International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Journal Européen des Systèmes Automatisés
Vol. 57, No. 2, April, 2024, pp. 517-531
Journal homepage: http://iieta.org/journals/jesa

Optimizing Time in Horizontal Mining Excavations: 10 Formats Inspired by Value Stream Mapping Principles

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https://doi.org/10.18280/jesa.570221

Received: 5 February 2024
Revised: 2 April 2024
Accepted: 17 April 2024
Available online: 28 April 2024

Keywords:
mining cycle; productivity; performance; value stream mapping, current phase

ABSTRACT

In this research, 10 formats are proposed as a single instrument, for taking mining cycle times based on the principles of the value chain map tool. As part of the methodology, we applied the 10 proposed formats in time recording, we analyzed the productive, contributory and non-contributory times, for this we used the Ishikawa diagram that shows us which activities have the greatest impact on low productivity in the horizontal excavations (Mining Cycle) later the mapping of the current state was carried out, finally the time efficiency was processed and calculated. To validate the results, we applied the proposal in the Esmeralda mining company, in its El Teniente mine for 4 months. As a result, we revealed that from a total cycle time of 22.85 hours: the productive time was 13.22 hours, the Contributory time was 4.53 hours and non-contributory time was 5.11 hours. We also revealed that the activities that show the lowest performance are: ventilation, marine loading, coining and drilling. The final conclusion is based on the contribution of the 10 formats and is applicable to underground mining companies who can use the 10 proposed formats to analyze productive, contributory and non-contributory times, and then take corresponding actions.

1. INTRODUCTION

The mining industry plays a crucial role in the extraction of minerals and natural resources essential to society [1]. In the context of subway mining operations, it is critical to understand and successfully manage productive times (PT), contributory times (CT) and non-contributory times (NCT). These times represent an integral part of the efficiency and profitability of any mining operation and have a direct impact on mine productivity, safety and profitability [2]. Each time is detailed as follows.

- Productive times refer to those activities in which the exploitation of horizontal excavations is carried out to prepare and exploit the mine. These activities are important in the mining operation and constitute the main source of income.
- Contributory times are related to activities of the mining cycle, which although not directly involved, contribute significantly to the mining process, preparation of work fronts, services (water, electricity, fuel, ventilation).
- Finally, non-contributory times include all activities that do not directly contribute to the main objective of the operation, such as waiting time, idle time or internal transportation.

Effective management of these three types of time is essential to optimize efficiency and ensure safety in subway mining operations.

The application of lean tools is very favorable for organizations, be it productive, commercial or service organizations, since it adjusts to the type of economic activity; it also has easy to understand tools such as; takt time, 5S, Eight wastes, Visual control or management at first sight, Manufacturing Cells, Poka Yoke, Jidoka, Intelligent automation such as, Kaisen, Kanban, SMED, Heijunka TPM or total productive maintenance [3, 4]. However, the Value Stream Mapping (VSM) tool presents significant advantages for evaluating the efficiency of the mining cycle compared to other lean tools. Its ability to offer a comprehensive view of the mining process, identify specific waste, focus on customer value and encourage continuous improvement make it a solid choice. By providing a detailed visual representation of the value stream and encouraging collaboration between teams, VSM is positioned as an effective tool to address the complexities of the mining sector and optimize its operations because the methodology processes are simple. Therefore, in this study "Value Stream Mapping".

Thus, the Value Stream Mapping (VSM) tool is presented as the appropriate option to establish the real conditions in mining, since it is a good tool to analyze and improve processes in a wide range of industries, allowing a detailed evaluation of production times and the identification of areas for improvement, considering that the optimization of the use of resources is a matter of great importance in the industry in general, being even more demanding in mining and construction [5-7].

The VSM allows a clear and detailed visualization of the production stages and processes involved in the generation of value, which helps to identify areas for improvement and opportunities to increase productivity and reduce production time and costs [8].

On the implementation of lean to improve production times in mining, there are reported cases of implementation in mining development projects [9]. Therefore, this sector is identified as the area that presents the greatest potential for lean implementation in the mining industry through the determination of mining cycle times.

Thus, in the mining industry, the study [10] is analyzed, where a subway mining development project was selected and implemented lean in tunnel excavation works, specifically in the levels of production, sinking, intermediate transport, ventilation and crushing. This implementation was divided into three stages: diagnosis, implementation and control. After analyzing the results of this research, we can indicate that the implementation of lean methods in subway mining development projects in execution has a positive impact on their performance. In particular, the results of this research indicate that the implementation of lean methodologies significantly improve the mean values. On the other hand, the results indicated that the implementation of lean methodologies produces a statistically significant reduction in variability in project performance. Although the results of this application were positive, there are some limitations. Therefore, the addition of other indicators could be considered, such as the behavior of the system in the blasting process, which generates impacts on all the activities of the mining cycle that would allow establishing results of greater impact.

Seifullina et al. [9] analyze a fluorspar mining company of the Votorantim Group, where the mapping of the productive process was performed using TPS concepts and techniques. They indicated that drilling and blasting (together form 45%) are considered essential operations. Preparation (14%) consists of connecting compressed air hoses, among other activities, and is considered an auxiliary operation.

Drill bit sharpening (<1%), change of clothes (2%), travel (10%) and lunch time (5%) are also considered auxiliary operations. Rest time (8%) is an auxiliary operation as it relieves miner fatigue, but is not directly critical to performing the primary operation. Useless operations include waiting (14%) and ventilation (1%), which make up 15% of the operating time performed. It was found that essential drilling and blasting operations were performed individually by the same driller who was responsible for sharpening drill bits and retrieving explosives. This generated downtime of the drilling rig while the driller performed the auxiliary tasks [9].

On the other hand, Lööw [11] presented their research the practice of lean production in mining, where they used idea translation theory. The purpose of their research was to detail how the mining industry has implemented and practiced lean production. The findings suggest that the form and extent of lean production in mining differs from other industries due to the characteristics of the industry. However, there are still blind spots related to the practice that is not reported in the type of material investigated.

Reviewing in the case of the mining company Codelco in the El Teniente Division in the Esmeralda mine regarding mining productivity by applying lean tools, as a result they had not been meeting the expected production, generating low productivity in the activities of the mining cycle, so, they hired the company Green Ingenieria & Consultoria Limitada in 2018, who diagnosed the three main problems that generated delays for the compliance of the effective hours in posture of the mining cycle; being the main activities: equipment handling, manpower and reportability in the mining cycle, directly affecting the 6.3 hrs of work available in posture per shift [12] as a consequence the specialized company has detected that the effective working times in posture per shift are only 4.94 hrs, affecting 21.5% of available work in posture per shift [13]. From this previous information, we conducted a study based on interference management, process management and reportability.

The objective of the research is to propose 10 formats based on the principles of the Value Stream Mapping tool: (1) Family of products, (2) Diagram of the current state to determine the efficiency of times in horizontal mining excavations, these formats allow determining the unproductive times or activities in the mining cycle of in a subway mine.

With the proposal, it is possible to identify unproductive times in the mining cycle, the formats lead to a more efficient allocation of available resources. Moreover, operational efficiency is closely linked to cost reduction. The identification and elimination of unproductive times in horizontal mining excavations can contribute significantly to the reduction of operating expenses. All this helps to optimize mining cycle times, allowing more activities to be performed in the same period, which translates into increased productivity and production.

In this context, we will explore in detail how to identify, measure and improve productive times (PT), contributory times (CT) and non-contributory times (NCT) in a subway mine.

This research focuses on the application of the lean philosophy, specifically using its "Value Stream Mapping" (VSM) tool as it allows to evaluate and optimize the productive times in horizontal mining excavations.

2. MATERIALS AND METHODS

Proposal of 10 formats for time taking in mining cycle activities.

The methodology used in this study for the development of 10 formats for data collection was carried out through the following steps:

Comprehensive analysis of the mining cycle: A detailed study of each stage of the mining process was carried out to identify critical areas, such as operation times, material consumption and operational interferences.

Interdisciplinary collaboration: A multidisciplinary team was formed with mining experts, process engineers and other professionals, integrating diverse perspectives and specialized knowledge in the development of the formats.

Review of best practices and lessons learned: Previous projects were reviewed and best practices in data collection in the mining industry were analyzed to avoid common mistakes and take advantage of lessons learned.

