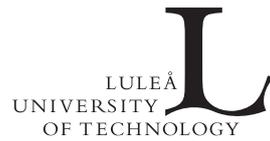


**Conceptual Models Regarding Mine
Layout/Infrastructure and Process
Flow at Greater Depths**

A Literature Review on Haulage Systems

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ABSTRACT

This report is part of the work done by Luleå University of Technology within the EU 7th framework project I²Mine, Innovative Technologies and Concepts for the Sustainable and Intelligent Deep Mine of the Future. The work is performed within work package 2 Novel mining and underground processing methods, subtask 2.1.1 Novel mining methods and processes for deep, steeply dipping orebodies. This subtask aims at identifying new conceptual methods and processes for mining of deep, steeply dipping orebodies. The literature review presented in this report is aiming at identifying haulage systems that might be applicable for the given conditions, and serves as input for the future work within subtask 2.1.1 which is carried out by the research subject Mining and Rock Engineering at LTU together with LKAB and Boliden from November 2011 to November 2015.

1 Haulage systems

The haulage system for ore and waste, one of the most important operations in underground mining, involves transportation of mined-out material from the faces (draw points) to the loading areas, and then to the mine surface (Atkinson, 1992). Material removed from the loading area can be transported vertically or horizontally to the surface. Vertical transportation includes shaft, vertical conveyors, skip hoisting, inclined shaft, and gravity flow transportation. Horizontal transportation includes rail, monorail, belt conveyors, rail-veyors, and trucks. Normally, these systems work in combination with other ore-handling components such as load-haul-dump (LHD) machines and crushers. In this analysis, LHDs, trucks, conveyors, monorail, and rail-veyors are discussed because they are appropriate haulage methods for ramp transportation.

1.1 Loading equipment

Underground loaders are the first equipment used in the ore-handling system. Loaders extract ore from the stope/face and dump it directly into an ore pass, a loading bay, or onto the haul equipment that transports the ore to the desired location. Several types of loaders are available, including rail-mounted, rubber-tired loaders, track-mounted, and shuttle loaders. As shown in Figure 1, rubber-tire loaders, also called load-haul-dump (LHD) machines, are commonly used in hard rock mines and may be diesel- or electric-powered.

Diesel LHDs have been utilized for material transportation in mining since the 1960s. These machines are versatile, and can easily move from one location to another, but they are more expensive to operate because of the costs of fuel, consumables, regular maintenance checks, and the ventilation systems needed to mitigate the heat and emissions produced (Thomas et al., 1987; Chadwick, 1996; Miller, 2002). Although electric LHDs have not been as common in underground mines (Paraszczak et al., 2013), they require less ventilation than diesel because they generate less heat, are quieter, and emit no exhaust gasses (Chadwick, 1996; Paraszczak et al., 2013; Paterson & Knights, 2013; Paraszczak et al., 2014). Electric LHDs may be powered by batteries, overhead electric lines, or trailing cables. Batteries offer the greatest flexibility; however, battery-powered vehicles are heavy and must be regularly recharged. Overhead power lines may be feasible when routes remain constant for an extended period of time, but are impractical for LHDs that require a high degree of maneuverability. A trailing cable plugged into the mine's electrical infrastructure is the most viable way to power electric LHDs; however, electric cable reduces the LHDs' versatility because of limited haul range and restricted movement and may present problems with cable faults, cable wear, and relocation issues.

