MANDELA MINING PRECINCT
MINDS FOR MINES

Cnr Carlow & Rustenburg roads
PO Box 91230, Auckland Park, 2006
+27 11 358 0003
enquiries@mandelaminingprecinct.org.za

FINAL MILESTONE REPORT

PROGRAMME	Longevity of Current Mines (LoCM)	**WORK PACKAGE**	LoCM21WP10 Dynamic Test Facility Upgrade Study
MILESTONE	LoCM21WP10-5 Final Report		

PROGRAMME MANAGER	Martin Pretorius	**DATE**	23 March 2023
RESEARCH AGENCY	Council for Scientific and Industrial Research (CSIR)		
PROJECT LEAD	Zamaswazi Nkosi	**PROJECT TEAM**	Sumaya Khan (CSIR)
			Mvikeli Mpofu (CSIR)
			Fleckson Magweregwede (CSIR)
			Prof. Francois Malan (UP)

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1 Executive Summary

This report presents the research findings of a work package aimed at identifying the requirements for establishing an independent dynamic test facility that can effectively test underground mine support units. The work package comprises five milestones, starting with project initiation (Milestone 1) and concluding with the final report (Milestone 5). Milestone 2 involves establishing criteria and requirements through literature investigations and engagements with mining personnel, while Milestone 3 involves engaging with underground support manufacturers and suppliers to establish criteria and requirements. To achieve the objectives of Milestones 2 and 3, a desktop study of international and local dynamic testing facilities was conducted, and engagements were made with representatives from gold and platinum mines and local underground mine support manufacturers and suppliers to develop appropriate survey questions. Thirty surveys were distributed to industry participants, resulting in 14 responses, of which eight were fully completed. A low response rate of 30% prompted additional engagements to gather further information. To achieve data saturation, additional engagements with three suppliers and three mine representatives were conducted. Milestone 4 involved identifying gaps in the requirements outlined in Milestones 2 and 3 and holding engagements with underground mine support manufacturers and researchers to fill these gaps.

The report identifies the need for an independent dynamic testing facility and highlights the importance of factors such as location, dynamic load testing methods and equipment, testing protocols, support types to be tested, storage capacity, the throughput of the facility, dynamic testing parameters, instrumentation, data acquisition, quality control, staffing requirements, accreditation, and maintenance and upkeep. The research shows that the establishment of an independent testing facility can ensure compliance with regulatory requirements, provide an unbiased and accurate testing environment, promote research and development, and offer a dedicated space for developing technical expertise and specialised testing capabilities. The location of the facility is crucial, with proximity and accessibility to customers, safety, and security being important considerations. The study found that the Gauteng Province is the best location for the facility as it is near most gold and platinum group metal (PGM) mines, making it easier for customers to access the facility and reducing transportation costs. The study investigated three testing methods: direct blasting/simulated blasting, drop weight, and hydraulic testing. Drop weight testing was found to be less expensive and have a higher loading rate, while hydraulic testing provides more control over loading rates and is known for its repeatability. Direct blasting/simulated blasting was excluded due to its inability to replicate rockburst conditions. The study highlights the need for a testing facility that can conduct various types of dynamic tests, as different types of supports require different testing methods. There is a need for a standardised dynamic testing protocol for testing support types, and an independent testing facility is required to perform tests consistently across different mines and support types. The report recommends careful consideration of testing methods and instrumentation, as well as strategies to minimise external factors that can cause inaccuracies in measurements. The report concludes that by taking all these factors into account, it is possible to establish a testing facility that can produce reliable results that comply with testing methods and protocols.

2 Aim of Work Package

This work package aims to establish the criteria and requirements for an independent dynamic test facility suitable to test current and future underground mine support units. The following milestones are completed for this work package:

- Milestone 1: Project initiation.
- Milestone 2: Establish criteria and requirements from industry engagements.
- Milestone 3: Establish criteria and requirements from engagements with underground support original equipment manufacturers (OEMs).
- Milestone 4: Draft report on the test criteria and requirements for a test facility.
- Milestone 5: Final report.

3 Methodology

3.1 Project methodology

Table 1 shows methods that were utilised to meet the project's objectives.

Table 1: Summarised methodology.

No.	Milestone	Methods
1.	Project initiation	• Complete project contracting. • Preparation of a start-up presentation detailing project intent and project plan.
2.	Establish criteria and requirements for a dynamic test facility from mining industry stakeholders and representatives	• Development of draft criteria and requirements from a mini desktop study of past and current test facilities. • Develop a survey to distribute to mining stakeholders and support manufacturers and suppliers. • Distribute the survey to mining stakeholders and support manufacturers and suppliers.
3.	Establish criteria and requirements of a dynamic test facility from the survey and engagements with mining stakeholders and support manufacturers and suppliers	• Analyse the survey responses to provide an overview of dynamic testing in the SAMI. • Update the draft criteria with inputs from the engagements and survey.
4.	Draft report on the criteria and requirements of a test facility	• Compile a report from learnings. • Host engagements with mining stakeholders and underground mine support manufacturers and suppliers to solicit inputs into the draft requirements developed from Milestones 2 and 3.
5.	Final findings report	• Updating changes to the draft as per the inputs from the technical steering committee (TSC) and Mandela Mining Precinct.

3.2 Project deliverables

Figure 1: Project milestone deliverable overview.

4 Research Findings

The following section presents the research findings of the study conducted to identify the criteria and requirements of an independent dynamic test facility suitable for testing current and future underground mine support units in South Africa. The study aimed to engage with relevant stakeholders in the mining industry to better understand the current testing practices and gaps in the market for independent testing facilities. Through a combination of desktop research, survey distribution, and engagements, the study gathered insights from rock engineering managers, senior rock engineers, mineral resource managers, production managers, seismologists, and underground mine support manufacturers and suppliers. The findings offer valuable insights into the current state of dynamic testing facilities in South Africa and provide recommendations for the establishment of future facilities.

4.1 Milestone 1: Project initiation

The project was initiated through the finalisation of contracts (proposal and collaboration agreements) and project inception meetings with the Programme Manager (PM) and the project team. A start-up presentation was prepared and shared with the PM (Appendix A – Start-up Presentation). Discussions were held with representatives from relevant underground mine support manufacturers and suppliers to obtain a high-level overview of current dynamic test facilities in South Africa (SA). Discussions were also held with the laboratory managers at rock testing laboratories to solicit information about the specifications and capabilities of dynamic testing equipment.

4.2 Milestone 2: Establish criteria and requirements of a dynamic test facility from mining industry stakeholders and representatives

The primary goal of Milestone 2 was to conduct a desktop study to determine the characteristics of facilities that perform dynamic testing on underground mine support. This objective involved identifying past and current international and local dynamic test facilities and collating draft requirements for a dynamic test facility from the information collected during the study. The second objective was to engage with mining industry stakeholders to gather information about dynamic testing and the test facilities used. To achieve this goal, potential stakeholders were identified, a survey was prepared and distributed, and potential participants were engaged through informal meetings and site visits.

4.2.1 Research findings

Some mining operations in South Africa have reached ultra-deep levels, up to 4 km deep, and as a result, stress influences mining practices more than before. Seismicity and associated rockburst damage are common occurrences in deep to ultra-deep underground mining environments, as well as in some shallow and intermediate-deep gold mines. The expansion of mining operations to deeper depths presents the potential for increased severity of seismicity and associated rockburst damage, which requires support systems that can perform effectively under conditions of seismicity. In South Africa, some support suppliers have developed in-house dynamic testing facilities where their products are tested. However, this presents a potential problem of "bias" as the manufacturers of the support systems are also the reviewers of the systems. Thus, there is a need for an independent testing facility that can be utilised by the mines, as well as suppliers without their own facilities, to conduct routine dynamic testing and quality control of support systems.

According to Hook and Wood (1987) and the Enterprises at the University of Pretoria (2017), the main function of ground support units is to utilise and maintain the inherent strength of the rock mass so that it becomes self-supporting. There are two types of support systems, namely rock reinforcement elements and surface support elements. Rock reinforcement elements, such as rock bolts and tendons, are installed inside the rock to prevent the deterioration of large-scale areas of ground, whereas surface rock support elements are installed on the exposed rock surface to prevent any small-scale instability of the rock mass. Surface support elements include steel wire mesh, shotcrete, timber props, and timber packs. Ground support elements are mainly selected based on the ground conditions and the excavation geometry. However, the quality of ground support installation affects its performance. For example, the effectiveness of anchoring plays a role in the performance of a rock bolt (Stacey, 2012). Thus, although theoretically, the support would have been predicted to prevent rock falls, the quality of installation may result in sub-performance and effectively lead to the risk of rock falls. The deterioration of ground support systems over time may occur because of changing stress conditions or prolonged stoppage of working places. However, some support types may deteriorate unexpectedly due to inherent quality issues, the use of an incorrect support type for specific conditions, or the dynamic nature of loading.

There are several reasons why ground support may be deemed inappropriate, including design-related issues, referred to as "design indeterminacy" by Stacey (2012). Stacey suggests that this design indeterminacy can be overcome by developing methods to quantify the actual capacity of support systems, rather than that of individual support elements. Such methods include the combination of laboratory tests (tests on core and various modifications of drop weight tests) and numerical modelling (Stacey, 2012; Potvin & Wesseloo, 2013). In the past, different types of tests have been trialled, including direct and indirect blast testing methods. However, these tests are costly, require special test conditions and environments, usually underground, and are usually not repeatable (Stacey, 2012).

Other important objectives of testing support, according to Player (2008), Stacey (2012), Potvin and Wesseloo (2013), and the Enterprises at the University of Pretoria (2017), are to quantify the capacity of the support for design purposes, evaluate support performance and provide empirical data for design purposes, check on the quality of the support and its installation, prove that the support can withstand the energy involved in the expected magnitude of a seismic event, and expose the support to in situ conditions to ensure the safety of mining personnel. Thus, it is essential to have a reliable and independent dynamic testing facility in South Africa to evaluate the performance of ground support systems and ensure the safety of mining personnel.

4.2.2 Legislation

In the South African mining industry, most support testing is carried out by suppliers using their own facilities and testing protocols that meet the requirements of the mine where the support is intended. The decommissioning and breakdown of older facilities such as the SRK facility, Terratek facility, and the CSIR Press have resulted in the discontinuation of testing of some essential support types and dynamic parameters. This poses a challenge for testing current and future newly developed support products. As a result, mining companies have taken the stance that any new product that cannot be tested in a laboratory environment cannot be considered for underground testing.

Under the Mine Health and Safety Act (MHSA), it is a legal obligation for employers in the mining industry to have a quality assurance system in place to test the performance characteristics of support units used in mines. This requirement is particularly important in underground mines where the risk of rockbursts, rock falls, or roof falls exists. Regulation 14.1 of the MHSA stipulates that this quality assurance system must ensure that the support units used at the mine provide the required performance characteristics for the expected loading conditions.

The Act also mandates that the testing of support be carried out by competent persons who are trained in the testing methods and procedures. The test results must be recorded and kept on file for inspection by the authorities. Additionally, employers must ensure that support units used in mines are well-maintained, inspected, and replaced when necessary to ensure that they continue to provide the required level of support.

The establishment of an independent facility that has the capacity and capability to meet the requirements of the mining industry would comply with the regulations outlined in the Act and also contribute to mitigating the risk of rockbursts and other forms of ground instability that can result in serious injuries or fatalities.

4.2.3 Dynamic load testing methods

Considerable research has been conducted on dynamic load tests, both locally and internationally, with countries such as Australia and Canada being at the forefront. Various authors, including Malan et al. (2006), Hadjigeorgiou & Potvin (2008), Stacey (2012), Potvin & Wesseloo (2013), and Enterprise at the University of Pretoria (2017), have highlighted the need for standardisation in dynamic load testing methods and reporting. By establishing standardised testing protocols, it will be possible to obtain unbiased and repeatable results, which will enable the development of a comprehensive database that can be used by all mining operations affected by seismicity. It's worth noting that different types of dynamic load tests are available, with drop tests being the most common configuration. Hydraulic testing equipment is another popular option. However, the momentum transfer test configuration is a rare type of drop test that is only used at the Western Australia School of Mines (WASM).

Enterprises at the University of Pretoria (2017) provide a detailed account of the dynamic test facilities for the testing of tendon and netting support in South Africa, Canada and Australia. Additional facilities that conduct dynamic testing of other additional types were revealed during the literature study. For this study, only a summary of the facilities is provided.

4.2.3.1 Drop weight method (free fall and momentum transfer)

Drop weight testing is a method that applies kinetic energy to support elements using gravity or a load transfer mechanism. It evaluates the dynamic behaviour of the support under loading conditions similar to those in the field, recording and analysing the load-displacement response of a single support unit, including elongates, roof bolts, cable bolts, rockbolts, packs etc.

