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Production analysis of functionally distributed machines for underground mining

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ABSTRACT

Recent years, underground mining method is becoming popular because of its potentially high productivity and efficiency. In this method, a mining machinery; load haul dump (LHD), is used as both an excavator and a transporter of ore. This paper proposes a distributed system that realizes the excavation and transport functions with separated vehicles, an excavator and a transporter. In addition, this research proposes a mining map and configurations suitable for the proposed distributed system. To evaluate the productivity of the proposed system, a simulation environment has been developed. Analysis using the simulator reveals what performance factors of the excavator and the transporter have large impacts on the productivity. Simulation results also demonstrate the difference of potential between LHD system and the distributed system that can be explained based on their functions allocation.

1. Introduction

Underground mining method is becoming popular in this decade [1–4]. Formerly open pit mining has been the most popular method, where soils and stones covering the target ore body are removed, and after that, ores are mined (Fig. 1a). However, in these days, the open pit mining method is becoming less efficient because the target ore body is becoming deeper and deeper. This means that a large amount of non-target soils and stones must be removed and transferred in the open pit mine. Contrastively, in the underground mining method, special machines directly access to the lower side of the target ore body (Fig. 1b). The ore body is exploded and fractured into small ores. Those small ores flow downward by their weight, and they are mined underground. Finally ores are transferred to the surface ground by conveyer equipment or hoist cranes. The underground mining method handles only target ores, and hence it is quite efficient. Moreover, the method can repeat the same procedure even if the target ore body becomes deeper and deeper.

In the underground mine, load haul dump (LHD) is the most popular operating machine. LHD is a kind of wheel loader (Fig. 2). The width and height of drift ways in the underground mine are very small because minimization of the workload to transfer non-target soils and stones is required. Consequently, LHD has a very low and thin profile.

There are basic needs for releasing operators from hard and insecure tasks in the underground mining. To respond to the requirement, there were some studies regarding automation of underground mining machines [5,6]. Especially, unmanned automatic driving of LHD is studied widely [7–9]. In these studies, they realized automatic navigation using laser range finder (LRF) or other sensors; however, they could not realize automatic excavation because the task requires intelligent recognition and complicated control. In current condition, a LHD is remotely controlled by an operator while excavating.

LHD is the de-facto standard of the underground mining machine. But LHD has some technical challenges or problems as an ore excavating and transporting machine.

(1) LHD realizes both excavation and transportation in the same machine. This means that a LHD cannot work as an excavator while working as a transporter, and vice versa. The configuration of LHD limits the working time as an excavator, and limits the maximum production because it does not exploit the potential productivity of an ore body.
(2) Once more, a LHD realizes both excavation and transportation in the same machine. Consequently, the unloaded weight of LHD is heavy compared with its load capacity. The heavy weight requires lots of fuel, and limits the maximum driving acceleration and velocity.

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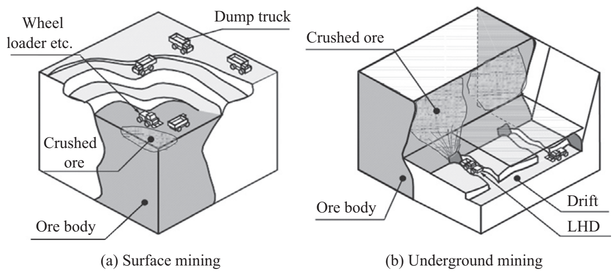

Fig. 1. Conceptual diagrams of surface mining and underground mining.

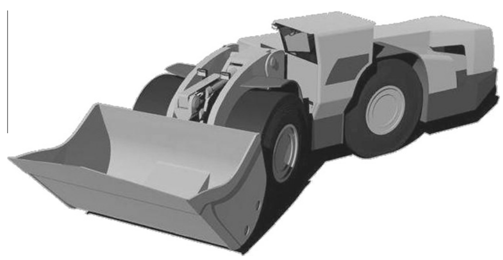

Fig. 2. Outer appearance of load haul dump.

(3) One LHD occupies a drift way; therefore, the performance increase of LHD itself is the only method to improve production. This brings that LHD is getting larger and larger, and wider drift ways are needed for larger LHD for smooth operation.

