Drastic Specific Energy and Water Reductions in Mine to Mill Operations

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ABSTRACT

One of the most vigorous of the continuous improvement methodologies is Six Sigma. While usually associated with improving manufacturing and product quality, leading manufacturers are using it to improve their extended supply chain and logistics capabilities. At the same time they are improving reliability, some companies have cut hundreds of millions of dollars of fat out of their supply chain.

Mine to Mill optimization is a transformation of culture from processing tons to processing a quality feed size distribution which reduces the overall operational costs and add the highest value to the mine. This is not a constant endeavor. As such, a dynamic performance monitoring and diagnosis is necessary. We will review a systemic way to performance improvements and avoiding metal losses from the blast to the metals.

We show the requirements of using raw data to analysis the data to define operational maps which provide assistance to run the mine and mill. A case study is provided with the mine and mill data was integrated combining process control and quality information resulting in reduction of water and energy consumption while improving the overall value of the mine. The results of reengineering the current system with this SIX SIGMA Strategy had the following results: an increase of ore milling: 4.6% decrease of mil power: 3.9%, decrease of fresh water consumption: 6.8%, with a total of net profits: US$ 31.8 million, the PI System infrastructure contribution: US$ 7.95 million. These estimates were for the period 2009/04/04 to 2009/12/31.

Keywords: Mine to Mill Integrated Operations, Energy and Water Reductions, Dynamic Performance Management in Metallurgical Complexes, OLAP and Data Mining, Equipment Availability, Overall Process Effectiveness.

INTRODUCTION

One major challenge to sustainability is the need for collaborative, enterprise data management of real-time and historical data not only within an organization, but also between businesses such as a mining company and the local water and energy utilities. Easily accessible real-time data and information is a key enabler to optimize decision making, and to achieving sustainability.

Major corporations are improving ways to design and manage their industrial complexes incorporating Dynamic Information Management Systems (Rojas & Valenzuela, 1998, Benavides, 2010, Kennedy et.al. 2008). To reduce water consumption and environmental impact, real-time data and analytical tools are needed to promote collaboration between domain experts in the company. To achieve positive results, a continuous improvement and innovative management strategy is imperative (Bascur and Kennedy, 1995, 1999). Bascur and Hertler (2009) discussed the requirements for building a collaborative enterprise environment to enable collaboration between the operational and strategic teams. These teams currently do not have access to the detailed information which allows them to identify long term initiatives and recommend new strategies (innovation) for changing. This collaborative and benchmarking strategy is fuelled by dynamic performance monitoring and a proactive environment that promotes situational awareness. Early adoption and incorporation of the operational design can be incorporated in the process object information models.

Real-time information is critical in determining how to best use scarce resources while considering social, economic, and environmental aspects. Looking at the metal processes, major resources include energy, utilities and water. However, water itself faces issues of scarcity, urbanization, and environmental protection that can directly impact its sustainability. `One of the main challenges to the mineral processing plants is the efficient management of water and energy. These represent a major part of the cost in the mining and mineral processing. Rising costs of water and energy have a direct impact on the profitability of the operation, especially as the grade of the ore is reduced over time. An example of the effect of grade and recovery on energy use in copper production, from work by D.W. Fuerstenau (2001) is shown in Figure 1. Comminution uses over 50% of the energy used to produce copper and as grade decreases the energy requirement increases sharply and can make the operation unprofitable. The other processes such as smelting and refining are not dependent on the ore grade.

An example of the typical water consumption in milling is 125 – 200 gallons per ton of rock in a SAG mill and 150 – 300 gallons per ton of rock in a ball mill. The use of water also impact the energy consumption since the water has to be pumped. So optimizing the water use not only reduces water use per ton but will also reduce energy consumption in the entire process. The energy consumption is very large, and opportunities for savings are not only in Comminution, but in the extraction operation (blasting, drilling, etc.) and in the material handling operations (diesel powered equipment, conveyers, pumps, etc.) According to the US Department of Energy study about 25% of the current energy use in the US mining industry can be saved by going from current operation to best practice operation, and over 50% to practical minimum operation.

