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Determining an optimal shiftwork duration by comparative analysis of active and inactive hours in underground mining: a case study

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Determining an optimal shiftwork duration by comparative analysis of active and inactive hours in underground mining: a case study

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I dedicate this work to my family and friends, who have always supported and encouraged me to persist.

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“The cure for anything is salt water:
sweat, tears or the sea.”
Isak Dinesen

ABSTRACT

MORAES, G. R. Determining an optimal shiftwork duration by comparative analysis of active and inactive hours in underground mining: a case study. 2024. Dissertação (Mestrado) – Departamento de Engenharia de Minas e de Petróleo, Escola Politécnica da Universidade de São Paulo, 2024.

This study analyzes productive and unproductive hours throughout four shift-length scenarios at an underground mine: 6-hour, 8-hour, 10-hour, and 12-hour. Furthermore, two sub-scenarios were investigated regarding the impact of performing a single or two blasts daily. The analysis sought to comprehend differences in the number of effective working hours in a day at an underground mine. Both investigations used data from Brazil's Cuiabá Mine, Brazil's largest and deepest underground gold mine currently in operation. In the first sub-scenario, which assumes two blasts daily, the 6-hour shift resulted in an Effective Working Time (EWT) of 13 hours and 30 minutes, or 56.3% of the day. In the 8-hour shift scenario, the EWT rose to 15 hours and 20 minutes, accounting for 63.9% of the day. The 10-hour and 12-hour scenarios produced the same result, with 15-hour and 30-minute EWT taking up 64.6% of the day. Considering one blast daily, the second sub-scenario discovered that the 6-hour scenario had an EWT of 16 hours and 15 minutes (67.7%). In the 8-hour scenario, the EWT increased to 18 hours and 25 minutes daily (76.7%). The 10-hour and 12-hour scenarios had identical results, with an EWT of 18 hours and 35 minutes daily (77.4%). When the findings from each sub-scenario are compared, it is reasonable to deduce that the EWT positively correlates with shift length. The incremental step from 6-h to 8-h situations is significantly higher (7.6% for sub-scenario 1 and 9% for sub-scenario 2). EWT increases from 8-hour to 10/12-hour shifts by 0.7% for single and two blasts daily. When comparing the two sub-scenarios, halting operations for blasting once a day is the most efficient alternative in terms of EWT, with the sub-scenario with a single blast yielding an average EWT 12.5% greater than sub-scenario of two blasts daily. Reducing the frequency of blasting and revising constraints on underground mine shift duration can improve the economic viability of underground mine development.

Keywords: shiftwork, effective work time, blasting, mine utilization, underground mining.

RESUMO

MORAES, G. R. Determining an optimal shiftwork duration by comparative analysis of active and inactive hours in underground mining: a case study. 2024. Dissertação (Mestrado) – Departamento de Engenharia de Minas e de Petróleo, Escola Politécnica da Universidade de São Paulo, 2024.

Este estudo analisa as horas produtivas e improdutivas para quatro cenários de duração de turno em uma mina subterrânea: 6, 8, 10 e 12 horas. Além disso, dois subcenários foram analisados em relação ao impacto de realizar um ou dois horários de desmontes por explosivos por dia. A análise procurou compreender as diferenças no número de horas de trabalho efetivo para um dia. Ambas as análises usaram dados da Mina Cuiabá, a maior e mais profunda mina de ouro subterrânea do Brasil em operação. No primeiro subcenário, que presume dois horários de desmontes diários, o turno de 6 horas resultou em um tempo de trabalho efetivo (TTE) de 13 horas e 30 minutos, 56,3% do dia. No cenário de turno de 8 horas, o TTE subiu para 15 horas e 20 minutos (63,9%). Os cenários de 10 e 12 horas produziram o mesmo resultado, com um TTE de 15 horas e 30 minutos (64,6%). Considerando um horário de desmonte diário, o segundo subcenário encontrou que o turno de 6 horas tem um TTE de 16 horas e 15 minutos (67,7%). Para o turno de 8 horas, o TTE aumentou para 18 horas e 25 minutos diariamente (76,7%). Os turnos de 10 e 12 horas tiveram resultados idênticos, com um TTE de 18 horas e 35 minutos diariamente (77,4%). Quando os resultados de cada subcenário são comparados, é razoável deduzir que o TTE se correlaciona positivamente com a duração do turno. O aumento incremental do TTE do turno de 6h para o de 8h é o maior (7,6% para o subcenário 1 e 9% para o subcenário 2). O aumento incremental do TTE do turno de 8 horas para o de 10/12 horas é 0,7%. Este resultado é o mesmo para ambos os subcenários. Ao comparar os dois subcenários, a paralisação das operações para desmonte uma vez ao dia é a alternativa mais eficiente em termos de TTE, com o subcenário com um único horário de desmonte produzindo um TTE médio 12,5% maior do que o outro subcenário. Reduzir a frequência de desmonte e revisar as restrições sobre a duração do turno de minas subterrâneas pode melhorar a viabilidade econômica das mesmas.

Palavras-chave: trabalho por turnos, tempo de trabalho efetivo, detonação, desmonte por explosivo, utilização de mina, mineração subterrânea.

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LIST OF ACRONYMS

BIF – Banded Iron Formation

CONOS – Close-to-Continuous Operations

EWT – Effective Working Time

FIFO – Fly-In, Fly-Out

FOPS – Falling Objects Protective Structure

OHS – Occupational Health and Safety

ROPS – Roll Over Protective Structure

TTE – Tempo de Trabalho Efetivo

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1 INTRODUCTION

1.1 RESEARCH BACKGROUND

As the extraction of resources from near-surface deposits progresses, underground mines across the globe are being pushed to operate at greater depths. The expenses and duration of transporting rock masses rise as mining depths grow (STACEY; WESSELOO; BELL, 2005). The transportation of rock masses from deeper levels to the surface poses a significant problem for underground mines, namely, enhancing mined materials and decreasing production expenses (GREBERG *et al.*, 2016). The construction of ramps, tunnels, shafts, drives, or other subterranean excavations is crucial, particularly in mining, as achieving production targets is closely tied to the presence of structures that enable entry into mined areas, and these entry points are created through tunnels (SUORINENI; KAISER; HENNING, 2008). This infrastructure is essential for the mining industry as it enables access to mineralized zones and facilitates the preparation of extraction units for later mineral extraction (JUAN P. VARGAS, 2017). The excavation and production in underground mines are intricate procedures involving many distinct operations. The mine's geometry and geology significantly limit the underground mining process (SONG *et al.*, 2015). The extended duration of travel, coupled with the supplementary tasks included in the mining process, diminishes the amount of time spent directly working and could impede the achievement of a daily compliant explosion (GUMBIE, 2018). Using remotely operated equipment is becoming popular in situations requiring significant movements to enter or exit the work area and in situations that pose a greater risk to employees (SGANZERLA; SEIXAS; CONTI, 2016). Nevertheless, shifting to remote operations is intricate and expensive, requiring a significant amount of time. Therefore, although remote operations are being pursued as a long-term objective, the design of work shifts has a crucial role in defining the duration of tunnel construction and could serve as a short to medium-term tactic for enhancing productivity (SÁNCHEZ; HARTLIEB, 2020). Hence, any factor that enhances the efficiency of constructing such infrastructure will benefit mining projects. The work shift design is a critical factor in determining the duration of tunnel construction (JUAN P. VARGAS, 2017).

Traditionally, continuous shift operations were organized based on dividing the 24-hour day into three 8-hour blocks: day, afternoon, and night (FERGUSON; DAWSON, 2012). Employers implemented adjusted working time arrangements in response to rising economic incentives for capital intensification and competition for skilled labor while striving to maintain or decrease costs (STEWARD; LARSEN, 1971). The reduced workweek emerged as a significant modification to working time arrangements, driven to balance economic competitiveness and employee involvement (HUNG, 1994). Due to economic, social, technological, and societal demands, implementing a 24-hour work schedule has become increasingly prevalent (FOLKARD; MONK, 1985). The workforce must embrace and adjust to various sorts of shiftwork schedules (SCOTT; LADOU, 1990). Different shiftwork schedules are being used globally, but when we focus on the duration of shifts, we can identify common types of shift systems. These categories include multiple variations to ensure 24-hour coverage (SMITH *et al.*, 1998). Prior studies have suggested that compulsory durations of work shifts may no longer be sufficient to fulfill the necessary mining tasks (RUPPRECHT, 2018). Implementing longer shift durations and embracing close-to-continuous operations (CONOS) could be beneficial in tackling these problems (LAZARE, 2013). Shift work must be evaluated regarding its impact on occupational health and safety (OHS) and worker well-being, considering various influencing factors. The understanding of the effects of worker commuting times from the stope face and the impact of working circumstances on worker weariness is limited (PELDERS; MAGWEREGWEDE; RUPPRECHT, 2021). According to the Brazilian constitution, Article 293 of Decree Law No. 5,452, enacted in 1943, states that employees working in underground mines should not work for more than six hours per day or thirty-six hours per week (BRASIL, 2017).

Approximately 15-17% of employees in Western workforces, such as Europe, Australia, and the United States, are presently involved in regular shift work (PARENT-THIRION *et al.*, 2007). Over the past 25 years, there has been a tremendous increase and diversification of shift patterns. Shift employment in service industries has increased the range of work schedules with the heightened competition. In contrast, factory-based businesses typically consistently need labor over time (PETERS, 2019). In today's Western world, there is a wide range of working time arrangements, from traditional Monday to Friday day work to more complex 12-hour shift systems that involve continuous shifts lasting two or more weeks. Examples of such arrangements include offshore and fly-in, fly-out (FIFO) operations (TUCKER *et al.*, 1998), (PAECH *et al.*, 2010). Furthermore, within a given roster 'type' (i.e., day work, 6-hour, 8-hour, 10-hour, or 12-hour shifts), there can be significant variation associated with start times, number of consecutive shifts, the structure and frequency of the rotation, commute length, and residential circumstances during and after work. All these elements mediate the impacts of a certain shift pattern and must be considered when analyzing outcome measurements. To establish the optimal alternative, direct comparisons were made between various work shifts (FERGUSON; DAWSON, 2012). Remote operations technology is being globally developed and utilized to run equipment from a distance, particularly in high-risk scenarios. Nevertheless, accomplishing a thorough eradication procedure is a protracted and costly endeavor. To enhance underground mines' economic viability, augmenting their short-term output is crucial (FISHER; SCHNITTGER; LTD, 2012). In this study, a complete investigation of several shiftwork, i.e., 6-h, 8-h, 10-h, and 12-hr, in a deep underground mine was carried out, along with the number of blasts in a day, to identify the optimal shiftwork duration for higher production efficiency.

1.2 STUDY AREA

The Cuiabá Mine is located in the Quadrilátero Ferrífero, which is about 33km away from Belo Horizonte, the capital of the Minas Gerais state in Brazil. The Cuiabá Mine is now engaged in active mining operations, reaching a depth of 1350 meters below the surface. It has two distinct access points from the surface. The initial approach necessitates vehicles traversing drops with an average inclination of 9 degrees. These drops offer an indirect route from the surface to the underground construction locations. The second entry consists of a vertical shaft that descends from the surface to a specific location called 'Level 11', situated at a depth of 840 meters below the surface. From this point, declines are utilized to further descend to the lowest areas of the mine (PEREIRA, 2017). The Cuiabá Mine, depicted in Figure 1, holds the distinction of being the largest subterranean gold mine in Brazil. It boasts a substantial resource of 5.78 million ounces (M oz) of gold, with an impressive grade of 10.26 grams per ton (g/t). The mine possesses 1.18 million ounces (M Oz) of ore reserves and has yielded 7 million ounces (M Oz) of gold. A recent study has discovered economically important deposits of gold in shear zones within quartz-carbonate vein systems located in metamafic rocks (VITORINO; FIGUEIREDO E SILVA; LOBATO, 2020). The remarkable orogenic gold deposit is situated within the Rio das Velhas greenstone belt, known for its distinct combination of mafic volcanic rocks, banded iron formation (BIF), and metamorphosed carbonaceous and micaceous phyllites that have undergone greenschist facies metamorphism (Figure

2). The main origin of profitable gold production in Cuiabá comes from sulfide ores that contain pyrite and pyrrhotite. These ores are found within Banded Iron Formation (BIF) and are generated through a replacement-style process (BARBOSA, 2011).

