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Garud Survey: A Case of Improving Safety and Transparency in Mining Operations Using Drone Technology

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Abstract:

SAI Minerals Pvt. Limited (SAI Minerals), a renowned company engaged in mining cement-grade limestone and manufacturing cement in Rajasthan, India, has been grappling with recurring survey reconciliation and safety issues across its mining operations. Additionally, in compliance with new government regulations, they are now required to conduct aerial surveys and submit digital images and survey reports to the Indian Bureau of Mines (IBM). SAI Minerals sought a permanent solution to these challenges and approached Garud Survey Private Limited (Garud Survey), a technology-driven surveying agency. SAI Minerals recognized that these issues not only impacted their production but also tarnished the company's reputation in the mining industry due to frequent accidents. Garud Survey recommended that the best approach to address the problem was to make the survey process faster and more accurate, enabling all stakeholders to have a clear and up-to-date view of the operational status. Garud Survey proposed the implementation of cutting-edge technology to identify and address the root cause of the problem. This case further explores the application of system analysis and design to the adoption and implementation of latest technology in a real-world use case, as well as the challenges associated with managing change.

Keywords: Mining, Technology adoption, Change management, Training, Survey, Drone, Operational Transparency, Safety, Industry 4.0.

[Department statements, if appropriate, will be added by the editors. Teaching cases and panel reports will have a statement, which is also added by the editors.]

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1 Introduction

On a chilly winter afternoon in January 2023, Vishal Modi, Director, Garud Survey[1], Jaipur, Rajasthan, was conducting a review of the progress of various projects with his operational team. During the meeting, he received a call from Vikas Jangid, Mines Manager, SAI Minerals, a large company engaged in limestone mining and cement manufacturing. Jangid invited Modi for a meeting with SAI's top management team, operations manager, and its safety officer to discuss issues related to survey reconciliation and safety concerns in their mines. In the telephone call, Jangid stated that there had been frequent safety incidents at some of SAI's mining sites, which had resulted in the Directorate General of Mines Safety (DGMS)[2] issuing notices to them. Furthermore, over the past six months, operations at three of SAI's mining sites had to be temporarily halted due to disputes raised by the mining contractor regarding discrepancies in the estimation of excavated ore volume for which the contractors had been compensated. Modi contemplated that if he understood the problems in detail, he could envisage technological solutions that would be attractive to SAI's management and their mining contractors.

Drawing on his extensive technology consulting experience in, Modi was confident that leveraging technology could greatly benefit SAI Minerals in establishing a transparent surveying process that would effectively address the survey reconciliation issues, as well as reduce safety risks. An appropriate technology and process solution would ensure uninterrupted mining operations, while maintaining the highest safety standards. This would also prevent safety/accident-related notices from regulatory authorities that had previously disrupted operational activities.

Modi believed that leveraging drone technology would offer a secure and transparent surveying solution that would significantly reduce overall surveying time. Moreover, it would facilitate compliance with the latest regulations that required miners to submit annual drone-based aerial survey reports to the Indian Bureau of Mines (IBM)[3].

Modi however realized that despite the potential benefits of drone technology in addressing SAI Minerals' challenges, there were several risks and issues that needed to be addressed. Primary among these included concerns related to infrastructure, technology adoption, implementation, and change management. In preparation for the upcoming meeting, Modi reflected on the safety incidents reported in the media over the past 6-12 months across various mining operations in Rajasthan and throughout India. He focused his attention on those that related to mine surveys. He realized that this preparatory analysis would aid him explore the feasibility and challenges associated with implementing drone technology in mining surveys during his upcoming discussion with SAI Minerals.

Given the above context, Modi wondered, "What all factors should I consider in my analysis and preparation so as to build a convincing case that would help SAI Minerals adopt drone technology as an alternative to manual mining survey techniques and help it meet its safety, productivity and compliance requirements?"

2 SAI Minerals and Mine Surveys

SAI Minerals was involved with mining and processing limestone and manufacturing cement for sales in the Indian and international markets. SAI Minerals had a total of 13 mining sites spread across approximately 30 square kilometers area, and two cement manufacturing plants in close proximity. It relied on outsourced contractors for most of its mining and logistics operations. The contractual agreement with its mining contractors entailed payments, on an INR / Ton basis, based on the quantity of limestone (mineral) and waste rock they excavated.

At the end of each month, the SAI survey team conducted mining-area and volumetric surveys using traditional survey practices and methods, utilizing Total Station and Differential Global Positioning System (DGPS) instruments[4]. The results of these surveys formed the basis for payment to the contractor for the mining activities performed during the period. This process involved a team of 4-5 people physically visiting all the excavation and dumping sites that were to be surveyed. Further survey team also need to

[1] https://www.garudsurvey.com/
[2] Please refer to Table 1 for brief description of various organizations and terminology related to mining sector.
[3] https://mines.gov.in/writereaddata/UploadFile/Noticedated05062021637611643079879217.pdf
[4] https://www.nakshatech.com/total-station-dgps-survey (Accessed on April 28, 2023)

coordinate with other stakeholders such as mine planner, mining contractors, stockpile manager, etc. Complete interaction amongst various stakeholders is depicted in figure-1. However, given the physical difficulties in reaching some of these relatively inaccessible locations, there often were inaccuracies in volumetric calculations and the omission of important geotechnical parameters. Such omissions led to problems such as "bench failure" and "slope failure," which could result in fatal accidents. Such safety issues posed risks to personnel and operations and had serious legal consequences, which included the temporary closure of mining operations.

