USING SMARTTAG™ TO TRACK ORE IN PROCESS INTEGRATION AND OPTIMIZATION PROJECTS: SOME CASE STUDIES IN A VARIETY OF APPLICATIONS

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Abstract

A mine is essentially a series of operations, including drilling and blasting, crushing, milling, flotation, and leaching, that are interconnected and therefore interrelated, with the performance of one operation affecting the performance of another. Optimizing each stage separately without considering the whole system often causes potential economic benefits and energy savings to be missed. However, the PIO methodology is a thorough approach which considers these individual process activities within the context of the whole process. The basic principle is to optimize the process as a whole, rather than each process step in isolation from the others.

Metso's Process Technology and Innovation (PTI) group offers a global consulting service for the mining and construction industries. A significant amount of this consulting work involves process integration and optimization (PIO) studies. When conducting a PIO study, every aspect of the process is considered. In addition to drilling and blasting, transportation, handling and storage, crushing, screening, grinding, flotation, separation, and recovery, other aspects including equipment utilization and energy consumption and even greenhouse gas emissions are also included if necessary.

In a PIO project, it is very important to understand what type of material is being processed at any point in time. That is, which domain or domains is the material part of? This is necessary in order to observe the effect of different ore sources (and the blending of sources) on concentrator performance. Linking the ore from the pit to the concentrator required the development of an ore tracking system. As a result, PTI developed a radio-frequency based material tracking system called SmartTag™. This system allows tracking of ore from its source through blasting, run-of-mine (ROM) pads, crushers, intermediate stockpiles, and finally into the concentrator.

Using the SmartTag™ system, definitive correlations can be made between the performance of the plant and the plant feed characteristics, including the domain from which the feed ore originated. Since its commercialization in 2007, SmartTag™ has been used in the majority of PTI's consulting projects and several permanent systems have been installed worldwide[1]. Successful applications of the SmartTag™ system have encouraged development to allow the system to be used in a wider variety of plants, in particular plants with finer crushing and screening stages.

This paper describes how the SmartTag™ system is being utilized by PTI and the benefits being gained by its use in PIO projects, as well as presenting some case studies.

Keywords: Integration, optimization, simulation, modelling, mine-to-mill, ore tracking

Introduction

Metso Process Technology and Innovation (PTI) is a group providing total process integration and optimization (PIO) services for the mining and construction industries. The term 'total process', is used to encapsulate the mining (drill and blast), comminution, flotation, leaching, and dewatering processes, and PTI studies aim to optimize each process within the constraints imposed by the operation of the other process. The objective of PIO projects is to maximize the overall profitability of a mining operation by fully exploiting the interaction between the mine and mill.
The PIO methodology, developed by Metso PTI, is a result of working with operations around the world over the past fifteen years to increase their production rates, reduce operating costs, and improve overall process, energy, and water efficiency.

Implementation of the PIO methodology has delivered significant improvements in mine efficiency, increases in the production of the operations with little or no capital expenditure, and reduced operating costs at mines around the world[2]. These increases typically range from 5 to 20 per cent, representing millions of dollars in increased revenue.

PTI have also developed and commercialized our own innovative products such as SmartTag™, SmartEar™, and SmartSAG™. These products are designed to enhance the operation of mineral processes.

Ensuring the quality and specifications of an ore product requires high accuracy in process control, from the properties of raw materials to customer delivery. In mining operations, this control involves characteristics of ore geology, content, hardness, process parameters such as size, power, inputs, and finally the logistics for storage and transportation. In a number of mining companies, the size of the particles and the contents are used to classify the quality of products very strictly, valuing or devaluing each ton processed and immediately impacting the revenue of the company.

One way to control the characteristics of the product is to track the raw material through the process. To increase the accuracy of this ore tracking from blasting to the plant, Metso PTI developed a system, SmartTag™, which is based on hardened RFID (Radio Frequency Identification) tags. This will be described in more detail in the following sections.

SmartTag™ was commercialized in 2007 and won the Queensland State iAward in the category of Industrial Application, competing alongside world leading-edge technologies in 2010. The system has been used by PTI in PIO and mine to mill projects to determine with great precision the origin of the material that feeds the plant during sampling campaigns and to associate plant performance with the characteristics of the material. Over 20 such projects have used this technology. Some other applications include measuring the residence time of stockpiles and the transit period of a circulating load, and estimating dilution and pile´s launching at blasting.

Since 2007 there have been significant advancements in RFID technology that have allowed PTI to extend the reach of SmartTag™ beyond secondary crushing to tertiary crushing and screening. This has been achieved by drastically reducing the size of the SmartTags from a diameter of 60 mm to 13 mm. The new smaller RFID tags have been successfully used in several studies.

PIO methodology

Investigations have shown that all the processes in the mine to mill value chain are inter-dependent and the results of the upstream mining processes (particularly blast results such as fragmentation, muck pile shape and movement, and damage) have a significant impact on the efficiency of downstream milling processes such as crushing and grinding[3].

The 'mine-to-mill PIO' approach involves the identification of the bottlenecks and opportunities in the total process, understanding the leverage each process has on the downstream processes (e.g. the impact of drill and blast results on load and haul and crushing/grinding processes), and then using that leverage to de-bottleneck the total process and maximize the overall profitability of the operation rather than just the individual process.

The objective of mine-to-mill PIO methodology is to develop and implement site-specific mining and milling strategies to minimize the overall cost per ton treated and maximize company profit in a sustainable manner.