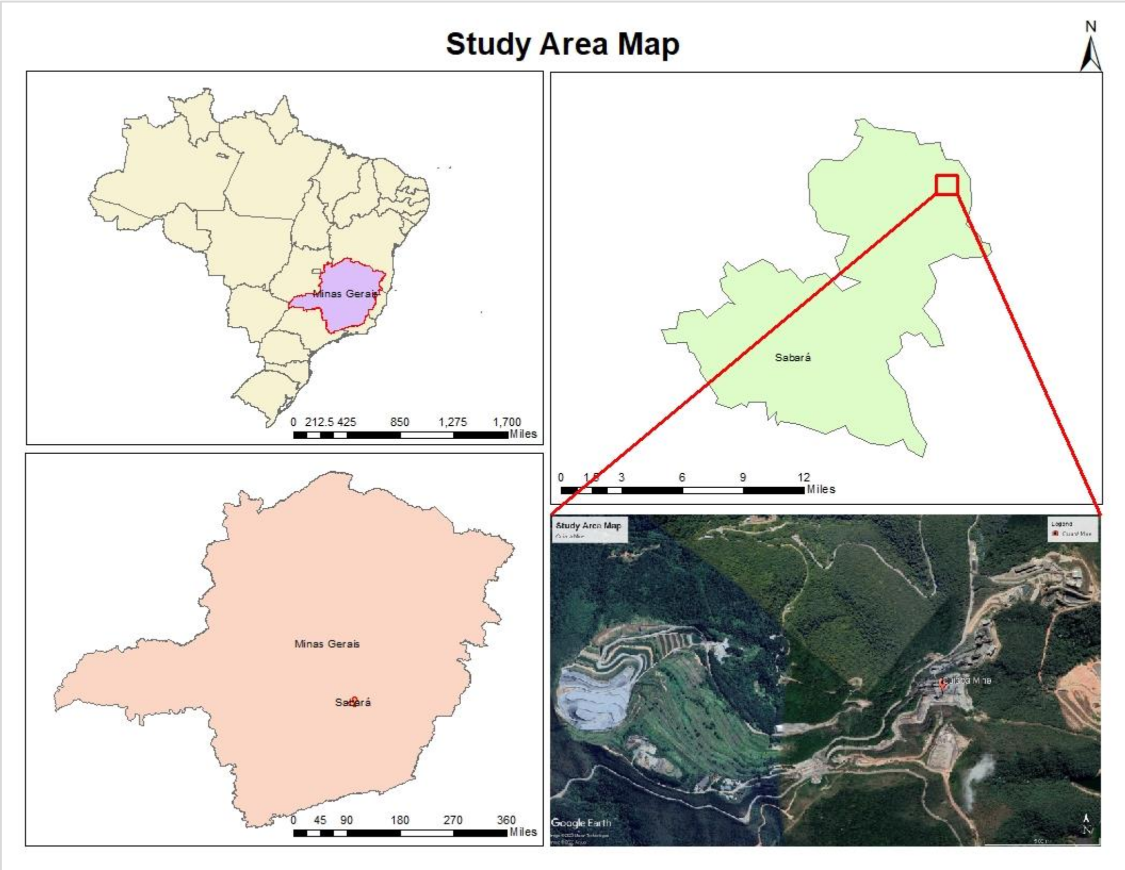

Figure 1. Study Area Map.

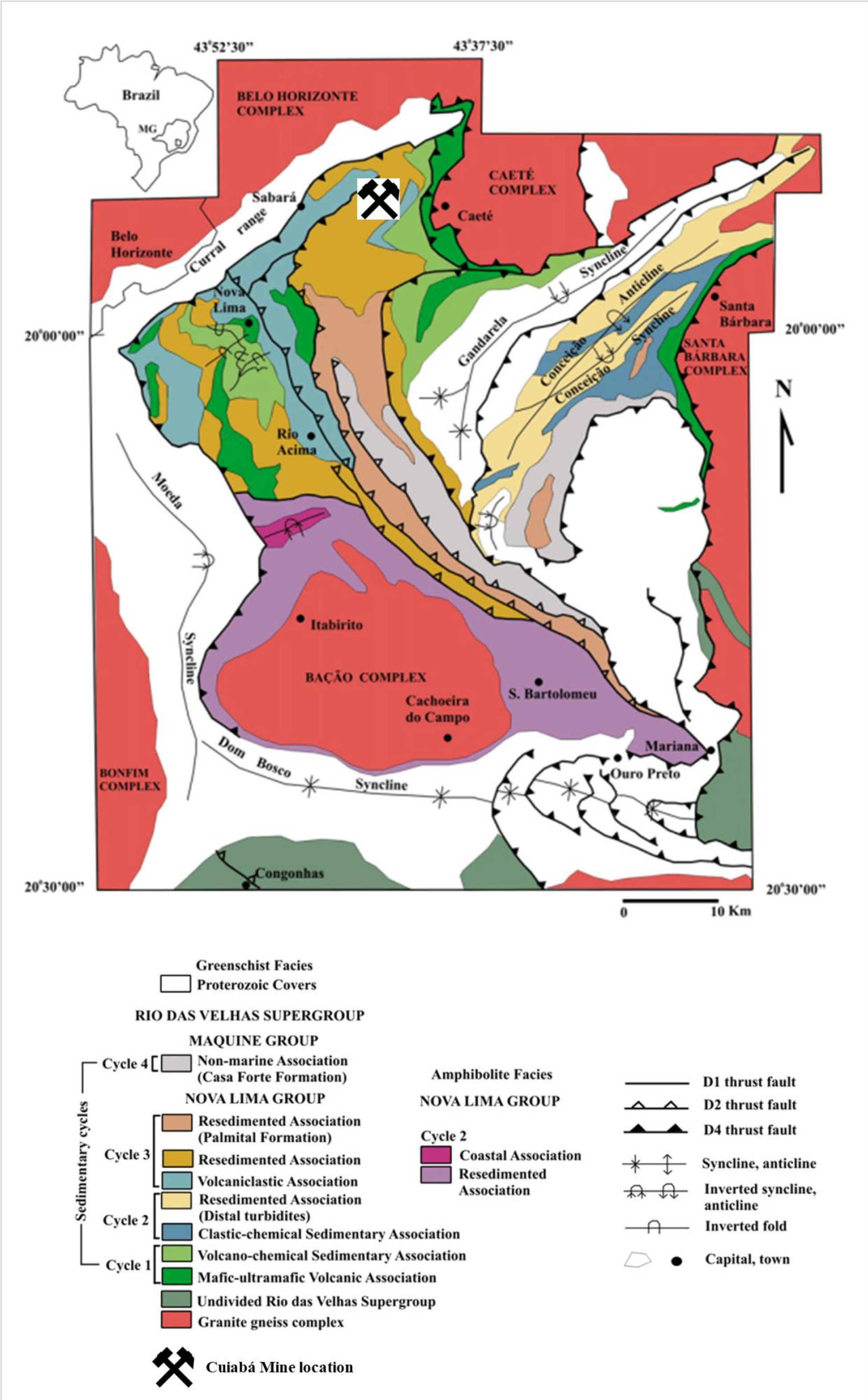

Figure 2 A simplified geological map comprising the greenstone belt of Rio das Velhas that is part of the Quadrilátero Ferrífero (BALTAZAR; ZUCCHETTI, 2007).

1.3 PROBLEM STATEMENT

The duration of workers' transition between shifts, both at the start and end of their work periods, in deep underground mines, can considerably reduce the actual working hours in such operations. The increase in the amount of unproductive time spent on people displacement is directly proportional to the number of shifts in a day and can have an impact on the economic viability of mines.

1.4 RESEARCH QUESTIONS

The purpose of this research is to do a comparative analysis of the productive and unproductive hours for different shift length and number of production halts for blasting in underground mining. This research aims to answer the following questions:

1. What is the optimal shift length, among 6-hour,10-hour, and 12-hour, for an underground mine based on productive working hours, considering the specific details of each scenario, including the well-being of employees?
2. How many blasting periods an underground mine should perform per day, aiming to increase mine production, taking into consideration a reduction of unproductive time?

1.5 RESEARCH OBJECTIVES

1. Determine an optimal shift length for underground mining.
2. Compare different shift lengths in terms of production hours per day.
3. Analyze the impact of different number of blasts daily for underground mining.

2 LITERATURE REVIEW

It is becoming increasingly necessary for underground mines all over the world to operate at higher depths as the process of extracting resources from deposits that are close to the surface continues to advance. As the depth of the mining operation increases, the costs and time required to transport rock masses also increase (STACEY; WESSELOO; BELL, 2005). Underground mines present a huge challenge when it comes to the transportation of rock masses from deeper levels to the surface. This challenge is primarily focused on increasing the amount of materials extracted and reducing associated production costs (GREBERG *et al.*, 2016). Achieving production targets is strongly related to the presence of buildings that enable entrance into mined areas, and these entry points are formed through tunnels (SUORINENI; KAISER; HENNING, 2008). Therefore, the construction of ramps, tunnels, shafts, drives, or other subterranean excavations is critically important, particularly in the mining industry. Access to mineralized zones and the preparation of extraction units for subsequent mineral extraction are both made easier by this infrastructure, which is why it is so important for the mining sector (JUAN P. VARGAS, 2017). In underground mines, the processes of excavation and production are complex procedures that involve a wide variety of distinct operations. When it comes to underground mining, the geometry and geology of the mine present considerable limitations (SONG *et al.*, 2015). It is possible that the achievement of a daily compliance explosion could be hampered by the prolonged period of travel, which, when combined with the additional chores that are a part of the mining process, reduces the amount of time that is spent directly working (GUMBIE, 2018).

In scenarios that require substantial movements to enter or quit the work area, as well as in situations that represent a greater risk to employees, the use of equipment that is operated remotely is becoming increasingly prevalent (SGANZERLA; SEIXAS; CONTI, 2016). On the other hand, transitioning to remote operations is not only complicated and costly, but it also takes a considerable amount of time.

Figure 3 Remote operations control room (www.immersivetechnologies.com/products/Remote-Operation-Technologies.htm).

Consequently, even though remote operations are being pursued as a long-term goal, the design of work shifts has a significant impact in determining the length of time required for tunnel construction and has the potential to serve as a strategy for increasing productivity in the near to medium term (SÁNCHEZ; HARTLIEB, 2020). Consequently, mining projects will profit from any feature that adds to the effectiveness of the construction of such infrastructure. The design of the work shift is an important component that plays a role in deciding the length of time required to construct the tunnel (JUAN P. VARGAS, 2017).

There are around 15-17% of workers in Western workforces, such as those in Europe, Australia, and the United States, who are currently engaged in regular shift work (PARENT-THIRION *et al.*, 2007). The shift patterns that have been in use during the previous quarter of a century have seen a significant expansion and diversification. In response to the rising level of competition, shift employment in service industries has resulted in an expansion of the variety of work schedules available. On the other hand, firms that are located on factories often require labor on a consistent basis over time (PETERS, 2019). There is a broad variety of working time arrangements available in the

Western world today. These range from the more conventional Monday to Friday day work to the more sophisticated 12-hour shift systems that involve continuous shifts that run for two weeks or longer. Among the types of agreements that fall into this category are fly-in, fly-out (FIFO) operations and offshore operations (PAECH *et al.*, 2010). Additionally, within a specific roster "type" (i.e., day work, 6-hour, 8-hour, 10-hour, or 12-hour shifts), there can be significant variations associated with start times, the number of consecutive shifts, the structure and frequency of the rotation, commute length, and residential circumstances during and after work. These variations can be attributed to a variety of factors. To properly analyze the results of the measurements, it is necessary to take into account all of these components, which operate as mediators of the effects of a particular shift pattern. Direct comparisons were made between the different work shifts being considered to determine which alternative was the best option (FERGUSON; DAWSON, 2012).

The Brazilian constitution, via Article 293 of Decree Law No. 5,452, stipulates that the normal duration of effective work for employees in underground mines must not exceed six hours per day or thirty-six hours weekly. The Article 295 of the same Decree Law stipulates that the normal duration of effective underground work can be extended up to eight hours daily or forty-eight hours weekly, through a written agreement between the employee and employer or collective labor agreement, being this extension subject to prior permission from the competent authority in occupational hygiene (BRASIL, 2017).

The referred Decree Law mentions a limited duration for the effective work and the effective work may start in different location for different workers. For a worker that operates a mine shaft elevator to access the underground, the effective work begins when he enters the shaft. However, for an operator of a drilling machine in the bottom of the mine, the effective work begins when the operator arrives at the work face where the machine is located. For this last operator to arrive at the work face, it may take up to one hour of displacement, which is not considered effective work. According to a few collective labor agreements this study had access too, the common ground for the industry is to accord up to 8 hours per day of work but not specifying effective work. This leads to an effective work of 6 hours in deep mine, due to the long distances required of displacement.

In 2021, the presidential provisional measure n° 1045 was being discussed for approval on the Brazilian congress and it had a proposal, among many others related to labor, to change the Article 293 and to increase normal duration of effective work for employees in underground mines from six to twelve hours per day, keeping the maximum of thirty-six hours per week. This presidential provisional measure was approved by the Chamber of Deputies in August 2021, but it was rejected by the Senate later (EMERGENCIAL, 2021).

The previously mentioned Decree Law was enacted in 1943, over eighty years ago, when concerns on occupational health and safety (OHS) were at a much lower consideration level than in 2020 decade. It is possible to see in Figure 4, an image from the 1940 decade, that operators did not wear masks, carbide lamps were still being used in some mines, mine equipment had no protection as roll over protective structure (ROPS) and falling objects protective structure (FOPS) and no closed cabin with air filter. On the opposite side, in underground mines in 2020 decade, as in Figure 5, many new layers of protection were added to the operators.

