MANDELA MINING PRECINCT
MINDS FOR MINES

Drilling, Charging, and Blasting management systems – Phase II

PROGRAMME	Longevity of Current Mines	**WORK PACKAGE**	LoCM24WP2MS6 Optimise Drilling, Charging, and Blasting management systems

FINAL REPORT

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1 EXECUTIVE SUMMARY

This LoCM24WP2, milestone report (MS6) with deliverable Research Findings forms part of the research effort to develop a laboratory demonstrator for an integrated Drilling, Charging, Blasting and Measuring Management System (DCBM) solution, specifically for a deep-mining operational context, without supporting ICT underground infra-structure. This report concludes the research project and summarises the key findings of the research performed during this work.

Conceptual design criteria and requirements were established during the initial stage of the project. A laboratory integrated DCBM test model was developed and was used to test the product integration and assess each product and its capabilities according to the technical readiness levels criteria.

From the research findings, the first outcome proved that the integrated DCBM test model performed well and was stable during lab-tests. The DCBM demonstrated the ability to operate successfully without an underground ICT backbone capability, which is a unique solution for the South African deep mining. The second outcome demonstrated that the portable stope controller, the human machine interface tablet and software, the hole measuring device, the particle size scanner and the automated charge filler and drill machined interface are compliant to the technical readiness levels ranging from TRL3 to TRL7.

2 AIM OF RESEARCH PROGRAMME

This project is a continuation of the work package LoCM23WP3 (Phase I) work. The Phase II aimed to research and develop the identified technology products to align with the established industry criteria and requirements as defined in Phase I.

The establishment of a cost-effective solution for integrated drilling, charging, blasting, and ore-measurement management (DCBM) capabilities, especially for a modernised deep-mining environment, has been explored during this research project. A set of high-level requirements has been defined from the research learnings. This research project has focused mostly on the laboratory design, Technical Readiness Level (TRL) 3 of an integrated Drilling, Charging, Blasting, and Measuring Management System (DCBM) solution, pathing its way to a suitable solution for use within mining operations in South-African mines, such as gold- and platinum mining operations. The solution also caters to mining operations that do not have supporting ICT infrastructure installed up to the stope area.

3 METHODOLOGY USED

The work package deliverables consisted of 6 milestone deliverables, these are:

3.1 Inception Report (MS1)

This deliverable aimed to quantify the proposed project research deliverables, utilising a team of collaborators to conduct research-orientated milestone deliverables, with participation of mining personnel, which shall be followed to accomplish the research objectives of the project**.**

A 4 stepped approach was decided, as follows:

- ***Identify research partners and present inception concept:*** This step has focused on the identification of possible industry technology partners, mainly to collaborate with the project research team to establish a laboratory-based DCBM demonstrator. Collaborators were identified that could contribute intelligent stope drilling, stope charging and blasting technologies which could be integrated into a DCBM, suitable to be used in deep-mining stope conditions***.***

- ***Conduct a start-up work session with research partners***: This is to liaise with mining expert advisors and possible industry technology suppliers willing and able to contribute technologies towards the research effort. Work sessions/discussions have been conducted with Mr. Jaco Gouws, from Harmony Gold to elicit the operational requirements from a mining client/users' perspective. The project team has also presented the suggested research approach (see Appendix A) to him for review inputs.

  Specific technical discussion sessions have also been conducted with possible technology suppliers of drilling, charging, blasting and ore-measurement technologies to explore possible collaboration possibilities.

- ***Define the research process:*** With Step 1 (Identify research partners) and Step 2 (Systems Engineering process) completed, defining the requirements baseline will also require input from expert mining engineering specialists as part of Step 3, which is provided by the University of Pretoria's mining engineering specialists. On completion of Step 3, it was realised that the laboratory computerised network platform (BASE network) could be integrated by the research partner Cybarete.

- ***Establish a laboratory DCBM demonstration platform:*** The establishment of the DCBM demonstration platform shall entail the interpretation of the requirements defined during the previous research work. The requirements shall be analysed to result into a conceptual architectural solution of a laboratory implementation of the integrated DCBM, to be used in future at a stoping workplace environment. The conceptual architecture shall be converted into software code, which could run on the BASE network platform, which shall hence demonstrate the integrated capabilities of the DCBM system.

