Optimizing the Metal Flow Process in a Copper Production Plant by Employing a Technology Framework

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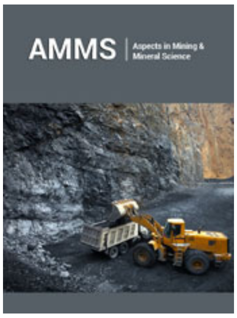

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Abstract

The mining and processing of metal ore is spread over a large range of activities from metal content estimation to processing and refining. The sub activities encompassed within these broad activities though, are independent. However, since they are sequential and the output of one activity becomes an input to the next activity, accurate mass and metal content transfer becomes mandatory at each point. The AMIRA P754 code for metal accounting is considered the standard for accurate and reliable metal accounting. Still, it is difficult for industry to fully implement codes like these because of the lack of reliable software tools and digital technologies for data collection, verification, storage, and analysis required for mine and plant metal accounting. There is therefore a need to develop an integrated system that will help with improving the metal accounting process for better compliance with the AMIRA code. This paper presents a conceptualized digital framework that enables collection and analysis of data from the processes, mandatory for correct application of AMIRA P754 code to improve accuracy in estimation and reporting. Such a system will help with improving metal content estimation, mine planning, understanding ore and metal flow, reducing losses and reduce discrepancies along the process.

Keywords: Metal accounting; Ore flow; Copper mining; Amira code; Planning

Introduction

The data collected during ore flow at a mine contains valuable information along the mining value chain, provided it is reliable and accurate. This data is collected at various stages through sampling, sample analysis, measurement of moisture, mass, density, etc. The AMIRA P754 code is the generally accepted standard providing guidelines to improve metal accounting and reconciliation of discrepancies AMIRA, 2007 [1]. Without such a standard the metal accounting system lacks credibility and is a continuous source of frustration for mine and plant managers. The reason is that without standards, reconciliation and investigation of discrepancies, metal accounting reports lack problem ownership and traceability. Large inconsistencies between data collected at different stages due to false capturing at one or more stages often affect production planning, cause shortfalls and loss of income planned for. The AMIRA code of practice emphasizes the use of digital systems for data collection, data entry, data storage, and analysis purposes. It not only reduces the potential for human error, but also helps in keeping important data organized on proper digital databases and software platforms. The timely collection of data and access of data to the concerned persons is therefore of prime importance. Usually there is a delay in data transfer from one processing stage to another. Digital tools are currently being used to provide a metal balance solution for the mine and plant, but it is often being done separately and in isolation. Furthermore, the flow of information between different processes in the mine and plant is limited and usually delayed without real or near real time digital systems. To address this issue, a digital system has been conceptualized in this study, which will help in data collection, analysis, and timely access of data to assist management and to improve planning. This paper describes the typical ore flow in a mine and plant, suggest how the process could be digitalized and propose potential points of data collection from the mining face to the final product. A case study of copper processing has been used for this purpose.

Overview of Copper Mining and Processing

The process of mining and processing of ore is spread over a long range of activities and have been outlined in the mining value chain by Guj et al. [2]. The mining operations after the extraction of the ore differs depending upon a number of factors, such as the type of mining, scale and fracture size, distances and modes of transport to the plant. In underground mines, the ore starts flowing after blasting and follow a complex geometry until arriving in development where it is transported horizontally to tipping points for vertical migration to a single point from where centralized loading or hoisting takes place for transport to the surface of the mine. This system is repeated for all levels of production, providing for a complex mix of material and dense stream of moving rock on multiple levels at the same point in time. These duplicate streams eventually merge to form a single feed to (crushing, milling, concentrator and/or smelting) plants for immediate treatment and/or stockpiles for later processing. The mode of transportation on the surface depends on the distance between the shaft (or stockpile at the shaft) to the plant. If the plant is near the stockpile, the ore is loaded (tipped in the case of a vertical shaft) onto conveyer belts by front end loaders and if the plant is far away, transportation is normally through a combination of conveyers, trucking and rail. The processing methods also differ depending on the type of ore being processed. For copper the main processing streams that follow the concentration process, are froth flotation and pyrometallurgical and hydrometallurgical processes. In pyrometallurgical processing, following the froth flotation process, the ores are processed by roasting, smelting, converting and finally casting of anodes. The cast anodes are then electrolytically refined to form 99.99% pure copper, which is then casted in bars or wires according to market specifications. Pyrometallurgical processing is used in the processing of approximately 80% of copper. In 2014, 14.2 million metric tons of copper were produced through pyrometallurgy, while 4.1 million metric tons was produced through hydrometallurgical processes [3]. Therefore, for the case study in this article the authors used the pyrometallurgical route of copper processing as the case study.

Typical ore flow in a mine

The mining phase of the mining value chain follows the exploration and mine development stages. The efficiency of the mining cycle is therefore dependent upon the accuracy of ore body modelling and evaluation during exploration and quality of the mine design that happens during the mine development stage. The mine design parameters then feed into short-term planning and scheduling during the production phase of the mining value chain. In order to reduce waste material, the mine plan is further refined using layouts that take a more detailed account of micro conditions and mine health and safety standards. Further complexity is added during execution of the layout and plan during rock breaking, cleaning and transport of the broken rock. One of the reasons for this complexity is the duplication of steps involved in a complex three-dimensional geometry. The causes of this complexity were described by Hills [4] as:

a. Multiple mine faces;
b. Large number of shafts and pits;
c. Different processing plants;
d. One plant receiving ore from different mines;
e. Production losses due to ore dilution;
f. Inefficient plant process; and
g. Different ore storage points.