The methodology involves a number of steps: benchmarking, rock characterization, measurements, modelling/simulation, and where required, material tracking. A PIO project is normally comprised of a number of site visits spaced over a few months. Typically during the first site visit, project objectives are defined, data is collected to establish current operating practice, and plans are made for conducting detailed audits, sampling for rock characterization, and plant surveys.

This is followed by data analysis, modelling, and simulation studies to determine how to exploit hidden inefficiencies. Recommendations are followed by further site visits to implement changes, monitor results, and ensure improvements are maintained over time. The PIO methodology is shown in Figure 1.

Ore tracking from mine to mill

In a mine, different ore characteristics have a direct impact on subsequent processing, the objective of which is to separate and concentrate minerals of economic interest. SmartTag™ is a tool to identify and track with great accuracy the origin of the ore and its characteristics through the mining processes. The system uses integrated circuits equipped with RFID technology, encased for protection in a highly-resistant polymer capable of withstanding blasting and subsequent transportation, storage, and size reduction processes, such as crushing and screening.

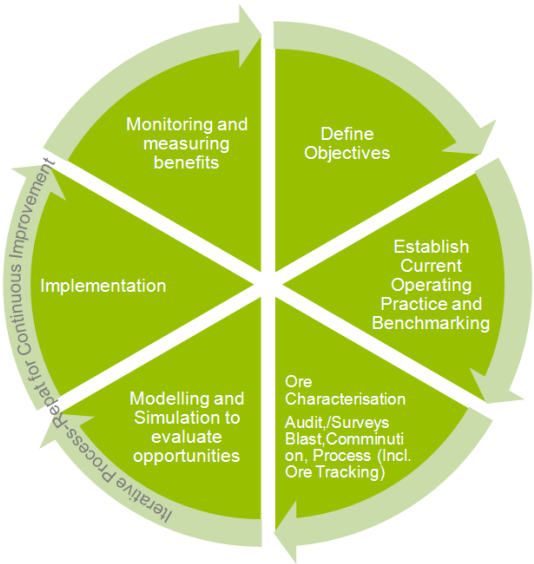

Figure 1-Schematic of the PIO process

A SmartTag™ RFID tag travels through a mine and mineral processing plant in a series of steps. Initially, the tag and insertion location is logged using a hand-held computer or PDA, then it is inserted into the rock mass in the same holes where blasting explosives are placed. The tag travels with the ore through digging, transport, and processing, before being detected by special detectors that are positioned along conveyor belts, when the time and specific tag is recorded. The RFID tag data is then loaded into a database and analysed as required. Figure 2 demonstrates the application of the SmartTag™ system for a typical flow of ore from a blast through to a concentrator.

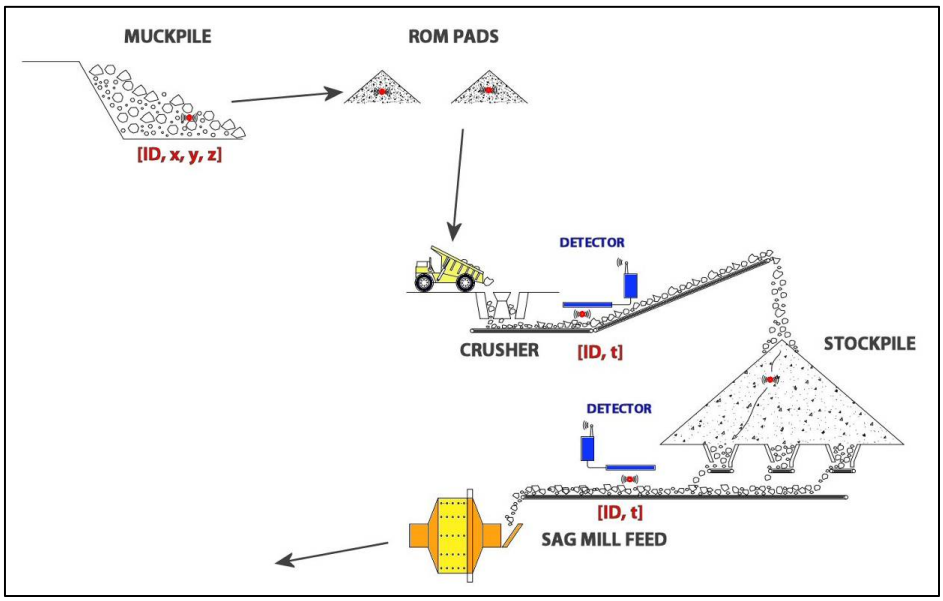

Figure 2-Schematic of RFID tag-based material tracking system

Metso PTI are currently extending the application of the SmartTag™ system to mark and track ore from mines through ports to final destinations offshore, allowing not only optimization of the mining process, but also monitoring and optimization of the transport logistics to final consumers, such as iron and steel producers in the cases of iron ore and coal[4].

The use of the SmartTag™ system allows tracking and correlation of the ore characteristics and quality with important operating parameters in the mine and processing plant, such as ore dilution, fragmentation, stockpile residence times, segregation, energy consumption, metal recovery, etc. With such knowledge, operating parameters can be optimized to respond rapidly to changes in ore characteristics, reducing operating costs and increases the profitability of the business.

The benefits of using SmartTag™ include linking spatial mine data to time-based processing data, increased confidence in measuring ore blend, proactive process changes for known ore types, identifying material-handling logistics issues, and accurate measurement of residence times in stockpiles and bins.

SmartTag™ system overview

As can be seen in Figure 3, the SmartTag™ system consists of five main components:

1. SmartTag™ tag
2. Portable reader (PDA)
3. Antenna
4. Tag reader and data logger
5. Database and software applications.

