INTEGRATING THE MINE-MILL OPERATIONS - INTELLIGENT MANUFACTURING SYSTEMS FOR THE MINING INDUSTRY

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ABSTRACT

The Mining and Metallurgical Industries are faced with ever-increasing complexities due to intense global competition, more-difficult-to-treat ores and concentrates, increased demands for environmental control and more complicated decisions regarding product distribution and quality. In North America, where we now mine relatively low-grade, refractory-type ores using highly-paid skilled labor, we can only compete with those regions of the world with high-grade, easy-to-treat ores and low-wage labor by operating our plants at maximum efficiency using automation and economies of scale.

As control of global markets continues to move to other continents, it is necessary for North American operators to adopt new techniques to increase profitability and continue to mine, mill and produce metals and other final products. An area of automation that remains to be adopted by the Mining industry is that being developed in the field of Manufacturing Science. Significant research has focused on methods to do the following:

- Collect and intelligently manage large amounts of data from across a company.
- Analyse data with a view to optimize across all departments and subsidiaries.
- Develop intelligent simulation models to predict and control interactions between different autonomous parts of an organization.
- Apply intelligent robots to perform routine tasks presently done by people.
- Simulate assembly lines and processes to find novel ways to reorganize complex process steps.

This paper reviews some of the principle methods of Factory Automation, Agent Technologies, Holonic Systems, Robotics and Intelligent Data Processing and suggests possible applications in the mining, mineral and metallurgical industries.

INTRODUCTION

Mining and mineral extraction are generally viewed as separate functions within the design and operation of a mining complex. Although certain stages within a mine-mill facility are batch processes, many are continuous. Attempts to improve efficiency or effectiveness of each stage is generally carried out in isolation without regard to up-stream or down-stream implications of a particular change except perhaps at the long-term corporate level. Although this approach may "optimize" an individual stage, it does not provide the opportunity to examine solutions that lie across several related processes.

Separate optimization of each stage does not guarantee that the overall process is optimized. Recent advances in the area of Factory Automation and Manufacturing Science suggest that the time has arrived to apply several new hardware and software techniques to the mine-mill complex. These include: intelligent database mining; just-in-time production scheduling; robotics; remote-sensing; automated mining systems; processing ore at the "face"; and final product manufacturing at the mine site.

The mining and metallurgical industries are at a crossroads. Faced with a long-term trend of ever-declining commodity prices together with increasingly complex ores and decreasing grades, mining companies today must implement one of two strategies:
1. continue the routine of cutting costs by labour-reduction and by adopting new technologies;

2. expand their organizational horizons to integrate across the mine and mill interface and to include value-added down-stream facilities.

The first option is the knee-jerk response as companies try to improve operating practices when times are tough and then take profits quickly by high-grading or pushing tonnage when resource prices improve. Although in the short-term (3-5 years) this policy can provide some relief, one must pick the cycles correctly or disaster may occur and often does. It is considered by most in our industry far-easier to focus on what we do best -- mining, processing and, in some cases, extraction -- and avoid the confusion of the value-added end-user markets.

However for long-term sustained growth, it is my contention that with the advent of the InterNet and its broad support for rapid communication and distribution, a successful mining company today must implement at least part of option 2. Companies must move from the position of simply producing concentrate to examining ways to achieve value-added opportunities in their end-user market(s).

This paper examines some of the software tools being applied in the Manufacturing industries to aid in complex decision-making to reorganize or adjust a facility to meet the heuristic demands of the end-user marketplace. The available tools offer assistance in a number of interesting and creative ways that include long-term and short-term planning as well as real-time process monitoring and control. It is suggested that use of these systems within the Mining industry either by individual companies or by a group of sector-based enterprises can provide significant relief to the problem of long-term profitability and sustainability. Significant improvement can be gained in the image of Mining as a sustainable profitable business center, an environmentally-friendly industry and as a modern-user of high-technology.