3.2 Requirements Specification and Test Criteria (MS2)

This deliverable was based on research work, to establish mining stakeholder requirements w.r.t the optimisation of reporting and capturing data in an integrated management system for the application of digitally measuring mining drilling, charging and blasting operational practices. The objective was to analyse existing products with capabilities to digitally measure production activities and consequently establish the definition in the operational context the various processes and then to derive the high-level system functional- and interface requirements for a future envisaged Drilling, Charging, Blasting and Measuring Management System (DCBM) solution system. The continuous focus was to take cognisance of the operational constraints of the confined workspace environment in the stope areas in its non-mechanised nature of the mining conditions.

The research methodology was focused on a Systems Engineering (SE) approach in the elicitation of mining client requirements for mining application (e.g. gold) and specifically related to a possible integrated management system solution. The potential outcome of the research effort shall be evaluating the implementation of a laboratory conceptual solution within a simulated laboratory environment.

3.3 Process Definition and Mapping (MS3&MS4)

This milestone had two deliverables, which firstly aimed to define the process to develop the workflow framework to illustrate the main activities and sub-activities involved in the drill and blast process in a conventional underground hard-rock mining environment. Secondly to map the process to include key data points to be collected at each stage of the process that will affect the design and its implementation to achieve a specific outcome/result to the workflow framework.

The methodology implemented to develop the workflow framework in this report is as follows:

- Literature study to identify available technologies or define the requirements for innovative technologies that may need to be developed for data collection in the NRHR mining environment;
- A brief analysis of the findings of the literature review and mapping of relevant OEMs to approach further development and collaboration;
- Define the workflow process that will integrate identified technologies towards capturing the measurements; and
- Define the process and map out current operations and processes to define a workflow framework to form the basis of an integrated ADCB management system network towards optimisation.

3.4 Development of the BASE Network Platform Management System (MS5)

Again, two milestone deliverables derived from this work, with the first deliverable which centred on developing the architecture for the *Drilling, Charging, Blasting, and Measurement (*DCBM) solution and demonstrating how the BASE platform integrates and operates within the system. To ensure successful deployment in a typical underground mining environment, we analysed the mining conditions to identify appropriate hardware. After this analysis, the necessary equipment was selected and procured.

To ensure successful deployment in a typical underground mining environment, the team analysed the mining conditions to identify appropriate hardware. After this analysis, the necessary equipment was selected and procured. The approach taken was founded on the systems engineering development process, integrating both theoretical design and practical considerations to create a preliminary DCBM solution for stope management, consisting of the following processes:- Requirements Analysis; High-level Systems Architecture Design; Hardware Analysis and Selection; and BASE Platform Design.

3.5 Research Findings (MS6)

The last deliverable concludes the research project and summarises the key findings of the research performed during this work. The key findings were elicited during the research stages and highlights key observations that should be pursued during a next research stage. The focus of this research stage was to demonstrate the viability of a laboratory-model integrated future Drilling, Charging, Blasting and Measuring Management System (DCBM) solution system baseline, which could be matured during follow-up research stages.

4 CONCEPTUAL DESIGN CRITERIA

4.1 Overview of DCBM integrated solution

A systems approach was utilised in executing and integrating the outputs of the various research work stage outputs of the research partners UP and Cybarete. A conceptual solution was initially explored, then integrated into a DCBM laboratory demonstrator solution (Figure 1) which could be tested for future viability.

