FROM BUTTONS TO BITS - ACHIEVING LEVEL 3 INTEGRATION

Christopher McElman
Product Manager, Open Pit
Modular Mining Systems
Port Coquitlam, B.C.

Sergey Seroukhov
Product Line Architect
Modular Mining Systems Inc.
Tucson, Arizona

ABSTRACT

Real-time mine management solutions have evolved over time from closed, proprietary solutions, to a "system of systems" that may include a wide variety of off-the-shelf components and technologies. Modular Mining Systems has embraced open standards for their NextGen products to bridge the technology gaps between these systems. However, the remaining logical gaps must be overcome, in order to achieve truly seamless integration between discrete systems.

When dealing with volatile real-time management problems, the effectiveness of business process modeling and middle-ware can break down. Scientific principles of military command and control applied to mining domain help to achieve better alignment and reach the highest level of integration.

The combination of open standards and off-the-shelf hardware and software with a deliberately structured command-and-control approach provides a clear evolutionary path from ad-hoc connected systems towards real-time management of a seamlessly integrated digital mine.

INTRODUCTION

Real-time mine management solutions enable mine operators to maximize the return on their capital investment by tracking, directing and optimizing mining activities. Common applications include real-time monitoring of production activities, optimized truck assignments, stake-less surveying, and equipment health monitoring.

An idealized depiction of the information systems and user groups of a typical mine production system is included in Figure 1. The systems and roles that require real-time interaction are highlighted in red. The mining production process is complex, requiring the interlinking of multiple management systems across various specialized areas, such as mine operations, maintenance, ore processing, and administration. The sheer number of inter-connections and the variety of data formats makes systems integration costly.

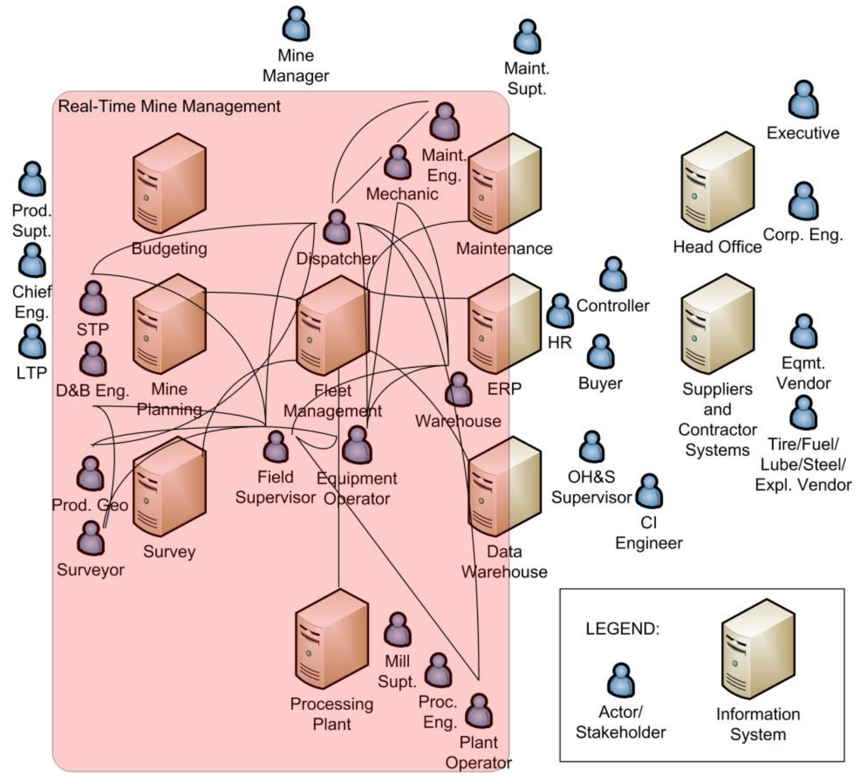


Figure 1. Complex inter-connection of mine management systems and stakeholders

Since 1979, Modular Mining Systems Inc. has led the mining fleet management industry, with over 150 systems installed at some of the world's largest mining operations. Initially, the technical requirements for these systems could not be met with off-the-shelf technologies. Modular's DISPATCH® systems originally relied on proprietary technologies for many of the system components. These components, ranging from data protocols and database storage to scripting and reporting were all built from the ground up. Modular's NextGen product line signals a departure from proprietary technologies on many different levels.

