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Rocks around the clock: a 24/7 approach to radar slope monitoring

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Abstract

BHP Western Australian Iron Ore (WAIO) operations use a suite of slope monitoring systems which are deployed to operational areas based on the ground control risk. Slope radars are one part of this system. During 2022, WAIO completed the deployment and integration of a network of 22 radar systems across its operations. This digital solution enables data transfer between physical radar systems located in open pits and to onsite offices, a vendor-supported remote control room in Indonesia and the WAIO Integrated Remote Operations Centre in Perth. Data analysis and monitoring of system and displacement alarms is now conducted around the clock: 24 hours per day, seven days per week.

Part one of this paper provides an overview of the technology solutions that were implemented to cater for increased capacity demands, remote access and service continuity.

Part two focuses on new processes including the partnerships established between BHP's geotechnical, remote operations and technology teams, in conjunction with the Hexagon mine monitoring team, which have all been integral to ensuring a reliable, robust and scalable slope monitoring solution.

Part three focuses on business replication across BHP Nickel West (NiW) operations as well as other Hexagon customers worldwide.

Keywords: *slope monitoring, slope radar, monitoring response, technology infrastructure*

1 Introduction and technology components

1.1 Introduction

BHP Western Australian Iron Ore (WAIO) open pit operations are in the Pilbara region of Western Australia, comprising five mines and four processing hubs connected to port facilities by more than 1,000 km of railway (Figure 1). This integrated network means that multiple pits and pushback areas are active at any one time, with 80 active pits across WAIO in FY22/23. WAIO operations use a suite of slope monitoring systems to manage ground control risks, including slope radars deployed to monitor pit slope displacements. The deployment of 22 slope radars into the WAIO monitoring network involved the development of supporting network architecture, infrastructure, virtualised hosting, security protocols and a technology support model. The design also enabled external vendor access to the systems, providing the mechanics for round-the-clock data and alarm monitoring from any location.

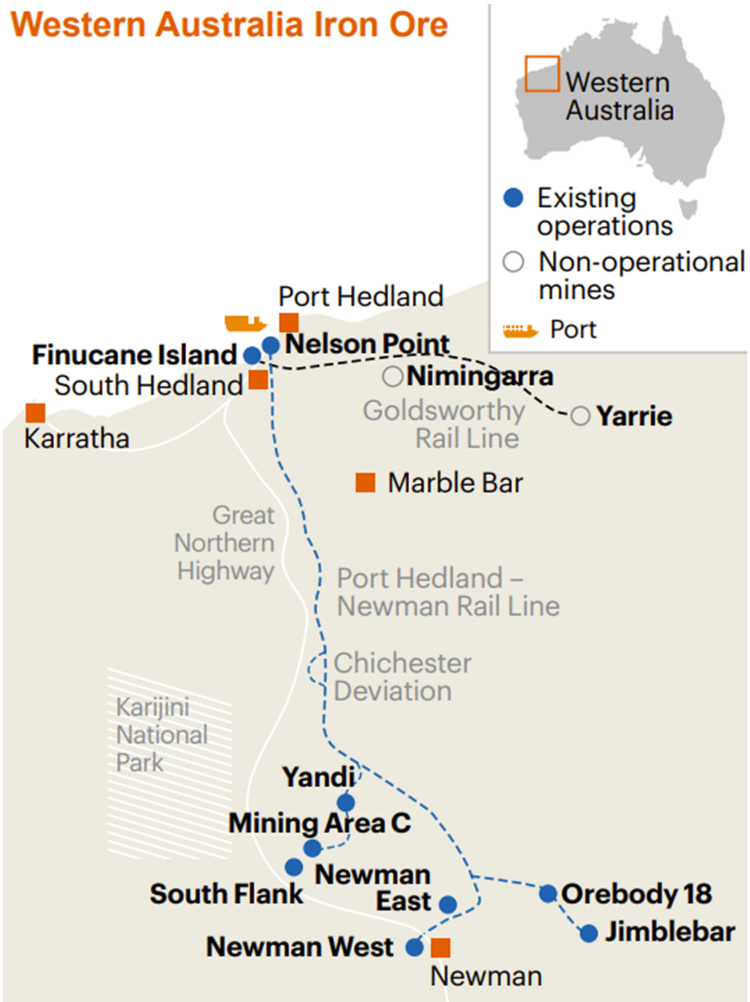


Figure 1 BHP WAIO operations, Pilbara region of Western Australia

1.2 WAIO slope radar requirements and benefits

BHP's Our Requirements for Safety outline the minimum safety standard WAIO operations must meet, including the requirement to manage all geotechnical risks (BHP 2021). Wessels & Dixon (2019) described the 'Pilbara challenge' of multi-pit, geographically spread, structurally complex and below water table iron ore operations in the Pilbara. These factors make it challenging for geotechnical engineers (geotechs) to monitor changes in risk level and allocate monitoring resources appropriately to priority areas. WAIO geotechs use a pit risk ranking method to assess the ground control risk for active and planned mining areas. The outcome of the risk assessment informs a slope monitoring plan defining the risk mitigation controls.

It is essential that a well-designed slope monitoring plan includes early detection of developing instability, ability to analyse current and predicted conditions, communication of alarms and confirmation of expected slope performance (de Graaf & Wessels 2013). For WAIO pit slopes with higher risk, known hazards, areas of previous instability or where there is limited prism monitoring coverage, slope radars are used. Synthetic aperture radars provide high-resolution imagery, with 10 million pixels at full resolution scan in a short acquisition time: a 20-second scan time for 180° or 40-second scan time for 360° (IDS Georadar 2022). With a scan range of up to 5 km, slope radars allow for monitoring from pit crests and away from active mining areas, and can obtain longer-term datasets for comparison with prisms monitoring data (Figure 2). WAIO use slope radars for background and 24-hours-per-day, 7-days-per-week (24/7) monitoring applications based on the pit risk assessment.

Figure 2 WAIO slope radar monitoring system

In late 2020, the WAIO geotech team defined WAIO slope radar monitoring solution requirements, with a key driver being the ability to expand across mining operations to accommodate over 20 radars in a virtualised and scalable environment. Additional initial scope included alerting and management of alerts via the WAIO integrated remote operations centre (IROC) team, and the solution needed to be fully supported by BHP information technology (IT), operational technology (OT), and networking teams. A project partnered between the BHP technology and geotechnical teams was initiated, with scope further defined to include full solution redundancy and failover, to accommodate both planned and unplanned outages, a data management framework for live and historical project retention, and future radar network expansion via documented processes.

To successfully design, build and integrate the additional slope radar systems, a partnership project was formed between the geotech team, BHP technology and Hexagon mine monitoring team.

1.3 Compute deployment

Projects to expand and integrate the radar network had historically proven to be outside of appetite to solve. Thus a basic desktop solution was relied upon until early 2021. With the new program to deploy 22 radars into the field across multiple mine sites utilising varying operational communications networks, the decision matrix for the technology component of this project was particularly complex. Dixon et al. (2022) described the infrastructure design in detail, however, certain elements are re-introduced below due to the criticality in supporting concurrent external access and scalability of the overarching solution.

A holistic WAIO slope monitoring solution including radar scanning capabilities, additional infield devices, monitoring teams and process flows is conceptualised below in Figure 3.

