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DOWN DEEP IN THE MINE

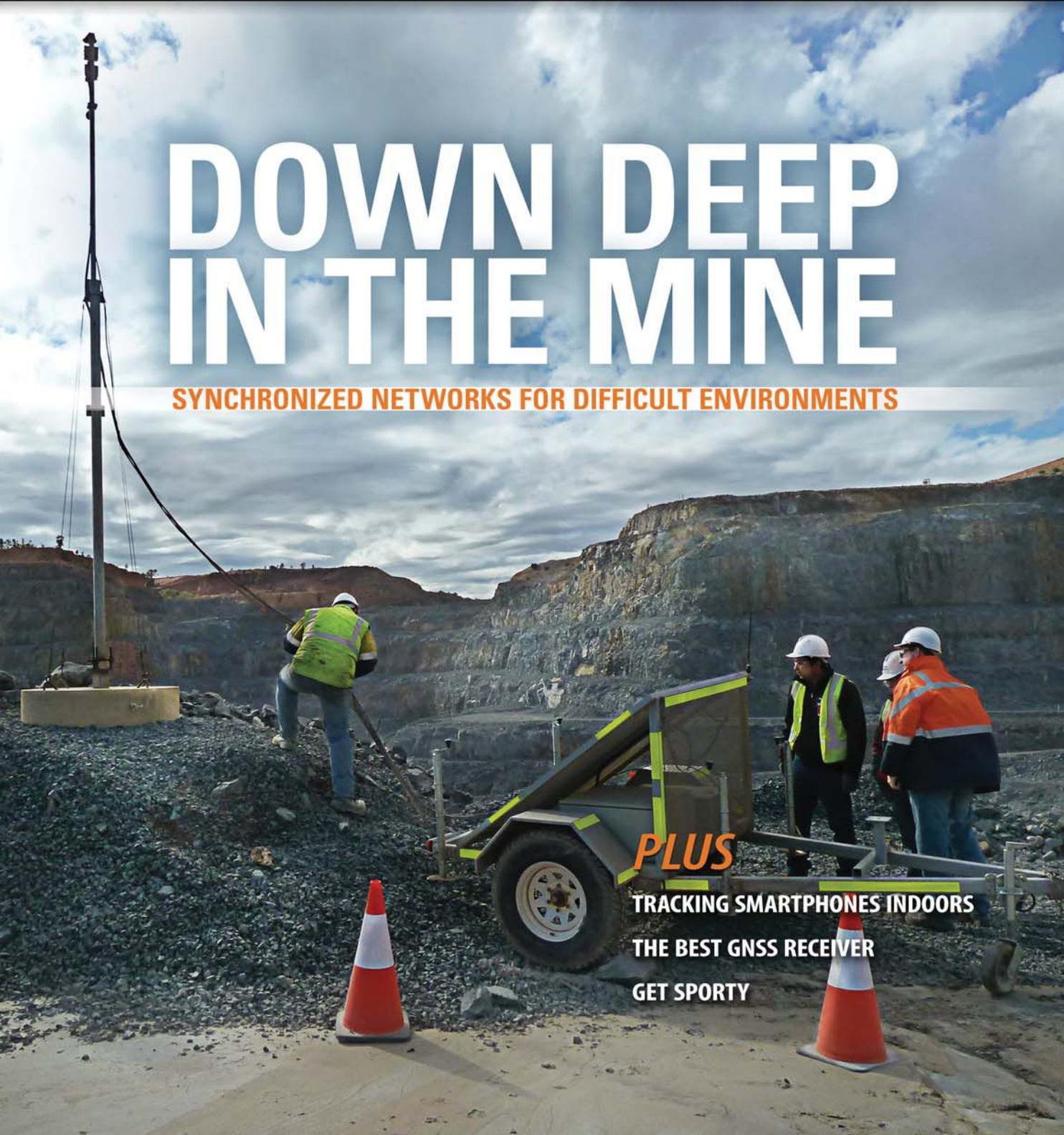
SYNCHRONIZED NETWORKS FOR DIFFICULT ENVIRONMENTS

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TRACKING SMARTPHONES INDOORS

THE BEST GNSS RECEIVER

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Synchronized Ground Networks Usher in Next-Gen GNSS

Locata Fills Satellite Availability Holes in Obstructed Environments

Chris Rizos, Nunzio Gambale, and Brendon Lilly

An integrated GNSS+Locata system installed on drills, shovels, and bulldozers — the full complement of high-precision machines on site — at Australia's Newmont Boddington Gold Mine has increased positioning accuracy and availability, as well as mine operational efficiencies, demonstrating an improvement in availability over GNSS-only of 75.3 to 98.7 percent.

