GPS Guidance System and Reduction of Open Pit Mining Costs and Revenue Loss

Andrew P. Jarosz [1], Raleigh Finlayson [2]

[1] WA School of Mines (Curtin University), Egan Street, Kalgoorlie, WA, 6433, Australia
Tel: + 61 8 90886163, Fax: +61 8 90886151, Email: a.jarosz@curtin.edu.au

[2] St Ives Gold Mining Company, Goldfields Australia Pty Ltd, Kambalda WA, 6444, Australia
Tel: +61 8 90881059, Email: raleigh.finlayson@gfaus.com.au

ABSTRACT

Mining companies, now and in the future, are required to minimise their overall costs to remain competitive, as higher grades and easily accessible deposits are mined out. Savings are achievable by minimising lost revenues (ore loss) and mining costs. The paper examines potential benefits provided by GPS/DGPS guidance systems, installed on excavators, shovels, drill rigs, dozers/graders and dump tracks, in lowering the overall mining costs, increasing utilisation of mining deposits and maximising profit. The analyses are based on data provided by selected metalliferous open pit operations in Western Australia.

KEYWORDS: mining, surveying, gps, guidance systems, costs, optimisation

Introduction

The presented paper is based on the student's report prepared to evaluate a potential of cost savings available to one of the mines in Kambalda region (Western Goldfields, Australia) trough the assistance of GPS Guidance System installed on earth-moving equipment. These earth-moving costs can significantly influence the overall profitability of a mining operation. The analysed mine is not immune from these requirements and is required to minimise their mining costs by up to A$6/t in order to ensure that its current resources can be reclassified into reserves for future mining. One million ounces of inferred gold located in Lake Lefroy is currently hinging on mining costs to be reduced in order to be economical to mine. Compared with industry standards, the analysed mine have average to high mining costs that need to be reduced to ensure it's long life open pit mining.
The systems currently available on the market are provided by Caterpillar, Wenco and Modular. Case studies, that have been conducted on other mine sites in the Goldfields Region and involving similar GPS guidance systems, were analysed. Each analysed mine have had specific purpose for adoption of the GPS system, however, all have the same underlying objective, to minimise costs and maximise profits. The case study sites investigated in the report were Kalgoorlie Consolidated Gold Mines (KCGM), Granny Smith and Tarmoola. The total savings achievable by minimising lost revenue (ore loss) and mining costs were investigated. It was concluded that a GPS guidance system(s) installed on excavators, shovel, drill rigs dozers/graders and dump trucks (DGPS) would be beneficial and result in a short payback period (dependant on the applications and system(s) introduced).

Location of the Study

The mine (St Ives) is located approximately 80 kilometers south of Kalgoorlie and 20 kilometres south of Kambalda in the Western Australian Gold Fields, as shown in Figure 1. Gold Fields Australia acquired the St Ives and Agnew mines from WMC Resources Ltd in December 2001. These two operations comprise Gold Fields Australian Mining Division.
St Ives takes its name from the largest of many small, historic workings scattered throughout the area, that is of Ives Reward, which was discovered by prospector Pat Ives in 1919. Mining here was discontinued for many years and was resumed in 1981 by WMC.
The St Ives gold deposits are situated in the north-west trending Norseman-Wiluna Greenstone Belt and were formed in the archaean era, about 2,600 million years ago. The deposits are located on secondary structures that splay off the regionally dominant Boulder-Lefroy Fault. The secondary structures include quartz vein arrays, breccia zones, mylonites and ultra-cataclasites that are often linked to form complex anastomosing lode systems. Host rocks are mainly mafic intrusives (dolerites) and mafic extrusives (basalts), but all rock types in the region are potentially prospective. Typical alteration haloes are zoned inwards from chlorite to biotite to albite-carbonate-pyrite with gold intimately associated with sulphides.

Figure 1 Locations of St Ives and Agnew mines.

GPS in Mining

The mining industry has been a leader in expanding usage of real-time GPS. Open pit mining offers an ideal environment for application of GPS, combining open skies with pressing demands on increased productivity. Some of the reasons that GPS is so beneficial to the mining industry are:

- Worldwide coverage
- Services an unlimited number of users
- Operates in all weather conditions
- Accurate 3D positioning
- Accurate timing
- No line-of-sight restrictions
- 24-hour availability
- Dynamic positioning system
- Free servicing

GPS has numerous applications in the mining industry which can both assist increased productivity demands (increase revenue) and reduce mining cost and lost revenue.
GPS applications in the mining industry include:

- Vehicle tracking and dispatch.
  A radio link can relay the real-time position of a truck as determined by the GPS antenna mounted on the truck to the mine office. Computer software at the office can determine and assign the most efficient route for each truck in the fleet.
- Material tracking.
  The GPS system can determined what material each truck is carrying and where each load was dumped. If any discrepancies occur, the system informs the operator before the material is dumped at the incorrect location.
- Bench height control.
  The grade of mined benches can be monitored in real-time without the need for manual survey, in both horizontal and vertical directions.
- Ore control.
  The combined applications of GPS positioning and in-board display monitors enable the shovel operator to see what exactly is being mined.
- Drill guidance.
  GPS guidance can be used to position the drill exactly over the design collar position and also drill to the exact design depth.
- Shovel and loader operations.
  The combined applications of real-time GPS positioning and the mine map can assist in mining to design.
- Haul Road grading and maintenance.
  Ensure roads are made and maintained to design.
- Survey Stakeout.
  Survey crews can be reduced from the traditional two man crews to single man.
- Topographic surveys for volumes.
  GPS data collected can be combined to assist in survey volume calculations.