THE LIMITS OF "ECONOMY-OF-SCALE"

Mining companies traditionally "stick to their knitting". They do their work in areas for which they clearly have expertise and leave the downstream processing to others: companies in Japan, Korea, and existing smelters, refineries and metal producers in other parts of the world. Only rarely can a company justify the expenditures required to extend their processing facilities into such activities. Conventional wisdom states that it is more efficient and economic to centralize extraction and refining operations and to receive intermediate concentrate products from distributed mining operations. However examples do exist of the opposite approach -- the advent of the mini-steel mills in Canada to process scrap and raw materials into steel; the evolution of hydrometallurgical processes to produce final product at the mine; the creation of power and other energy products by coal conversion such as the South African SASOL plants.

It is only unusually large or rich deposits that provide incentive to add complexity. Economies-of-scale generally prevail to dictate a centralized approach. However times are changing and some of the advantages of "economies-of-scale" are beginning to disappear. Many issues which in the past have been impediments are now opportunities:

<table>
<thead>
<tr>
<th>Impurities</th>
<th>The complex nature of our ores are increasing. Some deposits produce concentrate with impurities that demand separate, unique downstream processing. Custom smelters may not accept certain materials with high Hg, high As, high Se and other undesirables.</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Processes</td>
<td>Many deposits are better exploited using hydrometallurgical techniques such as Pressure Oxidation, Bio-Leaching, Electrowinning, etc., which provide for metal production at the mine-site.</td>
</tr>
<tr>
<td>Local Markets</td>
<td>Local markets may exist which can sustain production of final product.</td>
</tr>
<tr>
<td>Recycling</td>
<td>The desire for recycling may help to create such markets.</td>
</tr>
<tr>
<td>Value-added</td>
<td>Certain products can be made relatively cheaply allowing the addition of significant product value with minimal investment and operating costs; e.g., gold nuggets sell at a premium ranging from $50 - $200 per ounce above the official selling price of gold. Although nuggets represent only 1-2% of the gold jewelry market, local conditions may provide conditions to consider manufacturing &quot;artificial&quot; nuggets.</td>
</tr>
</tbody>
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Regulations

Regulations are often contradictory. In an attempt to solve one problem, new problems occur in another area; e.g., environmental laws on waste disposal are implemented without examining process options or the form of an element which may be the determining factor in its toxicity and/or bioavailability.

Infrastructure

Sustaining mining activity in remote regions of a country can contribute to jobs and economic growth if infrastructure support is provided.

Design Impact

Availability of downstream processing can affect decisions on the design and operation of a mine-mill enterprise to reduce costs.

Local Resources

The presence of local resources such as power, rail, shipping ports, etc., can provide significant incentive to invest in downstream processing.

Delivery Costs

Savings in transportation and product delivery costs can be derived from the presence of nearby smelting, refining and/or manufacturing facilities.

Complexities

Complex, interactive decision-making across an overall enterprise has not been possible because of poor data-communication, poor data-collection and poor data-analysis. Such is not the case today.

THE ADVENT OF "COMPLEX" ANALYSIS

Companies can now examine many more options in their decision-making than ever before. There may be a need for flexible design, operation and product marketing to respond to changing commodity prices, competition from other sectors (geographically- or technologically-based such as Al vs. Cu; composite materials vs. super-alloys; fibre-optics vs. coaxial cable; etc.), complex ore changes; complex technological changes (new systems of communication, new advanced materials, robotics, nanotechnology, etc.)

Starting with plant design and examining product diversification, we must adapt our plans and processes to meet these forces. A mine must be able to adjust production on-demand and avoid stockpiling. It must react to changes in ore conditions and customer demands.

INNOVATIVE MANUFACTURING SYSTEMS

Managing a company in the 21st century requires a new way to communicate with the external environment. Companies of the Third Millennium must transform into intelligent, learning organizations able to cope with globalization of information resources. The main problem will not be access to information but the ability to mine data and transform it into useful operating and strategic resources.

