vehicles may not pass without risk.

3.2.8 Additional WIFI Specifications

Tracking devices should have the ability to connect to WIFI as a client, in order to implement two-way signalling functionality and over the air (OTA) bulk update of configuration and firmware.

3.2.8.1 Two-Way Signalling (Down Stream)

1. Tracking devices should be available with a default configuration defined by Oyu Tolgoi.
2. Tracking devices should connect to WIFI at a configurable interval (i.e. 20s)
3. Once connected to WIFI, devices should connect to an Oyu Tolgoi provided publish/subscribe server (i.e. MQTT, MuleSoft AnyPoint) and publish all available status parameters (connected/visible APs, RSSI, battery voltage/level, movement history, light and button status).

4. While connected, devices should check for specific published messages (i.e. emergency, group or individual message), and optionally trigger an indicator, behaviour or message on the device. Examples include:
    a. Emergency message (down stream): Device indicator or light should flash a warning pattern indicating that user should evacuate, and audible or vibrating and message alerts should be activated if available.
    b. Group or individual message (down stream): Device indicator or light should flash a message pattern indicating that user should contact the control room.
5. On receipt of a message a user should be able to acknowledge receipt by holding down a button for a configurable interval.

3.2.8.2 Two-Way Signalling (Up Stream)

1. If a defined device button is held down for a configurable interval (i.e. 5s):
    a. Device should immediately connect to WIFI and provide publish/subscribe server.
    b. Device should publish an emergency message to a specific channel along with device and user identification information (i.e. caplamp ID, user ID, emergency), along with normal status update parameters.
    c. Once communication is successful device should indicate successful emergency notification.
2. If a risk to the user is detected via the device (i.e. man-down), device should connect to WIFI and publish user emergency message to a specific channel along with device and user identification information (i.e. caplamp ID, user ID, emergency type), along with normal status update parameters.

3.2.8.3 Docked Functionality

1. When in charging dock devices should provide factory reset functionality via a physical device button combination (i.e. long press, multiple press in specific period).
2. When in charging dock and at greater than a defined battery level (i.e. 50%), devices should connect to WIFI and check for firmware and configuration updates from a server.
    a. Firmware upgrade may need to be set as fully automatic or manually activated, to allow controlled deployment to devices. For manual deployment devices would stay connected and indicate the availability of an upgrade via an indicator, but only apply firmware when triggered by user via a physical device button combination (i.e. long press, multiple press in specific period).
    b. Configuration update should be possible to be set as fully automatic or manually activated, to allow controlled deployment to devices. For manual deployment devices would stay connected and indicate the availability of an update via an indicator, but only apply configuration when triggered by user via a physical device button combination (i.e. long press, multiple press in specific period).
    c. Upgrade and configuration mode status should be indicated on the device (i.e. flashing indicator).

3. When in a specific diagnostic/configuration charging dock devices should provide configuration functionality via USB, Bluetooth or other physical connection, as a backup mechanism in the event of OTA update failure. This dock should also provide diagnostics functionality which can be used to perform device tests.
4. The configuration and update process may make use of the OT provided pub/sub server as is used for status updates and messaging.

3.3 Device Requirements

3.3.1 Personnel Tracking Devices

The Personnel Tracking devices are intended for use by all personnel working in the underground mine. Multiple form factors may be required to suit different locations, job roles and to address single point of failure risks.

1. Tracking devices must be physically suitable for the underground mining environment and intended use, including:
    a. Tolerance to a 2m drop onto concrete;
    b. Tolerance to immersion in water, as well as dirt and dust (ingress protection rating of IP67);
    c. Tolerance for operation in ambient temperature of -20°C to 50°C.
2. Tracking devices must allow charging via a rack or wireless charging system, or have a battery life in excess of two years.
3. Tracking devices must operate while the wearer is moving at up to 10km/h on foot, or 40km/h in a vehicle.