Design of clear and concise formats: Clear and easy-to-complete formats were designed, with specific fields to capture relevant information and guarantee the consistency and accuracy of the data.

Iteration and feedback: An iterative review and feedback process was carried out, where the formats were tested and refined in the field with feedback from users, ensuring their practical usefulness and effectiveness in the field.

Therefore, the final product, the 10 proposed formats, allow the objective of the research to be efficiently addressed.

To apply the proposal of the 10 formats inspired by the lean methodology in the mining industry in horizontal excavations, (1) Family of products, (2) Diagram of the current state, during the months of August to February 2021, have been considered. The chosen study location was in Chile, Codelco, El Teniente Division, Esmeralda mine-Block Caving exploitation method at the production level, 100 meters from the horizontal excavations, from the Mine Works Management in mining preparation.

2.1 Stage 1 product family

In the development of this proposal adapted to the mining cycle of horizontal excavations, in order to identify the family of products that are subject to evaluation, we propose to carry out the following activities:

A. Management meeting to address low productivity in mining excavations. All departments involved participate.
B. Training of the management on the mining cycle and procedures to improve productivity and efficiency.
C. Selection of a specialized crew to identify and solve the problem of low productivity in the mining field.
D. Make the instruments to measure what is to be measured, for the case study will be the productive, contributory and non-contributory times of each activity of the mining cycle.

In order to execute the procedures (A, B, C and D), it is important to establish which are the activities that correspond to a mining cycle, as well as the units in which they should be measured, which will be the family of products to be studied.

After having identified the family to be mapped, we proceed to collect all the necessary data to carry out the research, in this case these data correspond to the times of the activities of the mining cycle, this allows us to design the current Value Stream Map.

For this purpose, formats have been proposed, whose contents represent in numbers the activities that are executed to achieve the development of an activity, among which are the activities that generate productive times (PT), contributory times (CT) and non-contributory times (NCT), subsequently in each card the itens (a, b, c) of the percentage of productive times (PT), contributory times (CT) and non-contributory times (NCT) are calculated, in each activity respectively.

This process is composed of a set of activities that follow an orderly, sequential and correlational process that is fulfilled in all the executions of a mining cycle of mining in general, its order goes as follows: ventilation, marine removal, wedging, fortification drilling, bolt grouting, mesh installation, spinning, shotcrete casting, face drilling and explosives loading, from which the productive times (PT), contributory times (CT) and non-contributory times (NCT) times will be calculated.

The time taking formats for each activity require careful measurement to identify the productive, contributory and non-contributory phases, since a series of procedures are carried out for the execution of each activity, such as inspection of the work area, compliance with checklists, crane entry, isolation of the work area, equipment transfer, installation and removal, which are the procedures that generate the contributory times for each activity. On the other hand, the execution of the activity itself represents the net productive time and, added to this, non-contributory times are produced, which represent opportunities for improvement, for which Tables 1-9 are presented as a proposal.

Table 1. Proposed format for time recording in the ventilation activity

Ventilation Emerald Mine Sinking Level and Production-Times in Seconds [s]				
N°	**Description**	**Take 01**	**Take 02**	**Take N**
	Activity Start time			
	Activity End time			
1	Evaluation of the area to be worked on			
2	Enabling the work area			
3	Confinement of the area			
4	Registration Check list			
5	Installation of the ventilation duct with crane at 30m from the front of the posture			
6	Turn on and check the ventilation sleeve			
7	Gas Level Verification			
8	Remove Crane			
a	Productive Times			
b	Contributory Times			
c	Non-contributory Times			
	Total time in minutes [min]			

Table 2. Proposed format for time recording in the marine loading activity

Marine Loading Esmeralda Mine Sinking Level and Production-Times in Seconds [s]				
N°	**Description**	**Take 01**	**Take 02**	**Take N**
	Activity Start time			
	Activity End time			
1	Inspection of the work area			
2	Registration checklist			
4	Confinement of the area			
3	Limpieza de marina			
4	Limpieza hastiales y zapatera			
a	Productive Times			
b	Contributory Times			
c	Non-contributory Times			
	Total time in minutes [min]			

Table 3. Proposed format for time recording in the wedging activity

Wedging Mina Esmeralda Sinking Level and Production-Times in Seconds [s]				
N°	**Description**	**Take 01**	**Take 02**	**Take N**
	Activity Start time			
	Activity End time			
1	Inspection of the work area			
2	Registration checklist			
3	Illumination			
4	Labor crown wedging machine			
5	Labor boxes wedging machine			
6	Labor front wedging machine			
7	Marking for holding bolts			
a	Productive Times			

b	Contributory Times				
c	Non-contributory Times				
	Total time in minutes [min]				

Table 4. Proposed format for time recording in the drilling and bolts activity

Drilling and bolts Mina Esmeralda Sinking Level and Production-Times in Seconds [s]				
N°	**Description**	**Take 01**	**Take 02**	**Take N**
	Activity Start time			
	Activity End time			
1	Inspection of the work area			
2	Confinement of the area			
3	Registration checklist			
4	Positioning Jumbo at the front			
5	Water and power installation			
6	Water pump installation			
7	Bolt drilling			
8	Split set drilling			
9	Uninstallation of jumbo set and water pump			
a	Productive Times			
b	Contributory Times			
c	Non-contributory Times			
	Total time in minutes [min]			

Table 5. Proposed format for time recording in bolt grouting activity

Bolt grouting Mina Esmeralda Sinking Level and Production-Times in Seconds [s]				
N°	**Description**	**Take 01**	**Take 02**	**Take N**
	Activity Start time			
	Activity End time			
1	Inspection of the work area			
2	Registration checklist			
3	Crane entry			
4	Confinement of the area			
5	Transfer of fortification elements			
6	Installation of air pump			
7	Grouting and bolt placement			
9	Jumbo equipment and air pump uninstallation			
a	Productive Time [min]			
b	Contributory Times [min]			
c	Non-contributory Times [min]			
	Total time in minutes [min]			

Table 6. Proposed format for time recording in spinning activity

Spinning Mina Esmeralda Sinking Level and Production-Times in Seconds [s]				
N°	**Description**	**Take 01**	**Take 02**	**Take N**
	Activity Start time			
	Activity End time			
1	Inspection of the work area			
2	Registration checklist			
3	Crane entry			
4	Confinement of the area			
5	Spinning			
6	Crane removal			
a	Productive Times			
b	Contributory Times			
c	Non-contributory Times			
	Total time in minutes [min]			

Table 7. Proposed format for time recording in shotcrete activity

Shotcrete Mina Esmeralda Sinking Level and Production-Times in Seconds [s]				
N°	**Description**	**Take 01**	**Take 02**	**Take N**
	Activity Start time			
	Activity End time			
1	Inspection of the work area			
2	Registration checklist			
3	Preparation of projection equipment			
4	Water and air installation			
5	Mixer checklist registration			
6	Mixer installation			
7	Confinement of the area			
8	Concrete spraying			
9	Uninstallation of equipment			
a	Productive Times			
b	Contributory Times			
c	Non-contributory Times			
	Total time in minutes [min]			

Table 8. Proposed format for time recording in face drilling activity

Face Drilling Mina Esmeralda Sinking Level and Production-Times in Seconds [s]				
N°	**Description**	**Take 01**	**Take 02**	**Take N**
	Activity Start time			
	Activity End time			
1	Inspection of the work area			
2	Confinement of the area			
3	Registration checklist			
4	Positioning Jumbo at the front			
5	Water and power installation			
6	Installation of water pump			
7	Drilling			
8	Uninstallation of Jumbo equipment and water pump			
a	Productive Times			
b	Contributory Times			
c	Non-contributory Times			
	Total time in minutes [min]			

Table 9. Proposed format for time recording explosive loading activity

Explosive Loading Mina Esmeralda Sinking Level and Production-Times in Seconds [s]				
N°	**Description**	**Take 01**	**Take 02**	**Take N**
	Activity Start time			
	Activity End time			
1	Inspection of the work area			
2	Confinement of the area			
3	Registration checklist			
4	Face drilling untie			
5	Evaluation and cleaning of the shots			
6	Loading of each shot with crane			
7	Detonating cord and safety fuse connection			
a	Productive Times			
b	Contributory Times			
c	Non-contributory Times			
	Total time in minutes [min]			

After the identification of the family of products corresponding to stage 1 of the VSM, it takes time to proceed to execute the methodology for the calculation of productivity indicators in the field. The final indicators are defined as the average obtained from all the measurements taken. Apply the calculation of productivity indicators described below.