Many of the new paradigms in mining have at their core the requirement for reliable, continuous centimeter-level positioning accuracy to enable increased automation of mining operations. The deployment of precision systems for navigating, controlling, and monitoring machinery such as drills, bulldozers, draglines, and shovels with real-time position information increases operational efficiency, and the automation reduces the need for workers to be exposed to hazardous conditions.

GPS singly, and GNSS collectively, despite their accuracy

and versatility, cannot satisfy the stringent requirements for many applications in mine surveying, and mine machine guidance and control. Increasingly, open-cut mines are getting deeper, reducing the sky-view angle necessary for GNSS to operate satisfactorily.

A new terrestrial high-accuracy positioning system can augment GNSS with additional terrestrial signals to enable centimeter-level accuracy, even when there are insufficient

▲ **LOCATALITE INSTALLATION** showing Jps transceiver tower.



▲ **FIGURE 1** Location of 12 LocataLites at NBG Mine.



▲ **NEWMONT BODDINGTON PIT**, 900 feet deep and going deeper all the time, creates difficulties for GNSS equipment positioning the mine's heavy machinery.

GNSS (GPS+GLONASS) satellite signals in view for reliable positioning and navigation. Locata relies on a network of synchronized ground-based transceivers that transmit positioning signals that can be tracked by suitably equipped user receivers.

In September 2012, Leica Geosystems launched the first commercial product integrating GNSS and Locata capabilities into a single high-accuracy and high-availability positioning device for open-cut mine machine automation applications: Leica Jigsaw Positioning System (Jps) – Powered by Locata. This article describes technical aspects of this technology and presents positioning results of actual mine operations.

In the near future — perhaps by 2020 — the number of GNSS and augmentation system satellites useful for high-accuracy positioning will increase to almost 150, with perhaps six times the number of broadcast signals on which carrier phase and pseudorange measurements can be made. However, the most severe limitation of GNSS performance will still remain: the accuracy of positioning deteriorates very rapidly when the user receiver loses direct view of the satellites. This typically occurs in deep open-cut mines as well as in skyscraper-dominated urban canyons.

Locata's positioning technology solution provides an option either to augment GNSS with extra

terrestrial signals, or to replace GNSS entirely. Locata relies on a network of synchronized ground-based transceivers (LocataLites) that transmit positioning signals that can be tracked by suitably equipped user receivers. These transceivers form a network (LocataNet) that can operate in combination with GNSS, or entirely independent of GNSS.

Next-Generation Positioning

Pseudolites are ground-based transmitters of GPS-like signals. Most pseudolites developed to date transmit signals at the GPS frequency bands. Both pseudorange and carrier-phase measurements can be made on the pseudolite signals. The use of pseudolites can be traced back to the early stages of GPS development in the late 1970s, when they were used to validate the GPS concept before launch of the first GPS satellites.

In 1997, Locata Corporation began developing a technology to provide an alternate local GPS signal capability that would overcome many of the limitations of pseudolite-based positioning systems by using a time-synchronized transceiver. The LocataLite transmits GPS-like positioning signals but also can receive, track, and process signals from other LocataLites. A network of LocataLites forms a LocataNet, and the first-generation system transmitted signals using the same L1 frequency as

GPS. Time-synchronized signals allow carrier-phase single-point positioning with centimeter-level accuracy for a mobile unit. In effect, the LocataNet is a new constellation of signals, with some unique features such as having no base station data requirement, requiring no wireless data link from reference station to mobile receiver, and no requirement for measurement double-differencing.

