Qualitative Review of Alternative Transport Systems for Open Pit Mines

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ABSTRACT

The depth of the open pit mines have increased considerably over the last several years. In fact, there are some open pit mines that are reaching a depth of more than 1000 meters. Currently, the use of conventional trucks for transporting material is probably one of the most flexible systems in open pit mines. Nevertheless, as the mines go deeper, the number of trucks increases, which may lead to operational problems, such as congestion, higher diesel consumption and labor requirements. In addition, in deep open pit mines, transportation of material by trucks represents more than 45% of the mining operational costs while fuel represents over 50 % of the transportation costs. It is thus reasonable to explore different ways of transporting materials through the use of alternative technologies.

In this work, a bibliographical revision of existing technologies and technologies that have the potential to be implemented in deep open pit mines is carried out. This bibliographical revision provides a brief qualitative description of different handling technologies, which allows an understanding of their advantages and disadvantages with respect to diesel consumption, equipment requirements, environmental and safety issues, labor requirements, operational flexibility, investment costs, and design parameters, among other variables. In addition, a brief conceptual analysis regarding the feasibility of the transportation technologies is presented for different shapes of ore bodies resulting in a matrix showing which technology is applicable to the various geometries of the ore bodies.

INTRODUCTION

In open pit mining, the operating mining costs can be viewed as consisting of unitary components: drilling, blasting, loading, hauling, engineering, dewatering, ancillary services and general costs (Figure 1). Among all the components, hauling generally represents more than 45 % of the total mining operating costs in a conventional truck hauling system and about 40 % to 50 % of the capital cost. Fuel consumption represents more than 50 % of the hauling operating cost with approximately 40 % to 50 % of the hauling operating costs occurring in the uphill segments of the haul route (Tutton & Streck, 2009).

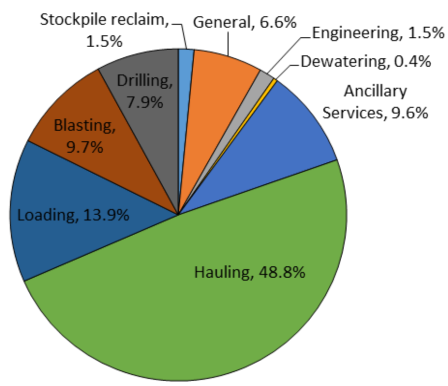

Figure 1 Typical equipment capital costs in large open pit mines (Tutton & Streck, 2009)

Nowadays, open pit mining is being challenged in scenarios where:

- Ore grades have a decreasing tendency.
- The mines' depths have increasing tendencies over the last several years (see Figure 2).
- Oil prices have an increasing tendency (Tutton & Streck, 2009).
- Trucks' tyres supply have become a great problem due to its scarcity (Tutton & Streck, 2009).

Therefore, this work focuses on presenting a general review of alternative haulage systems to the conventional truck haulage and their possible application to different orebody shapes. As this review is qualitative, and regarding the scarcity of information in most of alternative haulage systems, no comparison of energy or diesel efficiency is possible to be analyzed. Further studies, currently in progress, consider the economic and technical viabilities of these alternate systems in future mining operations.

METHODOLOGY

This paper first describes characteristics of truck haulage used in open pit mines followed by a general review of alternative haulage systems as options to consider for open pit operations taking into account technologies that have been proved in the mining industry and technologies that have the potential to be implemented in the near future. This near future will depend on variables such as specific mining (application dependence) and success of similar technologies in other industries (technology dependence).

TRUCK HAULAGE

The transportation of ore and waste using trucks is a flexible and proven materials-handling transportation system mainly because the implementation of trucks does not require semi- or permanent infrastructures, which are difficult to move as mining progresses. The use of trucks, though not a continuous mining system, allows the mine to have a more continuous operation than transporting material using a transportation system where the production depends on the mechanical availability of many individual components. For example, in an in-pit crushing and conveying system, the availability of the whole system depends not only on the availability of the crusher, but on the availability of each one of the conveyors, that comprises the whole system; the greater the number of components, the lower the availability of the system.

With the depth of open pit mines increasing considerably over the last few decades (from 1920's when open pit mines' depths where less than 200 meters to nowadays when depths reached by some open pit mines are 1,000 meters (Franz, 2008)), it is necessary to increment the truck fleet to maintain required production levels, which, despite the system´s flexibility, leads to longer cycle times. This has an economic impact on the operation due to an increase in the fuel and labor costs as well as an increment in the CAPEX because of a requirement of higher number of operating trucks.