Typically, it took 3-4 days to complete the surveying activities at one mining site. Sometimes, due to difficult surface terrains and the inaccessible nature of the area being surveyed, additional time was required. Weather conditions, such as extreme heat or cold, also impacted the survey team's productivity. Upon completion of a survey, the data obtained had to be transferred to the computer system for further analysis and processing.

These surveys were repetitive in nature, as each operational mining site had to be surveyed every month. This was done to quantify the excavation volume for which SAI had to pay the mining contractor. The survey reports were also a part of the production records that had to be maintained as a statutory requirement for royalty payment to the Government, and for internal records, planning, and management purposes.

In case of any dispute related to volume/tonnage calculation, a joint survey which involved personnel drawn from SAI Minerals and contractors was necessary. This was time-consuming and costly. The survey activities covered the mining area where mineral and/or waste excavation took place, and also included waste dump areas, run-of-mine stockpile areas[5], product stock pile areas, and sometimes lease boundary surveys. Royalty payment by SAI Minerals against every ton of mineral mined was also linked and reconciled with the survey volume.

2.1 The Current Crisis

SAI Minerals received a notice from the DGMS and had to halt mining activity in one of the key working areas of their mine site due to a recent accident where a member of the survey team was severely injured during survey operations. Moreover, in the past few months, there had been several instances where contractors stopped operations as they had not been paid on time, either due to delays in the survey process or disputes in volume reconciliation. Stoppages of mining operations had several cascading negative effects on logistics and processing plant operations, leading to unavailability of raw materials for cement manufacturing. In fact, SAI Minerals had recently missed a deadline for exporting high-grade cement to Dubai as they were unable to process the required limestone due to mining operations being halted by contractors over survey reconciliation issues. SAI Minerals was concerned that these disputes might result in contractors becoming reluctant to work for SAI. Also, frequent safety incidents were tarnishing SAI's reputation within the mining fraternity and regulatory departments of mines and geology. In an effort to rebuild trust and increase transparency in their survey and payment processes with stakeholders, SAI Minerals was exploring the use of technology. It was due to these challenges that the top management of SAI Minerals had Modi to discuss the surveying related problems.

3 The Meeting

The Meeting Attendees

B.N.Choudhary: Director, SAI Minerals, was a veteran industrialist with more than 55 years of experience in industrial mineral mining and processing. He was respected by his peers and by the members of the Federation of Mining Associations of Rajasthan.

Vikas Jangid: Mines Manager, SAI Minerals, was young, energetic, and passionate about mining operations. He was a professional mining engineer and was keen to improve the productivity of SAI Mineral's mining operations and maintaining highest safety standards.

Ashish Saxena: Sr. Manager Survey, was in-charge of the survey department of SAI Minerals. He held a diploma in mine surveying and was responsible for survey activities at all the mining sites and the processing plant.

[5] https://www.lawinsider.com/dictionary/rom-stockpiles

Mani: Finance manager, SAI Minerals, a commerce graduate who was excellent with numbers and responsible for clearing the payments of contractor as well as maintaining the production records to pay royalty to the government.

Vishal Modi: Director, Garud Survey, a technocrat with over 15 years of experience handling technology projects for clients across India. Garud Survey had its headquarters in Bikaner, and branch offices in Jaipur and Udaipur, Rajasthan. Garud Survey was the first start-up in Rajasthan that used drone technology in various projects for aerial surveys and were recognized as high quality professionals in aerial survey in agriculture, civil and mining industries. Garud Survey provided end-to-end consulting solutions as per company specific requirements and as per government regulations. It did business with both government entities and private companies.

The Meeting

Choudhary: Good morning. Thank you for assembling on such short notice. I trust that all of us have a clear understanding of the ongoing challenges and the criticality of urgently finding a solution that is fit for purpose.

Jangid: Thank you for your gracious hospitality. The frequent operational shutdowns by contractors and the recent notice from DGMS have been a cause of significant concern for us. We need to find a permanent solution to these problems.

Mani: Thank you, Jangid, for your understanding and concern. While we have experienced similar instances in the past, the recent accidents and operational shutdowns over the past six months have been of a more serious nature. These incidents not only affected the company's cash flows and caused operational disruptions, but had also tarnished our reputation in the local market and with government departments. Furthermore, with recent delays in exports, our international business was also impacted. It is imperative that we address these challenges and find effective solutions to mitigate their impact on our business as a whole

Saxena: Our survey department has been operating at full capacity to complete surveys within the scheduled timeline. The teams also strictly adhered to all guidelines and standard operating procedures (SOPs). However, in recent times, we have faced challenges in meeting deadlines due to the significant increase in the size of our operational areas and also difficulties in accessing key locations. The surface terrain in certain areas made physical access difficult. This resulted in longer survey times and also exposed our teams to unsafe working conditions. We have been actively addressing these issues to ensure the safety and efficiency of our survey operations, while maintaining compliance with all guidelines and SOPs.

