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A feasibility study of surface miner

Estudo de viabilidade utilizando minerador contínuo

Estudio de factibilidad utilizando minero continuo

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Abstract

Due all of the challenges faced for feasible mining, new technologies, software, mining equipment, and ore processing are constantly being developed by equipment manufacturers. The focus of this article is to present the premises necessary for the possible applications within the mining industry of the Continuous Surface Miner – a machine currently being used in coal and phosphate mining operations and being evaluated for its incorporation in other diverse mining projects. This article demonstrates the utilization of this equipment in the field of mineral engineering and how a study should be conducted for its application. Continuous Surface Miner compared to the traditional mine equipment, due to the underestimated productivity of the material to be cut demand a higher availability of equipment fleet. The results of the feasibility study show that the use the continuous surface miner did not present itself to be a better option for the mine equipment.
Keywords: Mining equipment; Continuous surface miner; Feasibility study; Iron ore mine.

Resumo

Devido todos os desafios encarados para a viabilizar uma operação de mina, novas tecnologias, softwares, equipamentos de mineração e processamento de minério estão sendo constantemente desenvolvidos pelos fabricantes de equipamentos. O foco deste artigo é apresentar as premissas necessárias para as possíveis aplicações dentro da indústria de mineração do Minerador Contínuo, máquina atualmente em uso nas operações de mineração de carvão e fosfato e sendo avaliada para sua incorporação em outros diversos projetos de mineração. Este artigo demonstra a utilização deste equipamento na área de engenharia mineral e como deve ser realizado um estudo para sua aplicação. O Minerador Contínuo em comparação com os equipamentos tradicionais de mina, devido à produtividade subestimada do material a ser cortado demanda uma maior disponibilidade da frota de equipamentos. Os resultados do estudo de viabilidade mostram que o uso do minerador contínuo não se apresentou como uma melhor opção para o equipamento da mina.
Palavras–chave: Equipamento de lavra; Minerador contínuo; Estudo de viabilidade; Minério de ferro.

Resumen

Junto con todos los desafíos para la minería factible, los fabricantes de equipos desarrollan constantemente nuevas tecnologías, software, equipos de minería y procesamiento de minerales. El enfoque de este artículo es presentar las premisas necesarias para las posibles aplicaciones dentro de la industria minera del Continuous Surface Miner, una máquina que actualmente se utiliza en operaciones de minería de carbón y fosfato y que está siendo evaluada para su incorporación en otros proyectos mineros diversos. Este artículo demuestra la utilización de este equipo en el campo de la ingeniería de minerales y cómo se debe realizar un estudio para su aplicación. El Surface Miner continuo en comparación con los equipos mineros tradicionales, debido a la subestimación de la productividad del material a

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cortar demanda una mayor disponibilidad de flota de equipos. Los resultados del estudio de factibilidad muestran que el uso del minero continuo de superficie no se presentó como una mejor opción para el equipo de la mina.
Palabras clave: equipo de minería; minero de superficie continua; estudio de factibilidad; mina de mineral de Hierro.

1. Introduction

Surface miners were developed in the mid-70s improving the design concept of the road milling machine that was popularly used to cut the old road surface during road construction (Dey & Bhattacharya, 2012) and their use has gained popularity since the 1990s, with improved cutting drum design and higher engine power leading to more efficient machines. These improvements have enabled operators to excavate rock in a more eco-friendly and economical manner (Origliasso et al., 2014). The surface miner essentially comprises a cutting unit, disposing unit (windrowing/conveyor loading) and propelling unit (Dey & Ghose, 2011). Some of the commercially available surface miners are listed in Table 1 along with their specifications(Prakash et al., 2013). Based upon the cutting principle, a surface miner can be categorized as a *multi-bucket cutting drum located in front of the machine* (e.g. Krupp Surface Miner), as a *bucketless cutting drum positioned either in front of the machine* (e.g. Vermeer Surface Miner) or in between *front and rear crawler* (e.g. Wirtgen Surface Miner).

Table 1 - Major specifications of some commercially available surface miners.

Parameters		Drum width	Machine power	Operating weight	Rated capacity	Maximum cutting depth	Maximum cutting speed	Operating gradiente
		m	kW	ton	m^3/h	mm	m/min	%
Wirtgen GmbH	SM2100	2.0	448	41	550	250	25	6
	SM2200	2.2	671	49	668	350	84	6
	SM2500	2.5	783	100	845	600	25	7
	SM3500	3.5	895	137	1900	470	25	12
	SM4200	4.2	1194	184	2400	600	20	5
Vemeer	T855	2.5	281	40.8	NA	812	28	NA
	T955	3.4	309	56.7	NA	812	20	NA
	T1055	3.4	317	61.2	NA	812	16	NA
	T1255	3.7	447	99.8	NA	610	12	NA
L&T	KSM223	2.2	597	NA	NA	350	83	8
	KSM304	3.0	895	100	NA	400	20	5
TAKRAF GmbH	MTS180	3.3	500	NA	180	700	NA	NA
	MTS300	4.0	750	NA	300	875	NA	NA
	MTS500	4.9	1650	NA	500	1050	NA	NA
	MTS800	5.6	2000	NA	800	1225	NA	NA
	MTS1250	6.5	2500	NA	1250	1400	NA	NA
	MTS2000	7.4	2500	NA	2000	1575	NA	NA
Bitelli	SF202	2.0	515	43	180	250	NA	NA