Modular's shift to open standards and off-the-shelf technology components represents an enormous step towards delivering better systems connectivity. However, seamless integration between systems is required to complete the migration to a fully digital mine. Moving forward, a new paradigm is required to digitize the fast, high-quality decisions that are necessary for real-time mine management.

PROBLEM DEFINITION

Several major mining companies have published their vision for the future as a digital, or fully automated mine (Albanese, 2008 and Orellana, 2007). The number of stakeholders, components and dependencies is large. The cost of traditional integration methods can expand exponentially as system scale and variety increases. More importantly, it may be necessary to integrate systems that have been designed based on different principles, with a focus on different objectives. Where system components are conceptually misaligned, no amount of investment can deliver seamless integration. This challenge must be addressed to create the system of systems required to deliver a digital mine.

PROBLEM ANALYSIS

Integration is by definition, a closing of the gaps between individual systems. These gaps can be characterized as either technological or logical. Open standards and standardization of technologies have eliminated many of the technological gaps. Several examples of these technological gaps and the tools that have been used to address them are described in Table 1.

Technology Gaps	Solutions
Incompatible hardware	Media converters, standardization of hardware
Multiple authentication formats	LDAP, Active Directory
Incompatible communications protocols	Web services, CORBA
Incompatible data formats	Middleware, SOA, XML transformations
Diverse user interfaces	Mashup technologies
Distributed data sources	Data warehouses

Table 1. Examples of technology gaps and current solutions

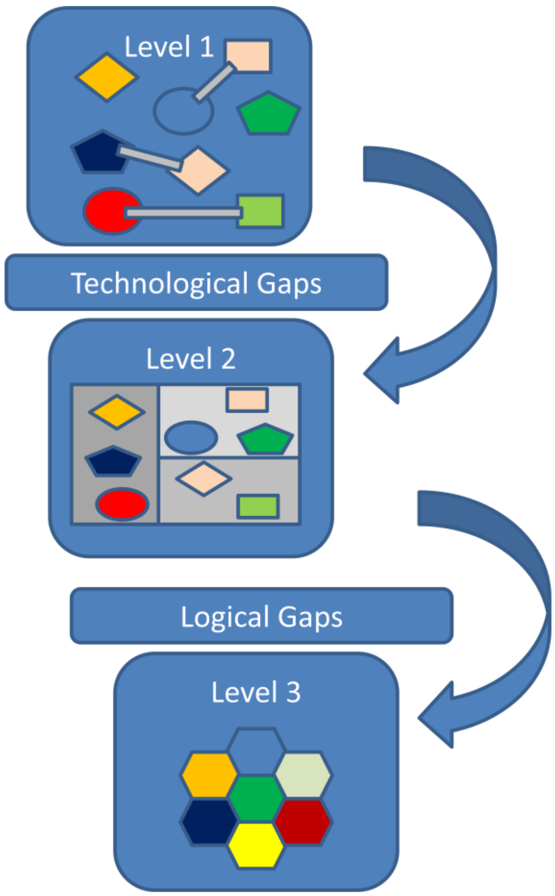
Modular's NextGen products incorporate many standardized, off-the-shelf hardware and software components to minimize technology integration gaps. All NextGen server, desktop, and mobile applications have been moved to the Microsoft® Windows operating system, using an SQL Server® relational database. Modular now uses standard technologies for authentication (Windows Integrated Security), reporting (SQL Server® Reporting Services), and data transfer (SQL Server® Integration Services). Instead of developing a proprietary web portal, Microsoft® Sharepoint Services was selected. All of these off-the-shelf technologies maximize compatibility and ease of inter-connection between real-time mine management systems, and the associated mine planning, enterprise resource planning, and maintenance management applications.

Technological gaps have been well addressed by existing tools and methodologies. For the most part, these issues are no longer a problem. However, simple connectivity does not guarantee seamless integration. The problems of logical gaps and conceptual misalignment remain. Achieving a high level of integration requires increasing costs and complexity (Paige & Inbar, 2008). Table 2 describes examples of logical gaps, and the limitations of existing integration solutions in the face of these gaps.