There are two types of drop weight testing methods: free-fall and momentum transfer. The free-fall method drops a weight from a specified height and speed onto the test specimen, measuring the support's strength and deformation under sudden and intense loading. The momentum transfer method uses a hammer or weight to deliver a controlled amount of energy to the support unit, transferring its momentum and defining the energy transfer as the product of the hammer's mass and velocity.

The test can be performed using a drop tower or a winch system, with sensors measuring the support element's acceleration, displacement, and load-bearing capacity. The free-fall method is simple, cost-effective, and provides large datasets, allowing for a qualitative comparison of different support types. However, it may not accurately represent the interaction between the rock mass and support elements, and the testing conditions may differ from the actual in-situ conditions, leading to less accurate results. Table 2 summarises the drop test facilities identified in the desktop study.

Table 2: Summary of local and international drop weight test facilities.

Location	Test Rig/Facility	Summary of description	Loading type	Key design objectives and requirements

Local	SIMRAC Dynamic Stope Test Facility (Savuka Mine)	The facility is no longer operational. It was located at Savuka Mine, southwest of Johannesburg. The facility was configured to test props (support elements) of up to 2 m in height, and due to the large testing area (5.5 x 6.5 m), it could be used to test support systems. The facility was limited in that it could not be used to test rockbolt reinforcement units and the instrumentation was not advanced.	Impact loading - Drop test	• Dynamic impact loading. • Membrane components and membrane systems anchored by rockbolts. • Distribution of load onto the containment support through a simulated fractured rock mass. • A rock mass which would participate in the loading and deformation. A large area of support, to consider the areal capacity of containment support.
	SRK Drop Weight Test Facility (MiningTek)	The facility is no longer operational. The drop weight facility was designed to simulate conditions representative of rockbursts, that is, input energies of up to 70 kJ and impact velocities up to approximately 8 m/s. There were two alternative set-ups for the rig. The first set-up was used to test panels of 1.6 m x 1.6 m in area. The instrumentation used included nine telescopic bars to measure maximum and permanent deformations and a ground motion monitor (GMM) with eight geophones to measure Peak Particle Velocities (PPVs). The second set-up of the rig was used to assess the interaction between a simulated rock mass and a tunnel support system under repeated impact loading conditions. It was possible to generate impact velocities up to 20 m/s using this setup. The configuration of the rig allowed for consistent and repeatable tests. However, the instrumentation used was limited, for example, tape measurements in elevation, still-photographs (before/after) and video recordings were used.	Impact loading - Drop Test	• Determining the performance characteristics of surface support systems (wire mesh, lacing and shotcrete) used in South African mines under dynamic loading. • Repeatable tests.
	SRK/Duraset Wedge-block loading device	The rig was designed for the dynamic testing of embedded cable and bolts longer than 1.2 m (up to 5.5 m). This rig used the 300 kJ drop weight SIMRAC	Impact loading - Drop Test	• Dynamic impact loading. Should accommodate cables and bolts longer than 2.2 m.

	stope support test facility described above. Electronic monitoring instruments record the rapid loads and displacements on the bolts thus, measuring the energy consumed during the test or at the breaking point. The disadvantage of the rig was that it could only test reinforcement elements and not a support system.		
New Concept Mining (NCM)	The company's Dynamic Impact Tester (DIT) was constructed to test ground support solutions through the dynamic testing of rockbolts to assess the response of the support tendons to a high strain rate axial event, that simulates a seismic event. A potentiometer is used to measure the drop height of the trolley relative to the impact plate before the trolley is released. Three load cell sets are installed to measure the impact forces during the test. Displacements are measured using two Basler Racer GigE line scan cameras. LabVIEW™ is used for automated data processing, and the output from this is automatically reported in a Microsoft Excel Workbook (Berghorst, 2019). The rig has been adapted to also test nets.	Impact loading - Drop test	• The rapid development and qualification of energy-absorbing rockbolts. • To test critical raw materials under dynamic loading conditions before manufacturing dynamically rated rockbolts with the material. • To help the industry understand the risks and benefits of specifying the expected magnitude of the impulse of energy that a rockbolt should withstand. • To investigate the effect of impact velocity on the measured dynamic capacity of a rockbolt.
Videx Mining	It is stated on the company website that there is "an onsite laboratory equipped with a calibrated pull-test machine enables proper raw material and finished product testing to ensure product conformance." (Videx Mining, 2020). The Enterprises at the University of Pretoria (2017) reported that dynamic testing of tendons at velocities of up to 6.7 m/s is conducted.	Impact loading - Drop Test	
Timrite Underground Mine Support Solutions	Two drop-weight facilities are utilised. The first facility is used for the dynamic testing of elongates, hydraulic props and packs at 3 m/s. The second facility is used to test nets.	Impact loading - Drop Test	• Dynamic impact loading. • At the maximum drop weight height a maximum velocity of

		The instrumentation used includes an accelerometer to measure the velocity and a potentiometer to measure the displacement (Timrite Underground Mine Support Solutions, 2022).		7.8 m/s can be achieved.
	Groundwork Geotechnical Sensing and Consulting	According to Groundwork Geotechnical Sensing and Consulting (2022), the company conducts the laboratory testing of elongate and tendon support units, evaluation of support systems and auditing of support units and systems.	TBD	TBD
International	Western Australian School of Mines (WASM)	The facility is unique in that instead of impact loading, it uses the momentum transfer mechanism to apply a dynamic load to the specimen. The rig functions such that the drop weight and the upper beam that simulates a stable rock and the connecting bolt configuration in between are considered as one system. The system freefalls until the upper beam and bolt system are sharply decelerated by the buffers (energy dissipation devices). Finally, the momentum transfer between the drop weight and bolt system is completed, triggering the dynamic load in the bolt. The facility was established for: • Investigating how the released seismic energy is absorbed by the ground control system or its elements • Investigating how support and reinforcement elements transfer dynamic loads. It is reported that this facility uses the most advanced instrumentation, which includes load cells for the measurement of forces, ultrasonic motion sensors to measure displacements and high-speed cameras to measure acceleration. These instruments enable comprehensive monitoring and the calculation of energy absorption at any given instant.	Momentum Transfer	• Sufficient strength in the engineering design and physical dimensioning of the facility to withstand the impact loads during testing. • It is studied whether the ground control system absorbs the energy, or the energy input fails the system. • Determination of energy balance during the test from force-displacement response curves. This required the design of instrumentation and monitoring points to provide multiple independent measurement methods of key parameters. • Knowledge of the energy consumed by elements in the ground control scheme and the test facility impact surface. • Calculation of the maximum input energy and the relative energy split between the simulated ejected block and the impact surface. The impact surface and the reinforcement system will have different relative loading stiffness, and these may influence the other's response to dynamic loading.

	Welded and high tensile wire chain wire can be tested.		
CANMET (GRC Laurentian)	It is reported that the facility was initially used to conduct dynamic tests on a small steel rod with cushions. The advantages of the facility were that the set-up time was relatively short, and testing was not expensive. Some of the limitations of the facility included: • A small drop in height and drop weight. • Multiple drops were required to fail rods. • It could only test single reinforcement units. The ASTM D7401-08 (ASTM D7401-08) standard is based on the impact-based dynamic testing machine located at the CANMET facility.	Impact loading - Drop Test	To demonstrate the influence of multiple impact loading, resulting in plastic strain accumulation, on rockbolts.
GRC-Creighton	The facility is no longer operational. It was established to test shotcrete panels and diamond panels under impact loads, representative of moderately sized rockbursts. The facility was configured to use the direct impact of a free-moving mass onto the support element. The main advantages of the facility were that there was a quick set-up time due to the ease of changing panels between tests and that the instrumentation was relatively advanced. The energy absorption calculation from the test results was not fully accurate in that the tests considered the performance of the surface support element from a direct impact of a falling mass and not the interaction of the surface attachment with the reinforcing element.	Impact loading	• Relatively cheap testing of support elements. The instrumentation would have to identify peak loads carried by the bolts and the impact energies dissipated by the mesh-reinforced shotcrete panels and supporting columns
Swiss Federal Rock Test Facility	The facility was established to apply dynamic rockburst loading to a large panel of surface support and four bolts (a support system as opposed to individual support elements). The facility used two different setups. In the stiff setup, it was possible to show that the test setup can impose enough	Impact loading Drop Test	• Demonstrate the behaviour of dynamic high-tensile mesh and dynamic rockbolts installed together. • Evaluating the dimensioning concept, where the retaining elements can be

		energy to activate four strong dynamic bolts. With the soft setup, mainly the mesh was loaded, and the anchors were lightly activated (Bucher, et al., 2013). The instrumentation used in these tests included devices load cells, high-speed cameras and accelerometers to evaluate the distribution of the forces on the mesh, bolt and system as a whole.		designed for dynamic conditions. Testing of a support system (panel and rockbolts).
	MIRARCO Impact Test	The instrumentation used on the rig includes a displacement-measuring rotary potentiometer (in retraction mode) and a velocity transducer to measure the movement of the drop weight. A limitation of the facility is it tests the performance of the surface support element from a direct impact of a falling mass and not the interaction of the surface attachment with the reinforcing element.	Impact loading - Drop Test	• To conduct impact tests on full-size1.5 x 2.7 m) mesh panels. A large-scale outdoor dynamic testing facility.
	Noranda Technology Centre (NTC) drop unit	This facility was used primarily to test cone and grouted bolts. Using this rig, it was relatively cheap and quick to conduct the tests. The Noranda Technology centre was closed, and the rig was transferred to CANMET laboratories in Ottawa, Canada. The main limitation of the rig was the configuration for the load transfer to the reinforcement unit through the surface hardware – the rig did not account for system stiffness and energy losses.	Impact loading - Drop Test	Testing modified cone bolts, which were installed in a test tube with an internal diameter of 38 mm and an external diameter of 47.5 mm.

4.2.3.2 Hydraulic test

Hydraulic testing involves the application of a dynamic load to a support unit using a hydraulic actuator. The actuator is a device that converts fluid pressure into mechanical motion and can be used to apply a controlled load to the support. Hydraulic tests are rarely found in literature as opposed to drop tests. Only three hydraulic test facilities were found in the literature survey. These facilities are the CSIR Terratek rig (not operational; Figure 2), Mine Support Products (MSP) (operational; Figure 3) and Elbroc (operational). Hydraulics tests are expected to be more accurate than drop tests, which are difficult to control (Enterprises University of Pretoria, 2017). Player *et al.* (2008) and the Enterprises at the University of Pretoria (2017) listed the following as the drawbacks of using the Terratek hydraulic test rig:

- Hydraulic tests may require in-depth skills and specific training to operate the equipment. This may result in greater costs compared to drop tests.
- It may be difficult to modify and adapt the input energy for hydraulic test equipment. The maximum output energy will be based on the original design of the machine. Furthermore, it may be difficult to conduct dynamic load testing of nets due to the required test dimensions.
- Hydraulic tests are associated with higher capital and maintenance costs compared to drop tests.

Figure 2: The Terratek hydraulic rig.

Figure 3: The MSP hydraulic rig.

Table 3 summarises the hydraulic test facilities identified in the desktop study.

Table 3: Summary of local and international hydraulic test facilities.

Location	Test Rig/Facility	Summary of description	Loading type	Key design objectives and requirements
Local	Terratek (MiningTek)	This hydraulic rig is no longer operational. It was used to test the following: • Props (of up to 1.6 m in length) in compression. • Rockbolts (re-bar, smooth bar, and wire cable) of a limited length in tension or shear. The main advantage of the rig was that it could be configured to apply dynamic loads in compression, tension or in shear. The facility was also able to conduct tests quickly, at up to three tests per hour (depending on the length of the element). The main disadvantages of the rig were: • Testing of individual reinforcement elements only and not support systems. • The limited maximum length of a reinforcement unit that could be tested. • Outdated instrumentation and no electronic data available.	Hydraulic system	Quasi-static and cyclic dynamic loading on rock tendons at varying loading rates (1 mm/sec to 20 mm/sec).
	Mine Support Products (MSP)	As part of its quality assurance, the company conducts dynamic testing based on the random selection of its products (props and nets) (Mine Support Products , 2022).	Hydraulic system	Load capacity of 500 kN Velocity of 3 m/s. Limitations: Maximum length of elongates - 3.5 m.

				Maximum length of bolts 1.2 m. Maximum static force 450 kN. Maximum Dynamic force 350 kN.
	Elbroc Mining Products	The company conducts dynamic tests using a hydraulic press to simulate rockburst conditions. Part of the instrumentation includes the display of a real-time load/deformation or load/time graph on the control room screen during the test and the storage of all the data for further analysis (Elbroc Mining Products, 2021).	Hydraulic system	• Simulation of dynamic rockburst conditions using a hydraulic press.