Proceed to calculate the productive, contributory and non-contributory times for each activity of the mining cycle.

Total Cycle Time (TCT): To obtain the total cycle time, the durations in seconds of the horizontal development activities in the shift must be added up.

Productive Time Percentage (PTP): It is calculated as the percentage of time that the productive time TP represents over the total cycle time.

$$PTC = \frac{TP}{TCT} * 100 \quad (1)$$

Contributory Time Percentage (CTP): It is calculated as the percentage of time represented by the contributory time CT over the total cycle time.

$$PTC = \frac{TC}{TCT} * 100 \quad (2)$$

Non-Contributory Time Percentage (NCTP): Calculated as the percentage of time represented by non-contributory time NCT over the total cycle time.

$$PTC = \frac{TNC}{TCT} * 100 \quad (3)$$

Production (P): The yield is calculated by dividing the time of flow units processed by the activity over the man-hours invested.

$$P = \frac{Activity\ in\ linear\ meters}{number\ of\ operationsxworking\ hours} = ml/HH \quad (4)$$

Yield (Y): Yield is calculated by dividing the number of operators per hours worked by the activities in linear meters.

$$R = \frac{number\ of\ operatorsxworking\ hours}{activity\ in\ linear\ meters} = HH/ml \quad (5)$$

Once the results of the productive, contributory and non-contributory times have been established, the Ishikawa diagram should be applied as an instrument as shown in Figure 1, to identify the activities that generate the focus of the problem, using the Ishikawa matrix as a tool that allows us to verify the point of low productivity, which will allow us to carry out stage 2 (Current State Diagram) of the Value Stream Map methodology process.

The Ishikawa analysis helps to identify the root causes of low productivity and high non-contributory times related to the mining cycle, as shown in Figure 2. By addressing these root causes, it allows us to improve the efficiency of operations and reduce the problems associated with low productivity in the mining cycle. This data will be used to apply Table 10, where productive times (PT), contributory times (CT) and non-contributory times (NC) will be determined.

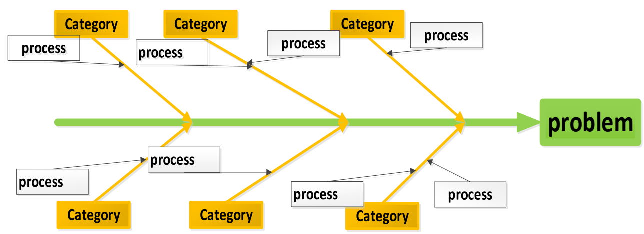


Figure 1. Determination of the focus of the problem

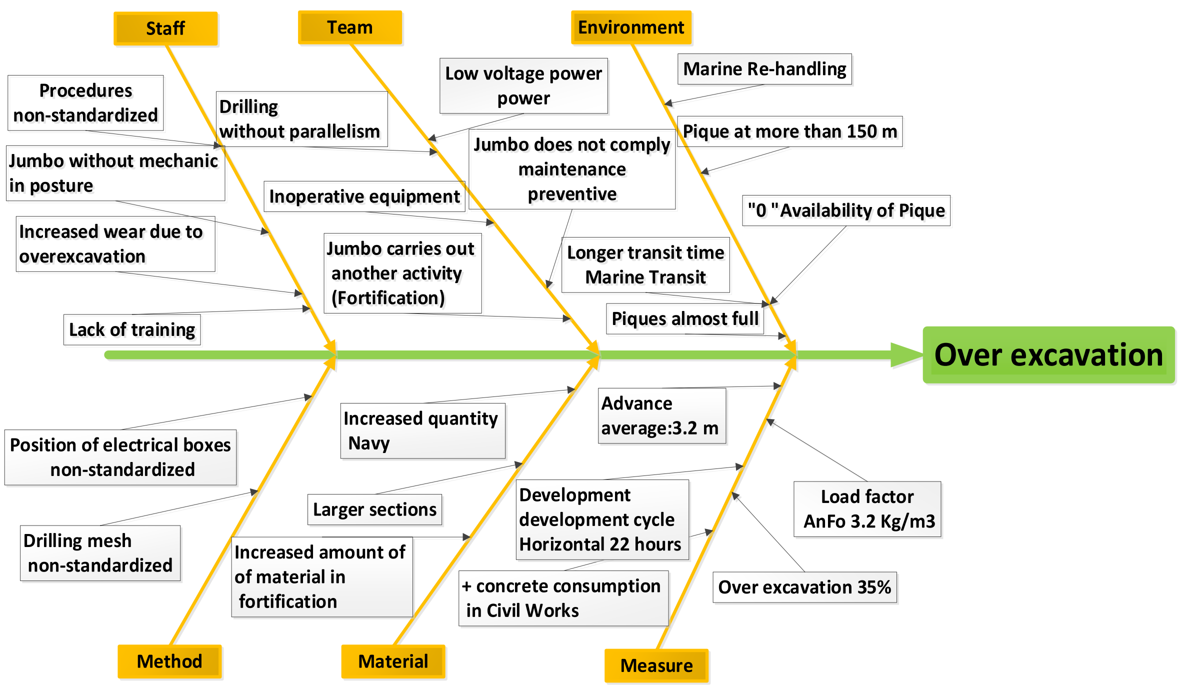


Figure 2. Results of the application of the Ishikawa diagram

After determining the productivity equations and establishing the indicators for each activity, Table 10 is proposed.

Table 10. Control sheet of productive, contributory and non-contributory times

Mining Cycle Activity Times in [%]				
N°	Activity	PT%	CT%	NCT%
1	Ventilation			
2	Marine loading			
3	Wedging			
4	Dilling bolt and Split set			
5	Grouting and bolting			
6	Spinning of fortification mesh			
7	Fortification with shotcrete			
8	Face drilling			
9	Face loading			
	Overall Average Activity			

The Ishikawa analysis is performed to know what the effect of longer times or lower efficiency is.

To determine which are the activities with the lowest efficiency, we consider the recommendation established by (Vogel, 1996), who maintains that quantitative values of efficiency above 70% are good.

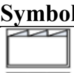
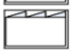
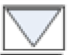
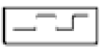
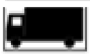
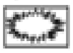
Once stage 1 of the VSM process has been completed, the current state diagram must be executed, having recognized in the first stage the activities that produce lower performance, according to the theory of Vogel, 1996, the reasons that make these activities less productive must then be established graphically.

In order to facilitate a deeper understanding of value chain maps in the context of the mining industry, a valuable tool is presented: an adaptation of the value chain mapping scheme developed by Porter in 1985.

This version emphasises the usefulness of the instrument and highlights its value to better understand value chain maps in the mining industry, taking into account Table 11, we proceed to construct the value chain map (VSM) to execute the development of the proposal.

Using Table 11, it is recommended to execute the current state value chain map.

Table 11. Symbology for the construction of value chain maps

Symbol	Name	Meaning
	External agent	Represents a supplier or customer.
	Activity	Represents an activity processing units.
	Pushed flow	Represents units being driven by the production of an activity.
	Supermarket	Represent kanban supermercad.
	Inventory	Represents the inventory.
	Production control	Represents the entity in control of production.
	Manual information	Represents the flow of information by manual means.
	Timeline	It shows in its valleys the time of activity that add value and in the moments in which they do not.
	Data box	Contains the indicators corresponding to the activity.
	Transportation	Represents the transportation of material from an off-site location to the job site.
	Retirement Kanban	Represents the flow of retirement kanban cards.
	Kaizen Event	Represents a kaizen event and the improvements to be implemented.
	Operator	Represents a worker performing an activity.

3. RESULTS

The validation of our proposed formats, based on the principles of the Value Stream Mapping tool, has proven to be highly effective in assessing and improving time efficiency in horizontal mining excavations. This innovative approach has been tested in a real environment, at the Esmeralda mine, in its El Teniente division located in the southern country of Chile.

In this validation process, we have had the collaboration of Geovita S.A., a company specialized in the execution of subway works, excavations with their associated fortifications, assemblies and civil works associated with mining, road and hydroelectric projects, responsible for the management of the activities related to the mining cycle in the El Teniente Mine. The experience and knowledge provided by Geovita have been fundamental to ensure the success and applicability of our proposal.

