Available online at www.sciencedirect.com

SCIENCE DIRECT®

European Journal of Operational Research 166 (2005) 497–506

EUROPEAN JOURNAL OF OPERATIONAL RESEARCH

www.elsevier.com/locate/dsw

O.R. Applications

A shortest-path algorithm for solving the fleet management problem in underground mines

Michel Gamache *, Renaud Grimard, Paul Cohen

École Polytechnique de Montréal, Dept. (CGM) C.P. 6079, Succ. Centre-Ville, Montréal, Qc, Canada H3C 3A7

Received 20 October 2003; accepted 9 February 2004
Available online 14 May 2004

Abstract

This paper describes the problem of managing a fleet of load-haul-dump (LHD) vehicles in an underground mine. The problem consists of dispatching, routing and scheduling vehicles whenever they need to be assigned to a new task. The solution approach is based on a shortest-path algorithm. Each decision takes into account the current status of the mine, the current traffic on all single-lane bi-directional road segments of the haulage network and operational constraints such as the fact that, while LHD vehicles move in forward or reverse modes, their bucket must be in dumping/loading position at destination.

Keywords: Fleet management; Dispatching; Routing; Scheduling; Underground mining

1. Introduction

In underground mining, one of the major infrastructure costs concerns the excavation for the development of drifts. Drifts constitute the basis of the haulage network and are essential for mining operations. Therefore, during planning phases, mining engineers try to limit as much as possible the development of drifts, thus creating compact haulage networks composed almost exclusively of one-lane bi-directional road segments. Moreover, in order to limit the needs for additional space, underground mines often opt for a fleet of LHD-type vehicles, involved in loading, hauling and dumping ore, waste and backfill material between origin and destination points.

In such limited networks, LHDs must share road segments. This situation leads to the necessity of having an efficient fleet management system. Among the decisions taken by the fleet management system, one consists in choosing a new destination for a LHD every time such a vehicle becomes available for a new task, i.e. essentially after the vehicle has loaded or dumped its material. The dispatching decision is based on a predetermined criterion: minimising cycle time, minimising waiting time or idle time, etc. Moreover, the dispatching decision must consider the traffic, i.e. the movement of other LHDs on the network, in order to globally improve the mobility of the vehicles and

* Corresponding author. Tel.: +1-514-340-4711x5920.
E-mail address: michel.gamache@polymtl.ca (M. Gamache).

0377-2217/$ - see front matter
doi:10.1016/j.ejor.2004.03.008

implicitly increase the productivity of the entire operation. Therefore, the task consists not only in dispatching vehicles from origins to destinations, but also in finding routes for those vehicles that will avoid collisions, queues at loading or dumping points, and deadlock conditions.

Due to these difficulties associated with the nature of the haulage network, presently in almost all underground mines, LHDs are preassigned at the beginning of the shift to one origin and one destination. The route between the origin and the destination is always the same and the priority between vehicles at intersection is based on a set of rules managed by operators (e.g. first in, first out) and/or managed by traffic lights. Such operation conditions are simple, but do not use all the potential offered by the environment. Productivity can be improved considering that vehicles must often wait at some loading points or at intersections while other loading points may be available.

Based upon the above considerations, a fleet management decision in underground mines consists of three main components: dispatching, routing and scheduling. The aim of dispatching is to choose, for one or many vehicles, a new destination (loading or dumping point). Routing consists in choosing the best route (road segments) from the origin to the destination. Finally, scheduling consists in deciding speeds and the waiting times of vehicles on road segments of a route to avoid conflicts between vehicles. In order to produce optimal decisions, the three components must simultaneously be solved in a unique problem.

In this paper, a unified solution approach that deals simultaneously with these three components, based upon ideas exploited in both open-pit mine dispatching and automatic guided vehicles (AGV) management systems, is presented. Section 2 of the paper presents previous works published in the literature. The components of the proposed approach are detailed in Section 3. Finally, extensions to the method are presented in Section 4.

2. Previous works

Open-pit mines have used dispatching systems for the last 30 years. The use of such systems was eased by the availability of monitoring systems and by the fact that dispatching problems in open-pit mines do not need to consider routing and scheduling aspects of the problem for each decision. Munirathinam and Yingling (1994) presented a survey of the dispatching systems in open-pit mines. One of their conclusions is that dispatching systems should be based on a plan-driven strategy. Plan-driven systems are made of two components. The first one establishes an optimal production plan by solving a mathematical program (linear or non-linear). This plan indicates, for each type of material, the amount that should be transported between origins and destinations in order to maximise production or minimise transportation costs. It also respects blending and capacity constraints. The second component of a plan-driven system dispatches trucks to shovels in order to minimise the deviation between the current production rates and those identified by the first component. In order to be efficient, plan-driven systems must be updated frequently since the mine status evolves during shifts A plan-driven strategy should also be part of an underground mine dispatching system.

Only a few papers deal with fleet management systems for underground mines. Among them, Nikos Vagenas (1991) worked on the management of semi-autonomous LHDs (called RAL), i.e. that travel autonomously but necessitate manual loading and dumping. The system uses a shortest path approach for selecting a route from origin to destination and uses various algorithms to control conflicts the network. The assignment method presented by Vagenas is well suited to underground mines. The method takes into account the relation between vehicles on the network and is based on two modules. The first one, which deals with the choice of a path for a RAL, relies on four algorithms: one for finding the shortest allowable path from the origin to the destination, one for detecting when a vehicle must slow down, one for solving bi-directional conflicts, and one for crossing a traffic zone. The second module, i.e. the dispatching module, uses heuristic procedures for identifying a destination for a RAL. Vehicle localization is mentioned as an issue but no information is provided on how to solve it.