

# **Integrating the Mine and Mill - Lessons from Manufacturing**

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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 efforts have focused in recent years on methods to do the following:

- Collect and intelligently manage large amounts of data from across the 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 factory processes to find novel ways to reorganize and deal with complex processing steps.

This paper will review some of the principle methods of Factory Automation, Agent Technologies, Holonic Systems, Robotics and Intelligent Data Processing and suggest 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-type processes, many are continuous. Attempts to improve efficiency or effectiveness of each stage are generally carried out in isolation without regard to up-stream or down-stream implications of a particular change except perhaps at a long-term corporate level. Although this approach may "optimize" an individual stage, it does not provide an 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 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.

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 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 position that with the advent of the InterNet with its support for rapid communication and distribution, a successful mining company today must implement at least part of option 2. In the future, companies must move from simple concentrate production and look for value-added opportunities in their **end-user** markets.

This paper examines some of the software tools being applied in Manufacturing to aid in complex decision-making to reorganize or adjust a mine/mill 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 range from long- and short-term planning to real-time process monitoring and control. It is suggested that using 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 -- 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 dictating a centralized approach. However times are changing rapidly and some of the advantages of "economies-of-scale" are beginning to disappear. Many issues which for years have been impediments are now opportunities:

<b>Impurities</b>	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.
<b>New Processes</b>	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.
<b>Local Markets</b>	Local markets may exist which can sustain production of final product.
<b>Recycling</b>	The desire for recycling may help to create such markets.
<b>Value-added</b>	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 "artificial" nuggets.
<b>Regulations</b>	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.
<b>Infrastructure</b>	Sustaining mining activity in remote regions of a country can contribute to jobs and economic growth if infrastructure support is provided.
<b>Design Impact</b>	Availability of down-stream processing can affect decisions on the design and operation of a mine-mill enterprise to reduce costs.
<b>Local resources</b>	The presence of local resources such as power, rail, shipping ports, etc., can provide significant incentive to invest in downstream processing.
<b>Delivery costs</b>	Savings in transportation and product delivery costs can be derived from the presence of nearby smelting, refining and/or manufacturing facilities.
<b>Complexities</b>	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

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

Beginning with plant design and working through to product diversification, we must adapt our processes to meet these forces. A mine must be able to adjust production on-demand and avoid stockpiling. It must react to changing ore conditions and customer demands.

### INNOVATIVE MANUFACTURING SYSTEMS

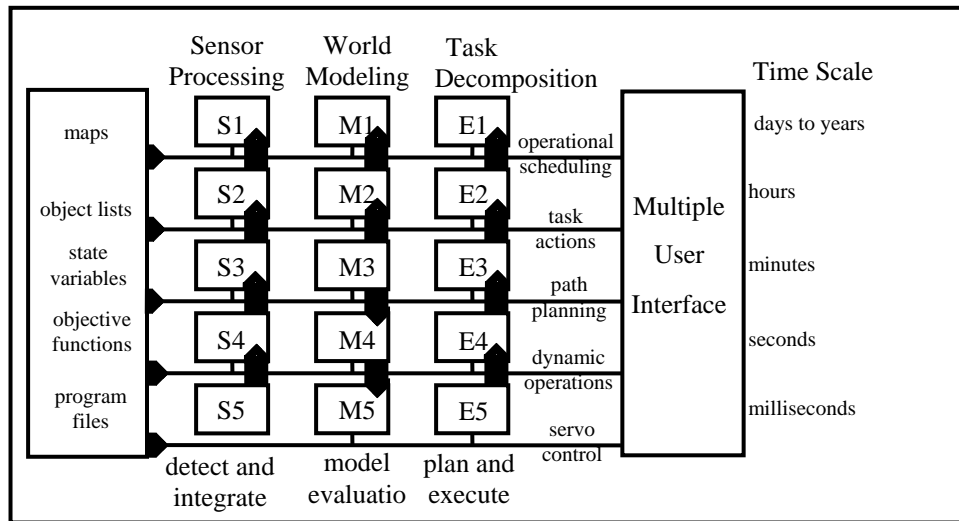
Managing a company in the 21<sup>st</sup> century requires new means to communicate with the external environment. Companies of the Third Millenium must transform into intelligent, learning organizations able to cope with globalization of information resources. The main problem will not be access to information but the ability to **mine data** and transform it into useful operating and strategic resources. (Szczerbicki and Gomolka, 1999)

As system models become increasingly complex, decomposition into smaller units is the usual way to structure a problem. Historically this has led to atomized structures consisting of a number of **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. (Gunasekaran and Sarhadi, 1997.) In the real-world, autonomous subsystems consist of groups of people and/or machines tied together by the flow of information.