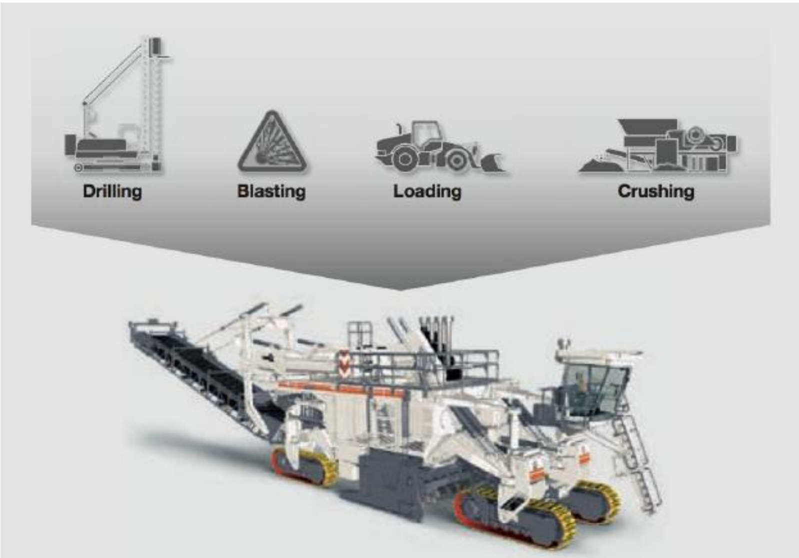
Source: Dey & Bhattacharya (2012).

Surface miner is a compact equipment that simultaneously cuts, crushes and loads the material (Figure 1). These advantages include: selective mining, improved productivity, ability to work close to the habitat/agricultural fields, environment-friendly, reduced noise emission, reduced fugitive dust emission, total elimination of ground vibration, no drilling and blasting, no fly rocks, no secondary blasting/breaking of boulders, stable, clean surfaces and benches, improved overall availability of the system, reduced operating cost, leading to easier coordination and process planning during planning, dispatching and maintenance; enhanced ROM-quality(Queiroz et al., 2020). Improved exploitation of the deposit, reduced processing after mining required, primary crushing stage can be omitted and gentle loading of trucks due to sized material, low investment costs in comparison to the range of equipment necessary for conventional mining, low operating costs due to less equipment and less personnel, cuts steep and stable surfaces and embankments (better exploitation), precise cutting of designed profiles (slopes, surfaces) and improved safety(Prakash et al., 2013; Silva et al., 2020).

A surface miner, however, has some major limitations, which should be considered before adopting the equipment. These limitations include a performance largely dependent on the length of cut area. The significant influence of the abrasivity on the cost of excavation lead to decrease performance due the increase in the rock strength(Kumar et al., 2020).

Despite the great accomplishments in mining technology over the last quarter century, mining methods and equipment applications have not radically changed. The progress has been mostly evolutionary, not revolutionary(Campos et al., 2022). And, although the use of the surface miner in different coal, limestone, gypsum, lignite, salt, phosphate, bauxite and iron ore projects is common and established today, this is not true in Brazil. The focus of this article is to present a design of the premises necessary for the possible applications of surface miners in an iron ore mine located in the Quadrilátero Ferrífero, Minas Gerais State, Brazil and conduct a feasibility study of using surface miner in an iron ore mine compared with using the traditional shovel and truck equipment.

Figure 1 - A single operation instead of four with the Wirtgen 4200 SM surface miner.



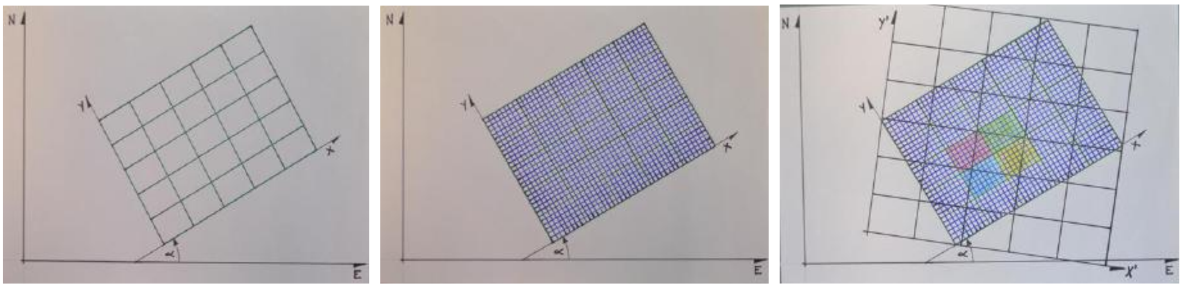
Source: http://www.wirtgen.de/pt/gama-de-produtos/mineradoras-de-superficie/media/surface_miner_infomaterial.php.

Continuous miner as shown on Figure 1 execute drilling, blasting, loading and crushing. This equipment can substitute a range of equipment, saving money and operational time.

2. Methodology

From an real block model, accepted are all of the definitions assumed during the construction phase of the model, which could be rotated and sub-divided. Figure 2 shows an example of this model whose principal axes X and Y are rotated from an alfa angle in relation to their geographic axes N and E (Dirkx et al., 2018).