A couple of examples of the potential savings are (the numbers are for year 2007 for the US mining industry) US DOE, 2007:

- Grinding – Current consumption 124 TKcal/yr, Best Practice consumption 106 TKcal/yr, and Practical Minimum consumption 35 TKcal/yr
- Material Handling (Diesel) – Current consumption 54 TKcal/yr, Best Practice consumption 35 TKcal/yr, and Practical Minimum consumption 26 TKcal/yr

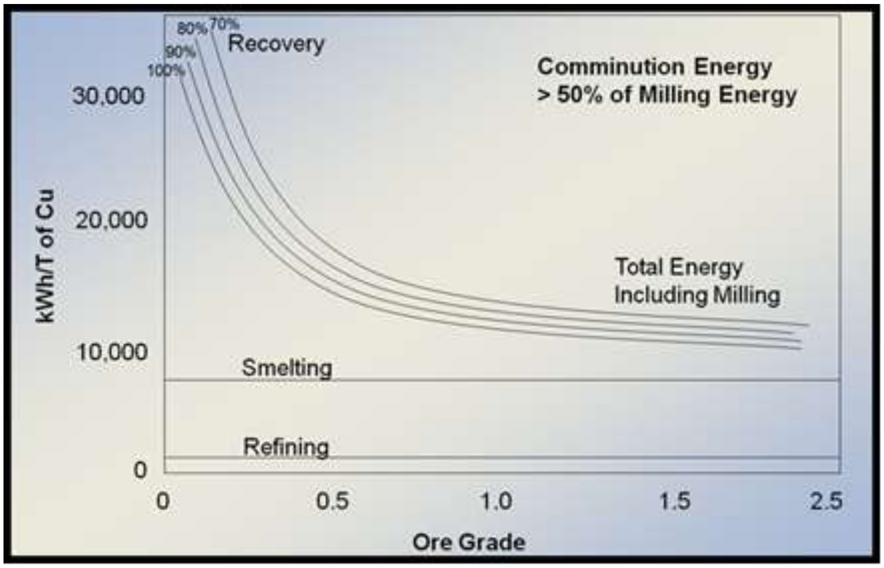

Figure 1 Energy Use versus Ore Grade and Recovery

CONTINUOUS IMPROVEMENT AND INNOVATION METHODOLOGY

The business drivers for performance management are compelling. Among them:

- Collaboration throughout the extended enterprise, including global resources, suppliers and customers
- Empowering individuals to make profit-contributing decisions at all levels of the organization
- Closing the loop between active planning and goal setting, and actual execution in real time
- Bridge centralized and decentralized organizational structures

The function of the real-time information infrastructure is to support continuous improvement, increased profits and reduced costs. This is quite different than Enterprise Management, which is targeted at continuous improvement of margin but driven by transactions instead of real time events.

With a traditional process information management system, information is gathered into a database and is disseminated as reports and on line inquiries to all requesters, and there the system's responsibilities END. This system is passive; it is not designed for ACTION. A real-time information infrastructure allows users to apply their knowledge and expertise to find the root causes and continuously improve performance.

Figure 2 - Continuous improvement and innovation of Ore type based on results

Figure 2 shows the required on line data to be able to identify the type of ore, ore hardness, type of insoluble, type of alterations, size distributions when available. It is by storing the type of ore and its effects associated with the process variables and the final grade recovery effects that SIX SIGMA monitoring and diagnosis strategies are achieved. We will describe how the set of data (MAPS) for statistical process control are developed same as we use GPS today. In a nut shell, studying and analysis the database we identify a priori the consequences.