3.3.1.1 Personnel Tracking Device Variants

Tags for use in a variety of locations and scenarios should be provided. Multiple variants may be proposed as a set, which collectively provides all required technologies. Tracking devices for light vehicles may also be required to comply with the requirements of this document, but detailed requirements will be defined elsewhere.

The inclusion of acceleration, temperature, humidity and gas sensors for environmental and user status monitoring is desirable, along with support for configurable alerts based on them.

3.3.1.1.1 Cap Lamp

1. Tracking device should be a cap lamp, or a module suitable for integration in a cap lamp.
2. Cordless cap lamps are preferred, but corded will be considered based on justification.

3. Tracking cap lamps should include monitoring of lamp and button status, to detect lamp failure or trigger of an emergency, via configurable button press action.
4. Tracking cap lamps should include the ability to control the lamp, to indicate an emergency situation to the wearer via configurable behaviour (i.e. emergency flash pattern).
5. This tracking device variant must provide compatibility with all of the following technologies:
    a. Wireless LAN (802.11a/g/n/ac).
    b. V2X DSRC (802.11p).
    c. Bluetooth Low Energy (BLE).
6. This tracking device variant may additionally provide compatibility with the following technologies:
    a. IEEE 802.15.4 UWB for high precision ranging and communication.
    b. V2X 3GPP (C-V2X).
7. If the device does not provide UWB high-accuracy tracking it must be proposed in combination with another wearable tracking device which includes this technology.

3.3.1.1.2 Helmet Mount

1. A tracking device variant which is suitable for mounting on a mining helmet.
2. Proposals for this variant should include mounting mechanisms and instructions specific to the current Oyu Tolgoi helmet model (MSA V-Guard type 1 Industrial helmet).
3. The tracking device should be securely attached but simple to detach, as it may be issued from a Kiosk as PPE.
4. This tracking device option must provide compatibility with all of the following standards:
    a. IEEE 802.15.4 UWB for high precision ranging and communication.
    b. Bluetooth Low Energy (BLE).
5. This tracking device option may additionally provide compatibility with the following technologies:
    a. Wireless LAN (802.11a/g/n/ac).
    b. V2X DSRC (802.11p).
    c. V2X 3GPP (C-V2X).

3.3.1.1.3 Helmet

1. A tracking device variant which is integrated to a helmet.

2. Proposals for this tracking device variant should provide detailed information on battery life and proposed charging and support infrastructure and procedures.
3. This tracking device variant should provide detailed information on input and notification mechanisms (i.e. buttons, integrated speakers, LED indicators).
4. This tracking device option must provide compatibility with all of the following standards:
    a. Wireless LAN (802.11a/g/n/ac).
    b. V2X DSRC (802.11p).
    c. IEEE 802.15.4 UWB for high precision ranging and communication.
    d. Bluetooth Low Energy (BLE).
5. This tracking device option may additionally provide compatibility with the following technologies:
    a. V2X 3GPP (C-V2X).

3.3.1.1.4 Belt Mount

1. This tag option must be available which is suitable to be carried in a belt pouch or on a belt, either by itself or combined with existing Oyu Tolgoi Gas Monitor pouch (dimensions available if required).
2. The tracking device should be firmly attached but simple to detach, as it may be issued from a Kiosk as PPE.
3. This tag option must provide compatibility with all of the following standards:
    a. Wireless LAN (802.11a/g/n/ac).
    b. V2X DSRC (802.11p).
    a. IEEE 802.15.4 UWB for high precision ranging and communication.
    b. Bluetooth Low Energy (BLE).
4. This tracking device option may additionally provide compatibility with the following technologies:
    a. V2X 3GPP (C-V2X).

3.3.1.1.5 Pocket Clip or Armband

1. This device variant should be suitable to suitable for attachment to a shirt pocket or an armband.
2. This tracking device variant should provide detailed information on input and notification mechanisms (i.e. buttons, vibration, integrated speakers, and LED indicators).