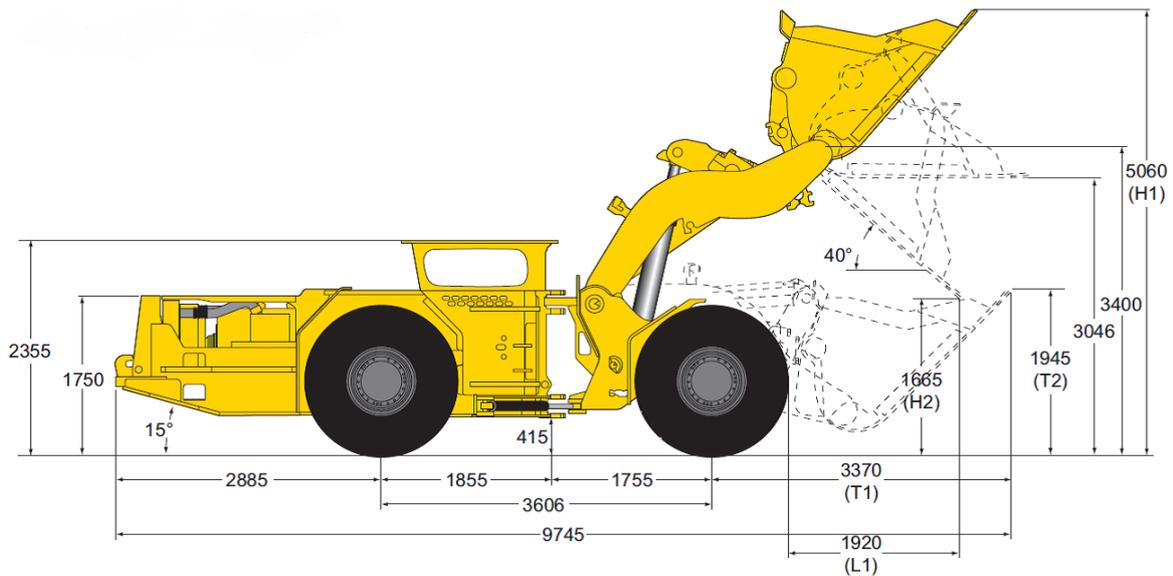


Figure 1. Example of rubber-tire LHD machine (courtesy of Sandvik)

1.2 Truck haulage

Truck haulage systems are widely used in underground operations for long-distance hauling of material from loading areas to shaft stations or directly to the surface (Atkinson, 1992). A truck uses development openings (declines) and main levels when hauling ore to the specified location. As shown in Figure 2, allowance must be for other services such as ventilation ducts, service pipes, and clearance to sidewalls. Trucks used underground can be divided into three categories: rigid-body rear dump trucks, articulated rear dump trucks, and tractor-trailer units. The most common truck used is the articulated rear dump truck (Atkinson, 1992). These types of trucks may be diesel or electric.

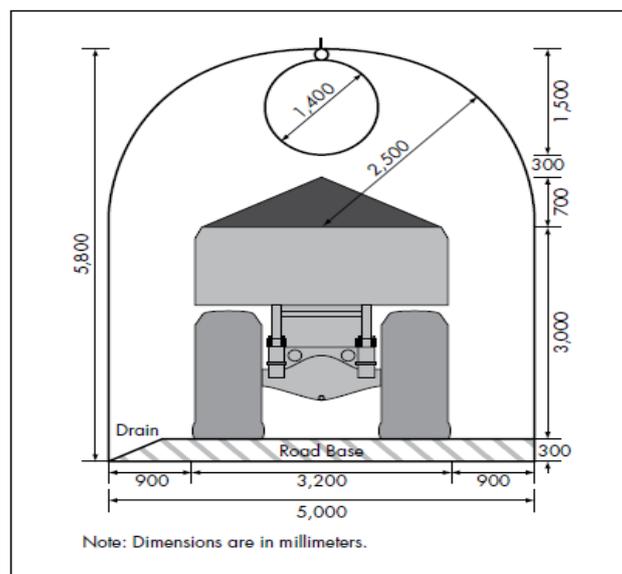


Figure 2. Dimensions of the development opening for haul trucks (Atkinson, 1992)

1.2.1 Diesel trucks

For many years, diesel trucks have been increasingly used for material transportation in open pit and underground mining. This haulage equipment is highly flexible in travel routes and fleet size, has no electrical hazards, and provides high productivity (Thomas et al., 1987). The disadvantages are the use of flammable fuel, higher heat emissions and noise levels, and the emission of toxic gases into the mine environment.