Logical Gaps/Conceptual Misalignments	Limitations of Existing Solutions
Structural Mismatch	Conversion between formats is possible using ontological models, but only to the extent that concepts are compatible.
Incomplete Information	Difficult to discover and combine information from multiple systems if a single source is incomplete. Simple business transactions require gathering of information from multiple sources. Production metrics do not contain links to the decisions. This limits the ability to understand why things happened.
Duplicated Information	Multiple parallel copies of information can reduce data integrity. Difficult for middleware to reconcile multiple data sources.
Different Levels of Granularity	If information has already been aggregated, it may be impossible to decompose to finer detail.

Table 2. Logical gaps and limitations of existing solutions

By interpreting the evolution of system integration as attempts to address technological and then logical gaps, three distinct levels of integration emerge.



Level 1: Closed systems, incompatible technologies, custom bridges and ad-hoc integration.
Challenge: “How to pass the information”

Level 2: Systems with open interfaces, high level of technology standardization, extensive use of EAI middleware
Challenge: “What information to pass where?” “How to ensure it is up-to-date, complete, trusted?”

Level 3: Systems use compatible technologies. Their design principles and communication protocols are aligned to the point that there are no gaps and components naturally fit each other.

Figure 2. Three levels of integration

Given sufficient time and resources, technological gaps no longer represent an unsolvable problem. Most enterprises are in transition from a Level 1 to Level 2 integration level, with some outliers at Level 1 and advanced innovators at solid Level 2. But some visionaries from Rio Tinto and Codelco have started dreaming about “digital mines” with automatic processes and digitized information flow, that are able to operate with minimal human involvement. Realization of this dream requires the highest level of integration; Level 3.

The main challenge that must be overcome to achieve seamless integration and build a digital mine lies with addressing logical gaps between systems. Even the most expensive middleware solutions cannot meet this objective. If a system is not designed to do certain things, it is nearly impossible to force it to do so. The next level requires the introduction and application of common principles, standards, and communication protocols to develop systems that naturally fit each other.

Traditionally integration problem has been viewed through a prism of "business processes" that require automation. Business Process Modeling techniques like IDEF0, Flow Chart, Business Process Definition Language used by different middleware solutions reflect the contemporary trend (Harmon, 2003)

Business processes model a deterministic transition of processing states with branches, conditions, and loops. For static, non-volatile systems, this paradigm is effective. However, for dynamic, volatile systems with constantly changing environments, there are numerous ways for a process to be executed.

Automation of processes in volatile environments is difficult because yesterday's process may not address today's new business need. For example, a process to model a mechanic's assignment to repair a piece of equipment in the field can break down easily if the equipment is not at the expected location, additional parts are required, or the mechanic is unable to find the equipment. In a battlefield situation, the same type of highly volatile environment applies. A soldier that is ordered to occupy a position may run into enemy fire, lose orientation or communication with their command center, or run out of fuel or supplies en route.

Without innovation, agility and courage, overcoming a flexible, unpredictable adversary is not possible. Given the question "How to effectively manage military operations?", armed forces around the world have invested millions of dollars in research to define the scientific principles to build an effective management system of such scale, complexity and agility (Atkinson, 2005). Today, a battlefield command and control system that links the entire chain of command from strategic planning to operations, tactical levels, and down to individual soldiers is no longer a fiction but a reality. These systems work by linking all elements in a common information space in real-time. (Wilson, 2004)

The military sphere has dedicated considerable research effort into defining and managing volatile environments according to scientific principles. (Alberts & Hayes, 2006) This different modeling perspective can be re-used in the mining environment. By modeling activities with command-and-control principles instead of rigid business processes, and by using these models to integrate business systems, a more flexible integration approach is produced. The focus of these models is not on repeatability of processes, but on efficient propagation of decisions.

SOLUTION

While looking for better ways to align real-time mine management systems it became apparent that that the principles of Military Command & Control (C2) can be converted and extended to industrial domains. This set of those principles is described as "Industrial Command and Control" to differentiate it from the original source.

So, what is the new better way to think about real-time management? According to C2 principles, regardless of the objectives or business processes, management activities constantly follow a cycle;

1. Observe. The decision-making entity must see what's happening,
2. Orient. Analyze the situation and decide on their goal(s).
3. Decide. Create, and commit to a plan to achieve those goals given the current environment.
4. Act. Execute the plan!