To counter this complexity, a systematic approach is required for the metal content determination [5]. Cawood [6] classified the losses as real and apparent loss. Apparent losses arise due to issues such as overestimation of metal content, inappropriate sampling standards and application of incorrect relative densities. Real losses are actual physical metal losses such as losses during tramming, hoisting, extraction etc.

Ore transportation

Ore transportation is the next step after mining in the value chain. The choice of correct transportation method is important for the smooth running of a mine. The selection of transportation facility for an underground mine depends on the following factors [7]

a. Ore reserve;
b. Production capacity;
c. Underground mining methods;
d. Ground conditions;
e. Thickness, depth and dip of ore body;
f. Life of mine plan;
g. Amortization;
h. Discount rates;
i. Development schedule; and
j. Price of equipment.

During transportation, loss of ore can also occur generally due to spillage, cross tramming and theft. To reduce such losses, better tracking of ore is required.

Ore flow in the plant

The metal losses in plant processes, apart from the errors in measurements, are first dependent on the quality of the information describing the plant feed, and second, correct monitoring of measurements along the processes. In addition, the efficiency of the plant depends on ore fragment size (as affected by rock breaking and transport methods). Reduction in fragment size further increase the potential for loss and more dilution. It is therefore important to carefully monitor fragment size to ensure that it complies with plant requirements. Similarly, particle size is an important factor for the optimization of the froth flotation process. The fine particles increase froth stability by enhancing the rigidity of bubbles in the flotation column. The effect of particle size on a flotation process in the Barrick Oborn copper concentrator was studied by Crosbie et al. The study showed that the efficiency of the flotation process is maximized when the particles' size range from ultrafine (1CS5) to 53µm and considerably low outside the range. 1CS5 is the classification that refers to the particle size of 8 micrometer.

Importance of reliable metal accounting

The process of metal accounting provides vital information to mine management and corporate offices. Metal accounting practices differ from mine to mine and plant to plant. The process relies on information from different sources that are merged along the flow. This information is used as an indicator of mine and plant performance. It also assists in mine planning and adjusting plant parameters. Apart from the internal usage, this data is also reflected in the financial accounts of the company [8]. Another factor that emphasizes the importance of the reliability of metal accounting is the introduction of treatment plants that do not operate under a single organisation. The ore products are sometimes sold at various stages of processing to different markets. Therefore, the knowledge of the exact value of metal present in the ore becomes critically important because it affects revenue streams. The ore processing is then divided into different markets. For example, matte produced in plant A may be sold to plant B for further processing. The purchaser of matte needs to know the exact value of copper in the matte and the quantity of matte being transported. Therefore, it is important to have accurate data collection, reporting and analysis facilities in an organization. The general practice in the mining industry is to carry out metal accounting to cater for production and other requirements such as custody transfer, which transfers further affect state royalty payments, rollovers and taxable income. The issue with this practice is that it is difficult to do it to a high level of accuracy. The typical reasons and issues with current metal accounting practices are [1]:

a. Lack of knowledge and understanding of the principles of mass balancing and metal accounting;

b. Lack of suitable measuring and sampling equipment;

c. Last minute and ill-considered installation of equipment which is required for accounting purpose;

d. Inadequate design of equipment;

e. Poor operation and maintenance of equipment;

f. Technical capacity and staff of laboratory facilities;

g. Accuracy and timely reporting of results; and

h. Lack of protocols for metal accounting.

