A decision-making method to assess the benefits of a semi-mobile in-pit crushing and conveying alternative during the early stages of a mining project

http://dx.doi.org/10.1590/0370-44672018720109

Rodrigo Augusto Nunes[1,3]
http://orcid.org/0000-0002-6613-1551
Homero Delboni Junior[2,4]
https://orcid.org/0000-0002-2856-7426
Giorgio de Tomi[2,5]
https://orcid.org/0000-0002-7836-1389
Cecília Beatriz Infante[2,6]
https://orcid.org/0000-0001-9999-1198
Bladen Allan[1,7]
http://orcid.org/0000-0001-9169-6290

[1]Yamana Gold Inc - Technical Services,
Toronto – Ontario – Canada

[2]Universidade de São Paulo – USP,
Departamento de Engenharia de Minas e Petróleo,
São Paulo – São Paulo – Brasil.

E-mails: [3]rodrigo_anunes@hotmail.com,
[4]hdelboni@usp.br, [5]gdetomi@usp.br,
[6]cicainfante@hotmail.com, [7]bladenallan@gmail.com

Abstract

A significant cost in the operating budget of most mining operations arises from purchasing and maintaining haulage trucks. Recently, in-pit crushing and conveying (IPCC) has been subject to research because of its potential to reduce haulage costs. The objective of this study is to identify early on in a project, by means of a decision-making method, whether or not the semi-mobile IPCC (SMIPCC) is an appropriate alternative to the conventional truck haulage method on the loading and hauling approaches. This method is based on cost analysis and the evaluation of environmental impacts, being successfully tested at an existing open-pit mine, where the results indicated that the IPCC was the most cost-effective option for the operation. Although the IPCC's initial CAPEX was 60% higher than the conventional approach, the IPCC's OPEX was 43% lower, resulting in a 28% reduction of the life-of-mine net present cost (NPC).

keywords: semi-mobile IPCC; cost saving; decision-making method; initial design study; CO reduction.

1. Introduction

One of the challenges while evaluating the early stages of open pit mining projects is to determine which of the alternatives for material transportation and which location for the primary crusher should be considered for further detailed studies and scenario selection. A parallel study between the alternative of the conventional truck haulage with the primary crusher located outside of the pit and the in-pit crushing and conveying alternative can be a long, expensive process. Mining companies with portfolios that contain many open pit projects usually face issues in evaluating the benefits of an IPCC implementation due to the massive workload and time necessary for completion. Properly evaluating these alternatives is important since the haulage costs in open pit mines can be 60% or more of the mine's operating cost (Ribeiro 2013). IPCC systems are now receiving more attention due to the rising cost of the truck haulage cycles, which can be attributed to the cost of diesel and spare parts, leading to the IPCC being the favourable option. In contrast, the IPCC is considered a low-cost alternative in terms of operating costs due to its continuous operation regime, reduced labour, and lower energy consumption, but it requires a high capital cost, and has reduced flexibility (Londoño *et al.* 2014).

There have been studies carried out in the past proposing the use of SMIPCC systems as an alternative to conventional trucking and regular IPCC systems, where the crusher is fully mobile and only a conveyor is used for haulage. A SMIPCC can exploit the advantages of both systems, conventional trucking and fully mobile IPCC, but it is important to ensure that the in-pit crusher is at an appropriate distance from the work front and that its location will be suitable for at least one year of operation before it needs to be moved (Rahmanpour *et al.* 2014). SMIPCC systems are considered flexible and adaptable because of the continuous use of trucks and being able to install a crusher in a suitable location (Nehring *et al.* 2018). In the majority of studies that compare IPCC with truck based haulage systems using conveyors, results in large operational savings due to a more efficient energy and capital allocation.

Although the IPCC concept is not new, as it was introduced in the 1950's in Germany (Ritter *et al.* 2014), companies are still concerned with the implementation of such an alternative due to the high risk involved. Another issue is that it is not as simple as choosing a particular haulage system; one also needs to know how to adapt it to the mine plan to ensure a reduction in the overall mining costs. Therefore, the uniqueness of a project poses a contractual constraint, as no pre-made off-the-shelf options are available (Dean *et al.* 2015).

Furthermore, from an environmental licensing process standpoint, the method used for decision-making can be a relevant tool to be used before going through the preliminary environmental licensing process, so that the SMIPCC alternative can be considered to demonstrate a reduction on the environmental impacts.

