WHITE PAPER

A Comparison of Mine Topographic Surveying Technologies

Satellite vs. Drone vs. LiDAR

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Weighing the Pros and Cons of Various Data Sources

This in-depth guide provides a detailed comparison of various mine topographic surveying—including optical satellites, drones, and LiDAR. This information helps mining professionals weigh the strengths and limitations of each tool against their operation's specific objectives at each stage of the project lifecycle.

Mine sites are dynamic environments where conditions change rapidly. Mining professionals require the latest information to ensure that their operations adhere to geotechnical standards and other relevant guidelines and protocols. This ongoing monitoring requires accurate, timely data to make critical decisions. Ensuring safety, compliance, and efficient management of mining operations demands robust topographic surveying technologies.

As industry advances and complexities have outpaced the traditional methods of manual ground surveys, new remote sensing technologies have emerged to streamline the data collection process. Each topographic surveying technology provides certain advantages and limitations, depending on the dynamic factors that change from one site to the next. By understanding these pros and cons—and how to balance them holistically—operators can choose the best tools for monitoring their sites to make informed decisions that drive their operations toward profit.

High-Resolution Optical Satellites

Data from high-resolution optical satellites has been commercially available since the early 2000s. By collecting two images of the same area from different angles, captured seconds to minutes apart, satellite data can be processed to derive three-dimensional topography.

Strengths

One of the key advantages optical satellites offer is their wide coverage range, which can survey hundreds of km² in a single, instantaneous snapshot. Because the topography is derived from a single data acquisition, satellites provide extremely consistent data across the entire coverage area, eliminating the challenges of correcting data for offset errors between multiple surveys.

As its name implies, high-resolution optical satellite data offers good resolution and both relative and absolute accuracy. When paired with previous bare ground surveys or ground control points, satellite data can achieve absolute vertical accuracies better than 15 centimeters. Note: drone data is not a good ground control for satellites due to the offsets previously discussed.

Another operational advantage of optical satellites is that they do not require site access, which can be highly beneficial when surveying remote, hard-to-access areas or dangerous conditions, such as politically unstable areas or war zones, that could pose safety concerns for ground surveyors or drone operators. Unlike crewed airborne LiDAR, satellites do not require flight permits or aircraft coordination to deploy.

In addition to fresh data collection for up-to-date surveys, a continuous archive of commercially available satellite data dating back to the 1960s can be used to generate historical site topography. Using this archived satellite imagery, operators can fill potential data gaps left by changes of ownership, personnel, and regulations to better understand site operations over time and plan for improved safety and efficiency moving forward.

Limitations

Although satellite imagery can cover much larger surface areas than other remote surveying technologies in a single shot, the accuracy is slightly lower. Additionally, satellite imagery can be affected by cloud cover and atmospheric conditions, which can limit collection windows. Competition with other users tasking the satellites to capture images in the same area can also hinder collection frequency.

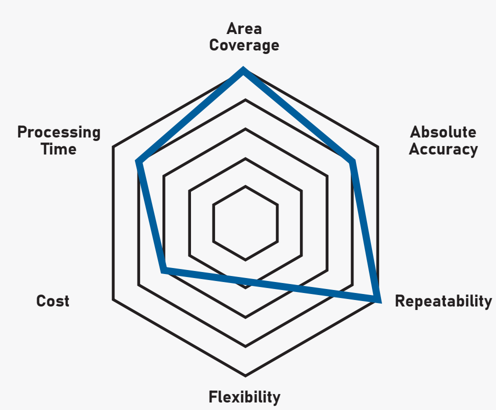
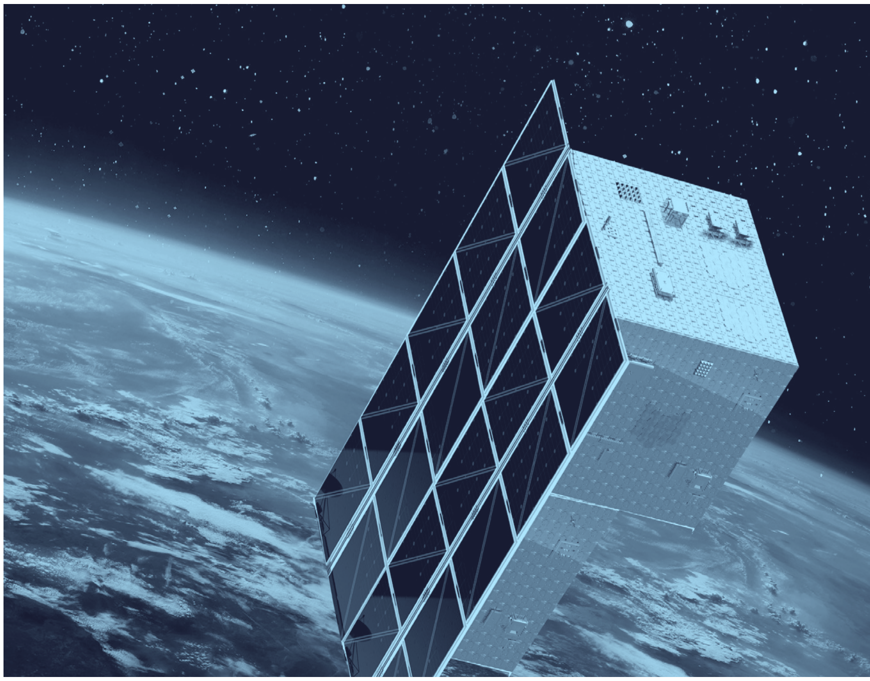