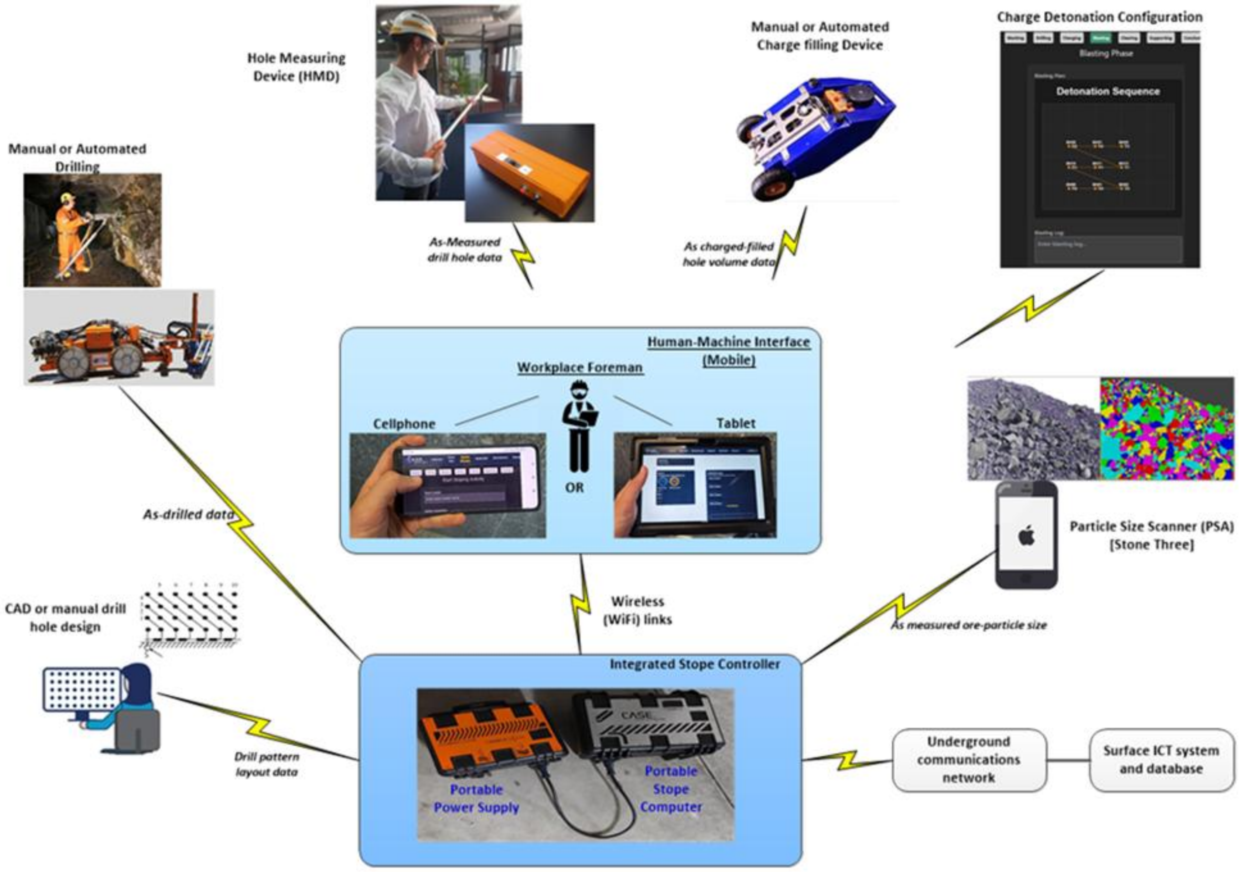

Figure 1: The DCBM integrated solution concept
[Source: Previous LoCM WP2MS 2b report]

The laboratory-model integrated DCBM solution concept has at its core objective the implementation of a digitally recorded stope drilling, charging, blasting, and ore measurement optimisation cycle with the capability to capture sufficient data to enable managers to optimise the process with each completed execution cycle. Each process stage, ranging from “as designed data”, “as drilled data”, “as charged data”, “as blasted data” and “as measured data” shall document the work-flow process as was executed.

The process commences with the finalisation of the required stope-face drill and charge-filling design per work area. The design will be received in a digital format by the stope operational qualified miner, before the physical layout of the drill pattern on the stope rock face. On completion of the physical drill pattern layout process, the pattern shall also be captured in a digital photo format for record purposes.

Manual or automated drilling of the holes as per design requirements, will continue until completed. Hole surveying and cleaning of the holes from debris will be required to establish the hole depth and the hole direction compliance of the set of drilled holes, w.r.t the initial design. On completion of the hole measurement stage, the controlled charge-filling process to commence. Each hole's actual charge-filling volume is measured electronically and stored in a database for reference purposes. Comparisons of actual charge-filling volume are to be compared to the charge-filling design to determine deviations and discrepancies.

5 RESULTS / DISCUSSION

5.1 Sub-system findings

The key research findings and observations of the key sub-system technologies utilised in the laboratory integrated DCBM test model is discussed below, and would be important to consider in a possible follow-up research stage.

5.1.1 Portable Stope Computer/controller sub-system

The portable stope computer/controller sub-system is enclosed in a portable ruggedized carrycase which contains the embedded computer hardware running the bespoke stope control software. The stope computer /controller is provided with power using the portable power supply (Figure 2) carry case sub-system. All the wireless (WiFi) interface links required to interface with the stope located subsystems (Figure 1), are provided by the stope computer/controller.