Our 10-format proposal, supported by the Value Stream Mapping methodology, offers a comprehensive and effective approach to evaluate and optimize horizontal mining excavation processes. The results of this validation highlight the relevance and feasibility of implementing these practices in the mining industry, paving the way towards greater efficiency and productivity in horizontal mining operations.

3.1. Results of stage 1 product family

Table 12. Family of products to be mapped

N°	Description
1	Ventilation
2	Marine withdrawal
3	Wedging
4	Drilling, fortification and split set
5	Bolt grouting
7	Spinning
8	Shotcrete
9	Face drilling
10	Loading

To show the results of the research carried out, the first stage is the identification of families, considering these as all the activities of the mining cycle at El Teniente mine, as shown in Table 12.

In accordance with Table 12, having identified the family of products, we proceeded to take the average times of each activity, using the proposals in Table 1, having as acronyms Nv-H: Sinking Level, C: Crossing, Rap: Ramp and XC: Access. On the other hand, the format should consider, as a fundamental summary of the data collection, the productive times (PT), contributory times (CT) and non-contributory times (NCT), obtaining the following results, which are shown in Tables 13-22.

Table 13. Time taking of each activity in the ventilation

Format N° 1: Esmeralda Mine Ventilation-Sinking and Production Level-Times in Seconds [s]								
N°	**Description**	**Take 01**	**Take 02**	**Take 03**	**Take 04**	**Take 05**	**Take 06**	**Take 07**
	Date and Working Level	06-Oct Nv-H	07-Oct Nv-H	07-Oct Nv-H	08-Oct Nv-H	08-Oct Nv-H	08-Oct Nv-P	08-Oct Nv-P
	Labor	C-27 Sur XC-5	C-43 Sur Acc-5	Rap N°2 FW	XC Acc 6 HW C31	XC Acc 6 FW C31	Z-47 al Fw C-55	Z-50 al FW C-43
	Activity Start Time	10:32 a.m	11:01 a.m	11:05 a.m	10:58 a.m	12:20 p.m	10.30 a.m	12:00 p.m.
	Activity End Time	11:31 a.m	12:10 p.m	12:41 p.m	12:11 p.m	1:19 p.m	11:49 a.m	1:20 p.m
1	Evaluation the area to be worked	312	321	362	248	456	543	664
2	Enabling the work area	111	128	109	126	105	129	134
3	Confinement of the area	240	232	432	476	254	465	345
4	Registration Checklist	308	301	356	461	351	475	321
5	Installation of the chute with crane at 30m from the front of the posture	1680	1870	1768	1587	1654	1598	1653
6	Start-up and verification of the ventilation sleeve	178	184	176	187	174	165	179
7	Gas Level Check	79	99	100	100	94	122	204
8	Remove Crane	100	72	98	165	145	76	64
a	Productive Times	30.97	34.23	32.40	29.57	30.47	29.38	30.53
b	Contributory Times	19	19	24	26	23	30	29
c	Non-Contributory Times	99	106	130	108	96	110	111
	Total time in minutes [min]	148.97	159.23	186.4	163.57	149.47	169.38	170.53

Table 14. Time taking of each activity in the marine loading

Formato N° 2: Marine Loading Esmeralda Mine Sinking and Production Level-Times in Seconds [s]											
N°	**Description**	**Take 01**	**Take 02**	**Take 03**	**Take 04**	**Take 05**	**Take 06**	**Take 07**	**Take 08**	**Take 09**	**Take 10**
	Date and Work Level	06-Oct Nv-H	06-Oct Nv-H	07-Oct Nv-H	07-Oct Nv-H	07-Oct Nv-H	07-Oct Nv-P	07-Oct Nv-P	07-Oct Nv-P	07-Oct Nv-P	08-Oct Nv-H
	Labor	C-27 Sur XC-5	XC-Acc 6 HW C31	C-45 Norte Acc-5	C-43 Sur Acc-5	C-29 Sur XC-5	C-43 al Sur Z40	C-47 al Sur Z-49	C-51 al Sur Z-44	Z-41 al HW C-45	C-27 SUR XC-5
	Activity Start Time	11: 33 a.m	4:16 p.m	1:25 a.m	3:56 p.m	11:15 a.m	11:30 a.m	6:00 p.m	2:10 p.m	11:00 a.m	10:45 a.m
	Activity End Time	1:50 p.m	6:32 p.m	4:02 a.m	6:38 p.m	1:31 p.m	1:44 p.m	11:30 p.m	5:29 p.m	1:31 p.m	1:02 p.m
1	Inspection of area to be worked	286	465	589	318	468	267	426	589	251	735
2	Registration checklist	256	356	578	538	398	254	631	559	243	438
4	Isolation of area to be worked	258	185	325	345	314	251	247	231	256	315
3	Marine cleaning	4318	4692	5201	5295	5612	4753	6528	6834	4893	4867
4	Gable cleaning	356	356	532	467	678	754	867	610	659	437
a	Productive Times	77.9	84.1	95.6	96.0	104.8	91.8	123.3	124.1	92.5	88.4
b	Contributory Times	13.3	16.8	24.9	20.0	19.7	12.9	21.7	23.0	12.5	24.8
c	Non-Contributory Times	46	36	30	36	12	30	70	52	46	24
	Total time in minutes [min]	137.2	136.9	150.5	152	136.5	134.7	215	199.1	151	137.2

Table 15. Time taking of each activity in the wedging

Format N° 3: Wedging Esmeralda Mine Sinking Level and Production-Times in Seconds [s]											
N°	**Description**	**Take 01**	**Take 02**	**Take 03**	**Take 04**	**Take 05**	**Take 06**	**Take 07**	**Take 08**	**Take 09**	**Take 10**
	Date and Work Level	06-Oct Nv-H	06-Oct Nv-H	06-Oct Nv-H	07-Oct Nv-H	07-Oct Nv-H	07-Oct Nv-P	07-Oct Nv-P	07-Oct Nv-P	07-Oct Nv-P	07-Oct Nv-P
	Labor	Calle 29	C-27	XC-Acceso 6	C-43 Sur	C-29	C-43 al	C-47 al	C-51 al	Z-41 al	C-45

		Sur XC-5	Sur XC-5	HW C31	Acc-5	Sur XC-5	Sur Z40	Sur Z-49	Sur Z-44	HW C-45	Norte Acc-5
	Activity Start Time	11:44 a.m	04:42 p.m	09:32 p.m	09:27 p.m	02:57 p.m	9.00 p.m	1:30 a.m.	05:31 p.m	02:45 p.m	10:30 p.m
	Activity End Time	1:02 a.m	06:32 p.m	11:09 p.m	11:34 p.m	4:19 p.m	10:34 p.m	3:19 a.m	06:50 p.m	04:10 p.m	11:56 p.m
1	Inspection of area to be worked	290	327	312	586	456	435	534	603	299	664
2	Registration checklist	456	600	345	335	312	543	421	487	357	478
3	Illumination	376	399	235	345	301	465	356	365	256	301
4	Wedging of the crown of the work	1086	1756	1767	2357	1156	1647	2523	1075	1059	1156
5	Wedging of the boxes of the work	796	913	974	1398	846	832	803	834	768	829
6	Wedging of the work face	178	879	567	900	699	443	350	412	301	456
7	Marking for Holding bolts	524	697	660	458	567	479	436	376	587	476
a	Productive Times	43	71	66	85	54	57	69	45	45	41
b	Contributory Times	19	22	15	21	18	24	22	24	15	24
c	Non-Contributory Times	16.5	18.2	17	21	9	13	19	11	25	21.3
	Total time in minutes [min]	78.5	111.2	98	127	81	94	110	80	85	86.3