Figure 2 - Original Block Model – Pixel Block Model – Block Model of the Project.



Source: Authors.

From the Original Model, a Pixel Model is created – a minutely sub-divided block model.

These minute blocks receive their attributes (lithology, density, content, etc.) from their overlapped location in the Original Model. A Project Model is then created with the dimensions of the blocks and the directions of the lines/columns of the format that are compatible with the intended mining strips, assuming or not a rotation different from the Pixel Model. Each block of the Project Model is composed of centroids corresponding to the blocks in the Pixel Model(Birch, 2019). From a block model established for conventional mining (shovel and trucks), a second model was created with blocks for strip mining using a surface miner. For comparison purposes, all steps related to the evaluation of a project including pit optimization, mining schedule and fleet sizing were applied in the two models.

The original model adopted herein came from the Galinheiro Mine. This mine was chosen in function of the rock typology and the stratigraphic units present in the region, as per a study performed in 2011 for the utilization of a surface miner (Singh et al., 2020). For each lithology, their respective unconfined compressive strength were determined. All of those studied were removed by the surface miner. It was estimated that in the case of dolomite (75 Mpa) and shale (90 Mpa), both with a solid structure, performance for their cutting would be poor. The principal information of the Original Block Models is presented in Table 2.

Table 2 - Original Block Model for Galinheiro Mine**.**

Galinheiro Model	Value
Max. Block Dimension X (m)	50
Min. Block Dimension X (m)	10
Max. Block Dimension Y (m)	50
Min. Block Dimension Y (m)	10
Max. Block Dimension Z (m)	50
Min. Block Dimension Z (m)	10
Number of Blocks	3930835
Blocks in X	106
Blocks in Y	56
Blocks in Z	20
Sub-Blocks in X	530
Sub-Blocks in Y	280
Sub-Blocks in Z	100
Chermical Variables	Fe, SiO_2, Al_2O_3, Mn, Lost Fire
Granulometric Variables	G1(+6.3 mm), G2(-6.3, +1 mm), G3(-1 + 0.15 mm), G1(-0.15 mm)

Source: Authors.

Besides the variable that identifies the lithology in the Original Block Models, there is also a TIPON variable that identifies the types of ores that will feed the plants in each process route as shown in Table 3.

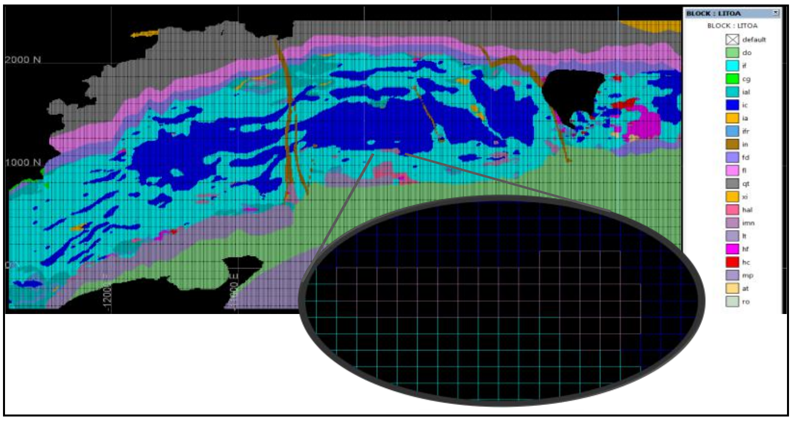
Table 3 - Ore Type Classification.

Code	Description
1	Friable and semi compacted itabirite separated by cut-off for ITM1
2	Friable and semi compacted itabirite separated by cut-off for ITM5
6	Hematites

ITMI: Plant for friable and average itabirites – final product: *Sinter Feed* e *Pellet Fine Feed*.
ITMS: Plant for ITMI cut-off itabirites – final product: *Pellet Fine Feed*.
ITM dry: Plant for hematites – final product: *Sinter Feed*.
Source: Authors.

The Original Block Model with irregular blocks was imported to the Vulcan 9.00 64-bit software, creating a Pixel Model, where the original blocks were sub-divided for minimum dimensions of 10x10x10 m(Pysmennyi et al., 2022). Figure 3 illustrates the lithologies present and the dimensions of the blocks, which can be observed in detail.

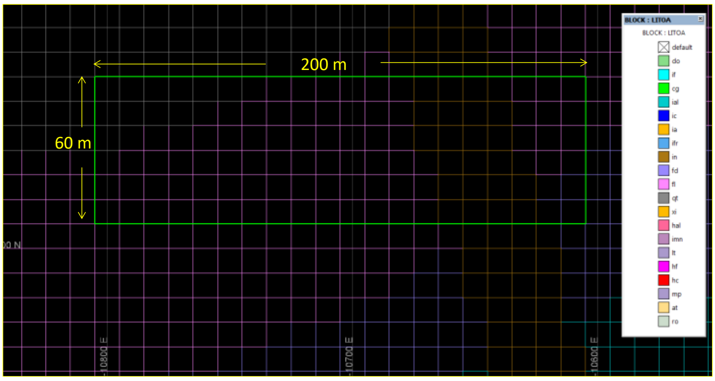
Figure 3 - Pixel Block Model for Galiheiro 10x10x10.



Source: Authors.

