An Agent-Based System Framework for Mine Scheduling and Simulation

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ABSTRACT

In today's mining environment, improving production, performance, productivity and profitability is crucial. Production, ancillary, plant and shipping equipment need to be monitored and controlled by online systems delivering production statistics and real-time information to everyone involved, including equipment operators. Traditional 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 based computing has been hailed as the most significant breakthrough in software development and the new revolution in software. Agent systems are being used in an increasingly wide variety of applications, including complex mission critical systems such as Air Traffic Control. This paper presents the possible ways that multi-agent systems can be applied to mine production and rehabilitation scheduling problems with focus on real time fleet management, plant and equipment performance monitoring, downtime and delay reporting, stockpile management, personnel and equipment tracking and product distribution and transportation.

1. INTRODUCTION

Mining is a very capital-intensive business where new ventures or expansion are often based on forecasts for long term profitability. Performance is dependent on how cost effective the mine equipment is from day one. The costs of owning and maintaining capital equipment require effective utilization of the mobile fleet for optimal productivity. In order to achieve this level of monitoring, information needs to be made available in real time. Sometimes trucks can be queuing at one loader whilst loaders at another location are idle waiting on trucks to arrive. In this situation both the loaders and trucks are being under-utilized. In other scenarios, shovels under-loading trucks results in production decreases and if overloaded, may cause damage or premature wear and tear resulting in costly repair bills and excessive down times. If this is allowed to occur on a regular basis without check, the mine may be incurring unnecessary additions to its operating costs without knowing it, costs that could be subtracting millions of dollars from profits.

Commonly, a mine develops a schedule (using Linear Programming methods) for its production operations using prototypical gathered data that is rarely sufficient to describe all aspects of reality in a mine. The weather changes, a truck or loading device breaks down, the digging is particularly hard, a bin gets full because of problems with a down stream conveyor; these are all real problems affecting every single operation on a daily basis. The design plans and targets that have then been set are now invalidated as the system attempts to cope, quite unsuccessfully of course, with the design goal. Truly intelligent systems do not simply plan in advance, but adjust their operations on a time scale comparable to that in which their environment changes.

2. AGENT BASED SYSTEMS IN PRODUCTION PLANNING AND SCHEDULING

Planning is the process of selecting and sequencing activities such that they achieve one or more goals and satisfy a set of domain constraints. Scheduling is the process of selecting among alternative plans and assigning resources and times to the set of activities in the plan. These assignments must obey a set of rules or constraints that reflect the temporal relationships between activities and the capacity limitations of a set of shared resources (Figure 1). The assignments also affect the optimality of a schedule with respect to criteria such as cost, tardiness, or throughput. In summary, scheduling is an optimization process where limited resources are allocated over time among both parallel and sequential activities.

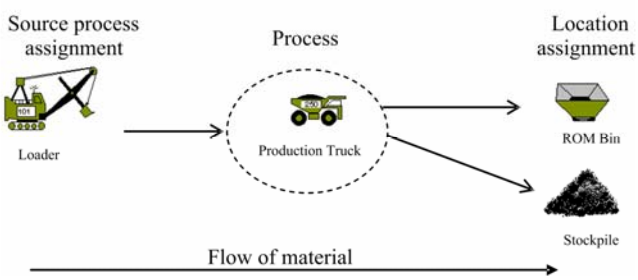

Figure 1: Example of assignment constraints from a mining situation - processes of type 'Production Truck' might be permitted only to receive material from processes of type 'Loader', and dump material to locations of types 'Stockpile' and 'ROM Bin'.