4.2.3.3 Direct/simulated blasting

The in situ simulated blasting method is used for dynamic testing of underground support by measuring the response of the rock mass and support to the simulated blast loading. This method is used to evaluate the performance of underground support, such as roof bolts, cable bolts, and rockbolts, under loading conditions that are similar to those of an actual blast (Figure 4).

Figure 4: Before and after blast image captured by high-speed camera showing the damage to the tested support system (Heal & Potvin, 2007).

4.2.4 Draft requirements for a dynamic load testing facility

As discussed in the previous sections, dynamic load testing methods vary depending on the particular testing facility. In general, the requirements for designing a dynamic testing facility are influenced by factors that include the following (Player et al., 2008; Potvin & Wesseloo, 2013; Enterprises at the University of Pretoria, 2017):

- The method of application of the energy (drop test, hydraulic test, momentum transfer etc.).
- The type of support to be tested (elements and/or support systems) and the associated support resistance and energy absorption criteria.
- The scale of the test based on the energy input.
- Repeatability of the tests.

- The availability of capital for the structure, instruments and monitoring technology and software for data analysis.

The design requirements for a dynamic load testing facility are described in the following section. It should be noted that these requirements are general and may be relevant for some dynamic loading tests and not others. The requirements are based on the literature on drop tests, hydraulic tests and momentum transfer dynamic loading. Results from the survey will provide an in-depth understanding of the parameters to consider for building a dynamic loading test facility.

4.2.4.1 Operational requirements

4.2.4.1.1 Testing protocols

The study revealed the importance of having a standardised testing protocol as reported by various authors (Malan, 2006; Player et al., 2008; Li et al., 2014). Past and current dynamic tests relied on site-specific testing and reporting procedures. This presents a challenge when comparing results obtained from different testing equipment. There is, therefore, an opportunity for a new dynamic testing facility to develop standard protocols to enable easy comparison between different products (e.g., tendons vs bolts) and test results of different rigs.

4.2.4.1.2 Capacity of the test facility

The testing facility should be able to handle the volume of dynamic support tests required by the relevant mines in the South African mining industry. Furthermore, the test facility should be able to accommodate/test the various types of support used by the relevant mines.

4.2.4.1.3 Technical requirements

The following test parameters were commonly found for the different dynamic test methods and various support types.

Method of simulating the dynamic load

As discussed in the preceding sections of the study, the various methods of simulating include free-fall drop tests, which are the most common, momentum transfer drop tests (only one active facility) and hydraulic tests. The choice of the method will depend on various factors that include cost, availability of skilled personnel and operational requirements.

Multiple loading cycles

Enterprises at the University of Pretoria (2017) recommend that a dynamic test rig should have the functionality to conduct multiple loads to emulate the multiple events a support element or system undergoes. In contrast, Player *et al.* (2008) highlight their reservations about dynamic tests with multiple loads by stating that multiple load tests "*fail to acknowledge that material properties change with increased strain, plastic deformation or that dynamic friction can reduce with velocity*". Multiple loads were found, in the study, to be relevant for tendons, nets and packs as reported by Malan et al. (2006) and the Enterprises at the University of Pretoria (2017).

Energy input

The energy input is an important criterion used to investigate the performance of support elements and systems for their effectiveness to resist rockbursts. Rockburst-resistant support systems can absorb the kinetic and potential energy associated with the hangingwall moving at a particular velocity (commonly 3 m/s). In dynamic tests, a fraction of the input energy is lost in the form of vibration, friction, sound and heat during impact (Daehnke *et al.,* 2001; Li *et al.,* 2014; Malan & Napier, 2018).

Enterprises at the University of Pretoria (2017) recommended an energy input of up to 120 kJ for the dynamic testing of tendons. The Savuka SRK facility, with a free fall drop test configuration, used the highest input energy (300 kJ) followed by the WASM (225 kJ), which uses the momentum transfer method.

Input velocity

In the South African mining industry, the maximum block ejection velocity is assumed to be 3 m/s for testing tendons, anchors and bolts. This value is used on assumption that 80% of damaging events will result in velocities less than 3 m/s. Malan and Napier (2018) argue that although the value of 3 m/s is used in South African mines, it was arbitrarily chosen based on rapid yield hydraulic props tests conducted by COMRO. Additionally, the correct assessment of the ejection velocity and the force exerted during rockbursts is difficult to conduct accurately and therefore, Malan and Napier (2018) recommend further research into this ejection velocity criterion. Other facilities covered in the study used velocities of up to 10 m/s, however, it should be noted that the test and machinery configurations are not identical.

Frame size

The frame of the test rig should accommodate the size of different support elements (e.g., bolts tendons, anchors etc.) and or systems (e.g., packs).

4.2.4.1.4 Data collection and reporting requirements

The study showed that the degree of instrumentation plays a major role in dynamic tests. Instruments are used to measure test parameters such as impact forces, peak loads carried by support elements like bolts, the permanent displacement of bolts and the drop height.

The various types of instruments used in the different facilities covered in the study include:

- High-speed cameras.
- Piezoelectric force sensors.
- Load cells.
- Strain gauges.
- Accelerometers.
- Potentiometers.
- Data acquisition software.
- Data reporting and modelling software.

The periodic calibration of these instruments is key to obtaining reliable test results as emphasized by Jager & Ryder (1999), Malan (2006) and Li et al. (2014).

4.2.5 Milestone Conclusions

Several international and local test facilities exist that are currently testing the dynamic behaviour of various types of support. The drop test is the most common type of dynamic load test, followed by hydraulic tests. The literature also revealed the use of in situ blast simulation tests for dynamic testing, however, several technical challenges are presented by this method. The draft requirements of a testing facility were established based on the requirements described in the literature. The requirements include the following:

- Operational requirements.
- Technical requirements.
- Data collection and recording requirements.

Further information about the local facilities and the test protocols of the mines will be solicited through the completion of an industry survey. The information received from the survey will help to refine the draft design requirements established from the desktop study and will provide a better understanding of the parameters currently used in the various facilities.

4.3 Milestone 3: Establish criteria and requirements of a dynamic test facility from underground mine support systems manufacturers

The purpose of Milestone 3 is to present an overview of dynamic testing practices in the South African mining industry, based on surveys received from participants at gold and platinum group metals mines (PGM) as well as from manufacturers and suppliers of underground support. The survey responses and consultation with subject matter experts are used to update the draft criteria and requirements for the dynamic test facility. Currently, South African underground gold mines are amongst the most seismically active in the world. Although to a lesser extent, the deep South African underground platinum mines also experience seismic problems. Since this research project aims to establish current and future requirements of a dynamic test facility, it is deemed necessary to conduct an industry-wide survey of the practices related to dynamic testing of support in the South African mining industry. Based on the preliminary findings of the desktop study, the gold mining industry is the main area of focus, as dynamic testing is expected to be routinely conducted on underground mine support units in deep to ultra-deep underground gold mines. Only some of the platinum mines are expected to use rockburst-resistant support units due to the range of depth levels of these mines. The rock engineering handbook by Jager & Ryder (1999) also supports this assumption by indicating, as shown in Table 4 that shallow and medium-depth mines experience fewer rockburst hazards compared with deep and ultra-deep mines.

Table 4: Values of parameters associated with different mining depths (Jager & Ryder, 1999).

Parameter	Shallow	Medium	Deep	Ultra-Deep
Typical depth(m)	< 1000	1000 – 2250	2250 – 3500	> 3500
Typical ERR(MJ/m2)	< 8	8 – 40	40 – 80	> 80
Vertical virgin stress(MPa)	< 25	25 – 60	60 – 95	> 95
Stress fracturing	Little/None	Moderate	Deep	Very deep
Stope closure(mm/m advance)	Low (<10)	Moderate (10-30)	High (30-60)	Very High (>60)
Infl. Of geology on h/w stability	Strong	Moderate	Moderate	Moderate
Possible ex-tent of FOG's	Can be large	Often small	Usually small	Small
Rockburst hazard	Minimal	Moderately Severe	Severe	Very severe

To ensure adequate coverage of the gold mining industry, the identification of operational underground gold mines was conducted. Figure 5 shows active underground gold mines in South Africa. According to the Minerals Council South Africa (2019), there are four specific gold mining regions, mined by companies registered with the industry body. After key mines were identified from the key gold mining regions, stakeholder engagements were established.

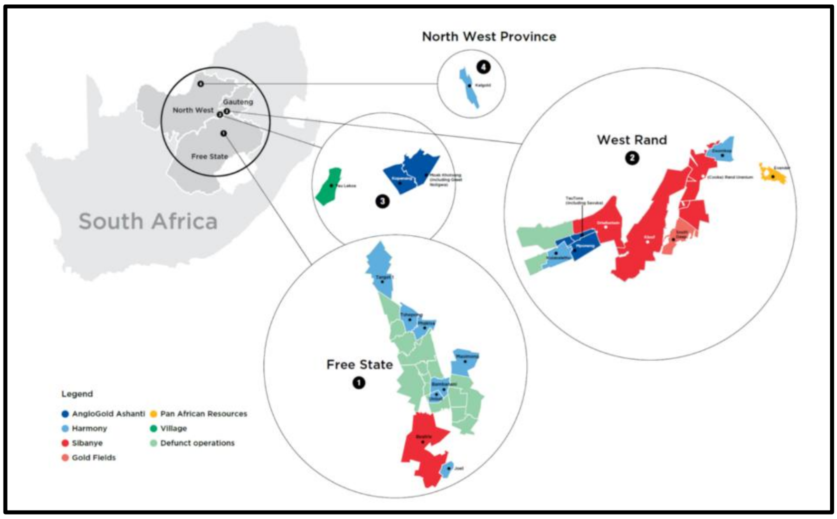

Figure 5: Gold mining operation in South Africa (Minerals Council South Africa, 2019).

For Milestone 3, a survey was conducted to gather information on the dynamic testing procedures followed at the mines. The survey was sent to the SAMI and included a wide range of information such as the type of support that is dynamically tested, the type of dynamic tests carried out, the facilities that carry out the tests, the testing capability of the systems, load capacity of the systems, and data acquisition systems. A total of thirty surveys were distributed to industry participants, and fourteen surveys were received back. Out of these, ten were fully completed. To achieve data saturation, additional engagements (virtual and in person meetings) with three suppliers and three mine representatives were conducted.

To complement the survey, engagements on virtual platforms were conducted with mining personnel and manufacturers and suppliers of underground support. These engagements were aimed at gathering further information about dynamic testing practices. The virtual platforms provided an opportunity to discuss and exchange information about the best practices for dynamic testing in the industry.

4.3.1 Research Findings

4.3.1.1 Survey Findings

The objective of the survey was to gather information on dynamic load testing practices in South Africa. Representatives of mines and support manufacturing and testing companies were requested to complete the survey. To ensure a focused approach to gathering relevant information, the survey was divided into two parts. Part 1 was intended for the mining industry stakeholders, while Part 2 was intended for underground mine support manufacturers, suppliers, and testers (Appendix B-Survey). Thirty stakeholders were contacted and a total of fourteen responses were received. However, only eight participants representing gold and PGM mines responded (completed the surveys), resulting in a response rate of only 30%. Of the eight participants, seven were from seismically active mines, as indicated in the survey responses. Additionally, one of the two manufacturers conducted dynamic testing of underground support.

The participants in the survey represented both gold and PGM mines. As shown in Figure 6, there were four respondents from the gold sector and four respondents from PGM operations. The depths of the mines represented by the survey participants are also depicted in Figure 6. The participants were asked to indicate whether their mines were seismically active, as these conditions are relevant for dynamic load testing. Figure 7 shows that seven out of the eight participants were from seismically active mines.

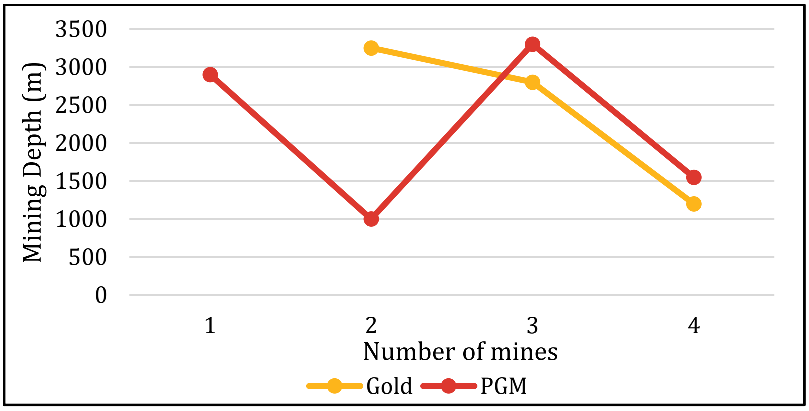

Figure 6: Distribution of survey participants across mines.

