ShovelSense Automated Smart Truck Diversion

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ABSTRACT

The mineral and metals industry can be accurately described as a "large" industry. However, this term does not only apply to the daily tonnage of ore that is moved globally, the size of the equipment that is used, or even the substantial number of unique operations around the world. The term "large", when applied to mining can also refer to the impact that it has on every other industry, and the increasing challenge to deliver more metals, faster, and cleaner.

The metals produced by the mining industry are prevalent in all technological breakthroughs that have emerged over the recent years; from the smartwatches around our wrists, electrification of vehicles and infrastructure, to the smart factories used in manufacturing. The demand for metals is increasing, contrasted by the declining grades mines are experiencing globally. Mines need to innovate to remain viable. Over the last decade, as other major industries modernized to embark on the upcoming Fourth Industrial Revolution – "Industry 4.0", the mining industry continued to rely on traditional methods. Recent innovations, such as drones and improvements to machinery at the mill have provided a step in the right direction but have failed to provide the massive improvements needed. MineSense's ShovelSense "smart shovel" technology uniquely operates at the mine face characterizing and sorting ore at the start of the mining process and is capable of delivering the transformative, breakthrough step-change mining needs right now.

ShovelSense provides real-time XRF-based grade information with each bucket at the point of extraction and seamlessly integrates into an operation's fleet management system to enable game-changing automated smart truck diversions that instantly route trucks to their proper destination: crusher, blended stockpile, or waste dump. ShovelSense recovers ore from waste and waste from ore by the truckload. Massive improvements to efficiency are realized with recovery and reduction of dilution in the kilotons, significantly impacting profitability and sustainability.

INTRODUCTION

Since their first commercial deployment in 2019, MineSense Technologies Ltd. has emerged as a leader in the mining industry's transition to "Mining 4.0", by offering "game-changing" technologies to mines around the world. Based out of Vancouver, Canada, MineSense is a sensor-based ore sorting and data analytics; clean-tech company, which provides detailed ore characteristics and material classification at the extraction face. MineSense achieves this using their advanced X-ray Fluorescence (XRF) based product line installed along various stages of the mining process.

ShovelSense® is MineSense's flagship product that adapts delicate XRF Sensors to the needs of the rugged metals industry by installing them directly to the buckets of mining shovels. Product development teams from MineSense designed ShovelSense to not only withstand the impact of material flowing into the bucket but to also be fully customized to fit the broad range of loader models utilized at many sites. This adaptability includes successful installations on electric rope shovels, hydraulic shovels, and front-end loaders from most leading manufacturers. The advantageous placement of ShovelSense's sensors allows for bucket filling cycles to become full data collection events, unlocking a wide array of use cases throughout their operations.

For applications downstream of the extraction face, MineSense offers BeltSense®. Utilizing the same XRF sensor technology as its counterpart, BeltSense® offers on-belt material data with its installation above conveyor systems. Like ShovelSense, BeltSense saves the burden of expensive conveyor system upgrades, by its ability to be scaled and retrofit to all existing systems. Material characteristic produced by the conveyor-mounted system allows for better control at the mill and the potential to adjust reagent concentrations accordingly.

When pairing the data from the two powerful systems together on the MineSense Digital Platform, sites gain a greater understanding of their material as it moves from the extraction point, all the way through to the beginning of the milling circuit.

THE SHOVELSENSE SYSTEM

MineSense's ShovelSense® system measures a range of element grades such as Cu, Fe, Ni, Zn, As, and other mineral elements in real-time, using a system of proprietary hardware, software data analytics, and algorithms.[1]

Bucket Application Package

ShovelSense application packages installed on the loader buckets consist of sensor heads, a Sensor Processing Unit (SPU) and various cables contained within a protective steel housing. The sensor head is the primary component of the system, containing the XRF emitter and detector as well as a laser (*Figure 1*). Depending on the bucket configuration, the application package will consist of multiple sensor heads to ensure the reliability of the system, as well as maximum coverage of the material entering the bucket. Data from each sensor head is individually recorded, then connected to the SPU (sensor processing unit) that converts the individual channels from each head into one aggregated stream.