Production scheduling is a difficult problem, particularly when it takes place in an open, dynamic environment such as a mine. In such environments, rarely do things go as expected. The set of things to do is generally dynamic. The system may be asked to do additional tasks that were not anticipated, and sometimes is allowed to omit certain tasks. The resources available to perform tasks are subject to change. Certain resources can become unavailable, and additional resources introduced. The beginning time and processing time of a task are also subject to variation. A task can take more time or less time than anticipated, and tasks can arrive early or late. Because of its highly combinatorial aspects, its dynamic nature and its practical interest for manufacturing systems, the scheduling problem has been widely studied in the literature by various methods: heuristics, constraint propagation techniques, constraint satisfaction problem formalism, simulated annealing, Taboo search, genetic algorithms, neural networks, etc.

Agent technology has recently been used in attempts to resolve production scheduling problems. Atkins et al. (2001) presented an architecture that combines planning and resource allocation algorithms to produce a set of plans which execute in hard real-time on a multi-resource platform and exhibit tolerance to a user-specified set of internal system faults. Frankovic et al. (2001) developed a market-based distributed production control system based on learning and cooperative agents. Goh et al. (2002) proposed a manufacturing optimization and configuration approach that integrates a multi-agent bidding mechanism and Monte Carlo optimization methodology. Agent technology has been applied to resource exploration and other mining related fields (Gallimore et al. 1998).

3. MINE SCHEDULING

3.1 Overview

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. Types of schedules include life of mine plan (long term), 5 year plan (long term), annual plan (medium to short term), and weekly and/or monthly schedules (short term).

Mining is divided into multiple phases including exploration, material extraction (drill and blast, excavation, etc.), hauling the product and waste materials (trucks, conveyor belts, etc.), beneficiation of the product (crushing, leaching, etc.), and shipping the product to the client.

3.2 Processes

The phases mentioned above 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. Technically, there are no restrictions on the mine entities that can be set up as processes. Typically, though, the various types of machinery of the mine constitute processes. A process is usually a single piece of equipment or a logical group of equipment that is a part of the productivity or daily operations of the mine.

3.3 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. Material can change location within a mine using one of the three routes shown in Figure 2.

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. Location production information consists of the quantity and quality of material removed from and/or added to each location. For each location it is calculated based on the cumulative production of processes where the location is involved, either as a source or a destination of the process.

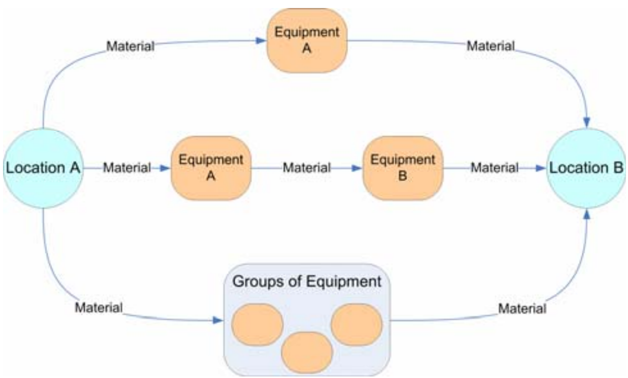

Figure 2: Possible routes of material movement between locations in a mine.

In a more generalised context, locations can also represent different states of material with no change in their actual position within the mine. For example, in-situ material can be 'relocated' to drill and blasted material via a drill and blast process.

4. AGENT BASED SYSTEM FRAMEWORK FOR MINE SCHEDULING

4.1 Overview

In this section we 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. This framework is used for the development of an agent-based schedule simulation system at the Department of Geotechnology and Environment of the Technological Education Institute of Western Macedonia. Figure 3 presents the information structure of a mining enterprise.