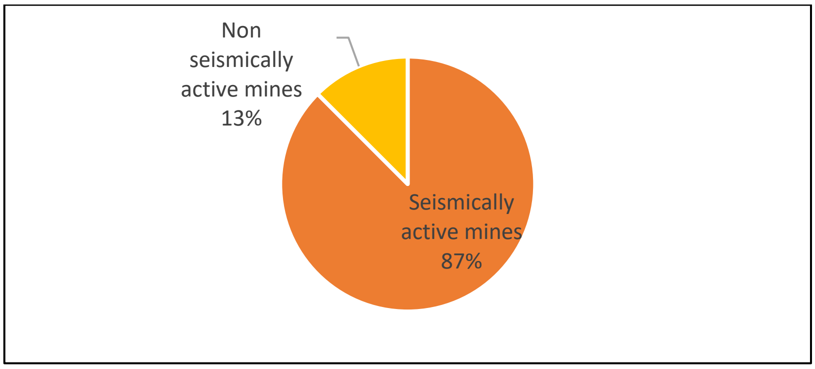

Figure 7: Responses to whether the mines represented are seismically active or not.

The responses from the participants indicated that the mines they represent conduct various support tests, including routine laboratory tests (the main focus of this project), initial underground tests, and routine underground evaluations of support performance. Table 5 presents the survey questions, and Figure 8 is a graph of the participants' responses to these questions.

Table 5: Survey questions on the types of support tests conducted by the mines.

Question number	Question
3	Which of the following support tests are conducted at your mine (by an independent facility or by the support manufacturer)?
3a	Quality control on delivered support units
3b	Routine lab tests (sample testing)
3c	Initial underground testing on the individual support unit
3d	Expanded underground trials (larger-scale tests on new support products before they are introduced or rolled out
3e	Routine underground assessments of support performance

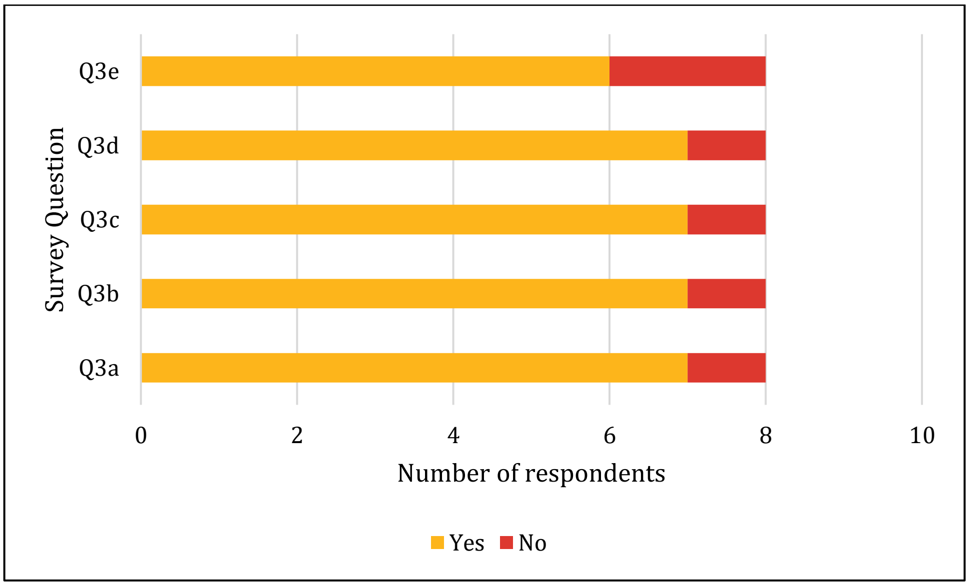

Figure 8: Responses to the question on the types of support tests conducted by the mines.

4.3.1.2 Is there a need for the establishment of an independent dynamic testing facility?

The literature and engagements highlighted several reasons why the establishment of independent regulatory or testing facilities is important. These may include:

- **Quality control:** An independent testing facility allows for unbiased and accurate testing, which can help ensure the quality and integrity of the underground support.
- **Technical expertise:** An independent testing facility would allow for the development of technical expertise, which could lead to the development of specialised testing capabilities.
- **Research and Development:** An independent testing facility can also be used to research and develop new underground support and technologies. It could also lead to the discovery of new properties of materials.
- **Compliance:** Meeting regulatory requirements for underground support testing and evaluation can be met by an independent testing facility.
- **Efficiency:** An independent dynamic testing facility can reduce the time for testing and evaluating underground support.

There is a consensus from industry participants, particularly from participants from gold mines, that there is a need to establish an independent dynamic testing facility for underground support. Some of the reasons highlighted by participants included the following:

- *"It will assist and will be beneficial to the industry. A facility that can accommodate at least the commonly used support units such as tendons elongates etc... A facility that can accommodate various sizes of these units...A facility where the testing can be observed easily and safely".*
- *"There are various independent testing facilities for static testing, but they do not have the dynamic testing capability".*
- *"Currently, dynamic loading facilities are restricted to OEMs".*
- *"Having an independent testing facility will stimulate research and development (R&D) into new products and ensure compliance of current products in the market".*

4.3.1.3 Location of the dynamic testing facilities

The desktop study conducted in Milestone 2 of this project revealed several operating and non-operating dynamic testing facilities both internationally and in South Africa (presented in **Error! Reference source not found.** and Table 3). The objective of Part 1 of the survey was to collect information about the dynamic testing facilities currently used by the South African gold and PGM mines. The responses from participants regarding the location of the facilities employed by the respective mines are summarised in Table 6.

Table 6: Summary of the test facilities that carry out dynamic testing on support units, as identified by participants.

Facility	Location
Elbroc Mining Products	Benoni, Gauteng
New Concept Mining	Johannesburg, Gauteng

RocBolt Technologies	Elandsfontein, Gauteng
Videx Mining Products	Germiston, Gauteng
Mine Support Products (MSP)	Vereeniging, Gauteng
BedRock Mining Support	Pretoria, Gauteng
M&J	Krugersdorp, Gauteng

An important factor that emerged from the survey is the location of the test facilities. It was noted that all the test facilities obtained from the responses are located in the Gauteng Province, which is near most of the gold and PGM mines. The convenient location means that support units can be transported by road. The location of a test facility is a critical factor that impacts its overall effectiveness and efficiency. Some of the important factors to consider when choosing the location of a test facility include:

- **Proximity and accessibility to customers:** The facility should be in a location that is easily accessible to its customers. This can help to reduce transportation costs and make it easier for customers to access the facility.
- **Strategic location:** The facility should be in a location that is strategically important for the industry or the company.
- **Safety and security:** The facility should be in an area that is safe and secure, to ensure the safety of personnel working in the facility and to protect the facility's assets.

Overall, the location of a test facility can have a significant impact on its effectiveness and efficiency. Choosing the right location can help to reduce costs, improve efficiency, and ensure the safety of personnel working in the facility.

4.3.1.4 Dynamic load testing methods

4.3.1.4.1 Direct blasting/Simulated blasting

The simulated blasting method is not considered in this study because it is not possible to replicate the same conditions as a rockburst and the results obtained from simulated blasting may not be representative of actual dynamic conditions. This makes it difficult to compare the results of multiple tests.

4.3.1.4.2 Drop weight test

In Milestone 2, several facilities that conduct drop testing were identified in South Africa (Figure 9), however, the majority of them were non-operational or their operational status could not be determined.

Figure 9: Drop weight (free fall) rig at Timrite.

4.3.1.4.3 Hydraulic test

During Milestone 2, three hydraulic rigs were identified: the MSP and Elbroc rigs, which are currently operational, and the Terratek rig, which was undergoing a refurbishment process when this report was compiled. Table 7 provides a summary of the responses given by participants when asked to identify the testing method utilised at the facilities that test their support.

Table 7: Dynamic testing methods used by participants.

Dynamic testing method	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5	Participant 6	Participant 7	Participant 8
Drop test	✓	Facility not named		Facility not named	✓	✓	Mine does not require dynamic testing of support	Facility not named
Hydraulic	✓		✓			✓		

Due to its inability to repeat results, simulated blasting was excluded as a method of dynamic testing. As a result, the only available alternatives are drop weight testing and hydraulic testing. After analysing the responses from the surveys and consultation with industry experts and suppliers, the following comparisons can be drawn between drop weight and hydraulic testing:

- **Loading method:** Drop weight testing uses gravity to deliver kinetic energy directly to support elements, while hydraulic dynamic testing uses a hydraulic actuator to apply a controlled load. The ease of modification of drop weight and hydraulic dynamic testing methods depends on several factors, including the design and construction of the test apparatus, the control and measurement systems, and the complexity of the test requirements. The drop weight method generally requires more significant modifications to change the test parameters, such as changing the weight or height of the drop, whereas hydraulic testing may allow for easier adjustments to test parameters through adjustments to the hydraulic pressure or flow.

- **Cost:** Drop weight testing is typically less expensive than hydraulic dynamic testing, as it requires less equipment and has a simpler setup. The hydraulic dynamic testing method can be expensive due to several factors, such as the cost of the hydraulic actuators, which are the key components that convert fluid pressure into mechanical motion. The hydraulic systems also require more skilled labour to operate, which can impact the operating costs and availability of suitable labour to perform the tests. In addition, the cost of maintaining the hydraulic systems and ensuring their reliability can also be high. Additionally, specialized training may be required for laboratory technicians to operate the hydraulic systems, which can be costly.
- **Loading rates:** The loading rate for drop weight testing is typically higher compared to hydraulic dynamic testing. Drop weight testing is a direct application of kinetic energy to the support elements using gravity, and as a result, the impact load can be increased or decreased by adjusting the mass of the falling weight. On the other hand, hydraulic dynamic testing relies on a hydraulic actuator to apply a controlled load to the support, which has a more limited range of applied loads compared to drop weight testing. This can be due to limitations in the fluid pressure used by the actuator and the size of the equipment used in the test. The load that is applied can impact the results of the test, and a higher load in dynamic testing can provide more reliable results, but also comes with increased costs and safety risks.
- **Load control:** Drop weight testing has almost no control over the applied loading rate, as it is an impact test and the force is determined by the weight of the falling object and its height of fall. Hydraulic dynamic testing offers more control over the applied loading rate, as it can be adjusted using the control system. Loading rate is an important parameter to be able to control as very high accelerations may cause failure of yielding support.
- **Repeatability of tests:** Both the drop weight and hydraulic dynamic testing methods provide a high level of repeatability in their testing procedures. Drop weight testing is known for its repeatability, as the test is performed under controlled conditions and the same weight is dropped from the same height, resulting in consistent loading. On the other hand, the hydraulic testing method can consistently repeat tests as the applied load can be precisely controlled. However, it should be noted that the reliable results provided by the hydraulic method can be influenced by whether the equipment is well-maintained or not and whether the tests are performed by experienced operators.
- **Equipment:** Both drop weight and hydraulic dynamic testing methods require specialized equipment to perform the tests. Drop weight testing uses a weight system that can be raised and then dropped to generate an impact load, while hydraulic dynamic testing uses a hydraulic actuator which converts fluid pressure into mechanical motion. The hydraulic testing method requires more complex machinery compared to drop weight testing, which can impact the cost of the equipment. The hydraulic actuator must

also be able to withstand high forces, which can also contribute to the cost. However, hydraulic dynamic testing is more flexible and can generate a wider range of loading conditions than drop weight testing.

Further engagements yielded the following additional insights regarding the two common dynamic testing methods:

- No single dynamic testing method is suitable to test all support types because the capacity and dimensions of support units are different.
- The choice between drop weight and hydraulic dynamic testing methods will depend on the specific requirements of the test and the characteristics of the underground support being tested.
- Hydraulic impact testing is not deemed suitable for dynamic testing of netting due to the dimensions required to have an impact on the net, as outlined in the established protocols. The limitation is caused by the need for a large enough hydraulic valve to generate enough impact energy over the area to be tested. This is also supported by Enterprises University of Pretoria (2017) which mentions that hydraulic testing is not suitable for the dynamic testing of nets due to the required dimensions of impact on the net.
- Similar to findings made by Enterprises University of Pretoria (2017) the drop weight free fall method was the favoured test methodology.

4.3.1.4.4 Testing protocols

The use of a standardised dynamic testing protocol for testing support types was recommended in the literature (Malan, et al., 2006; Player, et al., 2008; Li, et al., 2014). However, the literature also showed that the various local and international dynamic testing facilities are uniquely designed and these will result in varying testing protocols.