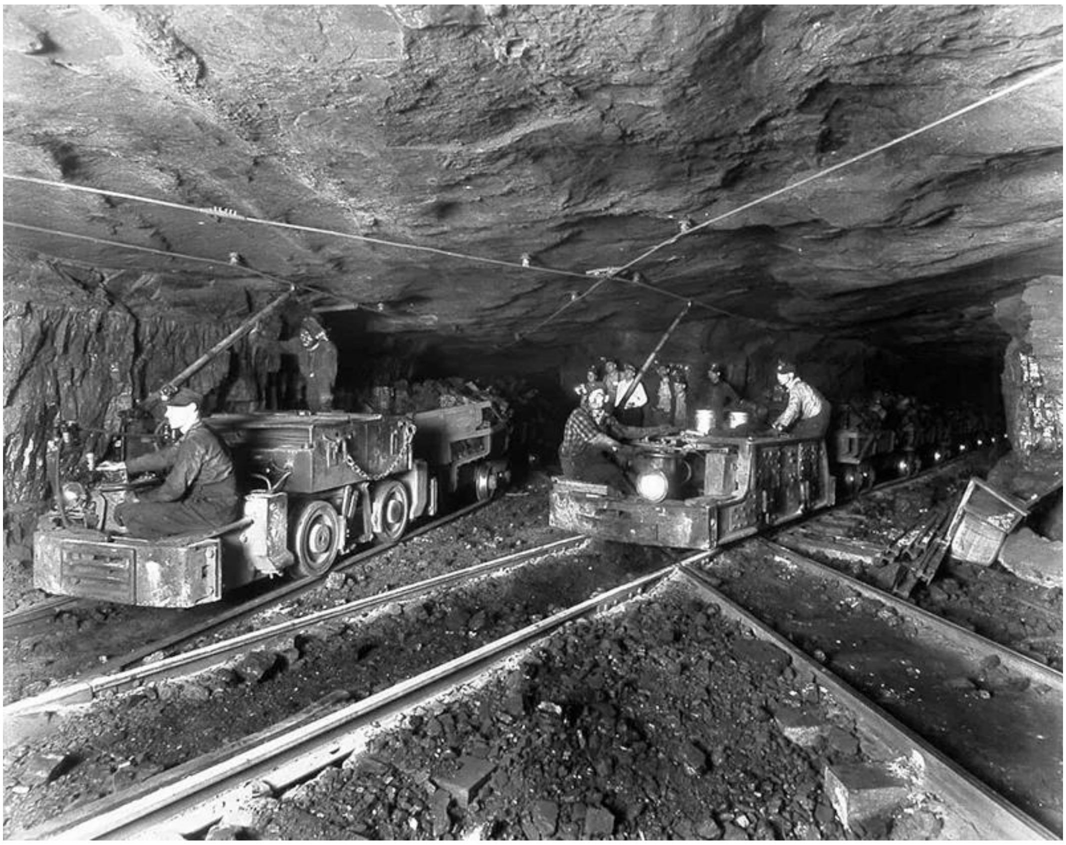

Figure 4. Underground coal mine in decade of 1940 (https://rarehistoricalphotos.com/vintage-coal-miner-photos/).

Figure 5. Underground gold mine in 2020 decade (https://istoedinheiro.com.br/brilho-de-dois-seculos/).

The technology of remote operations is currently being developed and deployed all over the world to operate machinery from a different location, particularly in high-risk situations. On the other hand, carrying out a comprehensive elimination process results in an undertaking that is both time-consuming and expensive. Increasing the short-term productivity of underground mines is important to improve the economic viability of subterranean mines (FISHER; SCHNITTGER; LTD, 2012). In this study, a comprehensive assessment of several shiftwork, including 6-hour, 8-hour, 10-hour, and 12-hour shifts, was carried out in a deep underground mine. Additionally, the number of explosions that occurred in a single day was taken into consideration to determine the ideal shiftwork duration for increased production efficiency.

3 MATERIALS AND METHODS

3.1 MATERIALS

The data used in the study was gathered by workers operating in underground environments. To provide a comprehensive dataset, data collection occurred over two months, September, and October of 2021, encompassing all days of the week and all four shifts daily. In addition, data was collected from employees in several departments who accessed the underground facilities, such as drilling, load and haul, infrastructure, maintenance, and geology. The data-gathering technique entailed giving paper sheets to employees selected at random. These sheets included a spreadsheet where employees were required to record their time-motion activities throughout their workday and a model of it can be found in Table 1 below, with the average time required for every activity.

Table 1 Spreadsheet of workers activities used for data-gathering.

Activities	Time
Walk from mine site entrance to cafeteria	00:05
Surface Snack	00:10
Surface displacement to locker room	00:05
Locker room (beginning of shift)	00:10
PPE collection	00:05
Shaft line wait time	00:22
Shaft travel time to enter the mine	00:10
Work assignment	00:10
Tool-box meeting	00:15
Underground displacement to parked light vehicles	00:10
Pick-up bits and materials	00:10
Travel time from shaft level to mine face	00:30
Hot seat shift change	00:10
Checklist / area inspection	00:20
Underground snack time	00:15
Travel time from mine face to shaft	00:30
Shaft travel time to exit the mine	00:05
Locker room (shift ending)	00:05
Surface displacement	00:10
Meal (lunch/dinner)	00:30
Walk from cafeteria to mine site entrance	00:05

3.2 METHODS

3.2.1 DATA PROCESSING

The first data processing step entailed converting all information into a digital format and organizing it into a spreadsheet. Considering the data's handwritten origin, indecipherable entries and any data points deviated significantly from the norm were omitted. The next stage in data processing was arranging the data in the specified order: by shift work, then by employee department, and finally by kind of motion. The last phase of data processing involved computing the mean duration for each category of movement or action.

3.2.2 SCENARIOS BY NUMBER OF WORKING HOURS

This study examined four shifts to discover the most efficient daily working hours. The four different shifts were 6-hour, 8-hour, 10-hour, and 12-hour. The outcomes of these shifts were compared to identify the ideal working hours. To determine the effective working hours, it was necessary to clearly define the underlying distinctions present in each of these shifts.

In the 6-hour shift, the base case involved dividing the workday into four shifts and consisting of five crew. Four teams are actively working daily, while one crew is taking a day off. Also, the mine and the union have established agreements, in conjunction with the national laws, that specify time limitations. These include a requirement of at least 11 hours of rest between the completion of one shift and the commencement of the next for the same crew, as well as a maximum daily duration of 8 hours and 30 minutes spent at the mine site.

The employment count fluctuates during the day. During weekdays, the first shift typically consists of approximately 450 employees, the second shift has around 250 employees, and the third and fourth shifts have approximately 200 individuals. During weekends and holidays, the initial shift is staffed by 250 people, whereas the other shifts have 200 employees on average. This study specifically examined a set of 200 people during each shift, which included both operational and support staff. Other individuals who enter the underground area include administrative personnel, contractors, and temporary workers who do not directly affect production. During a shift, the 200 employees involved in operations and support enter and exit the underground area through a shaft that can accommodate up to 50 people at a time. The process of going down and coming back up takes approximately 15 minutes per cycle. The employees are categorized into four cohorts of 50 individuals each. Group 1 commences its descent first and concludes its ascent last to maximize its duration of subterranean employment. Oppositely, Group 4 commences its descent last and concludes its ascent firstly, being the group with the lowest underground time. The group compositions consist of various roles and responsibilities. Group 1 involves activities such as mine development, drilling, and blasting. Group 2 comprises load and haul workers, crushing operators, and underground support workers. Group 3 is responsible for maintenance and infrastructure tasks. Lastly, Group 4 includes professionals in geology, rock mechanics, and essential contractors. The groups' composition may vary according to the needs of the operation. In addition to the vertical movement up and down, it is necessary to carry the employees from the shaft area to the mine faces, where production occurs. This process typically takes around 30 minutes.

Employees encounter periods of unproductive time on the surface due to activities such as moving between different locations on the site, using the cafeteria, taking meal breaks, using the locker room, gathering personal protective equipment (PPE), and waiting in line for the shaft. Underground unproductive time encompasses several activities, such as traveling via shaft, attending toolbox meetings, receiving work assignments, moving to and from production zones, taking snack breaks, collecting materials and tools, completing checklists, doing area inspections, and participating in hot seat shift changes. The duration of unproductive periods may slightly differ depending on the shift and group category.

In the 8-hour shift scenario, the working day is divided into three shifts instead of four of the base case, reducing the crew from five to four. This modification reduces unproductive periods, such as the transition between shifts, completion of checklists, inspection of work areas, conduction of toolbox meetings, and allocation of work tasks. The 10-hour and 12-hour shift scenarios exhibit striking similarities. In both scenarios, the working day is divided into two shifts, and crew remains constant at four. These scenarios additionally decrease wasted time as in 8-hour shifts.

3.2.3 SUB-SCENARIOS BY NUMBER OF BLASTING TIMES PER DAY

All individuals, except those immediately participating in blasting, must be evacuated from the underground for safety purposes before blasting operation. This leads to a complete halt in mine output, making it unproductive. Each scenario, determined by the number of hours, was divided into two sub-scenarios based on the daily blasting frequency for mine development. This study focus on the development blasting.

The first sub-scenario, serving as the fundamental scenario for blasting operations, involves two blasts daily, occurring at 7:05 a.m. and 7 p.m. During each blast session, a total of 6 mine faces are blasted for mine development. It takes approximately 40 minutes in the morning and 40 minutes in the evening to complete the blasting process and ensure the mine is safe, with the exit of blasting’s smoke, for all employees to access it. In the second sub-scenario, there is a single blast per day without reducing the number of mine faces being blasted. This allows for removing employees from the mine only once daily, resulting in a large reduction of unproductive time. Given the existing implementation of remote blasting in numerous mines, including Cuiabá Mine, the designated duration for a blast in this specific situation was 40 minutes, consistent with the original scenario.

3.2.4 SHIFT-TIME CALCULATION

To estimate the optimal number of working hours per day in each situation, it was first needed to create assumptions about unproductive time, as previously explained in the base case scenario. To establish assumptions, game rules for the activities enlisted in Table 1 were used. The game rules are noted down in Table 2 and they are based on Cuiabá Mine reality. Therefore, to replicate this work for a different mine, it is required to update the game rules based on reality of that mine.

Table 2. Game rules for each activity

Activities	Game Rule for time required
Walk from mine site entrance to cafeteria	Always the same.
Surface Snack	Always the same.
Surface displacement to locker room	Always the same.
Locker room (beginning of shift)	Always the same.
PPE collection	Always the same.
Shaft line wait time	There is a 15-minute time loss increased on each priority. Group priority changes according to: For shifts starting after a blast, Group 1 is the priority to descent, then Groups 2, 3 and 4. For other shifts, Group 4 is the priority, then Groups 3, 2 and 1.
Shaft travel time to enter the mine	Always the same.
Work assignment	Only required for shifts starting after a blast.
Tool-box meeting	Always the same.
Underground displacement to parked light vehicles.	Only required for shifts starting after a blast.
Pick-up bits and materials	Only required for shifts starting after a blast.
Travel time from shaft level to mine face	Always the same.
Hot seat shift change	Always the same.
Checklist / area inspection	Always the same.
Underground snack time	15 minutes for up to 5:40 EWT 30 minutes for up to 8:40 EWT 45 minutes for up to 11:40 EWT
Travel time from mine face to shaft	Always the same.
Shaft travel time to exit the mine	Always the same.
Locker room (shift ending)	Always the same.
Surface displacement	Always the same.
Meal (lunch/dinner)	Always the same.
Walk from cafeteria to mine site entrance	Always the same.
Maximum daily duration spent at the mine site	6-hour scenarios: 8 hours and 30 minutes (as in union agreement). 8-, 10- and 12-hour scenarios: no fixed limit.

After defining these assumptions, the next phase involved calculating the unproductive time for surface and underground operations, which were combined to get the overall unproductive time. Concurrently, determine how much time each scenario effectively works per shift during this stage. A spreadsheet was created to perform these calculations, as can be seen on Table 3. On this table, the lines in dark grey should be read as time of a day (i.e.: 7:10 a.m.), while the lines in white express the time taken to perform an unproductive activity and the line in green expresses the effective working time in hours.

Table 3. Spreadsheet used to calculate the effective working time for each Group for each scenario.

Activity	**Group**			
	Shift 1	**Shift 2**	**Shift 3**	**Shift 4**
Mine site entrance arrival				
Clock in time				
Surface displacement, snack, locker room, PPE				
Blast				
Shaft line wait				
Hour of shaft leaving surface				
Shaft travel time				
Toolbox meeting, work assignment, pick up bits/materials				
Travel time Shaft (Level 11) - Mine face				
Hour of arrival in mine face area				
Hot seat change (beginning of shift)				
Checklist, area inspection				
Hour of beginning of effective work				
Snack				
Hot seat change (ending of shift)				
Effective Working Time				
Hour of ending effective work				
Travel time between Mine Face and Shaft (Level 11)				
Amount of time before Group 1 shaft time				
Shaft travel time				
Hour of arrival in the surface				
Clock out time				
Looker room, lunch/dinner, displacement				
Bus station arrive				
Waiting bus to leave mine site				

A comparative examination of the results was carried out in the final step. This entailed evaluating the disparities in nonproductive time and productive working hours among the different shifts. This thorough assessment enables well-informed decision-making regarding the optimal duration of a work shift, following objectives related to productivity and resource allocation. Figure 3 represents a detailed flow chart of the methodology of the study.

