CHAPTER 1.7

Laboratory Automation

Wolfgang Baum and Kevin Ausburn

The mining industry is undergoing comprehensive change regarding automation and related robotics technology in all facets of its activity. Today, and more so in the future, automation use extends from exploration through mine-site drilling, mining, and metallurgical processing to smelting and refining. As part of this seismic shift, all laboratory activities pertaining to the preceding operational steps have been extensively impacted by automation. The authors emphasize that, once this text is published, the high-speed development of the hardware and software used in automation will have already surpassed some of this chapter's statements and descriptions. The reader is therefore advised to use this chapter in consultations with relevant automation-related magazines, equipment providers, and personal benchmarking of robotics technology in the laboratory field. It is of equal importance that the reader and technical staff active in lab automation also track and monitor the developments, practices, and innovations in nonmining laboratories since the pharmaceutical, chemical, cement, steel, and related industries have inherently been pioneers in automated laboratory use.

The scope of this chapter is to characterize the current use of automation and robotics technology in the most important laboratories for mining (i.e., sample preparation, chemical laboratories, mineralogical laboratories, metallurgical laboratories, and special production labs such as cathode, refinery, bullion, etc.). In addition, this chapter covers the use and application potential for automated analysis technology for online/cross-belt installation and downhole purposes, specifically for blastholes. To meet the extreme challenges of future mining (e.g., harder ores, deeper mining, water/power/steel-wear, increased production rates, lack of skilled labor, extending mine life, safety demands, and extended use of robotics technology) and remain competitive, mining companies need to aggressively modernize their lab facilities. In short, automation of laboratories is imperative for future mining (Allen et al. 2007; Baum 2007; Ausburn 2013; Baum 2014a, 2014b). The *ore factory*, a term coined in Australia, is becoming a mandatory strategic development for most miners. The industry's move toward remote control and operations centers that integrate multiple sites and multiple production segments all the way to ship-loading will require more lab automation to maintain the critical and fast data flow from mine geology, ore feeds, process samples, and end products.

BACKGROUND

The nonferrous metals mining industry established its first large-scale and remarkable entry into laboratory automation with the construction of semi- and/or fully automated labs in the Nevada gold mining operations of Newmont Mining in the late 1980s. Much earlier applications occurred in the cement and steel industries, some iron ore operations (Fer et Titane), heavy minerals (Richards Bay, South Africa), and other select industrial mineral applications. Select automation modules and partial lab automation were installed primarily in South Africa, Namibia, and in an aluminum smelter in Mozambique. Lab automation received more attention when breakthrough robotics labs such as Anglo's EBRL and the Phelps Dodge–Freeport Central Analytical Service Center labs were constructed (Best et al. 2007). The start-up of the Freeport AXN lab (an automated X-ray diffraction [XRD] and near-infrared [NIR] mineralogy lab) represents the first 24/7 plant mineralogy support lab in copper mining (Baum 2009). Central or other automation labs followed in Western Australia and elsewhere (e.g., BHP Newman, Rio Tinto Tom Price, Kumba Sishen, FMG Solomon).

Commercial labs have been slower in adapting to lab automation, some of which is related to challenges associated with installation. After the initial use of robotics technology by various labs, considerably more growth can be expected in the lab service industry to handle high sample volumes, deliver better quality, and reduce turnaround times. Container labs with automation modules were also introduced. The innovation leaders in large-scale lab automation clearly were mining operations in South Africa and Australia, followed by North American mining. During the last 15 years, automated fire assay labs were installed in the commercial lab business for gold, platinum, and nickel mining. Although the success of the previously mentioned labs was impressive, the mining

Wolfgang Baum, Managing Director, Ore & Plant Mineralogy LLC, San Diego, California, USA
Kevin Ausburn, Chief Mineralogist, FLSmidth USA Inc., Midvale, Utah, USA

industry as a whole requires considerably more “automation” efforts to update heritage labs and/or replace them with cutting-edge robotics labs. Without this activity, the single most important data-generation segments in mining operations, that is, laboratories, may not be as efficient and competitive as they could be.