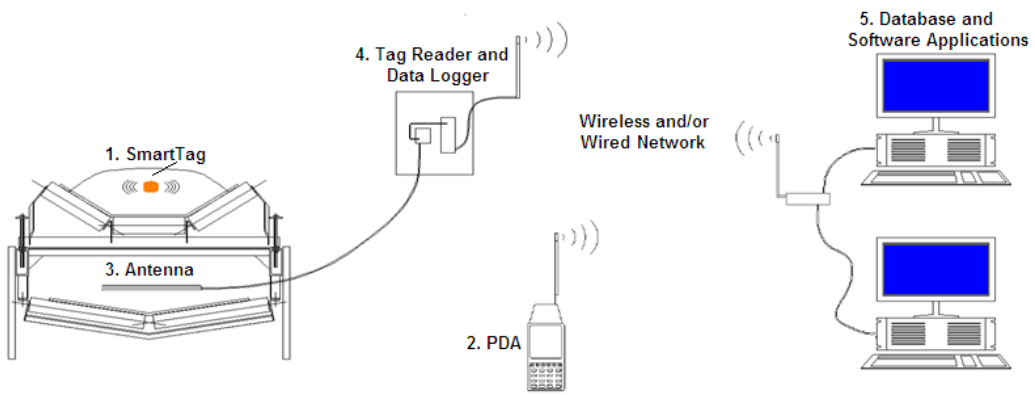

Figure 3-Schematic view of SmartTag™ system

RFID Tags

A SmartTag™ is a passive radio-frequency identification chip contained within a ruggedized protective casing. All internal electronics are passive and require no power source to be connected. When in use, the operational power is drawn from safe levels of electromagnetic energy that emanates from the reader antennas. Due to this feature, the SmartTag™ has a theoretically infinite shelf life.
The SmartTags come in four sizes, the super SmartTag (90mm Ø x 60mm), the Standard (60mm Ø x 30mm) the Mini (20mm Ø x 10mm), and the Micro (14 x 8 x 5mm). Figure 4 shows the different tag types.

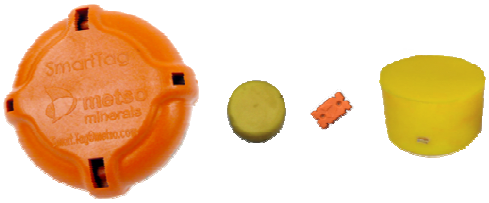

Figure 4-SmartTag™ types. Left to right: Normal, Mini, Micro, and Super (not to scale)

The Standard tag can be detected from a distance of 1 m, while the Mini and Micro tags can be detected up to a distance of 400 mm. The Mini and Micro tags are generally used for applications where screening or secondary crushing precludes the use of the larger tag. The Micro tag is designed to pass through 10 mm screens. Mixtures of different tag sizes can be used if necessary. The Super SmartTag™ has been developed to improve survival in underground applications where long falls can be expected in ore passes.

By reducing the size of the RFID tag, the size of the antenna in the RFID tag is also reduced. The size of the antenna in the RFID tag is directly proportional to the amount of charge that is induced for a given field strength. Therefore, the read range of a RFID tag will be reduced as the size of the RFID tag is reduced. Through investigation, the 20 mm RFID tags were found to have an insufficient read range for the standard SmartTag™ installation. PTI trialled two methods for fixing this issue; one method was to use two antennas while the second method was to place the antenna closer to the RFID tags.

Both systems were tested at an iron ore mine. For the second approach, the antenna was placed underneath the conveyor belt (rather than above the belt) to reduce the distance between the tags and the antenna. Both approaches, dual antennas or closer antenna distance, were found to have similar detection capability. However, based purely on the ease of installation, a single antenna located under the belt was chosen as the new standard installation method.

The second challenge faced in incorporating the Mini RFID tags into the SmartTag™ system was how to protect them sufficiently to survive a blast. A method previously used by PTI to achieve this was to encase the RFID tags in a two-part epoxy. The method works well for protecting the RFID tags, and although it is time-consuming and expensive it is currently the preferred method for protecting the RFID tags. Different encasing materials are still being investigated. After encasing in epoxy, the Mini SmartTags have a diameter of 20 mm. The size of the Mini RFID tags allows them to pass easily through screens with apertures down to 25 mm.

The tags can be inserted into the stemming of the blast at approximately the midpoint of the stemming column. This minimizes the chance of the blast shock wave damaging the device and the tag being ejected from the blast in the stemming. It must be assumed that the tag remains with its original parcel of ore, so this is an important consideration.

The tags can also be placed on the post-blast muck pile or ROM pads. The tags then follow the ore throughout its journey, being activated only by the SmartTag™ reader antennas.

Upon activation, they transmit their unique identification code before switching back off. The protective casing is strong enough to protect the tag from the shock of blasting and transit through crushers and stockpiles.

Portable reader

The SmartTag™ portable reader (Figure 5) is used to associate the unique identification code of SmartTags™ with the blast hole (or other location) they are placed in. The portable reader emits a safe level of electromagnetic energy to activate the SmartTag™ transmitter. The readers then 'listen' and record the response from the SmartTag™, which is its unique identification code.
For the initial placement of a SmartTag™ in the mine, the SmartTag™ portable reader is used. This system consists of a ruggedized handheld computer (PDA) with inbuilt GPS and SmartTag™ RFID reader.

Figure 5-SmartTag™ portable reader system

The PDA's GPS unit locates the three nearest locations, from which the user selects the relevant one. When the user holds the SmartTag™ to the top of the PDA, the reader sends out a low-power, close-range signal to power and activate the SmartTag™. The unique identification number of the SmartTag™ is then transmitted back to the PDA. The SmartTag™ ID number is then associated with the location. This process is repeated for each location that requires a SmartTag™.