To get a better understanding of the IPCC alternative, a new method is proposed that aims to estimate the technical, economic, and environmental benefits of the semi-mobile IPCC alternative from an early project stage. The proposed approach has been tested using data from the initial design studies FEL-1 (PMI 2013) of an open-pit copper-gold mine located in Brazil.

2. Materials and methods

The method was designed as a model that uses the data available from the early stages of the evaluation of mining projects, usually from the scoping studies, as its input parameters. The model analyzes both the conventional trucking and the SMIPCC scenarios. In order to properly estimate the truck requirements, production capacities, and costs, the following should be calculated: truck payload, engine powering and propulsion, cycle time estimations, and production rates (Hustrulid *et al.* 2013).

The input data can be classified into the following groups:

• Material: the material itself, in situ density, and swell factor

• Truck Size: to be chosen from a payload of either 100, 150, 200, or 250 short tonnes

• Operating: average haulage distance (flat, uphill, and downhill), rolling resistance, grade, speed limit, typical fixed times for spotting, dumping, and waiting, primary crushing P80 and design safety factor, working hours, hourly efficiency, conveyor's average speed, length, and elevation

• Production: throughput, and life-of-mine

• Economic: operating costs, discount rate, and exchange rate (if applicable)

The input models considered for the evaluation of the conventional trucking and the SMIPCC scenarios remain unchanged, with the exception of:

• Operating: Haulage distance (flat, uphill, and downhill) considering the location of the semi-mobile in-pit crusher, the conveyor average speed, length, and elevation

• Economic: capital and operating costs, considering the capital and operating costs resulting from the implementation of the conveyor, reduction of the haulage fleet, and relocation of the semi-mobile in-pit crusher

It is important to highlight the three assumptions used in this model:

(1) The mine's throughput and, consequently, the life of mine for the conventional and SMIPCC scenarios remain the same, given that only the haulage fleet and the conveyor's input must be changed from one scenario to the other.

(2) The truck payload (referred to below as the truck size) is an input parameter instead of a calculated one and is then used to select the loading equipment. This method is the reverse of the conventional fleet selection method. The payload relates to known off-road truck models that cover most mine operation cases.

(3) Since both alternatives use the same number of excavators, the excavator CAPEX and OPEX were not included in the economic analysis and calculations because their costs will be equal.

The model continues the analysis as follows:

(1) Truck and auxiliary equipment fleet dimensioning

(2) Conveyor dimensioning

(3) Economic Analysis

(4) Environmental Impact Analysis

The method proposed in the article aims to be a tool to help in deciding on the best type of transport alternative to be used. It includes important topics such as the transportation scenario for the open pit mine, a comparison between the conventional model and the SMIPCC, and the economic feasibility and sustainability of each scenario.

The truck fleet size is determined by evaluating the model that is based on the mine's production capacity and operating parameters, specifically, the average haulage distance (AHD). These two factors are very important as they hold a great weight in the decision to use the IPCC system (Nehring *et al.* 2018). By selecting the truck size (model) from one of the four options, the number of trucks is calculated, as well as the number of bulldozers and motor graders required (Figure 1). It is worth mentioning that, because the transportation model considered in this study is a SMIPCC, it is still necessary to use trucks to move the material from the mining face to the in-pit crusher, where it will then be crushed and loaded onto the conveyors (McCarthy 2011; Mohammadi *et al.* 2011). Therefore, only the AHD from the mining face to the in-pit crusher is considered in the SMIPCC sizing, whereas the entire route is considered for the conventional model. In Figure 1, the AHD node indicated by [1] is subject to change based on the material transport alternative selected. The output nodes, indicated by [2], can be determined by using a rule of thumb based on the required truck units of one bulldozer for every 20 trucks and one motor grader for every 15 trucks, with a minimum of one unit in both cases.

