Volume 4, No. 1 January 2025 - (1-20)
p-ISSN 2980-4868 | e-ISSN 2980-4841
https://ajesh.ph/index.php/gp

Lean Six Sigma in Digital Transformation Geotechnical Operational Integration using the G-Rocks Platform to Manage Geotechnical Hazards

Seno Maris Utomo[1*], Gatot Yudoko[2], Ridho Kresna Wattimena[3], Dradjad Irianto[4], Edy Wicaksono[5]
Institut Teknologi Bandung, Indonesia
Emails: senomarisutomo@gmail.com[1], gatot@sbm-itb.ac.id[2], rkwattimena@itb.ac.id[3], dradjadirianto@office.itb.ac.id[4], edy.wicaksono@sinarmasmining.com[5]

ABSTRACT

Delays in the collection, analysis, and dissemination of geotechnical data are critical barriers that threaten operational safety and efficiency at PT Borneo Indobara. This research aims to design and validate the G-ROCKS (Geotechnical Real-Time Observation and Control for Key Stability) platform using the DMADV framework to address these issues. This research method uses quantitative methods including the development of the G-ROCKS platform consisting of real-time monitoring tools, geofencing systems, and control centers that can be accessed via dashboards and mobile applications. The implementation of this platform resulted in significant improvements, including reducing the average response time from 17 minutes to less than 5 minutes, exceeding the emergency team's SOP target of a maximum of 7 minutes, and achieving a Six Sigma performance level of 4.5 with a design target of 6.0. These findings highlight the importance of integrated geotechnical systems in reducing risks, accelerating decision-making, and preventing landslides through actions aligned with Industry 4.0 standards. This research provides implications in the form of applicative insights for adopting digital solutions to improve safety and efficiency in the mining industry.

Keywords: Lean Six Sigma, DMADV Framework, G-ROCKS Platform, Geotechnical Hazard Management, Real-Time Monitoring, Digital Transformation.

INTRODUCTION

PT Borneo Indobara (PT. BIB), a major coal mining company in Indonesia, is embarking on a strategic expansion to increase its production capacity from 46.8 million tons to 54 million tons annually. While this ambitious growth underscores the company's commitment to meeting global energy demands, it also introduces significant operational and geotechnical challenges. In particular, managing slope stability in the context of expanding mining activities has emerged as a critical concern (Daffa, 2024).

Globally, geotechnical hazards, particularly landslides, have been a pressing issue in the mining industry. These hazards not only jeopardize operational safety but also have severe economic implications (Smith, 2013). According to data from the International Council on Mining and Metals (ICMM), geotechnical failures account for approximately 30% of all incidents in large-scale mining operations worldwide. This issue is further exacerbated by the increasing scale of mining projects and the complexities introduced by digital transformation and Industry 4.0 (Oesterreich & Teuteberg, 2016). The integration of advanced geotechnical risk management tools has become a necessity to address these challenges effectively.

For PT. BIB, these global concerns resonate at a localized level. The company's mining concession spans 24,100 hectares in South Kalimantan, an area characterized by weak soil material properties that significantly increase the potential for landslides as production scales up. Historical data from 2018 to 2023 reveals an alarming upward trend in landslide occurrences, as illustrated in Figure 1. The correlation between increased production and geotechnical instability underscores the urgent need for comprehensive risk management solutions. Projections for 2024 to 2027 indicate a continuation of this trend, with landslides expected to peak during the maximum production stage.

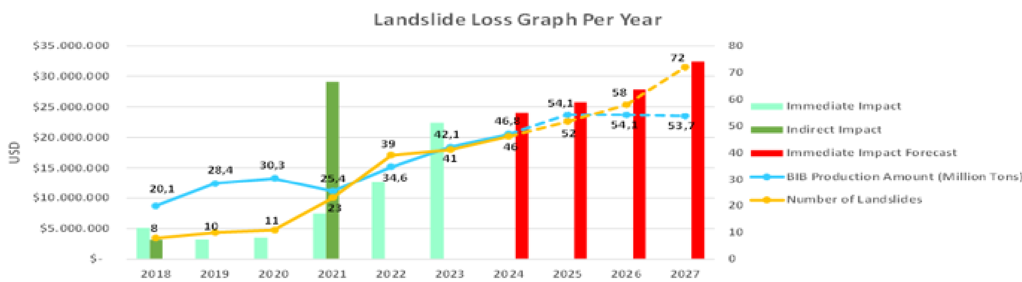

Figure 1. Historical Landslides from 2018-2023 and Forecast Landslides from 2024-2027)

The consequences of these geotechnical challenges are multifaceted (Martinez et al., 2022). Direct impacts include physical damage to infrastructure and equipment, while indirect impacts extend to production delays and compromised worker safety. Financially, these issues translate into significant losses for PT. BIB. Furthermore, the current geotechnical processes at PT. BIB are fragmented and lack integration, resulting in inefficiencies in data collection, analysis, and decision-making. These shortcomings not only compromise operational safety but also hinder the company's ability to respond swiftly to emergencies. Additionally, limited awareness and competence among mine workers regarding geotechnical conditions further exacerbate the situation.

In response to these challenges, PT. BIB recognizes the need to align its operations with government regulations on good mining practices. The KEPMEN 1827 K/30/MEM/2018 guidelines and the "Road to Mining Industry 4.0" program provide a framework for implementing these practices (Akbar et al., 2024). These regulations emphasize hazard identification, risk assessment, and the implementation of control measures to mitigate risks. For PT. BIB, this includes adopting slope monitoring technology, designing safer slopes, and integrating mine planning with geotechnical considerations (Simangunsong et al., 2024). However, the lack of fully integrated geotechnical monitoring equipment has been a persistent challenge. As noted by (Kenett & Shmueli, 2016), incomplete and delayed data collection undermines the ability to make informed decisions, often leaving critical information inaccessible to those who need it most.

The broader context of geotechnical risk management highlights the role of digital transformation in addressing these challenges. Previous reserach emphasizes that one of the primary challenges faced by geotechnical engineers in the 21st century is the collection, storage, and analysis of large volumes of data (Becerik-Gerber et al., 2014). The ability to manage this data effectively is critical for enhancing decision-making processes and improving operational safety. Digital platforms that integrate geotechnical data collection and analysis offer a promising solution to these challenges.