Antenna

The next component in the system, the antenna, is located at the conveyor belts. The antenna both induces a charge on the RFID tag and also receives a transmitted signal back from the RFID tag. Antennas can be mounted above or below the conveyor belt. Depending on the application, single or multiple antennas can be used.

For most single-antenna systems, as seen in Figure 6, the antenna is mounted below the belt and is connected to the reader via a single 2-core cable. The cable cannot exceed 3 m in length, as the performance of the antenna will drop off significantly past this length. The antenna must be positioned as close as possible to the conveyor belt.

Figure 6-A single SmartTag™ antenna

The design of the antenna is determined by two parameters, which are its size and its robustness. The size of the antenna dictates the size and the strength of the field it radiates. For this application the area of field strong enough to charge the RFID tag should be as large as possible; therefore, the antenna used for the SmartTag™ system is the largest available for this frequency of RFID system.

Tag reader and data logger

An RFID tag reader decodes the signal from the antenna and determines the ID of the RFID tag passing the antenna. Later versions of the readers also have auto-tuning capabilities which ensure that the maximum possible read distance is achieved at all time. In the SmartTag™ system, the reader then transmits the ID using serial communications.

A data logging or buffer stage improves the reliability of the systems and also makes movable systems possible. The data logger receives data directly from the RFID reader, stores the IDs with the time they were detected, and monitors vital system parameters, such as the tuning state of the antenna. The data logging stage also makes SmartTag™ less reliant on communication links (such as wireless) as the data is stored at the detection point until a link is established to the software applications. The critical communications links, such as the one between the antenna and the reader, are all wired and very reliable.

Database and software applications

The core of the SmartTag™ software is an SQL database. The database, located on a dedicated server, stores all the information about the detection points, detected RFID tags, and original locations. There are several SmartTag™ software applications for entering and managing the data and visualizing, reporting, and transferring the data to other applications and systems.

Using SmartTag™ in PIO projects

The two case studies summarized below were chosen to illustrate the applications of the SmartTag™ system by PTI and the benefits being gained by its use in PIO projects. The second case study also demonstrates several advantages of using the Mini RFID tags rather than the normal size RFID tags in secondary crushing circuits.

Case study 1: Application of SmartTags™ at a gold mine

PTI undertook a PIO project at an open pit gold mine and SmartTags™ were used to track ore from the audited blast through to the SAG mill[5]. As part of the mine–to-mill PIO study, one test blast was conducted in the pit and ore from this blast was mined in two flitches (top and bottom) and campaigned through the mill.

To quantify the effect of changes in blasting conditions, the PIO study processed the top and bottom flitch material separately into the grinding circuit. Following detonation of the audited blast, the top flitch material was mined and placed in a segregated stockpile on the ROM pad, ahead of the primary crusher. The bottom flitch material was dumped directly into the primary crusher.

It was planned to perform two grinding circuit surveys: one on the top flitch and the second on the bottom flitch. Ore tracking with SmartTag™ was used to physically confirm that the audited primary ore was being processed through the grinding circuit at the time of the survey, thus allowing correlation between fragmentation results and plant performance.

SmartTags™ were placed on the muck pile prior to mining as well as added to the ROM stockpile. A total of 200 tags were placed in each of both flitches – numbers 0 to 199 were used for the bottom flitch and 200 to 399 for the top flitch. Two antennae were used at the site, one on the primary crusher product belt and one after the stockpile on the SAG mill feed belt.

Tag detection results

Top flitch material was sent exclusively to the primary crusher starting at around 1:30 pm on 28 January and was to be sufficient to supply the primary ore mill feed for around 12 hours. The mill was to process this material until the 12-hour shutdown starting at 8:00 am on 29 January – immediately following the first grinding circuit survey.

When the mill came back up around 9:30 pm, the bottom flitch material (again around 12 hours of mill feed) was direct dumped into the crusher and the plan was to continue crushing this exclusively until the morning of 30 January after the second grinding circuit survey.

Figures 7 and 8 show the tag detection times for the primary crusher and SAG mill feed. The blue diamond points represent the top flitch while the purple square points represent the bottom flitch.

SmartTags™ were steadily detected at the primary crusher until the mill shutdown. Unfortunately, the coarse ore stockpile was drawn down ahead of crushing this material and the pile height fell steadily for the whole period when top flitch tags were detected. Comparing Figures 7 and 8 shows that the tags were picked up on the SAG mill feed belt very soon after being detected ahead of the stockpile.

In contrast, tags were detected for only 2½ hours with direct dumping of the bottom flitch into the primary crusher. All of the bottom flitch material was crushed during the mill shutdown as shown in Figure 7. After the mill started up again at 9:30 pm on 29 January, the majority of the bottom flitch tags passed through the SAG mill prior to 4:00 am on 30 January – well before the scheduled time for the second grinding circuit survey. After 4:00 am, the frequency of tag detections diminished, indicating that the mill feed was then a blend of bottom flitch with other unknown material.