Case Study

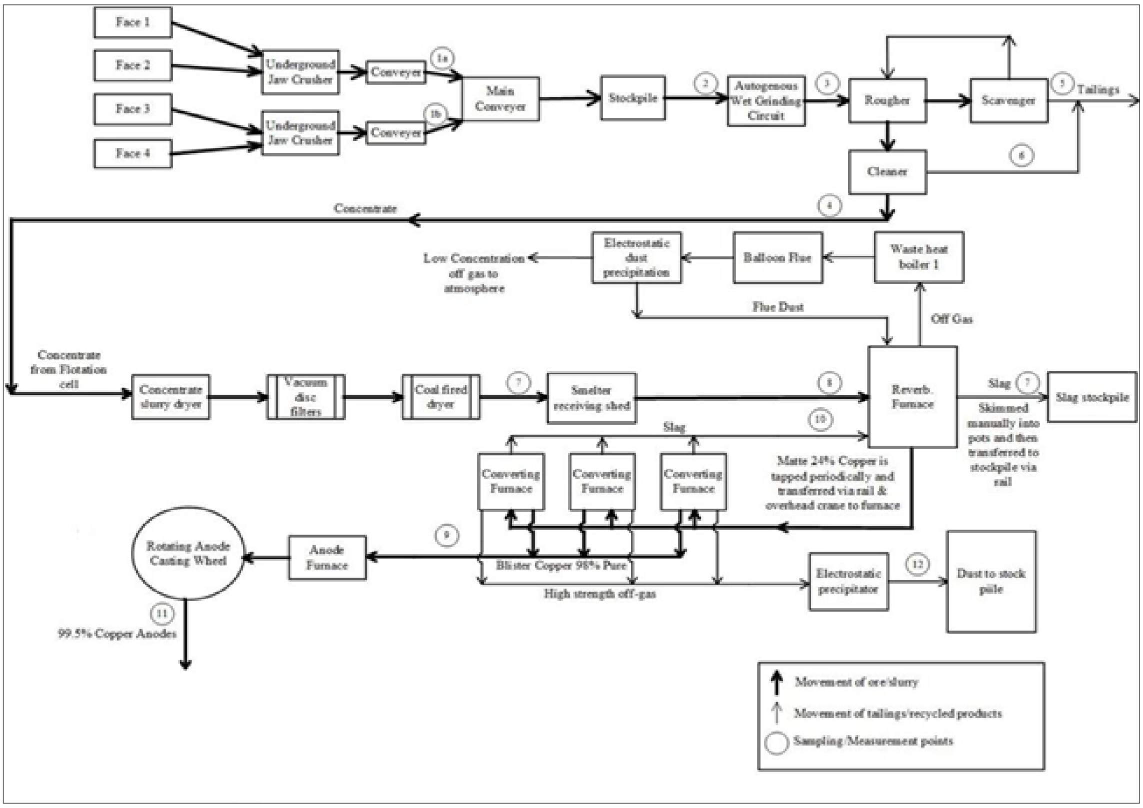


Figure 1: Ore flow of copper mine and plant [10].

A typical process flow of a copper mine and plant is shown in Figure 1. The idea is to use a hypothetical case study to analyze the ore flow in the overall process. The proposed points of measurement and sampling are also shown in the (Figure 1) and are selected in accordance with the AMIRA P754 code of metal accounting. The plant is producing copper anodes by refining ore through a pyro-metallurgical process. For metal accounting purposes, the smelting and conversion process are considered as one step. The ore flow, sampling points and analysis method are discussed below.

Mining

Copper ore is extracted from an underground mine. The mining face is sampled for the ore grade and waste dilution is calculated from survey measurements. The ore from four underground mine faces are fed to two crushers. The ore from the mining stope faces 1 and 2 is fed to crusher one and ore from faces three and four is fed to crusher two. These crushers reduce the size of the ore to facilitate the ore handling and movement on conveyor belts. The crushers have dedicated conveyor belts, which feed the main conveyor to the surface. The total ore mined is physically measured by a belt-weight meter mounted on the conveyor belts, which feed the primary conveyor belt, and the ore is analyzed by an on-belt x-ray analyzer on each conveyor. As a check, a mechanical sampler is also collected here for laboratory analysis. This analysis provides a cross check for the on-belt x-ray analyzer. In case of any discrepancy, the mine has a standard protocol on tolerances and how to deal with discrepancies. The face sampling also provides a check for the ore grade and the cumulative ore flow calculation as done by the survey office – typically done once or twice a month.

Stockpile

The ore delivered to the stockpile is generally measured by stockpile sampling and surveying. The opening stock, closing stock and ore delivered to the plant provides the measurements for the stockpile inventory. The ore is delivered to the plant using trucks. The number of trucks and truck factors is also used to provide an estimate of the ore delivered to the plant.

Milling

The ore transferred to the plant is measured using on-belt mass measurement. An X-ray analyzer for grade estimation and an automated sampler is used for the sample collection for ore analysis.

Froth flotation

The milled ore is dried and stored in the raw material shed in the plant. The feed for froth flotation is measured by an on-belt mass measurement scale and sampled by an automated sampler before entering the flotation cell. The rougher concentrate stream has a digital density meter, magnetic flow meter and a crosscut sampler to collect samples for metal accounting. The material is then transferred to the oxide cleaner, which then produces the final flotation concentrate. The final concentrate is then dried to feed into the roasting process. The dried concentrate is sampled and weighed before transfer while the final tailings (from scavenger and cleaner) have a multistage sample collector and an on-stream analyzer.

Smelting/Roasting

The samples are taken from each lot of dried concentrate and the mass is measured. The dried concentrate in the case study is transported using rail cars. The mass of each rail car is measured, and the mass is calculated from the total number of rail cars. For metal accounting purposes, the composite sample for each metal accounting period is used. For opening and closing stocks, the receipts of the concentrates are used. For daily measurement of feed grade, the opening stock grade and the receipt for the day provides an average grade. The reverberatory furnace slag is skimmed manually and for measurement of the slag produced, the mass of each ladle transferring the slag is measured. The slag is sampled manually using a spoon. The converter slag is grounded, weighed and sampled before it is added back to the reverberatory furnace. The slag is weighed on a belt-weight meter and sampled using an automated cross-belt sampler. The matte is sampled manually and weighed on a weighbridge. The matte is then transferred to the anode furnace using an overhead crane for fire refining and casting.