Jangid: The management acknowledges your leadership and the diligent efforts of the survey teams. However, issues related to survey reconciliation have occurred with increased frequency, leading to unrest among contractors and operational disruptions.

Mani: In the previous quarter, we were unable to meet our production targets due to operational issues which are clearly reflected in quarterly production report as shown in figure-2. We have collectively acknowledged the need to optimize the survey process to address this challenge. By reducing the total time required for surveying and processing, we can expedite the volumetric calculations, ensure timely payments to contractors, and streamline our accounting and royalty system with government requirements.

Saxena: Indeed, following our previous operations meeting, we have taken steps to address the situation. We have hired two additional employees in the survey department, and successfully streamlined operations at three of our sites. However, we are still encountering challenges in reaching certain locations for surveying after mining or excavation, due to inaccessibility caused by slippery terrain or other factors, such as dew and water accumulation. In fact, we recently had an accident on site where one of our survey assistants slipped and fell, resulting in him fracturing his ankle. Such incidents not only caused delays but also posed risks to the health, safety and well-being of the team members. Moreover, the time required for shifting teams from one site to another further adds to the challenges faced.

Modi: I think hiring additional survey assistants may not effectively address the issue if the locations to be surveyed are physically inaccessible and have difficult terrains. It will require time and effort to make these areas accessible and safe for surveyors and other personnel to carry out their work. Furthermore, I am

doubtful that this approach alone will significantly reduce the total surveying or processing time. We need to think outside of the box and better leverage technology to find permanent solutions to these problems.

Jangid: Yes, I agree. We can not expose our workers to unsafe working conditions. I also believe that the current size of the survey team is more than sufficient to handle the current quantum of work. We should find solutions so that we do not lose any production working hours. Modi, I hope you would be able to help us out.

Modi: Of course, I will try my best to find a suitable long-term solution. . I think that if we can reduce the surveying and processing time from 3-4 days/site at present to about one day per site, most of our problems will be solved. Toward this, we can leverage drone technology to carry out volumetric surveys of you're the mining and stock pile sites. An added advantage is that the survey team would not have to be exposed to unsafe working conditions.

Choudhary: I have heard a few things about drone technology recently but don't know how it works. We are not very tech-savvy around here. Can you explain how drones can help us and what we need to do?

Modi: Drones, also known as unmanned aerial vehicles (UAV's), are equipped with sensors and cameras that capture high-resolution images, videos, and other data from the air. Drone technology has revolutionized the way aerial surveys are conducted (refer figure – 3). As mining industry is also looking forward to leverage latest technologies, drones are becoming increasingly popular in transforming mining operations (refer figure – 4). The drone captured image/ video data can be processed and analyzed to generate accurate and detailed maps, digital elevation models[6] (DEMs), 3-D models, and reports, which are valuable for planning, monitoring and managing mining operations. Typically, a mining site can be surveyed within a few hours and the survey reports can be generated quickly for faster decision making and operational planning.

Jangid: Sounds interesting.

Choudhary: This is still not entirely clear to me. How can we calculate the volume of mined area or any stock pile from aerial images? Can you please explain how it will work?

Modi: Alright, let me simplify further. The surveying process can be broken down into five broad steps. These are (a) data collection, (b) image processing, (c) developing DEMs and 3D-models, (d) data analysis, and (e) reporting & visualization. We can geo-reference the sites and operational areas being operated by different mining contractors. Every month, the survey team, a drone-pilot, along with one assistant, will visit the survey site. The flight path for the survey can be pre-defined before reaching the site. The drone will take off from a designated point, fly over the site, and return to the same place. Physically inaccessible areas can also be easily covered by the drone. Based on my assessment of the mining operations area, it should not take more than 2-3 hours to complete the survey of one site. Since all four sites are in close proximity, we can cover all of them in 4-5 days. In parallel, the data captured by the drone will be processed by our office staff at the backend. Image processing software is backed up by artificial intelligence which helps to quantify and extract topography and volumetric information from the high definition images captured during drone survey[7]. It is an automated process that can be run overnight without manual intervention. Once the data is processed, the surveyor and planning team can use it for analysis and finalizing the volumetric calculations, which can then be utilized by the Accounts/Finance department for mineral accounting and contractors' payment. An example of volumetric survey calculation using drone image is shown in figure-5.

The advantage of this approach is that the surveyor and other team members will not have to traverse difficult terrains, will avoid being exposed to unsafe working conditions, and also any ongoing activities at the sites will not be disrupted as the survey team would work remotely. Additionally, the representation of the area can be displayed in a three-dimensional format, which can be easily understood by the contractors, allowing them to confirm and validate the progress of work with ease.

Choudhary: Really! Modi, it sounds too good to be true. I have serious reservations about whether this new system or process can be implemented. Our mining contractors are not very technology savvy. Why would they believe in the accuracy of the survey done by a drone? Also, who would be responsible in case the data is not collected accurately as the same will be used for mineral accounting?