As system models become increasingly complex, decomposition into smaller units is the usual way to structure the problem. Historically this has led to atomized structures consisting of many autonomous subsystems, each of which decide on what information to receive and send out. Autonomous subsystems are embedded into larger systems, since autonomy and independence are not equivalent concepts. These ideas are gaining strong interest and the atomized approach to information-flow modeling and evaluation is an idea whose time has come. In the real-world, autonomous subsystems consist of groups of people and/or machines tied together by the flow of information and materials.

Advances in computer technology have led to the design of extremely complex systems in areas such as advanced manufacturing systems, transportation systems and world models (economic and ecological). The complexity of these systems requires distributed supervisory functions. That is, an assembly of individual modules must be defined and coordinated within a comprehensive control architecture. While some controllers direct processes, others supervise. An effective architecture should possess the following features:

- Users can specify high-level tasks, which are then decomposed into detailed execution tasks according to an established hierarchy or distribution network,
- Users can plan and control at different resolutions of time and level of detail,
- The system can decompose complex behaviors into manageable sub-functions.
The system allows functions to be distributed across several intelligent controllers. An example of such an architectural structure is the design implementation suggested by NASA/NIST as shown in Figure 1 [4,5,6].

Managing complexity, changes and disturbances is a key issue in production systems. Distributed, agent-based or holonic structures represent an alternative to hierarchical systems. Several approaches to implement such structures include: simulation modeling to develop and test agent-based architectures; and the holonification of existing resources and "traditional" (centralized/hierarchical) systems. Cooperation of agent-based distributed control structures and evolutionary schedulers allow these systems to handle critical complexity, reactivity, disturbances and optimality issues simultaneously.

An agent is an "encapsulated" software entity with its own identity, state, behavior, thread of control, and ability to interact with other entities including people, other agents and "legacy" systems. An agent, whether real or virtual, is able to act on itself and on other agents. Its behavior is based on observations, knowledge and interactions with other agents in the system or process. An agent has several important features -- the ability to perceive at least partial representation of its environment, the ability to communicate with other agents, the ability to produce child agents, knowledge about its objectives and some rather unique autonomous behavior often characterized as selfishness [7,8].

Holonic manufacturing (Figure 2) is a new paradigm in manufacturing that consists of autonomous, intelligent, flexible, distributed, cooperative agents or holons [9]. The word "holon" derives from the field of hagiography -- a holon is defined as "a part of a whole". Three basic types of holons, resource holons, product holons and order holons, have been defined [10] although other types or sub-types might be characterized for certain specific systems. These entities use object-oriented concepts such as aggregation and specialization to perform their duties. The most promising feature of the holonic approach is that it provides a transition methodology from hierarchical to heterarchical systems, which are more representative of the real world.
The main design issues of an agent-based system are:

- **Structure**: internal structure of agents and the level of their self-containment,
- **Communication**: protocols, common interchange language,
- **Group formation**: persuading machines to participate in a group, reward/penalty systems,
- **Configurability**: open systems (addition, deletion, substitution of machines/groups),
- **Scalability**: appropriateness of scale-up to the level of the extended enterprise,
- **Local optima**: reaching global optima with agents pursuing their own individual goals.

An object-oriented framework to develop and evaluate distributed systems provides a model to represent a plant containing different agents. The object library holds two main types: resource agents and order agents. An order agent processes orders, announces jobs and dispatches job messages among different resources or groups (Figure 3). The model incorporates several resource agents that are initialized during dynamic configuration (resource names, processing capabilities, etc.).

Agents contain functionally-separated subagents. Each agent incorporates a communication subagent to deal with messages by using a contract network protocol. Each resource agent involves a supervisor subagent to control real-world actions. Agents use a registration mechanism by which they can register and deregister themselves. Each agent has local knowledge and data bases that store information on machine capacities, time intervals for different jobs, the groups in which the agent is interested, etc. Facts about the agent itself are accessed through the communication subagent by a request message [11].

Agent-based software engineering was invented to facilitate interoperability. There has been much interest and development in "middle"-ware to deal with software that is already written -- legacy software.

