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ANALYSIS ON THE USE OF A NEW EXPLOSIVE AND GEOLOGICAL CONDITION WITH A MINE-TO-MILL APPROACH FOR A LIMESTONE QUARRY LOCATED IN THE VICINITY OF MADRID, SPAIN

Author: GABRIEL GURREA MATUS
Supervisor: PABLO SEGARRA CATASÚS.

Co-Supervisor: SANTIAGO GÓMEZ MATEOS

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MONTANUNIVERSITÄT LEOBEN
www.unileoben.ac.at

AFFIDAVIT

I declare on oath that I wrote this thesis independently, did not use any sources and aids other than those specified, have fully and truthfully reported the use of generative methods and models of artificial intelligence, and did not otherwise use any other unauthorized aids.

I declare that I have read, understood and complied with the "Good Scientific Practice" of the Montanuniversität Leoben.

Furthermore, I declare that the electronic and printed versions of the submitted thesis are identical in form and content.

Date 13.02.2024

Gabriel Gurrea M.

Signature Author
Gabriel Ismael Gurrea Matus

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ABSTRACT

The main objective of this work is the analysis of the use of a new explosive and geological condition with a mine-to-mill approach for limestone in Valdilecha, Spain. Initially, a general description of the mine site is provided, where the focus is on the unitary process: Drill & Blast, Load & Hauling, and Processing stage.

A group of 15 blasts is analyzed, and of these several KPIs are defined to create a Base Line for the quarry. Then this information is contrasted with data gathered collected by the team and is processed using different tools, through this is possible to contrast the data and evaluate the use of different technologies. Then, the impact of a new explosive is evaluated on 3 blasts. Through this, a New Design scenario allows a comparison between downstream process KPIs.

Finally, the drill-to-mill approach seeks to digitally integrate the processes of drilling, blasting, loading, transport, and processing in the plant. It is expected that the information collected will allow the modeling of different scenarios and study their impact on the main production indicators, becoming a decision support tool for the management and administration of the daily operation of the quarry.

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1. INTRODUCTION

The raw materials industry is fundamental for modern civilization through this is possible to supply the resources needed for manufacturing, construction, and energy production. Additionally, it is a major contributor to global economies, providing jobs and driving growth. However, is also known that it faces great challenges in matter of sustainability and therefore management tool to minimize its environmental footprint and ensure a resilient future.

Moreover, according with Sánchez & Hartlieb (2021), mining companies are dealing with at least, one of these challenges: decreasing ore grades, deeper deposits, and harder rock masses, which is further affecting their productivity, in addition to this environmental and social awareness along with climate change. To overcome this issue, miners need to invest in technology and specialized professionals.

However, in recent years, the sector has experienced a remarkable shift as it integrates cutting-edge digital technologies, such as artificial intelligence, the Internet of Things (IoT), big data analytics, and automation, into its operations (Sánchez & Hartlieb, 2021). The introduction of these technologies will help them to become integrate process and gather data to get new insights.

Nevertheless, these innovations are typically affordable for large companies mostly in the metallic minerals sector due to their high costs. But now with the development of lower price solutions on the market, there are new opportunities for other deposit types, such as the Aggregates Extractive Industry (AEI) to implement this innovation, from exploration and extraction to processing, logistics, and safety protocols.

The AEI market is projected to grow from $340.61 billion in 2022 to $481.73 billion by 2029, at an annual growth rate of 5.1% in forecast period, 2022-2029. The main driver for this increase is the construction industry led by population rise, which needs more hospitals, healthcare centers, residential buildings, services, etc. In the EU, are approximately 26.000 mine sites and supply more than 3 billion t/year, with incomes > 20 billion €/year (Fortune Business Insights -GlobeNewswire, 2022).

DIGIECOQUARRY (https://Digiecoquarry.Eu/, 2023), who aim for a comprehensive development of the industry to guarantee the implementation of the best available technology (BAT) and develop further technologies. In this regard, a consortium was formed for several partners across the EU., and they had defined four main goals to develop:

1. Health and Safety (H&S) and security.
2. Efficiency, Selectivity and Profitability of quarrying operations.
3. Environmental Impact.
4. Social Acceptance.

The project's main objective is to validate in five pilot quarries an Innovative Quarrying System (IQS) to provide integrated digitalized, automatic, and real time process control for aggregate quarries.

This thesis project is contextualized in implementing the drill-to-mill concept in quarries to increase to reduce energy consumption and costs in muckpile digging, loading and hauling, and optimize plant performance. This approach aims to integrate data from each unitary process during the mine cycle, allowing a more sustainable profitable operation.

2. OBJETIVES AND SCOPE

2.1 Main Objective

- The main objective of this work is the analysis On the use of a new explosive and geological condition with a mine-to-mill approach for a limestone.

2.2 Secondary Objectives

- Analysis of drill and blast parameters.
- Validation of dispatch system used by the quarry.
- Determine the impact of the new explosive used and drill and blast parameters in the energy consumption on downstream processes.

2.3 Scope

The foundation of this thesis rests on an extensive data set gathered by the Explosive and Blasting research group at Universidad Politécnica de Madrid, UPM. Data collection spanned from the months of January to August, involving field measurements and data provided by monitoring systems installed in the mobile fleet and in the plant. The data were taken from the quarry mentioned above, serving as a real-world and regionally relevant case study that adds practical significance to the research findings.

This study provides an opportunity to understand the impact of drill-to-mill setup in a limestone quarry, based on the integration of new technologies where the focus will be on the detailed description of each process, the analysis considers 15 blasts carried out during the period January-July,2023.

3. BACKGROUND

3.1 Site Description

The quarry, situated in Valdilecha, approximately 50 km southeast from Madrid, Spain, is accessible via the R-3 highway (refer to Figure 1). It stands as a source of limestone ($CaCO_3$), a mineral with multifaceted significance in various industries, particularly construction and infrastructure development.

Figure 1: Quarry location.

Limestone serves as the cornerstone for the creation of indispensable materials like cement and concrete, which are crucial for the construction of critical infrastructure such as bridges, roads, and residential and commercial buildings. Therefore, the sustainable extraction, processing, and management of limestone resources hold importance in ensuring the robustness and expansion of the construction sector, as well as in advancing the overall development of the Valdilecha region. In this sense the quarry produces two basic types of material, sand and gravel (also called natural stone) and crushed stones, those are classified according to the size:

1. Sand type I (0/30 mm).
2. Sand type II (0/40 mm).
3. Gravel (40/80 mm).
4. Additionally, the quarry has a prestock of material lower than 300 mm and bigger than 80 mm.
5. Armourstone.

Figure 2: Aerial view of the Quarry.

Furthermore, the recent acquisition of the quarry by CEMEX, one of the world's largest and most influential companies in the construction materials sector, underscores the economic and strategic value of limestone in this locality.

This comprehensive project, encompassing both the extraction of raw materials and the on-site production of the final products, not only contributes substantially to the local economy but also exemplifies the industry's commitment to efficiency and sustainability. Table 1 shows the estimated land use percentage according to each productive stage, up to know a 6% has been already rehabilitated.

Table 1: Land use extension by productive zone

Location	Total Area m^2	Relative %
Estimated total surface	879,269	100
Estimated surface of the extraction area	566,902	64.4%
Estimated surface of the treatment plant area	42,956	4,9%
Estimated surface of the extractive waste facilities	0	0,00%
Estimated surface of the areas not extracted yet, still in original state	268,848	30,6%
Estimated surface of the rehabilitated area	563	0,06%

3.1.1 Geological and Geomorphological Framework

The geology of the zone is characterized with a sub horizontal or slightly inclined at the edges. There is evidence of recent neotectonics activity that affects the whole of the Central System and the Meso-Tertiary Tagus Basin, with large morpho-structural alignments defined by the Henares and Jarama rivers (Superficies Erosión Neógenas En La Zona De & Benito-Calvo Alfredo Pérez-González, 2010.).

From a general geomorphological point of view, the following elements stand out: The calcareous high plateaus of the Páramos, high plateaus due to an exhumed intramiocene erosion surface, forms of link between the high plateaus and the fluvial network (glacis systems, escarpments in dissymmetrical valleys and gradient reliefs due to the terraces of the Henares and Jarama rivers (Rodríguez, 2018)

Two fundamental domains can be distinguished: Tertiary materials and Quaternary materials of the glacial deposits and terraces of the Anchuelo and Pantueña streams. The first of these is made up of Tertiary materials within which the following types of facies can be recognized (Rodríguez, 2018) :

- Sandstones, sands and clays of the upper Alcalá Facies with abundant feldspars and variable proportion of metamorphic elements, which constitute the red series, of the Miocene Terminal.
- Gray clays, sandstones, gypsiferous marls, gypsum, bentonites and sepiolites that form the so-called White Facies (Anchuelo Facies, etc.) and are crowned by carbonate levels with flints.
- Conglomerates and sandstones of the intramiocene fluvial network, separated from the underlying units by a clear sedimentary break.
- Limestones of the Páramos that crown the Miocene series.
- Conglomerates and sandstones of the intramiocene fluvial network, separated from the underlying units by a clear sedimentary break.
- Limestones of the Páramos that crown the Miocene series.

Additionally, and for analysis purpose on this stuy the next lithologies are defined:

- Brecciated Limestone (BL): Brecciated Limestone is characterized by fragmented surfaces with a reddish color
- Massive Limestone (ML): The Massive Limestone has a uniform grayish color and structure
- Clay (C): Clay patches are present in both limestone types, and their density is rated as non existent, low, medium, or high, each associated with a numerical value from 0 to 3 based on color and distribution.

3.2 Mine to Mill (M2M)

Mine-to-Mill (M2M) is a project developed by the institute Julius Kruttschnitt Mineral Research Centre (JKMRC), the beginning of this was based on a project in the 1970s by the Australian Mineral Industry Research Association (AMIRA), where they were realizing different measurement to understand the impact of blasting in the crushability and grindability (McKee & Cooperative Research Centre for Optimising Resource Extraction, 2013.).

In this stage one of the main goals was to understand and develop models to predict the fragment size and the shape of the muck pile after blast. More relevant works come from Claude Cunningham who proposed the Kuz-Ram model which would be the basis of the studies of the JKMRC (McKee, 2013).

Likewise, Nielsen and Malvik (1999) were the first in studying the impact of blasting as main driver to improve energy efficiency of crushing and grinding stages trough laboratory tests.Later, the impact of blast fragmentation on truck-shovel performance would be incorporated (Ünal et al., 2001). Then Leung and Morell (McKee & Cooperative Research Centre for Optimising Resource Extraction, 2013.) both belonging to JKMRC would include further development for autogenous and semi autogenous grinding. At this point was known that should be possible to directly manipulate blasting to produce appropriate mill feed size distributions for increased grinding circuit throughput (Eloranta, 1997).

A proper implementation of M2M will allow to link mining with processing, and through this process increase efficiency of the operation, and even though is based on simple techniques, the implementation of this can be complicated(McKee, 2013). Several studies have been done in this matter showing that is possible to improve productivity 10 -20% (McKee, 2013), and decrease cost due less energy consumption in the comminution stages. According with (Nielsen & Malvik, 1999) is possible to say that M2M will focus on two main challenges, optimizing fragmentation and improve downstream process and therefore improve the operational margins..

3.3 Drill to Mill (D2M)

D2M is basically the same idea that M2M but in this case, the input obtained from rock characterisation are much more detailed than before because, new technologies are implemented, for example Measurement-While-Drilling (MWD) is used to assess rock mass characteristics. Therefore, is possible to optimise rock fragmentation, muckpile digging efficiency indicators and comminution performance. Moreover, D2M introduce new data sources based on Internet of Thing (IoT) systems, such as specific drilling parameter and forecasting of drilling productivity and others.

Figure 3 shows the integration of all value chain (seven stages), starting in *Site Preparation* and ending in the *Rehabilitation*. From each stage different information is included as an input to create a Business Intelligence Management model (BIM), which enables the opportunity to introduce technology to predict and create different scenarios like Artificial Intelligence or Machine Learning.