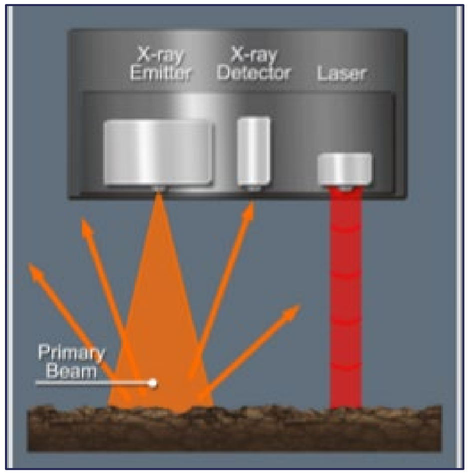


Figure 1: Diagram of MineSense sensor heads

MineSense Edge Controller

The MineSense Edge Controller (MEC) is a powerful computer located in a panel inside the shovel housing (*Figure 2*). The MEC aggregates the results provided by the SPU and converts the measured element peak intensities to truck grades using the dynamic grade prediction algorithm. The MEC transmits predicted grades to the local fleet management node for automated truck diversion decisions, (if configured to do so), as well as to the machine operator via a Human Machine Interface (HMI) inside the shovel cabin. All results are also stored on the MEC until they are transmitted automatically to the MineSense cloud database via the mine network. The client portal –available to each client as part of the MineSense digital platform– receives the results and makes them immediately available to other mine personnel.

Figure 2: MineSense Edge Controller; Installed inside of shovel house

ShovelSense Functionality

Activated by the loader that the system is installed on; the various ShovelSense components create a rapid series of events allowing each bucket filling cycle to become a robust data collection event.

Prior to the loader’s bucket filling, the x-ray emitter and X-ray detector are placed in a stand-by status, while the adjacent laser is continuously taking distance measurements inside the bucket. As digging commences, the laser detects the material flow into the bucket at which point the emitter and detector are signaled to initiate data collection. The sensors continuously collect element peak intensity data until the bucket completes filling, at which point stand-by status resumes.

The element peak intensity data collected from the sensor heads is pushed to the sensor processing unit (SPU); mounted on the back of the back. Once data is received by the SPU, individual spectra from each of the heads are aggregated into a single spectrum (*Figure 3*) and made available to the MEC panel where MineSense proprietary algorithms perform necessary grade and classification calculations for the truck.

The analysis performed on the data once the bucket has completed filling is instantaneous and provides the results needed for subsequent actions. MineSense geoscience, solutions and data teams work alongside site personnel to determine viable use cases, applications, and actions to follow the result determination. Most often this consists of pushing the material classification to the HMI panel in the cab of the shovel, as well as to the MineSense cloud server and site Fleet Management System (FMS) via the mine’s wireless network. The ability for ShovelSense hardware and software to provide material classification immediately to the site FMS, creates the opportunity to divert misclassified truck loads in real-time.