[6] https://equatorstudios.com/what-is-a-digital-elevation-model-dem
[7]https://escholarship.org/content/qt3ww8g75c/qt3ww8g75c_noSplash_3fca71ff80684489c26cf49fd54f4841.pdf?t=qv9eub

Modi: I understand your concerns, but the accuracy of the survey can be assured if we follow the laid out SOPs and use drones that comply with the specifications recommended by the Indian Bureau of Mines. In any case, as per the recent regulations, each company is expected to submit aerial survey reports along with the images to the government.

Saxena: I agree with Choudhary's concerns. Previously, we had implemented a mobile application for our contractors and management team to get real time information of the mineral being mined in each shift. Though it was a great idea, it did not work out. The daily reports were not reconciling with the month-end survey volume. The reception of the technological solution among contractors and personnel was inadequate, with grievances that it was resulting in redundant labor and deviating them from our single source of veritable data ideology. It signified that multiple iterations of the same data were disseminated among disparate departments, thus making it challenging to ascertain the most up-to-date and reliable data. I am afraid this new tech-based proposed solution may suffer a similar fate.

Modi: I know acceptance among contractors is a big concern as it is directly linked with their payment system. Even for the employees it will not be that easy. I have seen this issue take center stage in many of my earlier projects, but, nevertheless, we have been successful in implementing the system. We are confident that we can successfully implement a drone-based surveying technology for SAI Minerals.

Jangid: Thank you for the clarifications. I too had similar doubts before. Regarding the lack of tech-savviness of the contractors, I think we can manage that. The contractors are not directly involved in the survey work. They are mainly concerned about the survey's end results as it is linked to their payment amounts. However, there will be some involvement of contractors for sharing information, demarcation of areas etc., which can be managed by providing training to their key stakeholders.

Ashish: This is fantastic. I think SAI Minerals can identify a site for a pilot project and once successful, replicate the same model/process for the rest of its mining sites and processing plants.

Mani: I am still not convinced. I think that Modi's technology based solution looks pretty fancy, and it may cost us a fortune. With severe production losses in the recent past we are not in a position for making a big capital investment in the current financial year.

Modi: While we will come back with formal quotations, I can state upfront that there will be some investments required, however, I don't expect the cost to be exorbitant. The operational cost of a drone-based survey is considerably lower compared to traditional methods (Refer Table -2). By improving the total productive hours and production, and by avoiding unrest among mining contractors, we can make this project financially viable. We all understand that even a single hour of production loss can have a significant impact on revenues and profits. Additionally, considering that you are already required to provide aerial survey reports to the department, proper planning of this project can address both aspects effectively.

Choudhary: Modi, I appreciate your proposal, although it seems somewhat ambitious to me. However, the real test lies in the practical demonstration. If you can showcase the effectiveness of this approach to my fellow team members, and most importantly, to our mining contractors, we would be glad to consider it further.

Modi: I can do a small demo of the proof of concept in 7 days.

Jangid: Good! Let us meet in another 7 days at one of our mining site and take this forward.

Modi had seven days to prepare for the proof of concept and final presentation. Despite having experience with similar projects in the past, this time around, things were more complicated. There were various constraints to consider, such as the lack of infrastructure, limited resources, stakeholders (mining contractors) with low tech-literacy or education levels, and resistance to change, among others.

Jangid, brimming with excitement, approached Modi and handed him a note that contained a few crucial questions Modi needed to be prepared to answer these questions during the subsequent meeting. The questions included: Is drone survey the optimal solution for addressing the issues at hand? Should SAI Minerals adopt drone technology? What were the benefits and drawbacks of this solution? How to assure SAI minerals that the AI model and software which would be used for analyzing the drone generated data would lead to accurate results? What challenges might arise during the implementation of drone technology at SAI Minerals? What training programs would SAI Minerals have to conduct for managing the change?

4 Conclusion

Following these detailed discussions, SAI Minerals had two options to consider. First, it could continue with the status quo of physical mine-surveys and address the challenges of safety, accuracy and transparency through better training of survey-resources. Essentially, this 'wait and watch' approach would mean that SAI Minerals postpones its decision to adopt drone technology and waits until numerous other mines had moved to drone-technology based mining surveys. This conservative approach would mean that the uncertainties related to the new drone technology would have reduced significantly. However, the delay may result in continued operational risks and mine-survey safety issues.

Second, it could immediately adopt drone technology for mining survey. For this, it could leverage Modi's expertise to work out a plan for transitioning from its present manual processes to drone technology implementation. However, SAI Minerals was worried about the efficacy of drone technology in solving their mining survey related issues, and also unsure about the implementation challenges involved. SAI Minerals needed to be sure that the AI model and software which would be used for analyzing the drone generated data would lead to accurate results. They were also concerned about the training programs and technology skills needed for this transformation of the survey process.