1.2.2 Electric trucks

Electric trucks are gaining attention among deep underground mining operations. Examples of mine companies that operate electric trucks are Kidd Creek and Hope Brook Gold in Canada, Mount Isa in Australia, and Stillwater mine in the United States (Paraszczak et al., 2014). In comparison to diesel, electric trucks make minimal demands on ventilation systems, reduce the risk of underground diesel storage, move faster, and have lower operating costs. Some disadvantages of electric trucks are the higher initial investment in needed infrastructures and their low flexibility compared with trackless arrangements (Anon, 2009). Electric trucks may be powered with an electric cable, batteries, or from a trolley electric line mounted at the back of the drift. However, for transporting material over long distances in mines, electric cable and batteries are not feasible. Both lithium-iron and lithium-iron-phosphate batteries have a specific energy range of 0.4 MJ/Kg to 0.9 MJ/Kg, and therefore, must be rechargeable after a few hours of operation. As shown in Figure 3, best way to power electric trucks in mining is using a trolley electric line mounted at the back of the drift, a concept originally developed Kiruna, a Swedish truck company. The company produces two truck models: the EMT-35 and the EMT-50, which are 35-tonne and 50-tonne units respectively. During loading and dumping, electric-powered trucks are disconnected from the overhead power source and use a small diesel-powered motor, which produces minimum particulate emissions (Chadwick, 2011).



Figure 3. First Kiruna electric truck (Zinkgruvan mine, Sweden)

1.3 Belt conveyor

The two main types of industrial belt conveyors include a general material handling conveyor such as those used for moving boxes and other materials inside a factory, and a heavy or bulk material handling conveyor used to transport large volumes of resources in mining and agricultural activities. The mining industry uses the overland conveyor, which is a bulk material handling system that can transport material at high capacity over a long distance. The overland conveyor includes a conventional conveyor, cable belt, and rope cone conveyor. The conventional conveyor method is widely used to transport materials at a capacity more than 33,000 t/h and up to 20 kilometers (Goodyear & Rubber Company, 1976). Because these conveyors cannot be used in irregular terrain and unfavorable topography, they often require installation of indirect routes, which can increase costs.

As shown in Figure 4, belt conveyors consist of five main components: a head pulley with gear box and electric motors, tail pulley, rubber belt, carry and return idlers, and take-up pulley (Goodyear, 1976). A driving pulley propels the belt, which returns through the end pulley. Material is loaded in the tail and discharged at the head. The belt is supported by a series of rollers called idlers, mounted on the material-carrying side and on the return side of the conveyor and arranged by trough to increase the belt's carrying capacity. The return idlers support the return side of the conveyor belt.

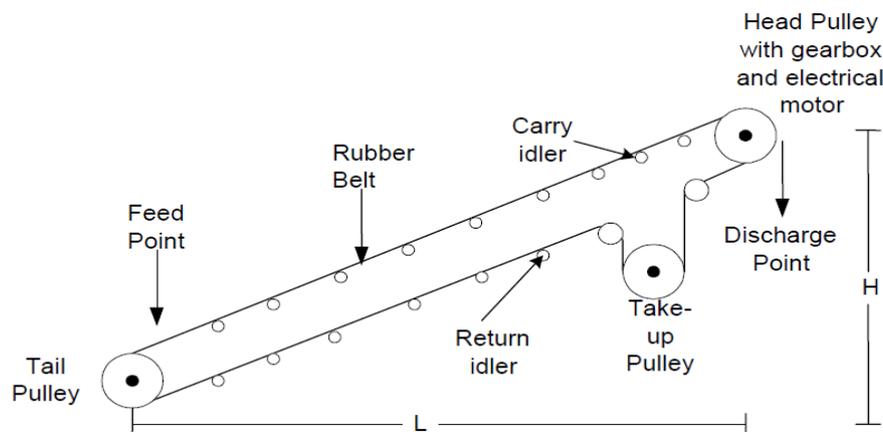


Figure 4. Basic belt conveyor components (Mark, 2007)