A review of previous studies underscores the potential of digital transformation in geotechnical risk management. For instance, (Huang et al., 2017) highlight the importance of integrated monitoring systems in reducing geotechnical risks in mining operations. Their research demonstrates that digital platforms can significantly enhance data accuracy and decision-making efficiency. Similarly, a research by (Phoon, 2020) explores the challenges and opportunities associated with managing large geotechnical datasets. The findings suggest that digital solutions can address many of the inefficiencies currently plaguing traditional geotechnical processes.

The novelty of this research lies in its focus on integrating the G-Rocks platform with the Six Sigma DMADV methodology. While previous studies have explored the benefits of digital transformation and geotechnical risk management separately, this research bridges the gap by combining these approaches. By doing so, it provides a comprehensive framework for addressing geotechnical challenges in the context of PT. BIB’s operational expansion.

The urgency of this research is underscored by the increasing frequency and severity of landslides at PT. BIB’s mining sites. Addressing these challenges is not only critical for achieving production targets but also for ensuring the safety and well-being of the company’s workforce. Furthermore, the integration of digital solutions aligns with the broader objectives of the “Road to Mining Industry 4.0” program, positioning PT. BIB as a leader in adopting innovative approaches to mining operations.

The objectives of this research are threefold. First, it aims to identify the key geotechnical challenges faced by PT. BIB in the context of its operational expansion. Second, it seeks to evaluate the effectiveness of the G-Rocks platform in addressing these challenges. Finally, it intends to develop a comprehensive framework for integrating digital solutions with geotechnical risk management processes. The benefits of this research extend beyond PT. BIB. By demonstrating the effectiveness of the G-Rocks platform and the Six Sigma DMADV methodology, this research provides a model that can be adapted and applied by other mining companies facing similar challenges. Additionally, the findings contribute to the broader field of geotechnical risk management, offering insights into the role of digital transformation in enhancing operational safety and efficiency.

RESEARCH METHOD

This research explored the risk management of geotech improvement through digitalization using an integration platform to address future problems. It uses a quantitative method to produce a good evaluation of Six Sigma between the current geotech operational conditions and geotech operational conditions using an integration platform.

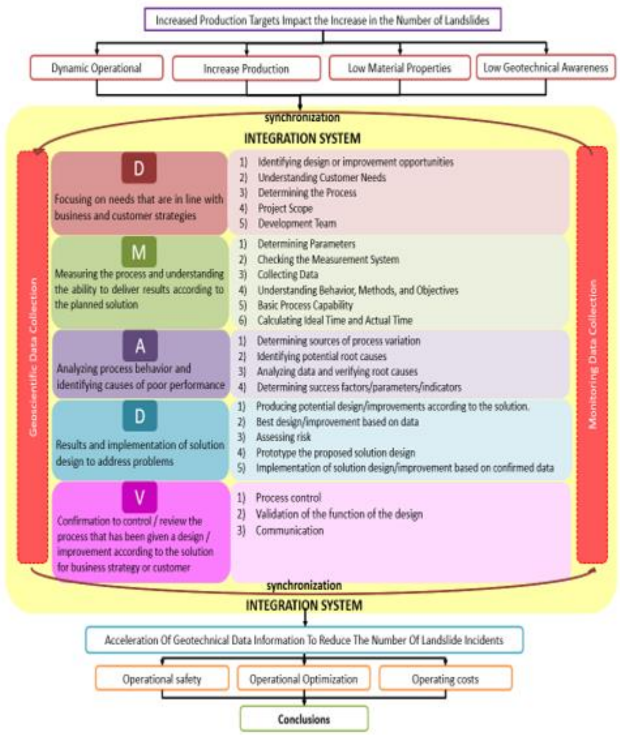

Figure 2. Research Design Diagram

This DMADV (Define, Measure, Analyze, Design, Validate) framework diagram shows the integration of systems to accelerate geotechnical data collection to reduce the number of landslide incidents due to increased production targets. The Define stage focuses on identifying business and customer needs. In contrast, the Measure stage emphasizes measuring the process and the ability to meet the planned solution through parameters, data collection, and process behavior analysis. The Analyze stage identifies the root causes of poor performance and determines success factors. In the Design stage, the proposed design solution is tested and implemented based on confirmed data, followed by the validation stage to control and ensure the design function is by the business strategy. This system integration aims to synchronize geoscientific and monitoring data to improve operational safety, efficiency, and cost management.

RESULT AND DISCUSSION

Define

The “Define” section of this project focuses on establishing boundaries and a clear understanding of the scope and objectives of the Geotechnical Management Information System at PT Borneo Indobara. A clear definition of the problems faced and the establishment of relevant performance indicators are crucial initial steps to ensure that the proposed solution is targeted and effective. In the Define stage in the DMADV framework using the SIPOC (Suppliers, Inputs, Process, Outputs, Customers) concept, the main focus is to identify business and customer needs in the context of accelerating geotechnical data information for geotechnical risk management to reduce landslide incidents, especially in dynamic mining operations with high production targets (Lima, 2023).

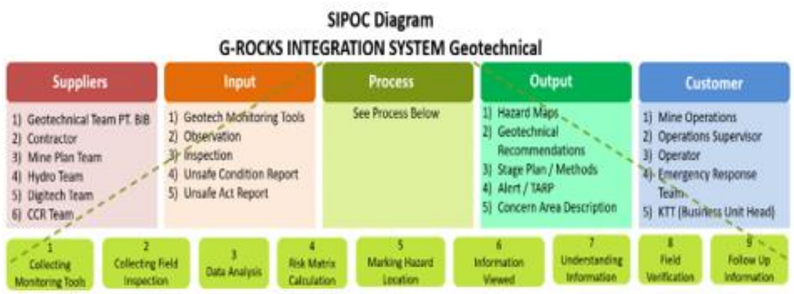

Figure 3. SIPOC Diagram G-ROCKS

Measurement

One of the most crucial stages in the DMADV method is the Measure stage, which aims to collect relevant data and establish a strong basis for the next steps. The measurement process at this stage includes identifying and gathering relevant information about variables that affect the quality or performance of the product or process to be designed. This section aims to measure each stage's duration in delivering geotechnical hazard information at PT Borneo Indobara using the Six Sigma method. Time measurement data has been collected to evaluate the efficiency of the current process and establish a baseline for proposed improvements.

Actual Conditions and Sigma Value Calculation

Measurement of actual conditions is done by taking 10 samples per activity, which is a compromise between time and cost constraints. A small sample size (8-10) is representative enough if the data approaches a normal distribution and does not have more than one mode, according to the Central Limit Theorem, which states that the distribution of sample means will approach a normal distribution, even though the population distribution is not normal, as long as the sample size is large enough. To ensure that the data approaches a normal distribution, a normality test is carried out using the Jarque-Bera Test, which tests the kurtosis and skewness of the data against a normal distribution. The hypotheses tested are:

1) H_0: The data follows a normal distribution.