5 Figures and Tables

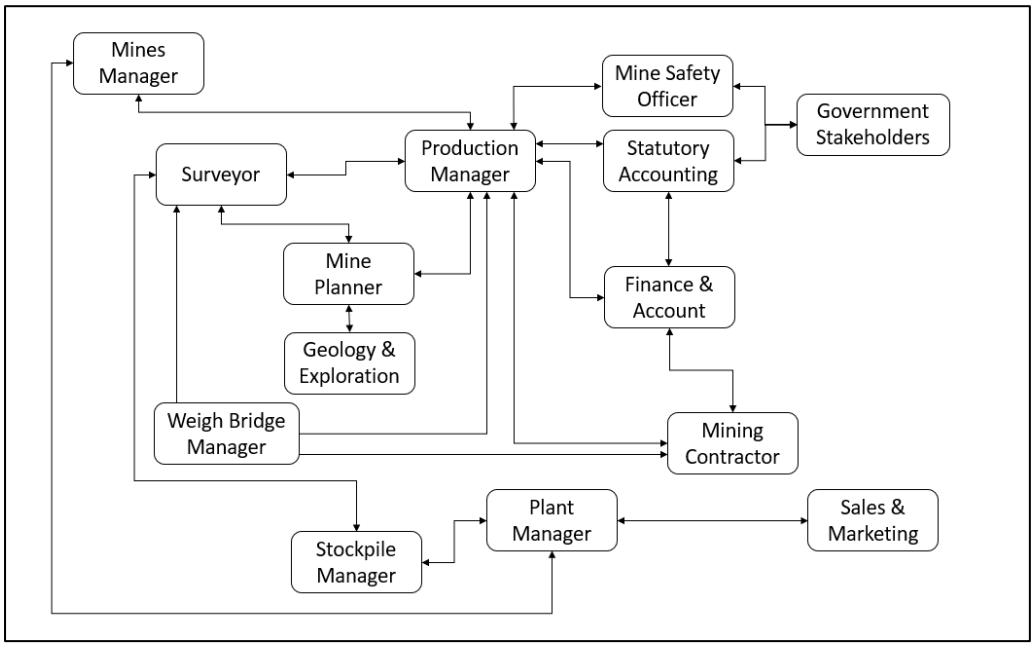

Figure 1. Mining Survey and Involved Stakeholders

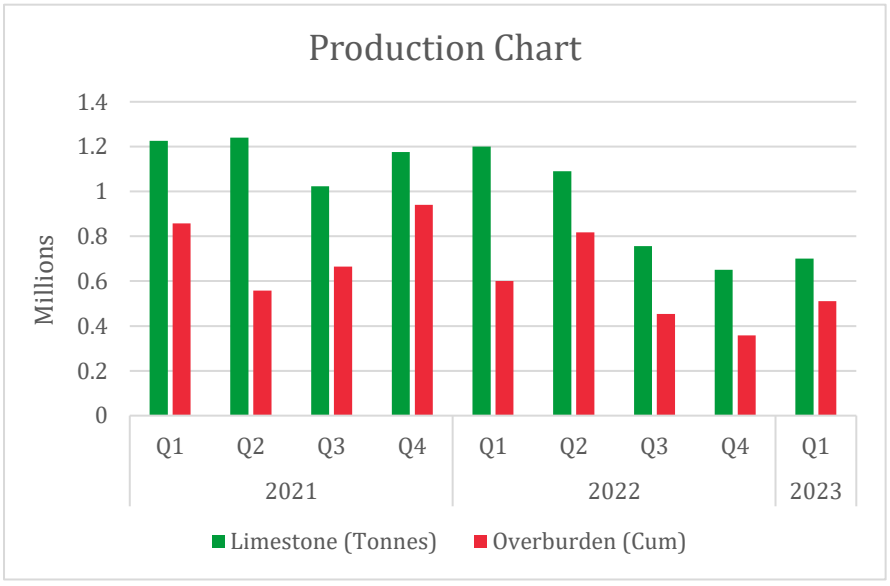

Figure 2. Quarterly Limestone and Overburden Excavation

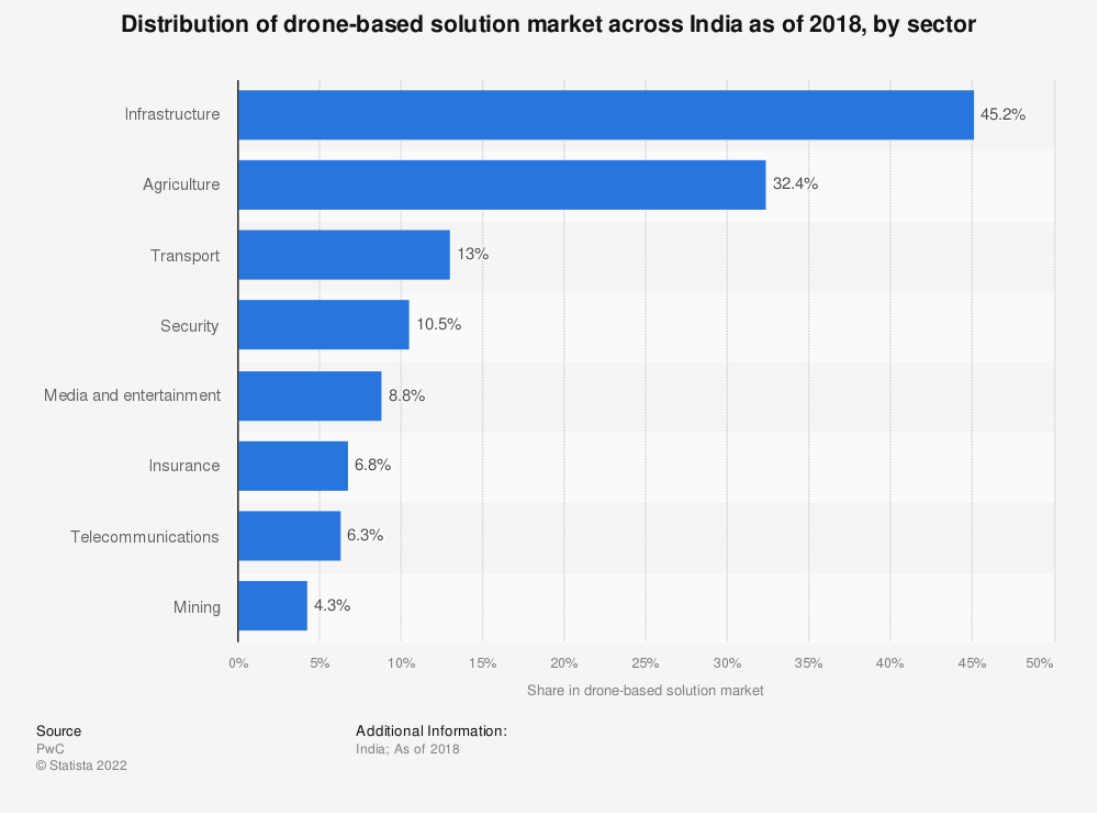