The leading laboratory automation equipment and service providers in the mining business are Herzog, IMP, ThyssenKrupp’s Industrial Solutions, FLSmidth, and Rocklabs. Various other providers deal with specialty equipment in the fields of comminution, screening, fusion, dissolution, digestion, solution handling, filtration, leaching, flotation, and the entire range of chemical and mineralogical analyses.

FEASIBILITY OF LAB AUTOMATION

In a mining operation, four types of laboratories are generally considered for automation: small mine-site labs, central labs for multiple operations, in-plant modules, and mobile/containerized labs. The overall equipment assessment involves an evaluation of whether the labs require retooling, expansion, or conversion to 24/7 operation and whether they should be fully automated or semiautomated or represent a completely new lab construction effort. The size of the operation is of considerable importance as automation and robotics technology become more economic and efficient with larger sample and determination volumes. A key parameter for the feasibility evaluation is also the type of laboratories required (e.g., sample preparation, chemical, mineralogical, cathode, fire assay).

With the rapidly growing need and use of ore characterization for geometallurgy, any existing and new operation considering an automated laboratory should evaluate the need for more than only chemical analyses. Today, mineralogical analyses are as critical as chemical data. Because of recent advances in modern XRD, Fourier transform near infrared (FT-NIR), NIR, Fourier transform infrared (FTIR), and automated mineral analyzers (to name the most important technologies), it is recommended that any laboratory expansion, upgrade, or conversion to automation should seriously assess the option of adding mineralogical lab capabilities.

Benefits

To determine the viability of a greenfield and/or upgraded automated laboratory, a central laboratory or a containerized lab for one operation, multiple mines, a commercial lab service organization, and/or in other applications such as test or development centers, a thorough evaluation of all business drivers and technical aspects, including turnaround times, requires a two-stage process:

1. **Preengineering Study (PES).** The PES consists of determining all baseline parameters for these labs including (but not limited to) sample types, sample sources, sample volumes, sample delivery during a 24/7 period, type of pulp preparation (client standard operating procedures [SOPs]), analytical data needed, site visit, conceptual layout, turnaround time for all lab clients, sample delivery schedule, site suitability, utility requirements, equipment lists for each lab, redundancy plans, preliminary staff needs, schematic architectural plans, and other factors. Various business cases should be assessed from a preliminary point of view.
2. **Feasibility Study (FS).** The FS details all aspects of the conceptual design, selection of equipment, detailed architectural plans, including construction documents, delivery and installation, confirmed capital cost for building and equipment, consumables and reagent list, hazard and operability study, training program, factory acceptance tests, shakedown tests, start-up support, service, spare parts and maintenance program, laboratory information management system (LIMS) use, safety program, waste handling, quality control (QC) program, operating cost, per-analyte cost, uninterruptible power supply system, and so forth.

Lack of good and reliable PES and FS work may result in a variety of problems, including increased downtime, lower availability, throughput and turnaround below nameplate, start-up delays, undersized equipment, substantial lack of redundancy, variance in sample preparation and related analytical variance, and higher operating costs.

After completion and review of the preceding studies, the project can move into the following phases:

- Approval and purchasing
- Construction
- Training of staff
- Factory acceptance testing
- Start-up and full operational functionality

Overall, the benefits of high-throughput automated labs are evident and have been proven in numerous operations:

- 24/7 operation
- Better safety and hygiene features
- Large sample weights (i.e., more representative samples)
- More reliable sample drying, comminution, and splitting
- Lower operating cost
- Better analytical data
- Faster turnaround

Budget

As each project requires an individual assessment related to budgetary plans, it is strongly recommended that any efforts targeting lab automation undergo a robust PES (which should typically include a 20%–30% cost redundancy) and keep a long-range perspective of cost-efficient capabilities to expand the lab in the near future. Without the PES, any budgetary estimates remain highly questionable.

Based on the preceding information, detailed economic parameters should be calculated, including (but not limited to) commissioning cost, cost per sample and cost per analysis, utility costs, spare parts, staff cost and savings, economic impact of better analytical data, improved turnaround time, safety improvements, return on investment of capital, service contract costs, continuous training costs, and intangible factors.