A data hierarchy starting by the raw analog data, followed by data validation, classification (as the unit running, in troubles, stopped, downtime, maintenance) (Bascur, 1988). Once the data is classified it can be reused in models to act as soft sensors or to predict other possible events. This is now implemented as PI Notifications, which enable to execute in real time configurable rules for quality, production, asset, environmental and KPIS. The notifications can be sent to people, applications or devices. The integration of mine and Ore Geological Information starting at the root is common sense from a Total Quality Management. As such using the integration of the mine data from the SCADA systems, from the laboratory data and the metallurgical subsystems we can generate cause and effect diagrams which can be organized in an object data base for overall analysis with data collected at the original resolution.

One of the most vigorous of the continuous improvement methodologies is Six Sigma. While usually associated with improving manufacturing and product quality, leading manufacturers are using it to improve their extended supply chain and logistics capabilities. At the same time they are improving reliability, some companies have cut hundreds of millions of dollars of fat out of their supply chain. It means plus or minus six standard deviations, which translates down to 3.4 errors per million occurrences. The Process of Measuring defects per million helps drive higher performance expectations. Six Sigma processes are designed to reduce process variability. A key concept is that what is measured should reflect quality from a customer's point of view.

An analysis framework infrastructure to treat real time information

Recent advances in software technology enable the scalable use of objects template to organize real time data into many contexts as required. A key development in OSIsoft PI System infrastructure is the PI Analysis Framework (PI AF) allows users to create templates of their assets, embed calculation logic and methodology into these templates, and create an asset structure (Bascur & Kennedy, 2001, Bascur & Curt 2009). This application provides a standardized object model of the corporate assets and a data directory allowing the building of the business intelligence processes. It also enables the creation of assets models from a centralized library of templates and the combining of real time data, events and non-real time data in a common toolset. The PI AF integrates the process and equipment data, the "Application Models" (logical, plant, physical, organizational, etc.), and the scheduling of calculations and procedures, providing a scalable and evolving infrastructure for the implementation of client applications. Plant models are time referenced, including specific business rules as defined from the event frames. Early work on grinding controls was used as foundation to rebuild the expert systems controls using virtual sensors (Bascur, 1977, 1990, 1991). The virtual sensors were built at layer "models" using the basic measurement from the plant but incorporating all the additional time series information from the process data and related information. As such, the reliability of the soft sensors went from 70% to 99.9% stabilizing the advanced controls and having valuable information for coordinating the operation of the whole concentrator.

