An Agent-Based System Framework for Mine Scheduling and Simulation

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Introduction

• In today’s mining environment, improving production, performance, productivity and profitability is crucial.

• Traditional scheduling systems currently in use today, operate in an iterative mode constantly switching between scheduling and execution.

• However, the real world tends to change in ways that invalidate such advance schedules.

• Agent systems are being used in an increasingly wide variety of applications, including complex mission critical systems.

• In this presentation we will discuss the various components of the agent based system framework for mine scheduling as well as the position of the system in the enterprise information structure.
Mine Production Scheduling

- Scheduling is required for the development and production activities in underground and open pit mines.
- Mine schedules commonly consist of mining block entities with assigned processes.
- These schedule entities or activities are located in time by a start date and duration or end date.
- The process assigned to each activity has particular equipment and/or human resources associated with.
Processes

- Mining operations can be broken down to smaller more distinct processes.
- A process is a representation of an entity that performs production-oriented tasks in the real world.
- The process concept is central to the information model of the mine.
- Because the processes are the productive or working entities of the mine, the rate or amount of mine production is measured in terms of the work the processes have done.
Processes

- Technically, there are no restrictions on the mine entities that can be set up as processes.
- Typically, a process is a single piece of equipment or a logical group of equipment that is a part of the productivity or daily operations of the mine.

<table>
<thead>
<tr>
<th>Open Cut or Underground Metal Mine</th>
<th>Underground Coal Mine</th>
<th>Processing or Beneficiation Plant</th>
</tr>
</thead>
</table>
Locations

- Products and other materials are mined from, hauled to, and stored in various locations within the mine.
- A **location** is a representation of a point on the mine map, usually one that is a source or a store of material.
- Typically, locations are in-pits where material is mined from, stockpiles at which material is stacked, bins which are filled and subsequently emptied, dump sites at which overburden is dumped, fuel tanks from where fuel is dispensed, etc.
- Many of these will be of interest to the site as they are a resource from which material is taken out or accumulated in, and it may be necessary to maintain statistics on them.
Locations

- The choice of locations depends on the actual structure of the site and various reporting and monitoring requirements.
- The interaction between locations and processes is the key to storing location production information.
- The movement of material between two locations is logged via the production of one or more intervening processes.

<table>
<thead>
<tr>
<th>Open Cut Mine</th>
<th>Underground Mines</th>
<th>Processing Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inpit, Dump, ROM Bin, ROM Stockpile, Inpit Stockpile, Expit Stockpile</td>
<td>Block, Panel, Underground Bin, Ore pass, Stope</td>
<td>ROM Stockpile, Product Stockpile, Circular Stockpile, Rectangular Stockpile, Reject Stockpile, Feed Bin</td>
</tr>
</tbody>
</table>
Processes and Locations Interaction

Flow of material

Source process assignment
Loader

Process
Production Truck

Location assignment
ROM Bin
Stockpile

Equipment A

Location A
Equipment A
Location B
Equipment B

Groups of Equipment
Agents and Agent-Based Systems

• Agents are autonomous and proactive computational systems that communicate and interact through a communication language or a protocol.

• These systems can be in the form of software or combine electronic and mechanical hardware through which they become aware of their operational environment and take actions to alter it.

• They are ideal for problem solving, decision making, design and learning.

• Agent systems are the central research area of the Distributed Artificial Intelligence domain for more than three decades.
Agent Based Systems in Production Planning and Scheduling

- Production scheduling is a difficult problem, particularly when it takes place in an open, dynamic environment such as a mine.
- Because of its complexity and its dynamic nature, the scheduling problem has been widely studied in the literature by various methods.
- Agent technology has recently been used in attempts to resolve production scheduling problems.
- Agent technology has been applied to resource exploration and other mining related fields.
An advantage of the agent system is its ability to receive real time information.

This ability allows users to handle directly possible changes in the production conditions.

In real life application, the system will be able to receive data from multiple mobile and stationary sources.
System Architecture

- The agent system for mine scheduling is essentially a group of specialized agents.
- It consists of the following agents:
  - **Static** agents for each material state alteration device.
  - **Loading** agents for each material loading device.
  - **Hauling** agents for each material hauling device.
  - **Service** agents for each device that provides service to static, loading and hauling agents.
  - **Auxiliary** agents for devices performing a function outside of the production process.
  - A **system manager** agent that receives the required schedule and generates orders.
  - An **order co-ordinator** agent for each order from the system manager agent.
# Examples of Equipment and Agent Types