2) H_1: The data does not follow a normal distribution.

Suppose the Jarque-Bera test results show a probability (p-value) more significant than the significance level (for example, α = 0.05). In that case, the null hypothesis (H0) cannot be rejected, which means the data follows a normal distribution. Conversely, if the probability is smaller than the significance level, the null hypothesis is rejected, which means the data does not follow a normal distribution.

Defects Per Million Opportunities (DPMO) calculation measures process performance by calculating the number of defects per million opportunities (Setijono, n.d.). DPMO is calculated based on the number of defects, the number of units tested, and the number of defect opportunities per unit. After DPMO is calculated, the sigma value is determined using the DPMO to sigma value conversion table, which indicates the level of process quality. In the graphic figure 5 the results of measurements and data processing from actual conditions according to the process stages

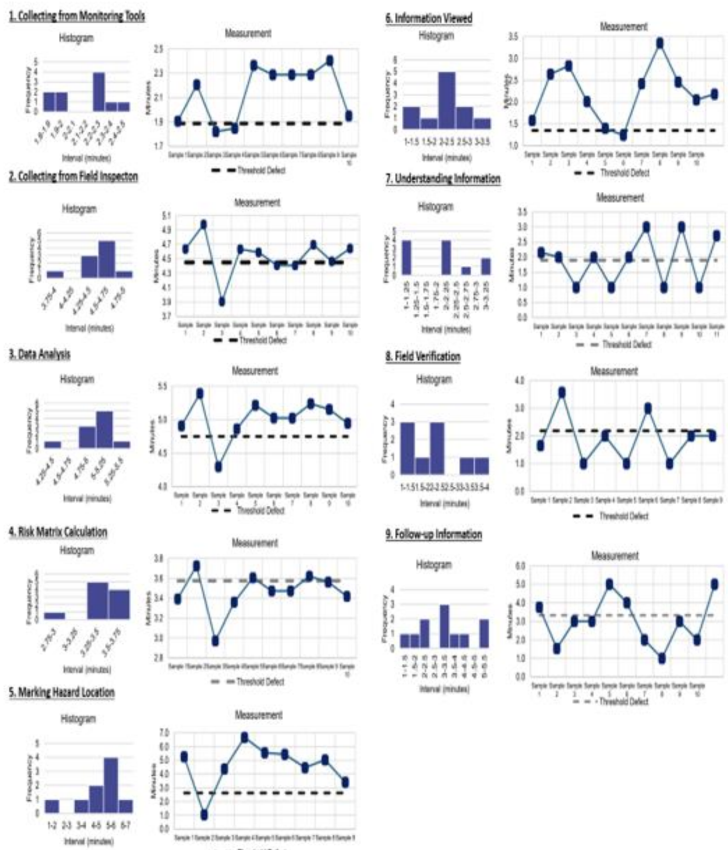

Figure 4. Measurement Results And Data Processing From Actual Conditions

Based on the calculation of actual conditions, such as the table 1 below, the Geotechnical Management Information System at PT Borneo Indobara is currently as follows:

Table 1. DPMO and Lean Six Sigma Calculation Results Actual Conditions

Data Sample Measurement	Collecting from Monitoring Tools	Collecting from Field Inspecton	Data Analysis	Risk Matrix Calculation	Marking Hazard Location	Information Viewed	Understanding Information	Field Verification	Follow-up Information
	Duration (minutes)	Duration (minutes)	Duration (minutes)	Duration (minutes)	Duration (minutes)	Duration (minutes)	Duration (minutes)	Duration (minutes)	Duration (minutes)
Sample 1	1,9	4,6	4,9	3,4	5,3	1,6	2,2	1,7	3,8
Sample 2	2,2	5	5,4	3,7	1	2,6	2	3,6	1,5
Sample 3	1,8	3,9	4,3	3	4,4	2,8	1	1	3
Sample 4	1,8	4,6	4,9	3,4	6,7	2	2	2	3
Sample 5	2,4	4,6	5,2	3,6	5,6	1,4	1	1	5
Sample 6	2,3	4,4	5	3,5	5,4	1,2	2	3	4
Sample 7	2,3	4,4	5	3,5	4,5	2,4	3	1	2
Sample 8	2,3	4,7	5,2	3,6	5	3,4	1	2	1
Sample 9	2,4	4,5	5,2	3,6	3,4	2,5	3	2	3
Sample 10	2	4,6	4,9	3,4	-	2,1	1	.	2
Sample 11	-	-	.	-	-	2.2	2,7	-	5
Spec Limit (minute)	1,9	4,5	4,8	3,6	2,6	1,4	1,2	2,2	3,3
Average	2,1	5	5	3,5	4,6	2,2	1,9	1,9	3
Standard Deviation	0,2	0,3	0,3	0,2	1,6	0,6	0,8	0,9	1,3
Jarque-Bera p-value	0,5	0,4	0,2	0,2	0,3	0,9	0,6	0,7	0,8
Defect	8	7	9	3	8	10	7	2	4
DPMO	800000	700000	900000	300000	888889	909091	636364	222222	363636
Sigma Level	0,66	0,98	0,22	2,02	0,28	0,16	1,15	2,26	1,85

This table shows the analysis of the time duration of several activities in a process, including data collection, analysis, risk calculation, and information verification. Each activity is measured in minutes for 9-11 samples, with a specific time limit set. Statistics such as average, standard deviation, defect rate (DPMO), and Sigma Level are used to evaluate the performance of each activity. Activities with low Sigma Level, such as "Information Viewed" (0.16), "Data Analysis" (0.22) and "Marking Hazard Location" (0.28), "Collecting From monitoring tools" (0.66), "Collecting From Field Inspection" (0.66), indicate a lot of defects and need significant improvement. In contrast, activities such as "Field Verification" (2.26) perform better. These results highlight that most processes still need improvement to achieve more optimal performance levels, especially activities with high DPMO and Sigma Level below 1. Improvements can focus on root cause analysis and corrective measures in processes that show low performance. This is important to reduce variability and improve overall system efficiency. It was found that the actual condition process of the data analysis and hazard reporting section took 17.1 minutes to collect monitoring tools data or 19.5 minutes to collect inspection data in the field. In the Figure 5 is the actual condition workflow:''