Important consider the high lithology variability show on Figure 3. Associated the lithology variability is possible identify horizontal trend of continuity. Considered in the Project Model were blocks with minimum operational dimensions of 200 m length, 60 m width and 10 m height, generated in Vulcan using as tools: *Block/Transfer/Perform Regularization*, followed by *Regularize Parameters*. Figure 4 illustrates the overlap of this model with the Pixel Model, where the new block (outlined in green) encompasses various different types of lithology(Zhao et al., 2022). These are the minimum dimensions for the operation of a surface miner with lateral loading of the truck.

Figure 4 - Project Model block dimensions.



Source: Authors.

As the TIPON variable characterizes the products to be generated and brings together various lithologies, simplifying the model, the creation of new variables for tonnage was considered. Quality variables was also considered for the different types of ores that feed the plants. With these variables, the model has all of the parameters necessary to feed the software for pit optimization (Table 4).

Table 4 – New Variables – 10x10x10 m Pixel Model.

Variable	Description	Plant	Product	Type
tone_itmi	friable and semi compacted itabirite tonnage	ITMI	sinter & pellet	1
tone_itmip	friable and semi compacted itabirite tonnage	ITMI	pellet	1
tone_itmis	friable and semi compacted itabirite tonnage	ITMI	sinter	1
tone_itms	friable and semi compacted itabirite tonnage	ITMI	sinter	2
tonne_waste	waste material tonnage	ITMS	sinter	6
fegl_s	global iron content	ITM (Dry)	sinter	3,4,5,7,13,23,63,73
fegl_d	global iron content	ITMS	sinter	2
rec_itmip	metalic recovery	ITM (Dry)	pellet	6
rec_itmis	metalic recovery	ITMI	sinter	1
rec_itms	metalic recovery	ITMI	pellet	1
bon_pel_itmi	bonus/penalities	ITMI	pellet	2
bon_pel_itms	bonus/penalities	ITMS	pellet	1
bon_pel_itmd	bonus/penalities	ITM (Dry)	sinter	2
bon_pel_itmi	bonus/penalities	ITMI	sinter	6

Source: Authors.

The variables created for the Project Model were calculated according to the following criteria:

I. Mass variables : total mass contained in the pixelated blocks

II. Quality variables : weighted average of the variable contained in the pixelated blocks

III. Geotechnical variable : dominant variable in the contained blocks

IV. Recovery variables : weighted average of the variable contained in the pixel blocks

Table 5 shows the cubage comparison of the original models and the project one for verification of the consistency of the Project Model.

Table 5 – Comparison of the two Models.

New Variables	Original Model	Project Model	
	A	B	(A-B)/A
Tons ITMI Sinter Feed	21,811,755.00	2,188,755.00	0%
Tons ITMI Pelled Feed	42,088,715.00	42,088,715.00	0%
Tons ITMS Pelled Feed	1,027,207,870.00	1,027,207,870.00	0%
Tons ITMD Sinter Feed	109,626,880.00	109,626,880.00	0%
Fe2	58.92	59.24	-0.6%
Fe3	49.04	49.19	-0.3%
Fegl_s	42.71	42.90	-0.4%
Fegl_d	66.33	65.69	1.0%

Source: Authors.

Establishment of the premises for the pit optimization procedure in the *Geovia Whittle 4.5.5*, optimization software included obtaining the value of each block of the geological model, calculated from the data for the iron mass of the product contained in the block and the price for a ton of iron. The product's sale price represents the average sale price from 2013 to 2015 in the international market and obtained from the PLATTS IODEX Table. Also determined were the bonus and demerits referring to the iron, alumina, and silica content in the products. All of the costs referring to the complete productive process from the mining to the client were considered. In addition to these values, current investments, administrative/overhead and royalties/CEFEM were included.

3. Literature Revision

3.1 Continuous surface miners

According to the Ali (2022), the current technology of continuous surface miners has mining as essential advantages: no explosion, operational simplicity, high selectivity, better quality of the mined ore, robustness of the equipment, clean cut at the edges of the banks, low operating cost per ton.

MCS (Continuous Surface Miners) are used in earthworks and excavation services, as well as in road construction and rehabilitation, characterized by producing stable slopes and well-defined surfaces in fresh rock (Ali, 2022).

The continuous surface miner is a versatile machine of proven performance, capable of cutting into soft, medium and hard rock. Currently, there are several mines using this equipment in various parts of the world, especially in the USA, Russia, Australia and Bosnia, in addition to India(Prakash et al., 2013).