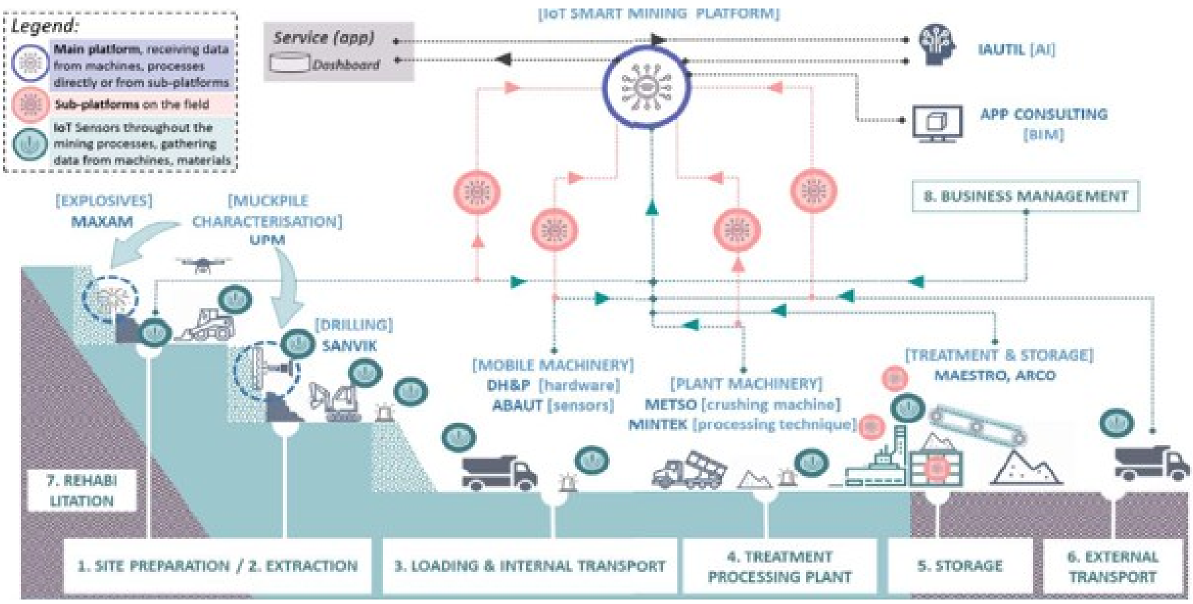


Figure 3: Intelligent Quarry System Concept. (Source: DIGIECOQUARRY project.)

4. METHODOLOGY

4.1 Operation description

Currently the quarry is being developed across two zones, North (NZ) and Northeast (NEZ). The NEZ is exploited in three benches. On the other hand, the NZ is nearest to the office and is less exploited than the previous one. Finally, the processing plant can be found in the northwest. The annual production is 1.2 Mt/year of limestone.

The machinery involved in the operation is compounded by one drill Rig, six-wheel loaders and three excavators, more details are given in Table 2.

Table 2: Site Machinery

Equipment	Model	Capacity	Quantity
Drill Rig	Atlas Copco ROC F6.	-	1
Wheel loaders:	Komatsu WA420.	3.2 m^3	1
	Caterpillar 988F.	5 m^3	1
	Caterpillar 980G	4 m^3	2
	Caterpillar 980GII.	4 m^3	1
	Caterpillar 980M.	5 m^3	1
Dumper	Perlini 131-33 E	37 t	1
	Komatsu HD405-6	37 t	2
	Komatsu HD605-7	57 t	4
Excavators	Liebherr A934B.	9.2 m^3	1
	Komatsu PC750SE-7.	5.3 m^3	1
	Caterpillar 390 FL.	4.6 m^3	1

Figure 4: Layout of the quarry

As it is usual, after the blast and depending on the quality of the ore, it is hauled to different destinations. According to information provided, there are seven possibilities, these are described in Table 3 and shown in Figure 5.

Table 3: Ore destination after blast.

Location	Description
Plant (Tolva)	Good quality with low-medium clay amount
Vertedero de zahorra (graded aggregate dump):	reject of the plant due to its bad quality and high content in clay;
Surge pile (Acopio Tolva)	Storage pile of good quality material
Armour stone (Escollera)	Large boulders (above 800 mm) used as armour stone
Stockpile (Piedra en Rama)	Medium quality material with medium clay content, that cannot be processed in winter due its high humidity and it is stocked in this pile until is dried, and the clay is separated naturally from the rock
Vertedero Voladura (landfill)	Bad quality material with high amount of clay.

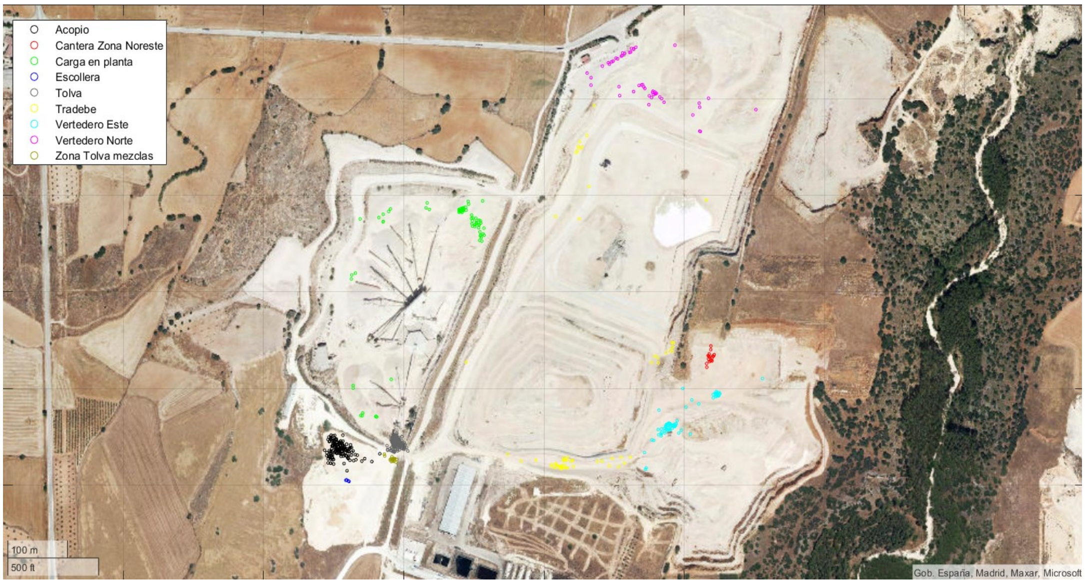


Figure 5: Ore destination after blast from the truck tracking system.

4.1.1 Drill and Blast (D&B) description.

The main characteristic identified related to D&B are listed in the

Table 4. The nomenclature followed is based on date to be blasted, listed by date, the main aspects of this are:

- The quarry performs between two to three blast per month, and the average volume blasted per month is 16,440 m^3or 37,200 t considering a density of 2.4 t/m^3.
- The boreholes are drilled with a diameter of 137 mm and a nominal inclination of 19° with respect to the vertical. A new drill rig was purchased in 2023 (March), with capacity to use navigation future to do the boreholes, view Figure 6.

Figure 6: Leopard LDI550 by Sandvik

Table 4: Theoretical parameter for each blast.

Date	Code	Bench	Zone	B *m*	S *m*	J *m*	H *m*	L *m*	Nh	Nr	V *m³*	q *kg/m³*	Type of Explosive
20/01/2023	230120	Banco 3	NEZ	5.75	7.00	3	14.18	15.00	24.00	2	13,283	0.23	ANFO
31/01/2023	230131	Banco 3	NEZ	5.00	7.00	3	8.61	9.11	37.00	5	10,201	0.23	ANFO
13/02/2023	230213	Banco 1 Oficina	NZ	5.75	7.00	3.5	15.20	16.08	26.00	2	15,530	0.23	ANFO
22/02/2023	230222	Banco 3	NEZ	5.75	7.00	3	13.27	14.03	30.00	3	15,251	0.23	ANFO
08/03/2023	230308	Banco 3	NEZ	5.75	7.00	3	14.18	15.00	29.00	2	16,301	0.24	ANFO
16/03/2023	230316	Banco 1 Oficina	NZ	5.25	7.00	3.5	14.18	15.00	41.00	5	19,845	0.25	ANFO
29/03/2023	230329	Banco 3	NEZ	5.75	7.00	3	14.18	15.00	34.00	4	18,113	0.23	ANFO
19/04/2023	230419	Banco 2	NEZ	6.00	7.00	3	13.49	14.26	19.00	2	10,184	0.22	ANFO
03/05/2023	230503	Banco 1 Oficina	NZ	6.00	7.00	3	14.18	15.00	24.00	3	13,230	0.22	ANFO
18/05/2023	230518	Banco 3	NEZ	5.50	7.00	3	13.63	14.42	24.00	3	11,656	0.32	WATERGEL
30/05/2023	230530	Banco 1 Oficina	NZ	5.50	7.00	3	13.40	14.18	17.00	3	7,641	0.42	WATERGEL
12/06/2023	230612	Banco 3	NEZ	5.00	7.00	3	14.18	15.00	26.00	4	11,550	0.31	WATERGEL
21/06/2023	230621	Banco 2 Oficina	NZ	5.25	7.00	3	18.91	20.00	28.00	3	18,375	0.29	WATERGEL
10/07/2023	230710	Banco 2 Oficina	NZ	5.25	7.00	3	16.20	17.13	31.00	5	16,367	0.34	WATERGEL
14/07/2023	231407	Banco 3	NEZ	5.50	7.00	3	14.18	15.00	28.00	3	14,438	0.30	WATERGEL

B and *S*: nominal burden and spacing between holes, respectively; *H*: Bench height, J: Stemming calculated as *L*- H cos(α); *L:* mean of measured blasthole length; N_h is total number of holes, Nr: Number of rows and *V*: total block volume, calculated as *nr.*B.*S.*H./cos(dip).*(Nh./Nr-1)*, *q*: Total powder factor.

- The nominal drilling grid is typically 5.75 x 7 m, but for the burden there may be variations, in the range of [5 to 6 m].
- The powder factor varies in a tight range, with mean and standard deviation of 0.27 std 0.02 kg/m^3.
- The drill grid is marked by the drill operator in the block with measuring tape, and in many cases, mainly when the block has two free faces, the direction of the blastholes is not correct.
- Surface delay used are non – electric detonators with a delay of 42 and 65 ms.
- Two types of explosives are used during the test period (Table 5 shows the main properties)

- For the Base line: bottom charge is an emulsion an ANFO as column charge.
- New Desing: RIOFLEX GX 10000 (watergel), a primary charge a booster (Rio booster 450 gr).
- Electronic detonator: RiotronicX +

Table 5: Explosive Technical data

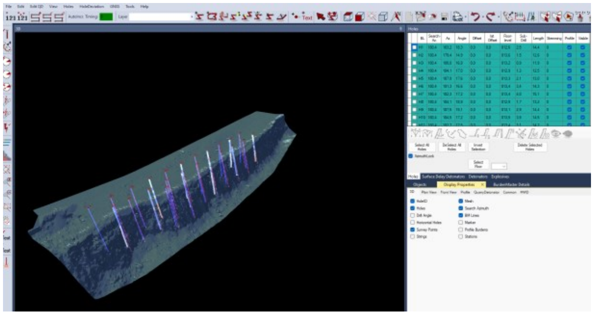
	Nitram	Rioflex	ANFO
Density (g/cm^3)	1.2	0.6 -1.35	0.8
VOD (m/s)	5,500	2,500 -7,500	3,300
Detonation Energy (MJ/kg)	3.8	4.2	2.2

One important consideration is the change of the type of explosive from blasting 230518, this was done because one of main goal of the project was validate a specific explosive that is capable of change the density according to rock conditions, in this case the trails were made in the last 6 blast. Is possible to appreciate that ***q*** was bigger in average a 30% respect with the blast made with ANFO. Usually the bottom charge is a emulsion cartridge and the initiation star from the bottom with a non-electric detonator.

According with the D2M process (section 3.3) several measurements were conducted in the field to have a better a real measurement of the blast design parameters, to do that and different instrument were used for this purpose, describe in the next table.

Table 6: Instrument used to assess blast KPI's.