3. The tracking device should be firmly attached but simple to detach, as it may be issued from a Kiosk as PPE.
4. This tracking device option must provide compatibility with all of the following standards:
    c. IEEE 802.15.4 UWB for high precision ranging and communication.
    d. Bluetooth Low Energy (BLE).
5. This tracking device option may additionally provide compatibility with the following technologies:
    b. Wireless LAN (802.11a/g/n/ac).
    c. V2X DSRC (802.11p).
    d. V2X 3GPP (C-V2X).

3.3.1.2 Modes of Operation

3.3.1.2.1 Normal

When battery charge is nominal the tracking device should broadcast data packets at a configurable interval while stationary, and another interval while moving. Transmission intervals should be configurable for WIFI, V2X, UWB and BLE networks.

3.3.1.2.2 Vehicle Proximity

When the tag is in proximity to vehicles tracking device should broadcast data packets at a configurable (short) interval designed to allow vehicle proximity and collision detection systems to avoid an unsafe situation. Data packets should indicate the proximity status, in order to allow proximity and collision detection systems to confirm tracking device proximity and react to avoid an unsafe situation.

3.3.1.2.3 Vehicle Cab

When the tag is in a vehicle cab the tracking device should broadcast data packets at a configurable (long) interval designed to preserve battery life in order to achieve the defined operational lifespan. Data packets should indicate the cab status, in order to allow proximity and collision detection systems to ignore the operator as being safe in a cab.

3.3.1.2.4 Standby

When battery charge is below a threshold the tracking device should broadcast data packets at a reduced interval designed to preserve battery life in order to achieve the defined operational lifespan. Data packets should indicate the low battery status, in order to allow vehicles in proximity to avoid an unsafe situation by slowing or stopping.

3.3.1.2.5 Charging

When tracking device is on charge it should broadcast data packets at a reduced interval. Data packets should indicate the battery charge status, in order to monitor charging readiness.

The tracking device should accept updates to configuration while on charge.

The tracking device should also allow transition to upgrade mode while on charge, in order to accept firmware updates. This may be triggered by some form of user input.

3.3.1.2.6 Upgrade

When tracking device is on charge and in Upgrade mode it should accept firmware upgrades.

The tracking device should allow transition back to Charging mode when firmware upgrades are complete.

3.3.2 Equipment Tracking Device

The Equipment Tracking Device is intended for use on mobile equipment in the underground mine. Multiple device form factors may be required to suit different classes of vehicle.

1. The devices must be suitable for fitment to underground mining vehicles, including:
    a. Compliant to equipment shock and vibration standards (IEC 60068-2-27 and IEC 60068-2-6);
    b. Compliant to electrical safety standards for earth moving machinery.
    c. Compliant to EMC standard for earth moving equipment (ISO 13766).
    d. Tolerance to high pressure washing, sealed at a minimum to IP66 (IP68 is desirable);
    e. Connectors should be suitable for earth moving machinery use (i.e. Deutsch, M12 or MIL).
    f. Tolerance to ambient temperature of -20°C to 60°C.
2. The tracking device must accept power from a 9-36VDC vehicle supply, for charging of internal battery.
3. The tracking device should provide one month of battery life, at standby update frequency.
4. The tracking device should provide 48 hours of typical use on a single charge, at normal update frequency.
5. The Tag should operate while the vehicle is moving at up to 40km/h.

3.3.2.1 Modes of Operation

3.3.2.1.1 Normal

When battery charge is nominal, the tracking device should broadcast data packets at a configurable interval while stationary, and another interval while moving. Transmission intervals should be configurable for WIFI, V2X, UWB and BLE networks.

Data packets should indicate the battery charge status, in order to monitor charging readiness.

3.3.2.1.2 Standby

When battery charge is below a threshold, the tracking device should broadcast data packets at a reduced interval designed to preserve battery life in order to achieve the defined operational lifespan.