The results of the survey showed that the procedures for selecting specimens for testing varied among the different mines represented by the participants. At one mine, specimens were selected randomly by the rock engineer, while at another mine, the units were chosen by the supplier and reviewed by the rock engineering practitioner. The survey responses indicated the involvement of a rock engineering practitioner in the specimen selection process, but there was a lack of uniformity across the mines. The mines relied on the protocols and quality controls established by the support manufacturers or suppliers who performed dynamic tests on their support. The manufacturers reported using ISO, ASTM, and SANS standards, as well as the "Guideline for Support Quality Assurance" by Malan et al. (2006) and SABS 1408:2019 as sources for their testing methodologies. Table 8 shows the control standards and testing methods used by support manufacturers/suppliers.

Table 8: Control standards and testing methods used by support manufacturers/suppliers.

Questions	Responses
What quality control standards does your manufacturing facility comply with?	ISO 9001-2015 (Quality management systems — Requirements)

Do you have a standard testing methodology to test the support units? If yes, what standards do you use?",	• SIM 04 02 05 Development of a practical guideline for support quality assurance for different systems used in tunnels and stopes • American Section of the International Association for Testing Materials (ASTM) e.g. International, 2008. Standard Test Methods for Laboratory Determination of Rock Anchor Capacities by Pull and Drop Tests. • SANS

4.3.1.4.5 Testing capability

4.3.1.4.5.1 Dynamically tested support types

The type of support used underground depends on various factors such as the specific needs of the mine, the depth of mining, the mining method, and the equipment available at the mine. Table 9 lists the types of support that are dynamically tested according to the information provided by mines and manufacturers that participated in the survey.

Table 9: Types of support that undergo dynamic testing as given by mines and manufacturers.

Participant #	Types of support - Gold	Types of support - PGM
Participant 1	• Elongates (timber) • Tendons • Netting	
Participant 2	• Elongates (timber) • Mechanical props • Backfill	
Participant 3	• Elongates (Camlok; Omniprop; timber) • Tendons • Netting	
Participant 4		• Tendons and • Elongates (timber)
Participant 5		• Elongates • Tendons • Netting
Participant 6	• Elongates (Rocprops; Omni props) • Tendons • Netting	
Participant 7		• Elongates • Tendons • Netting
Participant 8		• Elongates • Tendons • Netting
Participant 9	• Tendons • Elongates	

The responses from the survey participants indicated that all of the mines perform dynamic tests on tendons, elongates, and nets, which is consistent with the responses from the manufacturers. The manufacturers reported that tendons and elongates are the primary supports that are tested at their facilities. However, netting was not included as a support that is tested by the manufacturers because they were still in the process of developing a testing protocol for it at the time the report was submitted. The type of support that is tested at a facility is often determined by the capacity of the equipment. Participants mentioned that packs are not tested at the facility because their yielding load exceeds the capacity of the machine.

Further engagements yielded the following additional insights regarding dynamically tested support types:

- Dynamic testing of grout/cementitious packs is seen as a significant limitation due to the need for large machine capacities which current facilities do not possess. The CSIR Cottesloe site can only conduct static tests on timber and cementitious/grout packs, but not dynamic tests.
- That tendons and elongates will continue to be utilised in both current and future mines, with the potential for changes in the materials used for the support. For instance, the CSIR recently participated in a project that aimed to develop composite material as an alternative to timber elongates. So even though the support type is essentially the same, the materials used for the support might change. This may require different testing capabilities.

Currently, most dynamic testing facilities carry out testing of support units, which involves testing individual components such as rockbolts, cables, and resin, to determine their performance under dynamic loading conditions. According to the information collected, Groundwork Consulting is the only facility that carries out testing of support systems. It is ideal to conduct dynamic testing of support, as it would enable testing the entire system, including anchor bolts, cables, and resin, to determine the overall system's performance under dynamic loading conditions. The suppliers concurred that system testing is essential for safety and if the objective is to ensure safety, the systems must be tested.

4.3.1.4.6 Storage capacity and throughput of the test facility

The findings from the literature review emphasized the significance of a support testing facility having the ability to efficiently process the required volume of support units and/or systems from different mines without facing limitations in storage capacity or delays in testing. Malan et al. (2006) outlined a balance between the risk of not testing all support units and other factors such as testing cost and time required in their guideline for support quality assurance for various tunnel and stope systems.

The capacity of a test facility to handle a volume of tests depends on variables such as the sample size per mine, the frequency of testing, and the storage capacity of the facility. Malan et al. (2006) discussed using statistical methods to determine the optimal sample size that can be tested by a mine. The highlights of the statistical criteria used to determine the optimal sample size are detailed in Appendix C-Support sample size statistical criteria. The following test sample sizes were recommended by Malan et al. (2006) for the laboratory testing of the various support types:

- New timber elongates - large strength variability from unit to unit, generally caused by the inherent variability of the timber component of the elongate. A minimum of 10 tests will probably be required for an initial statistical evaluation. More tests may be required if the variability is large or a higher confidence level is required (Malan, et al., 2006).
- New packs - Each pack variation must have at least three slow test results for analysis; more may be desired if the variability in performance is high (> 10%). The average pack performance of at least three slow test results will be used for design purposes (Malan, et al., 2006).
- New pre-stressing devices - For rupture load, a minimum of 3 at maximum lift, 3 at 50% lift and 3 at 25% lift should be tested. This number should increase if there is a large variability in the results (Malan, et al., 2006).
- New removable steel props (yielding and non-yielding) - 3 identical units of each new product type for the slow tests and 3 dynamic tests for each new product if applicable (Malan, et al., 2006).
- New tendons - 10 units of each product type for each type of test (Malan, et al., 2006).

The Enterprises University of Pretoria (2017) recommended that there should be sufficient area to prepare and store support samples for up to 30 days. In addition, it was mentioned that the CANMET testing centre in Canada, which tests tendons, has a waiting list that ranges from three to six months on average for a single test. These factors highlight the importance of the test facility catering for the gold mines in Western Gauteng and possibly those in the Free State. There is also an opportunity that the test facility would be used by PGM mines that experience seismicity as indicated by the survey results.

In line with the aforementioned recommendations by Malan et al. (2006) and the requirement to determine the volume that can be handled by the test facility, the survey participants were asked how big a sample size is tested and whether any guidelines were followed. The majority of the responses indicated that a small number of samples are tested per support type. The responses were as follows:

- *Testing is done twice a year or ad hoc, where deemed necessary. The number of samples may vary but normally a minimum of units.*
- *Three per support unit.*
- *Every prop is tested using static methods*
- *Minimum 3 samples per consumable*
- *At least 3 per sample. For elongates, we select 10.*
- *3 units*
- *Minimum of 10 samples per tested support type, based on guidelines*
- *8 - 10 units based on SIMRAC guidelines*

The survey participants were requested to indicate how frequently they conduct dynamic tests on their support units. Half of the participants indicated that they conduct tests on their support units quarterly. One mine representative mentioned that in some cases, support units are tested on an ad hoc basis.

The survey participants answered that they receive test results after an average duration of between 1 to 2 weeks (Figure 10). One survey participant mentioned that some data is provided as the testing progresses.

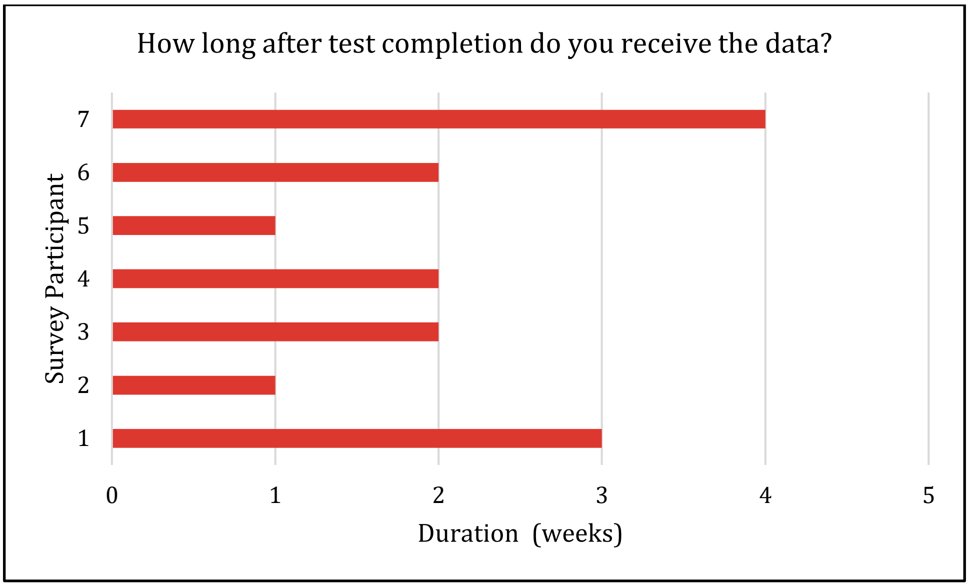

Figure 10: The time it takes to receive test results.

The responses from the participants and literature findings help identify the key considerations for the storage capacity and throughput parameters of a dynamic testing facility. The main factors are:

- Number of support units tested per mine and at what periodic intervals.
- Storage capacity of the facility.
- Duration to complete a test batch.
- Data analysis duration.

The other factor that should be considered is that the facility would be used to test support for research and development purposes. The number of tests, their duration and frequency should be estimated to avoid potential inundation of the facility with high volumes of validation tests and tests from mining.

4.3.1.4.7 Dynamic testing parameters

The main testing parameters identified in the desktop study are input velocity, input energy, deformation range, and drop weight, with acceleration mentioned to a lesser extent. In South Africa, the value of 3 m/s is used as the ejection velocity for dynamic loading tests of tendons and elongates. However, the Enterprises University of Pretoria (2017), found that this value of 3 m/s may be over-designed and further investigation is necessary. Table 10 summarises the recommendations from the two main sources of dynamic load testing information.

Table 10: Summary or laboratory test recommendations.

Support Type:	Source: Development of a practical guideline for support quality assurance for different systems used in tunnels and stopes (Malan, et al., 2006)	Source: Developing testing specifications for netting and the dynamic testing of tendons; and assess the feasibility of establishing an independently accredited support testing facility (Enterprises at the University of Pretoria, 2017)
Tendons	• Recommended the use of SABS 1408:2019.	• Input velocity - 3 m/s or greater. • Input energy – greater than 25 kJ and up to 120 kJ (Depending on the tendon specifications - should be sufficient to cause failure in single load; from the workshop, the strongest tendon tested absorbed 117 kJ). • Maximum dynamic yielding range - 500 mm displacement. • Mass of drop weight - sufficient to produce input energy up to 120 kJ (If drop test/freefall) given by equation for potential energy: PE = m*g*h. • Deformation range: Allow up to 500 mm.
Elongates	• Rapid tests are usually performed at 3 m/s, but a cyclical test is preferred. • Slow deformation - standard deformation rate of 30 mm/min for these tests. • Rapid deformation - a rate of 10-30 mm/min for 0-50 mm followed by 3 m/s for 150-250 mm and then a slow rate of 10-30 mm/min up to 300 mm.	
Packs	• The standard slow testing rate for packs should be 30 mm/min. • Each pack should be compressed to 600 mm or 50 %, whichever is less.	
Yielding and non-yielding steel props	• Dynamic compression tests at 3 m/s for yielding props. • Rapid deformation - apply a rate of 10-30 mm/min for 0-50 mm followed by 3 m/s for 150-250 mm followed by 10-30 mm/min up to 300 mm. • Slow deformation - Use a rate of between 10-30 mm/min.	

Nets		• Drop height – between 100 mm and 300 mm.
		• Drop weight.
		  ◦ For gold and coal (0.65 m X 0.75 m)- 450 kg.
		  ◦ For platinum (stoping 2.20 m X 0.80 m) – 2000 kg.
		  ◦ For Platinum (on & off reef development 1.7 m X 0.4 m) - 1000 kg.

The mine representatives were requested to provide performance characteristics of the different support units they use in their seismically active mines. The responses from the survey participants are shown in Table 11. Three participants indicated that their support units are tested at an ejection velocity of 3 m/s, a commonly used value, although recommendations were made to investigate this value further. One participant provided an acceleration value of 1.5 m/s². The yield range (200 mm and 300 mm) provided by some of the participants was consistent with the yield ranges recommended by Malan et al. (2006) and the Enterprise University of Pretoria (2017) (Appendix C-Support sample size statistical criteria).

Table 11: Responses from survey participants on support performance requirements.

	1	2	3	4	5	6	7	8
Ejection velocity	3 m/s	3 m/s	-	-	No criteria have not yet experienced dynamic failure of support units	3 m/s	n/a	n/a
Yield range	300 mm	200 mm	300 mm			5 mm		
Energy absorption	23.09 kJ/m² (fallout =1.3 m)	20 kJ/m²	23 kJ/m²	250 kJ		25 kJ/m²		
Acceleration	-	-	-	1.5 m/s²		-		

The support manufacturers and suppliers were asked to list the essential requirements for a dynamic support testing facility. One response was received, and it specified that a load capacity of 500 kN and a velocity of 3 m/s is used to test tendons and elongates.