Expectations

Key parameters for the PES must include a detailed definition and listing of expectations of both management and the lab’s clients. These expectations represent a critical design baseline for the PES. Summarized, these expectations encompass (but are not limited to) sample volume, sample types, specific sample preparation procedures, analytical parameters, turnaround for the analyses, QC, lab and equipment redundancy to prevent interruption of production support, and options for new analytical equipment, expansions, and potential rush work.

Sample Types and Volume

The lab's equipment and operational characteristics will be governed by the type of samples—from rock or process materials—to be processed. They may include a large range of materials from one or multiple commodities and/or by-products. Samples may include such material types as exploration samples, mine-site geology samples, concentrator samples, leach operation samples (run-of-mine [ROM] and/or heap leach), solutions, organic materials, solvent extraction and electrowinning of specific samples, metallurgical accounting samples, smelter samples, refinery samples, water, and/or other environmental samples.

During the PES, the sample evaluation should also include giving detailed attention to optimizing the sampling and sample size features, all of which inherently contribute to the largest errors for any laboratory work. For example, the coefficient of variation of fundamental errors in blasthole samples can be large (16%–>25%) and small splits may introduce substantial reproducibility problems. For example, in one case study the authors have worked on, an increase of the blasthole sample weight by 7 kg per sample reduced the variance by 5%.

Industry-wide, one of the problematic areas continues to be the current methods of blasthole sampling. These issues may be solved in the future by introduction of automated blasthole samplers (either from drilling companies, miners, and/or sampling equipment manufacturers). The current blasthole sampling practices (pipe, shovel, auger, grab, etc.) are not ideal and should be optimized. Any optimization will have significant beneficial features for reducing notorious variances or massive misrepresentations in resource assessments (Carrasco et al. 2004, 2005). As indicated by these authors, improper sampling and sample preparation can cause monumental economic losses. Therefore, it is recommended that any laboratory equipment and SOP change be accompanied by an evaluation of sample requirements. This applies to all types of sampling and not just to the blasthole material.

Staffing and Lab Management

Automated or robotics labs require a change in operational thinking, key personnel with a relevant skill set and sound pretraining, sufficient start-up time prior to accepting full production, and continuous staff training. When selecting lab personnel, a small core team of lab-specific experienced chemists, mineralogists, metallurgists, automation engineers, seasoned lab technicians, and QC/LIMS staff is required. A training program should be prepared with the equipment manufacturers, and it is highly advisable to send one or two equipment and robotics/software specialists to the lab for an extended start-up period. It is also beneficial to involve key operators during the factory acceptance tests (FATs). Eliminating proper FATs has, in the authors' experience, never been a good economic and technical decision.

Continuing benchmarking is the responsibility of the senior lab staff (e.g., lab manager, lab superintendent) and should include a good reference library, regular review of pertinent technical publications and attendance at lab-specific conferences, and the important "look across the fence," that is, fact-finding in automated lab environments outside of mining.

Without a doubt, any new or even upgraded lab will require a break-in period during which the operators can fine-tune the overall lab performance and functionality. Because shift operation will be required, equal performance of all shifts will be critical. New and adjusted safety measures will be of the essence for the automation environment, and a continuous effort by a dedicated team should zero in on lab economics and cost optimization. Training, as with any best-practice operation, is imperative for a successful automated lab, and so is a well-functioning LIMS.

Lab Location

Social and neighborhood issues, floodplain and floodway issues, noise, traffic, ground vibrations, air emissions, conflict with communities, and waste handling and disposal should be assessed during the lab selection process. Sample transportation and receiving logistics in the case of a central lab is of paramount importance.

Lab Quality Control

The use of existing lab technology and/or the introduction of new equipment and automated operating procedures mandates a thorough review and, potentially, reassessment of the practices used. The QC procedures are driven by lab type, equipment, material, and analysis. Typically, these procedures should encompass National Institute of Standards and Technology or internal standards, reruns, repeats, a minimum percentage of duplicates, blind samples, determination of repeatability, round-robin work, tracking of differences, assessment of data reporting, housekeeping, safety relations, maintenance, and training. External and internal lab audits or surveys are essential to detect and filter out problematic practices, less-than-optimal sample preparation, or analytical procedures and equipment issues.