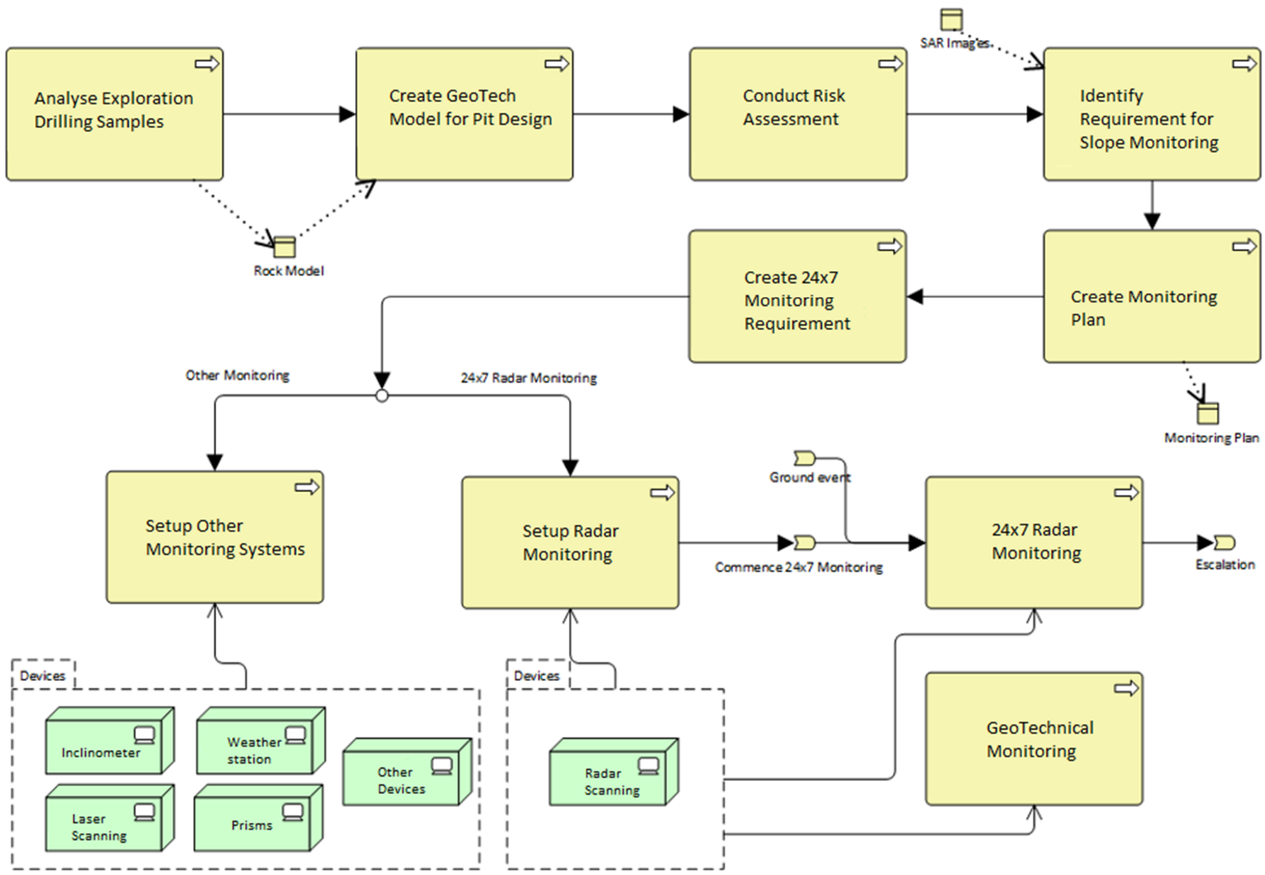


Figure 3 Conceptual slope monitoring model

Consideration of physical versus virtual infrastructure for the radar solution was determined by a series of key decision points around performance, accessibility, availability, survivability, supportability, cost and scalability. Providing a physical (desktop) compute environment reaps benefits to a point, yet the solution becomes difficult and costly to maintain and manage beyond a certain scale.

To introduce a complex server-to-multi-client application model across multiple business operations requiring highly available uptime for 24/7 monitoring, a centrally managed support model (including patching, updating and incident response management) and the scalability to meet growing business requirements, a virtualised infrastructure deployment becomes essential.

WAIO's technology project team designed and built a dedicated graphics processing unit (GPU) enabled compute cluster to accommodate the five-year business growth plan, with full failover redundancy across physical locations. The modelling included hosting all critical application and licensing workloads distributed across multiple locations to maintain service continuity in the event of disaster. Figure 4 depicts the hardware deployment in WAIO across two physical data centre locations on site (referred to as 'data halls' A and B) with six physical servers hosting application workloads, and a large array of shared network storage for accumulated project data.