Figure 3: Distribution of Drone-Based Solution Market Across India as of 2018, by Sector (Source: Statista)

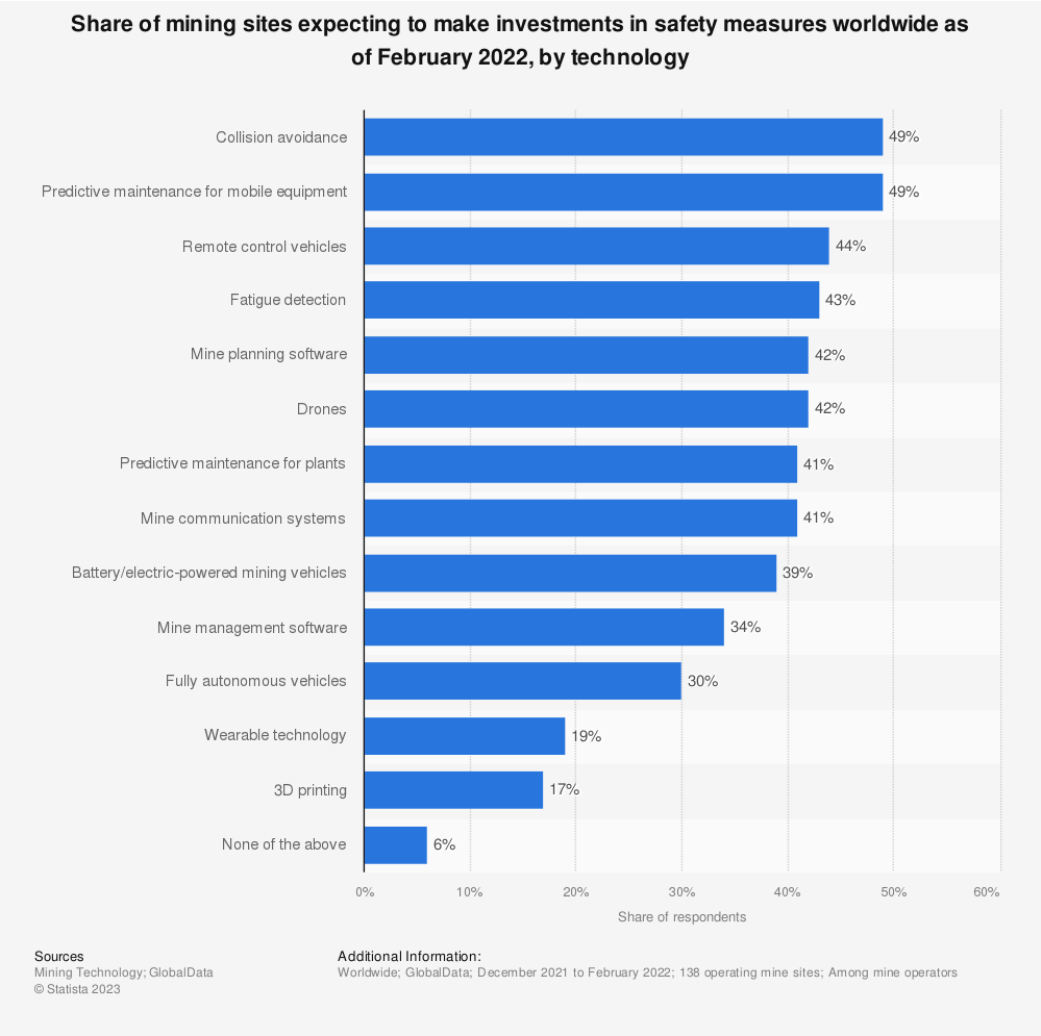

Figure 4. Share of Mining Sites Expecting to Make Investments in Safety Measures Worldwide as of February 2022, by Technology (Source: Statista)