- Earthmoving.
  Guidance to dozer operators increases dozer efficiency.
- Elevation for rehabilitation work.
  Tolerances for rehabilitation work can be achieved with minimal cost.
- Geological mapping.
  GPS can assist in creation of geological maps, whilst minimising costs,

There are four basic levels of accuracy associated with GPS: Autonomous – 15 to 100 metres; Differential (DGPS) – 0.5 to 5 metres; Real Time Kinematic Float (RTK Float) – 20cm to 1 metre; Real Time Kinematic Fixed (RTK Fixed) – 1cm to 5cm.

The most mining GPS systems are implemented as Differential GPS (DGPS) . These systems require a reference station that acts as a base for the entire GPS network at the mine site. The corrections calculated are from the GPS coordinates compared to the known coordinates of the references station and are transmitted by the radio network to the rovers in the field. When the rovers receive the corrections from the reference station, the corrections are applied to the position determined from the rovers GPS. In turn this enables the precise position to be known, all in real-time. One reference station can support unlimited rovers. To maintain communication between the reference station and the rovers a radio network is required at all times. If radio communication is required over long distances, radio repeaters can be installed around the site to relay the data corrections between the reference station to the rovers or onto another radio repeater in the network.
Most radios used in GPS full in one of the following frequency ranges: 150 – 174 MHz (VHF); 406 – 512 MHz (UHF) and 902 – 928 MHz (spread spectrum).

The GPS guidance systems are applied to many aspects of mining operation including:

Blasthole Drilling: GPS based blasthole drill systems available today provide drill monitoring, control and guidance. They consists of the following pieces of equipment: GPS receiver, GPS antenna, radio and radio antenna, cables, power supply, operator display, on-board computer, interfaces to third party software, sensors to monitor drill and aid in material recognition.
The prime objective of GPS positioning for drilling is to navigate the drill rig over the designed collar position. If achieved with the aid of GPS it eliminates the need for manual survey staking.
In order to achieve navigation to drillholes, a design file needs to be loaded into the on-board computer. The drill rig is then navigated to each selected drillhole in sequence. The on-board display shows the position of the drill rig in relation to the drillhole as it trams into position.
Once collared over the drillhole, the GPS determines the collar elevation and in conjunction with other technology, the correct depth of each hole is determined and continuously updated on the on-board display for the operator.

Shovels, Loaders, Dozers and Graders: The process starts with the loading of the design file onto the machines on-board computer. The design file will traditionally be ore block designs, pit designs or road designs. The design information is overlaid with the machines current position, which provides the operator with all the assistance, required to mine the pit and ore block to design.
As the machine progresses into the face the topography updates. The face position updates automatically from the GPS data coordinates received for the machine. The face position assists the operator and also the mine engineers in forecasting and scheduling decisions vital to running an efficient operation. The operator knows exactly when he/she is entering into a different ore block without totally relying on stakes or tape. The operator also knows when he/she is mining above or below the design floor grade; the on-board display highlights different colours on the display to denote if the machine is above, below or on grade.

Vehicle Tracking and Dispatch: DGPS accuracy is required for position accuracy for the mines dump trucks. The DGPS positions obtained from the dump trucks are sent back to the central mine office were a computer determines and assigns its dumping location and then, where the trucks next loading destination will be. The system is interactive with all machines in the network. The GPS system on the loading machines determines the material being mined from the design ore block file and it then determines what material each truck that has been loaded by that machine is carrying. This assignment is made automatically over the radio link and is displayed in the trucks cab. Once assigned, the system also tracks the trucks to ensure that the instructions are followed and no costly mistakes are made.

GPS Surveying: The GPS surveying rover pack is designed to be more lightweight and user friendly for survey personnel using the equipment on foot and walking over uneven ground. The basic pieces of equipment required for GPS surveying are: GPS receiver, GPS antenna, radio and radio antenna, lightweight batteries for power, cables, backpack, handheld data collector.
The distinct advantage of using GPS for surveying in open pit mining is that only a single surveyor is required to operate a GPS rover, compared to the traditional two-man crew when utilising a total-station (theodolite) method of surveying.

Future Developments: In the next future we will see the further refinement in size and flexibility of GPS receivers. We will see smaller more advanced receivers combined with map display technology for lower cost as demand and technology increase. Development is currently underway to integrate computer software, therefore creating more uses for GPS information. The next generation in GPS technology in mining will see additional sensors and sources of information applied and become interactive to provide users of the systems with the maximum information they will need to optimise their operations. The most exciting development on the horizon is an automated machine or truck guidance. These advances in technology will eventually significantly increase productivity and increase safety the industry.

GPS Guidance Systems

The following GPS Guidance System are available for installation on mining sites and were analysed in the referred study.

Computer Aided Earthmoving System (CAES) by Caterpillar - Minestar

The Computer Aided Earthmoving System (CAES) provides a real-time engineering plan that allows operators to instantaneously see how much material is required to be cut or filled without the use of survey staking. This ensures that a re-handle is greatly reduced. Material identification and pit floor design control is also achievable with the CAES system. The loading operator can see exactly what material is required to be mined in relation to the machine's current position; all in real-time. In turn all this information is relayed back to the office, reducing the number of mis-directed loads and allowing the mining engineers to accurately plan and forecast the shifts production.