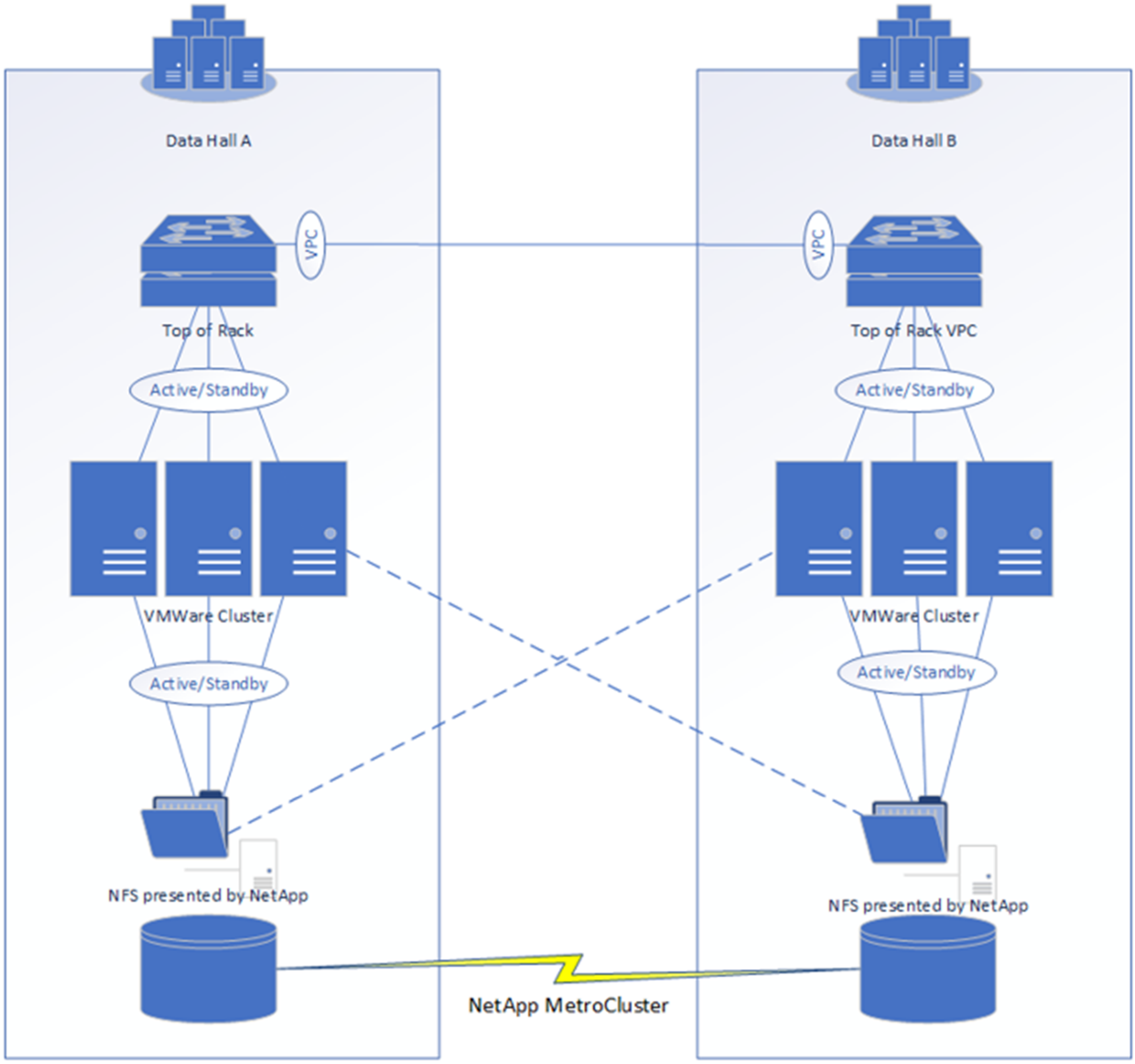


Figure 4 Data hall topology

Full slope monitoring solution failover was achieved by ensuring critical virtual loads only be provisioned to a maximum of 50% capacity across the physical servers. This enables any virtual server to be migrated live from one physical server to another with no impact to the technical applications via vMotion (VMware vSphere vMotion 2022). By doing so, all slope monitoring service continuity aspects were covered, from routine quarterly operating system patching and general IT maintenance through to a significant disaster involving complete loss of a single data centre.

1.4 Access control

To provision multi-user (concurrent), multi-session access for site-based geotechnical engineers, the IROC team located in Perth, the Hexagon mine monitoring team based in Indonesia, and IT support teams located globally, an additional application layer via Citrix was deployed. To provide additional access controls to the vendors' IBIS Dispatch alerting environment, monitored by the remote operations' safety technical officers (STOs), a 'consented access' model was deployed via remote shadow requests. Some elements of the solution are provisioned within the standard IT environment, which is where users access the corporate network through their standard laptop hardware. The main technical elements of the slope radar solution, including all virtual servers, applications and data, are hosted within the OT network. A demilitarised zone (DMZ) facilitates discrete OT authentication for users to gain access to the OT network via an access gateway (Figure 5).

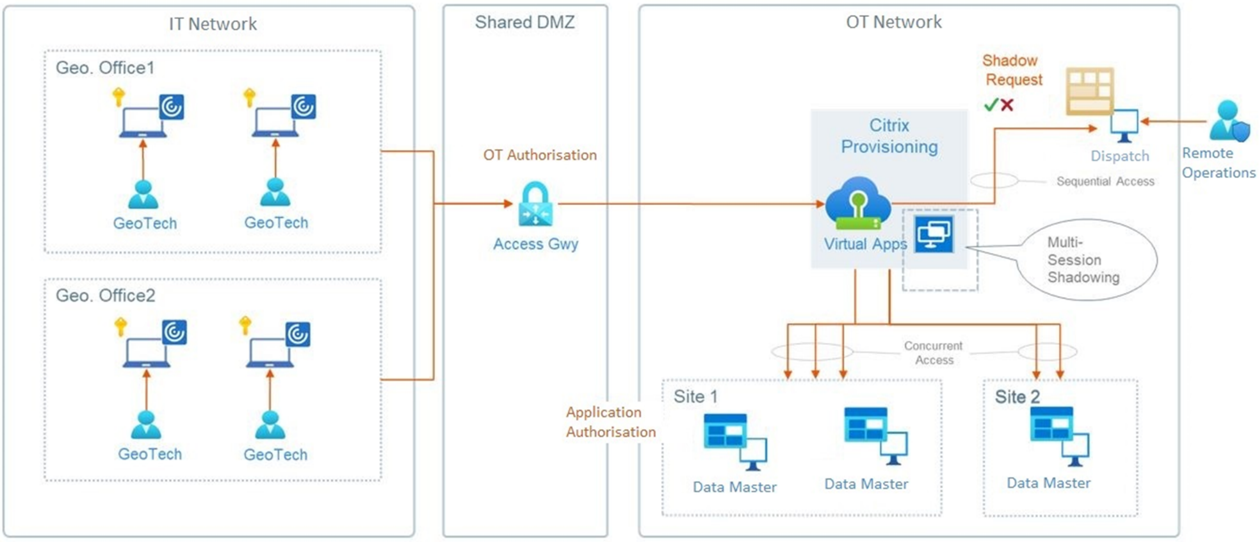


Figure 5 Concurrent user access and authentication controls

1.5 Monitoring technologies

Each layer of the solution is supported by various monitoring technologies and teams, including both vendor and enterprise monitoring solutions (Figure 6). Typical enterprise monitoring of the hosting environment includes disk space, application processes, license service health and virtual machine accessibility, supported by dashboard displays and automated email alerts to relevant stakeholder groups.