Table 16. Time taking of each activity in the bolt drilling and split set

Format N° 3: Wedging Esmeralda Mine Sinking Level and Production-Times in Seconds [s]											
N°	**Description**	**Take 01**	**Take 02**	**Take 03**	**Take 04**	**Take 05**	**Take 06**	**Take 07**	**Take 08**	**Take 09**	**Take 10**
	Date and Work Level	06-Oct Nv-H	06-Oct Nv-H	06-Oct Nv-H	06-Oct Nv-H	06-Oct Nv-P	06-Oct Nv-P	06-Oct Nv-P	07-Oct Nv-P	07-Oct Nv-P	07-Oct Nv-H
	Labor	C-29 Sur XC-5	C-27 Sur XC-5	XC Acc 6 HW C31	XC Acc 6 FW C31	Z-47 al Fw C-55	Z-50 al HW C-43	Z-50 al Hw C-47	C-43 Sur Acc-5	C-29 Sur XC-5	C-43 al Sur Z40
	Activity Start Time	2:15 p.m	9:30 p.m	1:30 a.m	10:30 a.m	3:00 p.m.	10:45 a.m	10:45 a.m	12:45 a.m	3:46 p.m	10:45 p.m
	Activity End Time	5:29 p.m	12:24 a.m	7:33 a.m	1:30 p.m	5:47 p.m	1:38 p.m	2:14 p.m	3:48 a.m	8:16 p.m	2:22 a.m
1	Inspection of the area to be worked	211	387	701	357	342	587	482	435	304	265
2	Isolation of area to be worked	160	321	253	231	169	357	287	300	264	275
3	Registration checklist	389	489	314	438	320	302	652	381	536	303
4	Positioning Jumbo in front	124	176	128	176	156	178	247	171	124	176
5	Power and water installation	246	470	587	356	456	359	536	351	467	547
6	Installation of water pump	186	238	125	438	240	175	235	235	306	303
7	Drilling Bolts	7000	7452	8363	6951	8000	6202	7253	7318	6335	8913
	Jumbo equipment and water pump uninstallation	851	768	1062	827	972	925	872	930	798	900
a	Productive Times	139.9	148	164.1	138.6	154.5	127.8	148.4	148.5	128.9	173.6
b	Contributory Times	20.2	30.5	39.1	35.2	25.1	30.9	35.7	25	30.5	25.6
c	Non-Contributory Times	34	25	160	21.3	0	14	20	10	10	18
	Total time in minutes [min]	194.1	203.5	363.2	195.1	179.6	172.7	204.1	183.5	169.4	217.2

Table 17. Time taking of each activity in the bolt grouting

Format N° 5: Bolt grouting Esmeralda Mine Sinking Level and Production-Times in Seconds [s]											
N°	**Description**	**Take 01**	**Take 02**	**Take 03**	**Take 04**	**Take 05**	**Take 06**	**Take 07**	**Take 08**	**Take 09**	**Take 10**
	Date and Work Level	06-Oct Nv-H	06-Oct Nv-H	06-Oct Nv-P	06-Oct Nv-P	06-Oct Nv-P	06-Oct Nv-P	07-Oct Nv-H	07-Oct Nv-H	07-Oct Nv-H	07-Oct Nv-P
	Labor	Calle 29 Sur XC-5	XC Acceso 6 FW C-31	C-43 al Sur Z-40	Z-47 al Fw C-55	Z-50 al HW C-43	Z-50 al Hw C-47	C-29 Sur XC-5	C-27 Sur XC-5	XC Acc 6 HW C31	C-51 al Sur Z-44

	Activity Start Time	5:45 p.m	1:15 a.m	11:44 a.m	9:00 p.m	1:45 p.m.	4:30 p.m	8:45 p.m	12:34 p.m	10:30 a.m	1:30 a.m
	Activity End Time	6:58 p.m	2:48 a.m	1:16 p.m	11:16 p.m	3:58 a.m	6:33 p.m	10:42 p.m	2:43 p.m	12:15 a.m	3:19 a.m
1	Inspection of the area to be worked	246	287	295	242	254	305	246	240	243	307
2	Registration checklist	600	686	543	487	587	654	487	480	308	278
3	Crane entry	154	186	134	68	132	132	126	136	187	125
4	Isolation of the area to be worked	142	128	125	134	97	67	186	245	125	79
5	Transfer of fortification elements	196	243	301	187	364	125	302	78	312	181
6	Instalation of air pump	184	301	183	128	183	247	182	183	189	129
7	Grouting and bolt installation	3632	3180	3648	5879	4321	5659	3354	3967	3801	3640
8	Uninstallation of jumbo equipment and air pump	246	184	300	185	243	185	297	300	301	360
a	Productive times [min]	70.5	68	65.8	101	79	101.3	63.9	73.1	70.4	64.7
b	Contributory times [min]	19.5	18.6	26.4	20.9	24	21.6	25.4	20.7	20.7	20.3
c	Non-contributory times [min]	0	7	0	14	30	0	6	0	14	24
	Total time in minutes [min]	90.0	90	93.6	92.2	135.8	133	122.9	95.3	93.8	105.1

Table 18. Time taking of each activity in the mesh

Format N° 6: Mesh Esmeralda Mine Sinking Level and Production - Times in Seconds [s]											
N°	**Description**	**Take 01**	**Take 02**	**Take 03**	**Take 04**	**Take 05**	**Take 06**	**Take 07**	**Take 08**	**Take 09**	**Take 10**
	Date and Work Level	06-Oct Nv-H	06-Oct Nv-H	06-Oct Nv-P	06-Oct Nv-P	06-Oct Nv-P	06-Oct Nv-P	07-Oct Nv-H	07-Oct Nv-H	07-Oct Nv-H	07-Oct Nv-H
	Labor	C-45 Norte Acc-5	C-29 Sur XC-5	C-43 al Sur Z-40	C-47 al Sur Z-49	C-51 al Sur Z-44	Z-50 al Hw C-47	C-29 Sur XC-5	C-27 Sur XC-5	XC Acc 6 HW C31	XC Acc 6 FW C31
	Activity Start Time	12:14 p.m	9:41 p.m	5:00 p.m	2:30 p.m	10:45 a.m.	9:46 p.m	1:30 a.m	9:00 p.m	2:30 p.m	4:30 p.m
	Activity End Time	1:35 p.m	11:17 p.m	6:34 p.m	4:04 p.m	12:46 p.m	11:18 p.m	3:58 a.m	10:16 p.m	4:26 p.m	6:30 p.m
1	Inspection of the area to be worked	178	76	321	246	368	246	305	162	241	300
2	Registration checklist	244	360	284	227	368	245	427	286	346	583
3	Crane entry	124	186	243	125	128	121	185	126	183	124
4	Isolation of the area to work	68	85	74	85	46	60	83	65	81	80
5	Mesh preparation	485	547	600	426	542	368	543	261	200	542
6	Laying of mesh	2687	3603	3125	3441	5808	3403	5742	3201	4625	3634
7	Crane removal	246	254	185	363	246	247	186	168	184	126
a	Productive Times	58.8	70.1	65.1	61.4	100.8	59.7	100.7	60.4	107.1	80.6
b	Contributory Times	10.4	15.1	15.5	20.5	24.3	18.5	25.8	10.8	10.6	9.3
c	Non-Contributory Times	16	14	24	13	0	17	24	10	15	30
	Total time in minutes [min]	85.20	99.20	104.60	94.90	125.10	95.20	150.50	81.20	132.70	119.90

Table 19. Time taking of each activity in the spinning

Format N° 7: Spinning Esmeralda Mine Sinking Level and Production-Times in Seconds [s]											
N°	**Description**	**Take 01**	**Take 02**	**Take 03**	**Take 04**	**Take 05**	**Take 06**	**Take 07**	**Take 08**	**Take 09**	**Take 10**
	Date and Work Level	06-Oct Nv-H	06-Oct Nv-H	06-Oct Nv-H	06-Oct Nv-P	06-Oct Nv-P	06-Oct Nv-P	06-Oct Nv-P	06-Oct Nv-P	07-Oct Nv-H	07-Oct Nv-H
	Labor	C-45 Norte Acc-5	C-43 Sur Acc-5	C-29 Sur XC-5	C-43 al Sur Z-40	C-47 al Sur Z-49	C-51 al Sur Z-44	Z-50 al FW C-43	Z-50 al Hw C-47	C-27 Sur XC-5	XC Acc 6 HW C31
	Activity Start Time	2:30 p.m	10:30 a.m	12:17 a.m	10:00 p.m	4:42 p.m.	2:30 p.m	12:47 a.m	3:30 a.m	11:30 p.m	4:30 p.m
	Activity End Time	4:37 p.m	12:28 p.m	2:27 a.m	11:32 p.m	6:58 p.m	4:38 p.m	2:31 a.m	5:17 a.m	1:41 a.m	6:45 p.m
1	Inspection of the area to be worked	120	246	365	300	426	306	367	194	256	367
2	Registration	368	486	543	320	295	486	438	539	603	663

	checklist										
3	Crane entry	69	73	84	185	125	180	174	121	198	185
4	Isolation of the area to work	67	185	123	239	126	175	84	68	125	180
5	Spinning	4647	5364	5678	3403	5080	5390	3880	3529	5607	5626
6	Crane removal	185	245	185	119	301	245	309	176	234	297
a	Productive Times	83.5	95.4	100.6	63.7	91.7	94.8	70.7	64.8	96.5	100.8
b	Contributory Times	7.5	14.6	15.7	12.4	14.2	18.2	16.9	12.3	20.6	21.2
c	Non-Contributory Times	36	7	14	16	30	15	17	30	14	13
	Total time in minutes [min]	126.9	117.0	130.3	92.1	135.9	128.0	104.5	107.1	131.1	135.0