Instrument	Description	Image
Drone	Matrix 300 RTK Universal (see Figure 7) Edition with a Zenmuse P1 photogrammetric sensor manufactured by DJI for rock mass characterization, and pre and post blast assessment, including fragmentation. Then this information is used in blasting. software- Quarry X and obtain drilling parameters (e.g. burden, spacing between blastholes, subdrill length and bench height).	 **Figure 7: Matrix 300 RTK**
Bore Hole track system	To assess the geometrical characteristics of the blasts, UPM-M measured in all the blasts the actual borehole path with a Pulsar Micro Probe Mk3 (HDP) (see Figure 8) manufactured by Geo-Konzept The 3D models built from pre-blast flights to assess rock mass conditions are used to obtain the actual hole collar position and the block geometry. All these data are integrated into a point cloud model from which the drilling characteristics are obtained.	 **Figure 8: Bore hole track system**
Optical televiewer	The optical televiewer is for rock mass characterization providing accurate information on the position of discontinuities and of their orientation and aperture.It causes, however, a disruption in production as the setting up of this equipment in the field takes about 30 to 45 minutes, considering the logging of about 12 m depth per hole.	 **Figure 9: Optical televiewer**

Endoscope	The endoscope records a colour video of the internal walls of the blastholes with a resolution of 752×582 pixels; the camera's depth down the hole measured with a resolution of 10 cm is shown in the top part of the video (see Figure 10). These characteristics are enough to identify discontinuities and lithologies (including the amount of clay) crossed by the holes and assess their position.	 **Figure 10: Endoscope**
QuarryX	This software enables engineers and technicians to create precise blast patterns and drill hole configurations, optimizing them for factors like fragmentation, safety, and environmental impact. With 3D modeling and simulation capabilities, users can visualize and predict the outcomes of various blast designs, ensuring efficient excavation. Additionally, these tools help manage materials, track environmental impacts, and generate documentation for compliance and project management.	 **Figure 11: QuarryX software**

4.1.2 Monitoring Tracking System (MTS)

ABAUT has developed a system of sensors that can be installed in any machine to monitor the mobile fleet in mines (REFERNCIA). Through this system is possible to monitor production volume and mass of material huled by time, machine(s) involved and work area(s). This enables us to track the amount of material transported from one location to another in a given period of time. This mass flow is the amount of material that is transported from different loading points (mining areas, tailings areas, stockpiles, processing plants) to different unloading points (crusher, stockpile).

Also is possible to measure productivity KPI, for example digging performance, and every individual transport cycle is recorded automatically. This enables a very detailed analysis of the material flow. In addition, productivity analysis provides insights into the daily organization of mobile work machines by revealing hourly and daily productivity figures.

Every machine to be analysed in a quarry must be equipped with a IoT sensor, this records the machines' activities every second and transmits this information to cloud system. There, the location, and activities of each machine are evaluated and visualized with a delay of approximately 15 to 20 minutes.

The table below shows the machines that have installed with a MTS sensor, in this case 5 trucks of the fleet are working with this system, and two loaders are currently using the system. From this sensor different information can be tracked, however for this work the main indicators (KPI's) are related with the cycle time of the truck-shovel, in Table 8 are defined the main time parameter recorded by the system.

Additionally, is necessary to mention that the hardware used to track the movement of the trucks can present several problems associated to the connection system, resulting in loss of information. To avoid this situation on July a new connexion design was implemented.

Table 7: Sensor installed in Dumpers and Loaders

Dumper	Type	Capacity (t)	Sensor	Loader	Sensor
405 N15	Komatsu HD405-6	37	R392	PC750 SE	R394
605 N16	Komatsu HD605-7	57	R398	Cat-390 N2 (R451)	R451
605 N17	Komatsu HD605-7	57	R430		
605 N21	Komatsu HD605-7	57	R460		
605 N22	Komatsu HD605-7	57	R432		
-	Perlini 131-33 E	37	No sensor		

Table 8: Stages of the hauling cycle.

Variable Name	Variable Name	Description
t_{SL}	Start time load	Time at which the truck starts to be loaded.
t_{SU}	Start time unload	Time at which the truck starts unloading at its destination
t_L	Duration loading (s)	Time required to load the truck.
t_U	Duration unloading (s)	Time required to unload the truck
5	Duration driving (s)	Time between loading and unloading points $t_{SU} - t_{SL}$
6	Duration entire (s)	$t_{SU} - t_{SL} + t_L + t_u$

Figure 12, shows a snapshot of the dashboard developed by ABAUT to track in real time the position of truck and shovel across the mine site, through this system the administrative personnel can track KPI's to understand if there is any difference according to the planned activities.

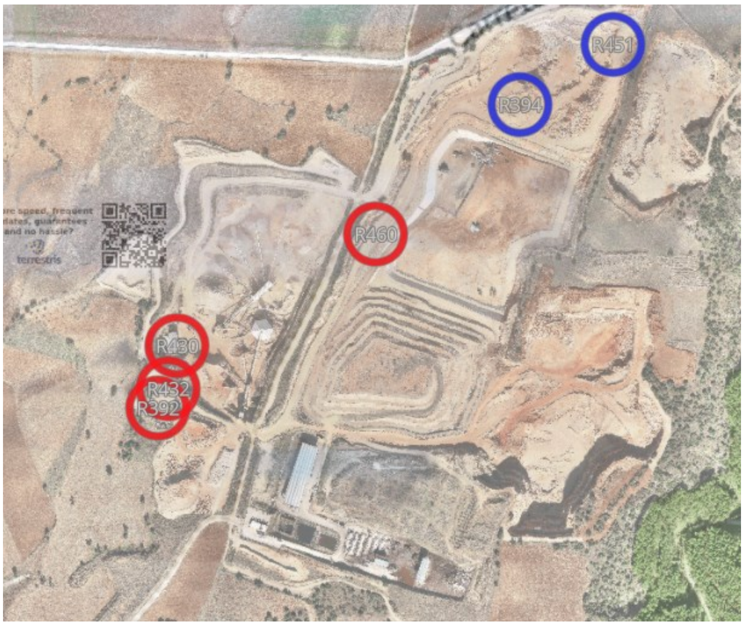


Figure 12: Dashboard of MTS (source: https://www.abaut.de/).

4.2 Plant description

To measure the performance of the manufacturing process companies, utilize Key Performance Indicators (KPI). Selecting appropriate KPIs at the company level and implementing them in the operational level is also a new challenge faced by the cement industry (Rahman et al., 2013). According to (Madlool et al., 2011), the average consumption of electrical energy in a quarry is 75 kWh/t, an only the 2% is associated with mining, crusher, and stacking. The declared consumption in this quarry is 1.35 kWh/t (DIGIECOQUARRY, 2021). associate to mine and processing stage.

4.2.1 Valdilecha ore processing plant description

The processing stage at Valdilecha was designed to obtain different products, in this sense we can find three comminution equipment are used in the quarry listed the next table. The main crusher is a Norberg C160 (jaw crusher) manufactured by Metso, see Figure 13.

Table 9: Comminution equipment for processing stage

Stage	Model
Primary Crushing	• Metso – Norberg C160
Secondary/ Tertiary	• Metso – NP 1313 Vertical • Metso – NP 1313 Vertical • Metso – VI 400 Vertical

The main characteristics of this crusher are:

- Closed setting to 1600 x 1200 mm, D80 960 mm.
- Electrical power 250 kW.
- Maximum production rate 790 t/h.

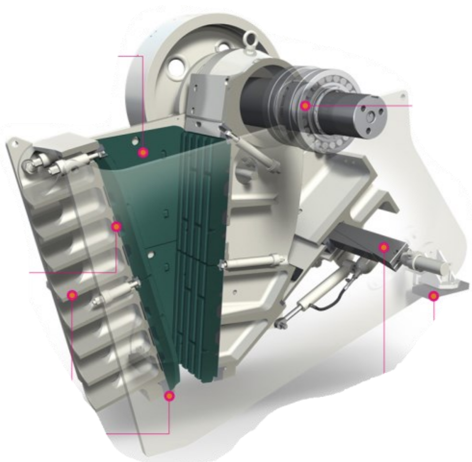


Figure 13: Metso – Norberg C160 (Source Metso)

Table 10: Screen types and models.

Equipment	Model
Inclined Screens Vibrant	○ Metso – CVB – 2060 ○ Metso – TS-303 ○ Metso – TS-303 ○ Metso – TS-303 ○ Metso – TS-303
Finger Screen/Discs	○ Müller 11-606-15-15/11-120-12*1,420

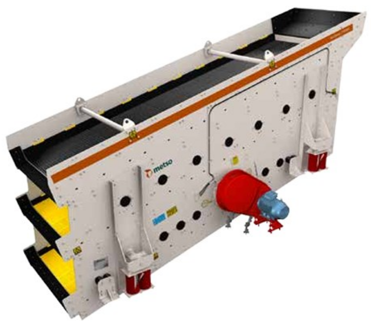


Figure 14: Inclined Screen 3 decks (Source - Metso)

Figure 15 and Figure 16 represents the layout of the plant, from the first is a process diagram, and the second one correspond to a picture plant control, the comminution process star when the ore is dumped into the hopper.

In general, there are two alternatives, and the process is controlled for the ore granulometry, in this sense:

- If the material has (< 90 mm) pass through a several systems of screeners and conveyor belts where is classified according granulometry and be allocated into the corresponding stocks, (left of Figure 15)
- On the other hand, if ore the is > 90 mm need to pass via the crusher, and then send through conveyor belts to the stocks, (right Figure 16)

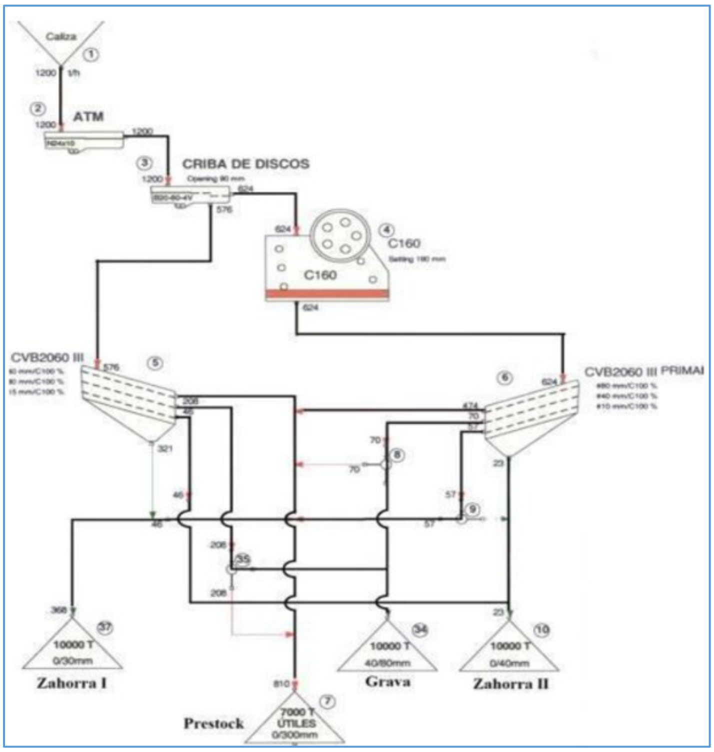


Figure 15: Plant Scheme (1) (Herrera, 2017)

From Figure 16, is easy to appreciate that the bypass (BP) system plays a fundamental role to obtain the right ore classification, more details of this are provided below.

- Material sent to the primary crusher is screened with three decks (CR2), two at cut-size of 40 mm and one at 30 mm, and depending on the requirements can be sent to C7 (40 mm), C9 or C7 (30 mm)
- On the other hand, material can go through CRD. The material 40-80 mm from CRD goes to Prestock through belt C11 (or to Stock 40/80 mm-Belt C10, if BP2 is active). The operation of CDD depends on the amount of clay and its humidity.