Improvements dating from 2005 use a proprietary signal transmission structure that operates in the license-free Industry Scientific and Medical (ISM) band (2.4–2.4835GHz), known globally as the Wi-Fi band. Within this ISM band, the LocataLite design allows for the transmission of two frequencies, each modulated with two spatially-diverse PRN codes. From the beginning the driver for the Locata technology was to develop a centimeter-level accuracy positioning system that could complement, or replace, conventional RTK-GNSS in environments such as open-cut mines, deep valleys, heavily forested areas, urban and even indoor locations, where obstruction of satellite-based signals occurs.

Leica Geosystems has been testing Locata in the Newmont Boddington Gold Mine (NBG) in Western Australia for several years. In 2006, NBG started installing Leica Geosystems high-precision GPS-based guidance systems for fleet management. The mine

operators determined early on that as the pit grew deeper, they would need an alternative positioning system for these guidance systems to continue working for the life of the mine. In March 2012, Leica Geosystems deployed a world-first production version of its Jigsaw Positioning system, integrating GNSS+Locata, at the NBG mine.

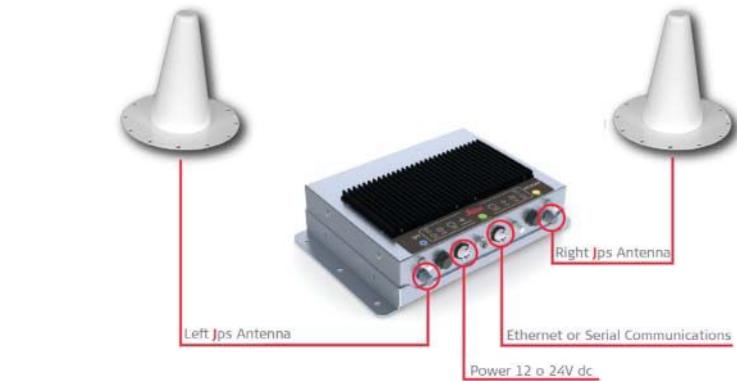
Expected to become Australia's largest gold producer, the mine consists of two pits (FIGURE 1). The North Pit at NBG is currently about 1 kilometer long, 600 meters wide, and now approaching 275 meters deep.

A single LocataNet consisting of 12 LocataLites was deployed during April and May 2012 in an initial installation designed to cover both pits in the mine. The results presented here are taken from tests in the North Pit.

Leica's version of the LocataLite is solar-powered and designed to be placed in the best locations to achieve the maximum benefit. As no special consideration for the location of a transmitter base station is required, the LocataLites can be placed in areas on the rim of the pit or just above the machines operating in the pit floor. The only set-up requirement is that they are able to see at least one other LocataLite to synchronize their transmissions to around 1 nanosecond or better throughout the mine.

Each Jps transmit tower has four small patch antennas mounted in an array. The uppermost is a GNSS antenna used to self-survey the top of the tower, and hence derive the positions of the other antennas below it on the tower. The Locata transmit 1 antenna is mounted directly under the GNSS antenna. The Locata receive antenna is directly under that, and the Locata transmit 2 antenna is around two meters lower down on the tower.

All the antennas are separated by a known distance, and the LocataLite transmit antennas can be tilted down into the pit to maximize the signal broadcast into the area. Each LocataLite transmits four independent



▲ FIGURE 3 Jps receiver with integrated GNSS and Locata receivers and two receiver antennas.

positioning signals, two signals from each transmit antenna. These signals provide a level of redundancy and greatly assist in the mitigation of multipath problems in the pit, thereby contributing to the robustness and reliability of the positioning solution.

Jps receivers were first installed on two production drill rigs in April 2012. Installation on drills was the highest priority because they are the machines at NBG that operate closest to pit walls and other obstructions, and therefore stood to benefit most from having more reliable positioning. Each Jps receiver incorporates two GNSS and two Locata receivers (FIGURE 3). One GNSS and Locata receiver pair is connected to a co-located antenna on one side of the machine and the other GNSS and Locata receiver pair is connected to the other co-located antenna. The GNSS receivers obtain their RTK corrections from an RTK base station. The Locata receivers do not require any corrections. The system uses the NMEA outputs from both pairs of receivers to determine the position and heading of the drill rig for navigation purposes.