Advances in computer technology have resulted in the design of extremely complex systems such as advanced manufacturing systems, transportation systems and world models (economic and ecological). The complexity of these systems requires supervisory functions to be distributed. That is, an ensemble of individual modules must be defined and coordinated within a comprehensive control architecture. While some controllers direct processes, others supervise. An effective architecture (Davis, 1999) should possess the following features:

- The user can specify high-level tasks, which can be decomposed into more detailed execution tasks according to an established hierarchy or distribution network,
- The user 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 a function to be distributed across several intelligent controllers.

An example of such a structure is the design architecture suggested by NASA/NIST as shown in Figure 1. (Moncton, 1997), (Albus and Quintero, 1990), (Lumia, 1994).



**Fig. 1:** NASA/NIST Standard Reference Modeling Environment (modified NASREM after Moncton, 1997).

Managing complexity, change, and disturbances are key issues 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 holonification of existing resources and traditional (centralized/hierarchical) systems. The cooperation of agent-based distributed control structures and evolutionary schedulers will allow systems to handle critical complexity, reactivity, disturbances and optimality issues all at the same time.

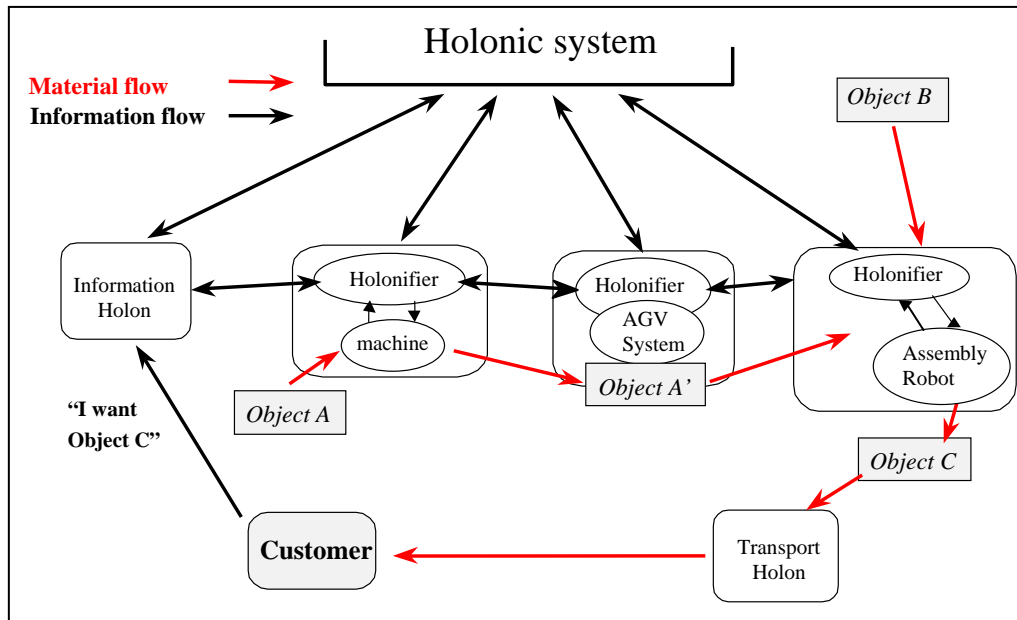
An **agent** is an "encapsulated" software entity with its own identity, state, behavior, thread of control, and ability to interact with other entities including people, other agents and "legacy" systems. An **agent**, whether real or virtual, can act on itself and on other agents. Its behavior is based on observations, knowledge and interactions with other agents in the system or process. An agent has several important abilities – to perceive at least a partial representation of its environment, to communicate with other agents, to produce child agents, and knowledge of its objectives and unique autonomous behavior often characterized as selfishness. (Monostori and Kádár, 1999), (Koussis et al., 1997).

**Holonic manufacturing** (Figure 2) is one of the new paradigms in manufacturing, consisting of autonomous, intelligent, flexible, distributed, cooperative agents or **holons** (Valckenaers et al., 1994). The word holon derives from the field of holography - a holon is a part of a whole. Three types of basic holons, **resource holons**, **product holons** and **order holons**, have been defined (Van Brussel et al., 1998). 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 from hierarchical to heterarchical systems.

The main design issues of an agent-based system are:

- **Structure:** internal structure of agents and the level of their self-containment,
- **Communication:** communication protocol, 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,
- **Global versus local optima:** reaching global optimum with agents pursuing their own goals.