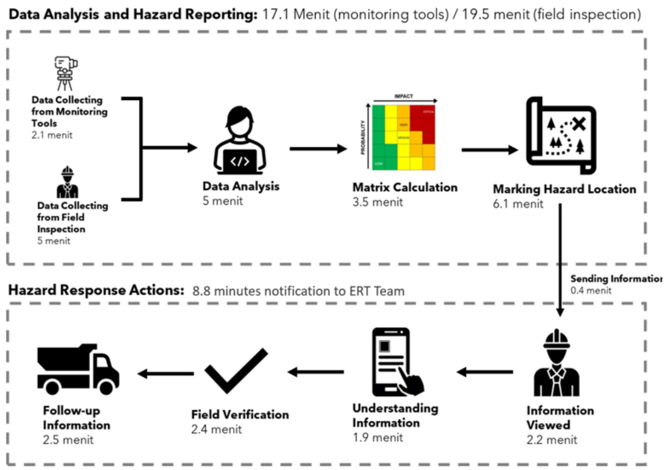

Figure 5. Geotechnical Workflow Actual Condition

Based on PT Borneo Indoboara's Standard Operating Procedure for the Golden Time Emergency Response Team, the longest is 7 minutes, while for the follow-up of hazard reports, it is 8.8 minutes; this causes a misalignment of time between the Golden Time Emergency Response Team and the follow-up of geotechnical hazards so that improvements are needed, especially in the follow-up of hazard responses. If we refer to the potential for digitalization, it tends to have a low sigma value. This shows that most of the processes in this system still have significant defects and require improvement. However, there is an exception in the information-sending process with a sigma value of 6. This process has been declared efficient because it is supported by available technology and well optimized. High efficiency in this information-sending process shows that the geotechnical management information system can achieve excellent performance with the right technology.

Analyze

This evaluation aims to detail the areas that need improvement and provide a strong basis for decision-making. To identify the root cause of the existing problems, we use the Root Cause Analysis approach with the Fishbone Analysis method & Pareto method.

Root Cause Analysis

Root Cause Analysis (RCA) is a systematic method for identifying the root causes of a problem or undesirable event (Rodríguez-Álvarez et al., 2024). The primary goal of RCA is to find the underlying causes of a problem rather than simply fixing the symptoms that are visible on the surface. By understanding the root causes, organizations can implement more effective and sustainable solutions that not only address the temporary problem but also prevent similar events from happening again in the future.

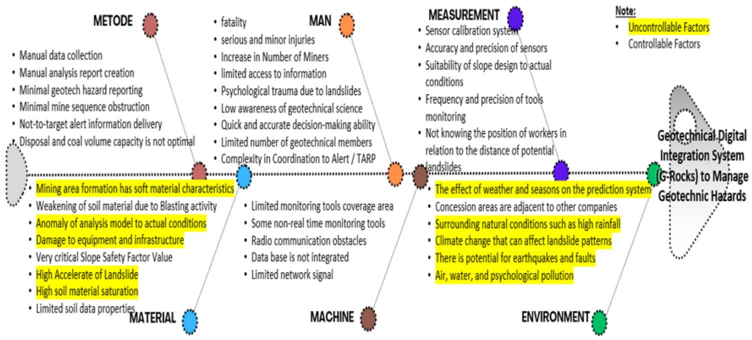

Figure 6. Result Fishbone Analysis G-ROCKS

This figure 6 provides an overview of the factors influencing geotechnical risk management in mining areas. These factors are divided into six categories: work methods, materials, people, machines, measurements, and the environment. Some factors are uncontrollable, such as weather conditions, climate change, and soil material characteristics, while others are controllable, such as measurement methods, use of technology, and time coordination. The main challenges faced include the weakness of monitoring tools, the mismatch between analysis models and field conditions, and risks influenced by environmental factors and human activities.

Pareto analysis is a strategic method for identifying priority elements in a system based on their impact on overall performance. In geotechnical project integration systems, it highlights key activities affecting operational efficiency and success rates. Using Pareto diagrams, improvement efforts can focus on critical factors influencing system performance. Integrated with a Six Sigma approach, the analysis evaluates fishbone categories like Man, Measurement, Method, and Machine under controllable condition factors. Notably, activities such as Hazard Location Marking and Data Analysis (both under Method) have sigma values below 1.0, categorized as "Poor" (red line), requiring significant improvement. Human Factors (Man) dominate as priority elements, emphasizing the need for training and competency development to boost efficiency. Addressing these priorities ensures enhanced system integration, reduced errors, and optimized project outcomes.

G-ROCKS Platform Design Needs

Based on the results of the previous in-depth analysis, various root problems have been identified that underlie the need to design solutions that can overcome existing constraints. These problems include multiple aspects of the system that could be more optimal in terms of operational efficiency, effectiveness in responding to emergencies, and management of limited resources. Therefore, it is essential to design a solution that not only fixes existing aspects but can also optimize the entire system to be more responsive to existing challenges. This solution must be holistic and comprehensive, answering every issue that has been identified, with the ultimate goal of significantly improving system performance and productivity.

The design of the solution to be developed must meet several critical criteria to ensure the success of its implementation. Each element in the design must consider various factors that affect system performance, such as data management, process optimization, more efficient use of technology, and increasing human resources capabilities. This design must also include a continuous monitoring and evaluation mechanism to ensure that the new system can continue to develop and adapt to changing needs and conditions. With this approach, the implemented solution is expected to not only solve the current problems but also provide added value in the long term, making the system more flexible, responsive, and ready to face future challenges. Thus, the proposed solution can be a strong foundation for improving overall operational efficiency, effectiveness, and sustainability. The table 2 following is a design that must be met in the design to overcome these problems:

Table 2. G-ROCKS Design Needs Results Based On Analysis

Activity	Design Needs
Collecting from Monitoring Tools	Database Integration of all geotechnical monitoring tools
Collecting from Field Inspection	Field inspections are made into digital and interactive forms so that they can be integrated with the database
Data Analysis	Integration produces automatic analysis reports with AI capabilities and data input based on the entire database, so that it can provide slope geometry recommendations
Risk Matrix Calculation	Risk matrix calculations can be integrated based on the database and calculated automatically to determine the geotech risk/hazard category
Marking Hazard Location	Integration of data analysis and risk matrices that can be plotted on a map to be applied to the geofencing method
Information Viewed	Alert/TARP notifications have been delivered and understood by the user
Understanding Information	User-friendly reports and visualization of potential landslide positions for the user
Field verification	Get confirmation or feedback from the user based on alert/TARP notifications
Follow-up Information	Effective communication features that can provide follow-up to the information provided.