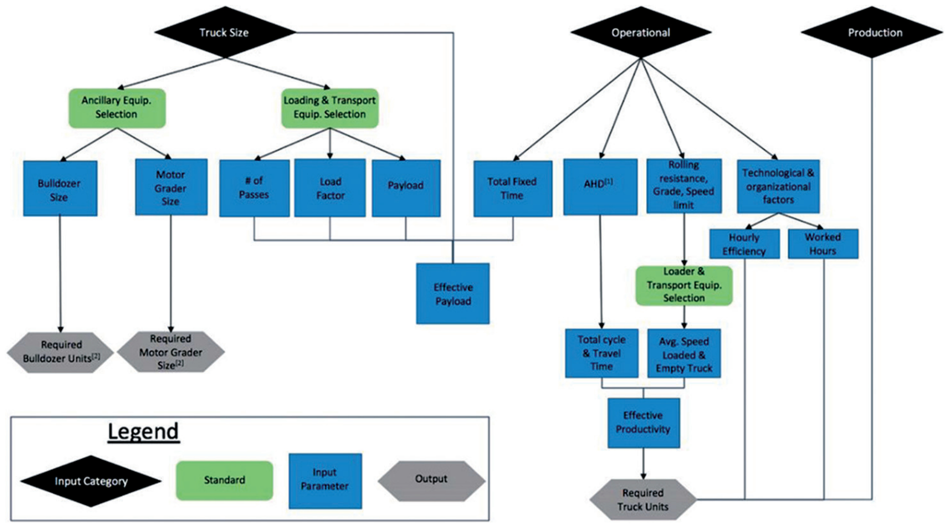

Figure 1
Fleet sizing flowchart.

The conveyor's characteristics, such as the width, the power of the required motor, and the data to calculate the SMIPCC installation costs, are selected based on the material characteristics and operating parameters, such as the P80 for the primary crusher, and the mine production data (Osmetti et al. 2012; Bertinshaw *et al.* 2012) (Figure 2). Also in Figure 2, refer to Osmetti *et al.*, (2012), and Bertinshaw *et al.*, (2012), for three of the input parameter nodes, [3], in order to determine the conveyor dimensioning.

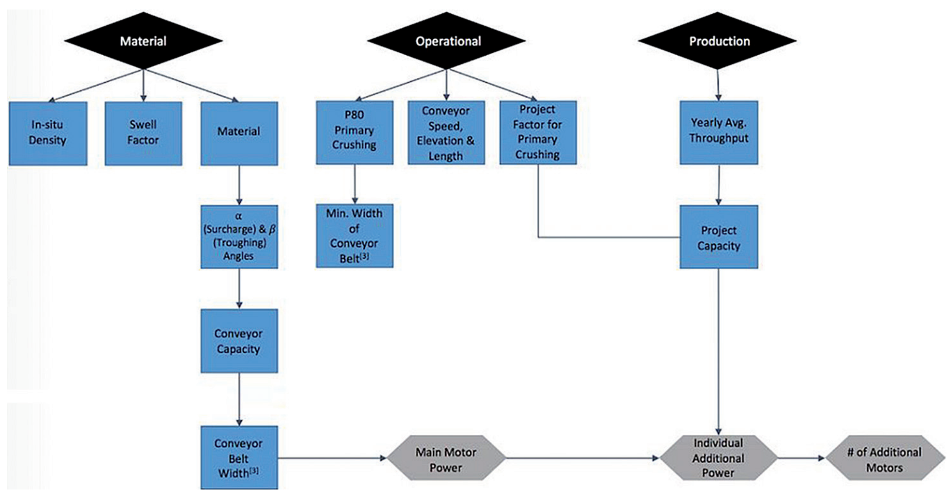

Figure 2
Conveyor sizing flowchart.

The economic analysis of the mine for the two alternatives is performed considering these inputs. All the costs are included in this analysis and are separated into capital expenditure (CAPEX) and operating expenditure (OPEX) throughout the life of the mine (LOM). The costs are brought to the present value based on the discount rate(s) selected, resulting in the net present value of the cost (NPC) (Figure 3).

Using the discount rate when evaluating mining projects serves the same purpose as it does when evaluating projects in other fields: it considers the time value of money and the project risk (Ataee-Pour *et al.* 2009). Since each project involves a different set of risks, the discount rates analyzed in each one will be different. Product standards for nodes [4] are used for the input parameters. These standards were based on the truck cost, freight cost, and the import tax associated to it. In addition to the discount rate and the LOM, the total OPEX for the conveyor [5] also considers relocating the in-pit crusher and the cost of the conveyor's electricity consumption.