1.4 Monorail transportation system

Rail transportation in underground mines is energy-efficient, suitable for long haulage, and has high tonnage production per shift. A rail system, which may operate alone or in combination with trackless systems, can be floor-mounted or roof-mounted. Floor-mounted trains are less flexible than trackless systems, and can be used only in mines with low-gradient slopes. Although rail systems are time-consuming to build, they can handle larger loads per trip than trackless systems. Roof-mounted or monorail systems are used to transport material, mechanical equipment, and personnel and can have many branches over long distances and varying gradients. The quality of the mine floor does not affect roof-mounted

systems, giving them the same flexibility as trackless arrangements. Monorail technology has been used in mining in South Africa for material and personnel transportation. Also, the technology has been developed in Jundee mining operations in Australia with the capability of hauling from the decline development (Chanda & Besa, 2008).

As shown in Figure 5, a monorail transport system is comprised of vehicles that form a flexible train unit, which can be equipped with personnel cabins (Figure 6), material containers, and bottom-discharge hoppers for material handling (Guse & Weibezhn, 1997). A rail track is anchored and suspended from the hanging wall and operated by electrical, diesel or battery drives. A conductor rail bolted directly to the rail supplies the energy to drive the train. Electric monorails are a low-energy, easily maintained system in underground hard rock mines with small cross sections and long inclines and with gradients of up to 34 degrees, payloads of up to 30 tonnes per single load for all containers (Chanda & Roberts, 2005). A single container can carry a maximum of five tonnes and a total monorail system may contain six containers. A monorail system will result in lower support costs, reduction in the air needed for ventilation, and minimal diesel exhaust. The monorail system can be loaded by either a front-end loader (FEL) with side dump, LHDs, or through pneumatic loading.

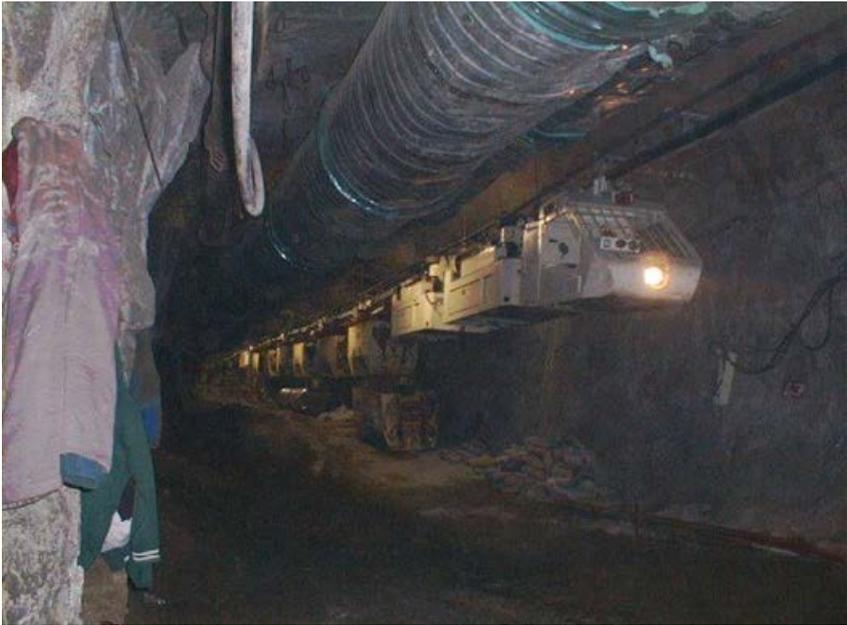


Figure 5. Monorail transportation system (Scharf, 2007)



Figure 6. Personnel transportation using monorail (Scharf, 2007)