Literature and the survey responses show that there have not been changes to dynamic load testing parameters in South Africa. The values recommended in 2006 are still currently used by various testing facilities. There is however a common suggestion to further investigate the ejection velocity of 3 m/s. A recent publication highlighting this issue is Malan and Napier (2018). This is illustrated in Figure 11 and this will require additional research in a dedicated project.

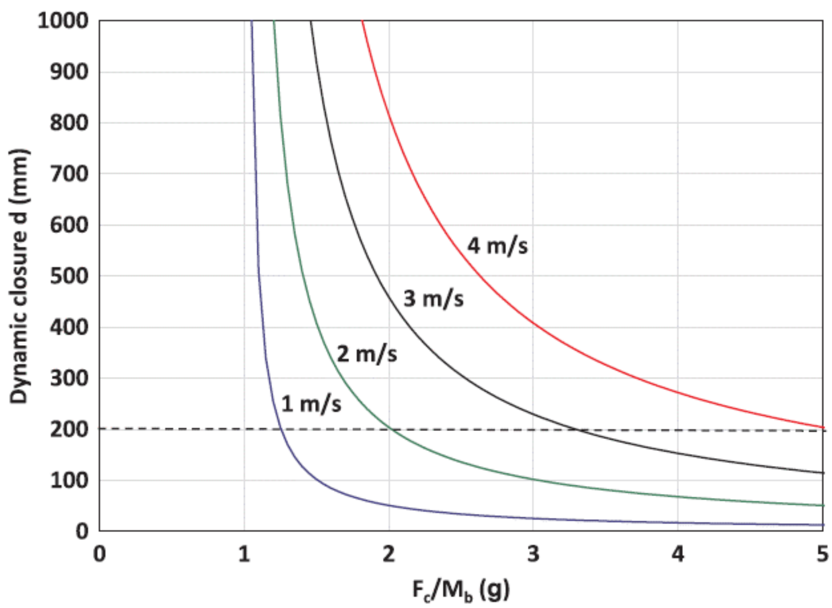

Figure 11: Dynamic closure, d, plotted as a function of the ratio (F_c/M_b). Note that to restrict the dynamic closure to a small value, e.g. 200 mm, the support requirements become onerous for high ejection velocities. (after Malan and Napier, 2018). F_c is the force supplied by the support unit and M_b is the mass of the block ejected.

Some of the reasons given for further investigation of the 3 m/s ejection velocity is because of the following:

- Deeper mining conditions prevail now compared to the time when the 3 m/s standard was developed. The deeper the mining and higher the stresses the more energy is stored in the rocks and the more energy is released.
- Some of the engagements revealed concerns over the 3 m/s ejection velocity. The reason is that 3 m/s represents constant velocity, however, during a seismic event the rock "accelerates" from time $t_1 = 0$, and the peak velocity is reached at time t_2. It is not clear how the acceleration from t_1 to t_2 affects the performance of the various support units and it is intuitively felt that very high accelerations will result in support failure. Therefore, recommendations to conduct studies related to acceleration are suggested as well. This should be included in a future research project.

The acceleration of the old Terratek machine should be considered a future requirement, it needs to be ensured that hydraulic dynamic testing equipment can provide at least this acceleration as a starting point. It will be of no use to claim tests are conducted at 3 m/s if it takes several seconds to reach this velocity in the test.

4.3.1.4.8 Instrumentation and data acquisition

A crucial aspect of any monitoring program is having confidence in the measurements and their results (Jager & Ryder, 1999). Although all instrument-based monitoring systems are inherently prone to inaccuracies, it is important to acknowledge and comprehend these inaccuracies to implement tactics and strategies to minimise their impact. The source of these inaccuracies can stem from shortcomings in the design of the monitoring instruments but are more commonly caused by various external factors.

The control systems of the drop weight and hydraulic systems are different in terms of their methods of application, response time, and accuracy. The control system of the drop weight test is relatively simple, usually consisting of a timer to control the release of the weight and a load cell to measure the force of impact. The response time of the drop weight test is quick, but the accuracy of the results can be affected by factors such as the energy absorption of the support and the size and shape of the specimen.

The hydraulic testing dynamic method, on the other hand, uses a hydraulic actuator to apply a controlled and continuous load to the specimen. The control system of the hydraulic testing dynamic method is more complex and consists of a computer-controlled hydraulic pump, a load cell to measure the force, and an electronic controller to regulate the test procedure. The response time of the hydraulic testing dynamic method is slower than that of the drop weight test, but the results are generally more accurate and repeatable, as the load can be precisely controlled and the testing can be performed at a constant rate. The two methods also differ in terms of accuracy, precision, resolution, and sensitivity. These terms can be defined as follows:

- **Accuracy:** Refers to the difference between an instrument's reading for a parameter and a known value of the same parameter. Drop weight tests are known to have higher accuracy compared to hydraulic dynamic tests as they apply a well-defined, reproducible impact force.

- **Precision:** Refers to the extent to which an instrument can reproduce a certain reading for the same input. Hydraulic dynamic tests have a higher precision as they can apply forces at a more controlled and steadier rate, allowing for more accurate measurements.
- **Resolution:** This is the smallest division on an instrument readout scale (i.e., the number of significant digits of outputs). Drop weight tests have a lower resolution compared to hydraulic dynamic tests as they only provide a snapshot of the material response to impact.
- **Sensitivity:** Refers to the smallest unit of measurement detectable by the instrument. Hydraulic dynamic tests are more sensitive to small variations in material properties as they can apply forces over a longer duration, providing more information about the material response.

To obtain trustworthy results, the instruments utilised must possess a satisfactory level of both accuracy and precision. A high level of accuracy does not guarantee high precision and the reverse is also true. Additionally, the appropriate combination of resolution and sensitivity must be present to provide valuable readings. A high resolution does not automatically indicate high sensitivity or accuracy (Jager & Ryder, 1999).

4.3.1.4.9 Options for establishing, refurbishing or using existing testing facilities

Enterprises University of Pretoria (2017) mentioned three options to be considered for the establishment of an independent testing facility, namely the construction of a new facility along with new testing machines; refurbishment of an existing facility and machines and; the use of existing operational facilities.

4.3.1.4.9.1 Construction of a new facility

It was mentioned that the building of a new testing facility would require the creation of separate testing machines, one for each support type to be tested. This decision was favourable due to the high volume of tests that were conducted and the long lead times for tendon testing reported at CANMET in Canada. The testing protocols for different support types differ, for example, tendons and netting are different, requiring different weights (assuming a drop weight facility) and input parameters, making it impractical to use one machine for both types of testing. Additionally, having two machines would reduce the risk of downtime, as tests can continue on one machine if the other is undergoing maintenance or modification.

Engagements revealed that having different machines to test different support types was the favoured option, as suggested by Enterprises University of Pretoria (2017). One engagement suggested the establishment of a facility with a universal machine. A universal machine could be engineered to be able to test elongates (compression) and tendons (tension). The equipment would have to accommodate the length of the elongates and tendons ~ 2 - 3 m. Several facilities exist that provide compression and tension but for static tests. However, an efficient plan to deal with down- and waiting times, would need to be developed.

Further engagements reveal that manufacturers are in support of the establishment of an independent test facility. This would be beneficial to them because they would be able to verify their tests on in-house developed products to ensure that they are producing accurate results and are complying with testing methods. According to some mining personnel, a new facility would allow them to verify the results obtained from manufacturers. One participant highlighted the need for a newly constructed independent facility for R&D trials of future support that they are developing.

4.3.1.4.9.2 Refurbishment of an existing facility

The next option to consider was the revitalisation of existing dynamic testing facilities. The literature review conducted in milestone 2 revealed that the available facilities in South Africa that can conduct dynamic testing are limited to the SRK and Terratek facilities at the CSIR. The evaluations conducted on the two facilities involved analysing the practicality of refurbishing the test machines that are no longer operational, as well as the financial comparison between refurbishing and constructing new test machinery (Enterprises University of Pretoria, 2017). The SRK facility was found to be insufficient for revitalization as a result of prolonged non-operation, leading to the corrosion of some components. The Terratek machine at CSIR was found to have several obstacles to refurbishment, such as non-operational hydraulic valves and a broken platen.

Engagements reveal that a refurbishment process for the Terratek rig was underway. According to the manufacturers responsible for the refurbishment, replacement of the hydraulic valves, the broken platen and upgrade to the machine's software was being carried out. Further details regarding the refurbishment process were not available at the time the report was submitted, and informal discussions with the manufacturers were underway.

4.3.1.4.9.3 Using an existing operational facility

The engagements with different manufacturers revealed their willingness to modify/upgrade their dynamic testing facilities and methods to comply with new or improved dynamic testing standards. This would also be to their benefit because it would produce more accurate results for their R&D trials and meet the desired results for the industry. The suppliers suggested that if the facilities are modified according to the required protocols, they may also receive accreditation from a relevant independent organization, providing access to additional accredited testing sites where both industry and suppliers can perform dynamic support tests following the protocols. This alternative solution, if successful, could eliminate the need for a new facility. The major support suppliers are expected to conduct most of their R&D testing in-house and their facilities will be kept operational for these purposes, not relying on certification income from periodic testing. Tests performed at the suppliers' facilities may be overseen by an independent representative to approve the testing method. The suppliers will also be able to test their support units and those from other suppliers or customers. A database could be created to showcase the test results under similar parameters, making it easier for customers to make informed decisions about the best support units for their needs.

4.3.1.5 Preliminary requirements for establishing a dynamic testing facility

The literature review, survey and engagements with manufacturers and mining personnel have highlighted common requirements concerning establishing an independent dynamic testing facility. The following are some of the key requirements that need to be considered when setting up such a facility:

- Physical space: The facility will need a large enough space to accommodate the testing equipment and the test specimens. The space will also need to be designed to safely contain the test specimens and prevent damage to surrounding areas. The facility should be of sufficient dimensions to protect all machine parts, and instrumentation from weather elements, as well as the operators' conducting tests.

- Testing equipment: The facility will need to be equipped with specialized testing equipment that can perform dynamic testing on underground support units or systems. This may include load frames, actuators, data acquisition systems, and control systems.

- Safety systems: The facility will need to be equipped with safety systems to protect the personnel working in the area. This may include emergency stop buttons, fire suppression systems, ventilation systems and other safety measures.

- Staff: The facility will need a team of trained personnel to operate the testing equipment and perform the dynamic tests. This may include engineers, technicians, and safety personnel. The composition and size of the team will be determined by the dynamic testing method selected.

- Quality control: The facility will need to have a quality control system in place to ensure that the tests are conducted consistently and accurately. This may include procedures for calibration, data management, and record keeping.

- Accreditation: The facility may need to be accredited by a recognized body to be recognized as a valid testing facility. This may include meeting specific standards and passing regular audits.

- Maintenance and Upkeep: The facility will need regular maintenance and upkeep to ensure that the equipment remains in good working order and meets the safety requirements.

- Standard Operating Procedures and Code of Practice: The facility will need written documentation which details the testing procedures and roles and responsibilities of employees at the facility.

4.3.2 Milestone Conclusions

In conclusion, to gain industry feedback on the dynamic testing practices, a survey was distributed, through email and by using an online application, to mining personnel and manufacturers and suppliers of underground support. The mining personnel included rock engineering managers, senior rock engineers and seismologists. At least four underground mine support manufacturers and supplier companies participated in the survey. Although the survey response was low (~30%) the post-survey engagements were successful and provided a more comprehensive and accurate understanding of the requirements of a dynamic testing facility. Additionally, data saturation was achieved through the additional engagements with three suppliers and three mine representatives.

Initial responses from the surveys supported the establishment of an independent testing facility. The participants believe that such a facility would be beneficial to the industry by testing commonly used support units, providing ease of observation, and ensuring safety during testing. They also stated that there is a lack of independent testing facilities that have dynamic testing capabilities and that currently, dynamic testing is only accessible to Original Equipment Manufacturers. Lastly, having an independent testing facility would encourage research and development into new products and guarantee compliance with current market products. The drop weight (specifically the freefall) and the hydraulic impact/loading methods were the favoured dynamic testing methods for the facility.

The survey results showed that mines perform dynamic tests on tendons, elongates, and nets where applicable. The manufacturers reported that tendons and elongates are primarily tested at their facilities, but the netting is not yet tested due to a lack of testing protocols. The type of support tested is determined by machine capacity. Limitations exist in dynamically testing grout/cementitious packs due to a need for high-voltage capabilities that current facilities lack. Engagements highlighted that tendons and elongates will continue to be used as primary support with potential material changes, therefore future facilities would need to be capable of testing these types of support. System testing of support is considered essential for safety and has the support of suppliers. Currently, only one manufacturer and supplier of underground support carries out testing of support systems.