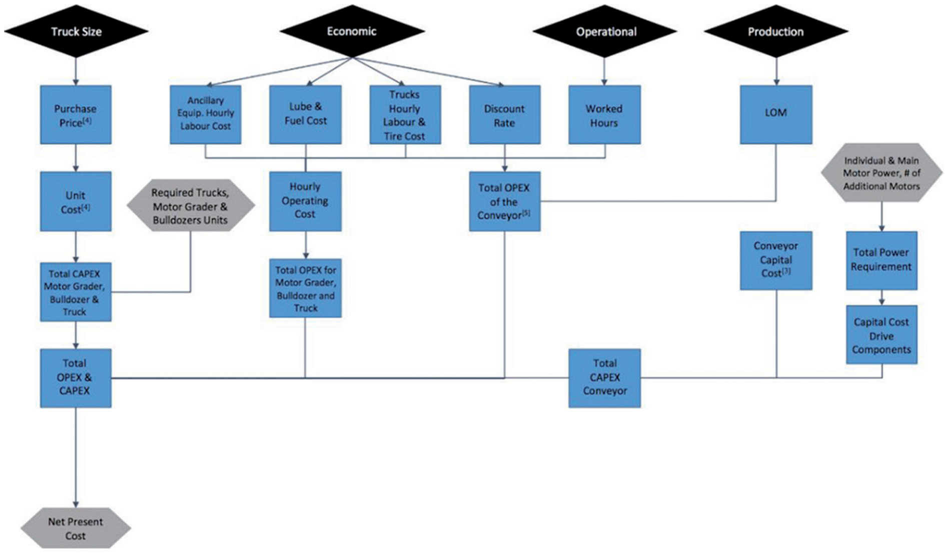

Figure 3
Economic analysis flowchart.

The model also proposes a comparison of each scenario's environmental analysis on gas emissions. Based on the previously sized fleet, the amount of equipment and the type of engine is assessed and the tonnage of gasses emitted during the LOM is calculated based on the EPA`s Tier 4 Standard (US EPA 2004). The gasses being analyzed are the following: carbon monoxide (CO), non-methane hydrocarbons (NMHC), nitrogen oxides (NOx), and particulate matter (PM) (Figure 4).

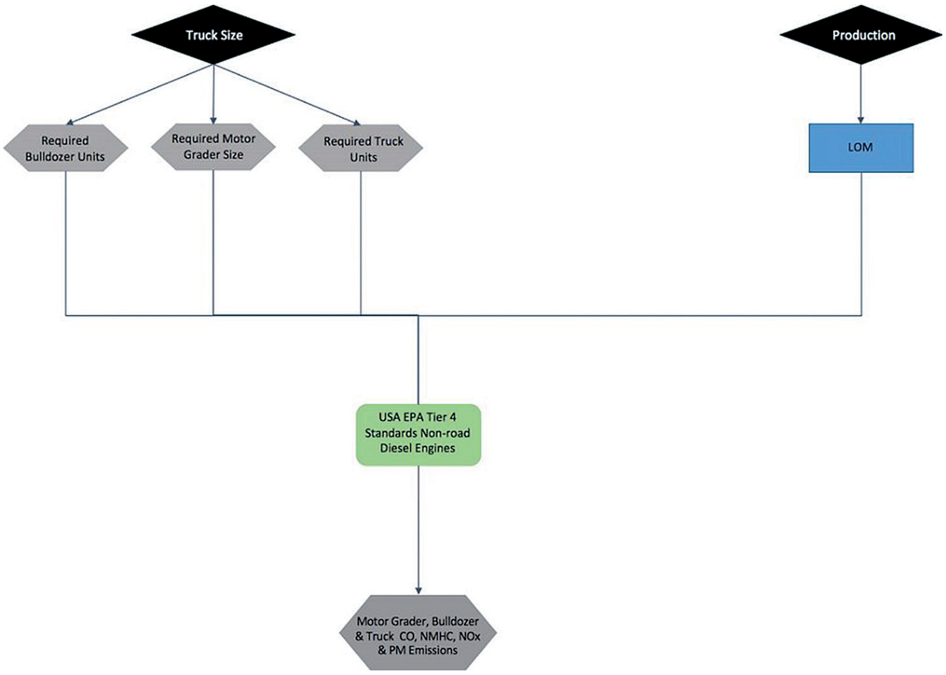

Figure 4
Environmental analysis flowchart.