1.5 Rail-veyor system

A rail-veyor, which consists of a light rail track, can be installed much more quickly than a conventional rail (Fantin, 2013). As shown in Figure 7, a rail-veyor has a low profile to allow for small-drift operations and can travel on grades of up to 20 percent. Rail-veyors have a rail-car system that acts as a long trough to allow continuous loading and unloading (Figure 8). Rail cars are inverted for unloading, which maximizes system performance. The systems can have multiple loading and unloading points. Cars move at 0.3 miles per second during loading, and once loading or unloading is complete, they can travel up and down the 20 percent gradient at up to 3 miles per second. In the dumping loop, the rail-veyor can travel at 1.5 miles per second. Vale's Copper Cliff North mine in Sudbury, Canada, which uses conventional methods, developed rail-veyors in 2008; however, the project was closed during the world financial crisis when commodity prices dropped. Following a successful surface trial at the Stobie mine, the rail-veyor has proven to be a potential transportation method for development and production in deeper operations (Chadwick, 2013).

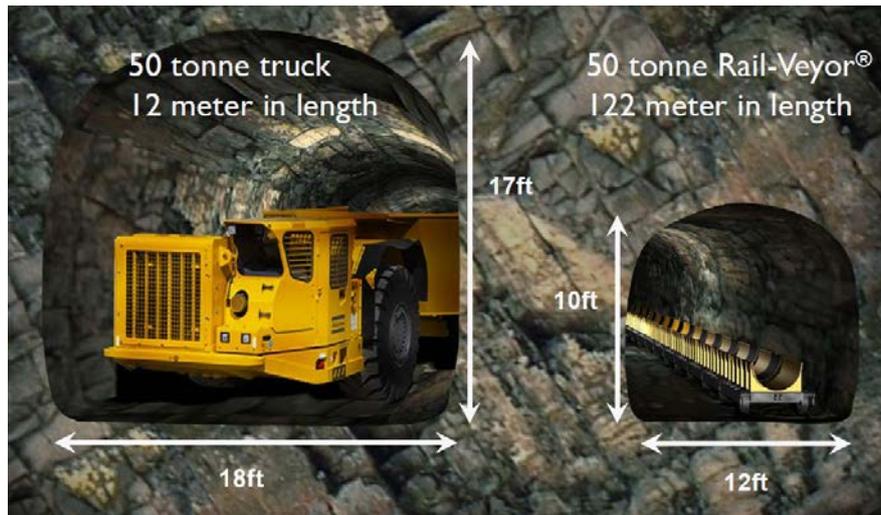


Figure 7. Rail-veyor opening profile (Fantin, 2013)



Figure 8. Material transportation on rail-veyor (<http://www.railveyor.com/>)

2 Equipment selection

The selection of equipment for haulage and transportation in underground mines is challenging because of the impact on production rates and costs. The amount of material to be moved is a determinant of the size and number of haul units needed. Loading equipment is selected to match production capacity, size of openings, and number of faces in operation. On the other hand, hauling equipment is selected to meet production requirements and to be compatible with the loading equipment.

2.1 Haulage equipment selection

During equipment selection, the size of loaders and haul equipment is an important factor to consider. The loader must fit within the planned development and drifts openings, and its maximum bucket reach must not exceed the height of the opening. The loader also should be able to reach and fill hauling equipment efficiently. The optimal bucket capacity can be estimated based on the loader's cycle time, bucket volume, broken density of the rock to be carried, and the fill factor, which depends on rock fragmentation.

2.1.1 Truck selection

The type of trucks and the size of the fleet are determined based on the selected loading equipment. Truck selection depends on many factors, including road geometry, production rate, haulage distance, mining method, ore reserve tonnage, haul road dimensions, safety, capital and operating costs, road intersections, required truck speed, corners and bends, road quality, and so on. Truck size also depends on the number of dump cycles the loader will use to fill a truck. A truck with high capacity and a loader with low capacity will increase the number of load haul dump cycles required to fill the truck; as a result, the haulage equipment's cycle time increases and production decreases. The "match factor" can be used to determine the optimal combination of loading and hauling units in an operation (Lizotte & Bonates, 1987). The Caterpillar Company first formulated this factor to quantify the apparent balance between numbers of loading and haul units. The production rate of loading units depends on truck size, haul distance, cycle time, material characteristics, and machine operational parameters such as speed. When the haul distance from the loading point to the dumping point is defined, and the ore properties are known, the theoretical hourly production rate can be obtained.