Space and storage were also considered important requirements for the facility. The key considerations for storage capacity and throughput parameters of a dynamic testing facility include the number of support units tested, storage capacity, duration to complete a test batch, and data analysis duration. Additionally, the facility would be used for both research and development testing and mining client testing, so the volume and frequency of tests must be estimated to prevent facility overload.

The main parameters considered for dynamic load testing included input velocity, input energy, deformation range, and drop weight, with acceleration being mentioned to a lesser extent. The value of 3 m/s was found to be used by all the mines and manufacturers as the ejection velocity for dynamic loading tests. Some of the engagements revealed concerns over the applicability of the 3 m/s ejection velocity due to the deeper mining conditions and higher stresses that prevail now. Other concerns were raised over the 3 m/s representing constant velocity when during a seismic event the rock “accelerates” and this may be a key parameter leading to support failure. Therefore, recommendations to conduct studies related to acceleration are suggested as well. The survey results further showed that no changes had been made to the dynamic load testing parameters since 2006.

Finally, engagements were held regarding the options of establishing a testing facility i.e., construction of a new facility, refurbishment of a non-operational facility and using an existing dynamic test facility, with the construction of a new facility being the most favourable option.

Below is a summary of the preliminary requirements for establishing a testing facility:

- Physical space.
- Testing equipment.
- Safety systems.

- Staff.
- Quality control.
- Accreditation.
- Maintenance and Upkeep.

4.4 Milestone 4: Establish criteria and requirements of a dynamic test facility from underground mine support systems manufacturers

In Milestone 4, our research delves into the necessary prerequisites for establishing an independent dynamic testing facility. Our aim is to scrutinise these prerequisites in light of industry standards, best practices, and pertinent regulations. To achieve this, we adopted a methodology that centered on identifying gaps in the requirements outlined in Milestones 2 and 3, followed by consultations with underground mine support manufacturers and researchers. Through this approach, we sought to gather information that would enable us to fill in the gaps we had identified earlier.

4.4.1 Research Findings

4.4.1.1 Key requirements for establishing an independent dynamic testing facility

The following key requirements for establishing an independent dynamic testing facility were identified through the distribution of the survey and engagements with mining stakeholders and underground mine support manufacturers:

- The need to establish an independent dynamic testing facility for underground support.
- Location of the facility.
- Dynamic load testing methods and equipment.
- Testing protocols.
- Support types to be tested.
- Storage capacity and throughput of the facility.
- Dynamic testing parameters.
- Instrumentation and data acquisition.
- Options for establishing, refurbishing or using an existing testing facility.

Additionally, the following requirements were identified:

- Physical space.
- Testing equipment.
- Safety systems.
- Staff.
- Quality control.
- Accreditation.
- Maintenance and upkeep.

4.4.1.2 The need to establish an independent dynamic testing facility for underground support

The analysis of the literature and engagements on the need to establish an independent dynamic testing facility reveals several trends and relevant findings:

- **Quality control:** The need for unbiased and accurate testing to ensure the quality and integrity of underground support is a key driver for establishing an independent testing facility.
- **Technical expertise:** Developing technical expertise and specialised testing capabilities are important drivers for the establishment of an independent testing facility.
- **Research and Development:** An independent testing facility can be used for the research and development of new underground support technologies and materials.
- **Compliance:** Meeting regulatory requirements for underground support testing and evaluation is another key driver for establishing an independent testing facility.
- **Efficiency:** An independent dynamic testing facility can reduce the time required for testing and evaluating underground support.

The findings regarding the need to establish an independent dynamic testing facility are generally consistent with industry standards, best practices, and applicable regulations. For instance, compliance with regulatory requirements is a critical aspect of underground mine support testing and evaluation, and the establishment of an independent testing facility can ensure compliance with these requirements. Similarly, the need for unbiased and accurate testing to ensure the quality and integrity of underground support aligns with industry standards and best practices.

Developing technical expertise and specialised testing capabilities are also important aspects of best practices in the mining industry. An independent testing facility can offer a dedicated space for developing such expertise and capabilities, which can lead to the discovery of new properties of materials and the development of new underground support technologies.

The need for research and development in the mining industry is widely recognized, and an independent testing facility can provide an excellent platform for such activities. This aligns with the best practices of continuous improvement and innovation.

The survey participants' concerns about the current limitations of dynamic loading facilities being restricted to OEMs highlight the need for an independent testing facility to provide a more open and accessible testing environment. This supports the best practices of ensuring a level playing field in the industry, where all participants have access to the necessary facilities and resources.

Overall, the findings suggest that establishing an independent dynamic testing facility for underground mine support aligns with industry standards, best practices, and applicable regulations. Such a facility can enhance the safety and integrity of underground mines, promote research and development, and improve the quality and efficiency of underground support testing and evaluation.

4.4.1.3 Location of the facility

The desktop study and analysis of survey responses, conducted in milestone 2 and 3 respectively, indicates that the location of dynamic testing facilities is critical to their effectiveness and efficiency. Proximity and accessibility to customers are crucial to reducing transportation costs and improving customer access. The facility's strategic location is also important for the industry or company, and safety and security should be considered to ensure the safety of personnel and the protection of the facility's assets.

All the test facilities obtained from the survey responses are located in the Gauteng Province, near most of the gold and PGM mines. The survey participants highlighted that the convenient location of their facilities in Gauteng allows support units to be transported by road, reducing transportation costs and making it easier for customers to access the facility.

4.4.1.4 Dynamic load testing methods

Three testing methods were initially investigated in the study, namely direct blasting/simulated blasting, drop weight testing, and hydraulic testing. However, the direct blasting/simulated blasting method was excluded from the study due to its inability to replicate the same conditions as a rockburst and the results not being representative of actual dynamic conditions, making it difficult to compare the results of multiple tests. Two dynamic testing methods were presented as alternatives: drop weight testing and hydraulic testing (Figure 12). Drop weight testing uses gravity to apply kinetic energy directly to support elements, while hydraulic testing involves the application of a dynamic load to a support unit using a hydraulic actuator. Several comparisons between the two methods can be made, including loading method, cost, loading rates, load control, and repeatability of tests. Drop weight testing is less expensive and has a higher loading rate, but hydraulic testing provides more control over the applied loading rate and is known for its repeatability. Both methods are repeatable, but the hydraulic method can be influenced by whether the equipment is well-maintained and whether the tests are performed by experienced operators. Both methods require specialised equipment to perform the tests, with hydraulic dynamic testing being more flexible in generating a wider range of loading conditions.

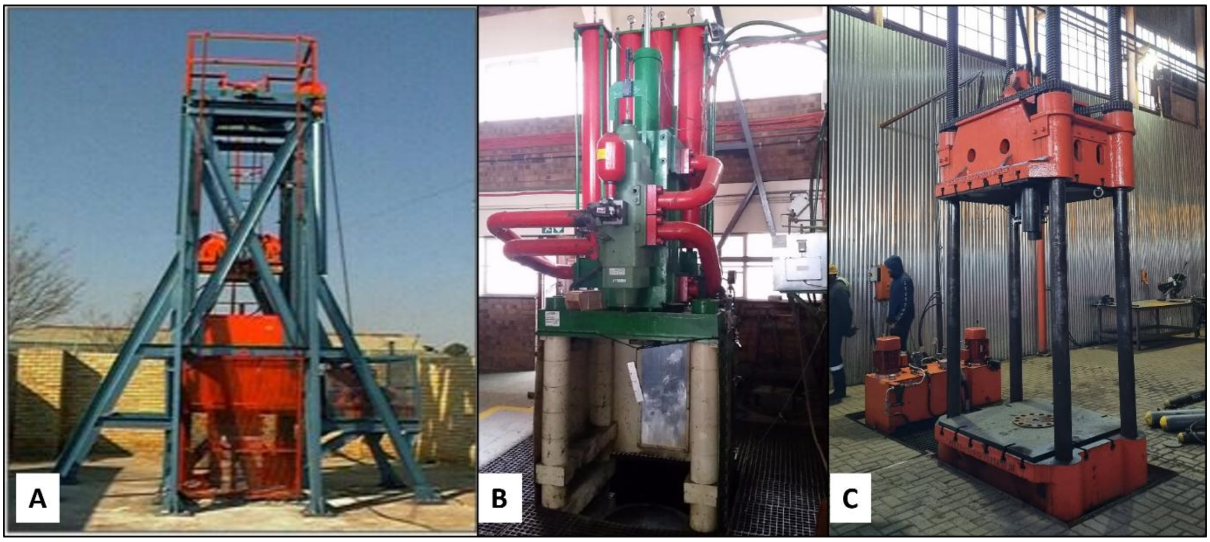

Figure 12: (a) Drop weight (free fall) rig at Timrite, (b) Terratek hydraulic rig at the CSIR, and (c) hydraulic rig at MSP.

Based on the information collected, no single dynamic testing method is suitable to test all support types. This means that different types of supports require different testing methods, and therefore, a testing facility that can conduct various types of dynamic tests is necessary. The study also highlights that the choice between drop weight and hydraulic dynamic testing methods depends on the specific requirements of the test and the characteristics of the underground support being tested. Therefore, it is important to determine the most appropriate testing method based on the specific support being tested.

Additionally, it was found that hydraulic testing is currently not suitable for dynamic testing of netting due to the limitations caused by the need for a large enough hydraulic valve to generate enough impact energy over the area to be tested. This means that the drop weight free fall method is the preferred testing methodology for netting.

Overall, the information suggests that a dynamic testing facility that can conduct various types of dynamic tests is necessary, and the most appropriate testing method should be determined based on the specific characteristics of the underground support being tested.

4.4.1.5 Testing protocols

The information gathered supports the use of a standardised dynamic testing protocol for testing support types. However, the survey responses indicate that there is a lack of uniformity across mines in terms of the procedures for selecting specimens for testing and there are inconsistencies in the testing protocols used by manufacturers and suppliers. Each mine depends on the protocols and quality controls established by the support manufacturers or suppliers who performed dynamic tests on their support. The survey shows that manufacturers use different standards to perform the tests, such as the ISO, ASTM, and SANS standards, as well as the "Guideline for Support Quality Assurance" by Malan et al. (2006) and SABS 1408:2019.

Overall, the findings suggest a need for a standardised dynamic testing facility that can perform tests consistently across different mines and support types. The lack of uniformity in the specimen selection and testing protocols may lead to inconsistencies in the results, making it difficult to compare the performance of different support types. A standardised testing facility would ensure that all support types are tested using the same protocol, allowing for fair comparisons and more accurate assessments of support performance.

4.4.1.6 Support types to be tested

Tendons, elongates, and nets are the primary support types that are dynamically tested, with manufacturers reporting that tendons and elongates are the most tested. Netting was not tested by manufacturers due to the lack of a testing protocol for it. The capacity of the equipment used for testing is a determining factor for the support types tested at a facility. Grout/cementitious packs are limited in dynamic testing due to the need for large machine capacities. Tendons and elongates will continue to be utilised, with potential changes in support material requiring different testing capabilities.

Currently, most dynamic testing facilities test support units, such as rockbolts, cables, and resin, to determine their performance under dynamic loading conditions. However, it is ideal to conduct dynamic testing of support systems, including anchor bolts, cables, and resin, to determine overall system performance. Groundwork Consulting is the only facility identified to perform testing of these support systems. The suppliers believe that system testing is essential for safety, and if the goal is to ensure compliance, the systems must be tested.

4.4.1.7 Storage capacity and throughput of the facility

Analysing the information collected regarding the storage capacity and throughput of the facility shows that the following should be considered:

- **Importance of efficient processing:** The literature review highlights the significance of a testing facility being able to efficiently process the required volume of support units from different mines without facing limitations in storage capacity or delays in testing. This emphasizes the need for a facility with adequate storage capacity and throughput parameters.
- **Optimal sample size:** The capacity of a test facility to handle a volume of tests depends on variables such as the sample size per mine, the frequency of testing, and the storage capacity of the facility. Statistical methods can be used to determine the optimal sample size that can be tested by a mine. Malan et al. (2006) provided recommendations for the laboratory testing of various support types, which can be used as a guideline for determining the optimal sample size.
- **Frequency of testing:** Half of the survey participants indicated that they conduct tests on their support units quarterly. This suggests that there is a regular need for testing support units and that a testing facility should be able to cater to this frequency of testing.
- **Turnaround time for test results:** The survey participants mentioned that they receive test results after an average duration of between 1 to 2 weeks. This indicates that there is a need for a testing facility with a quicker turnaround time for test results.

- **Need for research and development (R&D) testing:** The facility would also be used to test support for research and development purposes. This suggests that the testing facility should be able to handle high volumes of validation tests and tests from mining, and the number of tests, their duration, and frequency should be estimated accordingly.