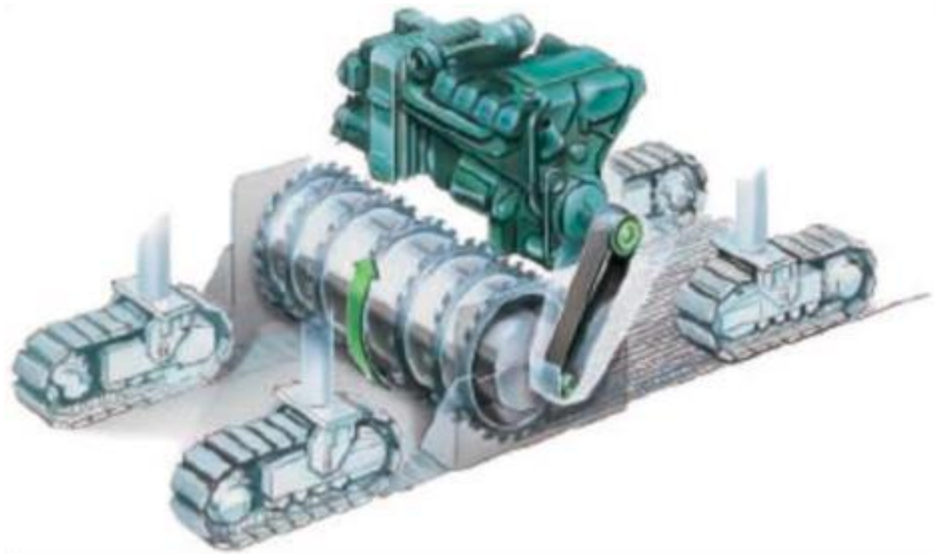
When smaller particles are directly generated by mining the cut material can be immediately used as crushed stone, making primary crushing unnecessary. Due to the particle size of the mined material, it can be loaded onto trucks without causing any damage or transported by conveyor belt without the need for primary crushing(Zamorano, 2011).

The performance, tool wear and cost-efficiency model of MCS operation are decisively dependent on the mechanical properties of the rock to be cut. Equipment manufacturers provide a simple performance x compressive strength range table of rocks that can be cut by the respective MCS.

3.2 Operation mode

Surface miners are built to mine efficiently and continuously. They are mounted on four tracks with many possibilities for speed adjustment of the rotating drum studded with the cutting tools. They are made of hard metal, they cut the material and grind it to a granulometry suitable for conveying on belts. The cutting drum rotates upwards(Raghavan et al., 2021). The cutting tools are arranged helically on the drum where they direct the fragmented material to the center of the drum, from where the material is transferred via a primary collecting belt to another secondary belt of discharge, as shown in Figure 5 (Tatiya, 2005).

Figure 5 - Center cutting drum.



Source: Authors.

The surface miners are powered by a diesel engine that efficiently drives the drum through a robust belt drive. The other systems, such as the belts and transmission chain, are hydraulically driven. In many cases the cutting drum is located in the center with a mechanical drive: The cutting drum is located in the center of the machine as shown Figure 5 between the four conveyors, close to the center of gravity of the machine(Pavloudakis et al., 2022). This ensures that the entire machine weight and installed power can be converted into cutting energy. As a result, the machine can cut hard materials with good cutting performance while maintaining its stability(Whittle, 2011).

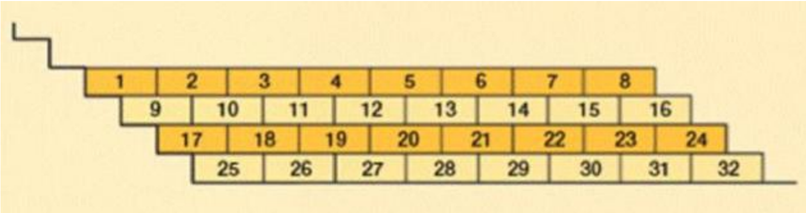
3.3 Operational sequence

Continuous miners extract material from the surface by cutting into thin layers (approximately 0.1 to 0.8 m thick). Entire deposits are mined through successive layer removals with a predetermined depth of cut.

As long as the depth of cut can be precisely defined and controlled, removing thin layers of rock or generating surfaces with pre-defined profiles are tasks generated with the same degree of precision(Souza & Melo, 2014).

The width and direction of the mined track can be determined by the direction of the miners. Slopes with a defined profile can be produced in this way, however, the minimum radius of curvature that can be mined is limited by the depth of cut and the hardness of the rock.

Figure 6 - Cutting sequence.



Source: Zha et al. (2017)

The equipment cuts the material between the ends of the pit. The cutting drum works with an upward movement, the equipment changes the cutting direction only after plowing the entire strip as demonstrated on Figure 6. The material is not cut during the return movement, that is, it travels back empty. After returning to the starting point, the machine is then adjusted for a new cut in the adjacent strip. This method is generally adopted for a mine that has a level length of less than 200 m, so that the time the equipment takes to turn around becomes longer than the empty return time.

This methodology can be applied at pit ends in poor operating conditions. Because the machine does not need to turn around at these ends or the pit width is not enough to allow the machine to turn around at the end of a cut.

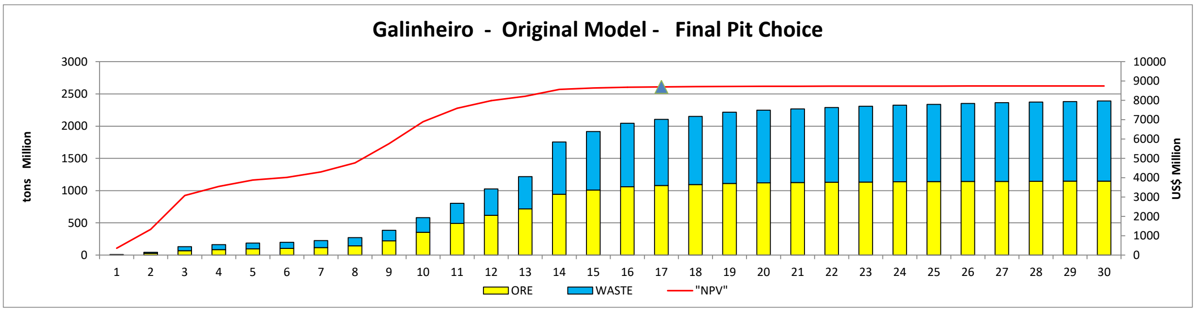
4. Results

The unitary mine costs considered for the use of the surface miner were: reductions of 30% for the total labor value, 20% for auxiliary services, and 20% for other costs in function of the decrease in number loader, excavator, and driller operators, as well as blasting teams and auxiliary equipment.