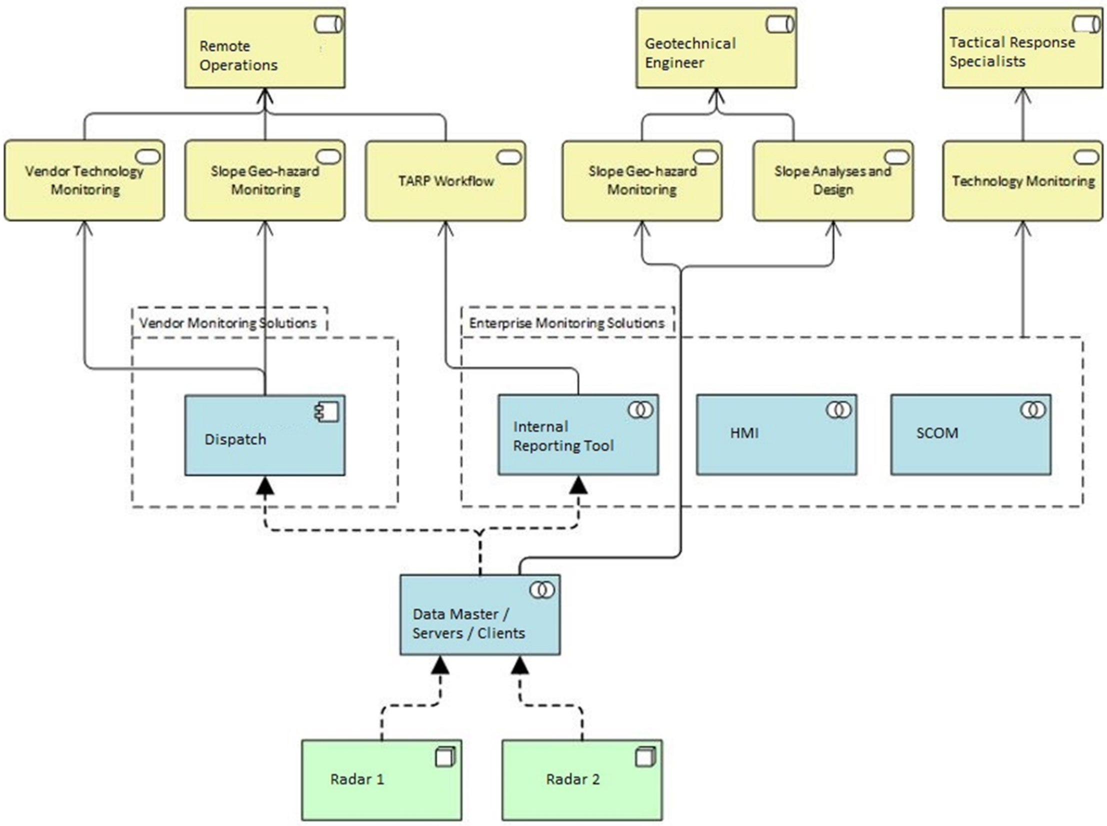


Figure 6 Remote monitoring solution design

1.6 Slope radar alerts

Slope radar analysis applications include alarming functionality, with alerts presented to various teams when slope displacement thresholds are exceeded, or connection (network) errors and other hardware faults occur. Figure 7 details the types of vendor alarms that are monitored. WAIO operates under a model where slope radar alarms are triggered to the onsite geotechs, Hexagon 24/7 offshore support team and IROC STOs using IBIS Dispatch alarm aggregation software.

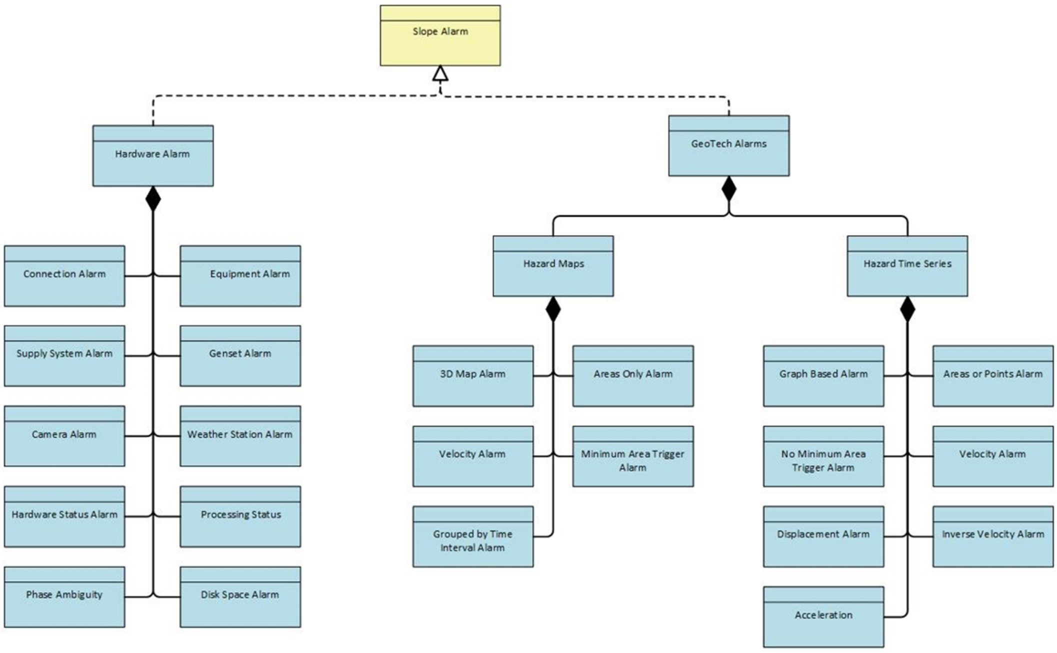


Figure 7 Vendor alarm overview

Other layers of technology used to support this solution include automated messaging services targeted to key business stakeholders in the event of alarms for escalation. Alongside the technical teams monitoring alarms within the Guardian application suite and IBIS Dispatch, there is a short message service (SMS) and simple mail transfer protocol (SMTP) relay service delivering text messages, phone calls and email messages to specific groups, depending on event severity (Figure 8).

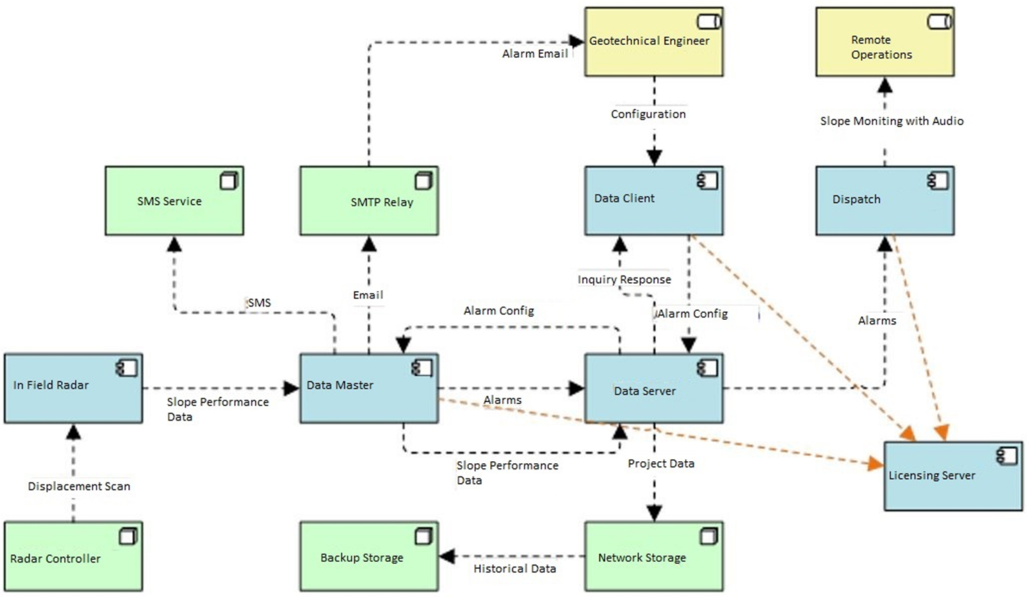


Figure 8 Application cooperation design

The slope monitoring solution described above has enabled the integration of 22 radar systems and response to radar alarms across WAIO operations. Part 2 will cover the practical application of 24/7 slope radar monitoring.

2 Practical application in WAIO operations

2.1 24/7 slope radar monitoring in WAIO

WAIO geotechs apply targeted radar monitoring 24/7 to monitor slope movements within discrete areas known to pose potential or immediate threats to the safety of mine personnel, equipment or the productivity of mining operations. 24/7 radar monitoring triggers alarms at WAIO's IROC, providing the opportunity to safely withdraw mine personnel and equipment from defined ground control exclusion zones.

WAIO's IROC has dual-failover locations based in Perth, Australia, and began operations in 2012. IROC is responsible for operating most of BHP's iron ore logistics and processes, connecting the mining and processing hubs to the port facilities. STOs and mine controllers are based at IROC. The STOs are a dedicated resource responsible for responding to radar alarms across WAIO pits when triggered in the IBIS Dispatch application. The various mine controllers coordinate the movements of excavators, trucks, drill rigs and other ancillary equipment within the WAIO open pits.