Anode casting

The anode furnace is used to remove the final traces of iron and sulphur from the matte. The melted copper is then poured directly into the mould. The anodes have relatively fine composition and physical structure. The mass of the anodes is measured using a mass balance and are sampled for laboratory analysis from each batch.

Mine to Plant Ore Flow Sheet

The metal accounting ore flow sheet developed for the case study is shown in Table 1. The ore flow sheet combines the measuring points of a mine, stockpile, froth flotation, smelting and refining processes. The tonnage, ore grade and production describe the combined ore flow as a cumulative calculation. The final cumulative average grade of copper produced from all the four faces is 3.1% in the case study. The concentrate received ore grade is 3.07% copper. The final concentrate produced by the smelter contains 28.7% copper which is lower than the theoretical value of 30% [9], probably due to the differences between the planned and actual head and feed grades. The smelter output is calculated as 98.6% blister copper, which compares well with typical grades around 99% copper [9]. The resultant smelter slag contains 1.6% copper, which is within limit of the typical slag copper concentration of 1-2% copper [9]. The final product of the smelting process is 2 947 dry tons of matte which contains 2 907 tons of copper. The final plant product is in the form of copper anodes where the mass of each copper anode is 400kg. The total copper anodes containing 99.4% copper are 7262. The total copper finally produced is 2 887 tons.

Table 1: Architecture of WMI-OFA along with the sources of data in mine and plant.

Mine	Actual (DMT)	% Cu (Actual)	Copper Produced (DMT)	Planned (DMT)	%Cu (Planned)
Ore mined (Face 1+2)	95000	3	2850	100,000	3.2
Ore received by mills	95000	3	2850	100,000	3.2
Total Ore grinded	95000	3	2850	100,000	3.2
Ore Mined (Face 3+4)	98000	3.2	3136	100,000	3.4
Ore received by mills	98000	3.2	3136	100,000	3.4
Total Ore grinded	98000	3.2	3136	100,000	3.4
Total ore mined	193000	3.1	5983	200,000	3.3
Difference	7000				
Stockpile	**Dry Metric Tonnes (DMT)**	**% Cu (Actual)**	**%Cu (Planned)**		
Ore received from mine	193000				
Ore sent to plant	150000				
Opening Stock	1000				
Closing Stock	44000				
Concentrator	**Dry metric Tonnes (DMT)**	**Cu%**	**Copper (Tonnes)**	**Recovery (%)**	
Mill received	150000	3.07	4605		
Total ore crushed	148000	3.07	4543		
Rougher Feed	148000	3.07	4543		
Rougher Concentrate	12500	20.1	2512		
Final Concentrate	10498	28.7	3012		
Cleaner/ Scavenger Tailings	137500	1.11	1530		
Smelter	**Mass (DMT)**	**Cu%**	**Cu (Tonnes)**		
Feed concentrate	10498	28.7	3012		
Reverberatory furnace slag					
Conv. Slag Concentrate to rev. furnace					
Total Smelter inputs (Actual)	10498	28.7	3012		
Total Smelter inputs (Planned)					
Blister Copper Produced (Actual)	2947	98.6	2907		
Blister Copper Produced (Planned)					
Converter slag produced					
Reverts to crushing					
Reverberatory furnace slag	7551	1.4	106		
Converter dust to stockpile					
Feed concentrate opening stock					
Feed concentrate closing stock					
Refinery		**Mass (DMT)**	**Cu%**	**Cu (Tonnes)**	
Concentrate Received		2947	98.6	2907	
Number of Anodes casted	7312				
Mass of Anodes casted		2924	99.4	2906	
Cast Anodes to recycle	50				
Total anodes produced	7262	2904.8	99.4	2887	

Conceptualization of the Digital Framework

General description

A digital system is conceptualized in this section. It will help to bridge the gap between individual information flows between different stages so that they merge into a single database for risk management and decision-making purposes. Gaps in information flow not only translate into production losses, but also limits the opportunity for the improvement in the overall process. For example, the smelting process receives data in the form of a report from froth flotation. If the mining data is unavailable to the plant manager, the smelting plant cannot adjust its settings before the concentrate arrives at the smelting plant. The digital tool will help in the analysis of the ore flow process and identify the bias with respect to the previous processes and will also assist in the mine and plant reconciliation process. The digital system architecture combines the major sources describing the ore flow, data collection points, data storage and data interpretation into one platform for analysis and decision-making. In addition, it highlights bias along the ore flow by comparing results in a real-time where discrepancies are compared with allowable tolerances and dealt with through a standard operation procedure–in this case an algorithm. The final reconciliation happens when physical plant output is compared with the cumulative ore flow calculation for the mine [10].