3. Results

Data from a Brazilian copper-gold mine was used for this analysis. This study was implemented for a FEL-1 based on the Project Management Body of Knowledge (PMI 2013). This decision-making process can be applied to any open pit mining project, as long as the specifications for each project are incorporated.

The life of mine was set as 20 years with an annual production of 16 million tons using 150-short ton trucks (Table 1). The AHD for the two alternatives was 1.6km. In the case of the SMIPCC scenario, the trucks travel 0.5km from the mining face to the in-pit crusher (IPC), and then for the next 1.1km, the material is transported by the conveyor to the transfer chute. In the conventional scenario, the trucks travel the entire 1.6km along the ramp that closely follows the conveyor's profile, to a crusher that would be located near the indicated transfer chute in Figure 5.

Truck size	[short tons]	150
LOM	[years]	20
Estimated Throughput	[Mt]	16
Material		Copper ores, crushed

Table 1
Production parameters.

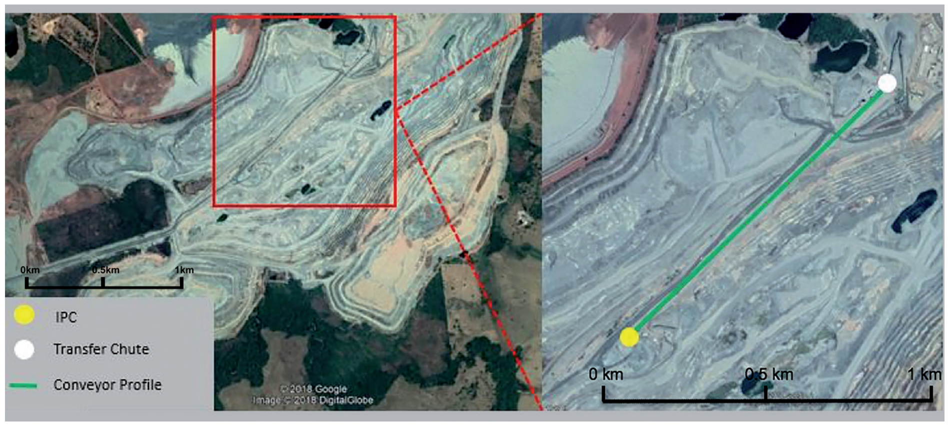

Figure 5
Location of the SMIPCC alternative (Source: Google Earth).

The inputs considered for the decision-making model were created using Excel and VBA Macro and are summarized in the table below (Table 2). The calculated fleet sizes for both alternatives are listed in Table 3.

INPUTS					
TRUCKS			EXCAVATORS		
Selected Truck	short tons	150	Bucket Size	m^3	14
	model	785D	Payload	t	38
Max. Speed	km/h	40	Fill Factor	%	85
RESISTANCES			OPERATING PARAMETERS		
Rolling Resistance	%	3	Working days / year	days	365
Grade Resistance	%	8	Shifts	shifts/day	3
Total Resistance (Flat)	%	3	Hours per shift	hrs/shift	8
Total Resistance (Uphill)	%	11	Availability	%	84
Total Resistance (Downhill)	%	11	Utilization	%	80
ORE PARAMETERS			Efficiency	%	83
Density	t/m^3	2.7	Hours per year	hrs/yrs	5887
Swell Factor	%	40	ECONOMIC PARAMETERS		
Moisture content	%	5	Annual Discount Rate	%	5
PRIMARY CRUSHING PARAMETERS			Exchange Rate	R$/US$	3.25
Required Nominal Capacity	t/h	2718	CF-CIF+Import Tax+ Custom Clearance	%	30
Design Safety Factor	fixed	1.4	OPEX		
Required Project Capacity	t/h	3805	Electricity Cost	US$/MWh	73.6
Estimated P80 - approx. 80% fines	mm	250	Diesel Cost	US$/l	0.7
CONVEYOR			Lubrication Cost	US$/l	0.1
Average velocity	m/s	3.5	Tire Cost	US$/h	68
Motor Efficiency	%	95	Labour Cost	US$/h	63.5

Table 2
Model Input Parameters for the study case.

Required Fleet Sizing		
Equipment	Conventional	SMIPCC
Trucks	8	3
Excavators	2	2
Graders	1	1
Bulldozers	1	1
Conveyor	0	1

Table 3
Required fleet Sizes for each alternative.