Figure:
Strengths and Limitations of High-Resolution Optical Satellites



Rapid-Revisit Optical Satellites

Rapid-revisit optical satellite constellations are a relatively new development in technology for generating topography compared to high-resolution optical satellites. These large constellations of smaller satellites can collect data more frequently than high-resolution satellites, offering up to weekly topography updates to monitor limited areas such as a tailings storage facility or stockpiles.

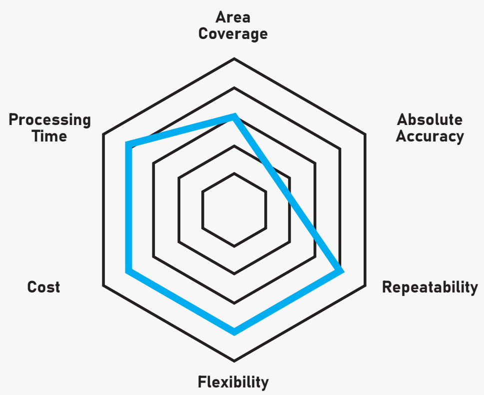


Figure:
Strengths and Limitations of Rapid-Revisit Optical Satellites

Strengths

As their name suggests, the main advantage of these satellites is the increased data collection frequency compared to larger, high-resolution optical satellite missions. Rapid-revisit optical satellites can survey larger areas than a single drone pickup, but smaller than high-resolution optical satellites or crewed airborne LiDAR.

Limitations

The pixel resolution and absolute accuracy from rapid-revisit optical satellites are currently lower than the levels offered by other tools, but the sensor technology is rapidly improving.

Drones

Drones (aka UAVs) have advanced greatly in the past few years, gaining popularity in the mining industry as companies invest in drone technology to quickly collect detailed, localized data to assist with tailings management, stockpile management, and other targeted topography.

Strengths

The greatest advantage drones bring to a mine site is their flexible, on-demand deployment, allowing for rapid data collection. When deployed as part of an in-house program, drones can be an extremely cost-effective tool for capturing topography details. Another advantage is that because drones fly at lower elevations than traditional crewed aircraft, they can avoid certain atmospheric conditions that hinder optical satellites from capturing clear data even in cloud cover. This lower flight altitude can lead to higher pixel resolution with vertical accuracy down to the centimeter level.

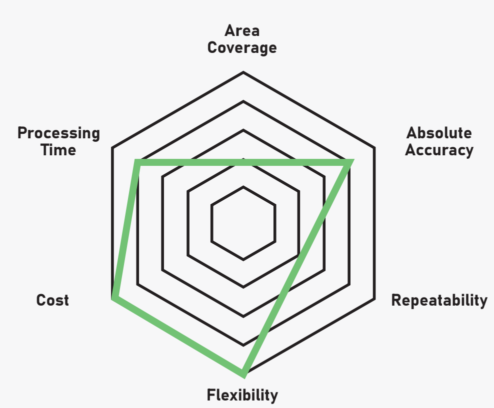


Figure: Strengths and Limitations of Drones

Limitations

Drones come with several constraints compared to other remote sensing technologies. First, limited battery life curbs the coverage area that drones can inspect in a single flight, leading to offsets between multiple data collections over a larger area. Drones are best used for detailed, localized surveys, rather than large-scale inspections. Weather conditions, such as high winds, rain, fog, and extreme temperatures can affect flight stability and data quality, constricting the operational window for drone surveys.