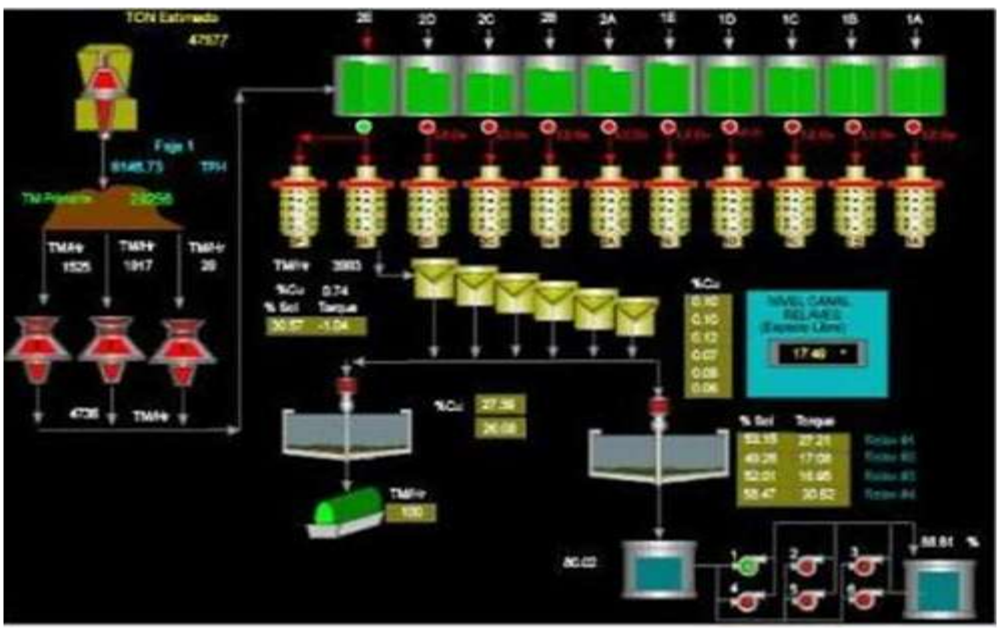

Figure 3 Concentrator Dynamic Performance Monitoring and Alert Notifications

The first step into incorporating knowledge to the data is to have a clear diagram of the process flow diagram. A view created by an engineer to analyze the overall concentrator performance in addition to each grinding circuit section is shown in Figure 3. Consumables, such as power and water, are monitored in real-time as well as the average, maximum, and minimum for each shift. The variability of consumption is therefore monitored and gives the engineer information to investigate abnormal consumption and identify the root cause for this occurrence. The status and availability of the assets in the grinding circuit are also monitored to give vital information on the events whether an asset is in running correctly, idling, in maintenance, down, or having trouble, how often it has been in these states and for how long. Correlating this information with the production and consumables information gives feedback to the engineer so that corrective action can be taken to prevent sub-optimal operation, and hence the wasting of water and energy.

Once the overview of the overall plant is defined the variables are classified into a cause of effect diagram. The cause of effect diagram, also called "fishbone diagram" because of its appearance, allows the engineer to map out a list of factor thought to affect a problem or desired outcomes. This type of diagram was invented by Koaru Ishikawa, and hence also called an "Ishikawa" diagram." It is an effective tool for studying processes and situations, and for planning.

A cause and effect diagram is essentially a pictorial display of a list. Each diagram has a large arrows pointing to the name problem. The branches off the large arrow represent main categories of potential causes (or solutions). Typical categories are equipment, personnel, method, materials, and environment. Teams can customize these categories to fit their processes. Smaller arrows, representing subcategories (list items), are drawn off each main branch as necessary.