The stope computer/controller is also responsible for managing all data-storage services; hence stope operations can continue without any connectivity to an ICT backbone service, which would be very advantageous within older deep-mining operations, which do not currently have ICT infra-structure available underground. This sub-system performed very well during integrative laboratory testing and would be one of the sub-systems earmarked to be used in representative operational testing in future.

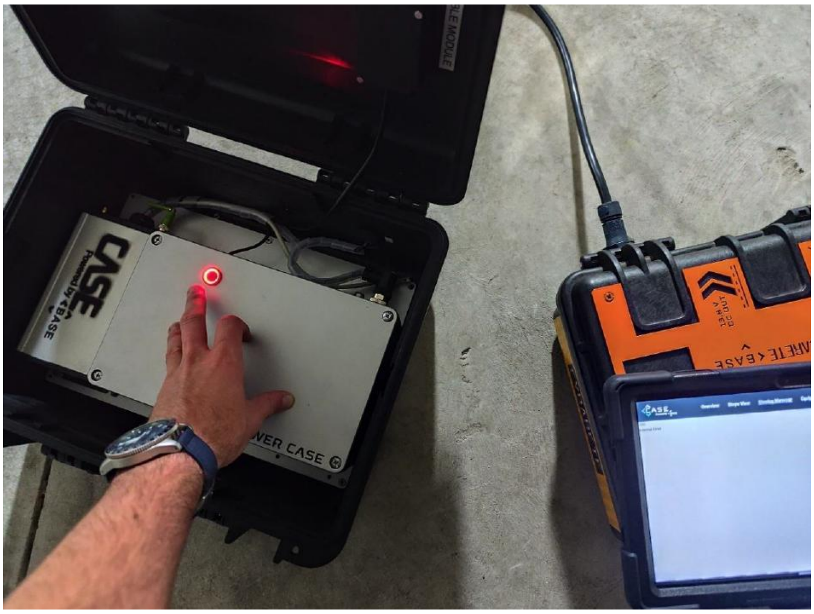

Figure 2: Portable stope computer/controller

5.1.2 Portable power supply unit (PSU) sub-system

The portable power supply unit depicted in Figure 3, could supply the mobile power at the stope workplace area to the mobile computer/controller unit. The power is supplied via a single screened cable to the computer/controller unit. The power supply unit is enclosed in a ruggedized mobile enclosure with easy lid access to the electronics for measurement and maintenance purposes. The power supply unit performed stable and well during all integrated laboratory solution testing operations and is earmarked as a sub-system to be used in future operational testing.

Figure 3: Drilling pattern on tablet GUI display

5.1.3 Mobile Human Machine Interface (HMI) Tablet/cell phone sub-system.

The Mobile Human Machine Interface (HMI) Tablet/cell phone sub-system is a ruggedised tablet device which is commercially available, installed with an Android Operating System (OS) which is running the CASE bespoke developed application software.