The CAES system provides managers, engineers and machine operators with significant benefits, including reducing survey time, less idle time and improved job quality. This results in a lower cost per ton for the movement of material.

An important function of any mining operation is safety. CAES is especially valuable in areas that are hazardous and difficult to survey. Dangerous areas near large machinery are safer when workers are not on the ground. CAES minimises the need to manually place survey stakes in hazardous areas. CAES improves accuracy, saves time, lowers the cost per ton and helps safeguard the ground crew. The system replaces the manpower and time intensive processes associated with conventional surveying, allowing surveyor to spend more time performing other planning duties, including utilising CAES*office*. The data flow diagram of overall CAES System and interaction between its components is represented in Figure 2.

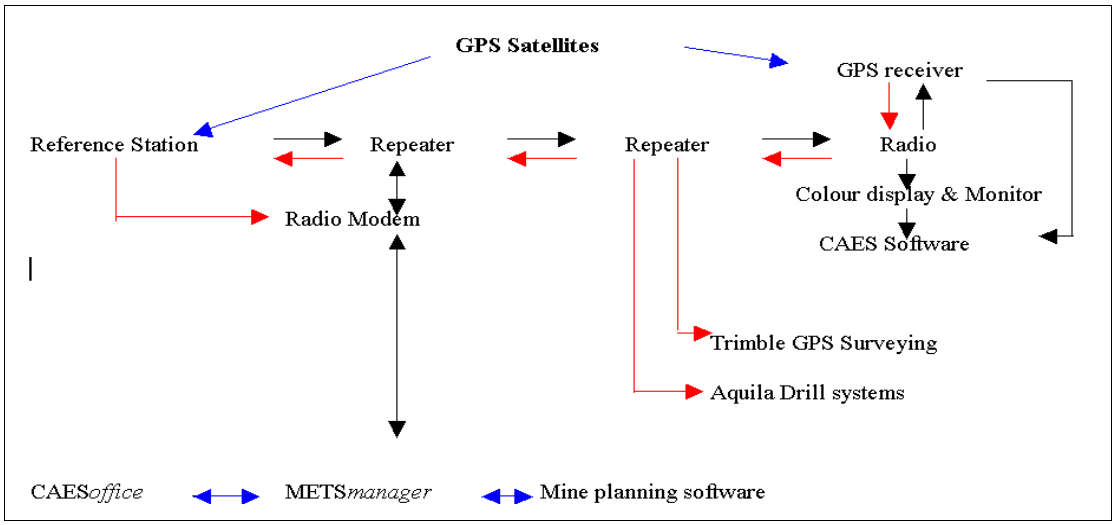

Figure 2 Diagram of CAES System.

The components that make up the dozer installed system are shown in Figure 3. These include antenna, display console, receiver and radio are shown. The data flow traverse is illustrated in Figure 4. Figures 5 and 6 are examples of the CAES*office and* METS*manager* screens available to mine management in their offices.

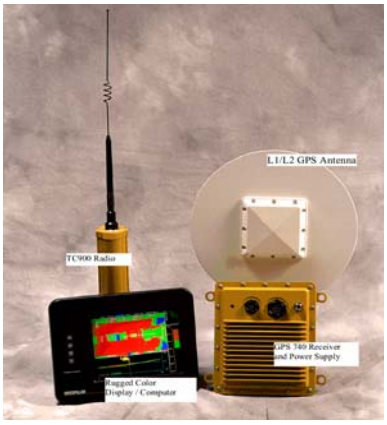

Figure 3 Components of CASE installed at dozer or drill-rig.

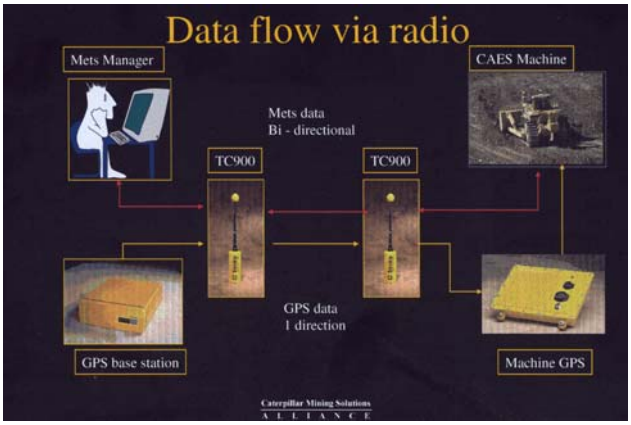

Figure 4 Diagram of data flow via radio.

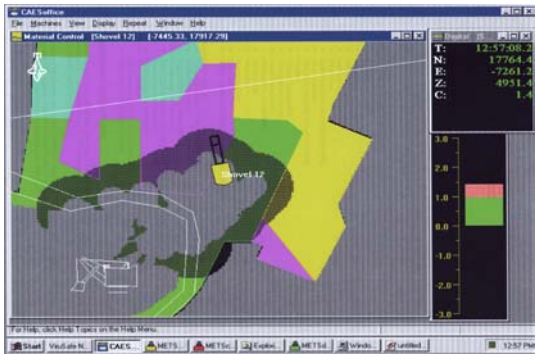

Figure 5 CAESoffice screen.