Architecture

Metal accounting of a mine and plant are currently carried out independently with limited flow of information between departmentalized accounting processes. Reports are prepared based on the analysed data. Presently only selected processed data is shared within a reporting template. The decision-making process is often in silos as the complete dataset is either unavailable or not provided in time for intervention. The current and proposed processes are shown in Figure 2. The proposed framework will allow the collection and storage of all the data from the mine and plant on a central server in a single database for analysis by all departments. The gathered data can then be visualized, analyzed, and used for a mine-wide reporting and decision-making. Where there are several mine shafts serving one plant, the individual servers can be connected so that data can still flow without human intervention. The proposed approach will increase transparency and help with reporting, system auditing and reconciliation of discrepancies. Automatic data collection will also allow recording and tracking of the data trail. The proposed system (named WMI-OFA (Wits Mining Institute Ore Flow Analyzer) is illustrated in Figure 3. The data gathered from the measurement points and sample analysis, all stored on the server, will be analyzed against allowable tolerances to reduce bias, variance calculations and data adjustments. With metal content known at all locations along the ore flow, calculations can easily be extended to include metal prices and costs for financial reporting purposes. All of this can happen in almost real-time and according to responsibility areas for investigational and correctional and decision-making purposes.

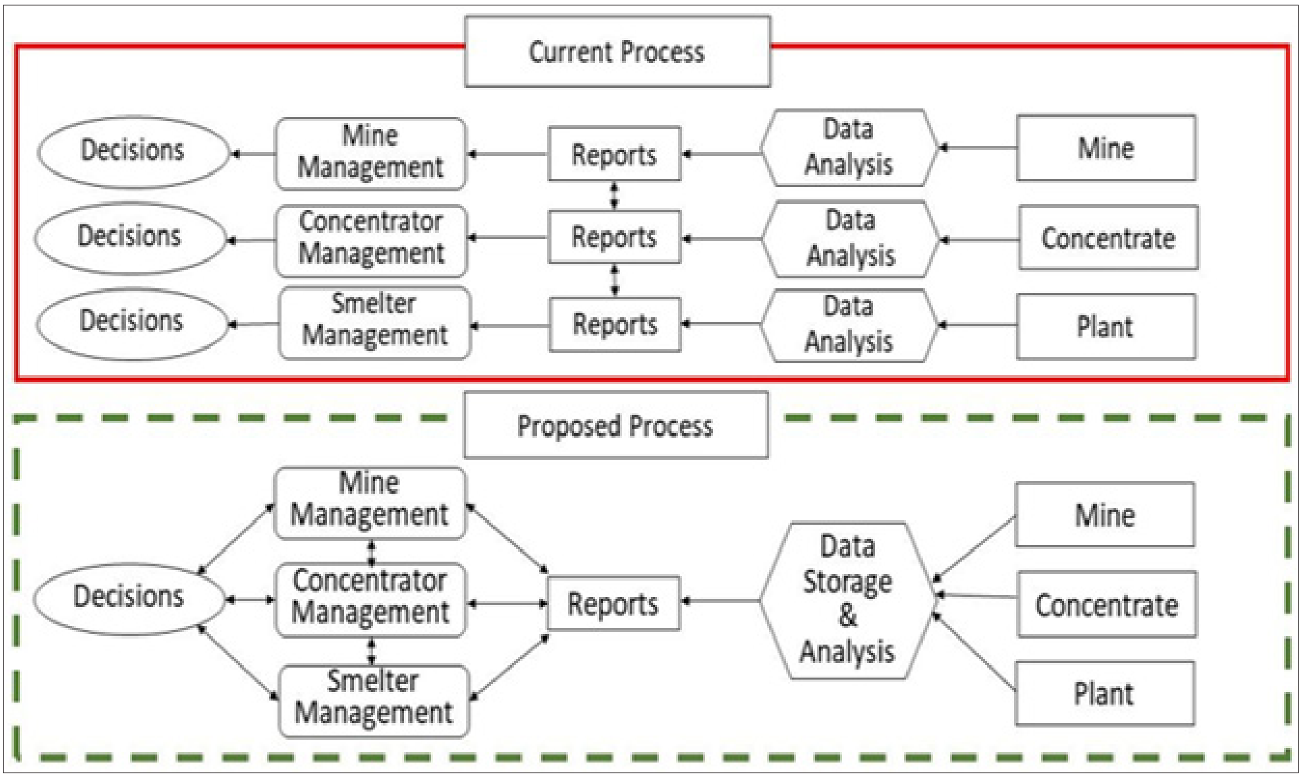


Figure 2: Current and proposed method of data collection and analysis in a mine and plant [10].