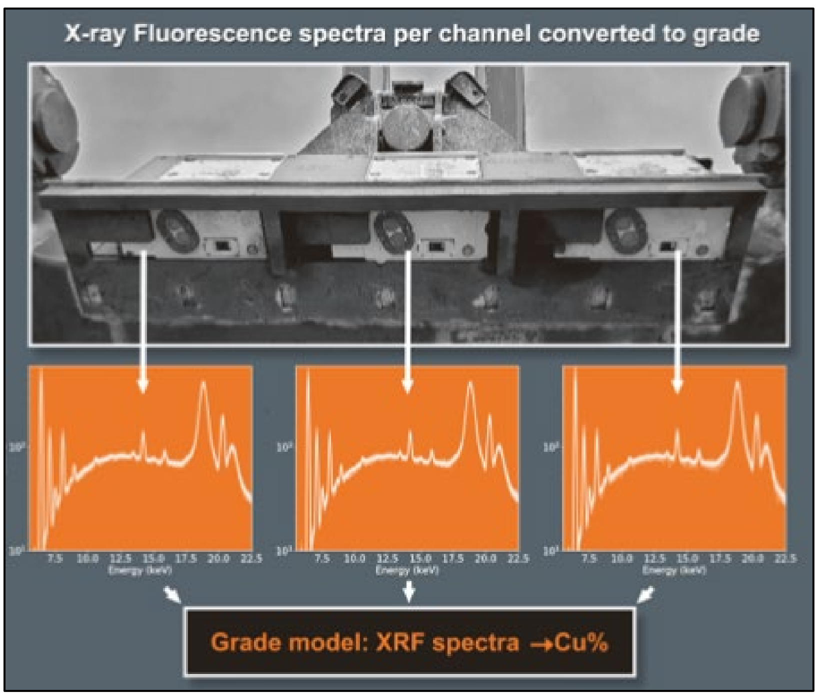


Figure 3: X-ray fluorescence spectra per channel converted to grade

SHOVELSENSE TRUCK DIVERSIONS

Fleet Management Integration

Data collected from each of the buckets are aggregated to produce a final classification or routing destination for material loaded in the bed of the receiving haul truck (*Figure 4*). Material designations can be configured by various methods. Often, sites will provide simplified cutoff grade values that will signal the system to classify the material as “Ore”, or “Waste” dependent on the calculated grade. Although, material classifications performed by ShovelSense are not limited to simplified Ore/Waste determinations but can be tailored to meet individual clients' requirements. Material designations can be configured to include grade bins (ex. High grade, Medium Grade, Low grade) as well as to differentiate between acid generating waste and non-acid generating waste. If more complex net smelter return (NSR) calculations are required for routing, MineSense algorithms have the capability of utilizing the necessary blasthole and block model data as a secondary input for the classification result.

Following the determination of the material classification or routing, MineSense provides an API connecting the ShovelSense results to the individual operation's FMS system. With the flexibility provided by the API, ShovelSense has successfully integrated with FMS systems from Caterpillar, Modular Mining, Wenco as well as other vendors and in-house systems to ensure that trucks are routed to the proper location.

TRUCK ID	ORIGINAL MATERIAL TYPE	SS MATERIAL TYPE	CLASSIFICATION
252006	HG	HG	Aligned
252007	HG	HG	Aligned
252008	HG	HG	Aligned
252009	HG	HG	Aligned
252010	HG	HG	Aligned
251992	WSTE_NAG	HG	Ore from Waste
251993	WSTE_NAG	HG	Ore from Waste
252012	WSTE_NAG	HG	Ore from Waste

Figure 4: Example dataset comparing ShovelSense material classifications against original site classifications

Truck Diversion Use Case Examples

When provided the ability to reroute trucks in a critical time of their operation, the sites utilizing ShovelSense have unlocked tools needed to mitigate operational challenges that directly impact production. Determining the best use cases for the technology is a team effort consisting of site representatives alongside MineSense personnel to assess these individual challenges and implement the most advantageous use cases.

Ore Loss

The ability to reroute mineralized material from the waste dump to the mill is a use case that is commonly exploited for the economic and productivity benefits that are generated. Referred to as "Ore from Waste", this ShovelSense use case alleviates the common challenge of reducing ore loss. Ore losses can be defined as any unrecoverable economic ore or any material that is not recovered using the mineral processing system (Marinin & Marinina & Wolniak, 2021).

Many factors, individual to each operation, can lead to the erroneous routing of economic material to the waste destination. Contributing factors include but are not limited to orebody complexity (heterogeneity), blasting practice/movement, and grade interpolation limitations amongst many others. Previously, the one common method to combat high ore loss percentages consisted of understanding the primary causes using reporting and periodic reconciliation, then applying the gained knowledge to implement operational actions to help lessen the impact of these causes. Although well-executed operational changes can help reduce ore loss, for established operations they are generally only considered once ore loss has already become an issue and the value has already been lost.