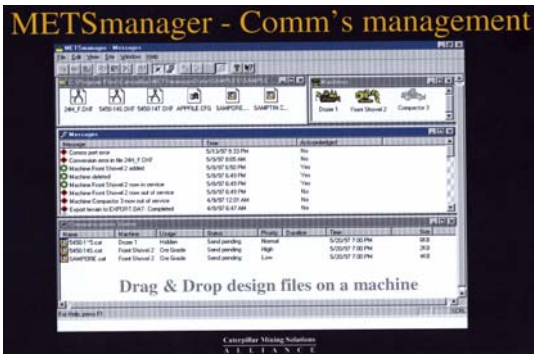

Figure 6 METSmanager screen.

Aquila Drill Management

The drill management component of the Minestar system is supplied by Aquila Mining Systems. Aquila is a pioneer in the development of advanced, computer-based monitoring, control and guidance systems for drilling activities in the mining industry. Aquila offers a rugged product specifically designed to survive in hash mining environments to maximise equipment productivity. Effective and efficient mine management and planning is enhanced with the Aquila drill management system, whilst reducing costs. Aquila systems can make drilling and blasting operations more accurate, productive and profitable with the utilisation of GPS technology in conjunction with advanced computer-based technology. The system provides the drilling operator with real time centimeter accuracy positioning to ensure that the blast holes are drilled exactly on design to maximise fragmentation and production whist reducing blasting costs.

The system offered by Caterpillar – Minestar is extensive and includes significant number of components that support different aspects of mining operation.

The list of additional components includes:

- The **Minestar Production** system that allows real-time production information to be obtainable during the shift for improved management control. A Minestar Office Database automatically logs all machine actions, which in turn allows the computation of material movement. Web-based reporting tools allow personnel to quickly produce reports than can be delivered anywhere in the world in seconds.
- The **Minestar Fleetcommander** . The system is designed to ensure mine-planning requirements are met, shovel utilisation is maximised and truck wait time is minimised all specifically aimed at lowering costs.
- The **Minestar Machine Tracking** system enables mine management to see exactly what each

machine within the fleet is loading and hauling. It is aimed at evaluating and analysing dump movement, haul road congestion and speed restrictions.

- The **Minestar Material Tracking** system is based on communication between the loading tool and truck. The material the truck is hauling can be assigned a destination based on grade and balancing of stockpile volumes. Once assigned, the truck can be tracked to its destination to ensure misrouted truck loads are detected. All information is collected in real-time; therefore this system acts as a preventative tool.
- The **Minestar Health** system is based on a Vital Information Management System (VIMS) which collects machine health information and transmits the vital information to the workshop for remote diagnostics. It allows to see what, where and when a problem is occurring from the maintenance facility.
- The **Minestar Business Enterprise** system has the ability to be linked to the Enterprise Information System. This enables mine accounting, mine planning, asset management and human resource systems to be linked to the machines in the field.

WENCO System

The Wenco system brings together GPS, radio communication, computer technology and software applications to track and improve the activity and performance of equipment in surface mines. It uses Windows CE OS for mobile computing applications. Oracle is used for data organisation and Crystal Reports is used to access the information. Wenco has become the worlds leading suppler of PC/Windows based Mine Management Systems.

Wenco offers a wide range of applications that build together a state-of-the-art computerised mine management system. The list of applications includes: high precision GPS, fleet management, dispatching, ore quality control, stockpile management, MineVision, bench elevation and bucket positioning, dozer guidance, drill navigation and sensor monitoring, TireMax, payload management, condition monitoring, alarm management, maintenance management, auto cycling, WencoDB, Wenco Inquires, reporting and SAMS – System Availability Measurement Software. The overall capabilities of WENCO System are comparable to system offered by Caterpillar – Minestar.

MODULAR System

Modular Mining System Inc., founded in 1979, is part of the Komatsu family of companies. Modular Mining Systems offers a full line of products and software to meet the needs of both open pit and underground operation management. Modular's INTELLIMINE system not only offers a DISPATCH system, but also incorporates truck assignments, GPS-based equipment positioning, equipment health monitoring, maintenance tracking, blending, Web based production reporting, and more.

Modular Mining products are designed to maximise the productivity of mining operations by tightly integrating all phases of production. This is achieved by utilising state of the art information, GPS and communication technology. Modular mining allows clients to achieve increases in productivity, averaging more than 10 percent. The system improves operational efficiency by providing integrated technologies that optimise the performance of the open pit mine assets.

The **ProVision Shovel** system is a fully integrated INTELLIMINE subsystem designed to improve ore control and bench elevation. Analysis of the shovel bucket position is achieved with high precision GPS. Swinging, digging and dumping actions are determined, which enables the system to highlight the polygon the shovel is currently mining and assign the exact dig points for each polygon mined during the shift.

For ore control, the system uses high precision GPS, along with design parameters from mine-planning packages, a wireless radio network and onboard Colour Graphics Consoles (CGC). The CGC shows the operator precisely where to dig, including a map of the material polygons at the bench face, the polygon the operator is currently digging (highlighted), the dig points in the polygon and the real time dig line (face position).

The system allows the operators to verify that they are digging and classifying the correct material, even at night and during inclement weather. It also translates to less dilution of material at polygon boundaries for more accurate load accounting and blending.

For bench elevation control, CGC uses a height gauge that informs the operator of the current floor level. This is used against the design elevation to determine cut and fill values. This virtually eliminates undercutting and/or overcutting, that usually result in costly reworking. The height gauge is also invaluable for mining ramps, inclined floors for drainage purposes and maintaining a flat pit floor.