To solve the above problems, in this paper, we propose a system configuration where the excavating function and transporting function are installed on different machines. The proposed system configuration with functionally distributed machines is analyzed in the view of productivity. The analysis aims to reveal what factors have large impacts on the productivity. Moreover, we propose a new mine map and mine configurations, and analyze their effects.

2. Related work

Generally, optimization of an automation system aims following items: productivity maximization, cost reduction, energy reduction, space saving, infrastructure saving, and safety enhancement. These items are also quite important in this study. Previous studies for system optimization can be classified into three classes by their methodologies: (1) scheduling optimization, (2) resource/task allocation and dispatching optimization; and (3) layout/route optimization [1,10–19]. These three methodologies intend to exploit the potential of pre-configured machines or infrastructures. They are effective when a system is composed of different and multiple elements and the optimal operation cannot be defined intuitively by a human operator.

In contrast, our target underground mining uses small number of specific machines and their operation patterns are finite, therefore, it is difficult to improve productivity drastically based on those three methodologies.

Instead of those methodologies, we adopt an approach to change system configurations. There are some related studies regarding optimization of system configurations. For example, Ekren et al. propose a fast evaluation model for autonomous vehicle storage and retrieval system (AVS/RS) [20]. The proposed model enables to select optimal ACS/RS when designing a new warehouse. Hoshino et al. proposed a design method to select the optimal configuration of automated guided vehicle (AGV) and optimal number of agents [21]. These approaches bring the underground mining a useful optimization method that changes system configurations and improves productivity. However, they also have limitations because they must optimize the system under the constraint of pre-defined machine functions.

This research does not persist in the current configuration of LHD, which means that we assume a "new/different function allocation" for mining machines and demonstrates its potential productivity.

3. Function distribution of excavating and transporting machine for underground mining

This section firstly discusses the qualitative impacts and effects brought about by the function distribution. Secondly, an appropriate mine map for the proposed system configuration is proposed. Finally, specifications required for underground mining machines are summarized.

Fig. 3 shows an overview of an underground mine with block caving method [2]. Definitions of technical terms in Fig. 3 are as follows: (1) draw point: a place where ores are excavated; (2) ore pass: a place where excavated ores are dumped and collected; (3) drift: a road that connects between draw points and ore passes; (4) cross cut: a temporal road used for development of draw points, and it cannot be used for locomotion between draw points or between drifts after the beginning of operation.

3.1. Distributed allocation of excavating and transporting functions

Fig. 4 shows the ratio of load capacity and unloaded weight for LHDs and dump trucks, and it shows LHD is extremely heavier than dump truck. This is because a LHD has both equipment for excavation and transportation in the same body. We propose a system configuration where the excavating function is realized by a machine and the transporting function is realized by another machine. "Continuous mining" adopts the similar approach [22,23]. It is composed of continuous excavating machines fixed at draw points and conveyer machines fixed at drift. It might be able to realize high productivity in regular operation, but it requires enormous initial cost. Moreover, if a large boulder emerges at a draw point, it is impossible to use a crashing machine at the draw point because the drift is occupied by conveyer machines. From the view of initial cost and recovery from an accident, the continuous mining has many assignments to be tackled with.

Hereafter, a vehicle for transporting ores is designated as "transporter", and conversely a vehicle for excavating ores is designated as "excavator". An excavator basically stops at a draw point,

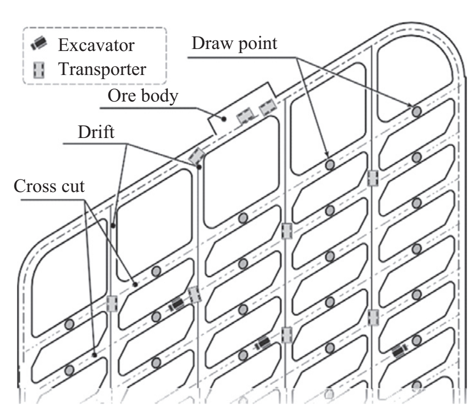

Fig. 3. Overview of underground mine.