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An enumeration algorithm for solving the fleet management problem in underground mines

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Abstract

This paper presents an enumeration algorithm based on dynamic programming for optimally solving the fleet management problem in underground mines. This problem consists of routing and scheduling bidirectional vehicles on a haulage network composed of one-lane bidirectional road segments. The method takes into account the displacement modes of the vehicles, either forward or in reverse, and makes sure that these vehicles move forward when they arrive at their service point. The method has been developed for the underground mine context, but it can be extended to the industrial environment.

Keywords: Fleet management; Dynamic programming; Enumeration tree; Bidirectional vehicles; Bidirectional segments

1. Description of the problem

Fleet management systems have been used in open-pit mines for the last 30 years. In these operations, the fleet management system consists essentially of dispatching trucks to shovels, crushers, waste dumps, or stockpiles. When a vehicle arrives at a service point for loading or dumping, a fleet management system must assign a new destination based on both the state of the vehicle and the state of the haulage network in the mine. Several dispatching criteria (see Munirathinam and Yingling [1]) and different solution strategies (see Alarie and Gamache [2]) have been used for solving the dispatching problem in open-pit mines.

Such a system is not well developed in underground mines. The transfer to underground mines of fleet management systems developed for open-pit operations cannot be done simply since important differences

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exist between the two contexts. The first difference concerns the lack, until recently, of adequate traffic monitoring devices in underground operations. The second difference pertains to the nature of the haulage system. While open-pit haulage systems are based upon trucks and shovels working together (servers-clients systems), several underground mines use load-haul-dump (LHD) vehicles that play the roles of servers and clients at the same time. A major obstacle to the development of management systems in underground operations concerns the nature of the haulage network. Since in most cases vehicles must share road segments that cannot accommodate more than one vehicle at a time, the optimal selection of assignments becomes a more challenging task than in open-pit contexts. In open-pit mines, the decision process is based upon the presence of vehicles at loading and dumping points and accounts for vehicles in motion on the haulage network only through their arrival times at destinations. In underground mines, because of the constraints imposed by the haulage network, the dispatching system must take into account all the routes and schedules of vehicles in motion throughout the network. The assignment task, therefore, involves not only dispatching vehicles from origins to destinations, but also finding routes that avoid collisions, queues at loading or dumping points and deadlock conditions.

Moreover, in underground mines, any solution approach must take into account that LHD vehicles can move forward or backward on the haulage network and that they must arrive at their destination moving forward. The complexity and the particularity of finding conflict-free routes for a set of bidirectional vehicles are strongly linked to the nature of the haulage network. The smaller the number of paths between origins and destinations, the higher the risk of creating conflicts between vehicles. In this paper, the haulage network that is considered is a restrictive one; i.e., it is composed of one-lane bidirectional road segments and intersections are not large enough to allow the presence of more than one vehicle at any given period of time. To avoid any conflict, the management system must permit and manage the waiting of some vehicles on the haulage network to obtain the best set of routes. This problem has been classified by Peters et al. [3] among the most difficult problems to solve when dealing with automated guided vehicle (AGV) systems.

An optimal enumeration algorithm based on dynamic programming is proposed for solving the fleet management problem in underground mines. Starting from an initial position for each vehicle, the objective is to find the best route and schedule for each vehicle in order to reach their destination in the shortest time while also avoiding conflicts on the haulage network.

The paper is divided as follows. In Section 2, an overview of the literature on the subject is presented. Section 3 defines the notion of state that is essential for the dynamic programming approach and details its components. Section 4 presents the rules that must be followed during the propagation of states in the dynamic programming approach in order to create new states that will be conflict free and will take into account the displacement mode of the vehicles. Section 5 describes, step by step, the solution approach and introduces dominance and reduction procedures used for accelerating the enumeration algorithm. Finally, Section 6 shows the results obtained by this approach on three different networks.

2. Review of the literature

Few papers deal with the fleet management problem in underground mines. However, several papers presenting the problems of managing a fleet of AGVs in the manufacturing context are related to the problem presented in this paper. Peters et al. [3] and Ganesharajaha et al. [4] present a classification of