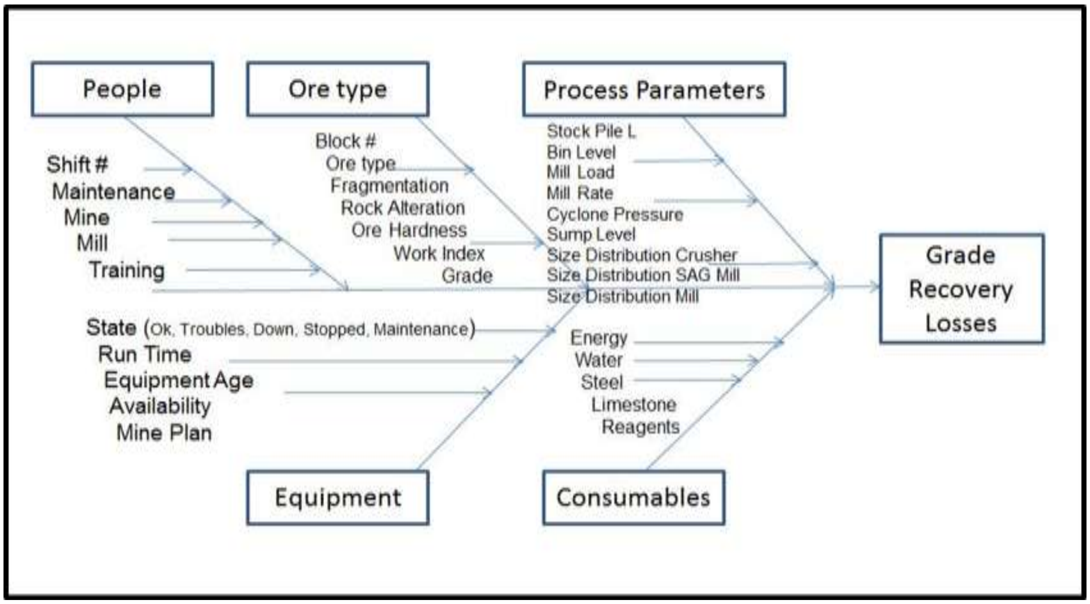

Figure 4 Cause and effect Ishikawa or fish bone analysis design structure

Arranging lists in this way often leads to greater understanding of a problem and possible contributing factors. For example, if one category was "equipment", you could generate a list of subcategories by asking questions such as: What was the state of the equipment for the period that we need to calculate the total energy consumption while treatment of certain ore type with a certain type of harness. What problems does this equipment have that could cause the problem we see? Similar questions can be asked for the other categories. **In general in mineral processing plants asset conditions are a main cause of metal losses due to the fast aging of the components such as ball mill liners, balls, conveyors and pumps. At the same time we need to be able to have the events for the equipment available to be able to integrate the raw data to transform the data into validated practical information.**

Figure 4 shows an example of a fish bone structure for concentrator analysis. It contains five key categories people, ore type, process parameters, equipment and consumables. Each of these branches contains subcategories of variables which can be organized depending on the type of cause and effect analysis to be done.

This is where the synergy of have the raw data at the original resolution available for aggregation using special statistical filters which due to the exemption reporting algorithms used in the PI System the data time series stream are quickly calculated for any selected period of time (shift, start and end time of running a certain material from the mine).

The PI Analysis Framework assist**s** in organizing all necessary data and to classify the categories of data by configuring a generic object which is extensible on demand. The template chosen in this case is the grinding production line including the flotation banks associated with it. This production line behaves like a lego piece. We can group it any way that we want for the analysis of the connected real time information, calculations, and events associated with it. The Ishikawa diagram can be configured using the PI AF object oriented data base to organize the raw data, time derived data, events, other related information, static data such as the model of shovel, hydrocyclone. Then one template is designed many other can be clones with the particular connections to the raw data as another identical twin object.

Having this common structure (apples to apples) the engineer we can group several pieces of lego and construct a desired combination by just selecting the necessary groupings. In this case, it was strategically defined a production line. This is a good starting point example. This can them be adapted and modified as required. As such, now we can ask questions for selected production lines. A metallurgical engineer by decide to have five of the production lines running with a certain type of ball charge to run slags combined with fresh ore. The user without any programming can analyze the performance of these productions lines individually or for the whole concentrator or plant for the overall energy consumption, ball wear, etc.

If he needs to know the overall energy, water, limestone, reagent and steel consumption for a period of time he can do so. The system will figure out how to integrate and filter the raw data and top roll up the selected combination of assets. As such, figure 6 shows PI AF structure template done by the engineer. He just need to configure and to connect the real time data which the way that he want to classify the causes for adaptive analysis (Bascur and Soudek, 2009).

The selected Categories can them be selected using OLAP tools such as PowerPivot or PowerView tools which are add-ins to excel to jointly query the PI System data streams and the PI Analysis Objects to group the information into PI CUBES. PowerPivot and PowerView are Excel add ins from Microsoft. These cubes of data are them realigned depending on the PI Slicers on the fly. This is due to the in memory capabilities of the tools and the fast performance to work with time series rather than data stored in traditional transactional table based databases.