Although drone deployment is generally fast and flexible, data processing is another consideration. The surveys derived from drone data are digital surface models (DSM), which include vegetation and buildings. Post-processing is required to scrub these features to produce an accurate bare ground surface. Another limitation is competition between different groups at the mine sites.

LiDAR

The first light detection and ranging (LiDAR) system was introduced in 1961 to track satellites for NASA (SatSense, 2021, para. 2). Since then, LiDAR has become a standard data collection system to measure elevation on mining sites, using sensors attached to piloted aircraft that emit laser pulses to collect incredibly accurate data about surface terrain.

Strengths

Crewed airborne LiDAR has become the benchmark for mine site surveys with high absolute accuracy. With vertical accuracies as low as 5 centimeters with ground control and the ability to capture an entire site in a single flight, LiDAR can be a valuable tool for creating a detailed baseline survey that can be used to match other subsequent data sources.

Another key advantage is LiDAR's ability to penetrate vegetation. This usually results in a bare earth or ground surface, Digital Terrain Model (DTM), or digital elevation model (DEM), which gives operators a precise survey of mine site topography.

Limitations

LiDAR's highly accurate advantages can be a double-edged sword. Since these systems collect large data sets with very high data density, LiDAR surveys can be long to process and difficult to manipulate, which can result in additional costs.

Plus, the need to dispatch crewed aircraft to conduct a LiDAR survey can present challenges for remote sites, making this technology a relatively complex, high-cost option for data collection. Although it can penetrate vegetation, rain can be problematic for LiDAR sensors as water droplets reflect and absorb the emitted laser beam.

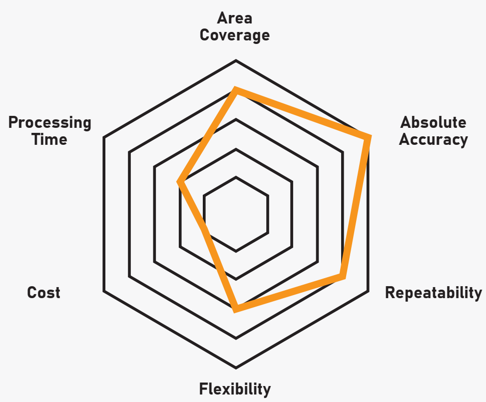


Figure: Strengths and Limitations of crewed Airborne LiDAR

SIDEBAR:

Defining Resolution and Accuracy

Spatial Resolution: Ground sampling distance (GSD) indicates image detail. Smaller GSD means higher resolution and more detail (e.g., 20 cm resolution shows more than 30 cm). Satellite imagery resolution is often categorized as coarse/low, medium, or fine/high.

Elevation Grid Resolution: This parameter denotes the spacing between individual data points within a digital elevation model (DEM). A higher resolution grid has a smaller distance between these points, facilitating a more intricate and precise representation of the terrain. This enhanced level of detail is essential for applications demanding accurate topographic measurements. However, it is important to acknowledge that higher resolution grids also entail larger file sizes and increased processing requirements.

Relative Accuracy: Relative accuracy refers to the internal quality of elevation data without using surveyed ground control points, meaning that the individual data points are accurate within a particular data set. The data collection system's calibration parameters and data processing techniques can affect relative accuracy.

Absolute Accuracy: Absolute accuracy, also known as global accuracy, refers to both horizontal and vertical accuracy of a data set, assessed by comparing survey data to ground-surveyed checkpoints.

When comparing the accuracy and resolution of high-resolution optical satellites, drones, and LiDAR, each technology offers distinct advantages. Drones typically achieve great pixel resolution and relative accuracy, often down to the centimeter level, although their absolute accuracy can be categorized as good to great, depending on quality control practices.

On the other hand, LiDAR excels in relative and absolute accuracy, providing finely detailed measurements with absolute accuracy in a range of 5 to 15 centimeters, making it a strong choice for precise elevation data.