Circumstances may change unexpectedly in a volatile environment, therefore, these steps must repeat over and over again to steer execution or to update goals based on the current situation.

This "Observe, Orient, Decide, Act" cycle in C2 is called the "OODA Loop" (Richards, 2001). When the OODA cycle is executed by decision-making entities, information inputs and outputs can be organized into the distinct categories depicted in figure 3.;

- Inputs: Goals and Objectives, Situation Information, Primary Outcome and Status Information about execution, Escalations
- Outputs: Decisions/Actions, Results of own actions, Escalations,

Interconnected "Decision Making Entities" form a "Decision Making Network" used to share information and pass decisions through a chain of command. The decision-making entity can be a senior executive who steers the company business and translates his decisions to company divisions and their leaders; a dispatcher who decides when and how use equipment to maximize production; or a truck operator whose tasks are as simple as drive, watch the road and communicate decisions to a truck using a steering wheel.

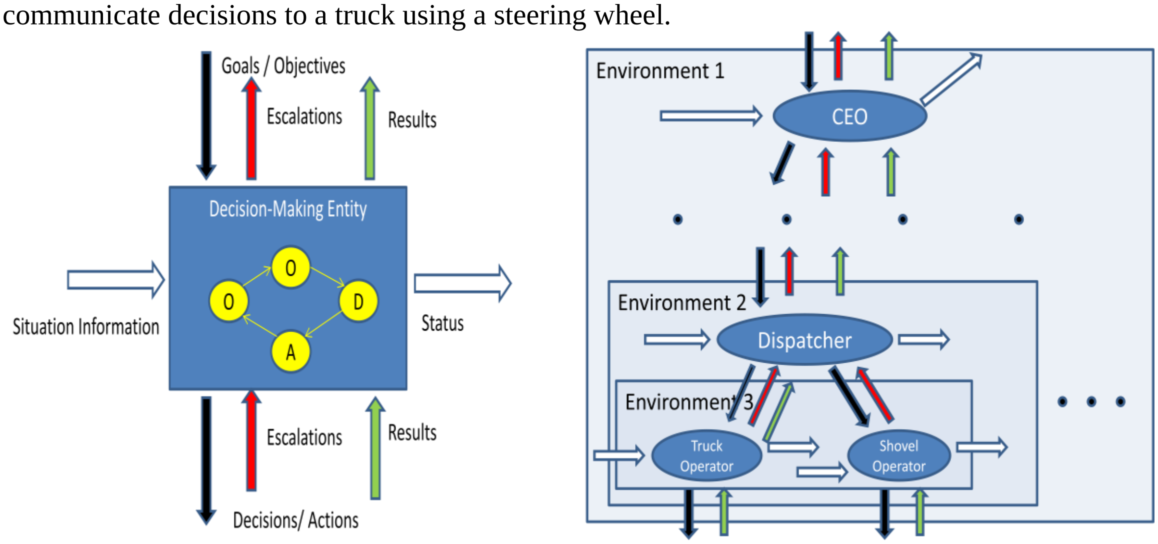


Figure 3. OODA Loop inputs/outputs and Decision Making Network

By following those principles to build a management system the concepts, boundaries and interconnections naturally flow from one component to another, from one system to another ensuring end-to-end chain of decisions, escalations, production results and metrics.

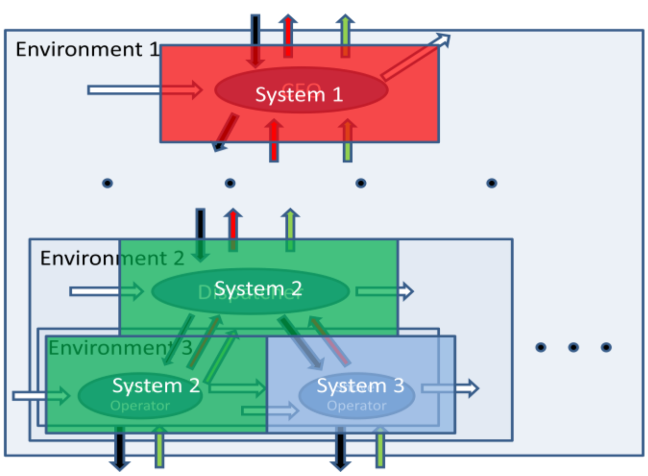


Figure 4. Composition of Realtime Management Systems based on Decision Making Network.