Finally, the ore is arranged into stocks according to the granulometry, these are;

- Zahorro I, material from 0/30 mm.
- Prestock, material from 0/300 mm.
- Gravel, material from 40/80 mm.
- Zahorro II, material from 0/40 mm

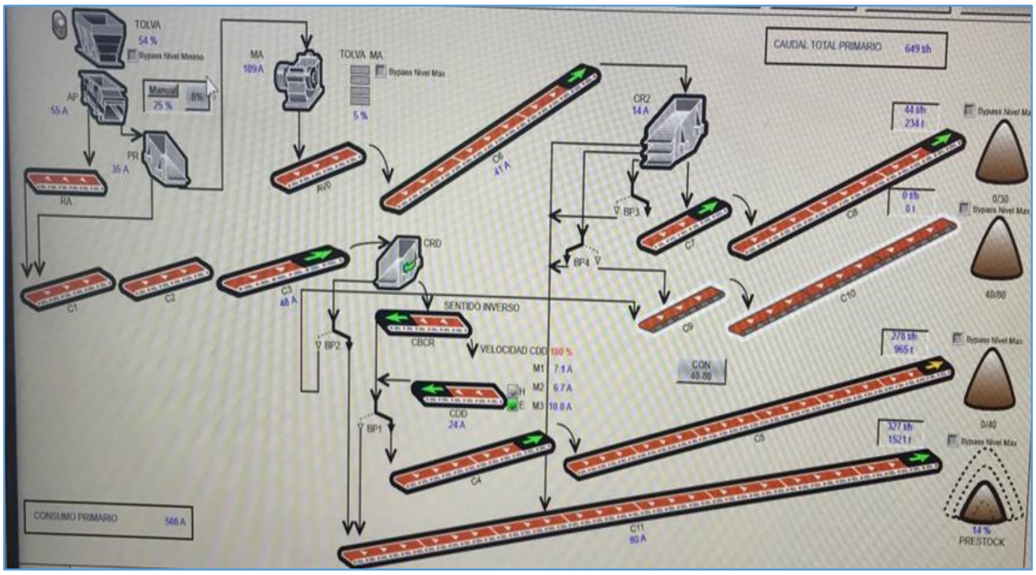


Figure 16: Plant Scheme (2).

Several KPIs are managed the processing stage, of these the most relevant are:

- Mass processed (t/day)
- Actual operation time (h),
- Plant downtime (h),
- Energy Consumption (kWh/t),

They are shown in Table 11, data is gathered by month from January to July 2023. From here is possible to appreciate that the mean treatment per day is 4,180 (t) with a mean EC of 0.52 (kWh/t). From May to July is possible to appreciate a sustained decrease in EC, this is due that the blast made during this period were done with a watergel who has higher energy than ANFO. In average the plant works 8.1 h/day and the treatment per hour is 509 (t/h).

Table 11: Main parameter processing plant per worked day

Month	Days	Mass processed (t/day)	Actual operation time (h)	Downtime (h)	Energy consumption (EC) (kWh/t)	Mass flow rate (t/h)
January	22	3,854.4	8.0	1.3	0.602	470.9
February	20	4,132.8	7.9	1.5	0.562	507.7
March	22	4,254.9	7.6	0.8	0.598	553.5
April	16	3,942.6	7.3	1.4	0.556	517.6
May	17	4,219.9	8.1	0.6	0.483	518.9
June	18	4,020.5	8.9	0.6	0.470	447.9
July	17	4,841.1	8.8	0.4	0.367	547.4
Mean	**19**	**4,180**	**8.1**	**0.95**	**0.520**	**509.1**

Figure 17, represents the relation between the material that goes to CDR (natural fines) and the material that goes through the crusher. allows to understand the impact of the drill & blast stage, the ideal scenario is to have a constant % of fines.

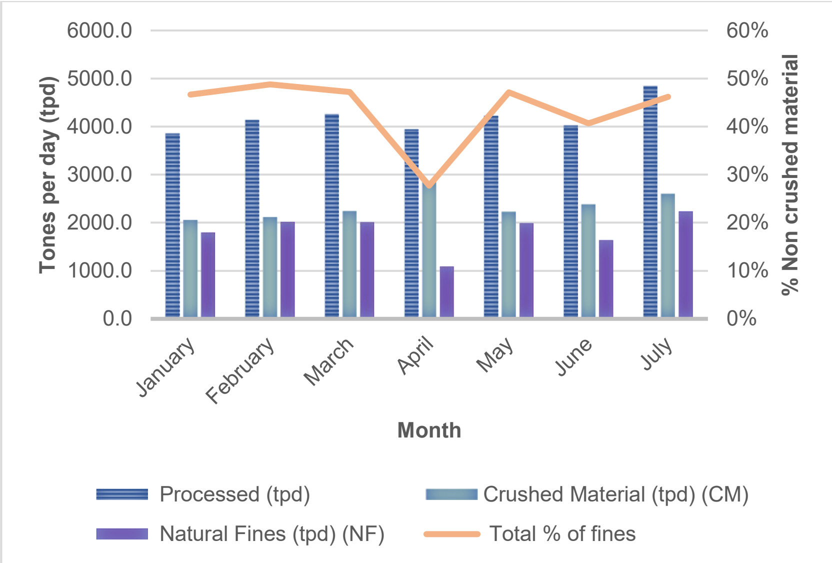


Figure 17: Proportion of material type.

4.3 Data set and data cleaning

The information collected for this study came from different files from different sources, each one of which aims to track the performance of a specific process, Table 12 provides a description for the used data sets.

The next section describes the procedure to select data and avoid errors, inconsistencies, and inaccuracies across the datasets mentioned. Is relevant to say that the main purpose is to group the KPIs per blast, to track trends and from there take conclusions.

Table 12: Data sets description.

Name	Source/File type	Content
Parte De Carga (A)	CEMEX-Manual/Excel	Gives the source of the material (blast id) that is hauled into the plant in a daily basis; it presupposes that only material from one source is fed into the plant.
Producción Camiones Valdlecha (B)	CEMEX-Manual/Excel	Indicates the number of trips made by each truck to the different dumping places in a daily basis. Hence is possible to know how many tons were moved, but the source of the material is unknown.
Automatic Fleet Tracking System (MTS) (C)	Abaut-Automatic/Excel	Allows to monitor and identify the loading and unloading destinations for each truck and shovel, as well as the time required for these activities.
Kpi Plant (D)	CEMEX-Automatic/Excel	The performance of the plant was sent daily to a server and stored in an excel file where the following KPIs
Parte De Perforación Y Voladura (E)	CEMEX– Manual/ Excel	Nominal drill & blast information such as geometrical parameters from the blast such as burden, spacing, borehole diameter etc. Additionally contains information related to type and quantity of explosive and the sequence used to blast.

The general procedure aims to identify unwanted information, fixing structural errors and handling missing data, Figure 18 shows a representation of how data was arranged to connect each unitary process, more details are given below.

- *Step 1(Mine planning)*: From **A** was possible to assign a group of days and a bench location to a blast code, as shown in the following table.

Table 13: Example of data from A

Date	Bench	Blast code
09-03-2023	Banco 3 North	230308
10-03-2023	Banco 3 North	230308
13-03-2023	Banco 3 North	230308
14-03-2023	Banco 3 North	230308
15-03-2023	Banco 3 North	230308

- *Step 2 (Load & Hauling)*: The main goal in this step was to cross the information given in **B** and **C**, this is one of the most important steps in this process, because it links two process, drill and blast and ore processing. More details of this procedure are in the section 4.3.1.
- *Step 3 (Plant KPIs)*: Finally, information obtained from **D** is included in the analysis.

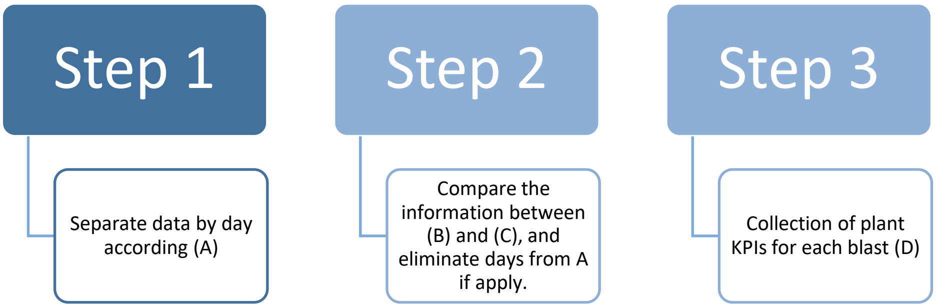


Figure 18: Data cleaning process

4.3.1 Data validation of MTS

Although the information from **B** is crossed with **C** is necessary to mention that these files are populated in the different ways, moreover **C** provides more information. As is mentioned in Table 12, **B** contains the number of trips per day made for each truck to each destination, these locations are described in Table 3. On the other hand, C gather the trucks information using a GPS hardware and therefore provide in real time more details, in total are 32 variables, mentioned in Annex I

To assess the data registered the information was processed and compared with Power BI, a Microsoft 365 application, that allows you to connect to various data sources, visualize the data in reports and dashboards. To track the variation between the data reported by the quarry and the MTS two KPIs where defined (see next table), the main purpose of this analysis is to understand if there is an underestimation or overestimation MTS

- the first one is Diff. Total Trips and compares the number of trips a

- and the second is Diff. Plant this look at the difference between the number of trips to the hopper (Tolva), see next table.

Table 14: KPIs defined to validate MTS.

KPI	EQUATION	DEFINITION
Diff. Total Trips	$\left({(N° \, Trips \, B - N° \, Trips \, C)}/{N° \, Trips \, B}\right) * 100$	Relative percentage of the difference between the total number trips recorded by the quarry and the number of trips recorded by MTS, for each blast.
Diff. Plant	$\left({(N° \, Trips \, Tolva \, B - N° \, Trips \, Tolva \, C)}/{N° \, Trips \, Tolva \, B}\right) * 100$	Difference between trips recorded by the quarry and the number of trips recorded by fleet tracking system for each blast, dumped to the hopper.

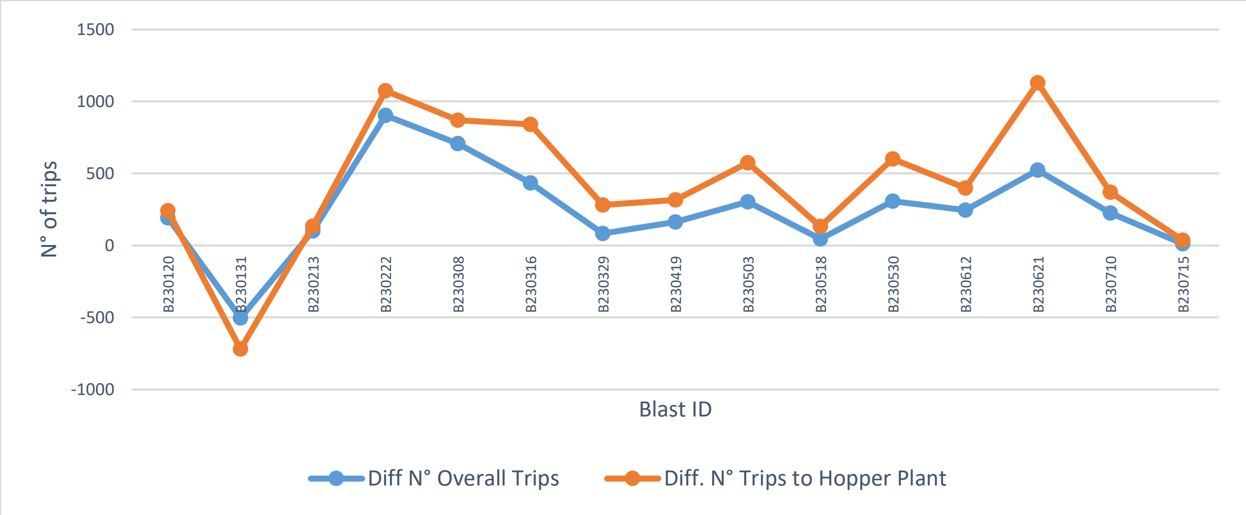
Results obtained from the KPIs analysis are shown in Table 15, in these table is possible appreciate the blast id, location, bench and number of days taken from **A.** In general, is possible to appreciate a considerable difference between the two system:

- The average *Diff Total Trips* and *Diff Plant* was 43% y 39%, with standard deviation of 24% and 23% respectively.
- However, the are some blasts where was possible to obtain much better result, 230120, 230213, 230518 and 230715,

Table 15: Result KPIs MTS

BLAST	LOCATION	BENCH	N° OF DAYS (A)	DIFF. TOTAL TRIPS	DIFF. PLANT
230120	NEZ	Banco 3	5	26%	13%
230131	NEZ	Banco 3	6	67%	53%
230213	NEZ	Banco 1	7	15%	6%
230222	NZ	Banco 3	9	61%	25%
230308	NEZ	Banco 3	7	66%	35%
230316	NZ	Banco 1	11	64%	54%
230329	NEZ	Banco 3	10	11%	39%
230419	NEZ	Banco 2	6	38%	42%
230503	NZ	Banco 1	7	46%	48%
230518	NEZ	Banco 3	7	9%	17%
230530	NEZ	Banco 1	6	60%	71%
230612	NEZ	Banco 3	8	32%	27%
230621	NEZ	Banco 2	9	71%	87%
230710	NEZ	Banco 2	4	69%	58%
230714	NEZ	Banco 3	4	7%	14%

This difference is due that the cigarette lighter connections of the MTS end to be loose or will be used for different purposes, additionally there is one truck without GPS.