By introducing ShovelSense technology, operations have achieved greater control of their ore, and have been able to stay one step ahead of ore losses. In fact, ShovelSense excels in complexity - when the natural and operational challenges leading to ore loss are greater, deploying ShovelSense becomes even more advantageous. These advantages have been proven time and time again with systems currently navigating through complex orebodies, successfully identifying and detecting economically valuable ore that has shifted into waste zones during blasting and overall providing a much greater resolution than traditional block modelling alone.

Dilution

Many of the same challenges that contribute to operations having a high ore loss percentage are also responsible for the site's dilution percentage at the mill. Dilution is defined by Câmara & Peroni as "the incorporation of waste material to ore due to the operational incapacity to efficiently separate the materials during the mining process, considering the physical processes, and the operating and geometric configurations of the mining with the equipment available" (Câmara & Peroni, 2014). Like ore loss, operations can gain control of the dilution at the mill through the diversions provided by ShovelSense. The benefit of both these use cases becomes more apparent when MineSense data teams provide visual representations of the individual truck diversions that are occurring at the face (*Figure 5*).

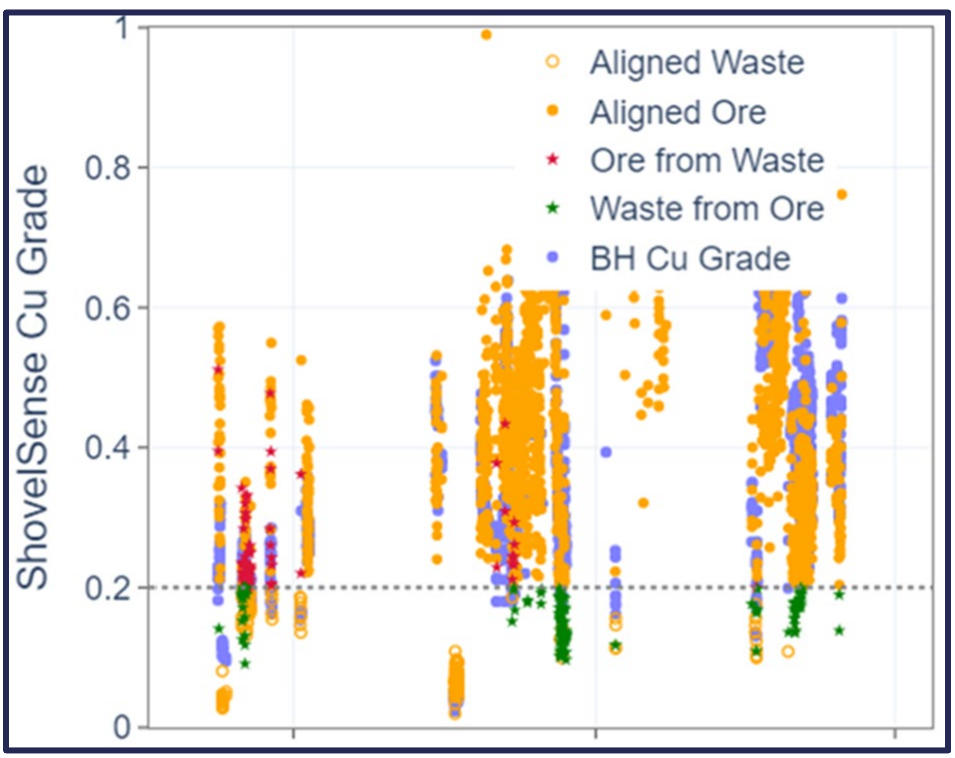


Figure 5: Example graph displaying ShovelSense truck diversions

Truck Diversion Case Study – Copper-porphyry Deposit

Recently, MineSense's ShovelSense system was deployed at a copper-porphyry mine in South America. During the initial 80 days after commencement of the system, results were collected from a shovel mining on a single bench, then analyzed by data science teams and compared against original mine plans. The study period yielded results from three distinct areas that allowed operations to identify sources of waste dilution and ore loss through the detection of truck diversion. (*Figure 6*)