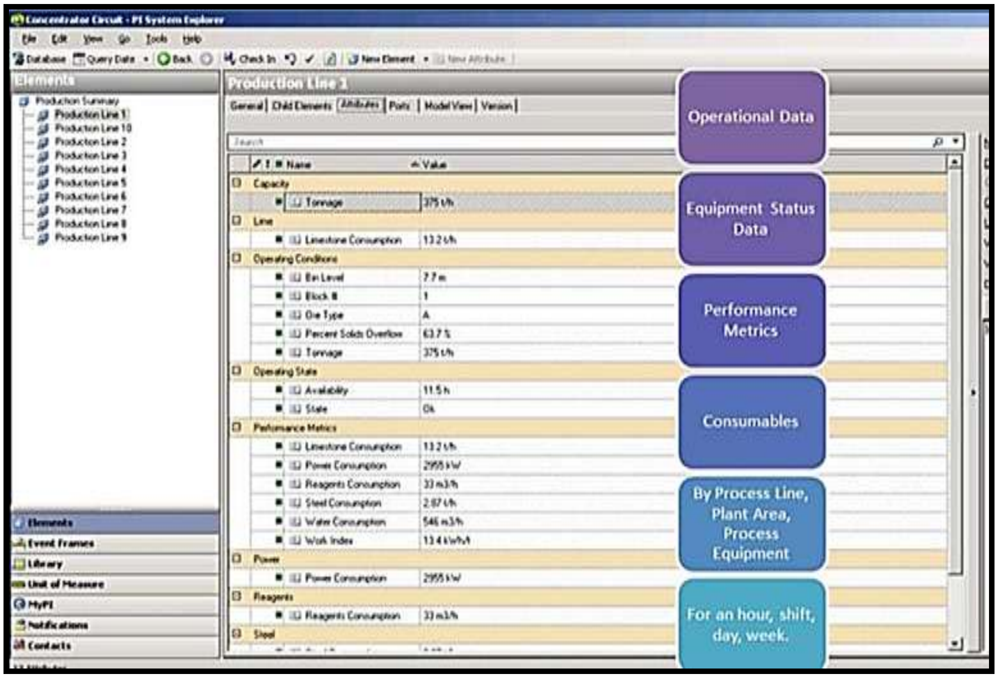

Figure 5 Concentrator Production Line Unifying Structure for Operational Intelligence Analysis

Figure 5 shows a sample asset structure for a concentrator. In this example, the assets are organized by production line with monitoring of consumables. Real-time statistics are used to calculate the minimum, maximum, and standard deviation of each consumable by asset, by production line, and by mill. The users modify the time range they are interested in from say 1hour to a shift or a day. The statistics are recalculated in real-time based on this time range. This way the operations and plant floor are using the same assets as the business systems are, but have different views of the same data for their own purposes and needs.

This process classifies and consolidates the measured values and provides information which correlates the state of the assets for energy and water conservation. These results are then used to focus on erroneous measurements so that they can be fixed. It is important to use validated numbers in evaluating performance of a process otherwise wrong conclusions can be derived. The validation process is performed over many shifts together with real-time statistical quality control (SQC) performed on the meters. The key validation is the classification of the assets operational state during each shift.

Operational Business Intelligence for Dynamic Monitoring and Analysis

After the measurements have been classified the analysis of the asset performance and the process can be performed. The information on these performance metrics must be made visible not only to the operators and unit engineers, but to the entire enterprise. Visibility of the data in real time is the key to continuous improvement and collaboration. This way the real time performance indicators, inventories, yields, etc. can be made visible to a wider audience and provides immediate feedback for the operation of the facility. This creates a collaboration environment with a feedback process for creating small focused projects for more efficiently using energy and water for the operation.

The real time information accesses the associated variables during the period of time (context interval) when this ore type was processed. Analysis of the metallurgical performance can be performed linking the grade/recovery with the grinding/blast strategies in a mineral processing plant. Real time based costing emerges as a reporting exercise when the proper application framework for real time information management is used. This integrated approach enables collaboration between operations, engineering, accounting and management to drive the organization's bottom line according to their business strategy. The operating personnel can look for opportunities using alternative processing methods and strategies (grinding efficiency, reagents, and blasting methods) to adapt to the changes in ore type to produce the least cost concentrates.