Graphic 1: **Differences in the number of trips reported by the MTS and the Quarry.**

Based on these results was necessary to eliminate data to decrease the differences, to do so days are eliminated from the data set if one of these conditions is met:

- Material dumped in the hopper comes from more than one destination.
- The difference between the travels registered by the quarry is 50% more than ABAUT by day discharged into the Hopper. This percentage is considered as intermediate criteria and avoid the elimination of excessive data.

As result of this, out of a total of 87 days is possible to validate 60 days, equivalent to the 69% of the data, an in average 3 days were eliminated by blast. KPIs are recalculated, then the average *Diff Total Trips* and *Diff Plant* are 29% and 22% respectively. Through this process, possible to secure the precedence of the ore, and therefore link it with a blast.

After that the new data set is used to realize D2M analysis based on cross validation with KPIs from the plant.

Table 16: Validated data for D2M analysis

BLAST	LOCATION	PARTE DE CARGA (A)	N° DAYS USED	DIFF. PLANT
230120	NEZ	5	*5*	13%
230131	NEZ	6	*2*	4%
230213	NEZ	7	*5*	6%
230222	NZ	9	*5*	31%
230308	NEZ	7	*5*	21%
230316	NZ	11	6	41%
230329	NEZ	10	7	15%
230419	NEZ	6	4	32%
230503	NZ	7	4	36%
230518	NEZ	7	7	17%
230612	NEZ	8	6	21%

5. RESULTS

This section describes the main results obtained from this study, those are presented in two scenarios, a Base line case, which refers to a reference point and a New design which is based in the application of a new explosive and electronic detonators, while the drilling grid is not modified (i.e. the boreholes position are marked in the block by the drill operator). In both are described and asses the unitary process for the blasts indicated in Table 17. As can be appreciated the first case consists in nine blasts and the second case only three.

Table 17: Blasts contained in each Scenarios.

Scenarios	Blast	Quarry Zone
Base line	230120	NEZ
	230131	NEZ
	230213	NZ
	230222	NEZ
	230308	NEZ
	230316	NZ
	230329	NEZ
	230419	NEZ
	230503	NZ
New design	230518	NEZ
	230612	NEZ
	230714	NEZ

Using the collected information thorough the method described in Table 6 was possible to create a 3D model for each blast, then the integration of these models allows to visualize the development in the benches. In Figure 19 is possible to appreciate the mesh created with a cloud point of NZ and NEZ, blue lines show the borehole deviation data measurement and the red dotted lines the intended borehole path.

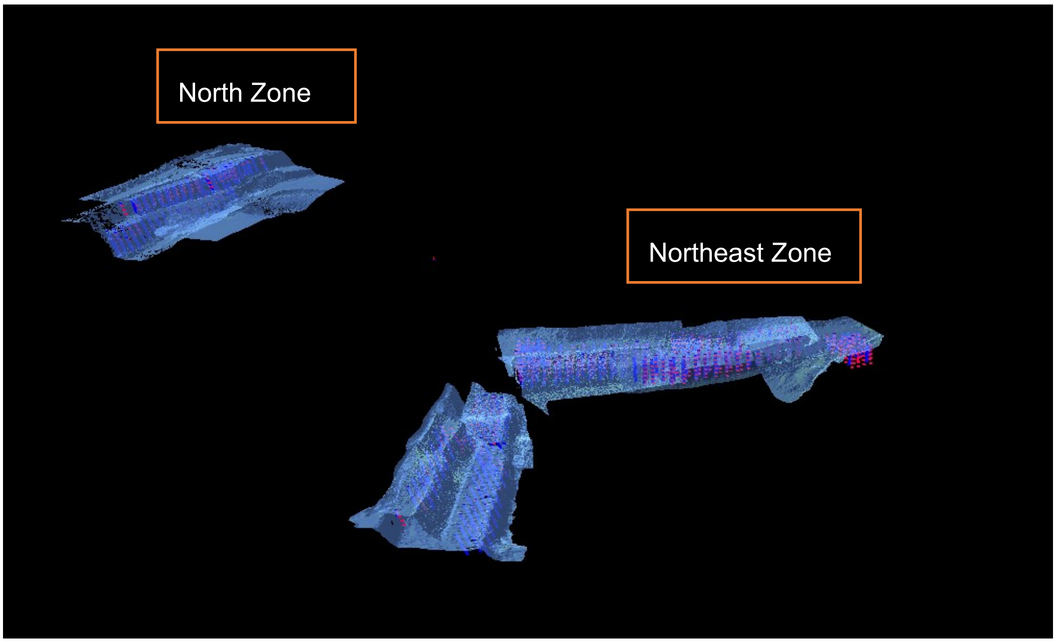


Figure 19: 3D Model of the Quarry.

5.1 Drill & Blast variations

The comparison of real blast parameter with the theoretical design was done with QuarryX. For each blast was created a 3D model, from this one was possible to compare real (measured) data with theoretical one. Figure 20 shows the 3D model for blast 230120, from this is possible to obtain a profile by hole and a plan view as shows **Figure 21** and Figure 22, respectively. Table 26 in ANEX shows the 3D models for the rest of the blasts.

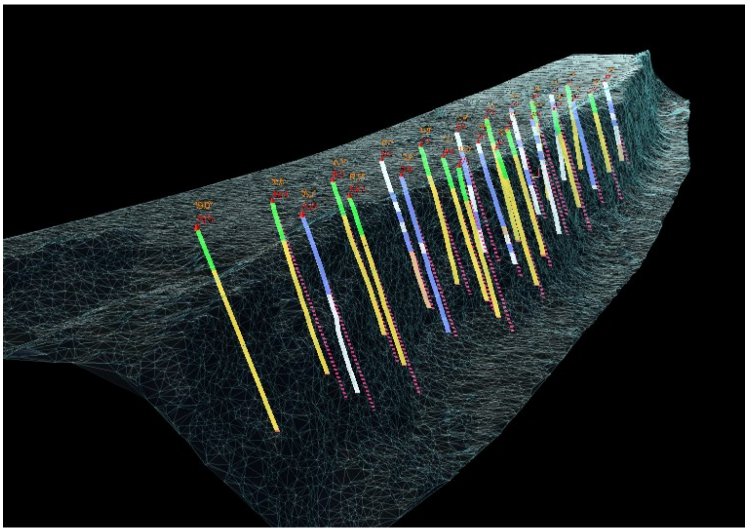


Figure 20: 3D representation of blast 230120

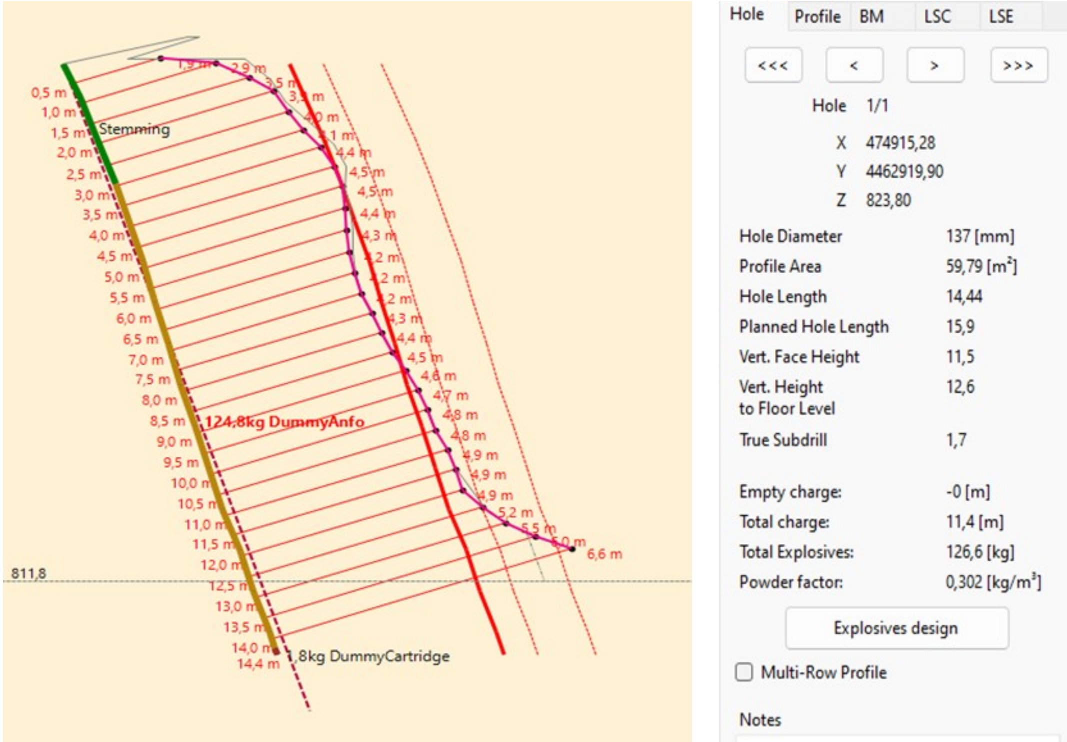


Figure 21: Profile borehole 1, blast 230120

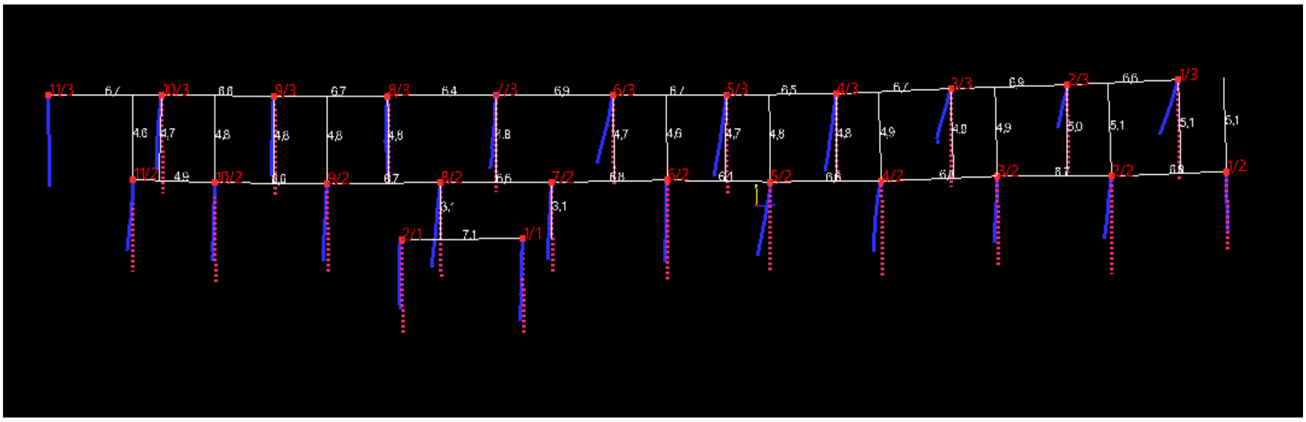


Figure 22: Plan view, blast 230120

Table 18 shows the result from this comparison. In general, it was possible to appreciate:

Base line case:

- Burdens can vary in a range of 5 - 32% depending on the blast, in average the variation was 17% with a standard deviation of 10%.
- Spacing can vary in tight range of 3 - 17% depending on the blast, in average the variation was 7% with a standard deviation of 4%.
- Bench height can vary in a range of 1 - 35% depending on the blast, in average the variation was 14% with a standard deviation of 11%.