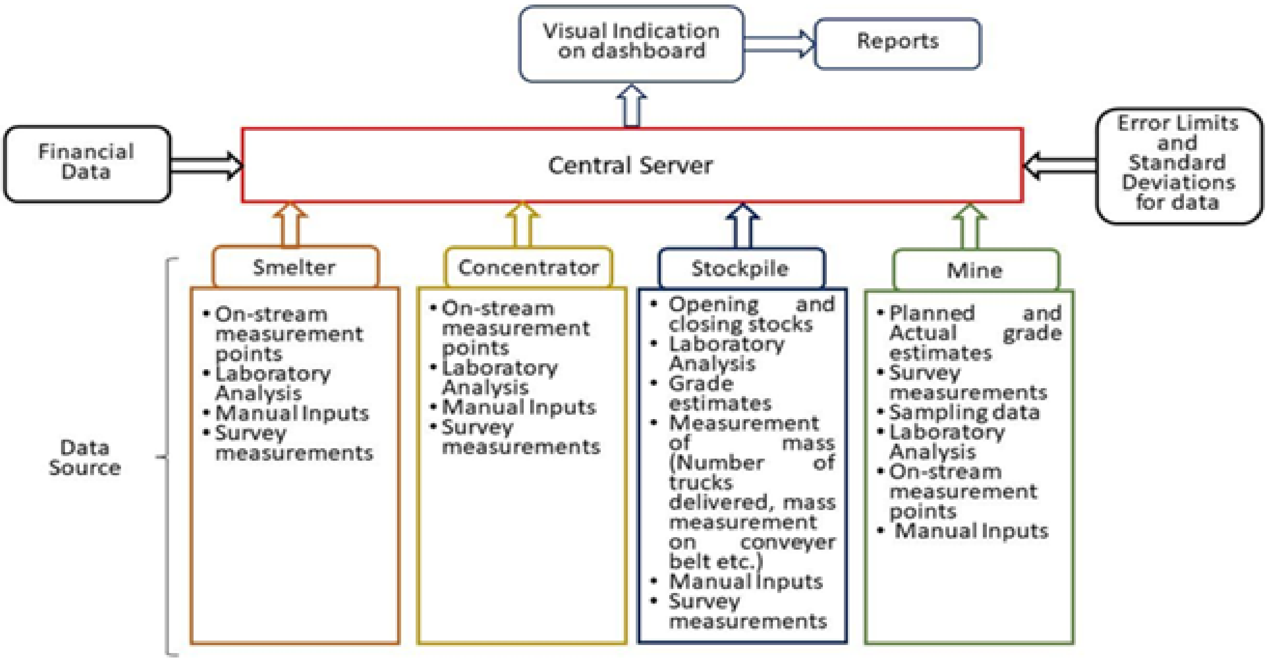


Figure 3: Architecture of WMI-OFA along with the sources of data in mine and plant [10].

Data acquisition

The data in the mine and plant is generated through different sources. It is important that the data from all sources should be collected and stored in the central server as shown in Figure 3. The major sources of data that are proposed for the storage in the server are outlined under each section and are also discussed under the following headings:

Mine

Planned and actual grade estimates: Planned production and grade estimates are stored in the database from the mine planning and scheduling information on production estimates. By doing this, mine managers will have a better indication of mine plan compliance on measuring day. The points of difference between the actual and planned values on any variable is calculated by and explanations on any variance can be explained by the interrogating the database of the system.

Survey measurements: Mine survey results provide an estimate of the tonnage mined from a specific area of the mine. It is already standard practice to compare survey tonnage along the material flow with the actual tonnage fed to the plant. Currently, this is happening once (sometimes twice) a month. A digital system is able to do such calculations more frequently and on any point-in-time of the month.

Sampling data: Sampling information is already captured and will therefore be easy to add to the system. Apart from such traditional sampling information, it will be much easier to integrate information from mechanical samplers and digital scanners doing grade estimations and separating waste from ore streams. The following data can typically be stored:

a. Sample name and identification (id);

b. Location of sample, date and time;

c. Purpose of sampling and standard criteria e.g. size;

d. Density and moisture content;

e. performed photo with measurements;

f. Maintenance and calibration records of mechanical and digital equipment, along with IP addresses;

g. Laboratory that did the analysis; and

h. Laboratory results.

i. Laboratory analysis results

The Laboratory Information Management System (LIMS) database must also be connected to the central server so that the system is automated. The sampling points for metallurgical accounting are outlined in Figure 1. The confidence limits of the analysis should be a part of data transferred to the database. These limits can then be used in the analysis and propagation of variance.

On- stream measurement points: The measurement of mass in a mine and plant is important as it is one of the major inputs of production during mining and processing. The mass measurement data should be automatically transferred from the measuring instruments to the database. The measurement devices are usually connected to the plant and mine management systems. If the necessary information for metal accounting is gathered in this way, the system is automatically integrated with the metal accounting tool. The data from on-belt analyzers in the mine and the plant is then stored in the database relative to the mass flow. For example, if the tonnage is being recorded on an hourly basis, then the ore grade should also be stored for each hour.

Manual inputs: These should be minimized but allowed for in the system in cases where automatic data capturing is not possible. This provision allows for flexibility of the system in certain unforeseen conditions. In case of manual inputs, there must be a proper record of the person entering data and it should also be reviewed and approved by a competent person.

Stockpile

The material movement in stockpiles has to be monitored and the information stored in the database. The ore received by the stockpile, ore delivered to the plant, number of trucks, mass of each truck, stockpile name/number, opening stocks, closing stocks, and ore grade in stockpile, are some of the variables that must be stored in the database. It is important that each of these activities have protocols so that the confidence in measurements can be understood. The source of the ore should also be mentioned if the mine has different stockpiles for different faces or different ore grades. For example, for the mine considered in this case study, it is assumed that faces one and two (Group 1) are mined in one shift while Faces three and four (Group 2) are done in the subsequent shift. The ore is also collected in two different stockpiles so that the origins are known.

Concentrator and smelter

The measurement and data collection strategies for concentrator and smelter outlined in Figure 3.

Data storage

The data stored in the relational database system should have the following attributes while being stored in the database:

Unique data name: The data name is a reference number assigned to each data entry into the database. This number is usually a combination of alphabetical and numeric values. It has to be assigned by the database automatically to each data set.