Hazards and miscellaneous features can be displayed on the CGC, including underground workings, misfires and no dig lines. This provides valuable safety and production information, whilst reducing reworking and costs. Data related to dig locations, bucket counts and material type is continually recorded as the shovel operates. This information is then available in the systems comprehensive reporting facility that provides a wealth of information for analysis of the shovel operation. These data can be transferred to a mine-planning package to determine the dig advance and update the mine model. The mine design material, including ore boundaries, pit designs and elevation designs are loaded in the INTELLIMINE central computer, which is then accessible by the mobile mining fleet via the wireless radio network. Any changes that occur in the mine design package are automatically updated to ensure mining is conducted to design.

The **High Precision Drill** positioning system uses high precision GPS in conjunction with an onboard Graphics Console (GC) to display the design drill pattern, using predefined blast hole coordinates in the system database. Utilising this information, the drill operators zoom in on the hole locations and begin drilling without the use of site markers. Once positioned, the drill operator can change the GC display to show drill depths, penetration rates and depths to the bottom of the hole. This system provides a significant cost saving by reducing costly under- and over-drilling.

The **High Precision Dozer** system is designed to improve the productivity of both track and wheel dozers in surface mines. Information displayed to the dozer operator includes a map of the work region, the dozers real-time position, continuously updated cut and fill requirements and the position of local hazards. The high precision GPS system provides centimetre accuracy, day and night without the requirement of flags, stakes or other survey requirements. It also eliminates costly rework due to insufficient survey demarcation.

The MODULAR includes also: Vehicle Health System (VHS) and Executive Reporting System. Modular Mining Systems and its partners are developing the Autonomous Haulage System, which will eventually allow mines to operate unmanned haul trucks. Once the system has been developed and commissioned it will signal the beginning of a new era in mining history for the top performing operations seeking further technological advancement and continuous improvement.

Case Studies of GPS Guidance Systems

Case Study 1: Kalgoorlie Consolidated Gold Mines (KCGM)

Kalgoorlie Consolidated Gold Mines (KCGM) is the joint venture operation between Newmont (50%) and Barrick (50%). The gold mining operation is located on the perimeter of Kalgoorlie/Boulder, Western Australia. The Fimiston Open Pit (commonly referred to as the Super Pit) is the largest open pit gold mine in Australia. When completed it will be approximately 4 kilometres long, 1.5 kilometres wide and 650 metres deep. It is anticipated that the mine will produce more than 10 million ounces of gold over its expected life of 16 years. Currently the open pit operation moves around 85 million tonnes of material per year making it the single largest open pit operation of any commodity in Australia, on a tonnes per annum basis. Of this some 12 million tonnes of gold bearing ore are produced and milled through the Fimiston Mill. The remaining material is comprised of lower grade ore and waste. The strip ratio for the operation is between 5.5 and 6.

KCGM is the largest gold mine in Australia, accounting for approximately 10% of Australia's gold production. The operation produces up to 850,000 ounces of gold per year.

The ore is found in steeply dipping, narrow lode systems with an average grade of 2.5 g/t. The open pit is mining through historical underground workings, that pose significant mining and safety issues.

The operation decided to cease contractor mining in late 1999 and opted for an "owner miner" operation primarily to reduce costs. There were also several other reasons the operation decided to go "owner miner" including:

- Continuous improvements in all facets of the operation, like mining planning, grade control, scheduling and mining equipment maintenance and utilisation,
- Improved safety and environmental performance,

- Higher truck and shovel productivity,
- Reduced duplication of management, and
- Lower mining and supervisory costs.

KCGM maintains close attention to geology, geotechnical planning, scheduling of earthmoving equipment, drill and blast technology and safety to maintain control of costs and efficiencies.

Mining is conducted using hydraulic shovels with bucket capacities of 35 cubic metres of broken material loaded into 220 tonne capacity haul trucks (Figure 7). The mining material is classified and then delineated by grade and transported to their correct destinations as detailed below:

- High grade (>1.2g/t) to the mill,
- Medium grade (0.9 to 1.2g/t) to the medium grade stockpile,
- "Sub-grade" (0.5 to 0.9 g/t) to the sub-grade stockpile,
- Waste (<0.5g/t) to the waste dump.

Figure 7 Overall image of KCGM operations from R-ramp

The mining fleet consists of 3 Komatsu PC8000 face shovels, 1 Komatsu PC3000 face shovel, 20 Cat 793C trucks and 9 pieces of support equipment – dozers, graders and water carts. The face shovels were chosen at KCGM mainly for minimising dilution and and high productivity factors. Other advantages of employing shovels include: ability to achieve relatively consistent floors, ability to dig clean faces and ability to mine clean ore contacts and work higher bench faces, thus minimising dilution and maximising productivity.

Caterpillar's Computer Aided Earthmoving System (CAES) is utilised to assist shovel operators in identifying material types. The system locates the position of the shovel with respect to the position of the material to be mined (e.g.) high grade, waste, etc. CAES also shows the operator the shovels position in relation to hazardous underground workings, which helps reduce risks to the operators and equipment. The system uses satellite technology to provide vital real-time centimetre accuracy to the operator. Other spatial information displayed includes: misfire locations, "no dig" lines and shot numbers.

The first CAES system was commissioned in September 1999. Five (5) fully functional CAES units were provided by Caterpillar to KCGM with the purchase of their 'owner miner' fleet. At this stage three (3) units were installed on shovels and two (2) units were installed on dozers. Additional units were purchased by KCGM at their own cost.