- Drill angle (DIP) can vary in a tight range of 0-11% depending on the blast, in average the variation was 5% with a standard deviation of 4%.
- The number of holes can vary in a range of 0-35% depending on the blast, in average the variation was 6% with a standard deviation of 12%.
- The number of rows can vary in a range of 0-33% depending on the blast, in average the variation was 4% with a standard deviation of 11%. However, how is possible to appreciate only one blast (230222) with one extra row.

New design case:

- Burdens can vary in a range of 2 - 24% depending on the blast, in average the variation was 12% with a standard deviation of 12%.
- Spacing can vary in tight range of 0 - 23% depending on the blast, in average the variation was 6% with a standard deviation of 6%.
- Bench height can vary in a range of 1 - 26% depending on the blast, in average the variation was 14% with a standard deviation of 11%.
- Drill angle (DIP) can vary in a tight range of 1-7% depending on the blast, in average the variation was 3% with a standard deviation of 3%.
- The number of holes can vary in a range of 0-6% depending on the blast, in average the variation was 2% with a standard deviation of 2%.
- The number of rows does not vary.

Table 18: Relative variations of blast parameters

Case	Code	Bench	Zone	ΔB	ΔS	ΔH	ΔDIP	ΔNh	ΔNr
				%	%	%	%	%	%
Base line	230120	Banco 3	NEZ	16	5	8	8	0	0
	230131	Banco 3	NEZ	30	6	35	11	35	0
	230213	Banco 1	NZ	11	9	11	11	0	0
	230222	Banco 3	NEZ	22	9	27	4	0	33
	230308	Banco 3	NEZ	10	4	8	0	0	0
	230316	Banco 1	NZ	7	4	1	0	0	0
	230329	Banco 3	NEZ	18	17	1	3	0	0
	230419	Banco 2	NEZ	5	3	18	5	11	0
	230503	Banco 1	NZ	32	4	15	1	4	0
New desing	230518	Banco 3	NEZ	4	4	3	2	4	0
	230612	Banco 3	NEZ	2	6	15	4	0	0
	230714	Banco 3	NEZ	9	1	15	2	0	0

B and *S*: burden and spacing between holes, respectively; *H*: Bench height, DIP: drill angle N_h is total number of holes, Nr: Number of rows.

The real volume calculation is done with VolumeX tools from QuarryX, this one work based on the profile area (indicated **Figure 21**) (distance from borehole to the face, times the bench height) of each borehole in the last row, after that, profile area is multiplicated by the spacing to get the volume. Figure 23, shows in a calypso all the profiles generated by VolumeX.

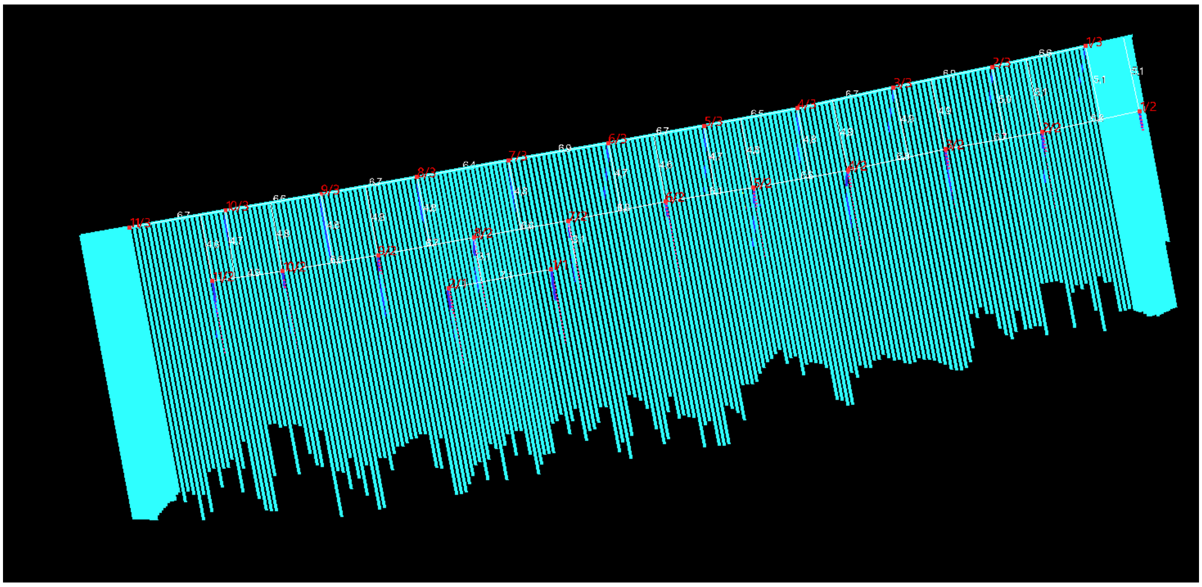


Figure 23: Volume calculation with VolumeX.

Finally, through this it is possible identify the main drivers related to volume variation, and then compare the difference between theoretical volume and real volume, Table 19shows the Theorical Volume (m^3), Real Volume (m^3) and VolumeX (m^3), the first two obtained as:

$$Nr.* B.* S.* H./cos(dip).* (Nh./Nr - 1) \quad \text{Eq. (1)}$$

B and S: nominal burden and spacing between holes, respectively; H: Bench height, N_h is total number of holes, Nr: Number of rows.

- Theorical Volume (m^3), corresponding to the information provided by the Quarry (
-
- Table 4)
- Real Volume (m^3), corresponding to the volume obtained as result of the new blast parameters (Table 18)
- VolumeX (m^3), value obtained with QuarryX.
- Volume Variation (%), 1 y 2, corresponds to the relative differences between:

$$\left(\frac{\text{TV} - \text{RV}}{TV}\right) * 100 \quad \text{Eq. (2)}$$

$$\left(\frac{\text{RV} - \text{VX}}{RV}\right) * 100 \quad \text{Eq. (3)}$$

Table 19: Difference between real and theoretical volume – Base Line blast

Case	Code	Theorical Volume (TV) (m^3)	Real Volume (RV) (m^3)	VolumeX (VX) (m^3)	Volume Variation 1 (%) (VV1)	(Volume Variation 2 (%) (VV2)
Base line	230120	13,283	9,649	10,603	27	10
	230131	10,201	5,324	7,622	48	43
	230213	15,530	11,140	14,440	28	30
	230222	15,251	12,351	10,734	19	13
	230308	16,301	12,933	13,369	21	3
	230316	19,845	20,000	18,020	1	10
	230329	18,113	17,467	16,663	4	5
	230419	10,184	6,725	7,824	34	16
	230503	13,230	7,739	10,591	42	37

Base line case:

- The average variation of VV1 is 25% with a standard deviation of 16%. The blast with the lowest variation is 230316 and the blast with biggest variation is 230131, 1 and 48% respectively.
- In the case of VV2 the average variation is 10% with a standard deviation of 3%. The blast with the lowest variation is 230329, and the blast with biggest variation is 230131 5% and 43% respectively.

New design:

- Average variation of VV1 is 17% with a standard deviation of 9%. The blast with the lowest variation is 230518 and the blast with biggest variation is 230714, 7 and 24% respectively.
- In the case of VV2 the average variation is 10% with a standard deviation of 3%. The blast with the lowest variation is 230612, and the blast with biggest variation is 230714, 7% and 11% respectively.

Using the result from Table 19 was possible to obtain the % of variation between the theoretical and real charge factor presented in Table 20, this was done with the total explosive per blast divided by the volume given by VolumeX.

- The average variation of FC for de Base line case is 38% with a standard deviation of 15% and for the New Desing an average of 27% with a standard deviation of 28%

Table 20: Variation of charge factor – Base Line blasts

Case	Code	Total Explosive (kg)	Theorical q (kg/ (m^3)	Real q (kg/ (m^3)	Δq %
Base line	230120	3,400	0.23	0.32	39
	230131	2,700	0.23	0.35	54
	230213	3,875	0.23	0.27	17
	230222	3,925	0.23	0.37	59

	230308	4,125	0.24	0.31	29
	230316	5,575	0.25	0.31	24
	230329	4,800	0.23	0.29	25
	230419	2,525	0.22	0.32	47
	230503	3,400	0.22	0.32	46
New design	230518	4,227	0.32	0.37	16
	230612	4,232	0.31	0.48	56
	230714	4,858	0.3	0.51	70

5.2 Load & hauling KPI's.

The analysis made on the information provided by MTS focuses on two main aspects, on the one hand the origin and destination of the blast material and on the other hand the loading time. Through this analysis, it is possible to understand the mineral and waste composition of each blast, and therefore identify or validate zones with better ore grade.

Table 21 shows the average material destination per blast for the Base line and New design case, also is included in the table the % of ore and waste determined through endoscope analysis (see Table 6) and the average loading time (digging KPI's), name destinations are defined based on Table 3. The main results from are:

- On average, NZ contains less clay than the NEZ, 15 % and 24%, respectively. The percentage destined to Tolva can be related to the limestone percentage, so in the case of higher percentage of limestone more material is destined to be processed.
- In average the 83% of the blast material is destinated to the hopper (Tolva) with standard deviation of 6%, in average 5% of the material is destinated to the rehabilitation (Tradebe), 5.5% is destinated to the landfills and stock, and Escollera 0.2%. Most be consider that the material sent to stock would be loaded to the hopper depending on quantity of this.
- In blasts 230213, 230316, 230503 most of the material is sent to the hopper or tradebe (where the material is dried), this is due to the good quality of the ore.
- Regarding the digging time the average time is 151 seconds. This considers different equipment loader and dumper, nevertheless, provides relevant information for the operation. In the same way, it is possible to appreciate the relationship between clay percentage and material destined to Landfills.

New Desing

- In average the 84% of the bast material is destinated to the hopper, and this percentage can be related to the Limestone%, so in the case of higher % of Limestone more material is destinated to be processed.
- Additionally, is relevant to analyse the Loading Time, in this case the average time 139 seconds, this considers different equipment loader and dumper, nevertheless provides relevant information for the operation.

Table 21: Material destination by blast, Base Line case.

Case	Blast	Zone	Bench	Clay %	Limestone %	Acopio %	Escollera %	Tolva %	Tradebe %	Vert. Este %	Vert. Norte %	Loading Time (s)
Base line	230120	NEZ	Banco 3	37.2	68.32	15	0.2	71.9	2.4	4.6	3.6	159
	230131	NEZ	Banco 3	31.7	76.02	4	0	85.1	3.0	6.0	0	168
	230213	NEZ	Banco 1 Of	24.0	98.34	3	0.2	90.7	5.1	0.8	0	146
	230222	NZ	Banco 3	1.66	64.01	5	0	83.9	1.8	7.3	0	148
	230308	NEZ	Banco 3	25.15	74.85	7	0	85.5	0.8	6.4	0	166
	230316	NZ	Banco 1 Of	20.10	79.90	1	0	91	4	0	0	154
	230329	NEZ	Banco 3	26.24	73.76	3	0	77	13	7	0	163
	230419	NEZ	Banco 2	0.30	99.70	0.5	0	80.5	3	15	0	125
	230503	NZ	Banco 1 Of	25.45	74.55	4	2	81	12	0	0	129
New design	230518	NEZ	Banco 3	24.25	75.75	1	0	88	7	4	0	126
	230612	NEZ	Banco 3	23.57	71.4	6	0	90	4	0	0	116
	230715	NEZ	Banco 3	28.5	71.5	14	0	74	2	9	0	125

Table 22 shows summarize the information by zone, when is compared the material extracted in NEZ, between the two cases, is possible to appreciate in the New design that more material was sent to the stocks, boulders are reduced to and more material is sent to the hopper, additionally the loading time is reduced in a 15 %. On the other hand, material sent from the NZ to the hopper is slightly higher and no material is sent to the waste.