The goal of the Jps receiver is to improve the availability of high-accuracy RTK positions with fixed carrier phase integer ambiguities. The results presented here are therefore divided into three sections:

- Improvements in availability over a two-month period for all the data in the North Pit.

- Improvements in availability for an area in the pit where the GNSS savings are expressed in dollar terms.
- Accuracy results achieved and maintained in this GNSS-degraded area.

The performance results shown here are real-world samples of the system operating on drills at NBG. However, it will be appreciated that GNSS satellites are in constant motion, so GNSS-only position availability in different parts of the pit changes by the hour. The results therefore only apply to those drills in those positions in the pit at that time. Another drill a little distance away in the same pit could experience far better or far worse GNSS availability at exactly the same time.

Overall Availability

FIGURE 4 shows the performance difference between using GNSS-only (left) and Jps GNSS+Locata (right). The data for these plots was recorded for the two drills that contained the Jps receiver in the North Pit during the months of April and May 2012. A green dot represents the time the receiver had a RTK fixed solution, and a red dot represents all other lower-quality position solutions — essentially when the receiver was unable to achieve the required RTK accuracy because of insufficient GNSS signals or geometry.

Although the availability of GNSS-only RTK fixed position solutions was

reasonably good over this entire area, being at the 92.3 percent level at that time, the Jps nevertheless provided a measurable improvement of 6.5 percent to availability, bringing it up to 98.8 percent. Considering that during those two months, the two drills spent a total of 72.24 operational days in the North Pit, this improvement equates to nearly 4.7 days or 112.7 hours of additional guidance availability.

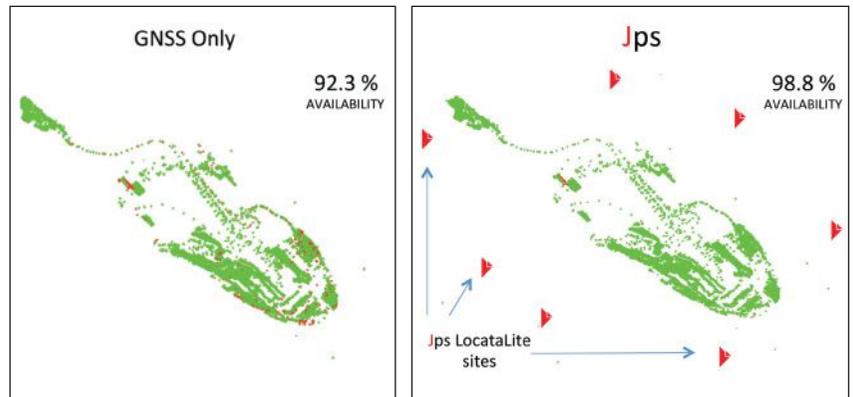
FIGURE 5 highlights the low positional quality for the GNSS-only solutions and how Jps significantly improved the availability in areas of limited GNSS satellite visibility.

Availability in Poor GNSS Visibility

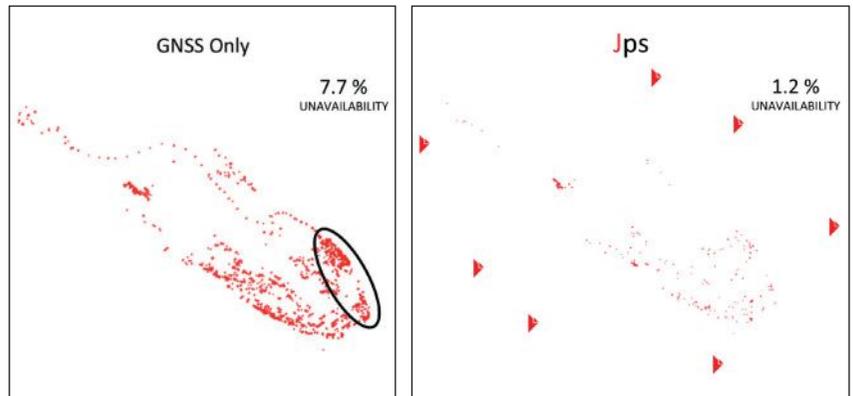
The ellipse in Figure 5 highlights a particular location in the North Pit where GNSS positioning consistently struggles due to the presence of the northern wall and to a lesser extent from the eastern wall. The integration of GNSS and Locata signals improved availability as shown in **FIGURE 6**, which in this case increased by 23.4 percent.