3.3.3 High-Accuracy Beacon Device

The Fixed Beacon Device is intended for use around open holes, hazards and to provide other standalone zones of control.

1. The device must be suitable for fitment to underground mining vehicles, including:
    a. Tolerance to high pressure washing, sealed at a minimum to IP66;
    b. Tolerance to ambient temperature of -20°C to 50°C.
2. The device must accept power from a 9-56VDC supply, for charging of internal battery.
3. The device should provide 72 hours of typical use on a single charge, at normal update frequency.
4. The device should provide configurable data parameters which can be used to indicate the hazard or functionality required to be implemented by receiving tracking devices.
5. This device must provide compatibility with all of the following standards:
    a. IEEE 802.15.4 UWB for high precision ranging and communication.
    b. Bluetooth Low Energy (BLE).

3.3.3.1 Modes of Operation

3.3.3.1.1 Normal

When battery charge is nominal, the device should broadcast data packets at a configurable interval. Transmission intervals should be configurable for WIFI, V2X, UWB and BLE networks.

3.3.3.1.2 Standby

When battery charge is below a threshold, the tag should broadcast data packets at a reduced interval designed to preserve battery life in order to achieve the defined operational lifespan.

3.3.4 Short-Range Beacon Device

This device is intended for use in Safety Bays, to provide confirmation that personnel are inside the safe area when vehicles pass.

1. The device must be suitable for fitment to a rock wall via bolt (i.e. has a flange mount or similar).
2. The device should be suitable for use in underground mining tunnels, including:
    a. Tolerance to water and dust ingress, sealed at a minimum to IP65;
    b. Tolerance to ambient temperature of -20°C to 50°C.
3. The device should provide 2 years of typical use on a single battery.
4. The device should provide configurable data parameters which can be used to indicate the hazard or functionality required to be implemented by receiving tracking devices, along with the zone size the device protects.
5. This device must provide compatibility with Bluetooth Low Energy (BLE) Beacon protocol.
6. This device may provide compatibility with WIFI, V2X and UWB, but it is anticipated that these may pose challenges to achieving the battery life requirement.

4 TRACKING DEVICE MANAGEMENT SYSTEM

4.1 General

The tracking device management system provides location tracking and device management services to the tracking devices.

1. The tracking system should log all faults and events.
2. The tracking system should provide management of tracking devices, allowing them to be configured, upgraded, diagnosed and disabled in bulk remotely.
3. The System should provide the facility to log and monitor all factors affecting performance and delivery of requirements (e.g. tag battery level, hardware and communication faults).

4.2 Data Interfaces

The System is intended to integrate with other tracking and management systems. It must integrate to the following primary systems for real-time data access, using well defined open standards and protocols. Connection may be to either of the systems below:

1. Low Precision Tracking System (Cisco CMX).
2. High Precision Tracking System (V2X to RSU or OBU)
3. Underground Location Services (UGLS) platform. (ZeroMQ, MQTT, Mulesoft AnyPoint or JSON)

4.3 Test Stations

The system should include test stations capable of validating the operation and assignment of tracking devices.

4.4 System Management

1. The system shall be able to interface with third party systems to import personnel records and to push location data to external systems for alerts, notifications and reporting.
2. The system shall be capable of creating additional fields to associate company specific records such as SAP ID, HID Card identifier etc.
3. The system must provide easy tag assignment functionality so the tag to personnel or asset association can be updated at the start and end of the shift.
4. The system shall be able to integrate with LDAP directory (Active Directory) for single sign-on.
5. The system should be able to import third party data such as passive/active RFID, asset tracking information.
6. The system shall provide the following infrastructure and tag management functionality:

a. Tag configuration and status monitoring
b. Tag diagnostic and fault detection
c. Tag battery management
d. Zone-specific tag behaviour management (if required)

7. The system shall provide historical data storage and basic analytics capability

5 SUPPORTING SYSTEMS

5.1 Wireless Access Network

The Wireless Access Network is based around Cisco industrial wireless access points and controllers, and provides 802.11a/b/g/n/ac wireless networking throughout the underground mine. This system can identify participating WIFI clients and tracking tags, providing source data for the Low Precision Location System.