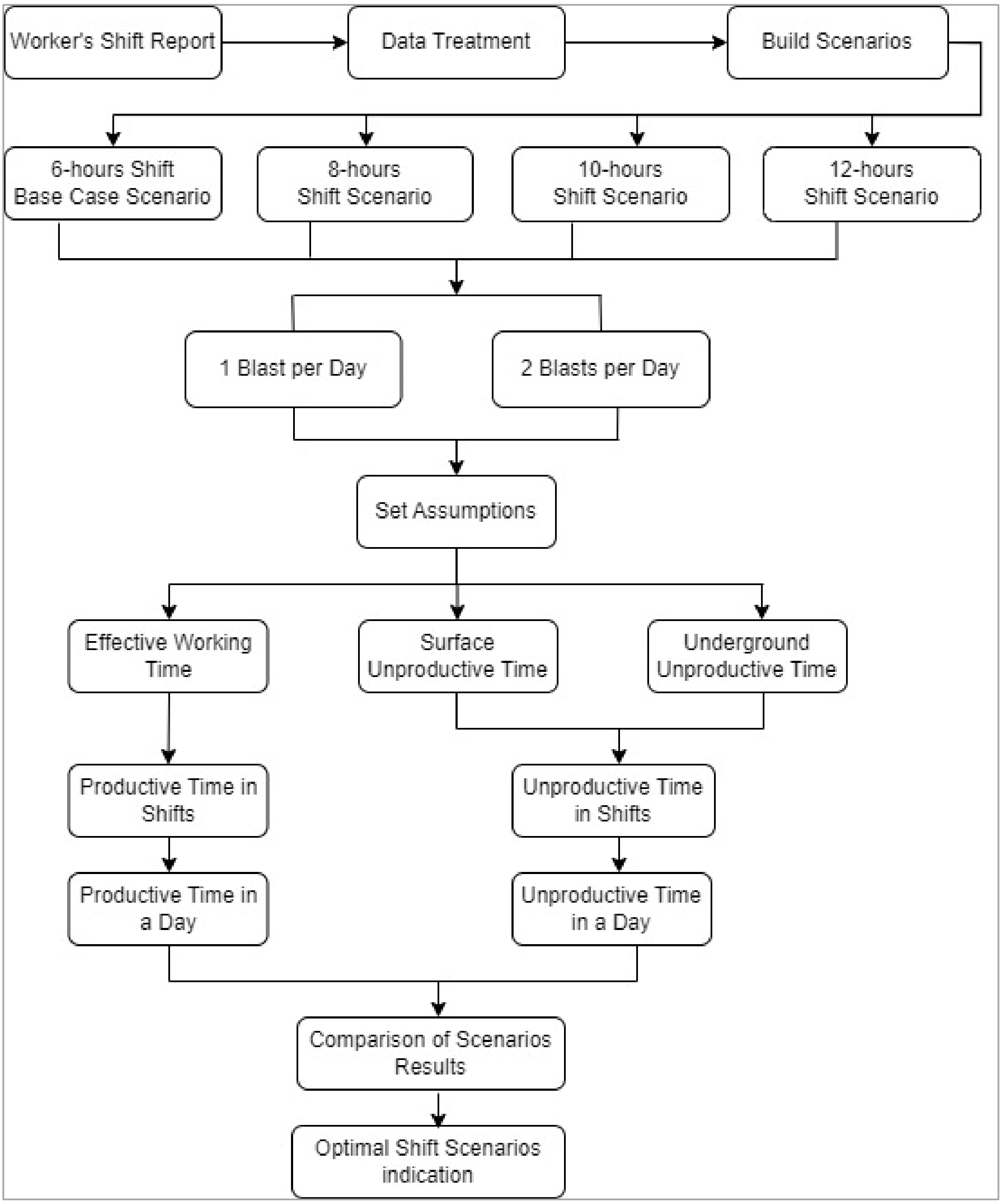

Figure 6. Methodology process flow.

3.2.5 MINE UTILIZATION INDICATOR

To evaluate and compare the results of different scenarios, this study proposed the creation of the indicator “Mine Utilization”. This indicator can be calculated by dividing the total effective working time of a day, in hours, by 24 hours. This indicator represents for how many hours the mine is being productive in a day.

4 RESULTS AND ANAYSIS

Calculating the efficient working time per shift and day involved evaluating the unproductive time for each situation and optimizing the ideal start and end times of shifts to maximize productivity. Table 1 reveals that workers can spend more than 4 hours per workday on unproductive activities, including 1 hour and 50 minutes for surface and underground displacement. It is worth noting that certain unproductive activities listed in Table 2 occur simultaneously with the productive activities of a separate group of workers due to overlapping shifts. Using Table 3 as a reference, the effective working time per shift and day were calculated by determining which assumptions of unproductive time should be taken in consideration in each shift and optimizing the hours to commence and to conclude shifts to maximize productivity.

The base case of 6-hour shift was modelled on the actual working conditions of Cuiabá Mine. In this scenario, shifts 1 and 3 always commence post-blasting, leading to a higher unproductive time spent on work assignment, collection of bits/materials, and underground displacement. For this scenario, all working groups are mandated to have a 15-minute snack break. However, owing to the duration of the shift, only Group 1, which is prioritized to access the mine, experiences 'hot seat' shift changes. This scenario considered a maximum daily duration spent at the mine site of 8 hours and 30 minutes, as mentioned Table 2. The results of the spreadsheets used to calculate the effective working time for each group on a 6-hour shift base case can be found on Table 4, Table 5, Table 6, and Table 7.

Table 4. Spreadsheet used to calculate the effective working time for Group 1 in Base Case shift.

Activity	Group 1			
	Shift 1	**Shift 2**	**Shift 3**	**Shift 4**
Mine site entrance arrival	07:10	12:30	19:05	23:20
Clock in time	07:35	13:05	19:30	23:55
Surface displacement, snack, locker room, PPE	00:35	00:35	00:35	00:35
Blast	07:05		19:00	
Shaft line wait	00:00	00:00	00:00	00:00
Hour of shaft leaving surface	07:45	13:05	19:40	23:55
Shaft travel time	00:10	00:10	00:10	00:10
Toolbox meeting, work assignment, pick up bits/materials	00:45	00:15	00:45	00:15
Travel time Level 11 - Mine face	00:30	00:30	00:30	00:30
Hour of arrival in mine face area	09:10	14:00	21:05	00:50
Hot seat change (beginning of shift)		00:10		00:10
Checklist, area inspection	00:20	00:20	00:20	00:20
Hour of beginning of effective work	09:30	14:30	21:25	01:20
Snack	00:15	00:15	00:15	00:15
Hot seat change (ending of shift)	00:10		00:10	
Effective Working Time	04:15	03:40	03:10	04:55
Hour of ending effective work	14:10	18:25	01:00	06:30
Travel time between Mine Face and Level 11	00:30	00:30	00:30	00:30
Amount of time before Group 1 shaft time				
Shaft travel time	00:05	00:05	00:05	00:05
Hour of arrival in the surface	14:45	19:00	01:35	07:05
Clock out time	14:45	19:00	01:35	07:05
Looker room, lunch/dinner, displacement	00:50	00:50	00:50	00:50
Bus station arrive	15:35	19:50	02:25	07:55
Waiting bus to leave mine site	00:00	00:00	00:00	00:00
Mine site entrance departure	15:35	19:50	02:25	07:55

Table 5. Spreadsheet used to calculate the effective working time for Group 2 in Base Case shift.

Activity	**Group 2**			
	Shift 1	**Shift 2**	**Shift 3**	**Shift 4**
Mine site entrance arrival	07:10	12:30	19:05	23:20
Clock in time	07:35	13:05	19:30	23:55
Surface displacement, snack, locker room, PPE	00:35	00:35	00:35	00:35
Blast	07:05		19:00	
Shaft line wait	00:15	00:15	00:15	00:15
Hour of shaft leaving surface	08:00	13:20	19:55	00:10
Shaft travel time	00:10	00:10	00:10	00:10
Toolbox meeting, work assignment, pick up bits/materials	00:45	00:15	00:45	00:15
Travel time Level 11 - Mine face	00:30	00:30	00:30	00:30
Hour of arrival in mine face area	09:25	14:15	21:20	01:05
Hot seat change (beginning of shift)				
Checklist, area inspection	00:20	00:20	00:20	00:20
Hour of beginning of effective work	09:45	14:35	21:40	01:25
Snack	00:15	00:15	00:15	00:15
Hot seat change (ending of shift)				
Effective Working Time	03:55	03:20	02:50	04:35
Hour of ending effective work	13:55	18:10	00:45	06:15
Travel time between Mine Face and Level 11	00:30	00:30	00:30	00:30
Amount of time before Group 1 shaft time	00:15	00:15	00:15	00:15
Shaft travel time	00:05	00:05	00:05	00:05
Hour of arrival in the surface	14:30	18:45	01:20	06:50
Clock out time	14:45	19:00	01:35	07:05
Looker room, lunch/dinner, displacement	00:50	00:50	00:50	00:50
Bus station arrive	15:20	19:35	02:10	07:40
Waiting bus to leave mine site	00:15	00:15	00:15	00:15
Mine site entrance departure	15:35	19:50	02:25	07:55

Table 6. Spreadsheet used to calculate the effective working time for Group 3 in Base Case shift.

Activity	Group 3			
	Shift 1	Shift 2	Shift 3	Shift 4
Mine site entrance arrival	07:10	12:30	19:05	23:20
Clock in time	07:35	13:05	19:30	23:55
Surface displacement, snack, locker room, PPE	00:35	00:35	00:35	00:35
Blast	07:05		19:00	
Shaft line wait	00:30	00:30	00:30	00:30
Hour of shaft leaving surface	08:15	13:35	20:10	00:25
Shaft travel time	00:10	00:10	00:10	00:10
Toolbox meeting, work assignment, pick up bits/materials	00:45	00:15	00:45	00:15
Travel time Level 11 - Mine face	00:30	00:30	00:30	00:30
Hour of arrival in mine face area	09:40	14:30	21:35	01:20
Hot seat change (beginning of shift)				
Checklist, area inspection	00:20	00:20	00:20	00:20
Hour of beginning of effective work	10:00	14:50	21:55	01:40
Snack	00:15	00:15	00:15	00:15
Hot seat change (ending of shift)				
Effective Working Time	03:25	02:50	02:20	04:05
Hour of ending effective work	13:40	17:55	00:30	06:00
Travel time between Mine Face and Level 11	00:30	00:30	00:30	00:30
Amount of time before Group 1 shaft time	00:30	00:30	00:30	00:30
Shaft travel time	00:05	00:05	00:05	00:05
Hour of arrival in the surface	14:15	18:30	01:05	06:35
Clock out time	14:45	19:00	01:35	07:05
Looker room, lunch/dinner, displacement	00:50	00:50	00:50	00:50
Bus station arrive	15:05	19:20	01:55	07:25
Waiting bus to leave mine site	00:30	00:30	00:30	00:30
Mine site entrance departure	15:35	19:50	02:25	07:55

Table 7. Spreadsheet used to calculate the effective working time for Group 4 in Base Case shift.

Activity	Group 4			
	Shift 1	Shift 2	Shift 3	Shift 4
Mine site entrance arrival	07:10	12:30	19:05	23:20
Clock in time	07:35	13:05	19:30	23:55
Surface displacement, snack, locker room, PPE	00:35	00:35	00:35	00:35
Blast	07:05		19:00	
Shaft line wait	00:45	00:45	00:45	00:45
Hour of shaft leaving surface	08:30	13:50	20:25	00:40
Shaft travel time	00:10	00:10	00:10	00:10
Toolbox meeting, work assignment, pick up bits/materials	00:45	00:15	00:45	00:15
Travel time Level 11 - Mine face	00:30	00:30	00:30	00:30
Hour of arrival in mine face area	09:55	14:45	21:50	01:35
Hot seat change (beginning of shift)				
Checklist, area inspection	00:20	00:20	00:20	00:20
Hour of beginning of effective work	10:15	15:05	22:10	01:55
Snack	00:15	00:15	00:15	00:15
Hot seat change (ending of shift)				
Effective Working Time	02:55	02:20	01:50	03:35
Hour of ending effective work	13:25	17:40	00:15	05:45
Travel time between Mine Face and Level 11	00:30	00:30	00:30	00:30
Amount of time before Group 1 shaft time	00:45	00:45	00:45	00:45
Shaft travel time	00:05	00:05	00:05	00:05
Hour of arrival in the surface	14:00	18:15	00:50	06:20
Clock out time	14:45	19:00	01:35	07:05
Looker room, lunch/dinner, displacement	00:50	00:50	00:50	00:50
Bus station arrive	14:50	19:05	01:40	07:10
Waiting bus to leave mine site	00:45	00:45	00:45	00:45
Mine site entrance departure	15:35	19:50	02:25	07:55

The results found on Tables 4 to 7 indicate Group 1 has four hours of effective working time on average. The same indicator is of 3 hours and 40 minutes for Group 2, 3 hours and 10 minutes for Group 3 and only 2 hours and 30 minutes for Group 4. The average of all groups resulted in 3 hours and 22 minutes of effective working time per shift, which represents 13 hours and 30 minutes per day.