As the machine downtime due to not having a RTK position costs the mine approximately U.S. \$1000 per hour for each drill, the improvement in availability of 112.7 hours for just the two drills shown in Figure 5 over the two months equates to a savings of \$112,700 in operational costs. This productivity increase is significant, considering that the GNSS-only availability in this case still seems relatively good at 92.3 percent. If the GNSS availability for those two months was more like 75 percent — as was the case shown in Figure 6 for the two days in May — then the cost savings become far greater, approaching nearly \$400,000, for just two drills over two months. Even a small increase in productivity brings a significant financial benefit (\$11,000 per hour) when all 11 drill rigs running in the mine are affected by loss of GNSS positioning availability, yet continue to operate with Jps.

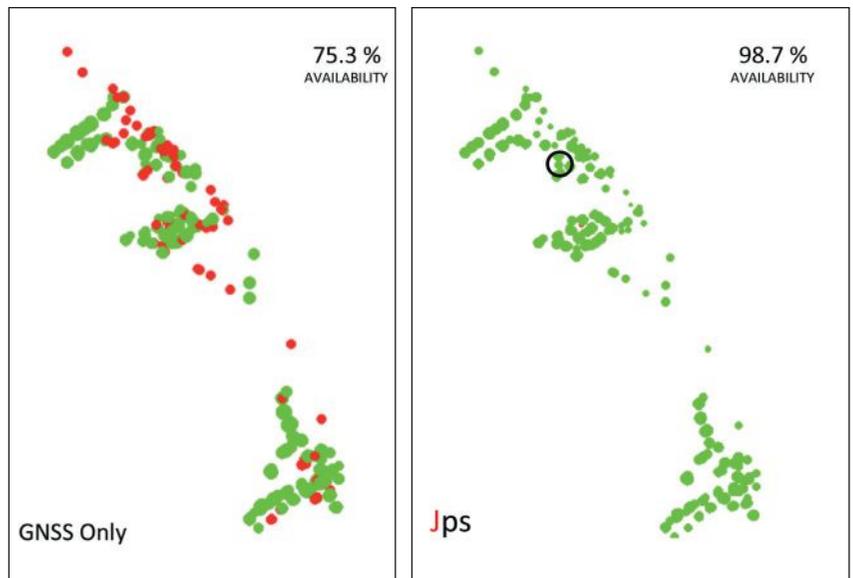
Today all 11 drills in the pits have



▲ FIGURE 4 Plots of availability and position quality in the North Pit at NBG for April and May 2012 for GNSS (left) and Jps (right). Green = RTK (fixed) solution, Red = all lesser quality solutions.



▲ FIGURE 5 Plots showing non-RTK quality positions, demonstrating that Jps can help reduce lesser-quality RTK solutions. (Performance in the circled area is highlighted in more detail in Figure 6.)



▲ FIGURE 6 Zoomed-in area where GNSS performance was poor between May 2 and May 4, 2012. The circled area shows where the accuracy tests were performed.

	GNSS-only	Jps	Difference
Latitude Average	-32.743013982°	-32.743014021°	0.004 m
Longitude Average	116.345888196°	116.345888076°	0.011 m
Height Average	133.745 m	133.772 m	0.027 m
Horizontal RMS	0.021 m	0.010 m	
Vertical RMS	0.079 m	0.015 m	

▲ **TABLE 1** Comparison of relative accuracy and RMS between the GNSS-only and GNSS+Locata solutions.

been fitted with the Jps GNSS+Locata Receivers. As a point of reference to emphasize the level of operational savings: if the Jps had been fitted to all 11 drills during the April and May 2012 period shown in the above results, the cost savings at that time would have been on the order of \$1,000,000. It is clear that the savings in production costs that can be gained from improving the availability to the fleet guidance system has a significant impact on the return-on-investment, potentially covering the installation costs within months of deployment. It should also be emphasized that as the pits get deeper, GNSS availability will only degrade further, and the evident production and dollar benefits of the integrated GNSS+Locata system become even larger.