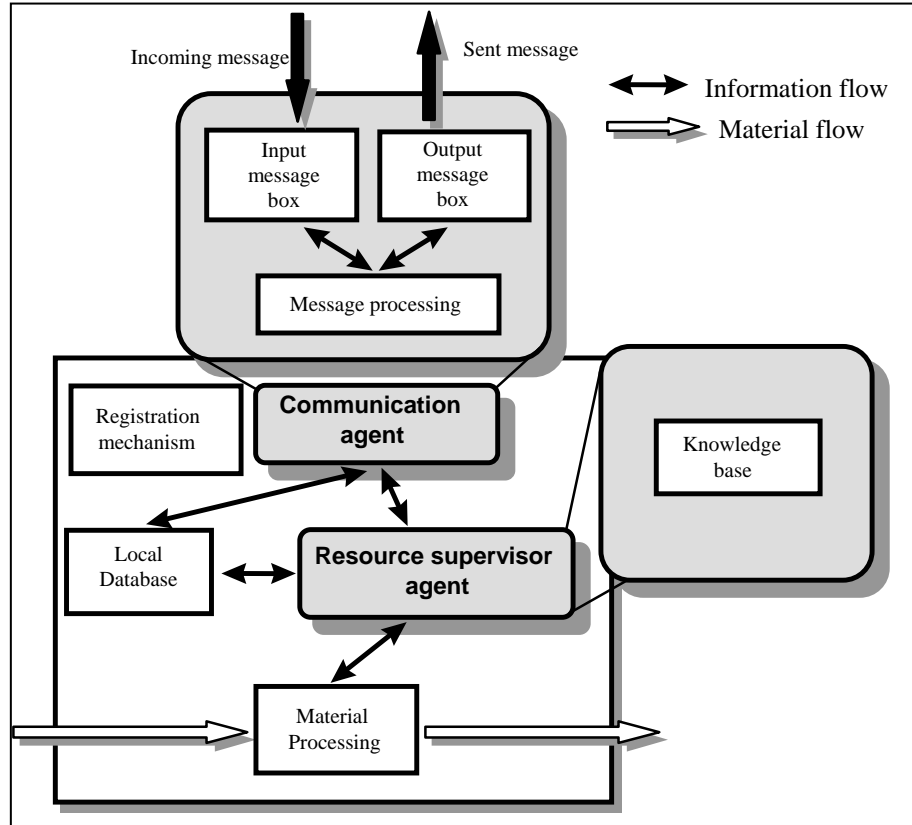


**Fig. 2:** Heterogeneous Holonic Manufacturing System consisting of real and soft holons.  
(after Monostori and Kádár, 1999)

An object-oriented framework to develop and evaluate distributed agent systems provides a model to represent a plant containing different agents. The object library will contain two types: **resource agent** and **order agent**. The order agent is responsible for order processing, job-announcements and job-dispatching between different resources or groups (Figure 3). The model incorporates several resource objects which are initialized during dynamic configuration (giving the resource name, processing-capabilities, etc.).

Agents contain different, functionally-separated subagents. Each agent incorporates a communication subagent to send and receive messages by using a contract network protocol. Each resource agent involves a supervisor subagent which controls all real-world actions. Agents contain a registration mechanism by which they can register and unregister themselves. Each agent has a local knowledge base and database which store information about machine capacities, time intervals for different jobs, the groups in which the agent is interested, etc.. Information about the agent itself is accessed through the communication subagent by a request message. (Monostori et al, 1998).

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**.



**Fig. 3:** Structure of a resource agent. (after Monostori and Kadar, 1999)

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

- number of agents required
- number of types of agents required
- complexities (number of actions that an agent can perform)

There are four different kinds of agents:

- those that deal with complex **problem-solving**,
- those that find, filter and present **information** to users,
- those that **provide services** to other agents to solve problems cooperatively,
- those that **provide translation services** between agents using different standards, communication protocols, languages, etc.

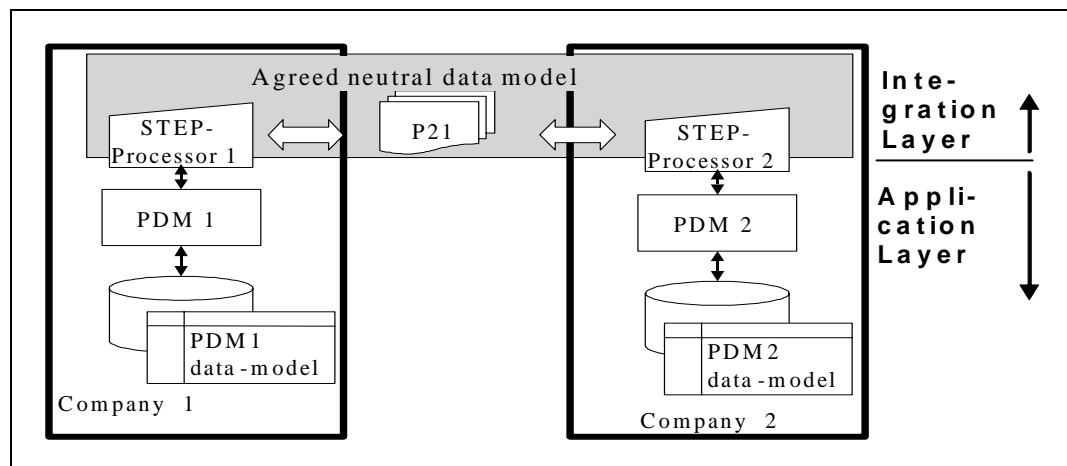
Large-scale, cooperative teams, comprised of interacting agents from all four groups, offer capabilities beyond the realm of conventional software design. An infrastructure that provides these features allows a developer to design small pieces of code that solve problems via interactions with other pieces, rather than duplicating functions provided by other modules.