Table 22: Material destination by zone, base line case.

Case	Zone	N° Blasts	Clay %	Limestone %	Acopio %	Escollera %	Tolva %	Tradebe %	Vertedero Este %	Vertedero Norte%	Loading Time (s)
Base Line	NEZ	6	24.1	81.8	3.65	0.02	80.59	3.60	10.63	0.36	142.90
	NZ	3	15.7	72.8	5	1.00	86.00	8.00	0.00	0.00	141.50
New design	NEZ	3	24.4	72.8	7	0	84	4	4	0	122

5.3 Plant KPI's

Table 23 shows the KPI's defined for the plant as function of the source from the pit, they are obtained after the filtering process described in section 4.3 is applied. The relative working time (*RWT*) is in average 90.3 % and a standard deviation of 4. The energy consumption per unit mass fed into the plant is in average

0.51 and 0.39 kwh/t in NEZ and NZ respectively. Also is possible to appreciate that the percentage of fines (P90) is higher in NZ.

The fraction of the material 0-30 mm that comes from the primary crusher (F_{B8}) varies in a tight range from 3.4 to 4.97 %, mostly due that the other material is screened to the other belts. Blasts made in NZ lead to the larger mass of product fraction 0-40 mm coming from the bypass (F_{B5}) 32.24% in average. Finally, the material put into the prestock (F_{B11}) varies from 62.79 to 66.02.

Table 23: Mean downstream KPIs by Zone, base line case.

Zone	N° of Blasts	Days	RWT %	RE, kwh/t	P90 %	FB5 %	FB8, %	FB11 %
NEZ	6	22	86.06	0.51	38.71	26.04	3.40	66.02
NZ	3	15	90.19	0.39	50.54	32.24	4.97	62.79

Table 24 shows the KPI's defined for the plant as function of the source from the pit. The relative working time (*RWT*) is on average 90.3 % and a standard deviation of 4 %. The energy consumption per unit mass fed into the plant are on average 0.49 and 0.4 kwh/t in NEZ and NZ, respectively. On the other hand, it is possible to observe that the percentage of natural fines in Banco 3 NEZ is the lowest and therefore, it has a higher energy consumption.

The fraction of the material 0-30 mm that comes from the primary crusher (F_{B8}) varies in a tight range from 4.62 to 7.73 %. Blasts made in NZ lead to the larger mass of product fraction 0-40 mm coming from the bypass (F_{B5}) 28 % in average. Finally, the average material put into the prestock (F_{B11}) is 65.49.

Table 24:Mean downstream KPIs of each blast, New design case.

Zone	Blast	Days	RWT %	RE kwh/t	P90	FB5 %	FB8 %	FB11 %
NEZ	230518	7	91.64	0.52	48.94	21.85	7.73	70.40
	230612	6	97.93	0.46	42.10	31.72	6.46	61.83
	230714	4	97.49	0.53	42.76	31.13	4.62	64.25

The comparison between Table 23 and Table 24 serves as a tool for evaluating the impact on the plant, in general is possible to appreciate that RWT in average increase 9.6%, and there are no relevant difference between RE, P90, FB5, and FB1.

6. CONCLUSIONS AND RECOMMENDATIONS ANALYSIS

The present work provides a study case for the implementation of a drill-to-mill (D2M) methodology in a quarry of limestone located in the south of Madrid. It is based on the European project called DIGIECOQUARRY, who aims to for a comprehensive development of the aggregate industry to guarantee the implementation of the best available technology and develop further technologies.

Data from 15 blasts are analyzed, along with data associated with geology, loading and haulage systems, and ore processing. The main issues identified during the study include the variability of blast parameters, problems with accuracy in the track fleet system, resulting in the elimination of data associated with the processing plant.

Towards digitalization

The primary emphasis of this work lies in the integration of data across every individual unitary process within the mining operations, encompassing drill and blast (D&B), load and hauling, and processing. A pivotal facet of this integration process lies in its reliance on digitalization tools, including Business Intelligence solutions, sophisticated software platforms, and state-of-the-art Monitoring and Tracking Systems rooted on the Internet of Things (IoT).

Due to the significant disparities observed between the information reported by the quarry and the data provided by the Monitoring Tracking System (MTS), it became imperative to undertake data curation measures, resulting in a 60% reduction of the original data set. This issue assumes critical significance as the MTS data serves as connection between D&B and the processing plant.

Specifically, the primary concerns revolve around two key aspects: firstly, a notable variance in the total number of trips recorded by both systems, and secondly, a discernible incongruity between the quarry's planned activities and the actual operations on the ground. Addressing these discrepancies entails a multifaceted approach encompassing data validation, root cause analysis, etc. As consequence of this issue the loading polygons of the MTS where again defined.

Based in the available information two scenarios are defined, a Base line case, which refers to a reference point or a set of initial measurements and data that serve as a baseline, and a New design which is based in the application of a new explosive and electronic detonators, the first one contains nine blasts and the second one contains three blasts.

The geological condition identified from the study are set for the NZ and NEZ, in this sense was identified that, on average, NZ contains less clay than the NEZ, 15 % and 24%, respectively. And the average limestone % for NZ and NEZ was 72.8 and 78.8 respectively. Specifically, was possible to identify two benches in NZ with the largest amount of limestone, Banco 2 and Banco 1 with 99,7 and 86.5%.

Regarding the drill and blast analysis was possible to identified considerable variation in the geometrical blast parameters, in specific for the Base line case was possible to identified, that burdens can vary in a range of 5 - 32%, spacing can vary in range of 3 - 17%, bench height can vary in a range of 1 - 35% , drill angle can vary in a range of 0-11%, number of holes can vary in a range of 0-35% and number of rows can vary in a range of 0-33%. And for the New design was identified that, Burdens can vary in 2 - 24%, spacing can vary in 0 - 23%, bench height can vary in a range of 1 - 26%, drill can vary in a tight range of 1-7%, number of holes can vary in 0-6%.

Then the blast volume was analysed, based in two KPI's VV1 and VV2, in this sense was identified that for the Base line case the average variation of VV1 is 25% with a standard deviation of 16%, in the case of VV2 the average variation is 10% with a standard deviation of 3%. For the New design the average variation of VV1 is 17% with a standard deviation of 9% and for VV2 the average variation is 10% with a standard deviation of 3%. Finally, the average variation of FC for de Base line case is 38% with a standard deviation of 15% and for the New Desing an average of 27% with a standard deviation of 28%

The change in the explosive increase the energy consumption and therefore more fines are produced. Additionally, is possible to allocate the decrease in the loading time to a improve in the fragmentation based in the introduction of new explosive and detonators.

When comparing the material extracted in NEZ, between the two cases, is possible to appreciate that in the New design more material was sent to the stocks, boulders are reduced to and more material is sent to the hopper, additionally the loading time is reduced in a 15 %. On the other hand, material sent from the NZ to the hopper is slightly higher and no material is sent to the waste.

Finally, towards digitalization, it's imperative to underscore that the foundation of any successful digital transformation lies in having reliable processes and procedures in place. Without a solid operational framework, the benefits of digitalization can be elusive. Therefore, before fully embracing digital technologies, should prioritize the refinement and standardization of our existing processes.

Furthermore, it's essential to establish a culture of continuous improvement, where feedback from employees and users of the new processes is encouraged and acted upon. This iterative approach ensures that our procedures remain reliable and adaptable as we integrate digital technologies.

This use of new technologies such as drones, borehole deviations, software, and others, help in the development of better technical decision during the blast design. This was a case where was possible to identify variation in volume and charge factor, considerable differences between blast design patterns as well as planification issues.

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8. ANEX

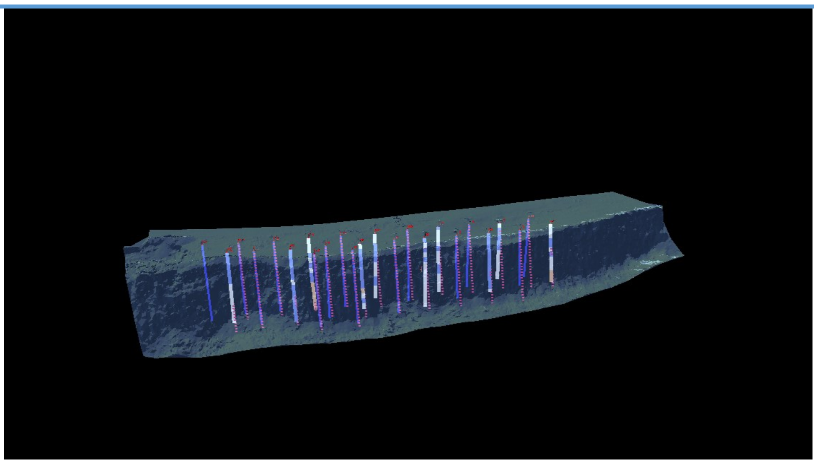
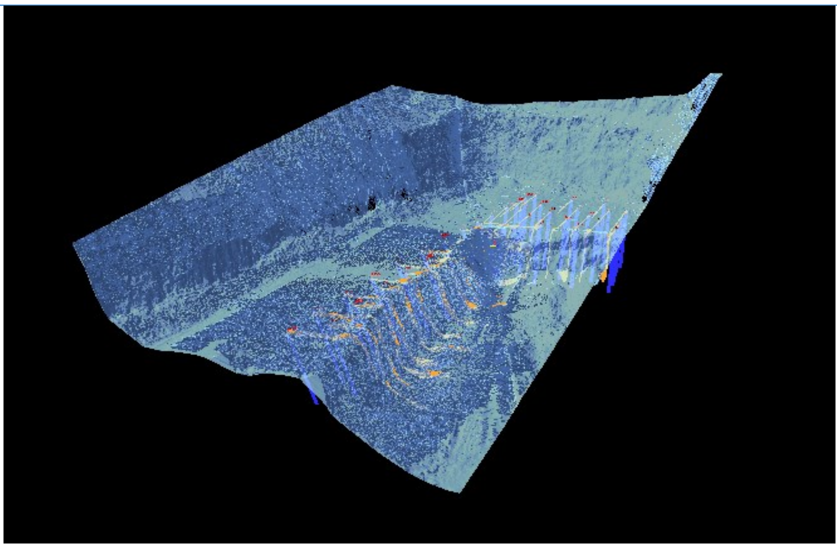
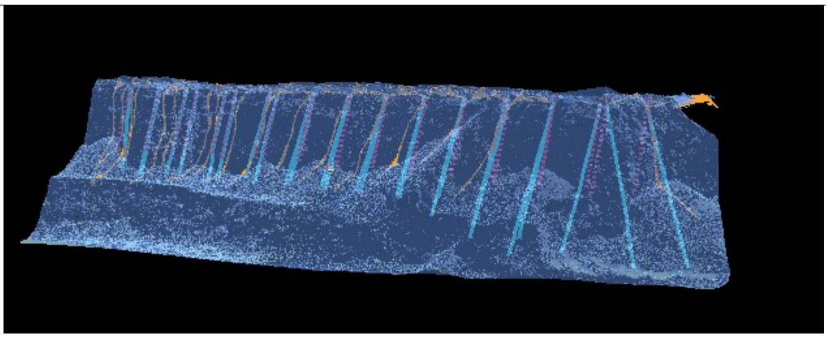
ANEX I