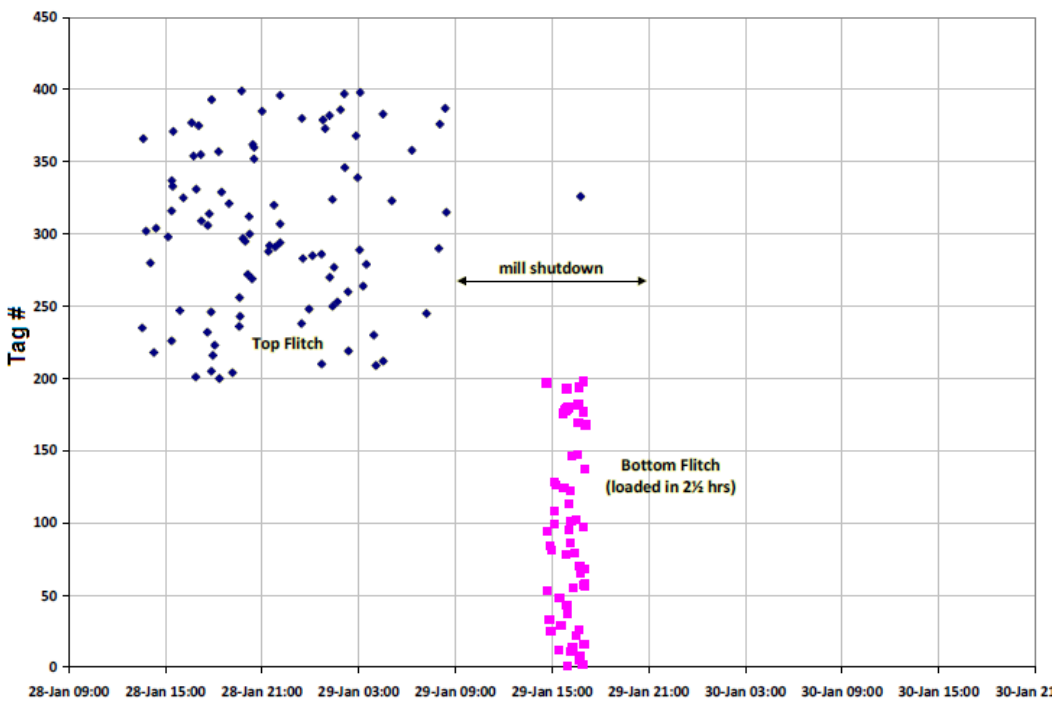

Figure 7-Primary crusher product tag detection times (before stockpile)

The difference in tag detection times between the SAG mill feed and primary crusher antennae can be used to estimate the coarse ore stockpile retention time. Figure 9 shows the residence time of the pile over the period when SmartTags™ were being detected. For the top flitch material, the time between detections slowly reduced from 3 to 4 hours down to a few minutes as the pile height dropped. It is also possible that, with such a short retention time, other material may have been falling into the cone above the feeders, in particular, very coarse rocks from the outside of the stockpile.

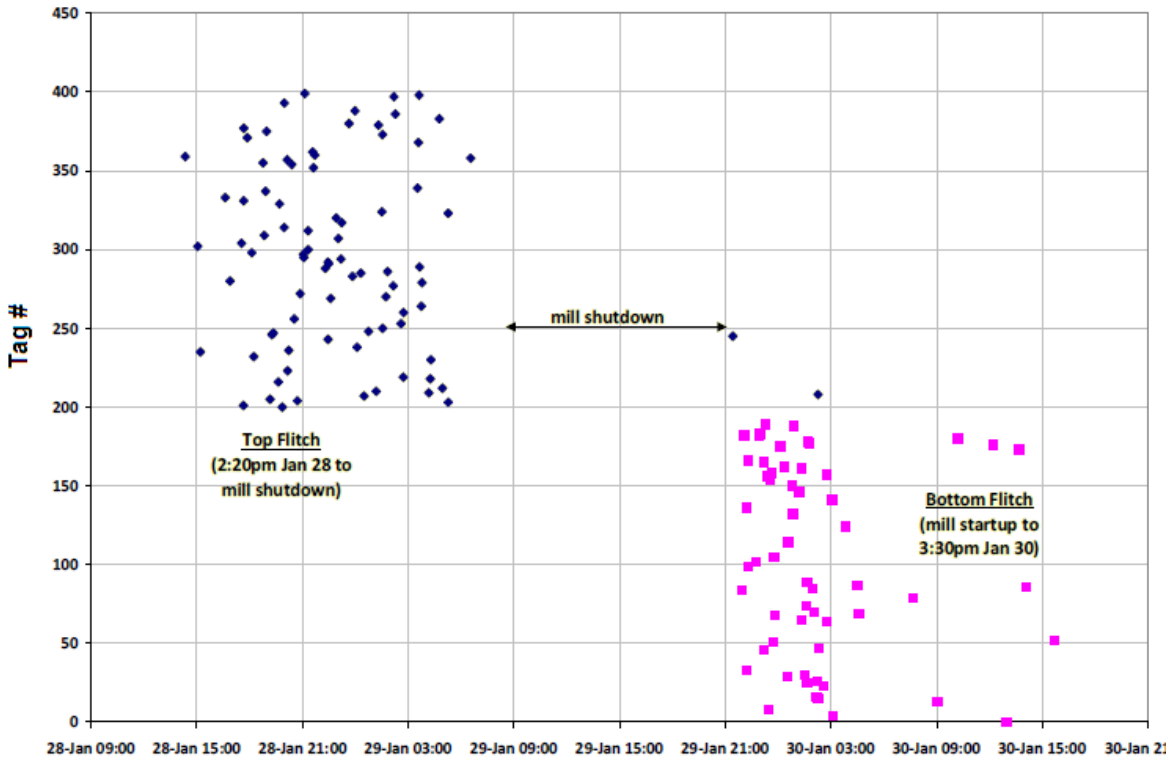

Figure 8-SAG mill feed tag detection times (after stockpile)