ALTERNATIVE TRANSPORT SYSTEMS CURRENTLY USED IN OPEN PIT MINES

The transport systems that are described next, are the most representative ones found in the literature that are currently used for open pit mines.

In-pit crushing and conveying (IPCC)

In the IPCC system, the material from the trucks is unloaded into a crusher located inside the pit with the purpose to decrease the number of operating trucks and their cycle times (a special case is the fully mobile IPCC, where no trucks are used).

There are four alternative IPCC systems depending on the crusher's type, which are briefly described in Table 1.

Table 1 IPCC crusher's characteristics (Tutton & Streck, 2009)

	IPCC Crushers			
	Fixed Crusher	**Semi Fixed Crusher**	**Semi Mobil Crusher**	**Fully Mobil Crusher**
Type	Gyratory or jaw	Gyratory or jaw	Twin roll or sizer	Twin roll or sizer
Relocations	Rarely relocated	Relocations every 3 to 5 years	Relocations every 6 to 18 months	Relocations as required to follow the shovel
Use	Deep hard rock mines	Deep hard rock mines	Not Common in deep hard rock mines	Not Common in deep hard rock mines

As can be seen from Table 1, semi-mobile and fully mobile crushers are not commonly used in deep, hard rock open pit mines because the throughput capacity of a sizer crusher decreases rapidly as the rock strength increases, as shown in Figure 2.

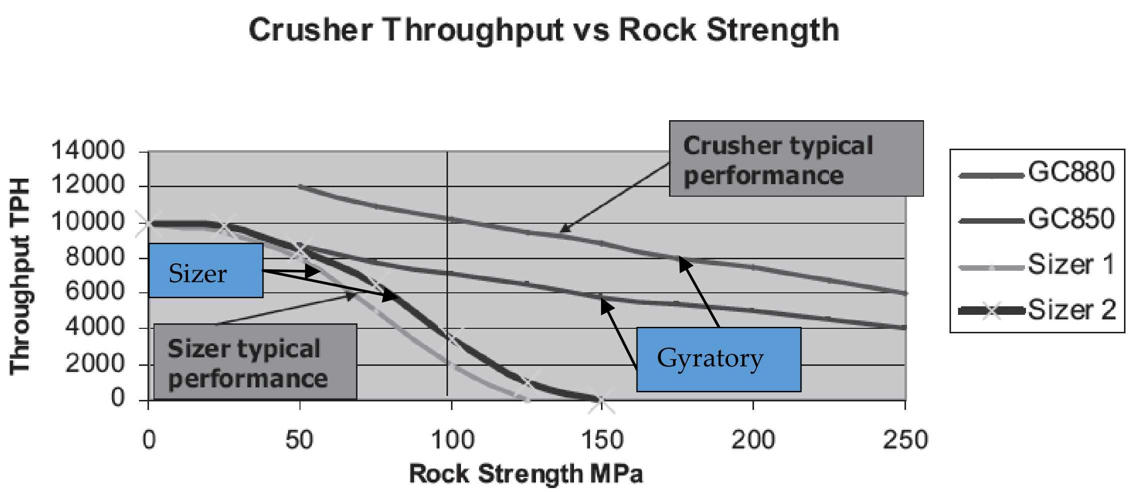

Figure 2 Crusher throughput vs rock strength (Morris, 2008)

The throughput capacity shown in Figure 2 is only indicative because it depends also on the rock fragmentation as well as the intended belt width (Morris, 2008).

High angle conveying (HAC)

A high angle conveyor belt is defined as any conveyor that can transport material up a slope that exceeds the dynamic stability angle of the transported material (Mitchell & Albertson, 1985). There are several methods to transport material using high angle conveyor belts including the sandwich belt, the corrugated belt and the pipe belt (Atkinson, 1992). The focus in this section is on the sandwich belt, because this kind of belt has no losses in capacity with the increase in the conveying angle (Radlowski, 1988). In fact, pressing conveyors have conclusive advantages in conditions of open pits especially for large production targets and large angle of an inclination (Sheshko, 2002). The first introduction of the sandwich belt concept occurred in 1951, in Germany, in the form of "Conveyor with Cover Belt". A cover belt was installed at the boom belt of a bucket wheel excavator to increase the conveying angle without the occurrence of material slide-back (Dos Santos, 2013).