The Design phase in the DMADV (Define, Measure, Analyze, Design, Verify) methodology for geotechnical system integration platform research aims to design solutions that meet user needs and expectations and optimize the overall system quality based on previously identified root causes.

Design

The Design phase in the DMADV (Define, Measure, Analyze, Design, Verify) methodology for geotechnical system integration platform research aims to design solutions that meet user needs and expectations and optimize the overall system quality based on previously identified root causes (Jaselskis et al., 2021).

G-ROCKS Platform Master Design

The screen and interface design in the Geotechnical Master Platform is designed to ensure a responsive, intuitive user experience that supports operational needs. The digital-based Geotechnical Master Platform is designed with two integrated systems, namely the G-ROCKS Command Center and the Geotechnical Information Mobile Apps, each of which has a different focus on use and interface but supports each other in providing a comprehensive solution for geotechnical risk management. The main difference between the two systems lies in the purpose of their use and the interface provided, which is tailored to the specific needs of users based on their responsibilities or job positions. G-ROCKS Command Center is a desktop-based system designed explicitly for geotechnical engineers. This system presents a comprehensive display with various geotechnical data analysis and visualization features that allow engineers to monitor and analyze geotechnical data in great detail. Engineers can interpret data results through this dashboard, identify potential problems or risks, and conduct simulations to design mitigation solutions. Another essential feature is the dashboard's ability to create hazard reports automatically and manually, making it easier to carry out risk assessments and make decisions faster and more accurately. Thus, this system supports the monitoring and control process of geotechnical risks more comprehensively and efficiently.

On the other hand, G-ROCKS Mobile Apps is a mobile-based application designed to support field team activities, especially for mine operation teams or all mine workers. This application has a more straightforward and accessible interface, allowing users in the field to receive hazard reports in real time. With direct notifications regarding potential hazards or deteriorating geotechnical conditions, this application enables the field team to immediately take preventive action or respond quickly to reduce the risk of landslides that may occur. In addition, this application is also equipped with a hazard report follow-up feature, which allows users to provide feedback on the report and verify it directly on-site. This makes the process of handling hazards in the field more efficient, effective, and well-coordinated, accelerating the response to situations that have the potential to endanger work safety.

With the integration between these two systems, this digital-based geotechnical platform not only improves the accuracy of analysis and monitoring, but also accelerates the process of handling potential landslides in the field, connecting data from the analysis center with tangible actions that can be taken by the field team directly. This integration ensures that the entire process, from analysis to execution in the field, runs more coordinated and transparently, as illustrated in the following sketch. Geotechnical engineers can monitor overall geotechnical conditions and perform in-depth data analysis through a desktop dashboard that provides a comprehensive and interactive view. The Figure 9 shows the main conceptual design of the G-ROCKS integration system.

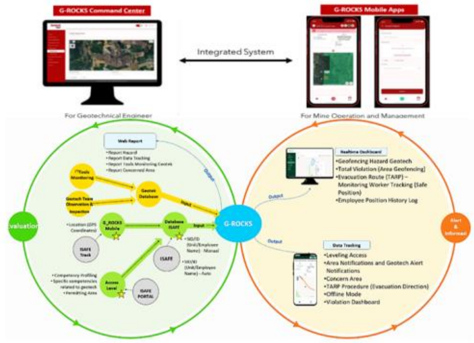

Figure 7. Main Conceptual Design Of The G-ROCKS Integration System

Geotechnical engineers can monitor overall geotechnical conditions and perform in-depth data analysis through a desktop dashboard that provides a comprehensive and interactive view. This dashboard allows engineers to obtain up-to-date information, identify potential problems, and formulate solutions based on available data to support safe and productive mine operations.

G-ROCKS Command Center

G-ROCKS Command Center is a desktop-based system designed explicitly for use by geotechnical engineers at PT Borneo Indobara. This system provides an intuitive and comprehensive user interface, allowing engineers to perform in-depth geotechnical data analysis quickly and efficiently. This dashboard is built to present information in real-time, enabling direct monitoring of geotechnical conditions across all mine sites managed by the company, from exploration to production. Engineers can access and analyze data collected from various geotechnical sensors and automatic monitoring tools spread across the mine site through this system. The data obtained includes information related to soil stability, ground movement, rock conditions, humidity, and other relevant geotechnical parameters. This system facilitates monitoring of mine conditions and provides tools to process and interpret the data needed to conduct more accurate geotechnical risk assessments.

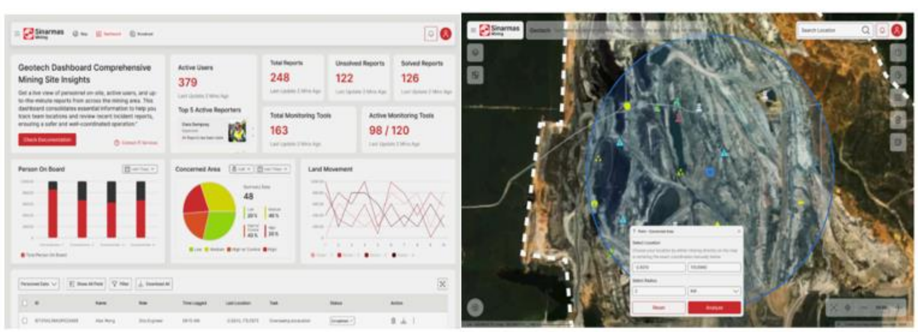

Figure 8. G-ROCKS Command Center Dashboard Main Design

In the figure 8 is a display of the dashboard platform designed to present data more efficiently and effectively. All data collected from monitoring tools is stored centrally and displayed in an easily accessible interactive map format, allowing users to visualize information more clearly. In addition, this platform is equipped with automation features that speed up the report generation process. Data that has been integrated and automatically analyzed can be used directly to generate comprehensive geotechnical hazard reports, saving time and reducing the potential for human error. The report generation process that was previously time-consuming and error-prone can now be done faster, more accurately, and more efficiently, which in turn supports more precise and effective decision-making. With the ability to present data in real-time and provide in-depth analysis, this platform not only speeds up the creation of geotechnical hazard reports but also increases the accuracy and precision of the information presented. The reliability of the information provided is critical in taking appropriate mitigation steps to reduce potential geotechnical risks and ensure operational safety in the mining area.