Table 20. Time taking of each activity in the shotcrete

Format N° 8: Shotcrete Esmeralda Mine Sinking Level and Production-Times in Seconds [s]											
N°	**Description**	**Take 01**	**Take 02**	**Take 03**	**Take 04**	**Take 05**	**Take 06**	**Take 07**	**Take 08**	**Take 09**	**Take 10**
	Date and Work Level	06-Oct Nv-H	06-Oct Nv-H	06-Oct Nv-H	06-Oct Nv-P	06-Oct Nv-P	06-Oct Nv-P	06-Oct Nv-P	06-Oct Nv-P	07-Oct Nv-H	07-Oct Nv-H
	Labor	C-45 Norte Acc-5	C-43 Sur Acc-5	C-29 Sur XC-5	C-43 al Sur Z-40	C-47 al Sur Z-49	C-51 al Sur Z-44	Z-41 al HW C-45	Z-50 al Hw C-47	C-27 Sur XC-5	XC Acc 6 HW C31
	Activity Start Time	5:45 p.m.	1:03 p.m	2:30 a.m	1:00 a.m	10:00 p.m	4:45 p.m.	10:45 a.m	6:00 a.m	1:44 a.m	8:00 p.m
	Activity End Time	7:01 p.m	2:44 p.m	4:13 a.m	2:32 a.m	12:00 a.m	6:30 p.m	12:18 p.m	7:42 a.m	3:28 a.m	10:00 p.m
1	Inspection of the area to be worked	537	421	778	472	598	486	547	483	427	486
2	Robot registration checklist	365	389	542	386	600	347	427	300	338	544
3	Projection equipment preparation	130	123	221	287	242	562	202	363	220	662
4	Water and air installation	101	275	243	114	104	203	143	153	143	226
5	Mixer registration checklist	104	165	210	124	163	265	153	147	153	245
6	Mixer installation	132	176	246	185	243	180	185	237	178	245
7	Isolation of the area to work	237	195	276	156	173	168	164	132	124	115
8	Concrete spraying	2759	2646	2635	2143	3264	3001	2954	3921	3728	3603
9	Uninstallation of equipment	175	165	135	210	185	153	276	143	265	246
a	Productive Times	75.7	72.1	70.9	72	72.4	75	69.2	77.4	77.9	86.1
b	Contributory Times	10	15.8	23.2	18	26.5	20.4	15	27.6	20	23.2
c	Non-Contributory Times	10	10	10	10	12	10	12	10	10	10
	Total time in minutes [min]	95.7	97.9	104.1	100.0	110.9	105.4	96.2	115.0	107.9	119.2

Table 21. Time taking of each activity in the face drilling

Format N° 9: Face drilling Esmeralda Mine Sinking Level and Production-Times in Seconds [s]											
N°	**Description**	**Take 01**	**Take 02**	**Take 03**	**Take 04**	**Take 05**	**Take 06**	**Take 07**	**Take 08**	**Take 09**	**Take 10**
	Date and Work Level	06-Oct Nv-H	06-Oct Nv-H	06-Oct Nv-H	06-Oct Nv-P	06-Oct Nv-P	06-Oct Nv-P	06-Oct Nv-P	07-Oct Nv-H	07-Oct Nv-H	07-Oct Nv-H
	Labor	C-45 Norte Acc-5	C-43 Sur Acc-5	C-29 Sur XC-5	C-43 al Sur Z-40	C-47 al Sur Z-49	C-51 al Sur Z-44	Z-41 al HW C-45	C-27 Sur XC-5	XC Acc 6 HW C31	XC Acc 6 FW C31
	Activity Start Time	9:30 p.m	3:15 p.m	4:27 a.m	2:45 a.m	1:00 a.m	9:16 p.m.	2:30 p.m	3:45 a.m	11:00 a.m	1:31 a.m
	Activity End Time	12:46 p.m	7:18 p.m	7:30 a.m	5:42 a.m	4:16 a.m	12:45 p.m	6:28 p.m	7:02 a.m	2:29 a.m	4:43 a.m
1	Inspection of the area to be worked	374	236	397	0	423	335	424	0	413	0
2	Isolation of the area to work	236	425	309	325	287	300	365	426	365	236
3	Registration checklist	415	436	486	432	481	433	473	413	472	532
4	Positioning Jumbo to the front	413	364	246	286	543	421	368	325	304	308

5	Power and water installation	683	545	584	513	634	546	524	558	534	553
6	Water pump installation	302	359	236	181	287	148	252	167	365	243
7	Drilling	7066	8839	7336	7294	7255	7067	7564	7381	7396	7788
8	Jumbo equipment and water pump uninstallation	273	285	248	225	236	282	368	243	386	238
a	Productive Times	117.8	147.3	122.3	121.6	120.9	117.8	126.1	123.0	123.3	129.8
b	Contributory Times	44.9	44.2	41.8	32.7	48.2	41.1	46.2	35.5	47.3	35.2
c	Non-Contributory Times	33	52	20	23	27	50	66	39	38	27
Total time in minutes [min]		195.7	243.5	184.0	177.3	196.1	208.9	238.3	197.6	208.6	192.0

Table 22. Time taking of each activity in the explosive loading

Format N° 10: Explosive Loading Esmeralda Mine Sinking Level and Production-Times in Seconds [s]											
N°	**Description**	**Take 01**	**Take 02**	**Take 03**	**Take 04**	**Take 05**	**Take 06**	**Take 07**	**Take 08**	**Take 09**	**Take 10**
	Date and Work Level	06-Oct Nv-H	06-Oct Nv-H	06-Oct Nv-P	06-Oct Nv-P	06-Oct Nv-P	07-Oct Nv-H	07-Oct Nv-H	07-Oct Nv-P	07-Oct Nv-P	07-Oct Nv-P
	Labor	C-45 Norte Acc-5	C-43 Sur Acc-5	C-43 al Sur Z40	C-51 al Sur Z-44	Z-41 al HW C-45	XC Acceso 6HW C31	XC Acceso 6 FW C31	Z-47 al Fw C-55	Z-50 al HW C-43	Z-50 al Hw C-47
	Activity Start Time	1:45 a.m	5:15 a.m	6:00 a.m	4:45 a.m	1:30 a.m	3:30 a.m.	5:30 a.m	1:30 a.m	3:45 a.m	10:00 p.m
	Activity End Time	3:32 a.m	6:44 a.m	7:32 a.m	6:32 a.m	2:48 a.m	5:28 a.m	7:27 a.m	3:16 a.m	5:28 a.m	11:43 p.m
1	Inspection of the area to be worked	485	225	357	237	372	295	243	299	301	304
2	Isolation of the area to work	85	106	82	53	47	43	78	101	78	126
3	Registration checklist	344	486	348	387	377	360	367	331	376	343
4	Face drilling untie	165	0	264	0	574	754	0	487	0	0
5	Evaluation and cleaning of the shots	184	207	241	125	0	279	154	127	0	0
6	Loading of each shot with crane	4441	3710	3147	4321	3993	4585	4594	3856	3743	4401
7	Detonating cord and safety fuse connection	397	320	496	798	837	495	659	713	845	720
a	Productive Times	80.6	67.2	60.7	85.3	80.5	84.7	87.6	76.2	76.5	85.4
b	Contributory Times	21.1	17.1	21.5	13.4	22.8	28.9	14.0	22.4	12.6	12.9
c	Non-Contributory Times	6	5	10	9	5	6	6	8	14	5
Total time in minutes [min]		107.7	89.2	92.3	107.7	108.3	119.5	107.6	106.6	103.1	103.2

As shown in Tables 13-22 of the proposed format, times have been taken for each activity that makes up the mining cycle, which allows first validating the format and then establishing the results of the productive, contributory and non-contributory times shown in indicators a, b and c at the end of each table, which allows to establish the real times of the mining cycle and compare them with the standard times of the contract.