The term "agent" can mean many things: mobile code, web search tool, interface tool, distributed component library, semantic broker (translator), applet, "disembodied" code with either temporal duration or persistency, electronic commerce with message-passing entities, dynamic services, intelligent routers, robots, etc.

Many programs need agent-task-fulfilling properties: assignment problems, burst bandwidth problems with mobile code capability, open source information agents, interoperability with brokering, etc. Agents can eliminate "data overload" and "information starvation" difficulties by providing "just-in-time" flow of information. Three key design aspects of an agent system are:

- number of agents required
- number of types of agents required
- number of actions that an agent can perform
There are four main task-functions that may also be used to define an agent:

- dealing with complex problem-solving,
- finding, filtering and presenting information to users,
- providing services to other agents in order to solve problems cooperatively,
- providing translation services between agents that use different standards, communication protocols, languages, etc.

Large-scale, cooperative teams consisting of interacting agents from all four groups, offer capabilities beyond the realm of conventional software design. An infrastructure that provides these features allows a developer the opportunity to design small pieces of code to solve specific problems that can interact with other pieces of code, rather than duplicating functions in each module. In this way, task-specific agents can be built up from smaller functional agents that can participate in multiple activities.

**Data Models and Communication**

A major problem in integrating complex systems is the method of communication used across the system. A number of important communication protocols have been established -- some of these will now be described.

**The STEP Standard**

The STEP Standard (STandard for the Exchange of Product Model Data - ISO 10303) established in 1985 was the first to use an integrated product model approach to provide semantic data models (Application Protocols such as AP214 and AP203) together with mechanisms for data exchange [12, 13].

The file-based exchange used by STEP is based on "Processors" which transform data from each Product Data Management system into files using a standard format and a standard data-model (Part 21, ISO 10303) (see Figure 4). The STEP standard also provides mechanisms to share data via the Standardized Data Access Interface defined by ISO 10303-22 in 1994 [14].
CORBA

The Object Management Group (OMG), a consortium of companies from all facets of the computer industry, has defined the Common Object Request Broker Architecture (CORBA). CORBA is middleware that allows intelligent components to discover each other and inter-operate on an object bus [15]. This object bus is referred to as the ORB.

(Object Request Broker). The ORB abstracts information needed for remote components to communicate with each other. Components interact across networks, servers, and operating systems as if all resided on the same machine. This makes it easy for the developer to create networked client/server applications.

The component boundaries are defined using a protocol known as the Interface Definition Language (IDL). The IDL file is compiled to generate client-side stubs and server-side skeletons, which permit components to access one another across languages, tools, operating systems and networks.

![Diagram](Fig. 5: Architecture of a CORBA Communication Protocol System. (after Nicoletti, 1999 [16]))

- **Interface identical for all ORB Implementations**
- **There may be multiple Object Adaptors**
- **Stubs and Skeletons are identical for each Object type**
- **ORB dependent interface**
So developers need only worry about object interaction rather than focusing on locating remote objects and passing information along a wire. CORBA defines an extensive set of bus-related services to create and delete objects, access them by name, store them in data-warehouses, externalize their states, and define ad-hoc relationships among them.

CORBA specifies a system that provides interoperability between objects in a heterogeneous, distributed environment that is transparent to the user. Its design is based on the OMG Object Model. OMG defines an object semantics to specify characteristics independent of the method of implementation [16].

CORBA operates as follows: clients request services from objects (servers) through a well-defined interface. This interface is specified by the IDL. A client accesses an object by issuing a request to the object. The request is an event containing:

1. information about the operation,
2. the object name of the service provider, and
3. any parameters.

To make a request, a client communicates with the ORB through its IDL stub or through a Dynamic Invocation Interface (DII). The stub presents a mapping between the language of the client implementation (C, C++, Java, and others) and the ORB core. The ORB then transfers the request to the Object Implementation which receives the request through an IDL or a dynamic skeleton as shown in Figure 5.

POTENTIAL APPLICATIONS IN MINING

The following list contains some potential applications that are worthy of study using an IMS agent-based or holonic system. It is conceivable that significant improvement in the day-to-day operation of a mine-mill complex can be achieved through these studies.