The unitary cost of a Wirtgen Model 4200SM surface miner corresponds to 5.38 higher than the value of the unitary cost of a conventional excavator/loader. This cost was estimated by the manufacturer of the equipment. Summed together with the other unitary costs of the mine, this cost summary produces an amount that is 1.25 higher than that the summary of the unitary costs of conventional mining. The primary crushing costs were not considered in the plant costs, since the cutting drum of the continuous miner already performs this first comminution of the material.

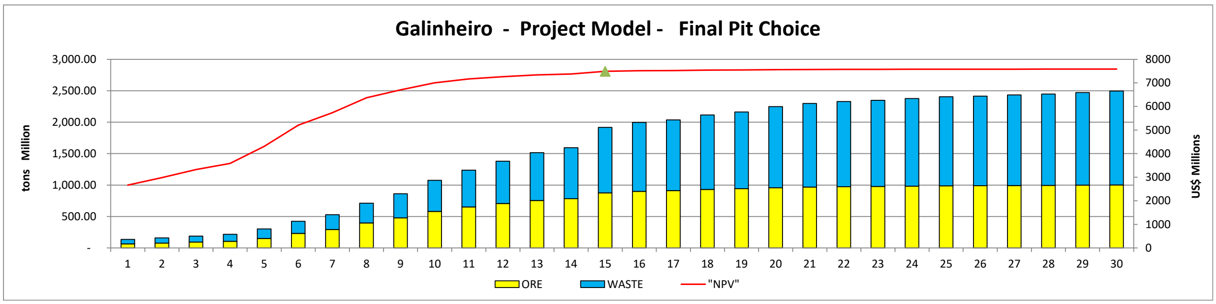
In addition to the economic and cost premises, all of the premises for the process and geotechnical parameters were fed into the software. A criterion for the maximization of “NPV” of the mine was adopted. At this stage, the capital investment was not considered, whereby only the operational costs and income from the products were considered. Figure 7 and Figure 8 depict the chosen process for the pits. Within the family of a nest of pits, the first pit that achieved a value of 99% of the “NPV” of the last pit was chosen. The process was repeated for both of the models.

Figure 7 - Pit by Pit Graph – Original Model



Source: Authors.

Figure 8 - Pit by Pit Graph– Project Model.



Source: Authors.

Table 6 shows the NPV results, the ore and waste mined, and the relationship waste/ore for the original and project models. Notice that the reserve of the Project Model presents a waste/ore relationship 25% greater than that of the Original Model. This quantity of waste reduces the ore to be mined by 14.5% and the NPV by 14% when the surface miner scenario is adopted.

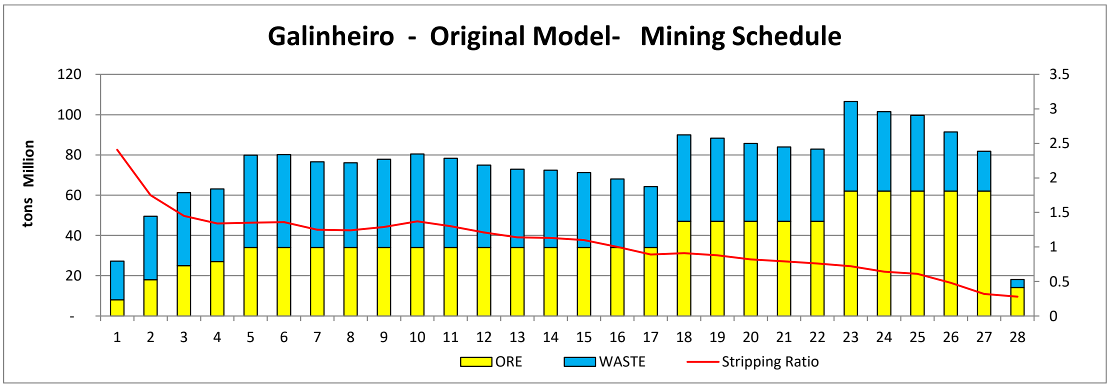
Table 6 - Comparison between final pits of the models.

Description	Unit	Original Model	Project Model	(B-A)/A
		A	B	%
NPV	M US$	9,370.89	8,025.61	-14.40%
Ore	t	1,025,278,275.00	876,489,900.00	-14.50%
Waste	t	1,079,110,615.00	1,041,063,938.00	-3.50%
W/O	t/t	0.95	1.19	25.0%

Source: Authors.