Central to the 24/7 radar monitoring process is a slope radar trigger, action, response plan (TARP) that covers the required responses by personnel in reaction to geotechnical events such as slope displacement (Geotech Hazard Map & Hazard Time Series – Red alarms) and hardware alarms (Sharon & Stacey 2020). WAIO geotechs are accountable for setting alarms as low-threshold warnings (yellow) and higher-threshold slope displacement (red) alarms based on site experience and mining activity. Only red displacement and system-related (grey) alarms, including loss of network connections and other hardware issues, are transmitted to IROC, with the yellow warning alarms configured locally for the geotech team. Figure 9 shows the initial stakeholders and process flow WAIO implemented for responding to grey system and displacement red slope radar alarms.

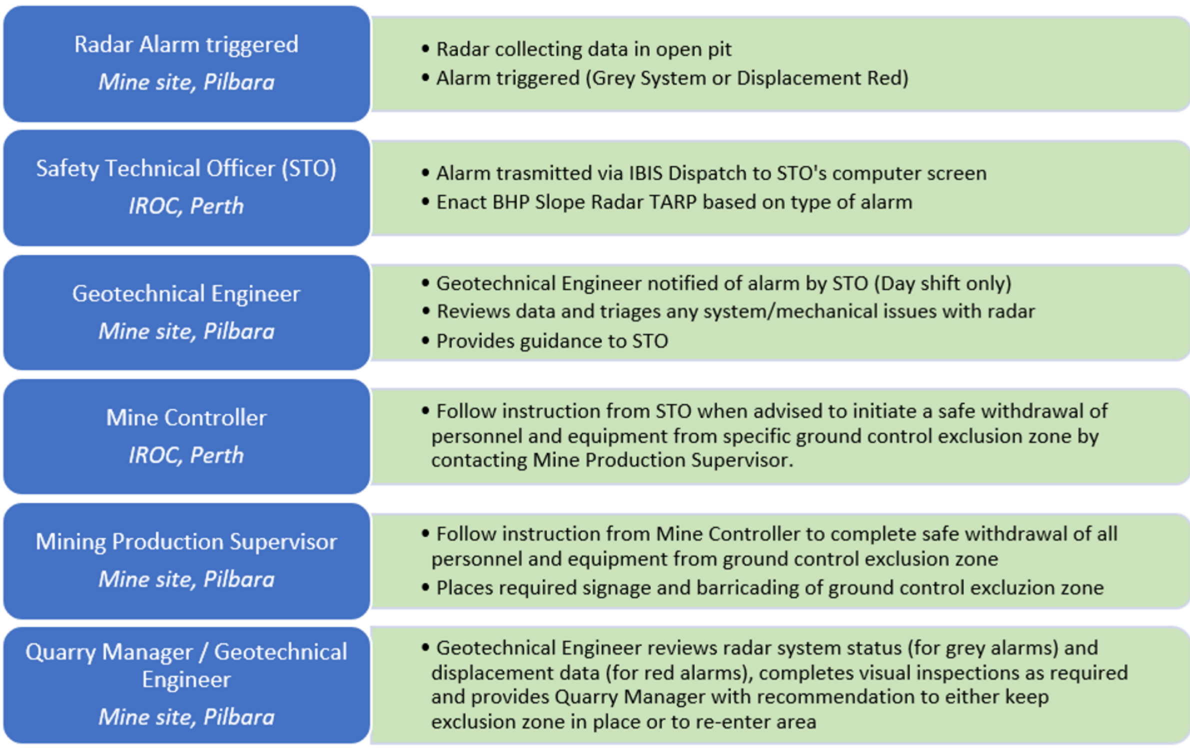


Figure 9 Initial WAIO 24/7 slope radar monitoring stakeholders and process flow

Initial 24/7 monitoring challenges were encountered as geotechs work day shifts and are often away from the site offices, performing other site-related activities. If the geotech is unable review and verify alarms within the defined time when contacted by the STO, a safe withdrawal of personnel and equipment from the ground control exclusion zone would be initiated, as per the TARP.

During night shifts the STO would initiate the safe withdrawal for all alarms. The ground control exclusion zone would remain closed until the following morning, at which point the geotech would review the radar system and data, and complete a visual inspection of the area. On average, there were 11 safe withdrawals per month, or 78 total withdrawals, between October 2021 and May 2022. With an average pit assessment and re-entry clearance time of six hours, this equated to approximately AUD 3 million of hauled material loss.

2.2 Hexagon 24/7 assisted monitoring

In November 2021, WAIO commenced the first phase of a new assisted monitoring service trial with Hexagon, featuring dedicated monitoring analysts located at Hexagon's remote control room in Balikpapan, Indonesia.

2.3 24/7 Phase 1: geotechs and Hexagon building relationships

Between November 2021 and May 2022, three WAIO radars were initially placed on the 24/7 monitoring service. The key phase requirements included, first and foremost, a focus on communications between geotechs and Hexagon aimed at building relationships, and for Hexagon to gain familiarity with slope conditions across WAIO sites. The development of a specific BHP/Hexagon TARP describing the data flow and communication process for different alarm types was also initiated. Addressing all previously discussed alarm types, a key requirement was building a portfolio of knowledge around the causes of alarms, along with the determination of a confidence factor in the data presented.

The Phase 1 trial also initiated the design of customised reporting requirements for WAIO, which are discussed below. Feedback reviews from geotechs and Hexagon analysists allowed for all processes to be subject to refinement, with the initial BHP slope radar TARP process described in Figure 9 above running in parallel to ensure business continuity.

2.4 24/7 Phase 2: integration of Hexagon into BHP slope radar TARP

During the period May to September 2022, after a successful Phase 1 trial, 24/7 monitoring of six systems commenced. The key phase requirement included an update to the BHP slope radar TARP to formally implement the Hexagon analyst role.

Whereas previously the communication was between the geotechs and STOs for alarm review and verification, the introduction of the Hexagon analysis into the flow formed a significant step. In essence, when a radar alarm is triggered and presented to the STO at IROC, the STO now makes a call direct to the Hexagon monitoring team for guidance on the next steps. Reviewing the actual radar data itself, the Hexagon team, in place of the site geotechs, provides verification of the alarm in following the BHP/Hexagon TARP (developed in Phase 1). Figure 10 details the revised stakeholders and process flow.

Phase 2 introduced a new alarm tracking system (Magnet) to replace SharePoint spreadsheets, which allows digital timestamping and profile logging as the responder follows the TARP steps. User training for both Magnet and the new TARP process was delivered to all stakeholders.