Overall, the identified trends and patterns highlight the importance of establishing an independent dynamic testing facility with adequate storage capacity, throughput parameters, and quick turnaround time for test results. The facility should also be able to handle a regular need for testing support units and cater to the requirements of R&D testing.

4.4.1.8 Dynamic testing parameters

The main parameters considered for dynamic load testing included input velocity, input energy, deformation range, and drop weight, with acceleration being mentioned to a lesser extent. The value of 3 m/s was found to be used by all the mines and manufacturers as the ejection velocity for dynamic loading tests. Some of the engagements revealed concerns over the applicability of the 3 m/s ejection velocity due to the deeper mining conditions and higher stresses that prevail now. Other concerns were raised over the 3 m/s representing constant velocity when during a seismic event the rock "accelerates" and this may be a key parameter leading to support failure. Efforts made to obtain past results of the Terratek machine and use them to calculate the minimum acceleration that would be considered in a new facility were unsuccessful. Therefore, recommendations to conduct studies related to acceleration are suggested. The survey results further showed that no changes had been made to the dynamic load testing parameters since 2006. Therefore, recommendations to also conduct studies related to the update of dynamic load testing parameters to improve their accuracy and effectiveness in ensuring the safety and efficacy of mining support units are made.

4.4.1.9 Instrumentation and data acquisition

The information gathered about the instrumentation and data acquisition system for the drop weight method and hydraulic method provided a comparison between the two methods, examining their control systems, response time, accuracy, precision, resolution, and sensitivity. The information showed that both testing methods are susceptible to inaccuracies, which can be mitigated by understanding the external factors that cause them.

The drop weight test is a relatively simple method that utilises a timer and load cell to measure impact force. Though it has a fast response time, accuracy can be impacted by factors such as specimen size and shape, and energy absorption of the support. In contrast, the hydraulic testing dynamic method is more complex, employing a computer-controlled hydraulic pump, load cell, and electronic controller to regulate testing procedures. This method has a slower response time but typically produces more accurate and repeatable results due to its precise load control and constant testing rate. The information emphasises the importance of achieving a satisfactory level of accuracy and precision for reliable results. It cautions that a high level of accuracy does not ensure high precision, and the appropriate combination of resolution and sensitivity is necessary for valuable readings.

These findings suggest that when establishing an independent dynamic testing facility, careful consideration of the testing method and instrumentation is essential. Factors such as the expected range of forces required response time, and the desired level of accuracy, precision, resolution, and sensitivity should be weighed when selecting the appropriate method and instrumentation. The facility should also have strategies in place to minimize external factors that can cause inaccuracies in measurements.

4.4.1.10 Options for establishing, refurbishing or using an existing testing facility

Manufacturers are supportive of the establishment of an independent test facility as it would allow them to verify their tests on in-house developed products and comply with testing methods. Mining personnel also see the need for a newly constructed independent facility for R&D trials of future support they are developing. From the survey results, the favoured option is the construction of a new facility with separate testing machines for different support types. This option would reduce downtime, as tests could continue on one machine if the other is undergoing maintenance or modification. It is also more practical, given the high volume of tests that need to be conducted, and the long lead times for tendon testing.

There is also a suggestion for the establishment of a universal machine that can test elongates (compression) and tendons (tension). While this option is feasible, it would require an efficient plan to deal with downtime and waiting times.

The revitalisation of existing dynamic testing facilities was also considered, but existing facilities would need significant revitalisation due to prolonged non-operation, leading to the corrosion of some components. Some of the suppliers that participated in the engagements suggested modifying/upgrading their operational dynamic testing facilities and methods to comply with new or improved dynamic testing standards, which may eliminate the need for a new facility.

4.4.1.11 Additional requirements to consider

Several additional requirements were identified through literature review, surveys, and engagements with manufacturers and mining personnel. They include the need for physical space, specialised testing equipment, safety systems, trained staff, quality control, accreditation, regular maintenance and upkeep, and written documentation such as standard operating procedures and a code of practice. All these factors must be taken into account when designing and setting up a facility that can perform accurate and reliable dynamic testing on underground support units or systems.

5 Conclusions

This research has identified the key requirements for establishing an independent dynamic test facility suitable for testing current and future underground mine support units. These requirements were identified through a survey and engagements with mining stakeholders and underground mine support manufacturers. The report has highlighted the need to establish an independent dynamic testing facility and the importance of location, dynamic load testing methods and equipment, testing protocols, support types to be tested, storage capacity and throughput of the facility, dynamic testing parameters, instrumentation and data acquisition, as well as options for establishing, refurbishing or using an existing testing facility. In addition, the report has identified several other important requirements including physical space, testing equipment, safety systems, staff, quality control, accreditation, and maintenance and upkeep. The findings have been compared with industry standards, best practices, and applicable regulations to provide a comprehensive guide for establishing an independent dynamic test facility.

The research has revealed several key trends and findings regarding the need to establish an independent dynamic testing facility. Quality control, technical expertise, research and development, compliance, and efficiency are all important drivers for the establishment of such a facility. These findings align with industry standards, best practices, and applicable regulations. The establishment of an independent testing facility can ensure compliance with regulatory requirements and provide an unbiased and accurate testing environment, consistent with industry standards and best practices. The facility can also offer a dedicated space for developing technical expertise and specialised testing capabilities, leading to innovation and continuous improvement. Additionally, an independent testing facility can promote research and development and provide a more open and accessible testing environment for all industry participants.

The research shows that the location of dynamic testing facilities is crucial for their effectiveness and efficiency. Proximity and accessibility to customers are important for reducing transportation costs and improving customer access, while safety and security must also be considered. The study found that all test facilities identified in this study are located in Gauteng Province near most gold and PGM mines, making it easier for customers to access the facility and reducing transportation costs. This location might be a challenge for coal mines, which are primarily located in the Mpumalanga and KwaZulu Natal Provinces. However, for the focus of this project, which is gold and PGM mines Gauteng is deemed the best location for the facility.

The study investigated three testing methods. Direct blasting/simulated blasting was found not to be feasible due to its inability to replicate rockburst conditions. Drop weight testing was found to be less expensive and have a higher loading rate, while hydraulic testing provides more control over loading rates and is known for its repeatability. The study highlights the need for a testing facility that can conduct various types of dynamic tests, as different types of supports require different testing methods. Therefore, the most suitable testing method will be determined by the type of support selected.

The gathered information supports the need for a standardised dynamic testing protocol for testing support types. However, there is a lack of uniformity across mines in terms of specimen selection and testing protocols used by manufacturers and suppliers. The findings suggest the need for an independent testing facility that can perform tests consistently across different mines and support types to ensure fair comparisons and accurate assessments of support performance. The primary support types tested are tendons, elongates, and nets. The research showed that tendons and elongates will continue to be used as primary support with potential material changes, therefore future facilities would, at the very least, need to be capable of testing these types of support. Currently, most dynamic testing facilities test support as units, but it is ideal to conduct dynamic testing of support systems to determine overall system performance. The testing of support systems will require bigger equipment that can accommodate the systems. The identified trends and patterns highlight the importance of establishing an independent dynamic testing facility with adequate storage capacity, throughput parameters, and quick turnaround time for test results to cater to the regular need for testing support units and R&D testing.

The comparison between the drop weight method and the hydraulic method has shown that both testing methods have their advantages and disadvantages. However, achieving a satisfactory level of accuracy and precision is crucial for reliable results, and the appropriate combination of resolution and sensitivity is necessary for valuable readings. When establishing an independent dynamic testing facility, careful consideration of the testing method and instrumentation is crucial, and strategies should be put in place to minimize external factors that can cause inaccuracies in measurements. Manufacturers and mining personnel support the need for a new facility with separate testing machines for different support types, while the establishment of a universal machine that can test elongates and tendons are also feasible. Although the development of a new facility was favourable throughout the engagements, it was recognised that the option to refurbish a non-operational facility or using an existing test facility was also viable. Additionally, several requirements must be considered when designing and setting up a facility that can perform accurate and reliable dynamic testing on underground support units or systems. By taking all these factors into account, it is possible to ensure that the testing facility can produce reliable results that comply with testing methods and standards.

6 Recommendations

Below are recommendations for future work:

- Conduct further investigations on acceleration as a parameter for dynamic load testing: The survey results revealed concerns over the applicability of the current ejection velocity of 3 m/s and the need for studies related to acceleration as a parameter leading to support failure during seismic events. Therefore, it is recommended to conduct further studies to improve the accuracy of dynamic testing parameters. This can include obtaining test results from various facilities and calculating the velocities achieved by each facility. This would determine the minimum acceleration that the new facility should achieve.
- Review and update dynamic load testing parameters: The survey results showed that no changes had been made to the dynamic load testing parameters since 2006. It is recommended to review and update the dynamic load testing parameters to improve their accuracy and effectiveness in ensuring the safety and efficacy of mining support units.
- Explore options for establishing a testing facility: The survey results revealed that the construction of a new facility was the most favourable option for establishing a testing facility. However, it is recommended to explore other options such as the refurbishment of a non-operational facility or using an existing dynamic test facility to determine the most cost-effective and efficient option. Conduct a feasibility study / techno-economic study to determine the most economically feasible option.
- Continue engagements with stakeholders involved in the refurbishment of the Terratek hydraulic rig at the CSIR to get the new machine specifications.

- Conduct engagements with manufacturers that can test support systems. Due to the variables involved in system testing, it might be easier to understand an existing testing protocol rather than starting from scratch and attempting to redesign it.

7 Way Forward

Address the recommendations outlined in section 7 and develop a detailed project plan for the next phase of the project.

8 Lessons Learned

Based on the project's findings, several lessons can be learned regarding the establishment of an independent dynamic test facility for underground mine support units. These lessons include:

- The importance of stakeholder engagement: Engaging with industry stakeholders, including underground support manufacturers and suppliers and mining personnel, was crucial for identifying the requirements of an independent dynamic test facility and achieving the objectives of the study.
- The value of a desktop study: A desktop study of international and local dynamic testing facilities provided valuable insights into best practices and industry standards that can inform the establishment of a dynamic test facility.
- The need for clear and relevant survey questions: The survey questions were clear and relevant to the objectives of the study. Before the survey was distributed to all participants it was QC'd by rock engineers to ensure that it was clear and relevant.
- The challenge of obtaining a high response rate: Despite efforts to engage with industry stakeholders, obtaining a high response rate was challenging. In this project, the response rate was only 30%. This may have been because of the long length of the survey. The long survey could have been overwhelming to participants, hence the return of incomplete surveys. Keeping the survey short and to the point can increase the chances of participants completing it.
- The importance of supplementing surveys with further engagements: Supplementing surveys with further engagements with mining personnel and manufacturers and suppliers provided additional information that complemented the survey responses.
- The need for ongoing communication and collaboration: Establishing an independent dynamic test facility requires ongoing communication and collaboration with stakeholders to ensure that the facility meets the changing needs of the industry. This study has enabled the establishment of relationships with various suppliers and mining personnel which will be important in the next phase of the project.

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10 Project Summary

Milestone	Deliverable	Start	End	Deviation	Challenges/ Successes
Project initiation	Contracting Start-up presentation	Mar/22	Mar/22	None	Completed
Establish criteria and requirements for industry engagements	Document of draft criteria from desktop study and industry engagements	Aug/22	Aug/22	Amendment of timelines	Delays in obtaining ethics approval for the questionnaire from the CSIR Research Ethics Committee. Delays in obtaining ethics approval significantly delayed the stakeholder engagement process and project continuation.
Establish criteria and requirements from engagements with u/g support OEMs	Updated document of draft criteria with inputs from engagements with u/g support manufacturers	Nov/22	Nov/22	Amendment of timelines	Delays in obtaining ethics approval for the questionnaire from the CSIR Research Ethics Committee. Delays in obtaining ethics approval significantly delayed the stakeholder engagement process and project continuation. Poor stakeholder participation and delays in obtaining surveys back from mining industry stakeholders. The stakeholder engagement process had to be extended to solicit more information from relevant mining personnel and suppliers.
Draft report on criteria and requirements of test facility	Report of criteria and requirements of test facility	Mar/23	Mar/23	Amendment of timelines	Delayed by milestones 2 & 3
Final report	Final report	Mar/23	Mar/23	Amendment of timelines	Delayed by milestone 4

11 Appendices

11.1 Appendix A – Start-up Presentation

LoCM21WP10-5 Appendix A.docx

11.2 Appendix B-Survey

LoCM21WP10-5 Appendix B.docx

11.3 Appendix C-Support sample size statistical criteria

LoCM21WP10-5 Appendix C.docx

12 Patents, prototypes, technology packages and demonstrators

There are no patents, prototype developments and or planned/held technology demonstrators for this project.

13 Human Capital Development

There was no human capital development carried out in this project.

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