The model for the 8-hour shift accounted for shifts 1 and 3 always starting after blasting. This shift was structured to include only three shifts per day. Due to the longer duration of these shifts, it was feasible to ensure that the shift change between shifts 1 and 2 was characterized as a 'hot seat' for all groups. Additionally, due to shift 2 having a longer span in this shift, the snack break was extended to 30 minutes, instead of the standard 15 minutes for it. Also, to optimize the shift, the second blast time of the day was set to occur at 22:10, instead of at 19:00 as in base case. This shift did not consider any maximum daily duration spent at the mine site. The results of the spreadsheets used to calculate the effective working time for each group on 8-hour/2 blasts sub-scenario can be found on Table 8, Table 9, Table 10, and Table 11.

Table 8. Spreadsheet used to calculate the effective working time for Group 1 in 8-hour/2 blasts sub-scenario.

Activity	Group 1		
	Shift 1	Shift 2	Shift 3
Mine site entrance arrival	07:10	12:45	22:15
Clock in time	07:35	13:20	22:40
Surface displacement, snack, locker room, PPE	00:35	0:35	00:35
Blast	07:05		22:10
Shaft line wait	00:00	00:45	00:00
Hour of shaft leaving surface	07:45	14:05	22:50
Shaft travel time	00:10	00:10	00:10
Toolbox meeting, work assignment, pick up bits/materials	00:45	00:15	00:45
Travel time Level 11 - Mine face	00:30	00:30	00:30
Hour of arrival in mine face area	09:10	15:00	00:15
Hot seat change (beginning of shift)		00:10	
Checklist, area inspection	00:20	00:20	00:20
Hour of beginning of effective work	09:30	15:30	00:35
Snack	00:15	00:30	00:15
Hot seat change (ending of shift)	00:10		
Effective Working Time	05:35	05:35	05:40
Hour of ending effective work	15:30	21:35	06:30
Travel time between Mine Face and Level 11	00:30	00:30	00:30
Amount of time before Group 1 shaft time			
Shaft travel time	00:05	00:05	00:05
Hour of arrival in the surface	16:05	22:10	07:05
Clock out time	16:05	22:10	07:05
Looker room, lunch/dinner, displacement	00:50	00:50	00:50
Bus station arrive	16:55	23:00	07:55
Waiting bus to leave mine site	00:00	00:00	00:00
Mine site entrance departure	16:55	23:00	07:55

Table 9. Spreadsheet used to calculate the effective working time for Group 2 in 8-hour/2 blasts sub-scenario.

Activity	Group 2		
	Shift 1	Shift 2	Shift 3
Mine site entrance arrival	07:10	12:45	22:15
Clock in time	07:35	13:20	22:40
Surface displacement, snack, locker room, PPE	00:35	00:35	00:35
Blast	07:05		22:10
Shaft line wait	00:15	00:30	00:15
Hour of shaft leaving surface	08:00	13:50	23:05
Shaft travel time	00:10	00:10	00:10
Toolbox meeting, work assignment, pick up bits/materials	00:45	00:15	00:45
Travel time Level 11 - Mine face	00:30	00:30	00:30
Hour of arrival in mine face area	09:25	14:45	00:30
Hot seat change (beginning of shift)		00:10	
Checklist, area inspection	00:20	00:20	00:20
Hour of beginning of effective work	09:45	15:15	00:50
Snack	00:15	00:30	00:15
Hot seat change (ending of shift)	00:10		
Effective Working Time	05:05	05:35	05:10
Hour of ending effective work	15:15	21:20	06:15
Travel time between Mine Face and Level 11	00:30	00:30	00:30
Amount of time before Group 1 shaft time	00:15	00:15	00:15
Shaft travel time	00:05	00:05	00:05
Hour of arrival in the surface	15:50	21:55	06:50
Clock out time	16:05	22:10	07:05
Looker room, lunch/dinner, displacement	00:50	00:50	00:50
Bus station arrive	16:40	22:45	07:40
Waiting bus to leave mine site	00:15	00:15	00:15
Mine site entrance departure	16:55	23:00	07:55

Table 10. Spreadsheet used to calculate the effective working time for Group 3 in 8-hour/2 blasts sub-scenario.

Activity	Group 3		
	Shift 1	**Shift 2**	**Shift 3**
Mine site entrance arrival	07:10	12:45	22:15
Clock in time	07:35	13:20	22:40
Surface displacement, snack, locker room, PPE	00:35	00:35	00:35
Blast	07:05		22:10
Shaft line wait	00:30	00:15	00:30
Hour of shaft leaving surface	08:15	13:35	23:20
Shaft travel time	00:10	00:10	00:10
Toolbox meeting, work assignment, pick up bits/materials	00:45	00:15	00:45
Travel time Level 11 - Mine face	00:30	00:30	00:30
Hour of arrival in mine face area	09:40	14:30	00:45
Hot seat change (beginning of shift)		00:10	
Checklist, area inspection	00:20	00:20	00:20
Hour of beginning of effective work	10:00	15:00	01:05
Snack	00:15	00:30	00:15
Hot seat change (ending of shift)	00:10		
Effective Working Time	04:35	05:35	04:40
Hour of ending effective work	15:00	21:05	06:00
Travel time between Mine Face and Level 11	00:30	00:30	00:30
Amount of time before Group 1 shaft time	00:30	00:30	00:30
Shaft travel time	00:05	00:05	00:05
Hour of arrival in the surface	15:35	21:40	06:35
Clock out time	16:05	22:10	07:05
Looker room, lunch/dinner, displacement	00:50	00:50	00:50
Bus station arrive	16:25	22:30	07:25
Waiting bus to leave mine site	00:30	00:30	00:30
Mine site entrance departure	16:55	23:00	07:55

Table 11. Spreadsheet used to calculate the effective working time for Group 4 in 8-hour/2 blasts sub-scenario.

Activity	**Group 4**		
	Shift 1	**Shift 2**	**Shift 3**
Mine site entrance arrival	07:10	12:45	22:15
Clock in time	07:35	13:20	22:40
Surface displacement, snack, locker room, PPE	00:35	00:35	00:35
Blast	07:05		22:10
Shaft line wait	00:45	00:00	00:45
Hour of shaft leaving surface	08:30	13:20	23:35
Shaft travel time	00:10	00:10	00:10
Toolbox meeting, work assignment, pick up bits/materials	00:45	00:15	00:45
Travel time Level 11 - Mine face	00:30	00:30	00:30
Hour of arrival in mine face area	09:55	14:15	01:00
Hot seat change (beginning of shift)		00:10	
Checklist, area inspection	00:20	00:20	00:20
Hour of beginning of effective work	10:15	14:45	01:20
Snack	00:15	00:30	00:15
Hot seat change (ending of shift)	00:10		
Effective Working Time	04:05	05:35	04:10
Hour of ending effective work	14:45	20:50	05:45
Travel time between Mine Face and Level 11	00:30	00:30	00:30
Amount of time before Group 1 shaft time	00:45	00:45	00:45
Shaft travel time	00:05	00:05	00:05
Hour of arrival in the surface	15:20	21:25	06:20
Clock out time	16:05	22:10	07:05
Looker room, lunch/dinner, displacement	00:50	00:50	00:50
Bus station arrive	16:10	22:15	07:10
Waiting bus to leave mine site	00:45	00:45	00:45
Mine site entrance departure	16:55	23:00	07:55

The results found on Tables 8 to 11 indicate Group 1 has 5 hours and 36 minutes of effective working time on average. The same indicator is 5 hours and 16 minutes for Group 2, 4 hours and 56 minutes for Group 3 and 4 hours and 36 minutes for Group 4. The average of all groups resulted in 5 hours and 6 minutes of effective working time per shift, which represents 15 hours and 20 minutes per day.

The models for the 10-hour and 12-hour shifts were designed to have two shifts per day. Both shifts were structured to begin after blasts, without any 'hot seat' shift changes. Given the more extended duration of these shifts, every working group was allotted a 30-minute snack break. This is a modification from the standard 15-minute break in consideration of the increased working hours. This scenario did not consider any maximum daily duration spent at the mine site. The results of the spreadsheets used to calculate the effective working time for each group on 10-hour and 12-hour/2 blasts shifts can be found on Table 12 and Table 13.

Table 12. Spreadsheet used to calculate the effective working time for Group 1 and 2 in 10-hour and 12-hour/2 blasts sub-scenarios.

Activity	**Group 1**		**Group 2**	
	Shift 1	**Shift 2**	**Shift 1**	**Shift 2**
Mine site entrance arrival	07:10	19:10	07:10	19:10
Clock in time	07:35	19:35	07:35	19:35
Surface displacement, snack, locker room, PPE	00:35	00:35	00:35	00:35
Blast	07:05	19:05	07:05	19:05
Shaft line wait	00:00	00:00	00:15	00:15
Hour of shaft leaving surface	07:45	19:45	08:00	20:00
Shaft travel time	00:10	00:10	00:10	00:10
Toolbox meeting, work assignment, pick up bits/materials	00:45	00:45	00:45	00:45
Travel time Level 11 - Mine face	00:30	00:30	00:30	00:30
Hour of arrival in mine face area	09:10	21:10	09:25	21:25
Hot seat change (beginning of shift)				
Checklist, area inspection	00:20	00:20	00:20	00:20
Hour of beginning of effective work	09:30	21:30	09:45	21:45
Snack	00:30	00:30	00:30	00:30
Hot seat change (ending of shift)				
Effective Working Time	08:30	08:30	08:00	08:00
Hour of ending effective work	18:30	06:30	18:15	06:15
Travel time between Mine Face and Level 11	00:30	00:30	00:30	00:30
Amount of time before Group 1 shaft time			00:15	00:15
Shaft travel time	00:05	00:05	00:05	00:05
Hour of arrival in the surface	19:05	07:05	18:50	06:50
Clock out time	19:05	07:05	19:05	07:05
Looker room, lunch/dinner, displacement	00:50	00:50	00:50	00:50
Bus station arrive	19:55	07:55	19:40	07:40
Waiting bus to leave mine site	00:00	00:00	00:15	00:15
Mine site entrance departure	19:55	07:55	19:55	07:55

Table 13. Spreadsheet used to calculate the effective working time for Group 3 and 4 in 10-hour and 12-hour/2 blasts sub-scenarios.

Activity	**Group 3**		**Group 4**	
	Shift 1	**Shift 2**	**Shift 1**	**Shift 2**
Mine site entrance arrival	07:10	19:10	07:10	19:10
Clock in time	07:35	19:35	07:35	19:35
Surface displacement, snack, locker room, PPE	00:35	00:35	00:35	00:35
Blast	07:05	19:05	07:05	19:05
Shaft line wait	00:30	00:30	00:45	00:45
Hour of shaft leaving surface	08:15	20:15	08:30	20:30
Shaft travel time	00:10	00:10	00:10	00:10
Toolbox meeting, work assignment, pick up bits/materials	00:45	00:45	00:45	00:45
Travel time Level 11 - Mine face	00:30	00:30	00:30	00:30
Hour of arrival in mine face area	09:40	21:40	09:55	21:55
Hot seat change (beginning of shift)				
Checklist, area inspection	00:20	00:20	00:20	00:20
Hour of beginning of effective work	10:00	22:00	10:15	22:15
Snack	00:30	00:30	00:30	00:30
Hot seat change (ending of shift)				
Effective Working Time	07:30	07:30	07:00	07:00
Hour of ending effective work	18:00	06:00	17:45	05:45
Travel time between Mine Face and Level 11	00:30	00:30	00:30	00:30
Amount of time before Group 1 shaft time	00:30	00:30	00:45	00:45
Shaft travel time	00:05	00:05	00:05	00:05
Hour of arrival in the surface	18:35	06:35	18:20	06:20
Clock out time	19:05	07:05	19:05	07:05
Looker room, lunch/dinner, displacement	00:50	00:50	00:50	00:50
Bus station arrive	19:25	07:25	19:10	07:10
Waiting bus to leave mine site	00:30	00:30	00:45	00:45
Mine site entrance departure	19:55	07:55	19:55	07:55

The results found on Tables 12 and 13 indicate Group 1 has 8 hours and 30 minutes of effective working time on average. The same indicator is of 8 hours for Group 2, 7 hours and 30 minutes for Group 3 and 7 hours for Group 4. The average of all groups resulted in 7 hours and 45 minutes of effective working time per shift, which represents 15 hours and 30 minutes per day.

Using information from Tables 4 to 13, it was possible to summarize the shifts on Table 14, which includes the effective working time per day and the mine utilization for all scenarios, for the specific sub-scenario of having two blasts per day.

Table 14. Description of work shifts, effecting work time per shift per day, and mine utilization for two blasts scenarios.

