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On the design and selection of vehicle coordination policies for underground mine production ramps

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ABSTRACT

Traffic management in underground mines, especially on production ramps, is a difficult problem to optimize and control. Most operations use one of a few common policies; e.g., the so-called "lock-out" and "loaded-vehicle-priority" policies. The work presented in this paper uses discrete-event simulation to study the efficiency of multiple policies. Based on simulation results, an improvement to the common lock-out policy is proposed. This new policy utilizes the rules of the lock-out policy but integrates an option that allows a group of vehicles to be given temporary priority in a certain direction of travel. Quantitative results are provided and, based on these, a systematic technique for ramp design that aims to optimize the efficiency of underground mine ramp traffic flow is described.

1. Introduction

This paper explores traffic management policies commonly used in underground mining operations, quantifies the parameters of the widely used "lock-out" policy and suggests a new, alternative policy. The lock-out policy is used as a basis for optimizing the preliminary design of a haulage ramp, and the selection of a haulage fleet for an underground mine production ramp.

The operating environment in underground mines is usually dark, dusty, and visibility is poor. Traffic can be a problem in mines where ore is hauled by truck or LHD directly to a crusher, conveyor belt, or up to surface [1,2]. In underground mines, ramps and passageways that are used for haulage are only wide enough to accommodate traffic in one direction at a time. However, to maximize productivity while keeping mining costs low, these ramps must also be capable of coordinating bidirectional traffic of vehicles. This situation introduces an added constraint over the dispatch problem in open pit mines [3]. This problem can also be observed in a wide variety of other industries such as examined by Bussieck et al. [4] and Tarshizi et al. [5].

Production and service vehicles usually travel along the ramp at different speeds, are hard to stop, and are often loaded with materials. Short drifts, long enough to accommodate one vehicle, serve as passing bays. These drifts are left along the length of the ramp; e.g., see Fig. 1. Mine levels are commonly used as well for passing. The typically long ramp length and dispersed passing bays, together with varying traffic densities, can greatly increase the total travel times for production vehicles on the ramp. This combination of factors can, in some cases, also lead to serious safety concerns.

Based on our own experience and that of our industry partners, in uncontrolled ramps the interaction of two groups of vehicles is one of the leading causes of time loss and safety issues. The least desirable interaction occurs when groups that are traveling in opposite directions meet on a ramp segment, possibly far from a passing bay or level. To resolve the situation, one of the groups must reverse back to the closest vehicle-passing bay. A complicated back-and-forth manoeuvre is often required to allow one group of vehicles to pass the other, one at a time if the bay is only large enough for one vehicle. It can be a frustrating process because each time only one vehicle can pass the group at the passing bay, meaning that the group must move back and forth around the passing bay until each vehicle in the other group has been passed. Much time, fuel and operator patience are lost in this manoeuvre. This type of vehicle interaction is a problem that must be completely avoided when implementing a haulage ramp management plan.

Optimization of mining processes has been researched since the early 1960s [6]. Early on, optimization and vehicle dispatching was accomplished by using heuristic algorithms to navigate the tight underground environment [7]. Today vehicle dispatching is acknowledged as an essential optimization tool in mining and other industries and dispatch systems are installed on a wide variety of machines [8].

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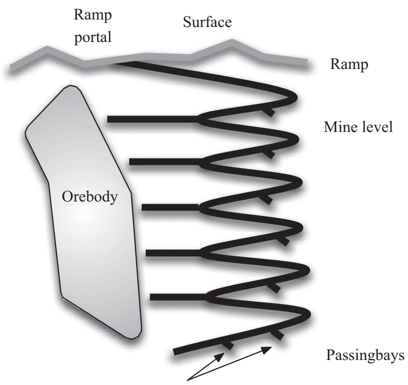

Fig. 1. Schematic drawing of a typical mine ramp-based underground haulage system, after [2].

However, satellite-based GPS tracking cannot be used for vehicle dispatching purposes in underground mining, which makes it difficult for modern dispatching systems to be of use. New technologies under development show promise to overcome this problem. For example, map-based localization techniques from robotics have recently been a focus of research and development activities [9,10]. Real time position data on vehicles underground would allow for continuous monitoring and optimization of the system. Such a position monitoring system could shorten overall vehicle travel times when a large number of vehicles are present on the ramp, as shown by Gamache et al. [11].