The cost values for the mine were obtained by complementing the above data from the previous two tables with the initial data from the mine (Table 4). A noticeable difference in the initial CAPEX (before year 3) is that the SMIPCC installation is approximately 60% higher than the conventional scenario. This is due to the high installation cost of the crusher and conveyor belt.

However, the sustaining CAPEX (after year 3) for the conventional alternative is more than two times greater than that of the SMIPCC, due to the need for fleet replacement. Furthermore, when considering the OPEX, for the conventional case without including the discount rate, it is about 43% greater than that of the SMIPCC because of high maintenance costs, tires, fuel, and labour.

Thousands		Conventional	SMIPCC
Initial CAPEX - Before Year 3	[US$]	$28,893	$46,966
Sustaining CAPEX – After Year 3	[US$]	$43,244	$18,534
OPEX	[US$]	$190,313	$107,959
NPC @ 5% discounted rate	[US$]	$174,619	$126,230

Table 4
Economic results.

The net present cost (NPC) is an important factor for a project. In this study, five different discount rates were taken into account, which expanded the possible number of scenarios. The considered discount rates were 0.0%, 2.5%, 5.0%, 7.5%, and 10.0%. The values obtained from using a discount rate of 5% are presented above (Table 4). Table 4 shows that the NPC for the conventional alternative is about 50 million dollars more expensive than using the semi-mobile IPCC. When considering the total cost per ton (CAPEX & OPEX), the SMIPCC has a value of almost 34% lower than that of the conventional alternative (Table 5).

		Conventional	SMIPCC
CAPEX&OPEX	[US$/t]	$0.82	$0.54
CAPEX	[US$/t]	$0.23	$0.20
OPEX	[US$/t]	$0.59	$0.34

Table 5
Cost per ton.

The results of the environmental analysis were also very insightful. During the LOM, when opting for only using trucks, the carbon monoxide emissions are more than double that of the SMIPCC alternative. The additional emissions are due to the high number of trucks required for the conventional trucking compared to the SMIPCC. For the examined mine, eight trucks are needed for the strictly trucking alternative, whereas when using the SMIPCC, only three trucks are needed. Therefore, the results also corroborate that the IPCC alternatives are also a means of reducing carbon emissions (McCarthy 2011; Cooper and Turnbull 2009).

		Conventional	SMIPCC
CO - Carbon Monoxide	[t]	3,586	1,516
NMHC – Non-methane Hydrocarbons	[t]	195	82
NOx - Nitrogen Oxides	[t]	3,344	1,274
PM - Particulate Matter	[t]	39	16

Table 6
Environmental analysis.

4. Discussion

The expected result of the decision-making method presented was to conclude on which alternative should be selected while considering the proposed parameters, the OPEX, the CAPEX, the NPC, and the environmental analysis. Achieving this result was successful. The evaluation method allowed for a broader view of the importance of such variables in the decision-making process. In the discussed case, the SMIPCC alternative resulted in a lower sustaining CAPEX and OPEX, as well as a lower cost per tonne as compared to the conventional alternative. There were also environmental benefits from using the SMIPCC system: the amount of carbon monoxide, non-methane hydrocarbons, nitrogen oxides, and other particulate matter was reduced. The economic, operational, and production data of the initial study were compared for both transportation systems (conventional and SMIPCC), which exposed the pros and cons of each one and allowed the company to improve data interpretation so they could make an informed decision on whether or not to continue to the next project phase. In the case of the studied mine, the SMIPCC was the more viable method considering the net present value and the lower costs and gas emissions. Even though the production is not extremely high, nor is the AHD very long, there was still a noticeable difference in costs.

5. Conclusion

The method presented is meant to be used for a conceptual study level (FEL-1). By using the proposed decision-making method, it is possible to identify the projects that have the potential for SMIPCC implementation without necessarily spending a large amount of time, which can be expensive and wasteful. Therefore, it enables mining companies to shift their focus to the alternatives that continue to show potential for further in depth studies. In general, IPCC installation is an attractive option due to its lower sustaining CAPEX and OPEX. After evaluating the decision-making model for the specific case treated, the sustaining CAPEX is approximately halved, and the OPEX is 34% lower. However, due to the high initial cost of installing the SMIPCC, which in this case is seen to be 60% higher, installation is only feasible when there is a long mine life. In addition, if the mine has a small AHD and/or low production, the IPCC is not very appealing because the initial

CAPEX may not be paid back during the LOM. In this particular case, the haulage distance and mine life are sufficient to notice a 0.28$/t decrease in total expenditure. Savings are not solely restricted to the costs; there are also noticeable environment benefits. For the discussed case, carbon monoxide emissions drop 58% when using the SMIPCC scenario. Later, the miner moved to a feasibility study and detailed design phases and the SMIPCC is now installed and in operation at the site.