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Function</th>
<th>Agent Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drill Rigs</td>
<td>To perform the drilling of holes within which explosives are placed</td>
<td>Static</td>
</tr>
<tr>
<td>Drag Lines</td>
<td>Used to move overburden in order to get to the underlying ore</td>
<td>Hauling</td>
</tr>
<tr>
<td>Shovels and Loaders</td>
<td>Used to dig and load waste materials or products into trucks</td>
<td>Loading</td>
</tr>
<tr>
<td>Trucks</td>
<td>Used to haul material from the pit to stockpiles, hoppers, or dump sites</td>
<td>Hauling</td>
</tr>
<tr>
<td>Dozers</td>
<td>To rip and push material into piles</td>
<td>Hauling</td>
</tr>
<tr>
<td>Graders</td>
<td>For levelling roads for the transport of material</td>
<td>Auxiliary</td>
</tr>
<tr>
<td>Fuel Trucks</td>
<td>To fuel production equipment used within the mine</td>
<td>Service</td>
</tr>
<tr>
<td>Fuel Stations</td>
<td>To fuel mobile production equipment and other ancillary equipment such as 4WDs, personnel vehicles, etc.</td>
<td>Service</td>
</tr>
<tr>
<td>Water Trucks</td>
<td>For dust control</td>
<td>Auxiliary</td>
</tr>
<tr>
<td>Environmental Monitoring Stations</td>
<td>To monitor dust, wind velocity, humidity, etc. to assist with determining when to blast, etc.</td>
<td>Auxiliary</td>
</tr>
<tr>
<td>Crushers</td>
<td>Used for sizing products appropriately</td>
<td>Static</td>
</tr>
<tr>
<td>Pumps</td>
<td>Often used for dewatering operations</td>
<td>Auxiliary</td>
</tr>
<tr>
<td>Power Substations</td>
<td>For provision of stable power to the enterprise</td>
<td>Auxiliary</td>
</tr>
<tr>
<td>Conveyors</td>
<td>For moving material within fixed locations</td>
<td>Hauling</td>
</tr>
<tr>
<td>Stackers</td>
<td>For placing products on stockpiles</td>
<td>Loading</td>
</tr>
<tr>
<td>Reclaimers</td>
<td>For removing materials from stockpiles</td>
<td>Loading</td>
</tr>
</tbody>
</table>
Agent Interaction Protocol

- The Contract Net protocol is used for the interaction between the various production related agents and the system manager.
- It is based on the contracting mechanism used by business to control the exchange of goods and services.
- The contract net protocol is appropriate for connection problems where we search for appropriate agents to work on a given task.
- The following actions can be performed by agents interacting with this protocol:
  - call for tenders
  - reception and evaluation of bids
  - contract awarding to the agent that wins
  - reception and evaluation of contract results after completion.
System Manager Agent

The system manager agent is the central coordinator of the entire agent based system.

The primary functionality of this agent includes:

- Converting mine schedule activities to appropriate orders to loading and auxiliary agents.
- Selecting a tender to announce (when multiple tenders are simultaneously initiated).
- Broadcasting tender announcements to all hauling agents.
- Receiving bids in response to a tender.
- Identifying the best bidder.
- Informing hauling and loading agents of the outcome of bids.
- Controlling and acting upon information placed on the blackboard (coordination outside Contract Net) by auxiliary, static and other agents.
Loading Agents

The loading agents are generated against loading equipment ready to serve hauling equipment or can simply be issued for all operational loading equipment. Primary functionality of the agent includes:

- Acting upon orders from the system manager based on mine schedule activities.
- Initiating tenders.
- Maintaining a current plan for the corresponding loading device. The current plan consists of a temporal sequence of contracts issued to hauling agents for servicing the loading device (including orders that have not been successful in attracting a bidder).
- Cancelling contracts in the event of loading device breakdown or slowdown in operations.
- Removing completed contracts from the list.
- Creating new tenders in the event of better than expected contract execution and there being a sufficient time slot in between to enable an additional load.
- Placing requests for refueling by a service agent.
Hauling Agents

Hauling agents are generated against all operation hauling devices.

The primary functionality of the hauling agent is:

• Maintaining a current plan for the corresponding hauling device.
• Making bids for announced tenders.
• Making offers for orders in the internal market.
• Dealing with deviations from the current plan.
• Placing requests for refueling by a service agent.
Other Agents

- **Static agents** relate to stationary equipment who need to be monitored as their operation indirectly affects production.
- **Auxiliary agents** are generated against stationary and mobile equipment crucial for maintaining appropriate working conditions in the mine or for ensuring a continuous production.
- **Service agents** are generated against equipment used to support the operation of production units.
- **Order co-ordinator agents** are generated to monitor each order in the system.
System Development

• The agent system is developed using a Java based platform called ABLE (Agent Building and Learning Environment) from IBM.

• It is a set of tools for the development of intelligent agents.

• Historical information such as mine schedules and production information is combined with virtual data to aid the development of the system.
System Applications

The agent based system can be used in a mining operation for the following tasks:

**In virtual conditions:**
1. Virtual execution of the mine schedule in order to identify possible problems.
2. Examination of the adequacy of selected equipment for the implementation of the mine schedule.
3. Equipment selection for the implementation of the mine schedule.

**In real conditions:**
1. Optimisation of available equipment usage.
2. Collection of production and equipment operation data.
3. Comparison and update of mine schedule with the actual situation in the mine.
Conclusions

• The agent system presented can help link mine schedules to actual production in a working mine using real time information.

• It can help execute a mine schedule by representing all operational production units and other important equipment with agents and by converting all mining activities to corresponding orders and contracts to agents.

• The future aims of this effort include further development of the prototype system with as real data as possible.

• The development of such datasets is also one of the most important steps for the successful development and application of the agent based system.