Relative Accuracy

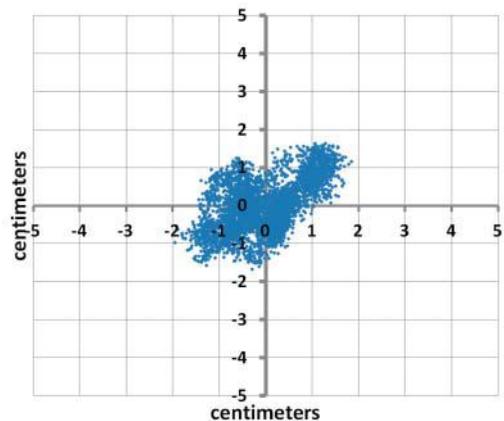
The above levels of improvement in availability are of no benefit if the position accuracy is not maintained within acceptable limits. In order to compare the relative accuracy between the two systems, a dataset was taken from the same data above (circle in Figure 6) when the machine was stationary.

The average position difference between the GNSS-only and Jps receivers for the hour-long dataset was 1.2 centimeters horizontally and 2.7 cm in the vertical component (TABLE 1). The spread of the position solutions for the two receivers were comparable in the horizontal, with Jps providing a slightly better horizontal RMS value due to the extra Locata signals being tracked and the stronger overall geometry. Additionally, Jps showed a better RMS in the vertical compared to GNSS-only.

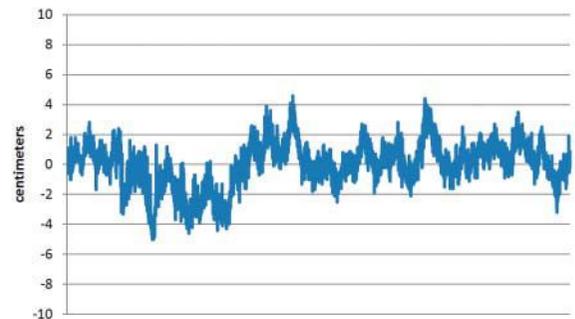
FIGURE 7A shows the spread of horizontal positions for the Jps receiver, where 0,0 is the mean horizontal position during this time. Note that all the positions are grouped within +/-2 cm of the mean without any outliers. FIGURE 7B shows the corresponding spread in the vertical positions. These are well within the acceptable accuracy limits required by the machine guidance systems used at the mine.

Concluding Remarks

Based on the experiences at Newmont Boddington Gold,



▲ **FIGURE 7A** Scatter plot of the positions from the Jps receiver over a period of over an hour.



▲ **FIGURE 7B** Vertical error for same sample set as Figure 7a.

use of Jps has improved the operational availability of open-pit drilling machines by at least 6.5 percent by reducing the outages in 3D positioning caused by poor GNSS satellite visibility commonly associated with deep pits. When Jps is subjected to much harsher conditions closer to high walls, the Jps continues to perform and the improvement in availability compared to GNSS-only is more significant while still maintaining RTK-GNSS levels of accuracy. The additional availability achieved translates directly into cost savings in production for the mine.

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Brisbane and Switzerland, other Hexagon companies such as Antcom Corporation and NovAtel, the Locata team in Canberra and the United States, and the people at Newmont Boddington Gold that have gone out of their way to make this a success.

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Moving the Game Forward: Transceivers Aboard Light Vehicles

John Carr and James Earl

Perspectives from a senior technical specialist and a production engineer at Newmont Boddington Gold Mine.

Newmont Fleet Management Services now continually monitors and plots the performance of JPS Locata alongside traditional GNSS in an effort to fine-tune the installed infrastructure. Learning to sculpt the perfect network continues as we move our JPS LocataLite transmitters to accommodate an ever-changing and

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expanding pit design.