Start-up, Optimization, and Avoidance of Problems

From the PES and FS, lab management should pay attention to the architectural layout and equipment functionality. A 24/7 lab operation with robotics technology requires considerably different philosophies and extremely good reliability for equipment, throughput, meeting of product specifications, dust control, and buffer capacity. Frequent engineering staff changes and rotation of liaison engineers from the manufacturers should be avoided under all circumstances.

The design team, including the equipment providers, should pay utmost attention to reducing lab downtime and availability of sample preparation and analysis systems. Consistent checks of abnormalities are mandated, along with routine status reports, weekly start-up team meetings, and the preparation of robust building, equipment, staff, safety, and SOP checklists. Lab crew issues need to be foreseen and require preventive efforts, including (but not limited to) skill sets, attitudes, responsible performance, shift cross-communication, housekeeping, repair checks, use of personal protective equipment, and spare-parts management with foresight, efficiency, and overall facility maintenance.

LAB AUTOMATION MODULES: MOBILE, MINE-SITE, AND CENTRAL

The authors' most important observation in lab design and construction has been that 90% of new labs, central labs, expanded labs, and conversions to automation and/or container labs are conceptualized or built with insufficient redundancy and expansion potential. Clearly, the historic and classical "bucking room" is being replaced by modern sample preparation labs. With the current and future trend to ever-higher throughput operations, *many labs will require substantial expansions, optimizations, or addition of new analytical capabilities*.

As a result of the rather conservative initial design concepts, the capital requirements for follow-up lab additions or capacity increases are unnecessarily high. Consequently, the industry's tendency to prioritize capital expenditures related to tonnage, throughput, overall mining, and plant issues has resulted, in many cases, in a severe neglect of laboratories, even as the laboratory segment (sample preparation, chemical, mineralogical, metallurgical) constitutes the most critical baseline tool for getting the economics right and for optimizing an operation. As such, it is hoped that the mining industry will pay substantially more attention to modern and efficient laboratory facilities in the future as cutting-edge competition caused by lower grades, higher throughput, capital-intensive larger plants, increased operating and sustainability cost, and a shrinking skill and talent base becomes more predominant in the market.

As the mining industry is moving underground, the lab automation business and operational thinking need to be adjusted accordingly. Many underground operations will offer significant opportunities for "subsurface labs," which could have a positive effect on mining and materials handling and reduce overall lab costs.

LAB AUTOMATION FOR SAMPLE PREPARATION

Virtually 90% of today's sample preparation demand in mining operations is amenable to fully automated equipment and procedures. This pertains to the major steps in sample preparation such as drying, crushing, grinding and pulverizing, splitting, dosing, pulp packaging, labeling, bar-code or other tracking technology, and reject material handling including bagging and storage. A large range of operating robotics sample preparation labs around the world include various levels of automated or partially automated sample preparation in commercial labs, specialty labs, central service labs, and container labs. An online search can be conducted to review equipment and assessment studies from key suppliers. Many specialty equipment providers exist, and the reader is advised to evaluate which contact is the most appropriate for his or her application.

In many cases, the flow sheets of sample preparation labs for multiple mining operations have to accommodate the following materials in regard to converting the as-received ore and rock samples into a highly representative assay pulp:

- Miscellaneous geology samples (core, cuttings, bulk, etc.)
- Blasthole samples
- Mill feeds, process streams, concentrates, flotation tailings
- Samples from ROM or heap leach operations
- Smelter samples
- Refinery samples

Mine and plant operators need to assess, in a team effort, how to conceptualize an automated lab to accommodate all sample materials in regard to preparation as pulps and analytical work.