Data sources and IP addresses of sensors: It should reflect the source of data, for example, if the mass measurement has to be stored in the database using an on-belt mass measurement device, and the name and location of the device should be mentioned as a data source. A record of static IP addresses is critical for allowing data to flow to the database of the server.

Time and date: The data is stored along with the date and time of its acquisition. It will help in identifying the data trail during the audits and the comparison of data will become more convenient.

Actual data: This is the actual data that needs to be recorded, such as mass or volume flow at a specific time.

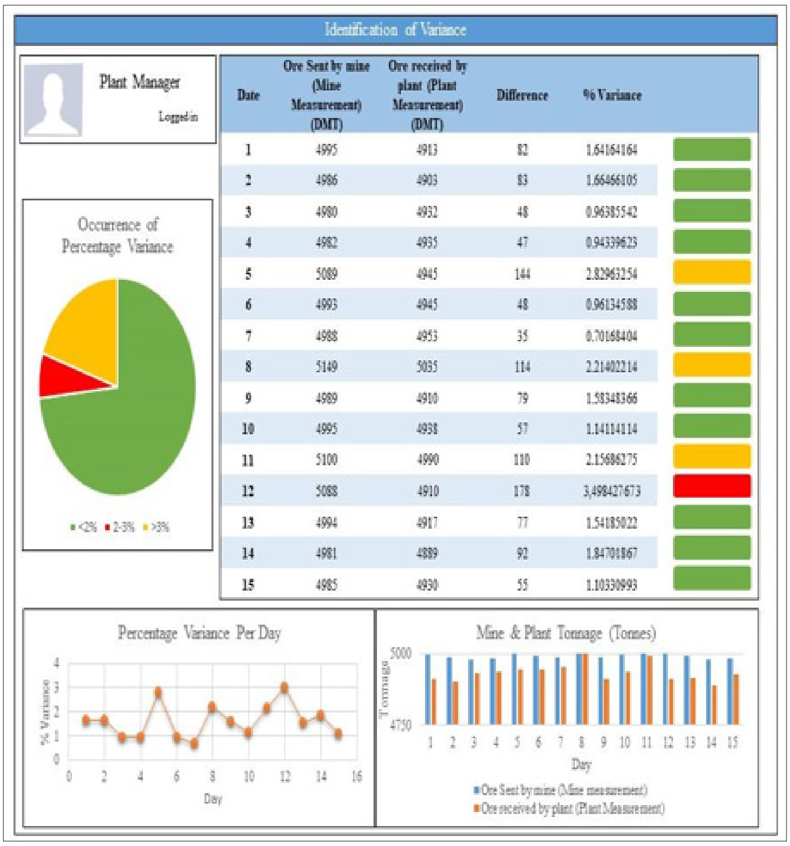
Manual data entry: The manual data entry should be avoided as it can introduce errors. When required, the reason of entry and the name of the person should also be listed along with the data. The manual data entry must be password protected to preserve data integrity.

Data analysis

Data analysis is an important part of metal accounting. Data analysis techniques are discussed in AMIRA P754 code in some detail. The analysis is carried out to ensure that the data being used for the metal accounting purpose is error free and fit for use. Each data collection technique contains some errors, e.g. the mass measurement devices have a standard deviation value. Therefore, it is important to know confidence levels and that the data acquired is within the allowable tolerances. The data analysis techniques and the allowable limits must be automated in the software unless discrepancies are outside allowable limits and investigation is required. A built-in functionality to flag potential mistakes that require investigation is essential. Investigations must be documented, and findings added as tutorials for overall system or protocol improvement.

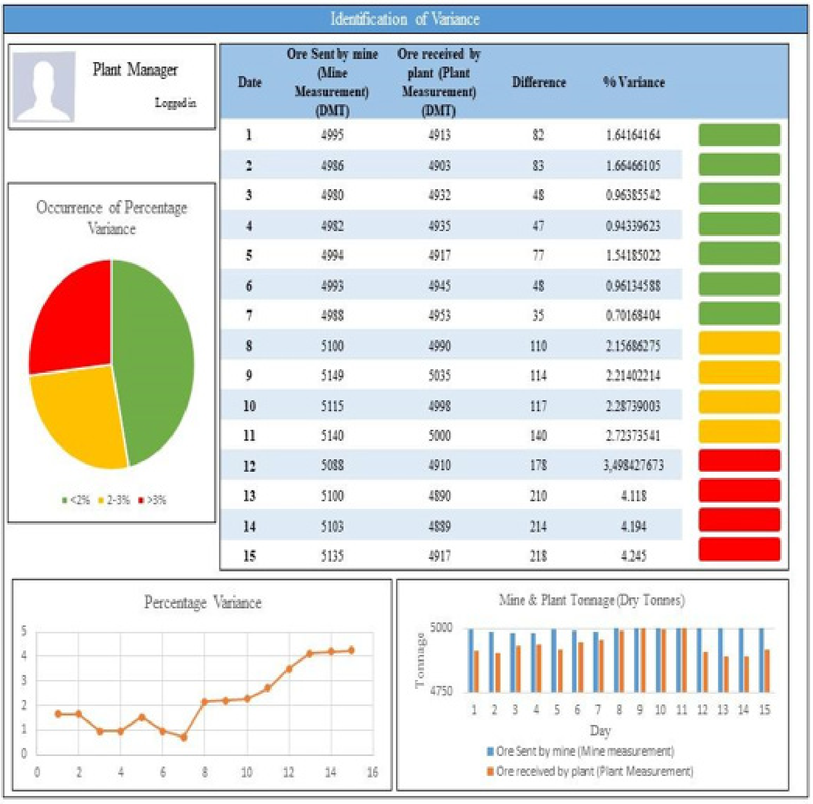
Reporting: It is important that the system is able to produce metal accounting reports at any point in time or any location. This is not possible with manual systems. This affects the mine and plant decision-making processes during the month as problems cannot be addressed in a proactive manner. The reports generated must comply to on-mine protocols and be in accordance with the AMIRA P754 code. Any digital platform should cater for the requirement of the provision of specific data for different managers by generating reports in the required standardized formats for any period.