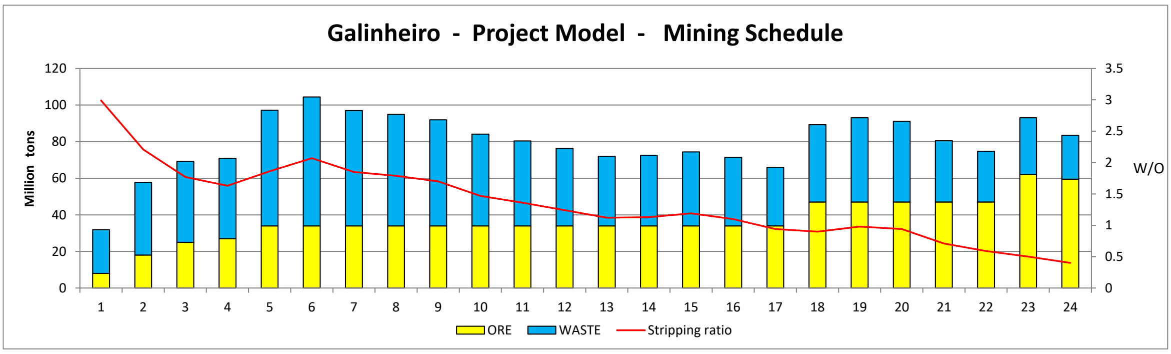
To compare the two models on the same basis, the same production scale was established for the two scenarios, based on the reserves of 2013. The mining schedule generated by *Whittle*, can be visualized in Figure 9 and Figure 10.

Figure 9 - Mining Schedule Graph – Original Model.



Source: Authors.

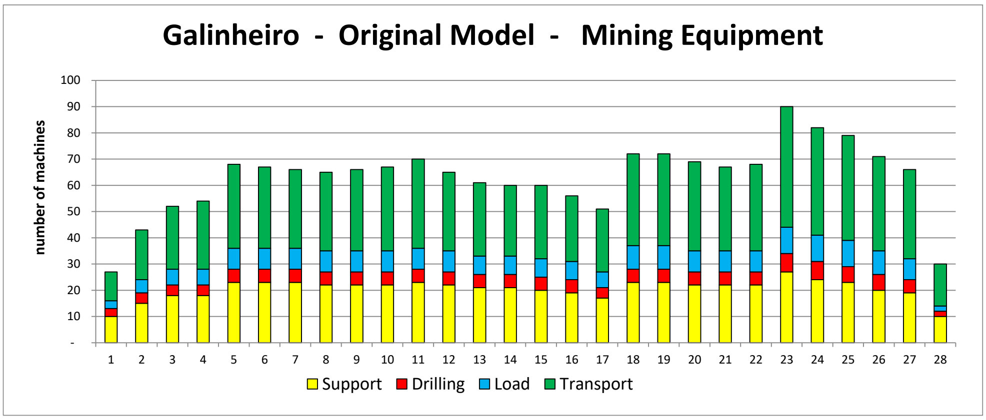
Figure 10 - Mining Schedule Graph – Project Model.



Source: Authors.

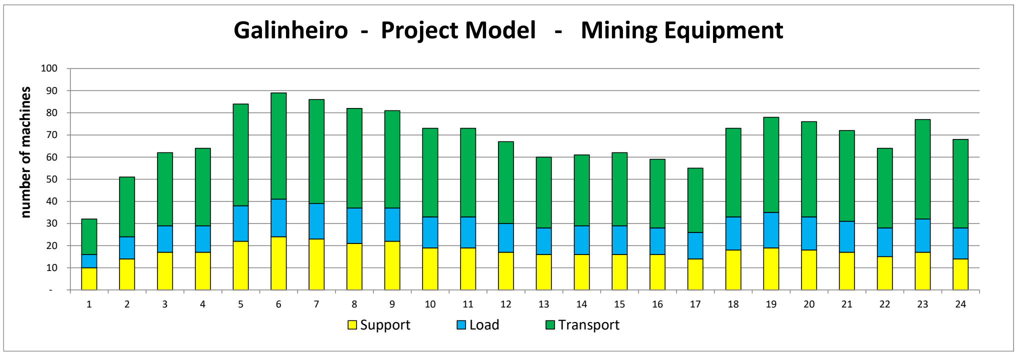
In the Project Model with the use of the surface miner, notice that there is a greater waste movement in the first years of mining, with a great impact on the cash flow. In the Original Model with the use of traditional equipment, notice the better distribution in the movement of waste year after year. With the destiny of the ITMs for each type of ore and the waste piles, the average transport distance (atd) is calculated using the *Haulage Profile* tool of the *Vulcan 9.0* software. The *software* SGDEM (System for Managing and Dimensioning Mine Equipment, was used to dimension the equipment for the fleet. Figure 11 and Figure 12 shows the results of the dimensioning.

Figure 11 - Equipment Dimensioning – Conventional Mining.



Source: Authors.

Figure 12 - Equipment Dimensioning – Surface Miner Mining.



Source: Authors.

The average productivity of the principle mining equipment utilized in the dimensioning of the fleet are presented in Table 7.

Table *7* - Average Productivity of Principal Equipment.