2.1.2 Belt conveyor selection

Conveyor design is based on the type of material to be moved, the distance and gradient over which it will be moved, and any constraints in the system. The nature of the material to be conveyed, available tunnel space, and the overall economics of the system will influence the conveyor's width and speed. Other factors in the design include the ability of the belt to conform properly to the trough formed by the idlers and the trough's effect on the belt. The tendency of the material to slide down the belt or to shift on itself affects the trough angle, which the conveyor can adapt relative to the horizontal plane (Ketelaar & Davidson, 1995).

Factors in the selection of conveyor belts include the belt width, surcharge angle, belt speed, inclination angle, troughing angle, driving and take-up pulleys, motors, and idler configuration. These factors influence the conveyor's performance and determine the belt's carrying capacity and power requirements. Simple geometry is used to derive the belt capacity, as shown in Figure 9.

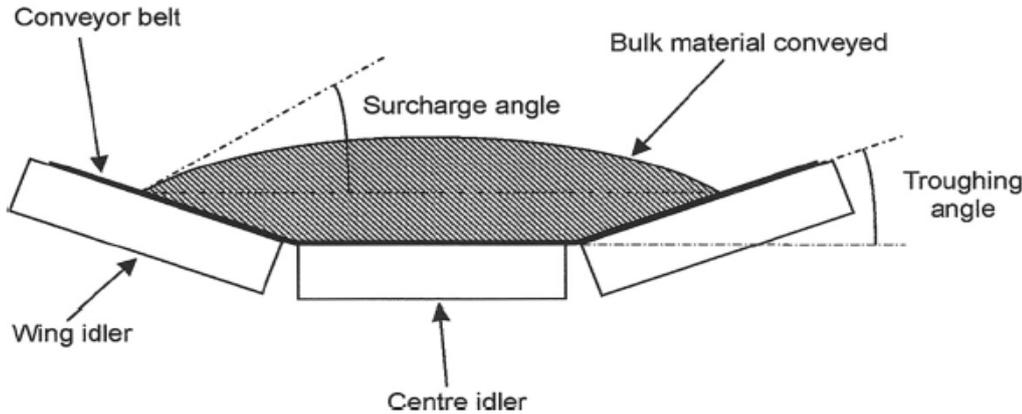


Figure 9. Cross section of conveyor belt with three equal idlers (Mark, 2007)

The surcharge angle is one of the most important characteristics in determining the carrying capacity because it governs the cross-section area of the material on the belt. Models for estimating the required belt capacity are available from several sources, such as CEMA (Conveyor Equipment Manufacturers Association), Goodyear, and FDA (Fenner Dunlop Australia).

3 Techniques for equipment selection

As Oberndorfer (1992) pointed out, many techniques are available with which to select equipment in the mining industry, as companies seek to handle materials at the minimum cost based on mine conditions. Selection also depends on the mining methods, mine infrastructure, and production capacity. The mining method implies a subset of suitable loading and hauling equipment that can be used. Selection may be based on analytical methods, genetic algorithms, discrete event simulation, Petri nets, and operations research. Analytical methods use mathematical principals to fully predict the implications of a theory and can be used to solve an equation without estimation. Genetic algorithms involve selection or search algorithms that generate solutions to optimization problems using techniques inspired by natural evolution such as mutation and past experience. Simulation is able to capture the dynamic and random nature of systems and can be combined with animation and graphical representation to offer a direct approach to understand a proposed mining system. Petri nets are graphical and mathematical modeling tools that describe various processes and are applicable to many systems. This method offers a graphical notation for stepwise processes that include choice, iteration, and concurrent execution. Operations research, such as integer programming, applies mathematics to arrive at optimal or near optimal solutions to complex decision-making problems.

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