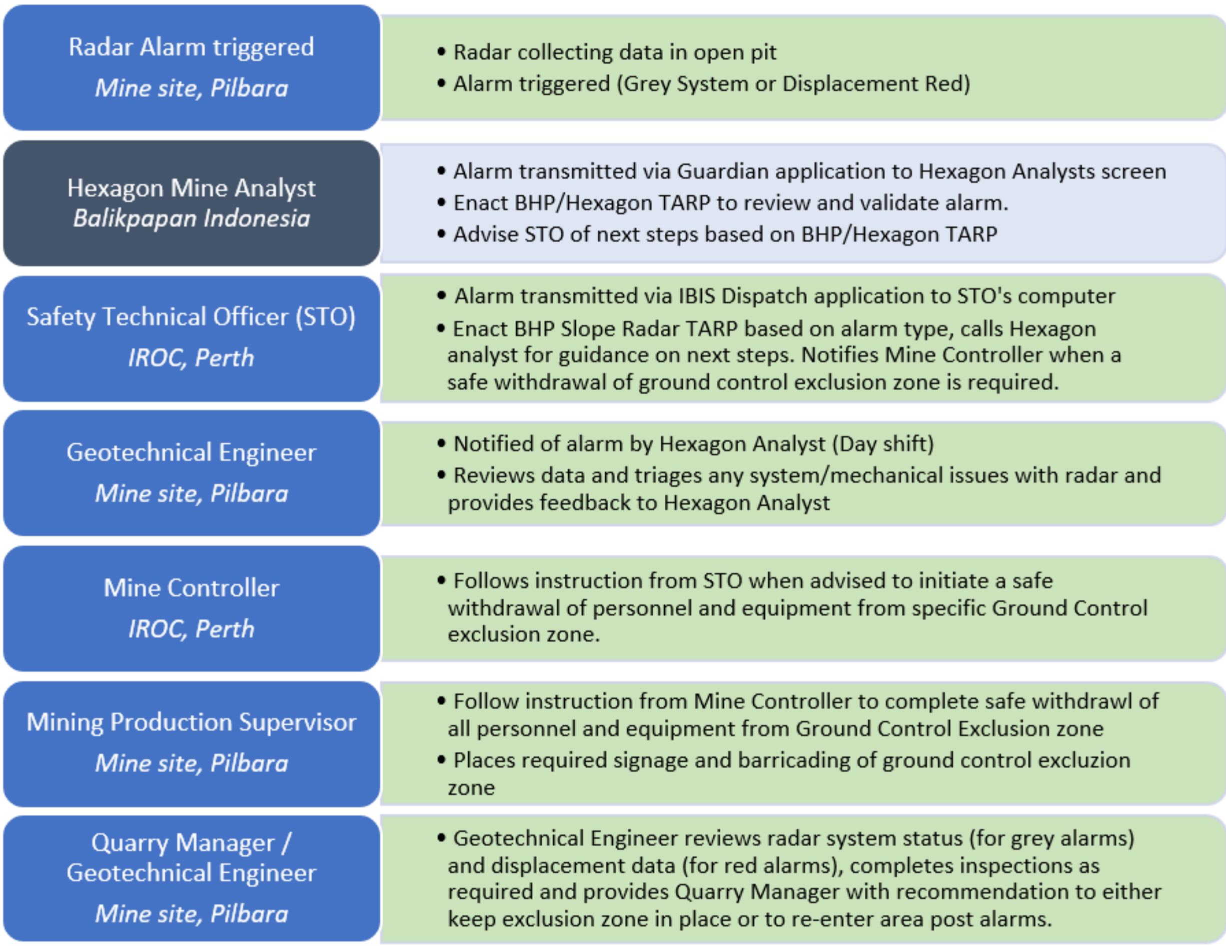


Figure 10 Revised WAIO 24/7 slope radar monitoring stakeholders and process flow

2.5 Realised outcomes and benefits

In September 2022, after successful Phase 1 and Phase 2 trials, the Hexagon 24/7 assisted monitoring service was formally integrated into the BHP slope radar TARP as ‘business as usual’ and was scaled up to accommodate all WAIO radars requiring 24/7 monitoring.

These analysts perform 24/7 reviews of radar data for new displacement hotspots, changes to deformation trends and triggered alarms. While the WAIO geotechs remain accountable for setting alarm thresholds and areas, the Hexagon analysts provide guidance on refinement of alarms.

Standardised daily, weekly and monthly reports summarising radar system performance and data analysis are provided to BHP. The daily report summarises hardware availability, general data quality and other noteworthy comments, linear deformation trend analysis, and a list of any alarms for that radar in the prior 24 hours.

The weekly report includes the weeks’ roll-up of the above content, plus information on the radar status and service availability, cumulative displacement and average velocity maps, time series displacement and velocity/inverse velocity plots, and commentary regarding any trends or observable slope movements. Figure 11 is an example of a weekly slope stability report, showing displacement and velocity time series graphs.

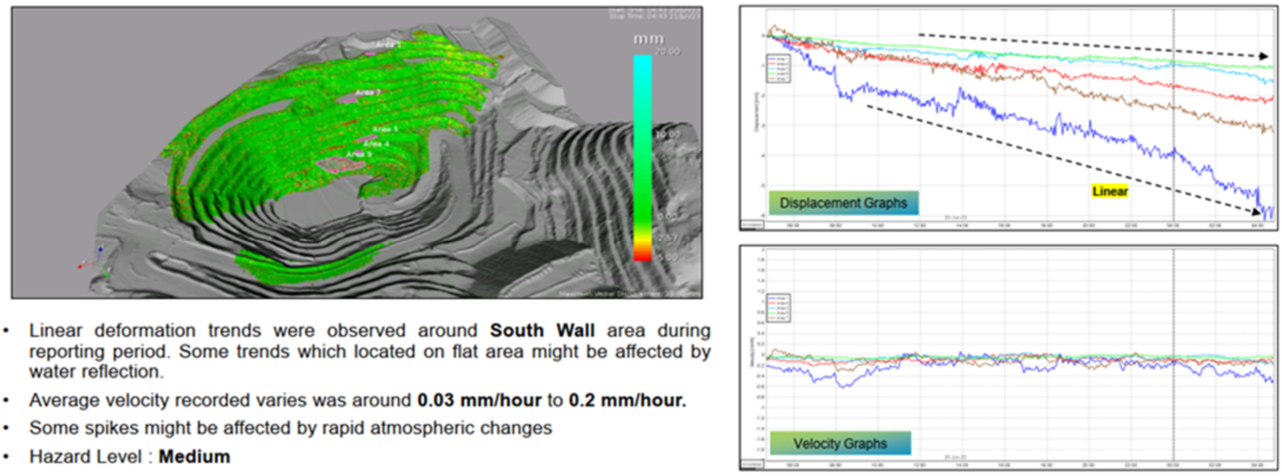


Figure 11 Hexagon weekly slope stability report

The monthly report is a series of dashboards depicting availability, total alarm counts, alarm types per month, Hexagon analyst validation for red and yellow alarms, and a detailed breakdown of causes for each type of observed alarm. The report contains a stacked dashboard for all monitored radars, and individual dashboards per radar. Figure 12 shows the cumulative radar dashboard for May 2023 and the year to date.