Autonomous hauling system (AHS)

The autonomous hauling system is based on the concept of driverless trucks to reduce labour costs and exposure of people in the mine environment.

The AHS system works as follows (Hustrulid, Kuchta & Martin, 2013):

- It takes advantage of the information and communication technologies such as GPS, obstacle detection sensors, a wireless communication network system, and a fleet management system (Hustrulid, Kuchta & Martin, 2013).
- Information concerning the hauling routes and speed is sent wirelessly from the fleet management system to the driverless trucks while they travel.
- For loading, the fleet management system guides the truck to the loading site, based on the position of the shovel's bucket.
- After loading, the fleet management system directs the truck along the route to the unloading point.

Trolley assisted haulage

The trolley-assisted haulage is a system in which the truck connects to an electric line through a pantograph. As the truck approaches the line, the operator lifts the pantograph and connects to the electric line. While the truck is connected to the line, the truck draws power from the line and its movement is assisted by electricity with savings in diesel consumption and higher speeds during the uphill segments. The reduction in the fuel consumption allows an increment in the engine's operating hours (lifetime). This way of transporting material is restricted only to electric trucks, where a convertor located on the truck, converts mechanical power from the engine into electric power and vice versa (Hustrulid, Kuchta & Martin, 2013).

When using this system, it is necessary to incorporate the following infrastructure in addition to a conventional truck haulage:

- Pantograph for each truck (one truck can only connect to one pantograph).
- Electric substations in the ramp.
- Trolley line.

Continuous loading using bucket wheel excavator (BWE)

The bucket wheel excavator is a piece of equipment that acts as a continuous loading system. It is mainly used in open pit coal mines. The material is excavated continuously by means of small buckets that are mounted on a rotating wheel. As the wheel rotates, the material is offloaded onto an internal belt, which transports the material out of the machine to a conveyor belt system. This kind of equipment can achieve great productions rates, the largest ones can load approximately 240,000 bcm per day. However, the material extracted by a BWE must be soft enough to be mechanically cut and loaded (without blasting) (Thompson, 2005).

Draglines

The dragline is a cyclic excavator and transport system combined; no intermediate transport system is required (Thompson, 2005). In a single cycle, the bucket of the dragline is lowered to the surface through the dragline's rope to excavate. Once the dragline has excavated from the surface, the bucket is moved using the dragline's hoisting ropes towards the dumping point of the material.

Advantages and disadvantages of existing alternative systems in open pit mines

Tables 2 and 3 provide a brief description of the advantages and disadvantages of the various alternative transport systems used in open pit mines, respectively.

Table 2 Summary of the main advantages of the alternative transport systems used in open pit mines

	IPCC	HAC	AHS	Trolley	BWE	Draglines
Reduced operating costs	x	x	X		x	x
Less diesel consumption	x	x	X	x	x	x
Less requirement of trucks	x	x	X	x	x	x
Less ancillary equipment requirement	x	x			x	x
Less dust and gas emissions	x	x		x	x	x
Less labour requirements	x	x	X	x	x	x
Higher availability	x	x				
Less tyre's supply	x	x	X	x	x	x
Proved in the industry	x	x	X	x	x	x
Achieve higher productions					x	x

Table 3 Summary of the main disadvantages of the alternative transport systems used in open pit mines

	IPCC	HAC	AHS	Trolley	BWE	Draglines
Less flexibility	x	x	x	x	x	x
Higher investment cost	x	x	x	x	x	x
Controlled blast near the infrastructure	x	x		x		
Mine op. depends on belts availability	x	x			x	
Wider ramps	x		x	x		
Phases' design must use straight geometry	x					
Higher road maintenance requirement			x	x		
Limited to certain geological conditions					x	x
Long maintenance outages					x	
Large Maintenance Costs					x	

ALTERNATIVE TRANSPORT SYSTEMS WITH POTENTIAL FOR OPEN PIT MINES

The transport systems that are described next, are the most representative ones found in the literature that have the potential to be used in the near future for open pit mines.

Trucklift system

In the trucklift system, a truck arrives loaded at the bottom of the platform, it is placed on the platform and lifted to the level where it leaves the platform and goes to its final destination. While the loaded truck is positioned for the upwards trip, an empty truck is transported on a parallel platform on the downward trip (Siemag-Tecberg, n.d.). Currently, only mid-size trucks can be transported from deep levels on steep slopes. For example, on a steep slope of 55°, a maximum truck payload of 240 metric tons can be transported.