In contrast, high-resolution optical satellites deliver good resolution and accuracy, typically 20 centimeters or lower. While drones can be affected by quality control issues, both LiDAR and optical satellites maintain consistent performance in their respective strengths.

SIDEBAR:

What About InSAR?

Since this technology is not used for topography surveys, InSAR is not included in our detailed analysis.

SAR:
A remote sensing technique that uses radar pulses to create high-resolution images of the Earth's surface.

Interferogram:
Shows the changes in phase between two images, revealing surface deformation or elevation changes.

Phase Analysis:
By comparing the phases of two or more images, InSAR can detect subtle changes, which can indicate surface deformation.

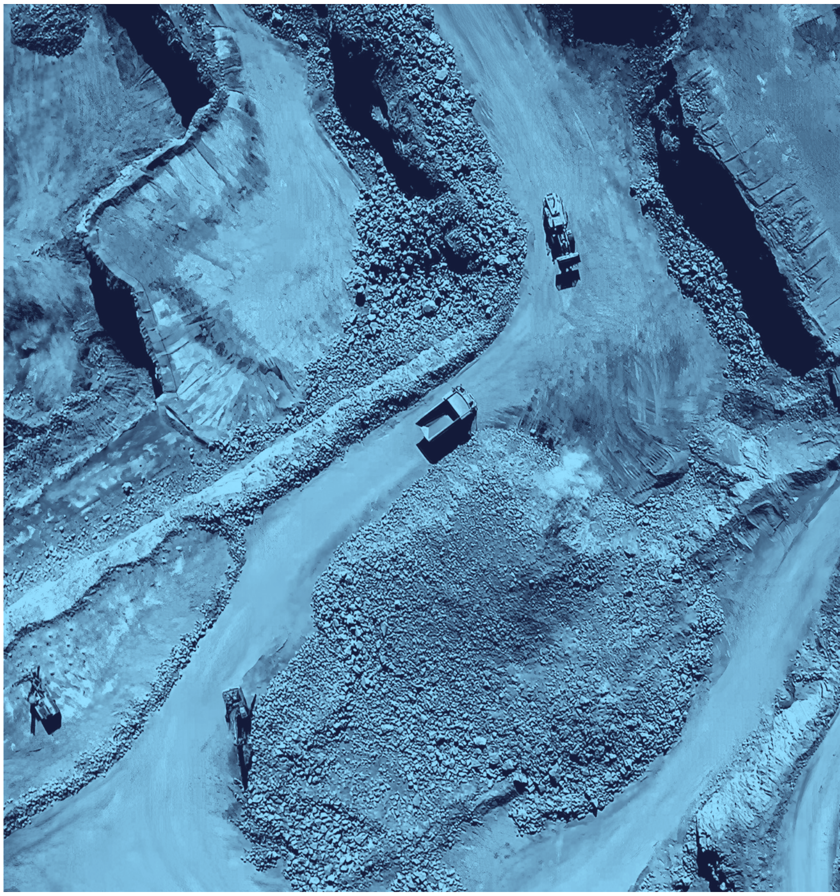
Data Processing:
The interferogram data is processed to extract meaningful information about surface deformation, such as the magnitude and direction of displacement.

Temporal Deformation Monitoring:
InSAR is not directly comparable to the other technologies discussed here, as it was designed for a very different purpose, specifically to detect millimeter-to-centimeter-level ground movement and surface changes across limited coverage areas up to 100 km².

Ground Movement vs. Topographic Surveying:
InSAR's use is primarily for applications such as tailings dam deformation tracking, subsidence and ground movement analysis, and landslide risk assessment.

Interferometric synthetic aperture radar (InSAR) was first explored in the 1980s but did not come into practical use until the 1990s (SatSense, 2021, para. 2).

Unlike the other technologies described in this document, which are used to derive topographic surveys, InSAR fills a specific niche in tracking surface deformation and elevation measurement.



Comparative Analysis of Mine Surveying Technologies

Each mine site presents unique challenges that affect the overall design and implementation of an effective survey program, which can be influenced by a range of factors such as the site's size, ease of access, and operating requirements.