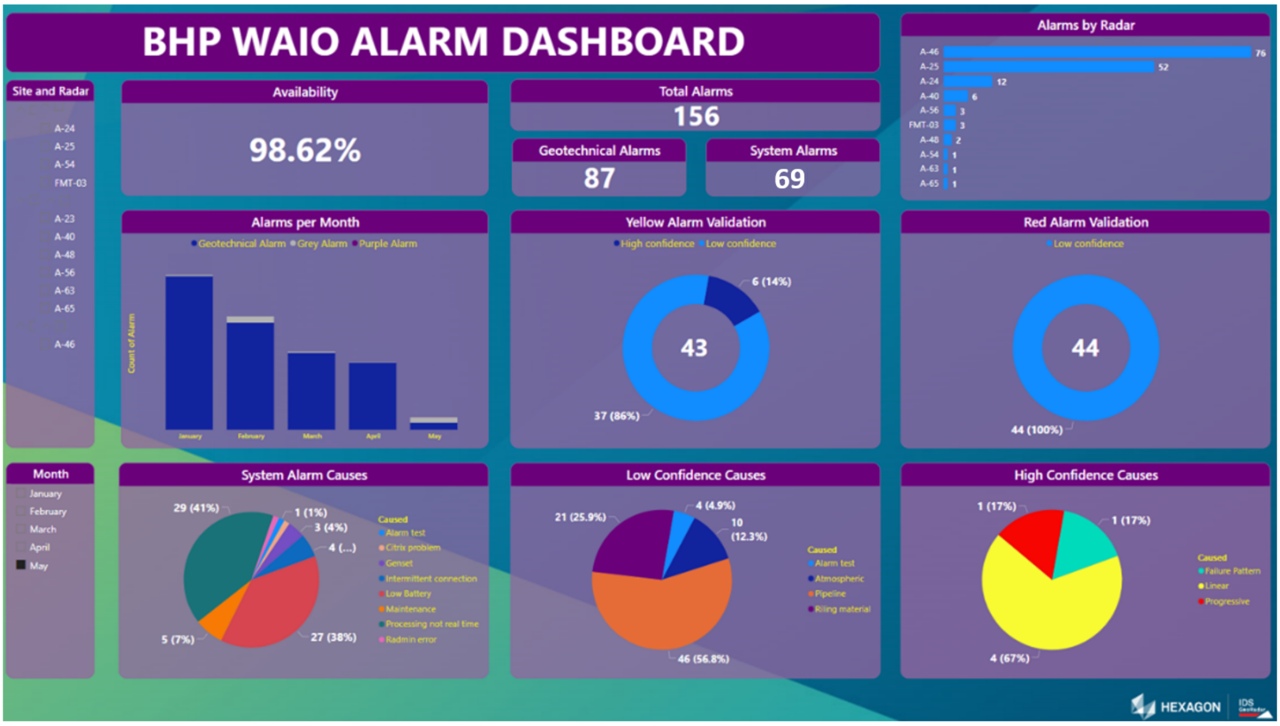
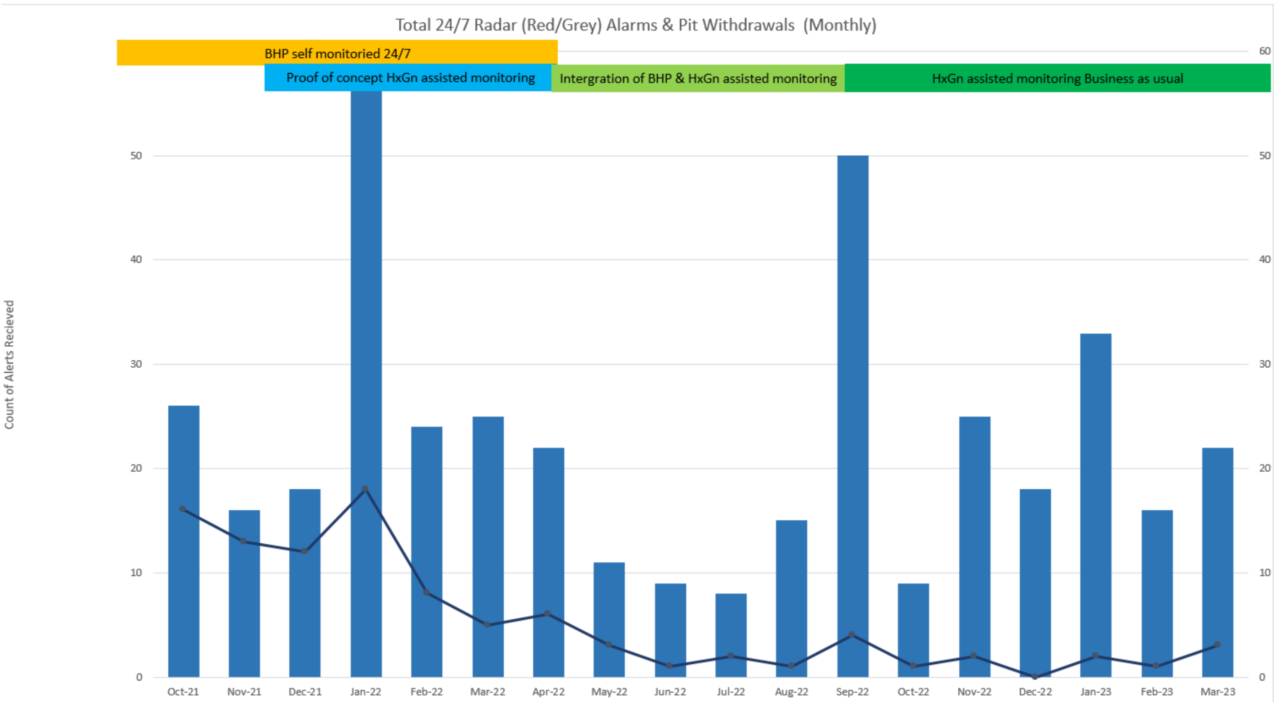


Figure 12 May 2023 monthly alarm dashboard (all 24/7 monitoring radars)

The implementation of 24/7 assisted monitoring has facilitated a timely and effective management of multiple radar monitoring systems and geotech resources. Leveraging the expertise of the Hexagon analysis team, the new process has realised a significant drop in the pit withdrawal rate, as depicted in Figure 13.



	Oct-21	Nov-21	Dec-21	Jan-22	Feb-22	Mar-22	Apr-22	May-22	Jun-22	Jul-22	Aug-22	Sep-22	Oct-22	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23
Total (Grey/Red)	26	16	18	57	24	25	22	11	9	8	15	50	9	25	18	33	16	22
Pit Withdrawals	16	13	12	18	8	5	6	3	1	2	1	4	1	2	0	2	1	3
24/7 Monitored Radars	1	3	3	3	3	3	3	6	6	6	6	6	10	10	10	10	10	10

Figure 13 Recorded alarms and pit withdrawals, October 2021 to March 2023

A substantial portion of historical pit withdrawals were related to various system alarms and false positives, coupled with the lack of availability of trained personnel to review and verify alarms within the required response time window. The continual availability of trained personnel to triage alarms by analysing the actual radar data and providing an assessment of the confidence in the alarm source has provided the greatest benefit from the 24/7 service.

The three key step changes in improving the quality of the radar alarming data occurred firstly when 24/7 assisted monitoring was integrated into the system in May 2022 (Phase 1 trial). Secondary improvements were made during a relationship building site visit from the Indonesian Hexagon analysis team. This site visit also initiated monthly technical sessions between BHP and Hexagon to discuss radar positioning, filtering, and masking configurations and alarm settings, which has achieved continual data quality improvements.

In the January to May 2023 period, Hexagon's assisted monitoring team reviewed over 5,000 alarms. Of these alarms, 3.5% presented as system health issues, with the remaining 96.5% as potential slope displacement alarms. Analysis showed that of these potential slope displacements, approximately 75% were classified as low-threshold warning (yellow) and 25% as slope displacement (red) alarms. However, deeper analysis of the underlying data yielded less than 17% of the highlighted red alarms as being attributed to actual slope displacement and requiring action. Many of the remainder of the alarms were attributed to atmospheric interference, dust, equipment movements, suboptimal alarm thresholds and other non-geotechnical risk factors. Hexagon's 24/7 assisted monitoring team has significantly contributed to BHP WAIO's safe production and mining productivity.