Skip conveying

This system is very similar to the trucklift system described in the previous section. In skip conveying, the material could be transported from the bottom of the mine or an intermediate station to the crusher located outside the pit up an inclination of up to 75°. As one loaded skip moves upwards, an empty skip is lowered down (Wolpers & Drottboom, 2015).

Ground Articulating Pipeline (GAP)

The Ground Articulating Pipeline (GAP) is a system that could be used in the future to transport oil sands as a slurry from production faces through a flexible pipeline system to the existing hydro-transport system. Its structure consists of a series of rigid pipelines, including the water and slurry pipelines, one fixed pipeline and one slurry mobile system. In the slurry mobile system, the material is dropped from the shovel and it is mixed with hot water to slurry the oil sands. The slurry is then pumped through the GAP system to the fixed pipeline (Li & Frimpong, 2014).

Advantages and disadvantages of existing alternative transport systems used in open pit mines

Table 4 and 5 provide a brief description of the advantages and disadvantages of alternative transport systems used in open pit mines, respectively.

Table 4 Summary of the main advantages for systems with potential for open pit mines

	Trucklift	Skip Conveying	GAP
Lower diesel consumption	X	x	x
Less requirement of trucks	X	x	x
Less requirement of ancillary equipment	X	x	x
Less dust and gas emissions	X	x	x
Less labor requirements	X	x	x
Safer mine operation due to less equipment	X	x	x
Less tire's and spare parts supply	X	x	x

Table 5 Summary of the main disadvantages for systems with potential for open pit mines

	Trucklift	Skip Conveying	GAP
Less flexibility	x	x	x
High investment cost	x		
Controlled blast near the infrastructure	x	x	
Mine operation depends on the system availability	x	x	x
Technology has not been proved in the industry	x	x	x
Technology is limited to a maximum payload	x		

APPLICABILITY OF TRANSPORT TECHNOLOGIES DEPENDING ON BODY SHAPES

Table 6 lists selected ore bodies shapes and their compatibility with the transport systems used in open pit mines, according to the characteristics of the handling technologies discussed in the previous section.

Table 6 Convenience for studying different transportation systems with varying ore body shapes

Ore Body	System	Geometry	Large	Phases' Sequence	Convenient to study?	Productivity	Capex
Tubular	IPCC	Yes	Yes	Yes	**Yes**	Depends on the mining schedule	Depends on the mining schedule
	HAC	Yes	Yes	Yes	**Yes**		
	Trolley	Yes	Yes	No	**No**		
	AHS	Yes	Yes	Yes	**Yes**		
Seam	IPCC	Yes	Yes	Yes	**Yes**	Depends on the mining schedule	Depends on the mining schedule
	HAC	Yes	Yes	Yes	**Yes**		
	Trolley	Yes	Yes	Yes	**Yes**		
	AHS	Yes	Yes	Yes	**Yes**		
Vertical	IPCC	Yes	Yes	Yes	**Yes**	Depends on the mining schedule	Depends on the mining schedule
	HAC	Yes	Yes	Yes	**Yes**		
	Trolley	Yes	Yes	No	**No**		
	AHS	Yes	Yes	Yes	**Yes**		

As can be seen from Table 6, almost all of the transportation systems can be implemented for different ore bodies shapes. Special ramps´ designs must be carried out for the IPCC and the HAC systems in case phases have a concentric shape. An exception is the trolley system, which can not be implemented in a tubular or vertical ore body due to its lack of flexibility for relocating the infrastructure.

CONCLUSIONS

This paper surveys a number of technologies that can be considered as alternatives for truck and shovel transport system for deep open pit mines. For these technologies, advantages and disadvantages have been outlined regarding the existing transport systems used in open pit mines as well as transport systems, which have the potential to be implemented in the future.

Most of the reviewed technologies are less flexible than the truck haulage system. Nevertheless, as open pits get deeper, more trucks are needed, implying more diesel and labor costs; issues that have a direct impact on the projects' economics. For these reasons, it is important to consider the possibility of transporting material using alternative transport systems, which might prove to be more economical.

This work focused on the qualitative aspects of handling systems technologies. In the future work, a comparison between different handling technologies within the mine plan using a real case study would be made, which would necessitate incorporation of technical and economic parameters that will depend on specific mine site conditions.

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