5.2 Personnel Location Identification System

The Personnel Location Identification (PLI) System provides location accuracy of approximately 50m for vehicles and personnel within the underground mine. It operates using Cisco WLAN Controllers, CMX and Rio Tinto's Mine Automation System (MAS).

5.3 V2X Network

The OT V2X Network is based around V2X road side units (RSUs), and provides 802.11p wireless peer-to-peer networking throughout the underground mine and between all heavy equipment. This system can also provide ranging between participating V2X devices and compatible tracking tags, providing source data for the High Precision Location System.

5.4 High Precision Tracking System

The High Precision Location System provides location accuracy of approximately one metre for vehicles within the underground mine. It makes use of the V2X network for time of flight ranging to vehicle on-board units.

5.5 PPE Allocation System

The PPE Allocation System tracks the issue of Self Contained Self Rescuers (SCSRs), Cap Lamps, Gas Monitors and other PPE to workers. The PPE Allocation system links user ID with issued devices using an ID card swipe reader.

5.6 Mine Access Control System

The Mine Access Control System controls access to the underground mine, ensuring that all personnel have the appropriate PPE (including Tracking Tags), authorisation and training.

5.7 Vehicle Control System

The Vehicle Control System reads vehicle status and health via installed telemetry and interacts directly with the vehicle to control specific vehicle functions such as gear selection, throttle position, engine retarder, service and emergency braking systems to provide control over vehicle speed and ultimately stop the vehicle. The VCS does not provide any sensing technology, yet is able to receive and respond to crawl and stop input commands from the PDS.

5.8 Collision Warning/Avoidance System

The Collision Warning/Avoidance System (CxS) applies detection technologies to identify people and vehicles in the vicinity of the enabled host vehicle. The system may be configured to provide warning to the operator of the vehicle about the presence of surrounding people or vehicles, provide warning to personnel within the detection range or both. The CxS may issue commands to the VCS in response to detection of personnel, vehicles or other hazards.

6 DEFINITIONS

6.1 Accuracy and precision

Determining the position of an object is based on measurements and observations which are all subject to noise and uncertainty. When measurements are combined to compute an estimate of the position, the result has a probability and error margin associated with it. Some definitions are a useful start in evaluating position accuracy. The terms are defined as follows by (Bartlett, 2013):

'**Ground truth**' is the actual position within the coordinate system.

'**Accuracy**' is a statistical measure of the deviation between the estimated position and the ground truth for the device. For example, the military measure CEP (circular error probability) of 2.5m would state that 50% of the estimated positions lie within 2.5m of the ground truth.

'**Precision**' is a statistical measure of the distribution or scatter of estimated positions without reference to a known ground truth. A CEP of 2.5m would state that 50% of estimated positions lie within a 2.5m radius circle, but does not state where the centre of the circle is located.

'**Resolution**' is used to define the numerical resolution of the position. A system might output the estimated position to 1mm, yet have a specified accuracy of 2.5m.

Incorporating location system outputs into safety critical applications such as collision avoidance requires highly accurate positioning estimates, with well-defined measures of accuracy. The following measures are common, but for safety applications it is also important to know whether the performance statistic is drawn from only those positions reported, excluding failed measurements. In very rare occasions the measurements outside the stated circle of probability may not be normally distributed, meaning they could be wildly inaccurate.

Common statistical measures of accuracy

Accuracy Measure	Probability (%)
Root mean square (RMS)	63 to 68
Circular error probability (CEP)	50
Twice the distance root mean square (2DRMS)	95 to 98
95% radius (R95)	95