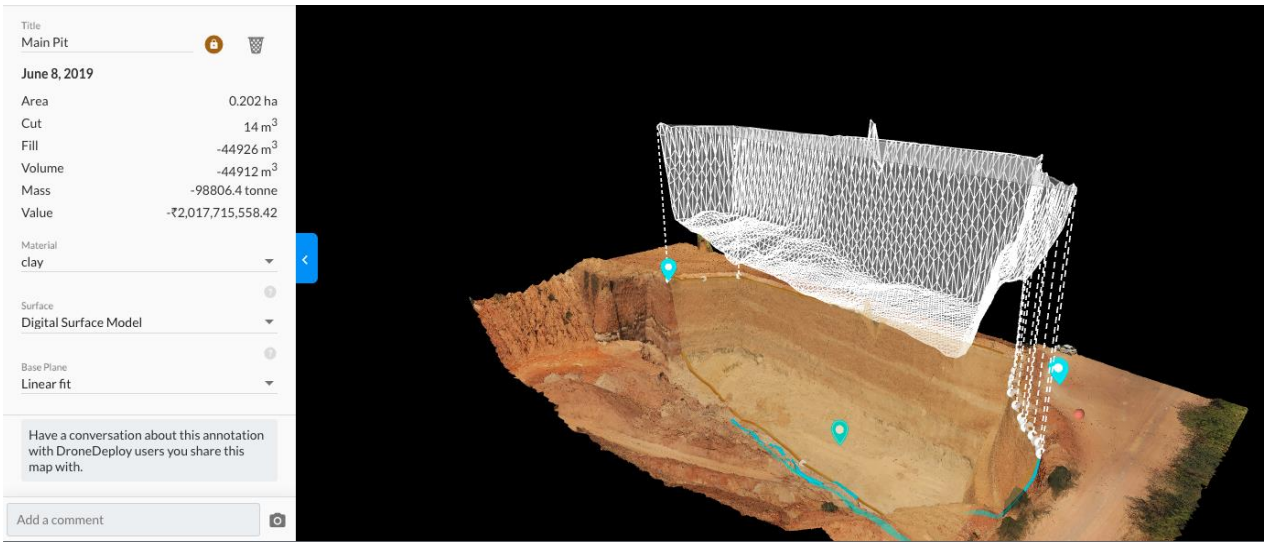

Figure 5. An Example of Volumetric Calculation Using Drone Image (Source – Garud Survey)

Table 1: Definitions of important terms from Mining sector (Source: Developed by authors)

S. No.	Term	Definition
1	3D-models	3-D models are used for creating rich and accurate models to provide operators with more information about mine operations and safety.
2	Bench failure	Bench failure is a type of slope failure.
3	Differential Global Positioning System (DGPS)	DGPS methods are used to improve the quality of location data collected using GPS receivers.
4	Digital elevation models (DEM)	DEM is a representation of the bare earth topographic surface. It does not include surface objects such as trees, building, etc.
5	Directorate General of Mines Safety (DGMS)	DGMS is the regulatory agency of the Government of India (GoI) that monitors matters regarding occupational safety, health and welfare of mine employees.
6	Dumping sites	Mine dumping sites are those locations where the waste material generated from the excavation process is stored.
7	Excavation sites	Mine excavation sites are those areas from which ore and waste has been or is being extracted (or mined) by various process like drilling, blasting, loading, hauling of rock (ore or waste).
8	Geo-referencing	Georeferencing helps relate the internal coordinates of a digital map to a ground system of geographic coordinates. In simple words Georeferencing is the process of aligning satellite imagery or other types of maps with real-world geographic coordinates.
9	Geotechnical parameters	Geotechnical parameters aims to ensure the safe design of pits and underground excavations by providing design parameter recommendations made through the analysis of rock mass properties generated by site investigation and rock mass sample testing. Key geotechnical properties include specific gravity, grain size distribution, plasticity, permeability, pre-mining state of stress, the frequency and surface condition of joints and other fractures in the rockmass, and the strength of the intact rock material.
10	Indian Bureau of Mines (IBM)	IBM is an entity under the Ministry of Mines, GoI, that is responsible for the conservation, scientific development of mineral resources, and environmental protection in mines.
11	INR	Indian National Rupee is the currency of India.
12	Mine Survey	Mine surveying is used for determining the relative positions of points on or below the earth's surface. It involves distance, direction & elevation measurement by using direct or indirect techniques. It involves volumetric surveys and mining-area surveys.
13	Mine Topography	Mine topography refers to the arrangement of natural and artificial physical features of a mine location.
14	Mines Manager	Mine manager is the overall in-charge of a mine and has responsibility of planning, organising and supervising mining activities, and overall safety of the operation.
15	Outsourced mining contractors	Mining companies enter into contractual agreements with outsourced contractors for avoiding large capital spending. Contractors bring in equipment such as fleet of trucks and excavators, that reduce mining company's fixed or capital costs.
16	Product stock pile	A mining stockpile is a pile or storage of materials / ores extracted during mining, as well as products produced from processing plant.
17	Run-of-mine stockpile	Run-of-mine stockpiles are temporary storages of ores to balance inflow and outflow of material and use for blending ore grades.
18	Slope failure	Slope failure is a significant hazard at mining sites. It occurs due to the failure of the rock slope. This is a result of excess loading shear stress in a rock mass getting redistributed in a way that the total load exceeds the rock's strength.
19	Sr. Manager (Survey)	Senior Manager (Survey) manages a team of mine surveyors who are responsible for accurately measuring and recording various mining activities and outputs.
20	Survey reconciliation	Survey reconciliation is an important process in mining that helps assess the output of the mine by estimating the volume, tonnage, grade and contained metal. It also helps to reconcile the rock tonnages which are being recorded through volumentric survey and using weight bridge and/or counting the trips.
21	Total Station	A total station (TS) is an electronic/optical instrument used for mine-surveying.