LAB AUTOMATION FOR CHEMICAL ANALYSES

Although most analytical equipment manufacturers have had supplemented systems with automation features and autosamplers for many years, a full integration of standard chemical lab equipment into a line, circuit, or other full robotics configuration is not yet a standard feature in mining. This includes (but is not limited to) reagent dosing, glassware handling, glassware cleaning, solution filtration or centrifuging, and multiple other analytical steps. Established use of robotics lab circuits today encompass the following:

- Large dosing stations
- Fire assay labs
- Solids filtration
- Auto titration
- Microwave digestion
- Automated hot-plate digestion
- Automated cathode analysis
- Auto dilution

For a mine-site chemical lab, operators should first assess the specific sample types and related analytical needs. Thereafter, a process flow diagram needs to be established to conceptualize how far and how deeply automation can be implemented. Here again, redundancy and extra-potential expansion capacity are of utmost importance. For a standard chemical production support lab, this diagram may include bar-coded samples shipped → assay pulp preparation → analysis → data report in LIMS → data transfer to data warehouse → mine customers access their results.

In terms of lab layout for blastholes, geology samples, and other bulk rock/ore samples, a general configuration may be as follows:

- Automated: drying–crushing–splitting–pulverizing–dosing
- Automated elemental analyses and/or selective leach tests plus manual/semiautomated analysis
- Automated/semiautomated concentrate analysis: separate automated preparation followed by analysis
- Automated or semiautomated specialty samples: solvent extraction, cathodes, mineralogy

Quality Assurance and Quality Control Efforts

QA/QC efforts should include a rigorous program that encompasses the following areas:

- A certain percentage of duplicates
- Upper and lower limits on all QCs
- Business rules
- Cross-checking of trend-drift analyses
- Instrument calibration and standards
- Round robin with other labs
- Monthly QA/QC reports for customers
- Annual lab audit by external auditor

LAB AUTOMATION: A KEY TOOL

Over the last 15 years, geometallurgy has become a focal point for better ore control, modeling, forecasting, and optimal process operation. In the early days, geometallurgical work primarily focused on hardness indices in models and simulation. Today, with the operation of multiple automated labs (both chemical and mineralogical), it has become apparent that robust geometallurgical planning and application can only be performed with the help of lab automation. Automated labs enable operations to submit and analyze large volumes of samples, thus improving overall ore-body profiling and providing daily production support data from mine geology to concentrators or heap leach operations.

LAB AUTOMATION FOR MINERALOGICAL ANALYSES

Mineralogy has three distinct analytical techniques that have been automated to varying degrees. The NIR/FT-NIR and/or FTIR analyses have been completely automated by mining companies. This includes all the sample preparation, analyses, and data reporting. This also allows the operations to collect quantitative mineralogy on selected alteration phases on hundreds of samples per day. The data can be transferred directly through LIMS programs into the common software used by the mine planners.

XRD analyses have been partially automated. The automation includes all the necessary sample preparations (crushing, splitting, pulverizing, mounting samples) and the transferring of the prepared sample mount into the XRD unit for analysis. The data (i.e., diffractogram) from the instrument can be sent directly to a server. Typically the data still require manual interpretation by an analyst to produce the quantitative mineralogy. This manual interpretation does become quite routine for an operator but can still take 5–10 minutes per sample to complete, which means that a single analyst can only complete 50–80 samples per day. Currently, no software programs are available that can automate the data interpretation of the variable, complex rocks present in virtually all mining operations.

Microscopy, either by light microscopy or scanning electron microscopy techniques (e.g., automated mineral analyzer units), has also been partially automated. The automation for these analyses is generally focused on selected areas of the sample preparation. Such areas include automated polishing and automated potting of the sample into the epoxy mount. Other necessary steps, such as screening, microsplitting, and carbon-coating the mounts, have not been automated, but it should be possible to automate these areas as well. The main challenge would be to design a way to connect all these areas together to automate the entire process, which would avoid the need for manual intervention to move the samples between each preparation step. Perhaps the main reason these analyses have not been fully automated is because the microscopy analyses are quite labor- and/or time-consuming. As such, these analyses are typically used for daily trend analyses or for determining causes for issues after the ore has been processed. Consequently, the automation of these microscopy techniques has been mainly pursued by high-capacity centralized support labs or by large commercial labs to improve their turnaround time.

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