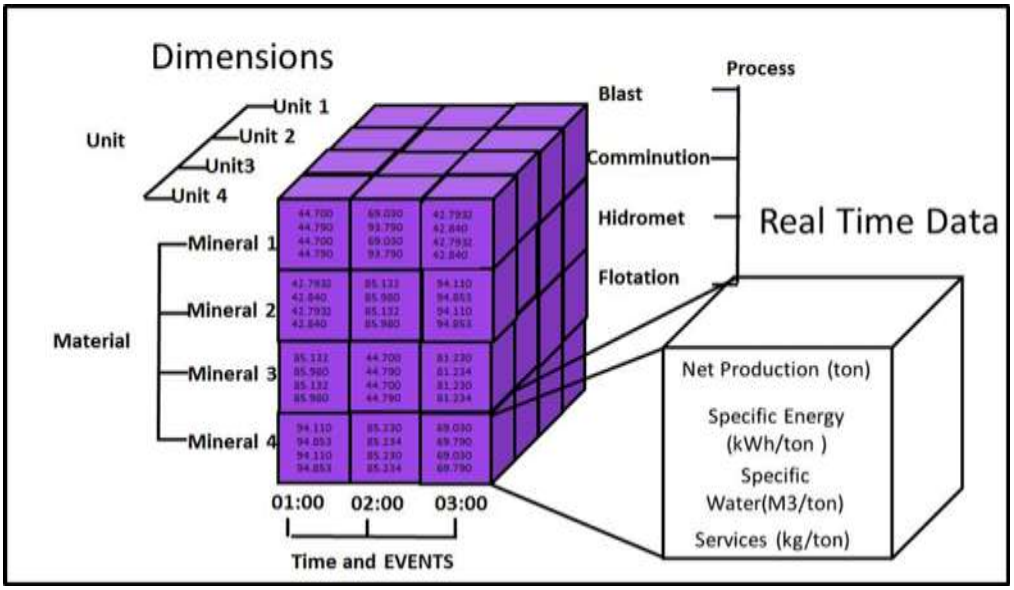

Figure 6: OLAP Cube Depiction of the Real Time Data with the context and data services

In addition to monitoring the grinding line from an operator's point of view, notifications are set up to watch for abnormal or deteriorating operational performance over time. The automatically generated notification alert the appropriate party (Managers, Maintenance, Support Center) when the mill is using more than the average consumables and when the availability drops below a minimum threshold. The notifications are set to notify based on business rules managed by the contact engineers or using real-time statistical quality control. Providing this feedback enables operations and asset availability personnel to quickly assess the problem and take corrective action. This makes a more efficient operation preventing waste of consumables and increasing throughput. As such, the operating, maintenance, enterprise competence centers can collaborate and work on the local tactics (root cause analysis) and on long term strategic initiatives for business improvements and innovation.

The KPIs are used for Dynamic Performance Management analyzing the different operational states when running well, in troubles, down, stopped or in maintenance. In each of the operating states the overall operating costs (energy, water, steel, reagents) are consolidated and reported based on ore type, hardness, mineralogy on the effect final recovery and grades. This type of implementation has been reported by Benavides, 2010 with saving of more than US$ 30 million per year.

The results of reengineering the current system with this SIX SIGMA Strategy had the following results: an increase of ore milling: 4.6% decrease of mil power: 3.9%, decrease of fresh water consumption: 6.8%, with a total of net profits: US$ 31.8 million, the PI System infrastructure contribution: US$ 7.95 million. These estimates were for the period 2009/04/04 to 2009/12/31. After the successful implementation of the mine and mill data was done further work. They are using done the latest modern tools. Benavides original presentation includes all the soft aspects of the implementation. The most important is the metrics used to get mining; maintenance and concentrator operators to analyze one set of metrics which they can compare by shift the effectiveness of the program day after day.

Figure 7 shows a PowerPivot screenshot which enables to perform the queries using Internet Explorer anywhere as a front end tool. On the top of the figure you can see the PI Slicers which are the variables used to modify the bottom part of the table based on the events chosen by the user. The variables are time interval, Ore Type Block #, Number of Production Lines (Bin, mill, flotation), Ore type, production line availability (Running, Troubles, Down, Stopped, Maintenance).

The dynamic tables summarizes the results including the required production lines with the total production for the selected time internal including the total consumption of limestone, Reagents, Steel, Water, Power and the Bin Levels and Work Index as additional possible causes. In addition, the MAX, MIN, and Standard deviations for all the variables are available to build what we call operational MAPS based on the type of ORE. As such, SIX SIGMA methodology is used to reduce the variability of the production while saving water and energy. Remember that many variables used are based on soft sensors from validated data from the process. This is only possible because the availability of the data at the original resolution and the time series algorithms to reduce the information at the PI AF layer to be passed to the Data Mining layer.