To achieve complete automation of management cycles a conceptually complete command & control system must integrate 5 key functional groups;

1. Common Operational Picture – to see what's going on
2. Planning & Analysis – to analyze situation and set goals and objectives
3. Decision Support - to help decide how to achieve objectives most efficiently
4. Resource Management – to communicate decisions to execution resources
5. Communication & Collaboration – is a glue, which supports all other functions.

Figure 5 shows how these functional areas support the OODA loop.

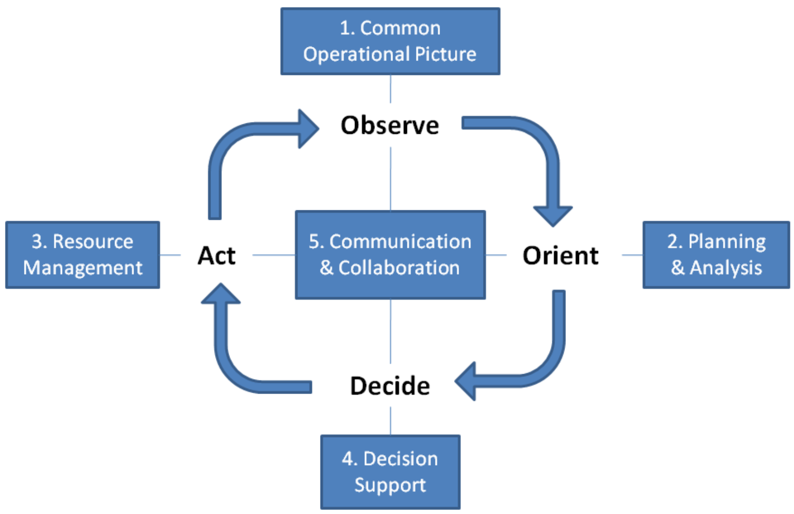


Figure 5. Five key functional elements of a command-and-control system.

The common operational picture in this case could consist of a digital map, showing terrain features, the haulage road network, equipment and material for excavation. The key planning tool would include a graphical timeline user interface, allowing drag-and-drop allocation of resources to tasks. A resource management user interface that provides a logistical, rather than geographical view would support execution of task assignments while ensuring that the common operational picture is updated. Decision support tools, such as optimized haulage assignments, would provide assistance making optimal resource allocation decisions. Finally, collaboration tools such as text and video chat, would allow coordination and feedback in real-time, regardless of distance between the parties.

Once data flows have been specified, it is then possible to standardize on communication formats. Military C2 includes the concept of an XML-based Battle Management Language (BML) that is used by military officers to communicate orders, and receive feedback in a formalized fashion. BML can communicate orders in concise, complete, unambiguous 5W form (Who, What, Where, When, Why) to any unit, simulator or even robots! This is just one example of possible standardization. A logical step would be to pursue this same approach for the various escalation and delegation pathways in the mining domain. In the future, we may see standard protocols to send escalations and production metrics, distribute situation information, and communicate status. A representative example describing a typical information flow and decision network involving a production planner, dispatcher and truck operator is described in Table 3.