Large twelve-meter benches and an aggressive mining plan have seen both North Pit and South Pit at NBG rapidly increase in depth, bringing the problems associated with GPS coverage in a deep-pit environment.

As mine sites develop and evolve, for the first time ever,

For the first time, we have the ability to dictate and control our own positioning coverage and guarantee that we can sustain high-precision navigation wherever we need it.

we have the ability to dictate and control which areas we direct our own positioning coverage, and guarantee we can sustain accurate high-precision navigation wherever we need it. This level of control has just never been available before, and is literally impossible with satellite-based positioning signals. With GPS you just get what you get.

We are rapidly re-evaluating what may now be possible. We believe we are only at the very beginnings of where we can go with the LocataNet in the mining environment.

Staying One Step Ahead. Shape changes from week to week keep operations continuously relocating around the mine benches; this can, in some instances, make optimal positioning of the Jps LocataNet challenging. In the early stages of the project, we relied on producing computer-generated radio-coverage heat-map models of the pit to determine optimum positions for the individual LocataLite transmitters on the pit rim, and this is still a valid path if given the time.

However, with more Jps rovers becoming available, we now tend to make highly accurate predictions about network configuration on the fly. We can now install spare rovers as portable units in light vehicles (LVs) used by technicians onsite. This roaming functionality allows use of the Jps web browser in the rover to instantly validate, in the pit, any changes that may be required for the network before drilling and digging equipment is moved into place. Thus we can monitor real-world signal conditions in specific areas and adjust LocataLite positions to optimize positioning availability for machines that will soon arrive.

The typical network monitoring scenario nowadays is to quickly move a JPS-enabled LV onto a bench or area yet to be drilled or excavated, and review the signals from the individual LocataLite transmitters in real time. Technicians then make any necessary placement changes to the network in advance of any mining equipment arriving. Our ability to now ensure maximum possible positioning and navigation coverage at all times was undreamt of even 12 months ago.

Dual Rover. A modified HP Leica Drill JS System utilizing a Dual Jps Locata Rover has been installed into the drilling supervisors' LV wagon. The drilling superintendent and

supervisors had been exploring ways of moving towards a paperless system that could not only check the drill pattern itself, but also the areas being mined around the pattern. They identified a use-case example where having accurate positional information available in a vehicle enables supervisors to quickly review the construction

and positioning of the protective windrows around the drill patterns. Access tracks and bench heights could also be checked without needing to call surveyors in to help. This degree of instantaneous clarity removes the guesswork associated with windrow

construction, designed to provide a safety barrier between trucking and drilling operations. Incorrectly placed windrows can lead to potential flow restrictions in either operation, so getting it right the first time in active areas is important.

Mark-up by Night. Drilling supervisors can now accurately measure and monitor progress across the drill patterns using Locata technology to display virtual maps of all active drilling areas. Another spin-off benefit has been the introduction of a fixed point mounted to the front vehicle bullbar, to provide emergency mark-up of patterns during the nightshift when surveyors are not available on site. This helps particularly when a localized Wi-Fi outage prevents drills from downloading the blast pattern to commence drilling operations in an area of the mine. Before Jps, use of this high-precision GPS technology in vehicle had been considered ineffective and impractical because of the unreliable GPS coverage in the bottom of both pits. Plans are now under way to install a similar system into the shovel and auxiliary supervisors' vehicles.

Forward! Recent group discussions found consensus that the best way to move forward with this technology now is continued integration into GPS, rather than stand-alone systems. Miners are generally a cautious lot: we could hedge our bets through a combined GPS+Locata solution package. Full-scale integration of Locata technology into future standard GPS products is perceived as a way companies such as NovAtel can provide the total package. We envisage a unified system available from all positioning receiver manufacturers that combines the benefits of GPS technology with the evident improvements and back-up that Locata has provided for environments where GPS is unable to function.

We have been in the enviable position of gaining a glimpse into the future, when the power of GPS-style positioning is improved to fill the GPS holes. The results we have obtained are, frankly, addictive. Having experienced this revolution first-hand, it would now be extremely painful to even contemplate going back to our previous GPS-only world.