3.2. Results of stage 2 current state diagram

To present the results of the current state analysis, initially the Ishikawa diagram tool was used, which allowed to clearly identify the activities that are contributing to the low productivity problems.

Therefore, the Ishikawa tool adapted to the context of the Esmeralda mine was applied.

The first action consisted of carrying out an exhaustive field review with a specialized team composed of three Lean Manufacturing experts, three shift leaders, six foremen and a superintendent. During this field phase, several irregularities were detected related to mine personnel, work methods, equipment condition, post-dumping aspects of the material, spaces available for the placement of marinas and mine site management standards.

The analysis revealed that, due to the aforementioned reasons, personnel are not performing their tasks in a standardized manner. In addition, the lack of mechanical personnel at the fronts was confirmed and it was verified that adequate training has not yet been provided to the personnel. Regarding methods, a problem was identified in the distribution of drilling mesh. Regarding equipment, the presence of inoperative equipment was observed. In relation to the material, an excess of marina was observed in comparison with the quantities established in the contract by the mine works management, generating problems in the availability of shafts for the placement of the marina. Finally, with regard to the sections defined in the contract, it was found that these exceeded the proposed value by %, this being the main cause of an over-excavation of 30%, exceeding the limits established by the mine works management, which originally proposed only 12%.

In the Ishikawa analysis it was possible to identify that four activities of the mining cycle (Ventilation, marine loading, wedging, face drilling) represent the focus of the problem of low productivity since they have longer or less efficient times, so the problem should be attacked considering only the improvement in these activities, taking into account the following reasons:

Personnel: The work procedures of the different activities are not controlled, generating inadequate procedures that are not noticed by the (technical site inspectors), so there are activities that exceed the standardized limits, resulting in over-excavations that generate more time in the wedging.

Equipment: The equipment is not repaired quickly because they do not have good logistics for the purchase of parts. The low voltage of the electrical power causes damage to the electrical box of the postures and the Jumbo box, which takes a long time because the procedure indicates that the electrician must be called to solve this problem (there are only two electricians for the two levels, sinking and production). The jumbo does not comply with preventive maintenance because the shift manager is responsible for delivering the equipment to the mechanical shop and this is not done.

The re-handling of materials causes more traffic of the Scoop Equipment having sawed postures by marine traffic and this generates interference, the marine stockpiling is done by the specialized company Geovita because of the need to continue blasting without thinking that it generates interference in the area by the transfer of the Scoop equipment. The biggest problem is the availability of rock chips, which is the responsibility of the mining company.

Method: The drilling mesh is designed for only a section size of 4.0 m × 4.5 m and does not change the drilling pattern which depends on the type of rock and explosive. The method has a lot of interference because of the 38 pieces of equipment that are moved by the two main positions, these are mining and civil works equipment plus the Mixer that supplies the two processes.

Material: Over-excavation generates a greater amount of: marine, split set, helical bolts, Shotcrete, equipment and time that are associated with building larger excavations. Civil works have a greater problem since over-excavation causes a greater consumption of concrete that is used in road surfaces, extraction points and confining walls.

All the described processes culminate in the main cause of the problem, which is the over excavation that generates the low yields, due to the fact that ventilation, marine loading, wedging and face drilling have a significant influence on these results, which are validated by measuring the execution times of the construction processes of the horizontal excavations described in stage 1.

In this research, we contextualise the activities with the lowest performance based on the results found in the calculation of performances carried out in the time taking in the previous stage, leaving Tables 23, 24, and Figure 3 as a tool adapted to the mining cycle of horizontal excavations.

From Tables 23, 24 and Figure 3, the main activities that generate the greatest delays have been identified as the families involved. The activities in the mining cycle must achieve at least 70% of productive work, and it can be seen that the activities that do not achieve this performance are ventilation with 18.96% productivity, marine loading with 63.13%, wedging with 60.57% and face drilling with 61.2%.

Table 23. Results of mining cycle averaging in minutes

Average Process Times in Minutes [min]				
Activity	PT	CT	NCT	TCT
Ventilation	31.1	24.3	108.6	164
Marine loading	97.85	18.96	38.2	155.01
Wedging	57.6	20.4	17.1	95.1
Bolt and Split set drilling	147.23	29.78	31.23	208.24
Bolt grouting	75.77	21.81	9.5	107.08
Mesh laying	76.47	16.08	16.3	108.85
Spinning	86.25	15.36	19.2	120.81
Shotcrete	74.87	19.97	10.4	105.24
Face drilling	125	41.71	37.5	204.21
Explosive loading	78.47	18.67	7.4	104.54

Table 24. Results of process averaging in minutes

Summary of Average Times in [%]			
Actividad	PT%	CT%	NCT%
Ventilation	18.96	14.81	66.23
Marine loading	63.13	12.23	24.64
Wedging	60.57	21.45	17.98
Bolt and Split set drilling	70.7	14.3	15
Bolt grouting	70.76	20.37	8.87
Mesh laying	70.25	14.77	14.98
Spinning	71.4	12.7	15.9
Shotcrete	71.14	18.98	9.88
Face drilling	61.2	20.4	18.4
Explosive loading	75.1	17.8	7.1
Average	63.32	16.78	19.90

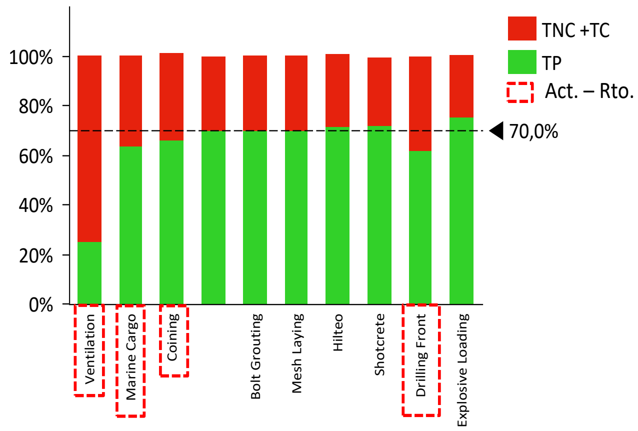


Figure 3. Identification of underperforming activities

In Figure 4, the maps of the current state of the value chain of the low performance activities (marine loading, wedging and face drilling) are constructed and presented, ventilation is a consequence of some activities and materials, which is why it will only be analyzed at the end, where the times assigned to each activity to perform the work in the positions are shown in detail, quantifying the % of Productive Time and the % of Contributory Time, separating these from Non-Contributory Time.

Figure 4 shows in detail the times assigned to each activity to perform the work in the positions, quantifies the % of Productive Time and % of Contributory Time, separating these from Non-Contributory Time.

When elaborating the current state map, it is immediately identified that the complete realization of the activities requires long periods of time, the total cycle time is 22.1 hours, as calculated in Figure 4 of the current state diagram. The time that does not add value is 5.3 hours, speaking only of the productive work hours. The statistical pie chart indicates the efficiency in percentage of compliance, being green the percentage of productive time, yellow the percentage of time that contributes to the activity and red the percentage of non-contributory time.

Figure 5 shows that the times established in the contract are not related to the times found when applying the current V.S.M., due to the fact that at the time of making the contract, the existence of operational interferences that are an important factor in the determination of the real yields is not taken into account, added to the fact that only a value of 19% of over excavation is considered while in reality an over excavation of 32% has been calculated, which generates operational increases in the mining cycle.