	Actor: Production Planner	Actor: Dispatcher	Actor: Truck Operator
Inputs			
Situation Information	Equipment availability, material inventories, maintenance schedules.	Weather, visibility, traffic, available personnel, equipment availability and productivity	Weather, visibility, equipment condition, fuel level, tire condition.
Resources	12x830E trucks, 3x4100 shovels.	10 Ready trucks, 2 ready shovels.	Truck 101.
Objective	Who: 830E Fleet What: Mine 25,000 t waste from east pit. When:Jan 1-Jan 15th Where: From east pit to west dump Why: June production target	Who: Dispatcher, What:Move waste When:7am-7pm Where: From benches 1,2 to West dump 6 Why: Meet shift production plan.	Who: Truck 101, What:Go to shovel 201 When: 7:20am Where:Bench 1, haul to west dump 6 Why: Meet morning production plan.
Internal Processing			
Observe	• Ore and waste inventories • Drill and blast plan • Production reports	• Mine Map • Haulage Graph • Production Reports	• Onboard map • Fuel level • Road barricades
Orient	• Material movement priorities • Shovel productivity • Haul road traffic schedule • Truck fleet availability	• Number of ready trucks • Number of ready shovels • Shovel productivity • Haul distances • Fuel levels	• East Pit Rim road to shovel 201. • Rim road is barricaded due to blasting. • Need alternate route.
Decide	Create plan	Sequence truck assignments.	Confirm assignment.
Act	Transmit short-term plan to dispatching system.	Send assignments to truck operators.	Travel to shovel 201 via alternate route.
Outputs			
Primary Outcome	Achieve planned waste movement Ore/waste moved.	Ore/waste moved. Status of equipment, variances between expected and actual travel times, distances, routes.	Drive truck from Bench 1 to Dump 6.
Status	• Waste stripping on target. • Ore production below target. • Ore inventory above target.	• Actual vs. required trucks = 10/8 • Current status of all equipment • Material moved to dump 6 • Current equipment locations	• Truck 101 Ready • Haul road to Bench 1 blocked.
Escalation	None	None	Operator to dispatcher. What: Rim road closed! Why: Blasting 6-8am

Table 3. Typical information flow and decision network involving a production planner, dispatcher and truck operator.

CONCLUSIONS

Mining operations and battlefields share a high degree of volatility that quickly renders static business processes obsolete. When applied to the mining domain, the principles of Command & Control, can guide development of agile real-time management systems to achieve the highest possible level of integration, despite high system complexity.

Modular's application of command-and-control principles to the NextGen product range will ensure that each decision-making entity has the technology tools to support each of the five C2 functional areas. This approach will simplify integration of Modular's fleet management systems into the system of systems that is required to deliver a real-time digital mine.

REFERENCES

ALBANESE, T. (2008). Rio Tinto chief executive unveils vision for 'mine of the future'. Retrieved June 17 2009, from http://www.riotinto.com/media/5157_7037.asp

ALBERTS, D.S. & HAYES, R.E. (2006). Understanding Command and Control, Retrieved June 17 2009, from http://www.dodccrp.org/files/Alberts_UC2.pdf.

ATKINSON, S.R. (2005). The Agile Organization. Retrieved June 17 2009, from http://www.dodccrp.org/files/Atkinson_Agile.pdf.

BOYD, J.R. (1987), Organic Design for Command and Control. Retrieved June 17 2009, from http://www.d-n-i.net/boyd/pdf/c&c.pdf.

Enterprise Application Integration. Retrieved June 17 2009, from http://en.wikipedia.org/wiki/Enterprise_application_integration.

HARMON, P. (2003). Business Process Change, Morgan Kaufmann, San Francisco, California, USA. 529p.

IDEF0 Function Modelling Method. Retrieved June 17 2009, from http://www.idef.com/idef0.html.

OODA Explained. (2006) Retrieved June 17 2009, from http://www.d-n-i.net/boyd/boyds_ooda_loop.ppt.

ORELLANA, M. (2007). Digital Codelco: Codelco's Strategy in the Use of Information & Communication Technology & Automation. Retrieved June 17 2009, from http://downloads.gecamin.cl/cierre_eventos/apcom2007/prsntcns/00048_00263_pr.pdf.

PAIGE, R., INBAR, D. (2008). Reality Check: The Costs of Data and Application Integration. Retrieved June 17 2009, from http://www.information-management.com/infodirect/2008_99/10002234-1.html.

RICHARDS, C.W. (2001). A Swift,Elusive Sword. Retrieved June 17 2009, from http://www.d-n-i.net/richards/sword_4_boyd.pdf.

SCHADE, U. and HIEB, M.R. (2006). Formalizing Battle Management Language: A Grammar for Specifying Orders. Paper 06S-SIW-068, Spring Simulation Interoperability Workshop, Huntsville, Alabama, April 2006a.

WILSON, C. (2004). Network Centric Warfare: Background and Oversight for Congress. p. 15 Retrieved June 18 2009, from http://www.globalsecurity.org/military/library/report/crs/33858.pdf.