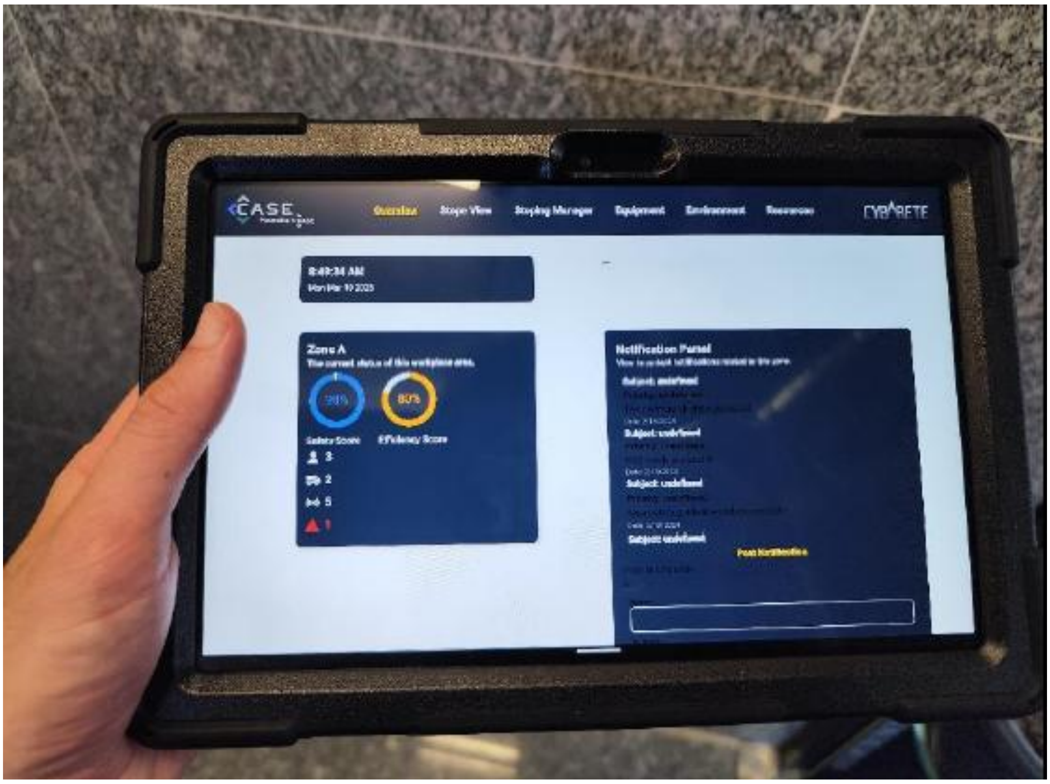

Figure 4: Ruggedized HMI mobile tablet device

The HMI tablet device is equipped with a touchscreen capability which is the primary human interface with the software functions. The HMI tablet is equipped with a wireless WiFi interface which interfaces with the portable stope computer/controller. The tablet HMI interface performed well during tests and is suitable to be used for underground utilisation.

5.1.4 Hole Measuring Device (HMD) prototype.

The Hole Measuring Device (HMD) prototype depicted in Figure 5 is a new innovative drill hole measuring device developed by the research team during the research activities. The device is a low-cost device, equipped with its own battery power supply and wireless WiFi link to communicate with the stope computer/controller.

The HMD performed well during laboratory measurement tests and has a capability to measure a drill hole to 1mm accuracy, and spatial orientation angle of 1 degree. This accuracy level would probably not be possible in rugged underground conditions, but an accuracy within 5mm would be more realistic in operational conditions. This device needs to go through a next stage of ruggedisation and maturity before tested underground in real conditions.