The CAES system can also be utilised for mining to a specific design grade. Pit floors and ramps mined to design grade are vital for minimising costly re-mining and/or ore loss. Good surface haulage conditions are vital for maximising tyre life. Dump truck tyres cost approximately $26,000 each; therefore maximising tyre life is essential. Dozers use CAES for grade control. This includes roadworks; ramps, rip lines, stockpiles and waste dump rehabilitation. All waste dump work (with the exception of final limits and environmentally sensitive areas) is performed stake free and is controlled entirely by CAES and mine design software, enhancing safety and economic benefits. The major benefit of the CAES system to KCGM has been associated with enhanced safety in relation to working and operating around underground voids.

CAES*office*, the office-based software allows KCGM site designers to see results instantly while tracking progress accurately without having to leave the office, therefore improving planning and forecasting.

Geologists use CAES*office* to mark ore boundaries as accurately as possible. System helps to predict when geologist should go down to shovel to spot ore contact and give shovel operators clearer instructions on how to approach a contact, as well as, steer them away from areas by designing 'No Dig' lines in the display data. Geologists are also responsible for creating and uploading the correct material files to the shovels.

Drill and Blast Engineers use CAES*office* to gain spotheight data from CAES to create DTM's for designing blasthole depths. The drill and blast department also create display data files of all charged shots in the pit using Surpac.

Mine Planning Engineers use CAES*office* for the Development of dumps in line with long-term strategy and monthly schedules by designing perimeters within which the dozer operators can work, hence controlling the dump development. This is redesigned each month and uploaded to the dozers by the engineers. Likewise, the mine planning engineers maintain a single file containing all current in-pit ramps. Pit and dump progress is also checked in CAES to assist in the development of schedules and plans.

Production Engineers and Foremen use CAES*office* as a type of GIS to assist with sharing of information at shift change and to plan digging and access in hazardous areas. CAES lets foremen design and construct temporary ramps without engineering or survey intervention.

Bucket positions are estimated by the CAES system on shovels based on the reach of the bucket. Crest positions are determined by CAES from the angle of repose of blasted rill material and bench heights. KCGM has found accuracy of the bucket positioning to be of +/- 2m.

Overall the CAES GPS guidance system has been successful at KCGM since its implementation in September 1999; it has proven to be robust and entirely suitable for mining applications.

WENCO System. Before implementation of CAES, the mining contractor (Roche Mining) opted for the 'Wenco' dispatch system primarily for costs benefit reasons. The system has proved to be successful since its implementation and is still utilised by KCGM today. Currently the Wenco dispatch system is installed on all 20 (Cat 793) dump trucks, all 4 Komatsu shovels and all the contractor auxiliary equipment.

Case Study 2: Granny Smith

The Granny Smith mine is owned through a joint venture between Placer Dome Asia Pacific Ltd (60%) and Aurion Gold Ltd. (formerly Delta Gold Limited) (40%). Placer (Granny Smith) Pty Ltd is the manager and is a wholly owned subsidiary of Placer Dome Asia Pacific Ltd. Production is subject to a 2.5% GSR royalty, payable to the State. Granny Smith open pit gold mine started production in February 1990. Located near Laverton, in Western Australia, the mine currently employs approximately 450 people, including 190 contractors. The original Granny Smith deposit, which consisted of three discontinuous zones (Granny, Goanna and Windich), was mined out in 1995. Five satellite deposits have also been depleted. Ore is currently supplied from the Wallaby deposit. Development of the Wallaby deposit began in October 2000 and ore production commenced in October 2001. The proven and probable mineral reserves at December 31, 2001 contained 2.5 million ounces of gold (0.2 million ounces proven and 2.3 million ounces probable). Granny Smith has a projected mine life of 9 years. During 2001, the mine produced 347,177 ounces of gold. Placer Dome's share of production was 208,306 ounces at an average cash and total cost of $167 and $181 per ounce, respectively.

Granny Smith currently has **Caterpillar's CAES** system installed on two shovels and one D10 Dozer, with the intention of installing another system on a 992 Loader. Initially the mine had the CAES system installed on two excavators and at one stage had the system running in two pits concurrently.

Two drill and blast drill rigs had the Aquila drill management systems installed in March 2001. Improved fragmentation was the main reason for the new systems on the drills. The net effect of improved fragmentation was increased productivity for the mining fleet. Orica, the explosives provider for all drill and blast requirements at Wallaby have a Bulk Master GPS system on all explosive trucks so that the precise amount of explosive are distributed over the entire shot as pre-determined from the material recognition function of the Drill Management system. Drilling operations in Wallaby pit are shown in Figure 8.

Figure 8 Drilling in Wallaby pit.