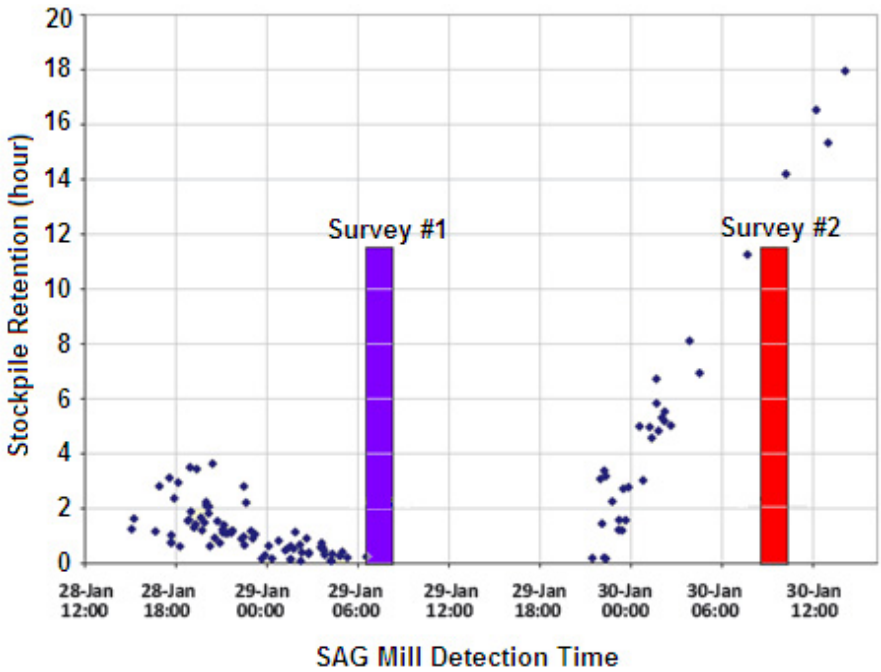

Figure 9–Coarse ore stockpile estimated residence time (based on tag detections)

For bottom flitch material, the stockpile was steadily built up following the mill shutdown and the residence time increased from a few minutes to 18 hours when the pile was full.

The use of SmartTags™ provided clear evidence that the audited material was entering the grinding circuit and the frequency of tag detections was used to indicate whether any other ore polygons were inadvertently being sent to the primary crusher. Placing antennae both ahead of and after the coarse stockpile allowed live retention time to be estimated.

Case study 2 – high-pressure grinding circuit

PTI was contracted to assess the performance of a circuit at a mine located in South America. The flowsheet for the operation including the locations of the SmartTag™ detection points is shown in Figure 10. The SmartTag™ system was used in this application to allow the PTI engineers to know exactly when a surveyed blast was being processed[6]. For this reason, detection points were located on conveyor belts carrying the product of the primary crusher, the output of the stockpile and the high-pressure grinding roll (HPGR) feed.

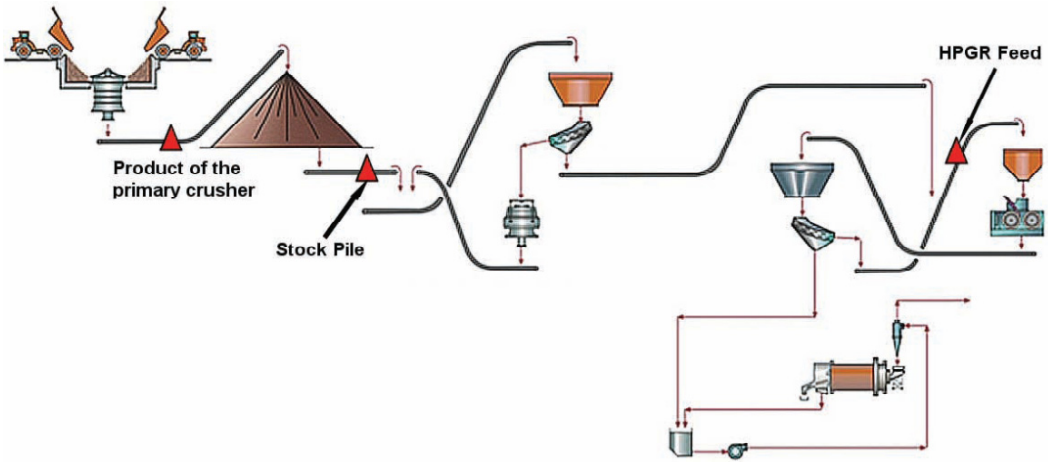

Figure 10-Crushing and grinding circuit and locations of detection points

As the blast was being audited, RFID tags were deposited into 68 blast holes, using an even split of 34 normal tags and 34 mini tags. A further 50 tags were later added into the trays of 25 trucks at the primary crusher, using one of each of the two different types of tags in each truck. Figure 11 shows the layout of the holes in the blast and the type of tag that each hole received.

Results

A total of 68 tags were identified at the primary crusher product detection point, 23 at the stockpile output detection point, and 41 at the HPGR feed detection point. Figure 12 shows the cumulative number of tags detected over time at each detection point.