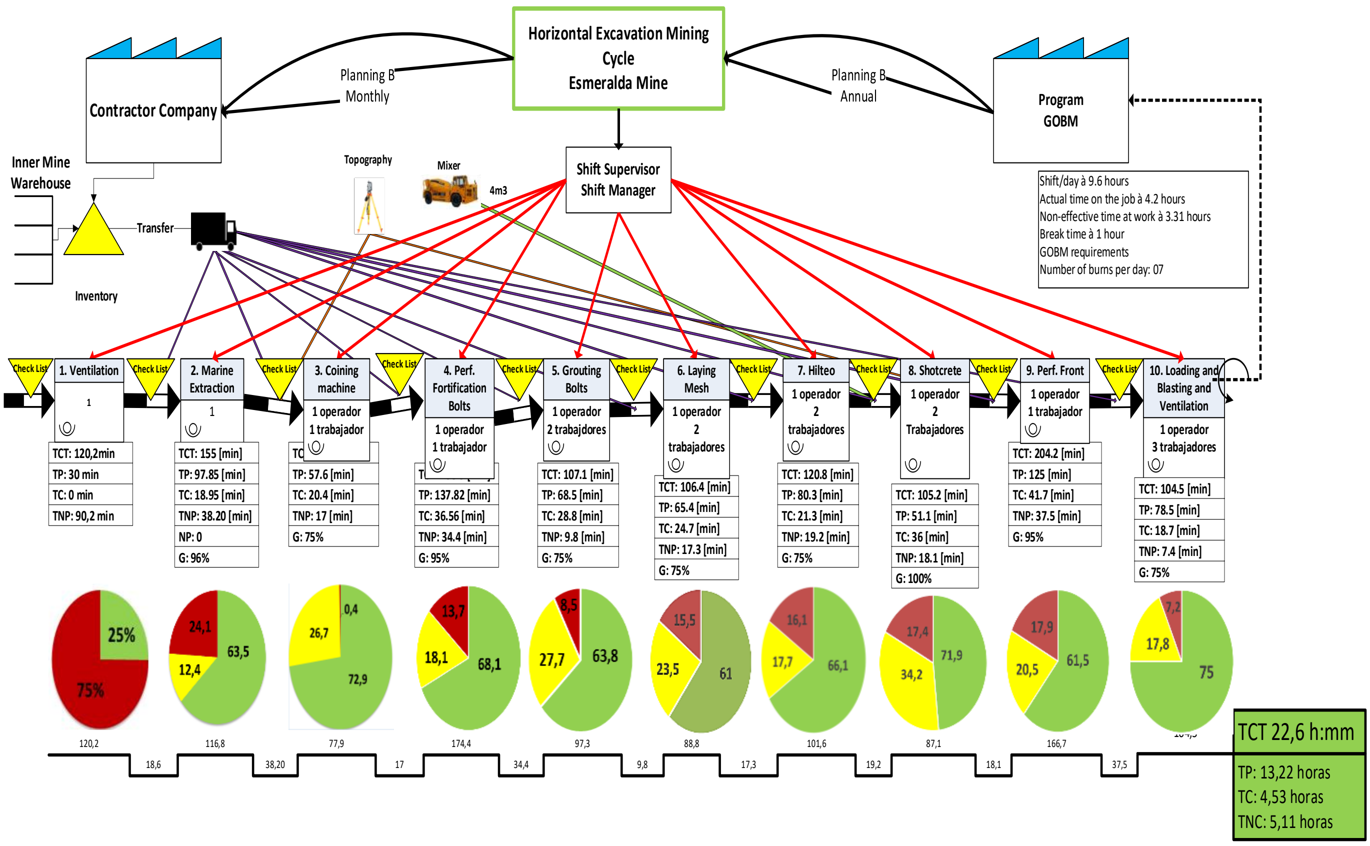


Figure 4. VSM of Horizontal Developments Current status of all activities in the mining cycle of horizontal excavations

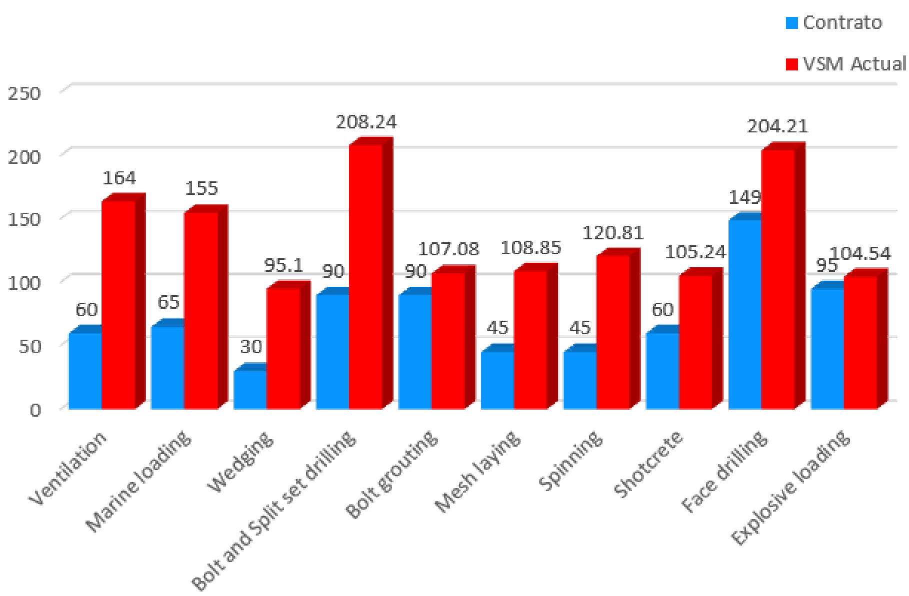


Figure 5. Identification of the times in the current VSM/Contract mining cycle

4. CONCLUSIONS

In this study, the importance and effectiveness of the application of the 10 formats designed for data collection in all activities of the mining cycle has been demonstrated. These formats have made it possible to collect detailed and precise information on the times of each activity, providing a comprehensive and updated vision of the entire mining process.

The results found during the application of these formats have been revealing. It was possible to accurately determine the productive (13.22 hours), contributory (4.53 hours) and non-contributory (5.11 hours) times in the different stages of the mining cycle. This time segmentation has provided a deeper understanding of operational efficiency, highlighting specific areas that require attention.

The use of these formats has also made it possible to compare the times obtained with those established in the contracts or production objectives. This comparison has revealed significant discrepancies in key activities such as venting (18.96%), marine loading (63.13%), coining (60.57%) and drilling (61.2%). These findings highlight the importance of strategically addressing underperforming areas to improve the overall efficiency of the mining cycle.

Furthermore, the application of the Ishikawa tool to analyze the collected data has been essential to identify the root causes of the identified problems. It was determined that overexcavation, caused by the use of certain explosives, is the main cause that affects productivity. These results provide a solid foundation for implementing corrective and strategic actions that directly address the identified challenges.

Finally, the results found during the application of the 10 formats for data collection in all activities of the mining cycle underline its value as a powerful tool to collect real data, identify areas of improvement and make informed decisions to optimize the mining process. Its systematic and rigorous application is essential to guarantee efficient and competitive management in the mining industry.

To ensure the efficiency and continued success of this approach, it is essential to approach the analysis from a global perspective, integrating data collection continuously into all daily operational reports, from excavations to management. This involves establishing a robust, automated information system that allows conditions and performance to be monitored in real time.

The availability of updated and detailed information at all levels of the mining operation is essential to make informed and timely decisions. The implementation of technology to automate the information system facilitates this process, allowing situations to be consulted in real time and to respond quickly and efficiently to any challenge or change in operating conditions.

Furthermore, given the dynamic and evolving nature of the mining industry, deepening operations requires a mindset of continuous improvement. Based on the findings of this study and the inherent flexibility of the lean methodology, pilot tests can be carried out and experiments with changes in mining activity. This allows you to proactively adapt to emerging challenges, identify opportunities for improvement and further optimize mining cycle performance.

Although this research comprehensively addresses productivity aspects in the mining cycle, it is important to highlight that the application of this tool is not limited only to temporal aspects. It is also useful to evaluate other indicators such as safety or environmental impact. However, these aspects are not the focus of this study, since no modifications will be made regarding them.

ACKNOWLEDGMENT

This work has been possible thanks to the collaboration of the mine works management of the mining preparation of the Esmeralda mine, El Teniente division, Codelco-Chile.

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NOMENCLATURE

BP	Bypass
CX	Cruise
N_V-H	Sinking level
N_V-P	Production level
TCT	Total cycle time
TP	Productive time
TC	Contributing time
TNC	Non-contributory time