Scenarios – Shifts Hours	Number of Shifts per Day	Avg. Effective Working Time per Shift	Effective Working Time per Day	Mine Utilization
6h Shift (Base Case)	4	03:22	13:30	56.3%
8h Shift	3	05:06	15:20	63.9%
10h Shift	2	07:45	15:30	64.6%
12h Shift	2	07:45	15:30	64.6%

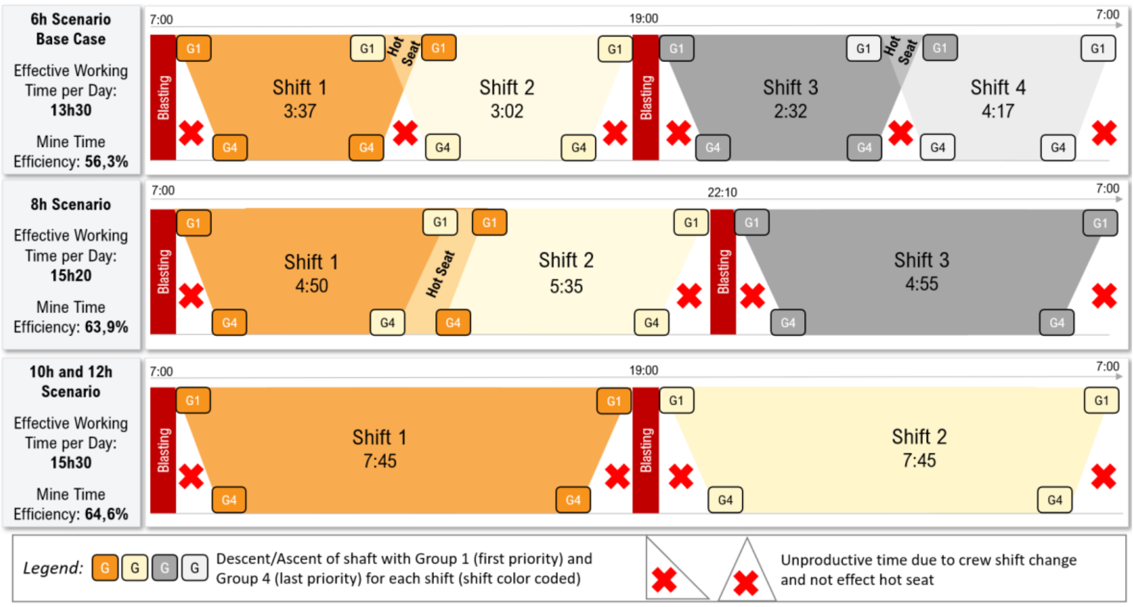

Figure 7. Visual interpretation of scenarios with two blasts and unproductive time in the shifts.

The visual depiction of the situations involving two blasts emphasizes the period of inefficiency caused by the transition of shift crew and repeated blasting in the regions marked by triangles and crosses in Figure 7. It can be deduced that in the 6-hour scenario (base case), the hot seat shift change could be more efficient; it only proves effective for personnel belonging to Group 1 (those with priority to descend in the shaft at the start of a shift). In the case of the 8-hour scenario, which is the only other one with a shift change for the hot seat, the visual demonstrates that it is feasible to have a completely efficient hot seat that covers all groups by extending the duration of the shift.

Furthermore, it can be inferred from the visual representation that an increase in "unproductive areas" (shown by triangles and crosses) decreases productive working time per day. In the 6-hour scenario, there are 6 crosses, but the other situations only have 4. The difference in mine utilization between the 6-hour and 8-hour scenarios is 7.6%, while the transition from 8-hour and 10/12-hour shifts results in increase of mine utilization by 0.7%. Workers are legally entitled to a 15-minute break for every three consecutive hours of productive work. Consequently, employees working 10-hour and 12-hour shifts are required to take a longer break of 30 minutes for snacks, rather than the usual 15 minutes in other shifts. Therefore, the incremental step in mine utilization from the 8-hour to 10/12-hour shift is smaller compared to increase from 6-hour to 8-hour shift.

This study, then, moved to modelling the second sub-scenario, which considered only single blast time daily. Starting with the 6-hour shift, which was modelled considering 4 shift per day and 'hot seat' shift changes being experienced only by Group 1. This scenario considered a maximum daily duration spent at the mine site of 8 hours and 30 minutes and a 15-minute snack break for all groups and shifts. The results of the spreadsheets used to calculate the effective working time for each group on 6-hour/single blast shift can be found on Table 15, Table 16, Table 17, and Table 18.

Table 15. Spreadsheet used to calculate the effective working time for Group 1 in 6-hour/single blast sub-scenario.

Activity	Group 1			
	Shift 1	Shift 2	Shift 3	Shift 4
Mine site entrance arrival	07:10	12:15	17:20	22:25
Clock in time	07:35	12:40	17:45	22:50
Surface displacement, snack, locker room, PPE	00:35	00:35	00:35	00:35
Blast	07:05			
Shaft line wait	00:00	00:00	00:00	00:00
Hour of shaft leaving surface	07:45	12:50	17:55	23:00
Shaft travel time	00:10	00:10	00:10	00:10
Toolbox meeting, work assignment, pick up bits/materials	00:45	00:15	00:15	00:15
Travel time Level 11 - Mine face	00:30	00:30	00:30	00:30
Hour of arrival in mine face area	09:10	13:45	18:50	23:55
Hot seat change (beginning of shift)		00:10	00:10	00:10
Checklist, area inspection	00:20	00:20	00:20	00:20
Hour of beginning of effective work	09:30	14:15	19:20	00:25
Snack	00:15	00:15	00:15	00:15
Hot seat change (ending of shift)	00:10	00:10	00:10	
Effective Working Time	04:20	04:40	04:40	04:50
Hour of ending effective work	14:15	19:20	00:25	05:30
Travel time between Mine Face and Level 11	00:30	00:30	00:30	00:30
Amount of time before Group 1 shaft time				
Shaft travel time	00:05	00:05	00:05	00:05
Hour of arrival in the surface	14:50	19:55	01:00	06:05
Clock out time	14:50	19:55	01:00	06:05
Looker room, lunch/dinner, displacement	00:50	00:50	00:50	00:50
Bus station arrive	15:40	20:45	01:50	06:55
Waiting bus to leave mine site	00:00	00:00	00:00	00:00
Mine site entrance departure	15:40	20:45	01:50	06:55

Table 16. Spreadsheet used to calculate the effective working time for Group 2 in 6-hour/single blast sub-scenario.

Activity	Group 2			
	Shift 1	**Shift 2**	**Shift 3**	**Shift 4**
Mine site entrance arrival	07:10	12:15	17:20	22:25
Clock in time	07:35	12:40	17:45	22:50
Surface displacement, snack, locker room, PPE	00:35	00:35	00:35	00:35
Blast	07:05			
Shaft line wait	00:15	00:15	00:15	00:15
Hour of shaft leaving surface	08:00	13:05	18:10	23:15
Shaft travel time	00:10	00:10	00:10	00:10
Toolbox meeting, work assignment, pick up bits/materials	00:45	00:15	00:15	00:15
Travel time Level 11 - Mine face	00:30	00:30	00:30	00:30
Hour of arrival in mine face area	09:25	14:00	19:05	00:10
Hot seat change (beginning of shift)				
Checklist, area inspection	00:20	00:20	00:20	00:20
Hour of beginning of effective work	09:45	14:20	19:25	00:30
Snack	00:15	00:15	00:15	00:15
Hot seat change (ending of shift)				
Effective Working Time	04:00	04:30	04:30	04:30
Hour of ending effective work	14:00	19:05	00:10	05:15
Travel time between Mine Face and Level 11	00:30	00:30	00:30	00:30
Amount of time before Group 1 shaft time	00:15	00:15	00:15	00:15
Shaft travel time	00:05	00:05	00:05	00:05
Hour of arrival in the surface	14:35	19:40	00:45	05:50
Clock out time	14:50	19:55	01:00	06:05
Looker room, lunch/dinner, displacement	00:50	00:50	00:50	00:50
Bus station arrive	15:25	20:30	01:35	06:40
Waiting bus to leave mine site	00:15	00:15	00:15	00:15
Mine site entrance departure	15:40	20:45	01:50	06:55

Table 17. Spreadsheet used to calculate the effective working time for Group 3 in 6-hour/single blast sub-scenario.

Activity	Group 3			
	Shift 1	Shift 2	Shift 3	Shift 4
Mine site entrance arrival	07:10	12:15	17:20	22:25
Clock in time	07:35	12:40	17:45	22:50
Surface displacement, snack, locker room, PPE	00:35	00:35	00:35	00:35
Blast	07:05			
Shaft line wait	00:30	00:30	00:30	00:30
Hour of shaft leaving surface	08:15	13:20	18:25	23:30
Shaft travel time	00:10	00:10	00:10	00:10
Toolbox meeting, work assignment, pick up bits/materials	00:45	00:15	00:15	00:15
Travel time Level 11 - Mine face	00:30	00:30	00:30	00:30
Hour of arrival in mine face area	09:40	14:15	19:20	00:25
Hot seat change (beginning of shift)				
Checklist, area inspection	00:20	00:20	00:20	00:20
Hour of beginning of effective work	10:00	14:35	19:40	00:45
Snack	00:15	00:15	00:15	00:15
Hot seat change (ending of shift)				
Effective Working Time	03:30	04:00	04:00	04:00
Hour of ending effective work	13:45	18:50	23:55	05:00
Travel time between Mine Face and Level 11	00:30	00:30	00:30	00:30
Amount of time before Group 1 shaft time	00:30	00:30	00:30	00:30
Shaft travel time	00:05	00:05	00:05	00:05
Hour of arrival in the surface	14:20	19:25	00:30	05:35
Clock out time	14:50	19:55	01:00	06:05
Looker room, lunch/dinner, displacement	00:50	00:50	00:50	00:50
Bus station arrive	15:10	20:15	01:20	06:25
Waiting bus to leave mine site	00:30	00:30	00:30	00:30
Mine site entrance departure	15:40	20:45	01:50	06:55

Table 18. Spreadsheet used to calculate the effective working time for Group 4 in 6-hour/single blast sub-scenario.

Activity	Group 4			
	Shift 1	Shift 2	Shift 3	Shift 4
Mine site entrance arrival	07:10	12:15	17:20	22:25
Clock in time	07:35	12:40	17:45	22:50
Surface displacement, snack, locker room, PPE	00:35	00:35	00:35	00:35
Blast	07:05			
Shaft line wait	00:45	00:45	00:45	00:45
Hour of shaft leaving surface	08:30	13:35	18:40	23:45
Shaft travel time	00:10	00:10	00:10	00:10
Toolbox meeting, work assignment, pick up bits/materials	00:45	00:15	00:15	00:15
Travel time Level 11 - Mine face	00:30	00:30	00:30	00:30
Hour of arrival in mine face area	09:55	14:30	19:35	00:40
Hot seat change (beginning of shift)				
Checklist, area inspection	00:20	00:20	00:20	00:20
Hour of beginning of effective work	10:15	14:50	19:55	01:00
Snack	00:15	00:15	00:15	00:15
Hot seat change (ending of shift)				
Effective Working Time	03:00	03:30	03:30	03:30
Hour of ending effective work	13:30	18:35	23:40	04:45
Travel time between Mine Face and Level 11	00:30	00:30	00:30	00:30
Amount of time before Group 1 shaft time	00:45	00:45	00:45	00:45
Shaft travel time	00:05	00:05	00:05	00:05
Hour of arrival in the surface	14:05	19:10	00:15	05:20
Clock out time	14:50	19:55	01:00	06:05
Looker room, lunch/dinner, displacement	00:50	00:50	00:50	00:50
Bus station arrive	14:55	20:00	01:05	06:10
Waiting bus to leave mine site	00:45	00:45	00:45	00:45
Mine site entrance departure	15:40	20:45	01:50	06:55

The results found on Tables 15 to 18 indicate Group 1 has 4 hours and 37 minutes of effective working time on average. The same indicator is 4 hours and 22 minutes for Group 2, 3 hours and 52 minutes for Group 3 and 3 hours and 22 minutes for Group 4. The average of all groups resulted in 4 hours and 3 minutes of effective working time per shift, which represents 16 hours and 15 minutes per day. It is possible to notice from the results that the last group departing the underground during shift 4 reaches the surface one hour ahead of the scheduled blasting time. However, owing to union agreement restrictions that limit employees to a maximum of 8 hours and 30 minutes on the mine site, it was not feasible to optimize this specific variable. As such, this hour remains unutilized and contributes to less-than-maximal operational efficiency.

The model for the 8-hour shift in this sub-scenario was designed to have all groups in all shifts performing a 'hot seat' shift change, which increases the effective working time of the scenario. Also, as all shifts have a longer span, the snack break was extended to 30 minutes for all groups. This scenario did not consider any maximum daily duration spent at the mine site. The results of the spreadsheets used to calculate the effective working time for each group on 8-hour/single blast sub-scenario can be found on Table 19, Table 20, Table 21, and Table 22.

Table 19. Spreadsheet used to calculate the effective working time for Group 1 in 8-hour/single blast sub-scenario.