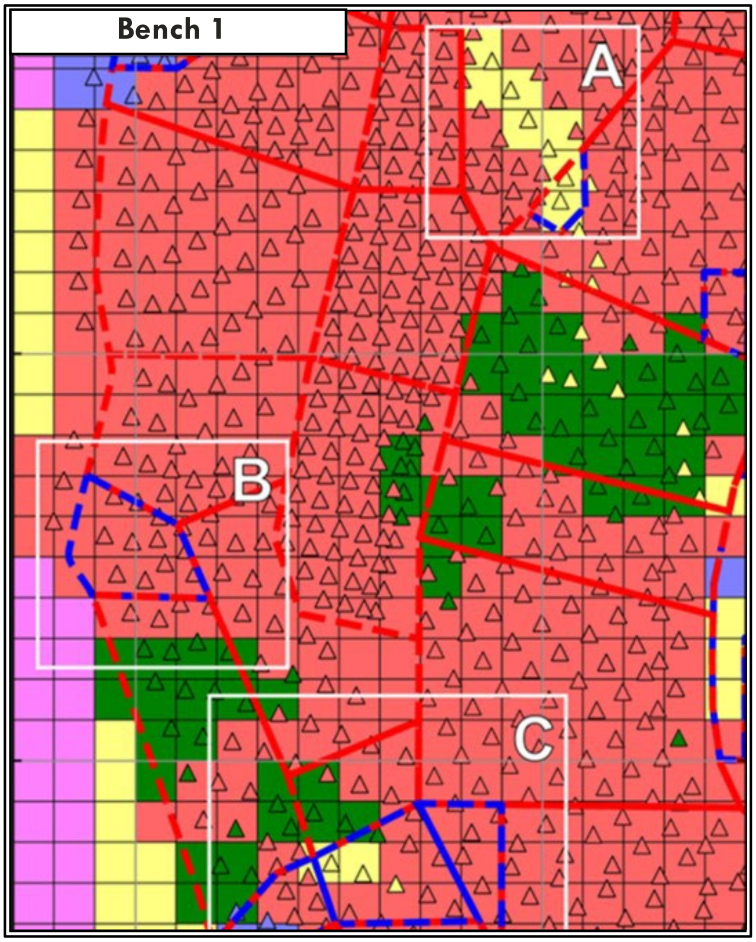
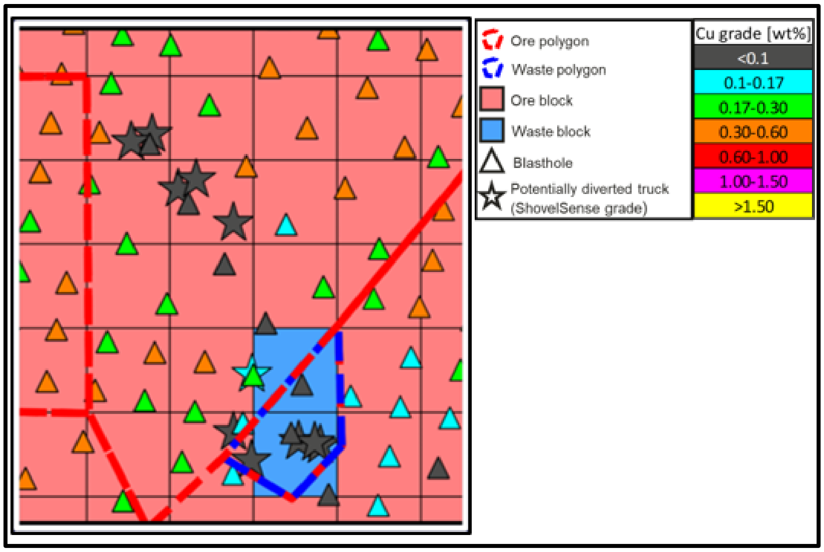
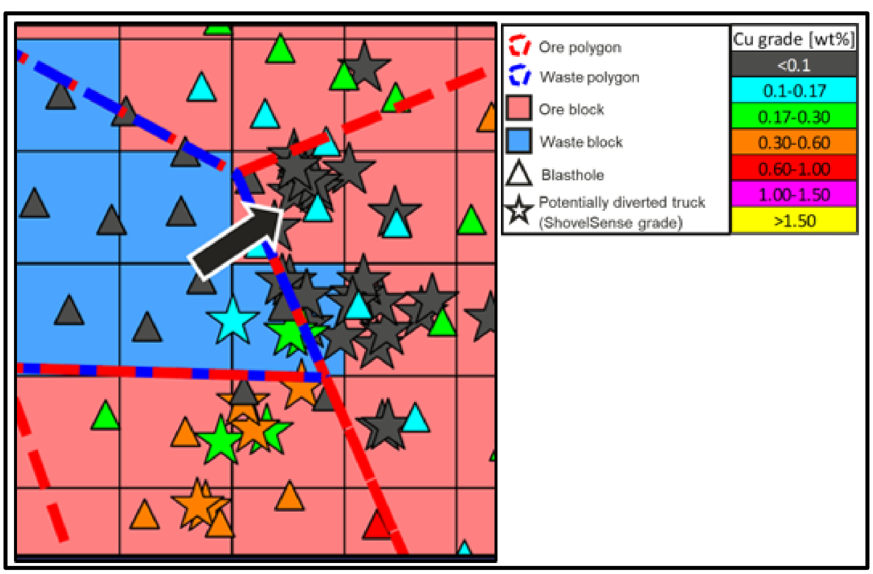