References

ATAEE-POUR, M., IRANNAJAD, M., TAHERI, M. Risk-adjusted discount rate (RADR) estimation for evaluating mining projects. ***The Finsia Journal of Applied Finance.*** Jassa, n. 4, Winter, p. 36-42, 2009.

BERTINSHAW, R., ROBINSON, N., TURNBULL, D., WOODWARD, V. Surface mining. In: NOAKES, M., LANZ, T. (Ed.). Cost estimation handbook. (2. ed.). Victoria, Australia, ***The Australasian Institute of Mining and Metallurgy,*** p. 100-125, 2012.

COOPER, A., TURNBULL, D. In-pit crushing and conveying (IPCC) – a tried and tested alternative to trucks. ***Proceedings of the New Leaders' 2009.*** Melbourne, Australia: The Australasian Institute of Mining and Metallurgy, 2009. p. 59-66.

DEAN, M., KIZIL, M. S., KNIGHTS, P., NEHRING, M. Selection and planning of fully mobile ipcc systems for deep open-pit metalliferous applications. In: INTERNATIONAL FUTURE MINING CONFERENCE, 3. ***Proceedings...*** AusIMM, p. 219-225, 2015.

HUSTRULID, W., KUCHTA, M., MARTIN, R. ***Open pit mine planning and design.*** (3. ed.). CRC Press, Taylor and Francis Group, 2013. 1308p.

LONDOÑO, J. G., KNIGHTS, P. F., KIZIL, M. S. Modelling of in-pit crusher conveyor alternatives. ***Mining Technology,*** v. 122, n. 4, p. 193-199, 2014.

MCCARTHY, R. In-pit crushing and conveying: fitting a square peg in a round open pit. ***Proceedings CIM Montreal 2011.*** Montreal, Canada: Canadian Institute of Mining, Metallurgy and Petroleum, 2011.

MOHAMMADI, M., HASHEMI, S., MOOSAKAZEMI, F. Review of in-pit crushing and conveying (IPCC) system and its case study in Copper Industry. In: WORLD COPPER CONFERENCE, 1. ***Proceedings...*** 2011.

NEHRING, M., KNIGHTS, P. F., KIZIL, M. S., HAY, E. A Comparison of strategic mine planning approaches for in-pit crushing and conveying, and Truck/Shovel Systems. ***International Journal of Mining Science and Technology,*** v. 28, n. 2, p. 205-214, 2018.

OSMETTI, R. J., ARBUTHNOT, I., ELVISH R. D. Beneficiation – materials handling. In: NOAKES, M., LANZ, T. (Ed.). Cost estimation handbook. (2. ed.). Victoria, Australia, ***The Australasian Institute of Mining and Metallurgy,*** p. 299-305, 2012.

[PMI] Project Management Institute. PMBOK Guide and Standards PMI. A Guide to the Project Management Body of Knowledge – PMBOK. (5. ed.). 2013.

RAHMANPOUR, M., OSANLOO, M., ADIBEE, N., SHIRAZI, M. A. An approach to locate an in pit crusher in open pit mines. ***International Journal of Engineering (IJE),*** v. 27, n. 9, p. 1475-1484, 2014.

RIBEIRO B. ***Estudo de viabilidade econômica para a implantação de correias transportadoras de rom de minério de ferro. Estudo de Caso da Mina Fábrica em Congonhas, Estado de Minas Gerais.*** Ouro Preto (MG): Federal University of Ouro Preto, 2013. 81 p. (Master's Thesis in Portuguese).

RITTER, R., HERZOG, A., DREBENSTEDT, C. Automated Dozer Concept Aims to Cut IPCC Downtime. E&MJ, p. 52-55, 2014.

[US EPA] United States Environmental Protection Agency Guidelines – Tier 4 Emission Standards – Nonroad Diesel Engines. May, 2004.

Received: 21 July 2018 - Accepted: 7 November 2018.