Activity	**Group 1**		
	Shift 1	**Shift 2**	**Shift 3**
Mine site entrance arrival	07:10	13:50	20:55
Clock in time	07:35	14:50	21:20
Surface displacement, snack, locker room, PPE	00:35	00:35	00:35
Blast	07:05		
Shaft line wait	00:00	00:45	00:45
Hour of shaft leaving surface	07:45	15:10	22:15
Shaft travel time	00:10	00:10	00:10
Toolbox meeting, work assignment, pick up bits/materials	00:45	00:15	00:15
Travel time Level 11 - Mine face	00:30	00:30	00:30
Hour of arrival in mine face area	09:10	16:05	23:10
Hot seat change (beginning of shift)		00:10	00:10
Checklist, area inspection	00:20	00:20	00:20
Hour of beginning of effective work	09:30	16:35	23:40
Snack	00:30	00:30	00:30
Hot seat change (ending of shift)	00:10	00:10	
Effective Working Time	06:25	06:25	06:20
Hour of ending effective work	16:35	23:40	06:30
Travel time between Mine Face and Level 11	00:30	00:30	00:30
Amount of time before Group 1 shaft time			
Shaft travel time	00:05	00:05	00:05
Hour of arrival in the surface	17:10	00:15	07:05
Clock out time	17:10	00:15	07:05
Looker room, lunch/dinner, displacement	00:50	00:50	00:50
Bus station arrive	18:00	01:05	07:55
Waiting bus to leave mine site	00:00	00:00	00:00
Mine site entrance departure	18:00	01:05	07:55

Table 20. Spreadsheet used to calculate the effective working time for Group 2 in 8-hour/single blast sub-scenario.

Activity	Group 2		
	Shift 1	Shift 2	Shift 3
Mine site entrance arrival	07:10	13:50	20:55
Clock in time	07:35	14:50	21:20
Surface displacement, snack, locker room, PPE	00:35	00:35	00:35
Blast	07:05		
Shaft line wait	00:15	00:30	00:30
Hour of shaft leaving surface	08:00	14:55	22:00
Shaft travel time	00:10	00:10	00:10
Toolbox meeting, work assignment, pick up bits/materials	00:45	00:15	00:15
Travel time Level 11 - Mine face	00:30	00:30	00:30
Hour of arrival in mine face area	09:25	15:50	22:55
Hot seat change (beginning of shift)		00:10	00:10
Checklist, area inspection	00:20	00:20	00:20
Hour of beginning of effective work	09:45	16:20	23:25
Snack	00:30	00:30	00:30
Hot seat change (ending of shift)	00:10	00:10	
Effective Working Time	05:55	06:25	06:20
Hour of ending effective work	16:20	23:25	06:15
Travel time between Mine Face and Level 11	00:30	00:30	00:30
Amount of time before Group 1 shaft time	00:15	00:15	00:15
Shaft travel time	00:05	00:05	00:05
Hour of arrival in the surface	16:55	00:00	06:50
Clock out time	17:10	00:15	07:05
Looker room, lunch/dinner, displacement	00:50	00:50	00:50
Bus station arrive	17:45	00:50	07:40
Waiting bus to leave mine site	00:15	00:15	00:15
Mine site entrance departure	18:00	01:05	07:55

Table 21. Spreadsheet used to calculate the effective working time for Group 3 in 8-hour/single blast sub-scenario.

Activity	Group 3		
	Shift 1	Shift 2	Shift 3
Mine site entrance arrival	07:10	13:50	20:55
Clock in time	07:35	14:50	21:20
Surface displacement, snack, locker room, PPE	00:35	00:35	00:35
Blast	07:05		
Shaft line wait	00:30	00:15	00:15
Hour of shaft leaving surface	08:15	14:40	21:45
Shaft travel time	00:10	00:10	00:10
Toolbox meeting, work assignment, pick up bits/materials	00:45	00:15	00:15
Travel time Level 11 - Mine face	00:30	00:30	00:30
Hour of arrival in mine face area	09:40	15:35	22:40
Hot seat change (beginning of shift)		00:10	00:10
Checklist, area inspection	00:20	00:20	00:20
Hour of beginning of effective work	10:00	16:05	23:10
Snack	00:30	00:30	00:30
Hot seat change (ending of shift)	00:10	00:10	
Effective Working Time	05:25	06:25	06:20
Hour of ending effective work	16:05	23:10	06:00
Travel time between Mine Face and Level 11	00:30	00:30	00:30
Amount of time before Group 1 shaft time	00:30	00:30	00:30
Shaft travel time	00:05	00:05	00:05
Hour of arrival in the surface	16:40	23:45	06:35
Clock out time	17:10	00:15	07:05
Looker room, lunch/dinner, displacement	00:50	00:50	00:50
Bus station arrive	17:30	00:35	07:25
Waiting bus to leave mine site	00:30	00:30	00:30
Mine site entrance departure	18:00	01:05	07:55

Table 22. Spreadsheet used to calculate the effective working time for Group 4 in 8-hour/single blast sub-scenario.

Activity	Group 4		
	Shift 1	Shift 2	Shift 3
Mine site entrance arrival	07:10	13:50	20:55
Clock in time	07:35	14:50	21:20
Surface displacement, snack, locker room, PPE	00:35	00:35	00:35
Blast	07:05		
Shaft line wait	00:45	00:00	00:00
Hour of shaft leaving surface	08:30	14:25	21:30
Shaft travel time	00:10	00:10	00:10
Toolbox meeting, work assignment, pick up bits/materials	00:45	00:15	00:15
Travel time Level 11 - Mine face	00:30	00:30	00:30
Hour of arrival in mine face area	09:55	15:20	22:25
Hot seat change (beginning of shift)		00:10	00:10
Checklist, area inspection	00:20	00:20	00:20
Hour of beginning of effective work	10:15	15:50	22:55
Snack	00:30	00:30	00:30
Hot seat change (ending of shift)	00:10	00:10	
Effective Working Time	04:55	06:25	06:20
Hour of ending effective work	15:50	22:55	05:45
Travel time between Mine Face and Level 11	00:30	00:30	00:30
Amount of time before Group 1 shaft time	00:45	00:45	00:45
Shaft travel time	00:05	00:05	00:05
Hour of arrival in the surface	16:25	23:30	06:20
Clock out time	17:10	00:15	07:05
Looker room, lunch/dinner, displacement	00:50	00:50	00:50
Bus station arrive	17:15	00:20	07:10
Waiting bus to leave mine site	00:45	00:45	00:45
Mine site entrance departure	18:00	01:05	07:55

The results found on Tables 19 to 22 indicate Group 1 has 6 hours and 23 minutes of effective working time on average. The same indicator is of 6 hours and 13 minutes for Group 2, 6 hours and 03 minutes for Group 3 and 5 hours and 53 minutes for Group 4. The average of all groups resulted in 6 hours and 08 minutes of effective working time per shift, which represents 18 hours and 25 minutes per day. It is possible to notice that the effective working time difference between Groups 1 and 4 is only 30 minutes, while it is 1 hours and 20 minutes for the 6-hour shift.

10-hour and 12-hour shifts in this sub-scenario were modeled to have all groups in all shifts performing a 'hot seat' shift change, which increases the effective working time of the scenario. Also, as all shifts have a longer span, the snack break was extended to 45 minutes to all groups. This scenario did not consider any maximum daily duration spent at the mine site. The results of the spreadsheets used to calculate the effective working time for each group on 10-hour and 12-hour/single blast sub-scenario can be found on Table 23 and Table 24.

Table 23. Spreadsheet used to calculate the effective working time for Group 1 and 2 in 10-hour and 12-hour/single blast sub-scenarios.

Activity	**Group 1**		**Group 2**	
	Shift 1	**Shift 2**	**Shift 1**	**Shift 2**
Mine site entrance arrival	07:10	17:25	07:10	17:25
Clock in time	07:35	17:50	07:35	17:50
Surface displacement, snack, locker room, PPE	00:35	00:35	00:35	00:35
Blast	07:05		07:05	
Shaft line wait	00:00	00:45	00:15	00:30
Hour of shaft leaving surface	07:45	18:45	08:00	18:30
Shaft travel time	00:10	00:10	00:10	00:10
Toolbox meeting, work assignment, pick up bits/materials	00:45	00:15	00:45	00:15
Travel time Level 11 - Mine face	00:30	00:30	00:30	00:30
Hour of arrival in mine face area	09:10	19:40	09:25	19:25
Hot seat change (beginning of shift)		00:10		00:10
Checklist, area inspection	00:20	00:20	00:20	00:20
Hour of beginning of effective work	09:30	20:10	09:45	19:55
Snack	00:45	00:45	00:45	00:45
Hot seat change (ending of shift)	00:10		00:10	
Effective Working Time	09:45	09:35	09:15	09:35
Hour of ending effective work	20:10	06:30	19:55	06:15
Travel time between Mine Face and Level 11	00:30	00:30	00:30	00:30
Amount of time before Group 1 shaft time			00:15	00:15
Shaft travel time	00:05	00:05	00:05	00:05
Hour of arrival in the surface	20:45	07:05	20:30	06:50
Clock out time	20:45	07:05	20:45	07:05
Looker room, lunch/dinner, displacement	00:50	00:50	00:50	00:50
Bus station arrive	21:35	07:55	21:20	07:40
Waiting bus to leave mine site	00:00	00:00	00:15	00:15
Mine site entrance departure	21:35	07:55	21:35	07:55

Table 24. Spreadsheet used to calculate the effective working time for Group 3 and 4 in 10-hour and 12-hour/single blast sub-scenarios.

Activity	Group 3		Group 4	
	Shift 1	Shift 2	Shift 1	Shift 2
Mine site entrance arrival	07:10	17:25	07:10	17:25
Clock in time	07:35	17:50	07:35	17:50
Surface displacement, snack, locker room, PPE	00:35	00:35	00:35	00:35
Blast	07:05		07:05	
Shaft line wait	00:30	00:15	00:45	00:00
Hour of shaft leaving surface	08:15	18:15	08:30	18:00
Shaft travel time	00:10	00:10	00:10	00:10
Toolbox meeting, work assignment, pick up bits/materials	00:45	00:15	00:45	00:15
Travel time Level 11 - Mine face	00:30	00:30	00:30	00:30
Hour of arrival in mine face area	09:40	19:10	09:55	18:55
Hot seat change (beginning of shift)		00:10		00:10
Checklist, area inspection	00:20	00:20	00:20	00:20
Hour of beginning of effective work	10:00	19:40	10:15	19:25
Snack	00:45	00:45	00:45	00:45
Hot seat change (ending of shift)	00:10		00:10	
Effective Working Time	08:45	09:35	08:15	09:35
Hour of ending effective work	19:40	06:00	19:25	05:45
Travel time between Mine Face and Level 11	00:30	00:30	00:30	00:30
Amount of time before Group 1 shaft time	00:30	00:30	00:45	00:45
Shaft travel time	00:05	00:05	00:05	00:05
Hour of arrival in the surface	20:15	06:35	20:00	06:20
Clock out time	20:45	07:05	20:45	07:05
Looker room, lunch/dinner, displacement	00:50	00:50	00:50	00:50
Bus station arrive	21:05	07:25	20:50	07:10
Waiting bus to leave mine site	00:30	00:30	00:45	00:45
Mine site entrance departure	21:35	07:55	21:35	07:55

The results found on Tables 23 and 24 indicate that Group 1 has 9 hours and 40 minutes of effective working time on average. The same indicator is 9 hours and 25 minutes for Group 2, 9 hours and 10 minutes for Group 3 and 8 hours and 55 minutes for Group 4. The average of all groups resulted in 9 hours and 17 minutes of effective working time per shift, which represents 18 hours and 35 minutes per day. These scenarios returned the longest shift duration in terms of effective working time of the study, up to 9 hours and 40 minutes, which is 3 hours and 16 minutes longer than the longest shift of the 8-hour shift.

Based on the information on 6-hour, 8-hour, 10-hour, and 12-hour shifts with single blast daily, we can conclude that all personnel rotations in a hot seat configuration might be efficient, reducing unproductive time. Table 25 below presents the possibilities for 6-hour, 8-hour, 10-hour, and 12-hour shifts in the sub-scenario of a single blast daily. Due to the decreased necessity of evacuating personnel from the mine for blasting operations, the number of "unproductive areas" in these situations depicted in Figure 7 is reduced to two for 8-hour, 10-hour, and 12-hour shifts. For the 6-hour shift, due to maximum daily duration of 8 hours and 30 minutes spent at the mine site, there are five "unproductive areas". It is not a surprise that these scenarios have the highest mine utilization. The 6-hour shift of a single blast has 11.5% higher mine utilization than the same shift of two blasts. Mine utilization by switching from the 6-hour to 8-hour shift of this sub-scenario is increased by 9%. In a similar manner comparing the 8-hour scenario to the 10/12-hour scenarios, an increase in mine utilization of only 0.7%. As described in previous sub-scenario, the incremental step of mine utilization between the 8-hour shift and 10-/12-hour shift is smaller than increase between 6-hour scenario and 8-hour shift due to the longer snack breaks required for longer shifts. Figure 5 summarizes various shift durations, effective working hours per shift/day under the sub-scenario of single blast daily and shows the reduction in unproductive time by decreasing times of transition of shift crew as well as decreasing times of the suspension of operations due to blasting in a day.

Table 25. Description of work shifts, effecting work time per shift per day, and mine utilization for one blasting scenario.