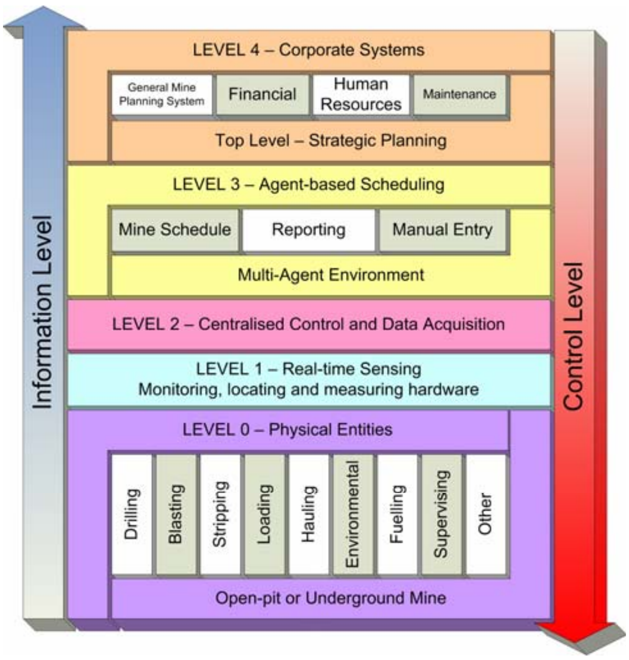

Figure 6: Simplified diagram of information and control level structure in an agent based mine planning and scheduling system.

The level of information is increasing going up the structure, while the level of control is increasing going down. The proposed agent based system would be placed between the strategic planning level (top) and the control and data acquisition level. From the perspective of running the mine on a shift by shift basis Levels 1 and 2 are extremely important. From the point of view of planning and making strategic decisions to improve the overall productivity and profitability of the mine, Level 3 is essential.

The agent based system may consist of the following agents:

- An agent for each material state alteration device (static agents), e.g. crushers.
- An agent for each material loading device (loading agents), e.g. shovels, loaders, stackers and reclaimers.
- An agent for each material hauling device (hauling agents), e.g. draglines, trucks and conveyors.
- An agent for each device that provides service to static, loading and hauling agents (service agents), e.g. fuel tracks and fuel stations.
- An agent for each device that performs a function not directly related to the production process (auxiliary agents), e.g. drill rigs, graders and water trucks.
- A system manager agent that receives the required schedule and generates appropriate orders.
- An order co-ordinator agent for each order from the system manager agent.

4.2 Agent Interaction Protocol

The Contract Net protocol is used for the interaction between the various service, loading and hauling agents, the order co-ordinator agent and the system manager. It is an interaction protocol for cooperative problem solving among agents (Huhns et al. 1999). 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 (Smith, 1980, Davis et al. 1983). It is the protocol in use by an existing agent-based dispatching system for the mineral extraction industry (Baptista, 2004). The following actions can be performed by agents interacting with this protocol:

Tenders are initiated by loading agents and announced by the system manager agent. Possibly many Tenders may be announced to generate a complete plan for a planning horizon of duration T at the start of the shift. Additional tenders may subsequently be announced as time progresses to maintain the planning horizon. Tenders for servicing can also be announced by all fuel powered equipment represented in the agent based system.

A *bid* is a response to a tender. In this system hauling agents respond to loading tenders with bids. Service agents can also bid for servicing tenders.

A *contract* is a commitment to provide a service. In this system, contracts tie the loading device that lets the tender with the successful bidder (hauling device) or a fuel truck or station to a fuel powered device. Hauling agents receive contracts corresponding to specific tenders from the system manager agent. Hauling agents may trade contracts amongst themselves.

An *offer* is a proposal from a hauling agent to execute a contract that another hauling agent has committed to executing. In this system, an offer is communicated by one hauling agent to another.

The following is an outline of the possible system operation. At the start of a shift, each loading agent initiates a tender by creating a tender specification and passing it to the system manager agent. Both at the start of a shift and at points during the course of a shift when multiple tenders are initiated (by multiple loading agents) at the same time, the system manager agent uses the tender priority (defined below) to select the tender to be announced first. The system manager agent announces the bid by making its terms of reference available to every hauling agent. Each hauling agent first determines if it is feasible to bid for this tender (using the bid feasibility computation procedure defined below). If a hauling agent determines that it is feasible to bid for a tender, it communicates its bid to the system manager agent. From the set of bids received, the system manager agent identifies the best bid as the winning bid. The hauling agent making the winning bid is awarded an order, while the remaining bidding agents are told that their bids were rejected. The system manager also informs the loading agent that let the tender of the outcome of the bidding process (i.e., details of the winning bid). Based on the capacity of the hauling device mentioned in the winning bid, the loading rate of the loading device, the start time announced in the tender and the arrive time of the hauling device, the loading agent computes the end time when the loading device would finish loading. If this is less than the current planning horizon of the loader, the loading agent initiates a new bid with a new start time equal to the end time. The process iterates until a plan covering the entire planning horizon is generated.