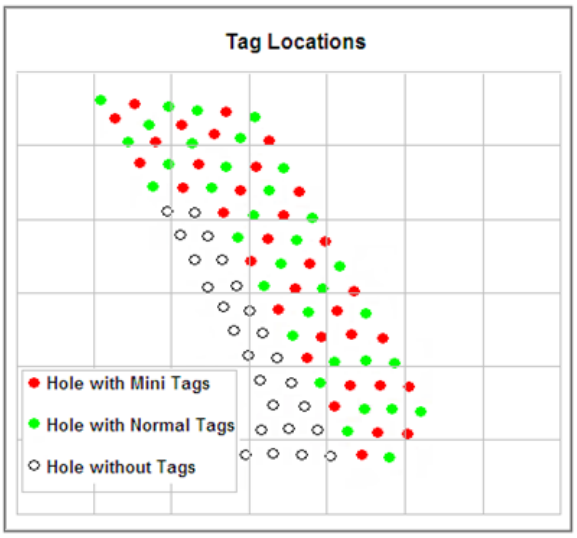

Figure 11-Holes where the RFID tags were placed

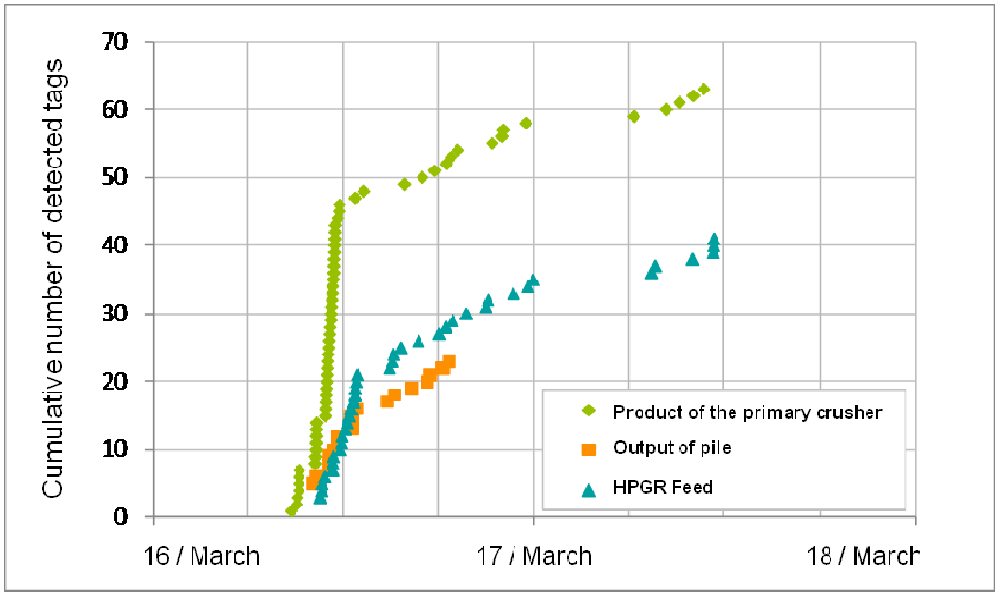

Figure 12-Cumulative number of RFID tags detected during the test

The stockpile antenna was installed above the belt rather than under the belt, and was decommissioned by an oversized rock on 16 March. This explains why there was no detection of tags after this date.

The blast occurred on 22 January and the excavation of the muck pile between 15 - 17 March (two months later). The SmartTag™ system monitored the material passing through the process over a period of 30 hours.

During this period, a total of 67 different tags were detected; 33 were of normal size and 34 were mini tags. Table I shows the number of tags detected for each detection point, the tag type and the origin (mine or truck).

As stated earlier, the stockpile antenna was damaged and this truncated the results in Table I.

Table I-Detected RFID tags at each detection point

Tags	Primary crush product	Stockpile	HPGR feed
60 mm, truck	22 of 25	14 of 22	11 of 22
20 mm, truck	21 of 25	3 of 21	15 of 21
60 mm, mine	11 of 34	2 of 11	3 of 11
20 mm, mine	10 of 34	1 of 10	8 of 10
Total 60 mm	33	16	14
Total 20 mm	34	4	23
Total	67	20	37
Recovery 60 mm total	55.9%	48.5%	42.4%
Recovery 20 mm total	52.5%	12.9%	67.6%

For the stockpile and HPGR feed detection points, the recovery was calculated with reference to the 64 distinct tags detected at the primary crusher. Of the normal tags detected at the primary crusher detection point, 42.4 per cent were then detected at the HPGR feed detection point; whereas for the mini tags 67.6 per cent of tags detected at the primary crusher were also detected at the HPGR feed. This shows that the survival of the mini tags in the circuit is higher than the normal tags. In a hypothetical situation, where the secondary screening mesh is smaller than 50 × 50 mm, normal tags certainly would not reach the HPGR.

The detection of tags at the primary crusher was also affected by the removal of the SmartTag™ system before the entire blast was processed (for logistical reasons).

The RFID tags were used to track the material during an optimization campaign at the plant. The blast map in Figure 13 shows that during the plant survey the material that fed the plant originated from the central portion of the blast.

An unexpected result was that three of the mini tags were twice detected at the HPGR feed detection point. An explanation for this is that they survived the HPGRs and returned with the circulating ore (screened to +5 mm). The transit times of these three tags are shown in Table II. The differences in the transit times in the circuit are probably due to different levels in the HPGR feed bins.