Table 2: Cost Estimate of Drone Implementation (Source: Developed by authors)

Sl. No.	Item	Year				
		1	2	3	4	5
1	Hardware & On boarding Cost	700000	50000	50000	50000	50000
2	Cloud Cost	100000	100000	100000	100000	100000
3	Ongoing Maintenance Cost	80000	80000	80000	80000	80000
4	Monitoring Cost	60000	60000	60000	60000	60000
5	System & Software licensing	300000	-	-	-	-
6	Certified Pilots & operators	70000	70000	70000	70000	70000
Note: All figures in Indian Rupees. 1 USD = 81.84 Indian Rupees (Source: www.xe.com on date 15/4/2023 at 9:40 am)						

References

Nguyen, L. Q., Dang, M. T., Bui, L. K., Ngoc, Q. B., & Tran, T. X. (2023). Application of unmanned aerial vehicles for surveying and mapping in mines: A review doi:10.1007/978-3-031-20463-0_1

Shahmoradi, J., Talebi, E., Roghanchi, P., & Hassanalian, M. (2020). A comprehensive review of applications of drone technology in the mining industry. Drones, 4(3), 1-25. doi:10.3390/drones4030034

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. *MIS Quarterly*, 425–478.

Lee, S., & Choi, Y. (2016). Reviews of unmanned aerial vehicle (drone) technology trends and its applications in the mining industry. Geosystem Engineering, 19(4), 197-204. doi:10.1080/12269328.2016.1162115

Peppard, J., Ward, J., & Daniel, E. (2008). Managing the realization of business benefits from IT investments. MIS Quarterly Executive, 6(1), 3.

Rogers Everett, M. (1995). Diffusion of innovations. New York, 12.

Ajayi, O. G., & Ajulo, J. (2021). Investigating the Applicability of Unmanned Aerial Vehicles (UAV) Photogrammetry for the Estimation of the Volume of Stockpiles. *Quaestiones Geographicae*, *40*(1), 25–38.

Battulwar, R., Valencia, J., Winkelmaier, G., Parvin, B., & Sattarvand, J. (2019). High-resolution modeling of open-pit slopes using UAV and photogrammetry. In *Mining Goes Digital* (pp. 661–670). CRC Press.

Esposito, G., Mastrorocco, G., Salvini, R., Oliveti, M., & Starita, P. (2017). Application of UAV photogrammetry for the multi-temporal estimation of surface extent and volumetric excavation in the Sa Pigada Bianca open-pit mine, Sardinia, Italy. *Environmental Earth Sciences*, *76*(3), 103.

Lee, S., & Choi, Y. (2016). Reviews of unmanned aerial vehicle (drone) technology trends and its applications in the mining industry. *Geosystem Engineering*, *19*(4), 197–204.

Majeed, R., Abdullah, N. A., Mushtaq, M. F., & Kazmi, R. (2021). Drone security: Issues and challenges. *Parameters*, *2*, 5GHz.

Matsimbe, J., Mdolo, W., Kapachika, C., Musonda, I., & Dinka, M. O. (2022). Comparative utilization of drone technology vs. traditional methods in open pit stockpile volumetric computation: A case of njuli quarry, Malawi. *Frontiers in Built Environment*, *8*.

Nguyen, L. Q., Dang, M. T., Bui, L. K., Ngoc, Q. B., & Tran, T. X. (2023). Application of Unmanned Aerial Vehicles for Surveying and Mapping in Mines: A Review. *Advances in Geospatial Technology in Mining and Earth Sciences: Selected Papers of the 2nd International Conference on Geo-Spatial Technologies and Earth Resources 2022*, 1–22.

Raeva, P. L., Filipova, S. L., & Filipov, D. G. (2016). Volume computation of a stockpile–a study case comparing GPS and UAV measurements in an open pit quarry. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, *41*, 999.

Siqueira, H. L., Marcato, J., Matsubara, E. T., Eltner, A., Colares, R. A., & Santos, F. M. (2019). The impact of ground control point quantity on area and volume measurements with UAV SFM photogrammetry applied in open pit mines. *IGARSS 2019-2019 IEEE International Geoscience and Remote Sensing Symposium*, 9093–9096.

Stalin, J. L., & Kumar, K. S. (2021). Application of UAV Remote Sensing Technology for Sand Quarry Volumetric Audit and Environmental Impact Assessment: A Case Study Done in Neyvasal Sand Quarry, Cuddalore District, Tamil Nadu—India. *Journal of the Indian Society of Remote Sensing*, *49*, 179–191.

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