Agents of the other categories (auxiliary and static) that do not interact using the Contract Net protocol can communicate through a Blackboard system where real time data and requests for actions are placed or a coordination protocol. The role of each type of agent and its operation is analysed in the following paragraphs.

4.3 Loading Agent

The loading agents are generated against loading equipment ready to serve hauling equipment or can simply be issued for all operational loading equipment. Initially, loading equipment not part of the truck dispatch circuit will not have a loading agent announcing contracts. 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 refuelling by a service agent.

While no tenders are being floated, the loading agent goes through its period up to the planning horizon, and once again floats tenders for the periods in between when it has blank spots in its loading schedule.

4.4 Hauling Agent

The primary functionality of the hauling agent is:

- Maintaining a current plan for the corresponding hauling device. A current plan consists of a temporal sequence of contracts.
- Making bids for announced tenders. If a truck has a locked assignment then it bids only on tenders for the loader it is locked to. In these situations the contract manager agent will realise that this truck should be the preferred bidder.
- Making offers for orders in the internal market.
- Dealing with deviations from the current plan.
- Placing requests for refuelling by a service or auxiliary agent.

4.5 Static Agent

This agent is generated against stationary equipment that needs to be monitored. Examples are environmental monitoring stations, dewatering pumps and crushers. Such equipment is crucial for maintaining appropriate working conditions in the mine or for ensuring a continuous production. Static agents can act as sources of real time information or request actions to be taken by agents of the next category (auxiliary agents). For example, a station monitoring dust levels along the haul road can request the dispatch of a water truck.

4.6 Auxiliary Agent

Auxiliary agents are generated against mobile equipment such as drill rigs and water trucks. They act upon requests from the system manager that are linked with the production process. Requests to auxiliary agents can also be generated by static agents for environmental control in the mine.

4.7 Service Agent

A service agent is generated against equipment, mobile or stationary, that is used to keep loading and hauling devices in operation, such as Fuel Trucks. They are indirectly linked to the production process and for this reason they do not necessarily need to be part of the contract based negotiations. However, if their number is sufficiently high to require better control of their assignments, special service contracts can be generated for them. They receive orders from the System Manager agent following requests by loading and hauling agents for servicing. They also keep track and report on parameters such as operator, status, etc., number of equipment filled/served, and quantities of fuel and other materials dispensed

4.8 System Manager Agent

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.

4.9 Contract and Tender Coordinator Agent

The primary functionality of this agent is to maintain the outstanding contracts within the market place (including tenders that have not had successful bidders) and receive and process offers in conjunction with the System Manager Agent for the order in the internal market. The coordinator agent is also responsible for determining the outcome of an offer and re-assigning the contract to a different hauling agent.

5. CONCLUSIONS AND FUTURE WORK

The agent based system framework described in this paper can be used to develop mine scheduling solutions that are fully customizable to a number of mining scenarios and provide a much more dynamic scheduling environment than current mine scheduling applications. Development of a prototype system using agent development tools and its application on simulated mine schedules and site operation data is currently underway. The development of such schedules and data is in itself a time consuming aspect of the work as it is very hard to collect appropriate information from existing mining sites. This is the case even in mines with installed dispatch and telemetry systems. The application of the prototype system to mine simulation for equipment selection and mine feasibility study purposes is also one of the main aims of the research project.

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