CAES was trialed at Sunrise pit from April 1, 2000 to June 30, 2000. The purpose of the trial was to establish the performance of CAES against predefined performance targets, and to assist with the justification to purchase the system. To determine the benefits of the system, the mining units were tested with and without CAES (full trial and blind trial). The blind trials incorporated fully functional CAES, with the operators screen blacked out so that the CAES advantages are not available to the operator. To measure performance against the specified targets, two main trials were performed. The CAES excavator trial consisted of manual shift productivity reports against CAES data. The CAES data was filtered for inconsistencies. A total of 171,000 GPS positions were considered. The analysis of the data was performed by matching the truckload times with the CAES times and comparing the load types to check for inconsistencies. All misclassified buckets were closely analysed, to ensure the data was valid. Since most misclassifications were found at the boundary of ore blocks, a tolerance of 1.5m was allowed around ore boundaries. This tolerance was chosen, as it is roughly half the width of the EX3500's bucket and is consistent with inaccuracies introduced with the current methods of ore mark-up (survey tolerance, painting tolerances, and rilling of ore faces). Buckets that fell outside the tolerance were used in dilution calculations. The trial conducted on the excavator showed a significant reduction in ore sent to the waste dump (0.963% of waste was actually ore misdirected when operating without CAES, and 0.366% with CAES). This satisfied the first performance target (reduction of 50% in ore mined as waste). In addition, it was realised that a higher proportion of waste was being sent to the ore stockpiles, a proportion which was similarly reduced with the introduction of CAES (9.18% of ore sent to stockpiles was actually waste when operating without CAES, compared to 4.46% with CAES). Improved operator familiarity with the system could yield even better results.

The results of the two trials showed that dilution was effectively halved using the CAES system. This improvement, when applied to the full period of the trial (3 months) equates to a direct saving of $627,830 ($209,276/month). A payback period of 0.2 years was determined from the initial costs and the direct savings achieved. Based on this result alone, the system easily met the criteria required to justify the expenditure.

The Granny Smith operators have been very positive towards the system, realising the potential benefits and recognising it as an effective tool to help them provide a better quality product. Following the success of the initial installations, the Granny Smith engineers have recommended to their

management, the immediate purchase of an additional system to complement their CAES fleet. The approximate cost per operational piece of loading equipment with a CAES system installed is US$75,000. Additional costs are incurred with base stations and repeaters. However considering the 'pay back' period is only 0.2 years; the initial costs seem insignificant compared to the systems full potential cost savings.

Case Study 3: Tarmoola

Tarmoola is located approximately 29 kilometres North/East of Leonora and forms part of the North/Eastern Goldfields gold district, which includes Sons of Gwalia's Leonora operation. Mount Edon Gold Mines brought the Tarmoola gold mine into production in May 1990. Camelot Resources and Teck Corporation acquired Edon in March 1998. This consolidated ownership was renamed and became PacMin Mining Corporation. Sons of Gwalia completed a takeover of Tarmoola in October 2001. In the 11 years until 30 June 2001, the Tarmoola mine produced a total of 1.1 million ounces of gold. The Tarmoola mine is a large scale open pit operation extracting in excess of 30 million tonnes of material per annum. The processing plant treats some 3.5 million tonnes of gold bearing ore each year.

Currently Tarmoola utilises the **Wenco** dispatch module. The system was acquired for accurate reporting of mining production. The system uses "weightometers" on the trucks to determine payload information, which is relayed to the mining office for analysis via a wireless network. The Wenco system also provides critical information to the maintenance department, which enables them to service and maintain the mining fleet with efficiency and without delaying production. This system also enables tracking and recording of causes of equipment failures and mechanical deficiencies. The third major reason for adoption of a dispatch module was material tracking purpose. This system was the most financially beneficial component of the entire system. It uses DGPS mounted in the trucks to locate their dumping destinations. The system uses beacons along the haul roads to ensure that the truck is travelling to the correct dumping location relevant to the material it is carrying. An alarm notification system is in place on the mine site, which notifies the truck operator and the mining office that a misallocated dump may occur; therefore enabling the truck to re-route and dump its load at the correct destination.

The benefit of the system is that it allows the company to track and correct the losses detailed above, which previously were suspected but not quantified. This further enables the company to justify the implementation of the system with cost analysis calculations related to payback periods and future financial benefits of the system.

Analysis of Benefits and Cost Savings for St Ives Mine

The comprehensive compilation of all the benefits and cost savings as determined from the investigations, conducted at the case study mines, is presented in this section. The benefits and cost savings are specifically related to St Ives open pits. All direct and indirect benefits of the installation of a GPS guidance system installed at St Ives open pits have been considered and investigated.. Cost saving analysis is performed for all applications, which may result in a direct cost saving to St Ives.

The benefits and cost savings are evaluated by application and cost saving potential, therefore enabling St Ives management to gauge the potential benefits and cost savings for each application. At the conclusion of this section, a weighted average analysis is conducted to provide St Ives management with the potential cost savings that would be achievable with the installation of a GPS guidance system.

The Table 1 shows all the potential benefits and cost savings achievable for each of the GPS guidance systems classified by machine type. The applications designated with an (*) are deemed to be those that provide the most substantial costs savings and/or benefits.

The potential cost savings achievable for all the GPS guidance applications available by machine type are compiled in Table 2. The monthly and annual savings are determined based on the cost analysis . Conservative percentages have been applied on top of the conservatism already applied to the cost savings figures. This approach was applied to analysis to guarantee the return on investment. As shown in Table 2, the projected potential annual savings are of A$3,681,390. This equates to approximately A$1,533,912 for current pit reserves (until May 2003). The conservative approach to analysis should provide management with secure, yet realistic cost saving per annum.