G-ROCKS Mobile Apps

This research concludes that the integration of the G-ROCKS system with the DMADV framework effectively addresses inefficiencies in geotechnical information distribution, focusing on critical stages with sigma values <2, such as data analysis and hazard location marking. The solution includes a centralized Command Center for rapid decision-making and Mobile Apps for real-time notifications and reporting, with implementation progressing toward the February 2025 launch of G-ROCKS 1.0. Future research can enhance this framework by exploring scalability, AI integration, sustainability, and user-centric innovations to advance geotechnical hazard management globally.

One of the main features of this application is Geofencing, which aims to improve user safety in the field. Using highly accurate GPS technology, this feature lets the platform track the user's real-time position. Thus, the system can ensure that users are always in a safe area and provide warnings when they enter a dangerous zone. The hazard map provided in the application has clear boundaries for each risk zone, and potentially hazardous areas are marked with striking colors and symbols, making them easy for users to recognize. If a user enters a risky area, the platform will automatically send a striking warning notification in the form of an alarm sound and text message, ensuring that users can immediately take action to avoid the danger zone. The Figure 9 below shows the design of the G-ROCKS Mobile Apps.

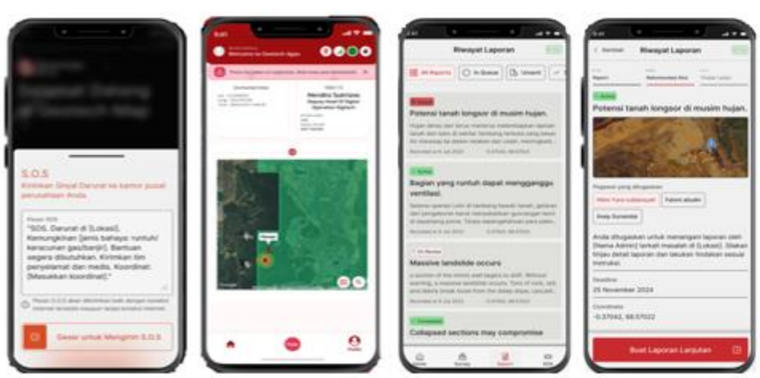

Figure 9. G-ROCKS Mobile Apps

In addition, this application is also equipped with an interactive form feature, designed to make it easier for users to conduct inspections and verifications in the field. This feature automatically records the user's GPS location, ensuring that every inspection and verification activity can be recorded accurately and integrated with the system. Thus, this platform not only helps provide fast and accurate hazard information but also increases efficiency and accuracy in the field documentation process, which supports better decision-making and more effective risk mitigation actions.

Design Plan Target

Based on the design plan that has been determined, various targets will be formulated that are expected to be achieved if the design is successfully implemented. By considering the main aspects of the design, we set several main targets that include increasing operational efficiency, information accuracy, team responsiveness, user satisfaction, and data integration. These targets will be the primary reference for evaluating the success of the design implementation and ensuring that the new system can meet the needs and expectations set. The details of the design stages are as follows:

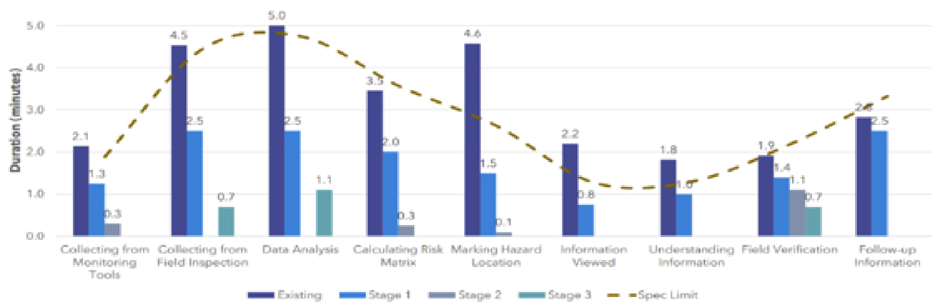

Figure 10. G-ROCKS Design Feature Results For Design Stage

a. Stage 1 is a recapitulation of the initial stage (Stage 1) features of developing a digital-based geotechnical management information system. Data Analysis and Hazard Reporting:
   a) From Monitoring Tools: 7.7 minutes
   b) From Field Inspection: 8.9 minutes
   c) Hazard Response Actions: 5.7 minutes
b. Stage 2 recapitulates the intermediate stage (Stage 2) features of the development of a digital-based geotechnical management information system. Data Analysis and Hazard Reporting:
   a) From Monitoring Tools: 3.6 minutes
   b) From Field Inspection: 5.8 minutes
   c) Hazard Response Actions: 5.4 minutes
c. Stage 3 recapitulates the final stage (Stage 3) features of the development of a digital-based geotechnical management information system. Data Analysis and Hazard Reporting:
   a) From Monitoring Tools: 1.9 minutes
   b) From Field Inspection: 2.6 minutes

c) Hazard Response Actions: 5.0 minutes

The figure 13 following compares the sigma values of existing conditions with the design stages 1, 2, and 3. Note that sigma values other than existing conditions are predictive, direct verification is needed if they have been successfully implemented.

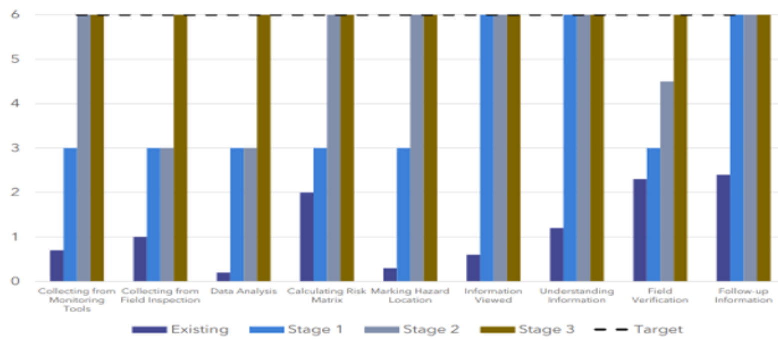

Figure 11. Lean Six Sixma G-ROCKS Design Feature Results For Design Stage

Verify

The final stage of DMADV is verification or Control (Baptista et al., 2020). At this stage, the project team tests and evaluates the designed solutions to ensure they meet the project objectives and customer expectations. The steps taken include:

a. Conducting final testing of prototypes or product/process models.
b. Validating the performance of new products/improvements against established standards and specifications and ensuring that corrected errors will not reoccur.
c. Developing a plan for implementing and launching new products/improvements into the production or operational environment.