Some of the main factors that mining operators must consider as they weigh the advantages and limitations of various remote surveying technologies include:

- **Coverage Area:** How large of a geographic area can this tool survey in a single pickup?
- **Accuracy:** What is the absolute vertical accuracy of the survey? (See SIDEBAR: Defining Resolution and Accuracy)
- **Repeatability:** How repeatable are the results from one survey to the next?
- **Flexibility:** How quickly can a survey be coordinated and data be captured?
- **Cost:** What expenses are involved in implementing this surveying technology?
- **Processing Time:** How quickly can the raw data be processed into a usable survey?
- **Collection Frequency:** How often can (or should) data collection be repeated?
- **Technology Lifespan:** How long can a company rely on this tool once implemented?

This analysis will compare how optical satellites, drones, and crewed airborne LiDAR perform in each of these criteria to help mine operators analyze the strengths and limitations of each technology. These results will highlight how to best harness advantages and offset limitations by leveraging complementary tools through a holistic approach to surveying.

Coverage Area

1. **High-resolution optical satellites** offer the widest coverage area, by far, with the ability to survey hundreds of km² in a single shot, ranging up to thousands of km² and down to areas as small as 50 km². Note: through some resellers, and for specific sensors, clients may be able to order 25 km², depending on surveying needs within that area. This broad-range surveying capability allows operators to collect imagery from an entire mine site all at once, bypassing the problem of having to correct offset errors between multiple surveys.
2. **Rapid-revisit optical satellites** have a much smaller coverage area, in the tens of km², versus hundreds.
3. **LiDAR** surveys can cover large areas in a single flight, but not as vast as satellites (exact numbers vary between LiDAR systems).
4. **Drones** provide the smallest coverage area, typically covering up to 4 km² per flight. This limited coverage range is one of the most significant drawbacks of drone technology.

Accuracy

1. **LiDAR** is generally the most accurate surveying technology, with both relative and absolute accuracy ranging from 5 to 15 centimeters.
2. Depending on the ground control points used, **drones and high-resolution optical satellites** offer levels of accuracy between 10 and 15 centimeters (however, as long as drones have the proper ground and quality controls in place, they offer slightly higher accuracy). While not quite as accurate as LiDAR data, drone and satellite imaging create reliable topography surveys for mining and tailings engineering applications.
3. **Rapid-revisit optical satellites** have a lower accuracy than other technologies.

Repeatability

1. **High-resolution optical satellites** offer the best repeatability of data from one survey to the next, primarily because they capture stereo imagery from two or more angles simultaneously and collect large swaths of data in a single shot, eliminating room for error. Since subsequent data collections come from equivalent sensors and go through the same processing system, the results from multiple surveys are easily comparable.
2. **Rapid-revisit optical satellites** offer highly repeatable results, albeit over a smaller square surface area than their high-resolution cousins.
3. **LiDAR** is the next best choice in terms of repeatability, again due to the larger area being surveyed and the consistency of the data between surveys.
4. **Drones** can be problematic when repeating subsequent surveys because they cover such limited areas, requiring data to be stitched together, which can result in offset errors and information gaps. They are also more prone to human error than the other technologies, which means data can vary across different operators from one flight to the next.

Flexibility

1. **Drones**, when part of an in-house drone program, are typically the easiest surveying technology to coordinate and deploy—as long as scheduling requests can be managed efficiently between various areas and competing needs within a site. However, drones require permits and an on-site operator, which can limit access in remote or dangerous areas. While they can navigate beneath cloud cover that could obstruct other technologies, drones can be grounded by other weather conditions, such as high winds, rain, fog, and extreme temperatures.
2. **High-resolution optical satellites** require more coordination than drones, but not nearly as much as LiDAR. Satellites must contend with atmospheric conditions and competition from other entities wanting to collect data in the same areas, but once tasked, satellites can generally capture images fairly quickly. Compared to other technologies, the most flexible advantage that satellites offer is that they do not require operators or permits.
3. **Rapid-revisit optical satellites** offer even more flexibility, providing collection opportunities weekly anywhere in the world, with collection occurring quickly after tasking.
4. **Crewed airborne LiDAR** is the most difficult surveying technology to deploy, as it requires access to airports, aircraft, and permits, which can be challenging to coordinate, especially in remote regions.

Cost

1. **Drones** typically offer the lowest cost solution for topographical surveys, particularly when incorporated into a mining company's operating expenses as part of an internal program. Hiring a third-party drone operator can be more expensive.
2. **Satellites** are becoming more affordable as more constellations are deployed, making this data more accessible and cost-effective for monitoring mining operations.
3. **LiDAR** costs can vary by region, but the expenses involved in deploying the aircraft used to capture LiDAR surveys, plus the additional costs incurred processing dense data, often make this option the most cost-prohibitive.