### Data Models and Communication in Manufacturing

One of the major problems for integrating complex systems is communication across the system. A number of protocols have been established -- some of which will now be described.

The STEP Standard (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) as well as mechanisms for data exchange. (Karcher and Wirtz, 1999).

The file-based exchange of 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). STEP standard also provides mechanisms to share data via the Standardized Data Access Interface (ISO10303-22, 1994.).



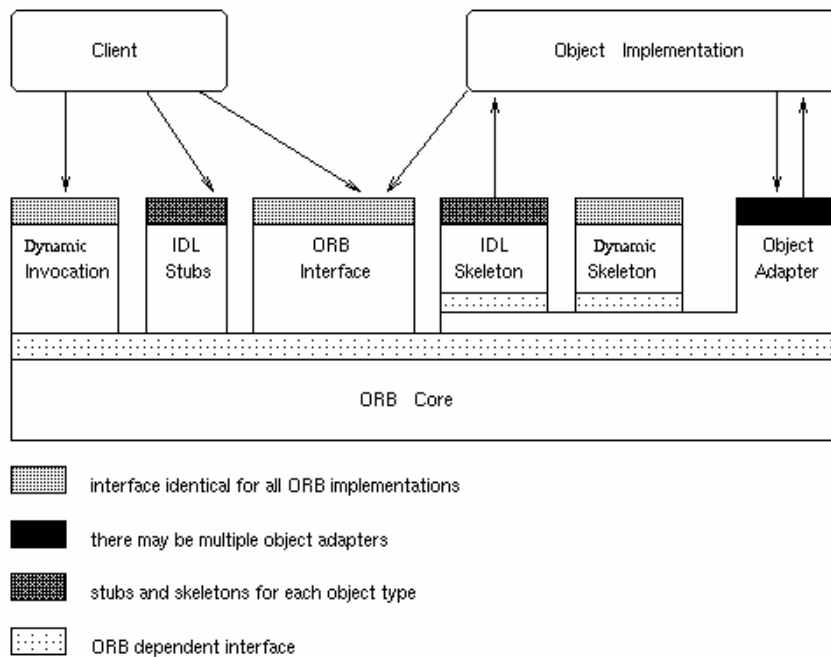
**Fig. 4.** A STEP based Integration Layer (after Karcher and Wirtz, 1999).

### 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 middle-ware that allows intelligent components to discover each other and inter-operate on an object bus (Orfali et al., 1997). This object bus is referred to as the Object Request Broker (ORB). The ORB abstracts the 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's boundaries are defined using the Interface Definition Language (IDL). The IDL file is compiled to generate client-side **stubs** and server-side **skeletons**, which permit components access one another across languages, tools, operating systems and networks. So a developer 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.

The Common Object Request Broker (CORBA) (Nicoletti, 1999), specifies a system which 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.



**Fig. 5:** Architecture of a CORBA Communication Protocol System (after Nicoletti, 1999).

CORBA operates as follows: *clients* request services from *objects* (servers) through a well-defined interface. This interface is specified in the IDL. A client accesses an object by issuing a *request* to the object. The request is an event which carries information about the operation, the *object reference* (or name) of the service provider, and any parameters. To make a request, a client communicates with the ORB through its IDL *stub* or through the Dynamic Invocation Interface (DII). The stub represents 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**

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**
- Enhanced Comminution Systems**
- Coordinated Real-Time Maintenance**
- Autonomous Operations**
- Tele-remote Operations**
- Enhanced Data Communication Protocols**
- Discovery of New Ideas**
- Value-Added Production at the Mine (examples)**
  - Polar Diamond - BHP/Ekati**
  - Millennium Diamond - De Beers**
  - Gold Jewelry Production on-site - Harmony Mine in South Africa**
  - Chemical Products from Coal**

### **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. The tools currently being used within the manufacturing sector have potential to provide solutions in integrating across our different departments.

These tools provide methods to collect and store data in real-time for control and decision-making at a variety of corporate levels from direct unit control to supervisory and long-range planning.

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

Failure to adopt these approaches will result in companies continuing to hope for commodity price relief without the innovation work being done to sustain the enterprise into the future.

### **ACKNOWLEDGEMENT**

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