Identification of bias: The detection of mistakes and errors in measurements is important for the metal accounting. The WMI–OFA digital concept tool will be able to identify the measurement variances outside allowable limits. For example, (Figures 4 & 5) show an example of the ore delivered to a flotation plant from the mine over a period of 15 days. The ore delivered to the plant is assumed to be measured by taking the mass of each truck using a scale fitted on the conveyor belt. The percentage variance allowed, and the respective indications on the dashboard, are shown in Table 2. It is assumed that a variance of up to 2% is allowed. If the variance value is more than 2%, the dashboard shows the level of discrepancy in yellow and red colors, respectively. This draws attention to a potential problem that must be investigated. Such investigation includes automated algorithms for reverse-calculating problem points–in a sense doing a mine call factor calculation, but such calculation will include coordinates of potential problem areas. This will assist mine managers tremendously because the typical mine call factor investigation can be emotionally ‘charged’. Apart from the indication of variance, the dashboard provides customized graphical visualization of percentage variance at a given time, the difference of mine and plant tonnages, and the pie chart showing the occurrence of variance in the data set as per the requirements of the management concerned.



Date	Ore Sent by mine (Mine Measurement) (DMT)	Ore received by plant (Plant Measurement) (DMT)	Difference	% Variance	
1	4995	4913	82	1.64164164	🟩
2	4986	4903	83	1.66466105	🟩
3	4980	4932	48	0.96385542	🟩
4	4982	4935	47	0.94339623	🟩
5	5089	4945	144	2.82963254	🟨
6	4993	4945	48	0.96134588	🟩
7	4988	4953	35	0.70168404	🟩
8	5149	5035	114	2.21402214	🟨
9	4989	4910	79	1.58348366	🟩
10	4995	4938	57	1.14114114	🟩
11	5100	4990	110	2.15686275	🟨
12	5088	4910	178	3,498427673	🟥
13	4994	4917	77	1.54185022	🟩
14	4981	4889	92	1.84701867	🟩
15	4985	4930	55	1.10330993	🟩

Figure 4: Example of visual indication of bias in mass measurements on a dashboard of WMI–OFA.



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4	4982	4935	47	0.94339623	🟩
5	4994	4917	77	1.54185022	🟩
6	4993	4945	48	0.96134588	🟩
7	4988	4953	35	0.70168404	🟩
8	5100	4990	110	2.15686275	🟨
9	5149	5035	114	2.21402214	🟨
10	5115	4998	117	2.28739003	🟨
11	5140	5000	140	2.72373541	🟨
12	5088	4910	178	3,498427673	🟥
13	5100	4890	210	4.118	🟥
14	5103	4889	214	4.194	🟥
15	5135	4917	218	4.245	🟥

Figure 5: Dashboard indication of continuous increase of variance in measurement on WMI–OFA.

Table 2: Limits of variance and visual indication.

Limit	Indication
Up to 2%	🟩
Between 2%-3%	🟨
More than 3%	🟥

Advantages of 'WMI–OFA'

The advantages of deploying a digital framework such as WMI-OFA are:

a. Direct data input from mine and plant at data collection points;

b. Tracking the ore flow from the mining face up to the final product in the plant;

c. Keeping records of mass and material flows;

d. Integrating mine and plant metal accounting systems;

e. Integration with the Laboratory management systems;

f. Complying with existing standards of metal accounting systems and best practices;

g. Access to all stakeholders in their specific domains;

h. Safe from data tempering;

i. Analysis of data received from different sources;

j. Produce reports;

k. Detecting any irregularity in the system for follow-up investigation, and most importantly,

l. More confidence in results

Conclusion

It is a common practice in mines and plants to use spreadsheets for data storage and analysis of ore flow information. These spreadsheets become more complex over time as they increase in the size and complexity. Manual data entry overwriting of formulas increase the potential for mistakes and errors. Replacing the spreadsheets with a single database that receives information from sensors and software processing will reduce complexity and enable automation. In addition, the application of digital technologies in a mine and plant for ore flow analysis can help minimizing potential losses and increase mine plan compliance.

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