Feature Control Process

The verification process ensures that the system or process that has been implemented can meet the standards and requirements that have been determined. Verification aims to confirm that the implemented solutions or controls are running effectively and consistently in managing essential variables that affect the final result. In this context, verification is not just an inspection, but a deeper step to ensure that each element in the control system functions according to the desired parameters, be it in manufacturing process control, automation control, or broader operational management. The feature control process is essential to ensure product quality and increase user satisfaction and trust in the product or system used. Proper control is needed to ensure functionality, quality, and suitability to user needs so that it can be relied on under various conditions. The figure 12 and figure 13 following is a table of verification results in the feature control process for the G-ROCKS Command Center development progress stage:

Feature	Task	Task Description	Verify Progress
Interactive Form Matrix Calculation and Concerned Area			
Create Mine Details Data	front end slicing	Slicing UI to add MD data	100.00%
	create data from point	Logic to perform MD addition using radius points	100.00%
	create data from digitization	Logic to perform MD addition with line and polygon digitization	100.00%
	upload from shp	Logic to add MD using SHP upload	100.00%
	upload from dxf	Logic to perform MD add using DXF Upload	100.00%
Create Slope Failure Data	front end slicing	Slicing to Create Data Failure Slopes	100.00%
	logic implementation	Logic for creating Slope Failure	100.00%
	create data from digitization	Logic to perform Slope Failure addition with line and polygon digitization	100.00%
	upload from shp	Logic for adding Slope Failure using SHP upload	100.00%
	upload from dxf	Logic for adding Slope Failure using Upload DXF	100.00%
Create Road Network Data	front end slicing	Slicing to create road network data	0.00%
	logic implementation	Logic for creating road network data	0.00%
Monitoring Tools	front end slicing	Slicing to create Monitoring Tools	100.00%
	create data from point	Logic for adding Monitoring Tools using points	100.00%
	logic implementation	Logic for creating Monitoring Tools	100.00%
	Upload xyz as CSV & Add XYZ data	Logic for uploading xyz data	0.00%
	calculate delta between xyz backend	Endpoint to generate deltas from the backend	0.00%
Slope Failure Query	query slope failure (based on geometry)	Query Slope Failure data using Geometry	0.00%
	query slope failure (based on geometry) backend	Endpoint for querying Slope Failure data using Geometry	0.00%
Routing	routing endpoint	Endpoint for routing from the start point to the nearest Muster Point (pg-routing)	0.00%
	shortest muster point calculation endpoint	Endpoint to determine the nearest muster point	0.00%
Summary General Report	front end slicing	Slicing Dashboard Infographic for: - Details - Concerned Area - Person on Board - Total Employees - Monitoring Tools - General Report	100.00%
	logic implementation	Logic for: - Details - Concerned Area - Person on Board - Total Employees - Monitoring Tools - General Report	50.00%
Dashboard Report Visualization			
User report-Table	Slicing and Logic	Displays all report results data	100.00%
Person on Board Table	Slicing and Logic	Displays data for all users who are currently online in a table	50.00%
	Fastify Server	WS to receive GPS data	0.00%
	Backend Integration to Fastify	Integration server to retrieve data from fastify	0.00%
Concerned Area Table	Slicing and Logic	Displays a list of all concerned areas	100.00%
Export User report	Export User Report as CSV	Export report data into CSV	0.00%
Export Person On Board	Export Person on Board	Exporting Pad Table	0.00%
Export Map	Export Map	Exporting Maps	0.00%
Export Infographic	Export Infographic	Exporting Infographics	0.00%
Broadcasting message			
Create Broadcast	Slicing and Logic	Create a Broadcast and send to selected users/roles	0.00%
Export Broadcast	Export Broadcast to CSV	Export broadcasts that have been sent to and Export Details of a broadcast to CSV	0.00%
Alert Table History	Slicing and Logic	Table of all Broadcasts ever sent	0.00%
Broadcast Details	Slicing and Logic	Details of a broadcast that was sent	0.00%
Panic Dashboard Notification	Alert from SOS Button	Receive SOS Alerts sent from mobile	0.00%

Table 12. Feature Control Process for The G-ROCKS Command Center Development

Feature	Task	Task Description	Verify Progress
Set Up			
Users List	iSafe Integration	perform integration with iSAFE	20.00%
User Activity Log	Directus Login	provides user activity log feature on Directus	100.00%
User & Role Management	RBAC	create role in Directus	50.00%
Base			
Login Screen	Slicing	Slicing Login Screen	100.00%
Basic Map	Front End Implementation	Creating a basic map on the front end	100.00%
Basic Map	Mobile Implementation	Creating a basic map on Mobile	100.00%
Interactive Form Matrix Calculation and Concerned Area			
Create Concerned Area	front end slicing	Slicing UI to add CA data	100.00%
	create data from point	Logic for adding CA using radius points	100.00%
	create data from digitization	Logic to perform CA addition with line and polygon digitization	100.00%
	upload from shp	Logic for adding CA using SHP upload	100.00%
	upload from dxf	Logic to add CA using DXF Upload	100.00%
	DXF Front End Logic	Create an endpoint to receive DXF data	100.00%
Add Matrix Data	front end slicing	Slicing Add Data Matrix	75.00%
	logic implementation	Performing Matrix Calculations	80.00%
	calculation matrix endpoint	Endpoint on BE to perform matrix calculations	100.00%
	backend follow up table	Follow-up Table on BE	100.00%
Matrix Table	front end slicing	Performing Slicing of matrix table for a CA	0.00%
	logic implementation	Logic to display matrix table	0.00%
Concerned Area Proposal	CA Proposal by Contractor	Logic for submitting for review by contractor	50.00%
	Approval by Geotech Engineer	Logic for doing approval submitted by contractor	50.00%
	Draft, Reject, On Review, and Completed Mechanism	Logic to see Draft, Reject, On Review and Completed lists on Contractor	50.00%
Data Catalogue	Data Catalogue Logic	Logic to display data to Data Catalogue	70.00%
	Layer Management Logic	Logic to display layers to layer management	100.00%
	Other Layers (Muster Point, Mine Details, Slope Failure, Road Network)	Logic to display data to Data Catalogue and Layer Management from Muster Point, Mine Details, Slope Failures, Road Network	80.00%
Create Muster Point	Front end slicing	Performing Slicing to Create Muster Points	100.00%
	Muster Point Logic	Logic for Creating Muster Points	100.00%
Feature Info	Slicing	Create Info Feature for all Data	100.00%
	Logic	Logic for each feature info	100.00%