Table II-Transit time through the HPGR circuit

ID tag	Transit time (min)
335	86
224	23
251	2

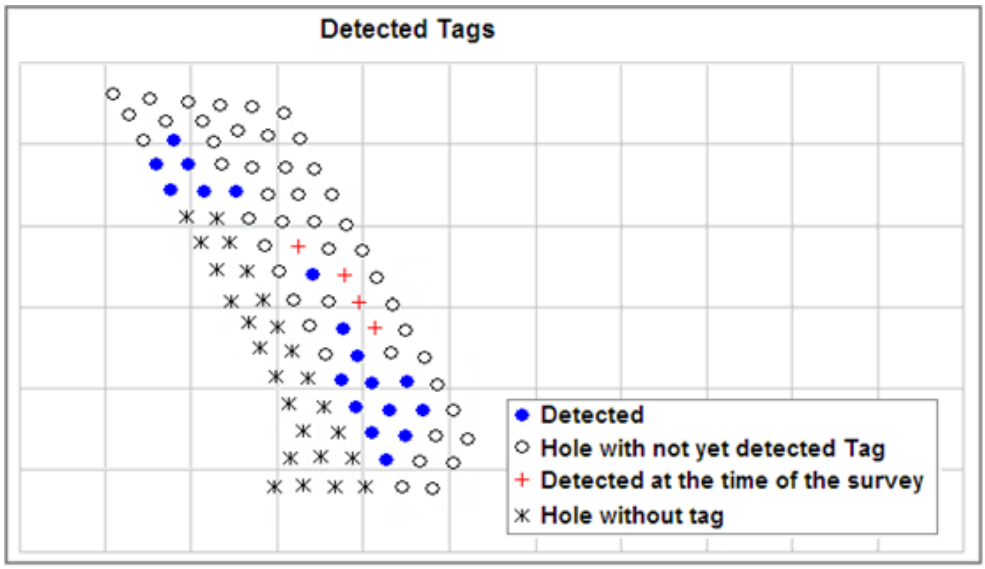

Figure 13-Detected RFID tags during the period of sampling

Conclusions

The concept of mine-to-mill has been applied in the mining industry now for over a decade. Metso PTI have been involved with many of these projects and developed a proven methodology called Process Integration and Optimisation. The methodology involves benchmarking, rock characterization, measurements, modelling/simulation, and where required, material tracking. The rock characterization step defines blasting domains and allows different blasting and crushing strategies to be developed.

This methodology has been used in a wide range of applications from conventional circuit optimization, throughput forecasting, and greenfield operations. For existing operations, significant increases in performance have been realized through the application of this methodology.

PTI have successfully developed an ore tracking system for use in both open pit and underground mining operations. The tags are used to track ore as it flows from the blast to the downstream processes. This ensures that the spatial origin of material being processed is accurately known at all times and that important ore properties are able to be tracked. The use of RFID tags in this manner also allows the estimation of other operational parameters such as ore dilution, stockpile residence time, and segregation.

PTI has successfully incorporated a smaller or 'mini tag' into their SmartTag™ system. The changes to the system installation are minor and increase the reliability of the system as a whole. In several examples the mini tags have proven to be, on average, more robust than normal sized RFID tags.

PTI envisage that the successful incorporation of the mini tags into the SmartTag™ system it will allow applications for the system to be expanded. These new applications could include a wider use in the iron ore industry, where size is the critical material quality. PTI is now working on proving the reliability of the next size of tags, the even smaller 'micro tag', which can pass through a 10 mm mesh screen.

With the decreasing size of RFID tags and the development of SmartTag™ into a truly distributed system SmartTag™ can be extended past the mine to cover the whole minerals supply chain. Detection points can now be located in the plant, the port, and even at the location of the customer, such as the feed to a blast furnace.

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Dr. Erik Isokangas manages the Process Technology & Innovation (PTI) Centre for Europe, Russia / CIS, the Middle East, and Africa, developing the PTI business in this region and providing local support for consulting, research, and innovation systems.

Erik graduated in 1996 with a doctorate (PhD) in process control in the mineral sands industry from the JK Mineral Research Centre, University of Queensland. He also holds a Bachelor Degree in Electrical Engineering from the University of Queensland.

Over the past 20 years in the industry, Erik has worked for companies such as BHP Australia Coal, Thiess Pty Ltd, and Ground Probe in Australia, and Hochtief in Germany. He has had a wide variety of roles including: the development and delivery of various mining technologies, project management, consulting, and information systems management.

Erik has also specialised in simulation and modelling, particularly in material handling systems and construction planning, developing unique solutions that are used on mine sites to solve complex delivery issues.

Dr Birol Sönmez, *PTI Manager – Turkey*, Metso

Birol Sönmez joined Metso at the end of 2010 as Manager of Process Technology & Innovation for Turkey. He manages the regional centre, which will provide local support for consulting (continuous improvement and asset optimisation activities), internal R&D and innovation systems (hardware and software).
He is responsible for collection of process data from industrial mining plants as well as application and development of mathematical models and simulations for the process Integration and Optimisation projects.

Before joining Metso, he was employed at a number of companies at which he acquired experience in plant audits, sampling, mass balancing, modelling and simulation of the mineral processing circuits -totalling more than 15 years of experience. He has been involved in several mineral processing projects and gained site/practical experience in quarry and beneficiation plant operations improvements.

Birol joined the mineral processing department of Hacettepe University in Turkey as a MSc student in 1989. He attended to three of postgraduate courses, namely "Computer Applications in Mineral Processing", "Instrumentation Control and Modelling in Mineral Processing" and " Mineral Processing Simulation". He also worked as research assistant in the department from 1989 to 2000. He assisted mineral processing lectures laboratories and supervised final year dissertation projects.

In 2000, he spent eight years at Eregli Iron & Steel Works which is the largest iron and steel company in Turkey as a R&D Engineer and Chief of Supply Strategies. During his time at Eregli, Birol managed several waste utilization research projects and gained valuable expertise in developing strategies for the purchasing steel plant raw materials.

In 2008, Birol worked at Demirexport Copper-Zinc, Iron, Chromium and aggrega operations as a head of Process Technologies, taking part in projects for optimization of the crushing, grinding and flotation circuits, and aggregate production plant. In addition he was in charge of the metallurgical evaluations of all the production circuits contributing to the continuous improvement of the process.

He got his PhD from the University of Hacettepe, Turkey in 1999 with a thesis titled "development of a simulation package for coal washing plants".