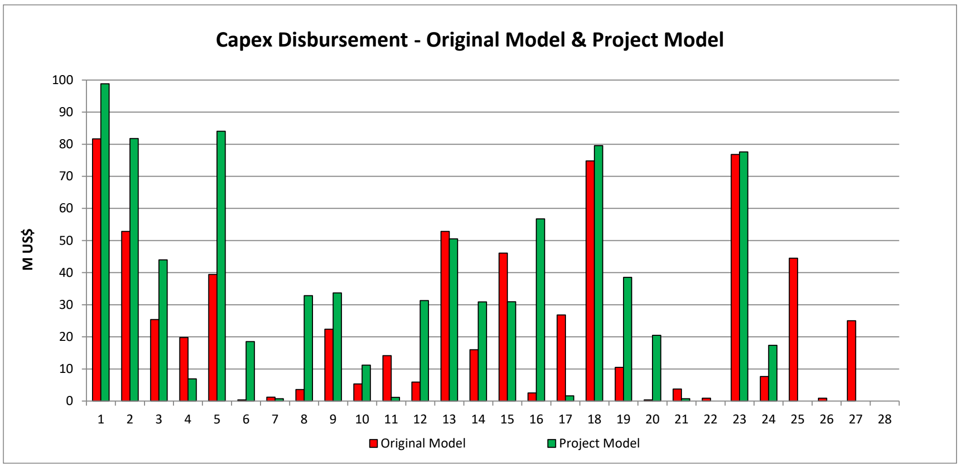
Average Productivity (t/h)		
Principal Equipment	Original Model	Project Model
Hidraulic Excavator 52t	218300	x
Continous Miner 4200 - 1600 hp	x	1068.31
Bucket Loader - 38 t	1600	1600
Truck 190 t	427.64	347.21
Crawler Driller 10 inch	2183.12	x
Crawler Driller 4 inch	1312.84	x

Source: Authors.

The estimated production for the surface miner was based on a recent study performed in Carajás, where unconfined compressive strength tests were performed on samples of cangue and estimates done for the respective products for the Wirtgen 4200SM surface miner. When correlating these productivities with the lithologies of the Project Model, the value of 1.068 t/h proved to be the average productivity of the surface miner.

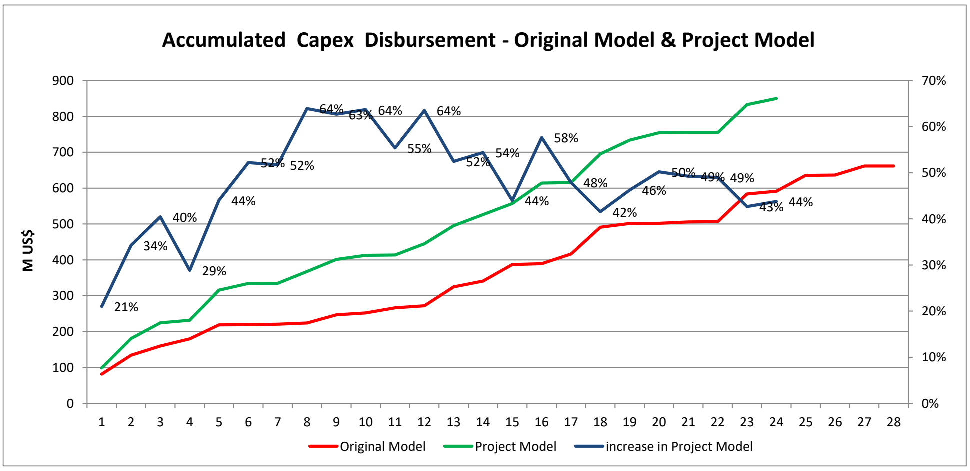
For an equivalent productivity of a hydraulic excavator, the continuous cutting velocity would have to be 12 m/min, being that for a lesser unconfined compressive strength (30 Mpa) of the lithologies present, the cutting velocity would attain 9 m/min. The Figure 12 shows the annual disbursement for Capex and Figure 13 compares the accumulated disbursement between the two models.

Figure 13 - Capex Disbursement (MUS$) – Original and Project Models.



Source: Authors.

Figure 14 - Accumulated Capex disbursement comparison between the two models.



Source: Authors.

Notice in Source: Authors.

Figure 14 that the disbursement value in the Project Model reached around 64% more than the Capex of the Original Model. This is mainly due to the high value of the continuous mining and the low productivity of the equipment for the material considered, forcing as such the acquisition of more units. In the project with *Whittle*, the Capex disbursement values were inserted in each scenario to evaluate the NPV decrease in the models. The Original Model underwent of decrease of 15.8% where there was a Capex disbursement, while the Project Model underwent a decrease of 18.2%. In other words, there was a greater impact on the total NPV due to the elevated values for Opex and Capex, inherent to the use of this equipment in the mine under consideration.

5. Conclusion

Considering block dimensions imposed by the use of the surface miner, there was a significant loss of the reserve when optimized with the Project Model; 14.5% less ore when compared with the Original Model. When using the surface miner, the reserve presented a waste/ore relationship of 1.19 t/t, around 25% greater when compared to the waste/ore relationship of 0.95 t/t presented in the Original Model; this is very significant. This relationship is greater in the first years, which negatively impacts the cash flow of the mine sequencing of the Project Model.

The option to use the continuous miner did not present itself to be a better option for the mine equipment in this study of the Galinheiro Mine, when compared to the traditional mine equipment, due to the low estimated productivity of the material to be cut, demanding a greater equipment fleet.

In future works we expect identity the economic limit of continuous miner on metallic deposits. Important consider the aim to determine cutoff grade between regular equipment and continuous miners.

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