Table 13. Feature Control Process for The G-ROCKS Command Center Development

The verification process for the dashboard features has made significant progress, with visual elements like the main dashboard display achieving 75% completion, indicating an almost finalized interface design. However, complex functional features, such as integrating geotechnical data into interactive hazard maps (40% verified) and refining the notification system (50% verified), require more testing and optimization. Challenges remain in real-time data integration, accuracy of displayed information, and ensuring notifications work effectively in dynamic hazard situations. While visual displays and some real-time data aspects are performing well, priority must be given to refining data processing, hazard map integration, and notification systems to ensure the dashboard is both user-friendly and capable of delivering accurate, actionable information for effective decision-making in real-world scenarios. The verified main features involve various aspects of the application, such as the user interface (UI) display, notifications, and real-time data processing and presentation. The following is a table 13 of verification results in the feature control process for the G-ROCKS Mobile Apps development progress stage:

Feature	Task	Task Description	Verify Progress
Mobile Apps Homepage			
Home Page Slicing	Mobile Slicing	Slicing for the Home Page	100.00%
Report Slicing	Mobile Slicing	Performing Slicing for Reports	100.00%
Survey Slicing	Mobile Slicing	Performing Slicing for Survey	100.00%
SOS Page Slicing	Mobile Slicing	Performing Slicing for SOS	100.00%
Geometry Data on Map	Geometry Data on Map	Display Geometry Data on a map	100.00%
Mobile Interactive Maps			
Person Tracking	Person Tracking and Sending to Server	Sending Location Data to server every 5 minutes	100.00%
Popup Details / Feature Info	Slicing and Logic	Displays information in a slider for each point on the map.	0.00%
Offline Capabilities			
Offline Capabilities	Syncing to DB	Synchronizing data with the database	100.00%
	Work while offline	Still display data when offline (geometry)	100.00%
		Still display data when offline (raster)	100.00%
	Save Report and Evidence Data to Local DB	Save to local DB when no internet access	0.00%

Table 14. Feature Control Process for The G-ROCKS

Essential elements of the mobile application have been verified and are functioning correctly, with features such as User Activity Log and User & Role Management reaching 100% and 80% verification, respectively, ensuring effective user activity tracking and role management. However, complex features like Real-time Hazard Notification and Geofencing, at 60% and 50% progress, require further refinement due to the challenges of real-time data processing and user location tracking. Additionally, the Interactive Forms for Field Inspections, at 70% progress, need enhancements to ensure accurate field data integration. Prioritizing the testing and optimization of Geofencing and Real-time Hazard Notification is crucial to achieve timely alerts, accurate hazard warnings, and optimal functionality in dynamic field conditions, ensuring both user safety and a seamless user experience.

G-ROCKS Implementation Plan

The implementation of G-ROCKS was carefully designed to ensure a smooth transition from the planning stage to full implementation in the field. This phased approach focused not only on technical development and data integration but also on user training and continuous monitoring to optimize the platform's functionality. This allowed for early detection of potential problems and ensured the system could adapt to evolving operational needs. By completing the implementation within a 12-month, G-ROCKS could provide significant benefits in geotechnical data management, occupational safety, and operational efficiency while ensuring that users could operate with a stable and secure system.

Overall, the success of the G-ROCKS implementation will depend heavily on effective coordination between technical development, user training, and ongoing maintenance. This phased approach is justified by the need to ensure that the platform functions well throughout the operational phase, from data collection in the field to data-driven decision-making. Thus, G-ROCKS will be a very effective tool in supporting safety, risk management, and efficiency improvement in the geotechnical and mining sectors. The following figure 13 is a roadmap diagram for the implementation of the G-ROCKS Platform at PT. Borneo Indobara.

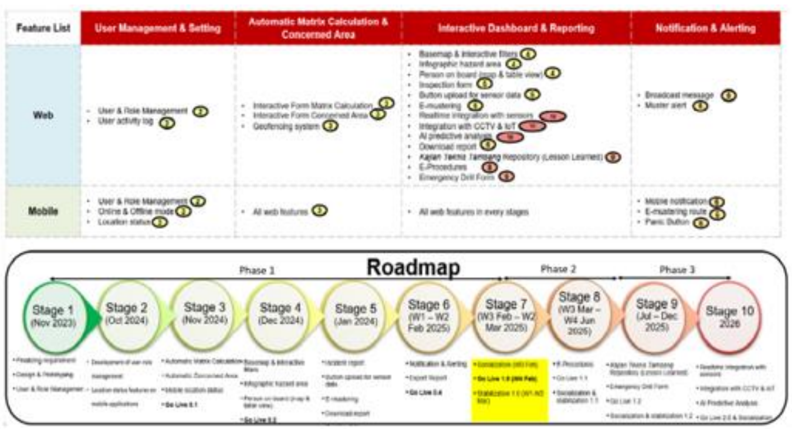

Figure 15. G-ROCKS Platform Implementation Roadmap Diagram

This figure 15 shows the development roadmap for a geotechnical integration system designed to improve risk management in mining areas through key feature development and phased implementation until 2026. The system includes features such as user management, automated matrix calculations, interactive dashboards for real-time data reporting, and mobile-based notifications and alerts. Development is carried out progressively in 9 stages, starting with user and role management (Stage 1) through real-time sensor integration and AI-based predictive analytics (Stage 10). Each stage adds new elements, such as geofencing features, interactive data visualization, and technical repositories, while involving the system's socialization and stabilization process. This approach allows for a structured and sustainable implementation, focusing on improving operational efficiency, risk management, and safety in the field.

CONCLUSION

The conclusions in this research demonstrate the challenges in geotechnical information distribution by identifying critical issues in the Man, Measurement, Method, and Machine dimensions, which hinder efficiency and timely hazard management. Using Fishbone and Pareto analysis, key stages with sigma values <2 - such as Viewed Information, Data Analysis, and Follow-up Information - were prioritized for improvement. The proposed G-ROCKS system, which is integrated with the DMADV framework, offers a comprehensive solution through a centralized Command Center for systematic data analysis and a Mobile App for real-time notification and geofencing. The implementation roadmap, divided into three phases, is progressing with the launch of G-ROCKS 1.0 scheduled for February 2025. This research contributes to the advancement of geotechnical hazard systems by integrating modern technologies and process optimization, laying the foundation for future research on scalability, AI integration, sustainability, and improved user-centered design.

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