Scenario – Shifts Hours	Number of Shifts per Day	Average Effective Working Time per Shift	Effective Working Time per Day	Mine Utilization
6h Shift	4	04:03	16:15	67.7%
8h Shift	3	06:08	18:25	76.7%
10h Shift	2	09:17	18:35	77.4%
12h Shift	2	09:17	18:35	77.4%

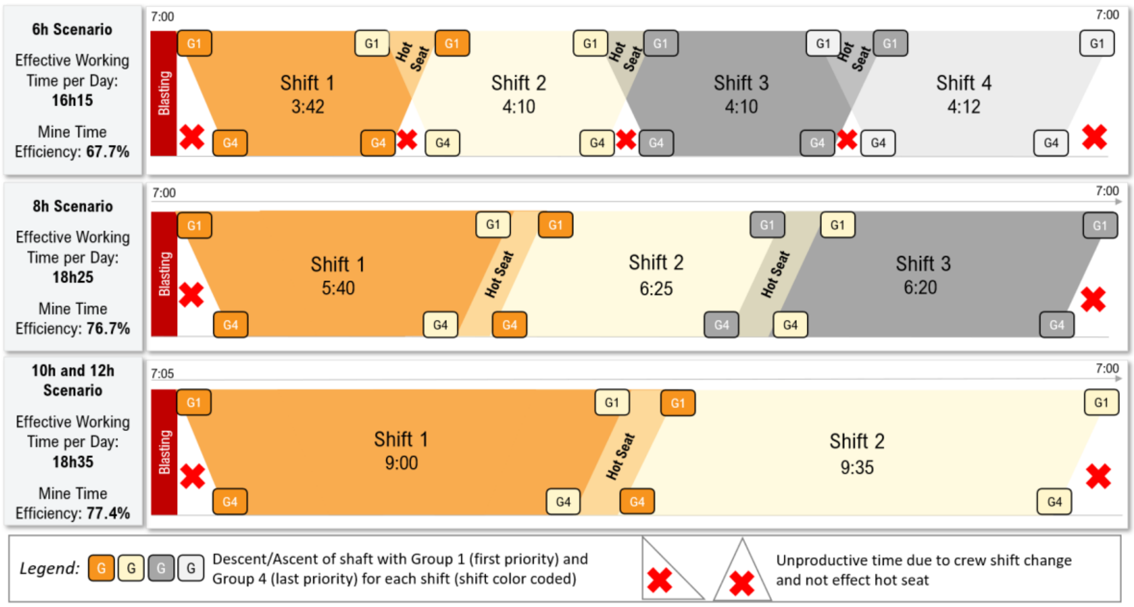

Figure 8. Visual representation of the scenarios with a single blast time and unproductive time in the shifts.

Upon analyzing the outcomes of both sub-scenarios (one and two blasts per day), it becomes evident that opting for a single blast per day is the optimal approach for maximizing daily productivity. Mine utilization is notably superior, with an average increase of 12.5% compared to any situation that includes two blasts daily. The results also demonstrated the influence of altering shift durations on employee groups' daily effective working time. Group 1 employees, who work in development, drilling, and blasting, are given the highest priority for underground access. On the other hand, Group 4 employees, who are involved in rock mechanics and include key contractors, are given the lowest priority. As previously mentioned, the order of priority might be modified according to the mine's requirements throughout the year. In the first scenario, employees belonging to Group 1 are the first to go down into the mine and the last to come back up, whereas Group 4 follows the opposite order. Thus, Group 1 has the most Effective Working Time daily. The images in Figure 9 and Figure 10 illustrate the variations in the Effective Working Time per Day for Groups 1 and 4 in each scenario, considering the total number of hours worked by all workers from these groups daily.

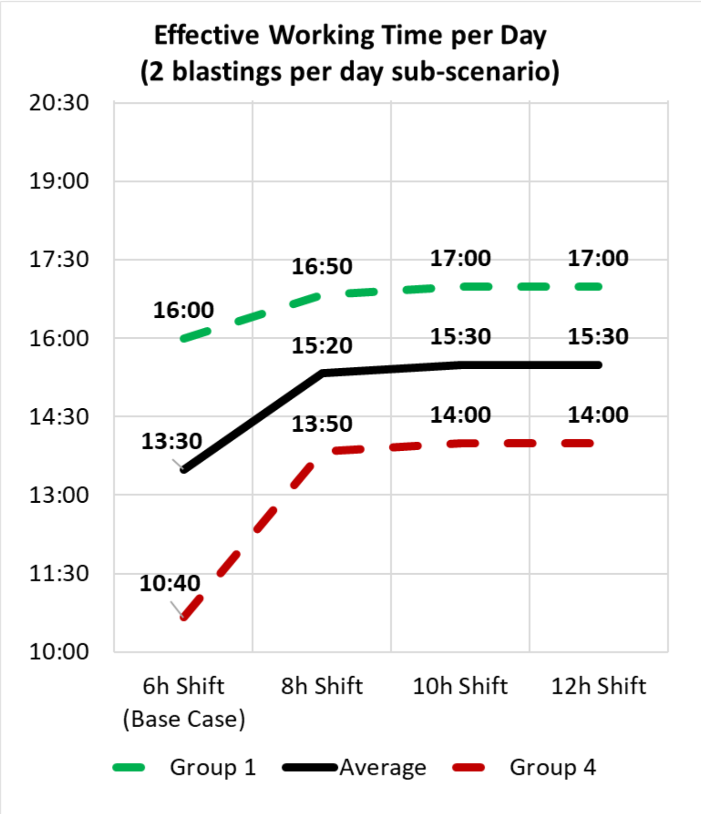

Figure 9. Effective Working Time per Day for Groups 1 and 4, determined by the average working hours of all employees for 2 blastings per day sub-scenario.

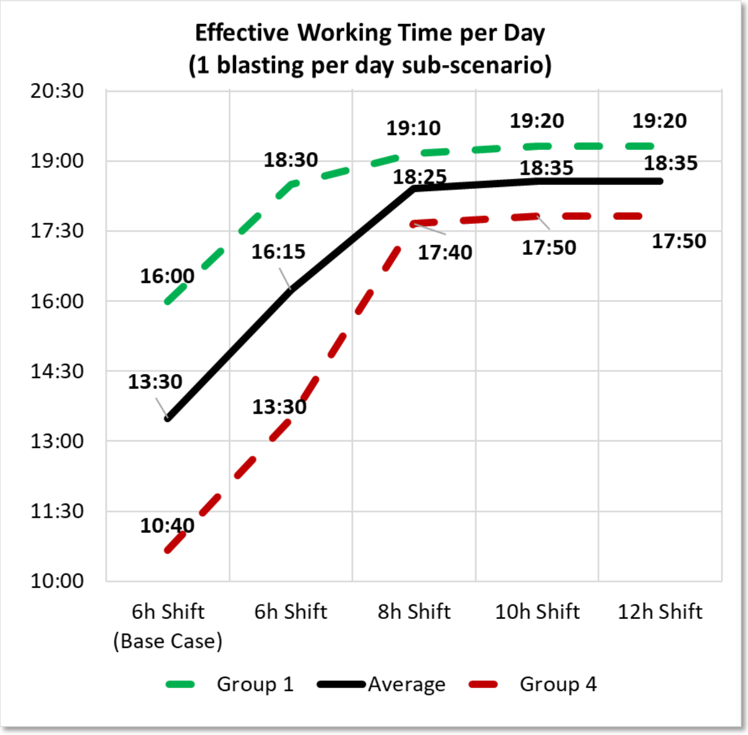

Figure 10. Effective Working Time per Day for Groups 1 and 4, determined by the average working hours of all employees for 1 blasting per day sub-scenario.

Both graphs indicate that Group 4 experiences the greatest benefit from changing the shift lengths. In the sub-scenario with two blasts per day, the transition from 6-hour- to 8-hour shifts leads to an increase in the effective working time of 3 hours and 10 minutes for Group 4. Group 1 experiences an increase of 50 minutes in the same shift duration. In the case of 10/12-hour shifts, Group 4 sees an increase of 3 hours and 20 minutes, while Group 1 sees an increase of 1 hour compared to the base case. When there is only one blast per day in the sub-scenario, the effective working time increase is even more significant. Group 4 has an increase of up to 2 hours and 50 minutes, while Group 1 experiences an increase of 2 hours and 30 minutes, compared to a 6-hour shift with two blasts per day. In the sub-scenario of a single blast per day, Group 4 saw a 4 hours and 10 minutes increase in shift duration when transitioning from a 6-hour- to an 8-hour shift. Group 1 experienced a 40-minute increase in effective working time. Additionally, in the case of 10/12-hour shifts, it is only 10 minutes more than the 8-hour shift. Moreover, the graphs demonstrate that increasing the duration of a shift beyond 8 hours does not yield significant advantages in either sub-scenario. Additionally, scenarios including one blast per day are advantageous for an underground mine.

5 DISCUSSION

The findings indicated a positive correlation between the shift duration and the Mine Utilization, in which increasing duration of the shift will increase the Mine Utilization, thus the effective working hours. The linear correlation for sub-scenario 1 is R2=0.67 and for sub-scenario 2 is R2=0.66. The quadratic polynomial correlations for sub-scenario 1 and sub-scenario 2 are R2=0.96. The correlation is better expressed in a quadratic polynomial function than a linear function because the most significant rise in Mine Utilization is observed when transitioning from a 6-hour to an 8-hour shift. Even though there is a little increase between 8-hour and 10-hour shifts, there is no noticeable disparity between the 10-hour and 12-hour shifts.

Analyzing the results in terms of groups, for both Group 4 and Group 1, the effective working time increased in the two blasts sub-scenario. When comparing all shifts to the base case, the effective working time for Group 4 increases by an average of 3 hours and 17 minutes for sub-scenario 1 and 6 hours for sub-scenario 2. In comparison to the base case, Group 1 experiences an average increase of 57 minutes for sub-scenario 1, and 3 hours and 5 minutes for sub-scenario 2. Based on these results, Group 4, which has the lowest EWT in the base case, experiences the greatest improvement when the shift durations are altered. Group 1, which has the greatest EWT in the base case, experiences the least amount of improvement. Although variations in the EWT may impact the production of gold ounces, this study will not engage in a discussion on this matter, as it could potentially disclose sensitive corporate information.

The Brazilian legislation, implemented in 1943, stipulates that the maximum duration of underground work shifts is six hours, and this regulation is still in force at present. The motivation behind this study is the inefficiencies of the current shift pattern, especially considering the substantial progress made in occupational health and safety, particularly in deep mines, during the past eighty years. The use of air-conditioning machinery has enhanced the efficiency of mine ventilation systems. At the same time, the development of personal protection equipment such as masks, hard helmets, lamps, and boots has significantly revolutionized the working environment in underground mines. Moreover, the installation of refuge rooms has additionally contributed to the creation of safer working environments. These technological developments have led to other mining nations, such as Australia and Chile, increasing the maximum length of underground work shifts to 12 hours. Considering these enhancements, it may be necessary to reassess the conventional six-hour work schedule to maximize productivity while maintaining worker safety. Delaying this review could harm the economic viability of developing new underground mines or investing in brownfield operations in the country. The optimal shift rostering system for the mining industry must consider and balance employee needs, operational requirements, and OHS standards. When evaluating shift periods and fatigues, it is imperative to consider multiple factors and tailor the assessment to the specific requirements of each operation. For the effective implementation of changes to shift periods, consultation among stakeholders, including mining corporations and worker representatives is vital.

Altering legislation in Brazil entails a protracted procedure that necessitates endorsement from the Chamber of Deputies and the Senate, followed by the President's authorization. The duration of this procedure may span several months, encompassing various stages such as committee evaluation and public hearings. Following these procedures, the suggested alteration is presented to the legislative chambers for a vote and may not get approval. Hence, according to this study's findings, a viable objective for enhancing production in Brazil's underground deep mines would be to decrease the frequency of blasting each day in the short to medium term. Nevertheless, transitioning to a single blast daily poses its own logistical difficulties. A greater quantity of mine faces being detonated simultaneously, necessitating a more developed mine with more producing zones. This could result in elevated operational expenses and heightened investment requirements.

6 CONCLUSION

This study examined the most advantageous duration for a shift in a deep underground mine analyzing predetermined shifts of 6-hour, 8-hour, 10-hour, and 12-hour duration. The scenarios were categorized into two subgroups: one consisting of two blasts and the other consisting of one blast daily. The ideal duration of a shift was established by comparing the Mine Utilization of each scenario. The most significant increase in Mine Utilization was observed when transitioning from a 6-hour to an 8-hour shift (8.3% on average). It is possible to notice a small increase in the Mine Utilization between 8-hour and 10-hour shifts (0.7% on average), but there is no noticeable disparity between the 10-hour and 12-hour shifts. In terms of effective working time per shift, it increases 1 hour and 54 minutes on average from 6-hour to 8-hour shift pattern, and it increases 2 hour and 53 minutes on average from 8-hour to 10-hour/12-hour shifts pattern.

Analyzing the minimal increase in Mine Utilization of just 0.7% and the substantial increase in effective working shift duration of almost 3 hours when comparing the 8-hour shift to the 10- and 12-hour shifts, it is reasonable to conclude that the 8-hour shift appears to be the most optimal pattern. When comparing both subgroups (one blast and two blasts), the scenarios considering only one blast period per day presented a substantial increase of 12.45% in Mine Utilization on average. Therefore, it is reasonable to conclude that performing one period of blast per day appears to be the most optimal pattern. These assessments are based on balancing efficiency and longer working hours, where minimal gains do not justify the added workload and potential strain on workers. Also, these assessments can be generalized for deep underground mines in Brazil, which shares the similar characteristics as the necessity to halt operations for blasting, considerable amount of time spent on underground displacement to arrive and to leave an operational area, necessity of multiple shaft trips to hoist employees per shift.

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