Processing time

1. **Drones** often employ software that enables fairly quick processing of data captured during surveys, sometimes within hours. But even with the best software, data still requires post-processing to merge multiple pickups, handle any offsets, remove vegetation, buildings, and other obstructions, and achieve bare ground views.
2. **Satellites** offer bare ground surface data that is available within days after collection.
3. **LiDAR** collects very dense data sets, which can take months to process into usable topography data.

Collection frequency

1. **Drone** data can easily be collected on a weekly basis to survey targeted, localized areas of a site.
2. **Rapid-revisit optical satellites** can collect topography data monthly or weekly.
3. **High-resolution optical satellites** are typically used to survey sites monthly to quarterly. Many operators opt for monthly satellite surveys in the summer months to optimize their surveying programs when the weather is more suitable for collection.
4. **LiDAR** data is not generally collected more than once yearly due to its high costs and processing complexities. Two to five years is a more common timeframe to help manage the expense.

Technology lifespan

1. **High-resolution optical satellites** generally launch with an expected lifespan of approximately eight years. However, this is a very conservative estimate, as Maxar Technologies' WorldView-1 (launched in 2007), WorldView-2 (launched in 2009), and WorldView-3 (launched in 2014) are still operational today (ESA, 2022, para. 2, bullets 1 - 3). Satellite companies are constantly innovating, often developing new satellites before (or immediately after) the launch of the previous generation to ensure data continuity.
2. **LiDAR** lifespans depend on various factors, including the quality of their hardware components, the calibration of their sensors, and the frequency and intensity of usage. As LiDAR technologies evolve, these ongoing advancements drive the need for upgrades or replacements. Because it is mounted on an aircraft, the actual sensor is easily replaceable, so lifespan is not as critical as a satellite that cannot be fixed or a drone that is an asset of the mine site.
3. **Drone** lifespans are generally determined by their battery life and charge cycles. A drone's battery life determines how long it can stay in flight, with high-end commercial drones offering flight times of 45 to 60 minutes (ESA, 2022, para. 2, bullets 1 - 3). Specialized industrial drones leveraging advanced battery technologies can possibly double this flight time. Lithium-ion polymer (LiPo) batteries can usually only be recharged between 300 and 500 cycles before a noticeable loss in capacity.

Balancing the Strengths and Weaknesses of Surveying

As this comparative analysis shows, each surveying technology presents unique advantages, disadvantages, and inevitable trade-offs that mining professionals must balance.

- **High-resolution optical satellites** are ideal for covering larger areas. Although the data accuracy is slightly lower than other technologies, it is still more than adequate for most mining and tailings engineering applications. This makes it a valuable tool for capturing an entire mine site in a single snapshot without requiring permits or on-site operators.
- **Drones** excel at covering small areas with good resolution and high relative accuracy. However, they require multiple flights to cover larger areas, which can result in offset errors. They also require permits and on-site operators, which is unsuitable for remote or dangerous areas.
- **LiDAR** offers the best absolute accuracy and can even penetrate vegetative areas. However, these advantages come at a cost. This technology is the most expensive and complex to coordinate, and it requires the longest processing time to turn raw data into usable information.
- **Rapid-Revisit Optical Satellites** can survey larger coverage areas than drones and collect data more frequently than high-resolution optical satellites. However, the pixel resolution and absolute accuracy from rapid-revisit optical satellites are currently lower than the other technologies discussed here.

With a holistic approach to using these tools in combination, mining professionals can offset the limitations of each technology and leverage their unique advantages as part of a robust survey program. For example:

- **Satellites and LiDAR data** can provide full-scope baseline surveys that serve as quality control for targeted drone data.
- **Satellites and LiDAR data** can provide long-term monitoring (and even historical views in the case of archived satellite data). In contrast, rapid-revisit optical satellites and drones can focus on weekly changes in tailings storage facilities.

By combining these complementary technologies, operators can maximize the value of various data sets to obtain a more complete picture of their mine site topography, gaining the precision and confidence to make critical data-driven decisions that can impact the safety, efficiency, and profitability of their mining operations.

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