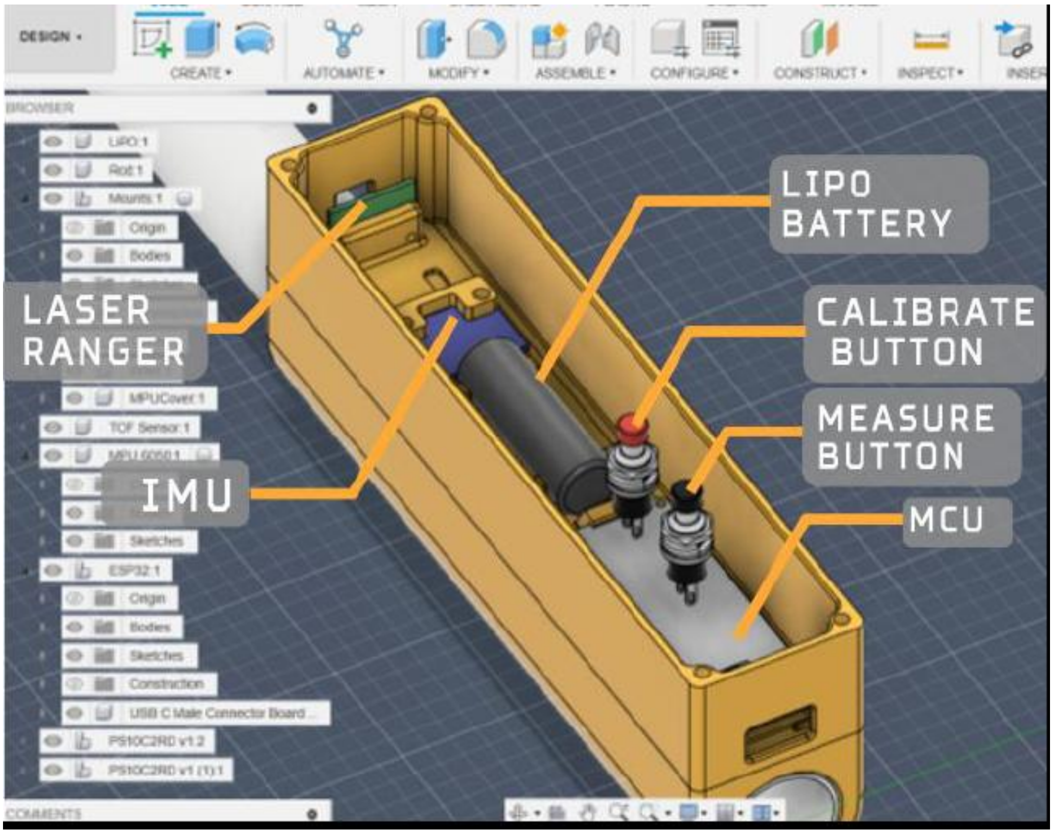

Figure 5: Hole Measuring Device (HMD)
[Source: Cybarete]

5.1.5 Particle Size Scanner (PSA)

The Particle Size Scanner (PSA) is an Apple iPhone (Figure 6) based scanner which has the ability to scan the ore particles optically and then generate a report and optical images which is communicated to the stope controller via WiFi link.

Figure 6: Apple iPhone: Particle Size Scanner (PSA)
[Source: Stone Three]

The integrated stope controller computer can receive particle size data and reports from the iPhone device on request. This is the last sensor in the stope workflow process which provides a quality parameter to the mine operational managers on the success of the blasting process.

5.1.6 Interfaces emulation of certain devices

The data interfaces for the automated drill, the automated charge filling device and the automated blasting controller have been emulated within the stope computer/controller. During the laboratory integration process these data interfaces have been emulated to represent typical datasets that could be expected during an operational test. During the next research stage industry suppliers shall be requested to participate in the operational tests and hence provide the real devices during validation tests.

6 RESEARCH FINDINGS

6.1 Research Outcome 1: Integrated performance of laboratory DCBM model

The integrated DCBM test model performed well and was stable during lab-tests. The DCBM demonstrated the ability to operate successfully without an underground ICT backbone capability, which is a unique solution for the South African deep mining community. The DCBM illustrated the capability to capture a stope drill pattern design and measure the as-drilled hole pattern to obtain the real hole dimensions (depth and orientation). The hole volumes have been calculated and demonstrated the capability to interface with an automated charge filler to fill each hole according to its specific hole volume. The DCBM could read the blasting pattern with relevant blasting data and could read a report from the particle size scanner. The DCBM has established the feasibility of a future stope workflow manager, which could be matured for operational testing during a next research stage.

6.2 Research Outcome 2: Technology readiness levels

The Technology Readiness Level (TRL) summary, as depicted in Table 1, estimates the technology readiness of the various key sub-system technologies utilised for the integrated stope DCBM system. The TRL levels range from Level 1 to Level 7, depending on the specific maturity level of the technology.

Table 1: Technology Readiness Level summary of sub-system technologies

Relative technology development level	TRL	Level Definition	Description of engineering research work	Key questions for stage pass	Key technologies for a drilling, charging, blasting and ore-measurement management (DCBM) capability							
					Portable Stope Computer/controller	Portable power supply unit (PSU)	Mobile Human Machine Interface (HMI) Tablet/cell phone	Hole Measuring Device (HMD) prototype	Particle Size Scanner (PSA)	Automated drill machine	Automated charge filler	Automated blasting/detonation controller
Basic technology research	1	Basic research	Basic science research	Have basic principles been observed and reported								
			Not focussed on a specific application									
			Principles observed and reported									
	2	Concept formulation	Some practical applications identified	Has a concept application been formulated?								
			Materials or processes required confirmed	Analytical models or simulatins developed?								
			Technology concept/hypothesis formulated									
			Research protocols are developed									
Feasability research	3	Critical function or proof of concept established	Laboratory measurements validate analytical predictions of separate technology elements	Has analytical and experimental proof of concepts been demonstrated?				3				
			Hypothesis tested, alternatove concepts explored.	Have models been tested within a limited mining contexts.								
			Research studies support models developed.									
Technology development	4	Validation in the laboratory environment	Design and development of laboratory components	Has a "breadboard unit" or "test tube model" been demonstrated in a laboratory environment/controlled conditions?			4					
			Test results confirm design and meet technical requirements.									
			Laboratory integration of critical components feasable.									
Technology development	5	Laboratory scale, validation in relevant environment	Validation under relevant operational conditions, mimicked in the laboratory .	Has a "breadboard unit" or" test tube model" performance been demonstrated in a relevant environment or context?	5	5						
				Have research results of pilot lots conveyed a draft technical data pack confirmed by reviewers?								