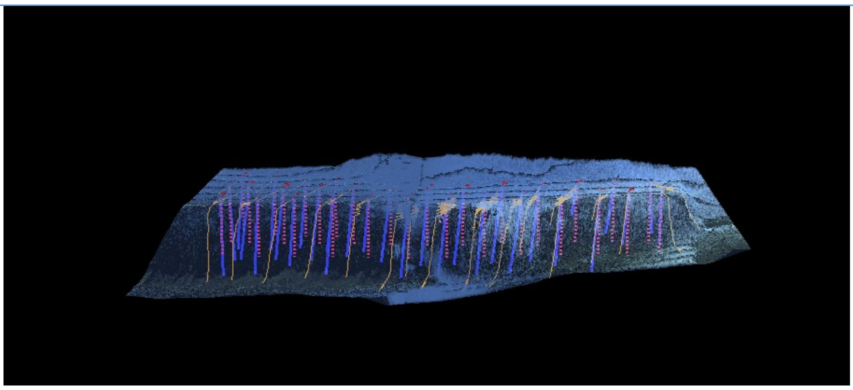
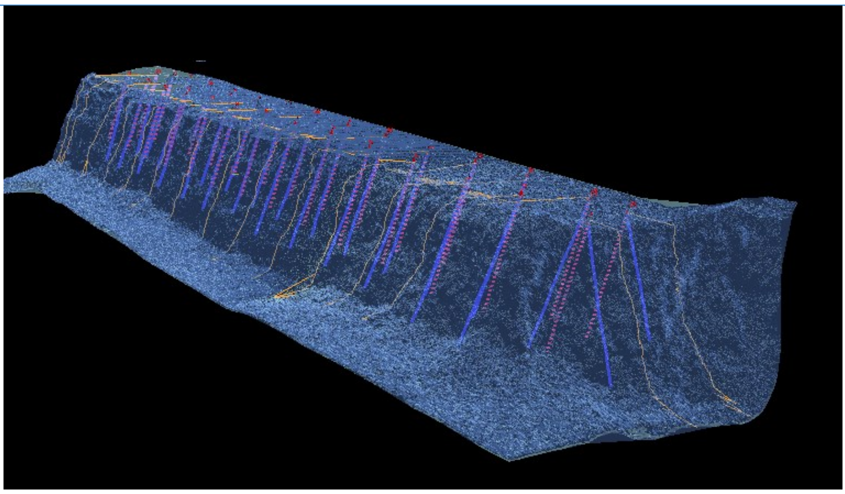
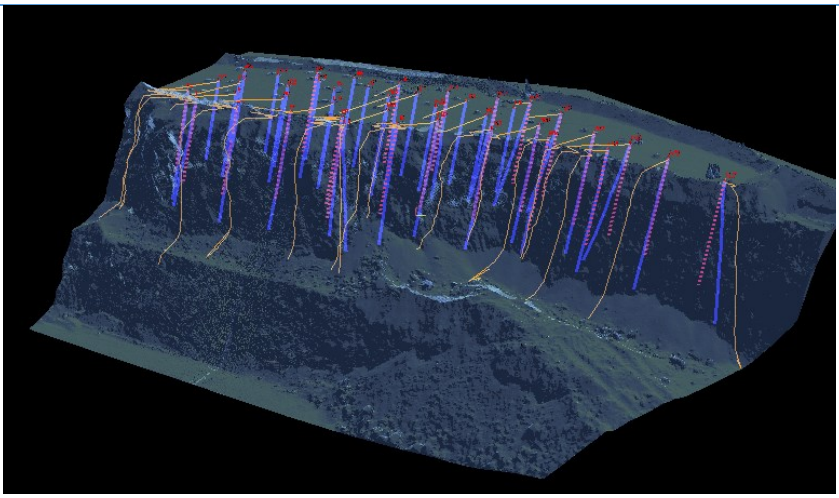
Table 25: Variables contained in C, associated to each sensor.

Location	Truck	Loader
id	start time load	loader sensor id
site id	start time unload	loader sensor id unique
load location lat	truck sensor id	loader numberplate
load location lon	truck sensor id unique	
load location alt	truck numberplate	
load location id	distance road	
load location name	distance road total cycle	
unload location lat	duration driving	
unload location lon	duration cycle time	
unload location alt	duration entire	
unload location id	duration loading	
unload location name	duration unloading	
	driving alt ascending	
	driving alt descending	

ANEX II: 3D representation of blast

Table 26: 3D model of blasts - Base Line

Blast	Location	3D Model
230120	Banco 3	 **Figure 24: Blast 230120**
230131	Banco 3	 **Figure 25: Blast 230131**
230213	*Banco 1 Oficina*	 **Figure 26: Blast 230213**

230222	Banco 3	 **Figure 27: Blast 23022**
230308	Banco 3	 **Figure 28: Blast 230308**
230316	Banco 1 Oficina	 **Figure 29: Blast 230316**

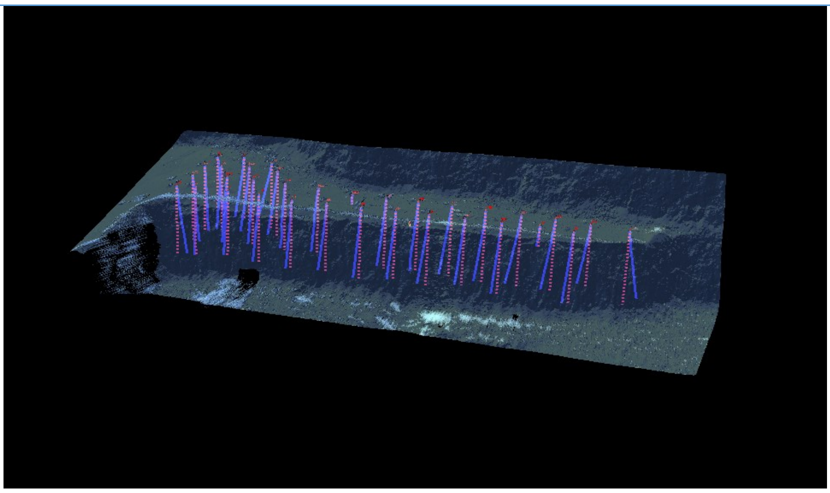
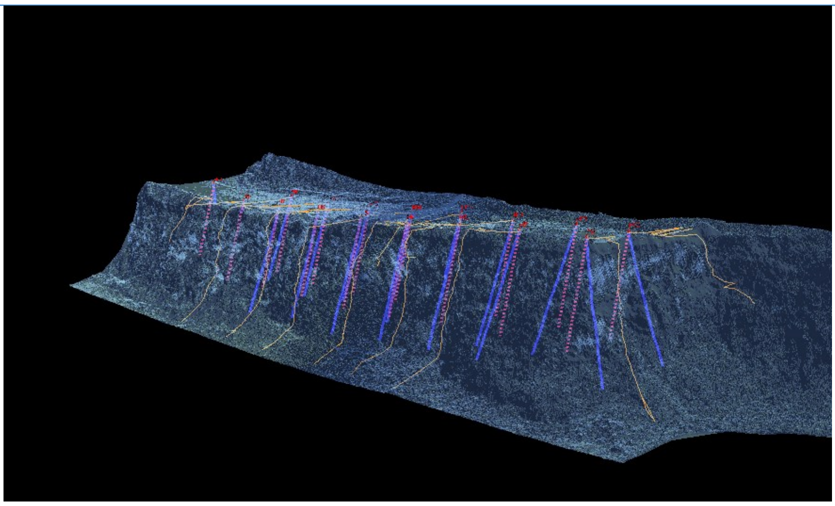
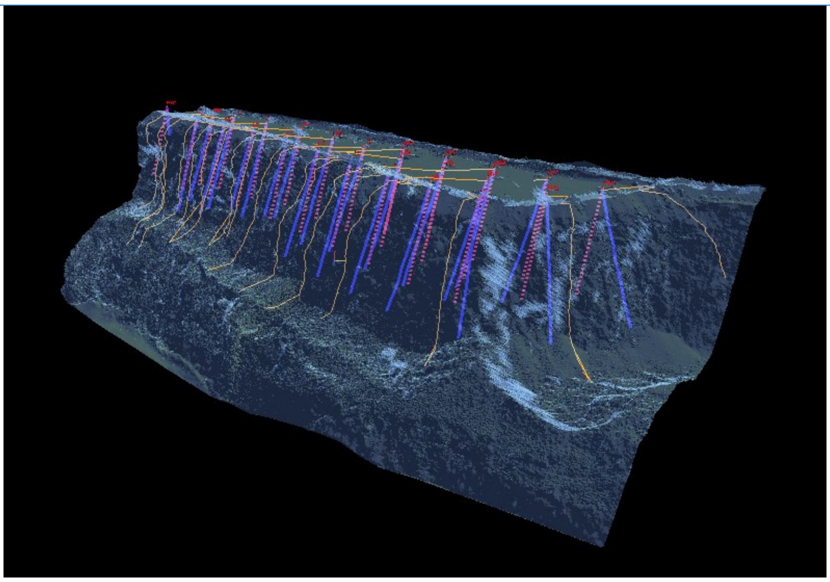
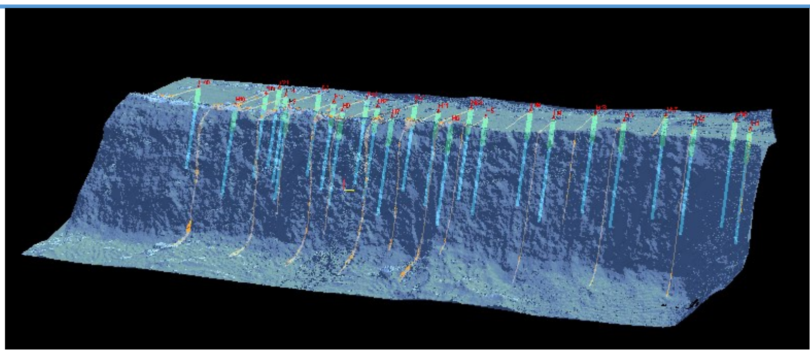
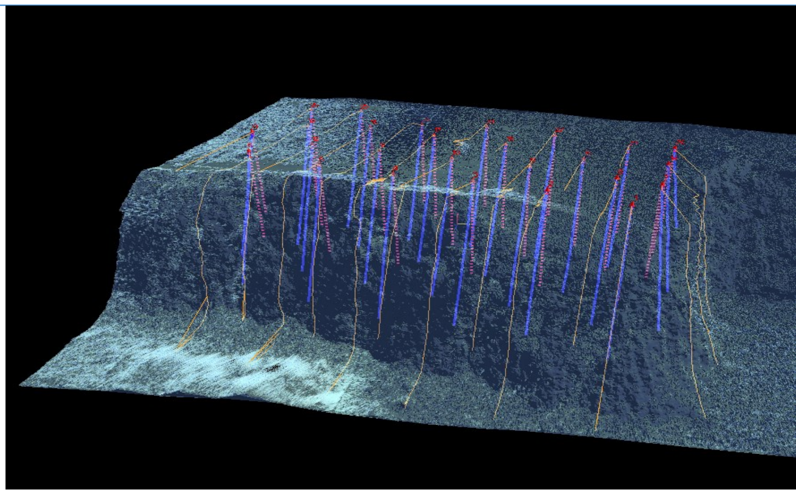
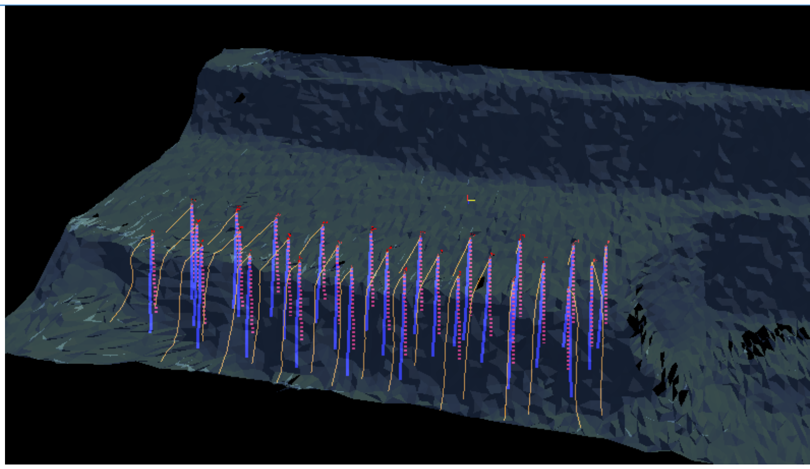
230329	Banco 3	 Figure 30: Blast 230329
230419	Banco 2	 Figure 31: Blast 230419
230503	Banco 1 Oficina	 Figure 32: Blast 230503

Table 27: 3D model blasts - New Desing

Blast	Location	3D Model
230518	Banco 3	 **Figure 33: Blast 230518**
230612	Banco 3	 **Figure 34: Blast 230612**
230715	Banco 3	 **Figure 35: Blast 230715**