Discrete-event simulation can be used to study and optimize a wide variety of problems that involve objects moving along paths to various nodes, as shown by Bussieck et al. [4], Winter and Zimmermann [8], and Thomas [12]. It is also one of the most popular tools used in solving other vehicle dispatch problems encountered in underground mines [2,6]. Discrete-event simulation has been used for solving fleet management problems in a mine level [13]. With the availability of large amounts of computing power, today complex simulations can be run in a very practical amount of time.

Ramp design is an important aspect in the feasibility process for underground mining [14]. The ramp represents a very large capital cost and, in many cases, is critical for operations. As such, design optimization is warranted to minimize costs, maximize productivity, and to ensure accurate cost estimates for project feasibility studies, as described by Vagenas [15]. However, there are relatively few studies about ramp optimization for the purposes of improving vehicle traffic and throughput. On the other hand, much work has been done on equipment selection for a preset ramp design; e.g., see [16].

In this paper, discrete-event simulation software (Simul8) is used to simulate an underground haulage ramp. Policies that are commonly used in mining were tested in the simulator, and the results obtained were used to parameterize each policy. The so-called lock-out policy was found to be the most effective policy in terms of productivity. An alternate policy is also proposed, which improves the efficiency of the lock-out policy during times of increased traffic. This new policy was then tested on a fixed ramp length, with varying vehicle and passing bay numbers. Based on these results, a technique is presented to allow for easy ramp and fleet design, with focus on optimization of productivity.

2. Mine ramp traffic management policies

At present, there are three types of ramp traffic management policies that are most commonly used in underground mines across Canada and around the world. These three policies are: simple routing, loaded priority and lock-out.

The simple routing policy is a radio-based communications policy that is suitable for low-volume traffic. It relies on drivers to communicate over radio when they enter certain ramp segments, thus helping to avoid situations where other drivers enter these segments, possibly resulting in a traffic conflict, lost time, or an accident. The remaining two policies are discussed next; see also [14]. In the current paper, the lock-out policy is examined in detail, and a fourth solution, which we demonstrate enhances the lock-out policy, is offered.

The loaded priority policy allows loaded vehicles (i.e., those hauling ore or waste) to continue up the ramp without stopping at passing bays. Vehicles that are empty and traveling downwards are expected to keep out of the way of these vehicles by use of the passing bays. This policy is inefficient with higher volumes of traffic, and especially when the loading time of a vehicle is shorter than that of any ramp segment (this is easily shown by simulation or in practice). Intuitively, if the loading time is shorter than travel time on a ramp segment, vehicles will tend to bunch up at the dumping point, as entrance onto the ramp will be difficult with a high number of vehicles traveling upwards. This policy promotes grouping of vehicles, which results in long lines at the loading and dumping points and periods of time in which there are no vehicles either at the loading or dumping points.

The lock-out system is relatively common because it is easy to implement in a mine haulage ramp. All that is needed is a set of traffic lights, which can be manually changed through the use of a pull rope. The lock-out system works by only allowing one vehicle to travel on each ramp segment, and requires that vehicles wait until the segment is "free" before entering it, regardless of whether the vehicle is traveling in the opposite direction or not. This system has some inherent inefficiencies, as vehicles that could travel together cannot according to the lock-out policy rules. When manually driven, human errors can also result in efficiencies.

To study and test the performance of ramp-management policies, a model haulage ramp was created using a commercial discrete-event simulator software called Simul8. The software works by allowing the user to create a system of simulation "objects" that can modify and route other "work objects" throughout the system. This allows for the simulation of many vehicles (i.e., work objects) on the same ramp circuit.

To simulate bidirectional traffic in a single-lane passage, two parallel routes were created in Simul8, and a check was implemented to indicate a conflict if vehicles were present in both routes at the same time. A simple spreadsheet was used to keep track of vehicle positions on each ramp segment. If a crash was detected, the simulation was stopped, and a violation of the policy was indicated. The spreadsheets were updated at each discrete event to catch any possible violations of the policy. To test one policy or variation against a different policy, an exact copy of the ramp was made and the logic of one of the duplicated ramp systems was replaced with that of the other policy to be studied. The ramp system was also designed in such a way that the incorporation of randomness in timing, other disturbances, as well as changes in traffic availability can be modeled. For this study, a ramp model that consisted of a single loading point, a single dump point, and seven ramp segments, each spaced with one passing bay was created for testing between policies. These parameters were kept fixed in order to see the effect of varying only policy, in the absence of other factors (i.e., the focus here is on policy design, not ramp layout design).

3. Analysis of the lock-out policy

The lock-out policy works by allowing a vehicle to reserve a specified segment of ramp by pulling a string before entry into