Intelligent Stockpiles

Stockpiling of ores can be reduced to a minimum or can be set-up to provide ore blending or individual treatment of specific ore types. IMS systems can provide the data and knowledge to begin to examine this practice [17, 18].

Enhanced Comminution Systems

Establishment of optimum run-of-mine sized ore using blasting, primary crushing and autogenous grinding can be done through the employment of IMS systems [19]. Real examples of these benefits have been demonstrated by Mt. Isa [20] and Highland Valley Copper [21].

Coordinated Real-Time Maintenance

Coordination of scheduled maintenance has been done at several Canadian mines. Collection of cross-corporate data on equipment needs can enhance such coordination and lead to increased production and reduced costs. Operating times can increase significantly.

Tele-remote Operations

Baiden has demonstrated the tremendous advantages to be derived from telerobotic operation of underground equipment. These benefits include increased productivity, improved worker safety and reduced capital costs. A doubling of productivity is possible [22].

Enhanced Data Communication

CORBA-based Internet communication systems can provide baseline support to collect, store and present corporate-wide data for all enterprise levels. Wireless communication is now state-of-the-art allowing remote analysis of “live” data. Cost-savings from reduction in personnel and information coordination are considerable.

Discovery of New Ideas

By operating the models as a simulator, it is possible that new milling circuit designs can be devised to provide enhanced operation under certain heuristic situations.

Value-Added Production at the Mine

Diversification of mine production can help to withstand fluctuations in the conventional resource-sector markets. Several examples of companies who have already done this or who need to examine this option are as follows:

Polar Diamond - BHP/Ekati

BHP's new Ekati Mine is supplying a subsidiary firm in Yellowknife with a portion of their diamond production to manufacture the "Polar" Diamond with a picture of a polar bear lasered on the girdle of the cut stones.

Millennium Diamond - De Beers

De Beers have long been leaders in promoting end-use sales of their diamond production. The latest promotion is the creation of special Millennium diamonds with a strategy similar to that of BHP.
Gold Jewelry Production on-site

The Harmony Mine in South Africa have developed a novel process to produce 5-9s gold on site. A special training centre has been set up to train 40 local artisans per year to manufacture jewelry at the mine site.

Other gold mines should follow this example. In BC, there are likely opportunities to work with First Nations groups to provide new employment benefits in remote communities based on local cultural activities.

Chemical Products from Coal

The North American coal industry faces increased environmental concern for global warming from the release of green-house gases such as CO₂. As well, the competition form abroad has increased tremendously, particularly from Indonesia, leading to extremely low prices for Thermal Coal and Metallurgical Coal -- the only two products of significance in the coal industry.

With the expected increases in transportation and heating fuel costs, the industry needs to look towards value-added production of other energy-vector products such as fuels from coal and hydrogen production as was in vogue during the oil-crisis of the 1970s.

RECOMMENDATIONS AND CONCLUSIONS

With the increasing pressures of low commodity prices and foreign competition, mining companies must examine alternative strategies to deal with these complexities and remain sustainable. Tools currently being used within the manufacturing sector have potential to provide solutions in integrating data from across different departments.

These tools provide ways to collect, store and present real-time data for a variety of decision-making including direct or supervisory control and long-range planning.

Opportunities exist to enhance mine economics through value-added production by focusing on ways to recover and manufacture end-user products at the mine site and supply end-user customers with mine-derived products.

Failure to adopt these approaches will result in continued need for relief from commodity price drops without the innovations required to provide sustainability.

ACKNOWLEDGEMENT

The author wishes to acknowledge the support and assistance by members of the IPMM group (Intelligent Processing and Manufacturing of Materials). IPMM consists of over 400 researchers around the world from a diverse set of backgrounds who share a common interest in intelligent processes. IPMM holds a bi-annual conference -- the 3rd IPMM Conference is scheduled for July 29 - August 3, 2001 in Vancouver, B.C.

REFERENCES


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