Potential Benefits and cost savings with GPS guidance systems					
	GPS guidance on…				
Benefits and Cost Savings	Excavators/Shovel	Dozers	Graders	Trucks (Dispatch)	Drill & Blast
Reduce misidentified loads *	X				
Correct floor elevation *	X	X	X		
Increased Productivity *	X	X	X	X	X
Reduce idle time	X	X		X	X
Improved mine planning	X			X	X
Mine to design	X	X			X
Mining subgrade blocks	X				
No dig lines	X	X			
Edge of blast information	X	X			
Reduced survey requirements	X	X			X
24/7 survey assistance *	X	X	X	X	X
Working around voids *	X	X			
Reduce floor dilution & ore loss *		X	X		
Establish dropcut on grade	X	X	X		
Flatten heave		X			
Waste removal on ore zones	X	X	X		
Waste dump construction		X			
Backfilling pits		X			
Material tracking *	X			X	
Accurate overhaul cost				X	
Tonnage/truck determination	X			X	
Reduce idle time	X	X		X	X
Improved fragmentation *					X
Reduced labor cost	X	X		X	X

Table 1 Overall potential cost savings and benefits by machine type.

Potential Cost Savings (A$)					
GPS	Cost saving	Monthly	Annual	Conservative	Adjusted
Machine	Application	Savings	Savings	(%)	Annual savings
	Misidentified loads	$297,123	$3,565,476	50%	$1,782,738
Excavators	Mine to correct floor elevation	$93,150	$1,117,800	50%	$558,900
Shovel	Increased Productivity	$19,000	$228,000	25%	$57,000
	Mining to design	$4,138	$49,650	50%	$24,825
	Doze to design floor elevation	$19,244	$230,929	50%	$115,465
Dozer	Doze/Grade within ore boundaries	$10,491	$125,892	25%	$31,473.00
	Material Tracking	$90,772	$1,089,264	50%	$544,632
Trucks	Accurate overhaul costs	$45,221	$542,652	75%	$406,989
	Improved fragmentation	$17,603	$211,236	50%	$105,618
Drill & Blast	Minimal survey requirements	$11,250	$135,000	25%	$33,750
	Minimal dipping requirements	$6,667	$80,000	25%	$20,000
TOTAL		**$614,658**	**$7,375,899**	**43%**	**$3,681,390**

Table 2 Potential cost savings for all GPS guidance system applications.

The estimation of costs of GPS guidance system for the various mining machines was based on purchase prices of similar systems when acquired by other mine sites. Costs would be significantly cheaper if an entire mining fleet was purchased with GPS guidance system installed. Based on the full purchase prices for an entire mining, drilling and blasting fleet the estimated total costs is approximately A$1,194,115. This includes system for four (4) mining machines, ten (10) trucks (Dispatch), two (2) radio repeaters and four (4) production drill rigs. This entire purchase price is less than the return on investment calculated for the current mining pit reserves (4-5 months production). Therefore the payback period determined for the system is 3.8 months, with all conservatism included.

Conclusions

The analysis of GPS Guidance System case studies suggest that such systems may have significant impact on management of earth-moving equipment and at accuracy of mining operations. The pay back period may vary depending on the time and resources put into the system to realise it's full potential either directly or indirectly. The ideal environment for the installation of a GPS guidance system would be in a mine with a long life (>1 year). This way the payback of the system would be ensured and the benefits and cost savings could be realised for longer.

The analysed case study suggests that the mine would benefit from the installation of a GPS guidance system. The payback period is estimated to be only 3.8 months based on an approximate initial invested capital of A$1,200,000 for a full GPS guidance and dispatch system. The report determines that the potential cost savings at average size open pit mine with a GPS guidance system installed is in the order of A$300,000/month. For the St Ives mine, based on the current reserves remaining for all pits and assuming average production rates, the potential cost savings are A$1,533,912 . All future reserves would also enjoy the benefits and cost savings achievable with a GPS guidance system.

Acknowledgements

Authors would like to acknowledge the assistance and help from the following individuals, sources and companies when preparing this report: professionals at St Ives Gold Mine , Kalgoorlie Consolidated Gold Mines (KCGM), Granny Smith Gold Mine, Caterpillar, Wenco and Modular.

References

Trimble Navigation Limited. 1997, *GPS for mining*, United States.

Wenco International Mining Systems. 2003, http://www.wencomine.com, *News*, Vancouver, Canada.

Wenco International Mining Systems. 2003, http://www.wencomine.com/products. asp, *Product Overview*, Vancouver, Canada.

Caterpillar. 2003, http://www.cat.com/products/shared/technology_products/01_products, *Technology Products*, United States.

Caterpillar. 2003, http://www.cat.com/products/shared/technology_products/future developments, *Future Developments*, United States.

Caterpillar. 2003, http://ww.cat.com/products/shared/technology_products/02_product_information, *Product Information*, United States.

Modular Mining Systems. 2003, whttp://www.mmsi.com/modular/news, *Company News*, Arizona, USA.

Greene, D. 2001. Value of GPS and Computer Aided Earthmoving Systems in Landfills, SWANA Landfill Symposium 2001. *(668K PDF, available from http://www.cat.com/products/shared/technology_products/pdf/swana_landfill_symposium2001.pdf)*

Greene, D. and Buhl, B. 2000. Transitioning Surface Gold Mining into the 21st Century,Transitioning Surface Gold Mining into the 21st Century, SME Conference. *(698K PDF, available from http://www.cat.com/products/shared/technology_products/pdf/cortez_sme_paper.pdf)*

CAES Improves Safety at KCGM, *Australia's Mining Monthly magazine, October 2000.(23K PDF)*

CAES Finds “Missing” Ore at Placer Granny Smith, *a paper discussing the benefits Placer Granny Smith has seen from using CAES, October 2000. (25K PDF)*