By utilising the Hexagon team for 24/7 monitoring and alarm triage, the relatively small operations geotech teams across WAIO sites are thus freed to perform other proactive and safety-critical tasks both infield and in site offices, with the reduction of calls outside of normal working hours in turn reducing fatigue risk for day shift personnel. The close working relationships between geotechs and Hexagon analysts has fostered trust, built upon the latter displaying high levels of competency and willingness to adopt BHP's safe working practices. Hexagon's monitoring team are backed by skilled radar engineers who provide technical assistance in optimising radar configurations during set-up and ongoing performance monitoring. It was shown that radar availability for the period January to May 2023 was at 99.52%, which is a result of early escalation by the 24/7 analysist to BHP and Hexagon support teams as required.

Assisted 24/7 monitoring has now become a proven 'business as usual' service within WAIO. The development of the solution, from infrastructure design to physical deployment of hardware, software configurations and integrated processes between all teams, has been extensively documented and transitioned to various operational support teams within BHP. The multi-year project artefacts, discussed in the next section, have enabled BHP to secure a replicable standard across other business units, with Hexagon's monitoring team now equipped with capabilities to expand its services to the wider industry.

3 Industry replication

Replicating the BHP WAIO solution has gained importance as Hexagon seeks to leverage proven successful implementations, paving the way for enhanced performance, cost-effectiveness and future-proofing across its vast customer base worldwide. This has positive implications for both BHP and the wider industry.

3.1 Hexagon service scalability

As previously discussed, the period November 2021 to September 2022 saw the 24/7 monitoring trials extended from one to six radars, with this now being 10 radars across WAIO. These 24/7 monitoring radars necessitate a safe withdrawal when a red alarm is activated and validated, while the remaining background radars across WAIO do not require immediate safe withdrawal action.

Depending on mine planning and operation activities, additional radars may need to be included in the 24/7 assisted monitoring portfolio. BHP has worked extensively with Hexagon to firstly increase organisational capabilities, proven through the Phase 1 and Phase 2 trials, leaving Hexagon with the ability to scale up capacity to meet demand.

Figure 14 illustrates the Hexagon team growth compared to the total number of radars across WAIO. It should be noted that at the time of writing this paper, 10 of the 22 radars in commission were being actively monitored by Hexagon, with plans for an additional two already in motion.

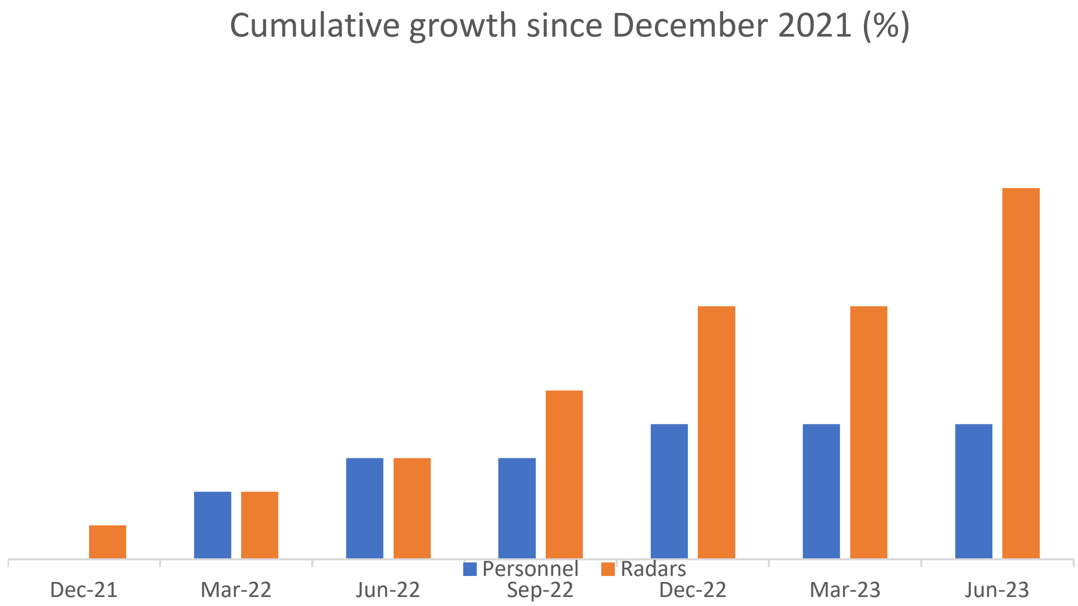


Figure 14 Hexagon team capacity growth across WAIO

3.2 Scalability of slope monitoring at WAIO

Scalability refers to the ability of a system or solution to adapt and expand seamlessly in response to growing demands or changing requirements. The 2020 technology project began with a requirement to provision an integrated environment hosting 11 radars. Being a virtualised environment, thus allowing new virtual servers to be commissioned, the inaugural design allowed for natural year-on-year growth of slope monitoring capabilities. Following a significant rockfall event in early 2021, material risk assessments were revisited and the number of required radars over the five-year plan increased from 11 to 22.

Contrary to Figure 4 in Part 1, the compute deployment originally involved commissioning of four host servers only. However, the design of the hosting environment facilitated physical compute expansion, leading to the provision of two additional servers, with the expansion of this environment proving to be seamless. In this compute cluster all resources are allocated to a pool, allowing them to be shared across multiple virtual machines as per allocation rules.

The current compute capacity at WAIO is enough for approximately double the existing radar fleet with no additional infrastructure spend required. It should be noted, however, that other emerging slope monitoring software and technologies with high-end GPU requirements are also being assessed. These may naturally be hosted simultaneously in this same compute cluster.

3.3 Replication within BHP

Underpinning the framework of this project is a repository of document artefacts describing the solution at both a conceptual and detailed design level, which can be leveraged for deployments across BHP. Guided by a comprehensive high-level design, each of the critical disciplines has been captured in both low-level designs and as-built documentation. This includes design documentation across hosting, networking, security and firewall, application and Citrix delivery disciplines.

Rigorous transition to operations processes were followed during the project delivery, with the team documenting disaster recovery, service design and service continuity plans, plus specialist work instructions, general support knowledge base articles and wiki pages for centralised information capture. Additional business processes were formulated in partnership with key stakeholder groups, including end-to-end support models, and the refined TARP.

Another key artefact for this project was the development of a new radar implementation plan. This is a visual guide depicting all project elements, including pre-radar procurement decisions and engagements (vendor contracts, radio frequency studies), IT checklists (network, bandwidth, compute and storage availability), periphery monitoring decisions (internal monitoring applications, xMatters, remotely monitored safety dashboards), links to all relevant work instructions and shared documents, plus engagement with maintenance planning teams.

A key element for solution replication is the lessons learned from upscaling the original desktop solution to an enterprise environment. Replication of this solution is currently underway across other BHP business units and functions.

In September 2022, BHP Nickel West operation commenced a project to replicate the infrastructure built by WAIO operations. Sharing project documentation has allowed the project timeline to be accelerated significantly, with the project already in procurement phase.

4 Conclusion

This case study has demonstrated that when defining slope radar monitoring requirements, the number of systems is only one consideration. By developing a scalable solution which enables radar data transfer between the physical radar systems located in open pits to a virtualised server environment accessible from any remote location, BHP and Hexagon have shown that a strong technical partnership can provide significant value. This value is realised in terms of increased safety of personnel on site, reduced risks associated with communication flows and false alarms, and increased mine production continuity. Having clearly defined processes and well-documented deployment plans leads to improved future project performances and lessened risk.

Acknowledgement

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