Figure 6: Depiction of shovel digging area. Areas labelled "A","B","C" display focus areas causing high number of detected diversions

During the trial period, ShovelSense was able to identify various regions that contained waste material that was originally classified as ore. The specific zone displayed (*figure 7)* is an example of a zone that included "Ore to Waste" diversion due to the complexity of the orebody in the region. When the diversions were evaluated, it was concluded that a large barren dyke was present within a mostly mineralized zone. Although site geologist has successfully identified an isolated area of barren waste material within the mining area, the limitations caused by blasthole sample spacing and traditional modeling did not allow them to see the true extent of the formation. This specific area yielded 15 total trucks that were identified as potential ShovelSense diversions.



ShovelSense benefits are not only limited to areas containing high heterogeneity within the orebody. As mentioned previously, many operational challenges also have a contributing factor to the diversion identified by ShovelSense; including the blast movement visualized in figure 8. Unlike the previous example where diversions were caused by incorrect classifications due to the unseen natural formations of the deposit, this example was determined to be an area that was correctly classified but still contained many diversions. When the root cause was evaluated, it was found that operations had encountered blasting difficulties leading to inefficient shots inadvertently being fired within the zone. This did not present an issue for the ShovelSense system, as ~35 total potential diversions were identified; consisting of both "Ore from Waste" and "Waste from Ore" reroutes.



The conclusion of the study period resulted in the evaluation of 6270 trucks. Of these trucks, it was found that ShovelSense was aligned with the original mine plan's "ore" truck classification in 3833 (61.1%) instances. Similarly, ShovelSense aligned on site Waste classifications in 1740(27.8%)

instances. When trucks that that did not align on classification were evaluated, it was found that the payload grade did not meet minimum cutoff for 294(4.7%) of trucks that site had originally classified as Ore. Likewise, grade was above minimum cutoff values for 403(6.4%) of the trucks that had originally been classified as waste; resulting in ~11% of the total trucks studied identified as misclassifications.

CONCLUSION

MineSense's ShovelSense technology is leading a new era in digital smart mining by making a difference to mining operations starting at the extraction face. ShovelSense ore characterization empowers mining operations to maximize the full potential of their ore body, by measuring and understanding it in real-time by the bucket. From there, informed, automated truck routing and be conducted to minimize ore loss and dilution significantly. In an 80 day evaluation, ShovelSense diverted 11% of total trucks resulting in kilotons of high-value economic material recovered and additional revenue exceeding $2M USD.

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