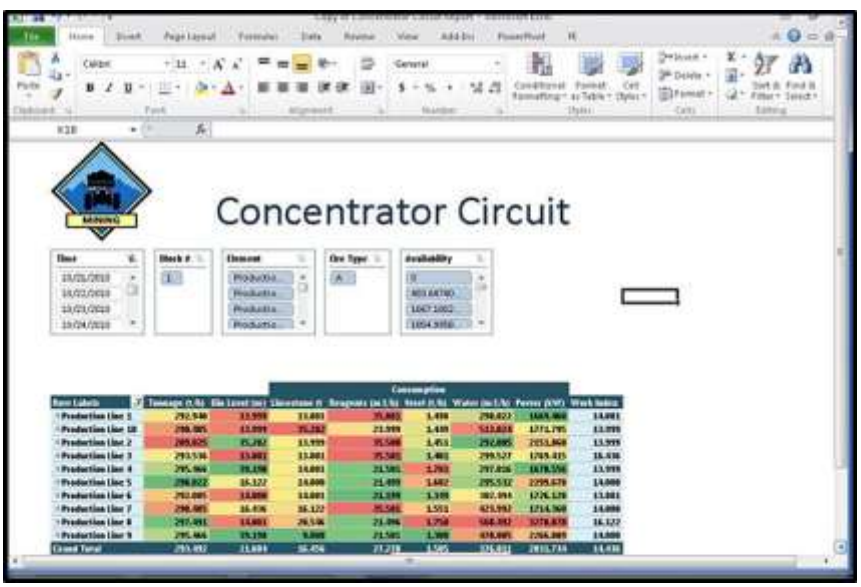

Figure 7 Example of OLAP Cubes and PI Slicers to perform dynamic operation analysis

Since many additional questions lead to detailed discussions of how a process works, cause and effect diagrams are most effective after the process has been described and the problem well-defined. By then, team members will have a good idea of which factors to include on the diagrams. This is why an information infrastructure is vital as tools for the users to adapt to other situations and continuously learn and maintain the system LIFE.

Remember that cause and effect diagrams identify only possible causes. Even when everyone agrees on these possible causes, only data will point to actual causes. As such, the potential of the life information systems allows creating virtual sensors or metrics which can be used to derive suggestions. Is like updating you map on your GPS device to continue the starting metaphor.

RESULTS AND DISCUSSION

Despite the advances in automatic data collection and archiving, operators and engineers to the business decision makers face the problem of exploiting the information that is relevant for the plant operation and the profitability of the business enterprise. Visibility and transparency of the information is necessary for an efficiently run business. This improves collaboration and gives real time feedback on the different decisions made at any level in the organization. The efficient use of water and energy is related to running the business in an efficient manner. The best approach is to have the infrastructure in place to be able to conduct small focused projects, collaboration between different groups in the organization, and understanding that this is a continuous improvement process.

To put into a context of today technologies the raw data is used to build the operational maps which enable the operation management to navigate and operate optimally. They enable operations and maintenance teams to dynamically monitor their equipment enhancing the operating times, reducing waste by running in real time observers which provide early warnings. As such they can reduce the speed or change operating conditions to avoid metals losses and expensive shut downs or downtimes due to power problems or drastic changes in the hydrodynamics conditions or chemistry changes of the raw materials.

ACKNOWLEDGEMENTS

We would like to thanks OSIsoft, LLC and Southern Peru Copper Cuajone for their support and encouragement and the opportunities to publish the paper. The authors are indebted to the assistance of Mariana Sanding and Ales Soudek from OSIsoft and Jean Calderon from Southern Peru Copper. Part of this technical contribution will presented at the IMPC 2012 in New Delhi, India.

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