Technology demonstration	6	Integrated prototype system verified in operational environment	Prototype demonstration in an operational mining environment.	Has a prototype been demonstrated in a relevant environment or context?						6	6	
			Measurement and evaluation of data of operational environment.	Is the measured data compliant with performance and safety requirements to proceed to the nex stage?								
Systems Commisioning	7	Integrated pilot system demonstrated in operational environment	Integrated full-scale pilot system demonstrated in an operational environment or site.	Has a prototype unit been demonstrated in the operational environment?					7			7
			Data are collected, presented, and discussed with appropriate regulatory	Is there an approved reviewed test data?								

6.2.1 Technology Readiness Level Assessment Findings

Portable Stope Controller: The estimated Technology Readiness Level (TRL) for the "Portable Stope Computer/Controller" is estimated at Level 5. This is mostly attributed to the fact that these units were used to support other mining-related research testing work within an operational context. The design is well documented as well as performed stabile withing a mine operational rugged context.

Human Machine Interface (HMI) Tablet and software: The estimated Technology Readiness Level (TRL) for the HMI tablet is TRL 4. The tablet hardware is of commercially available and has performed well under a representative laboratory environment. The bespoke application software was developed during the research work and is designed to run within an Android Operating System (OS) environment. The application software has performed well in a representative laboratory context, and the choice of the Android OS is to support open standards and to save on licensing fees, often associated with other operating systems such as Windows.

Hole Measuring Device (HMD): The HMD's TRL level is estimated a Level 3. This is a new innovative device designed during this research phase. It's the first device model that was used in the solution integration effort, hence it is to be expected that a follow-up development stage would be required to enhance the TRL level. The HMD device performed well under laboratory test conditions and can measure hole depths to an accuracy of 1mm. This needs to be validated in a representative mining environment in a follow-up research stage. The integration of the HMD into a real hole-cleaning device is recommended, hence more ruggedization of the enclosure and electronics would be required for utilisation of testing in an operational context.

Particle Size Scanner (PSA): The PSA device used in the integration project was an Apple iPhone with bespoke developed software by research partner "Stone Three". The estimated TRL Level for the PSA is Level 7. This scanner has already been deployed within a deep-mining operational environment and hence has reached a level of maturity that does not require further development work.

Interfaces to the automated Charge Filler and drilling machine: The interfaces to the automated Charge Filler and drilling machine could be estimated at TRL Level 6. As these machines could not be deployed in a laboratory context, the open industry standard data interfaces were implemented in the integrated solution and emulated during laboratory tests. These interfaces are all mature open standard industry interfaces such as Ethernet, WiFi, CAN, RS485, RS422 and RS232 interfaces, and can be integrated with the real hardware and tested within an operational environment in future research stages.

7 CONCLUSIONS FROM MILESTONE

This milestone deliverable has provided an overview of the key findings of this LoCM24WP2 research project. This project progressed from the elicitation of stakeholder needs in developing a DCBM solution for future deployment in deep-mining operational scenarios, the definition of functional requirements and test criteria, to the integration of a viable laboratory model DCBM solution. The research project sourced key required technologies from research partners to integrate a laboratory solution that has proven the viability of a DCBM concept and hence established a baseline for future development stages to mature the technology towards a possible product.

8 WAY FORWARD

Certain key sub-system technologies utilised in the integration of the DCBM solution will require further development to mature the technology towards higher TRL levels before using these products in a real mining environment. The Hole Measuring Device (HMD) would be a future low-cost option to measure drill hole depths and would require a further follow-up development stage to ruggedize the sub-system further to integrate with an existing hole-cleaning pipe system. Ruggedization of the HMD device shall also be a priority to operate within a rugged underground operational context.

The integration of the laboratory model DCBM with real automated charge filling systems as well as drilling and blasting controllers shall be a priority to prepare the integrated solution for real underground testing in the next research stage.

9 RECOMMENDATIONS

It is recommended that this laboratory-tested integrated DCBM solution is a viable concept to integrate in future deep-mining stope operations. To enhance the technology readiness level of the solution to the next stage of development, further development and assessments would be required.

The laboratory concept solution was the first physical realisation of the workflow concept, hence it is now important, to validate the concept for future implementation and testing in a real-mine operational environment.

future deployment in deep-mining operations.

--------end of report-------