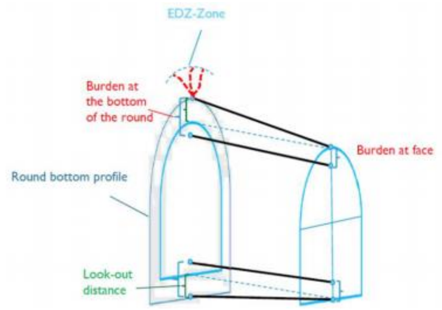
# A NEW APPROACH FOR QUALIFYING BLASTING WORKS IN UNDERGROUND

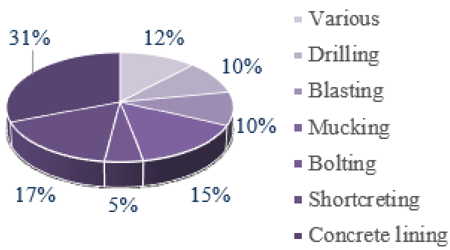
Pascal Montagneux

*EPC GROUPE*

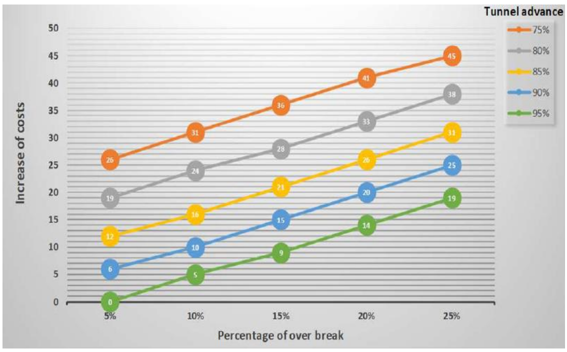

Tunnel cycle management




Theoretical drill plan design

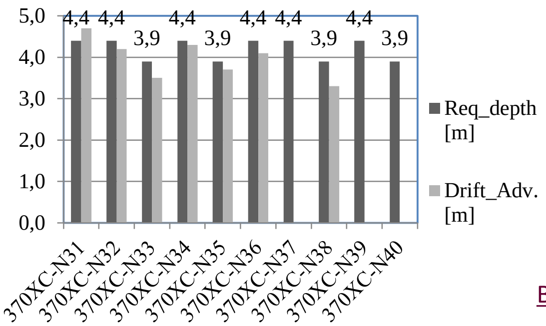



Typical costs repartition in D&B tunnel excavation



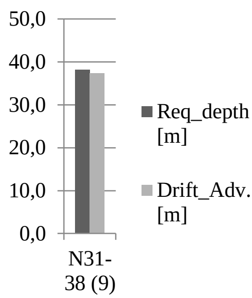

Over costs function of drill adavnce and over beak

## Case Study : Sweden

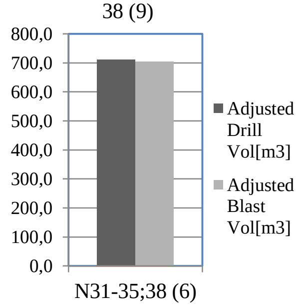



Round advance

Advance measurement (drill lenghs vs blasted tunnel)




Blasted volume vs drilled volume measurement



# A new approach for qualifying blasting works in underground

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## 1 ABSTARCT

EPC Groupe (French explosives manufacturer for 125 years) has developed a new monitoring software for qualifying, and then, improving quality and efficiency of drilling and blasting jobs in tunneling works.

Everybody knows that in tunnels built with Drill & Blast method, everything starts with a good quality of drilling and then blasting. If these two first tasks are not well done or controlled, the downstream operations will be impacted with low efficiency and then over costs.

One of the great difficulty is to get all informations (advance, over and under breaks, fragmentation, and all KPI's linked to the downstream operations) into one tools in order to have a quick overview of the quality of D&B works, and then, correct as soon as possible, leverages on the drilling pattern, blast pattern and/or timing sequence.

With the help of modern tools (using of digital tools for measuring many parameters), and the help of photogrammetry (using simply the camera of a smartphone), it could be easier to get in one box, all information's related to D&B efficiency linked to downstream operation measured with KPI's.

This paper presents the tools, and how it is used to qualify the quality of D&B operations in different audits driven in UG mines and tunnels works.

## 2 INTRODUCTION

There are several methods to build a tunnel. Two big types of excavation methods distinguish themselves. One is called traditional and use mechanical equipment in soft rock, or drill & blast excavation in hard rock, and, another one is called mechanized and use TBM whatever geology encountered.

### 2.1 *Facts*

#### 1.1.1 *Importance of underground excavation in the world*

AITES recently realized a study market tunnels which specifies that at the world level, the construction of tunnels and subterranean spaces represented 86 billion of euros in 2016, which represents an increase of 23 % with regard to 2013. In terms of length of tunnel bored, the annual average is about 5 200 km for all the types of tunnels

The future trends of tunnel construction are amplified by the sustainable development.

In the developed countries, the rhythm of the building work of tunnels is rather constant with major projects in Europe such as Big Paris, Crossrail2 and HS2 in the United Kingdom, Brenner, Lyon-Turin under the Alps.

This sustainable development process and the necessity of communication between countries are not confined in Europe: we observe a large development of mass transit system in all the cities of China, but also a big development to come in India as well as to Qatar and in Saudi Arabia.

### 1.1.2 *Predominance of TBM excavation*

The tunnel boring machine market is largely driven by the increase in spending on road and railway infrastructure. Countries such as China, Japan, Italy, South Korea, Norway, and Germany have vast tunnel networks. The key reason is to connect major cities within the country, sometimes even international, with minimum commute time. This largely optimizes the transportation costs and connects cities to boost commerce. The other method for building tunnels is by using explosives;

The TBM industry use of such fears to convince clients and contractors to use TBM technology for boring underground excavation; *"explosives are highly dangerous, and it is often difficult to control the explosion. They are also a threat for men and machines working in the tunnel. Slight deviation in the charge of explosives can completely jeopardize the project. Thus, tunnel boring machines are the ideal alternatives for tunneling operations"*. In spite of the use of marketing arguments of which most are fallacious, it is necessary to have the intellectual honesty to admit that it has been quite a while since the conventional method *(i.e Drill & Blast method)* did not produce technological revolution, making her more competitive and thus more attractive.

## 2.2 *Reasons of hope for D&B method*

Explosives manufacturers are not to stand idly by during all these years. Some research and development were done on the products, equipments but It will have been necessary to wait for the beginning of the 21th century, with the advent of the new digital tools and the considerable increase of the computing powers of computers, to see the light at the end of the tunnel.

### 2.2.1 *Recent evolution for D&B method in the last 20th years*

The most dangerous products, as dynamites or similar products, were replaced hopefully, most often by emulsions (packaged or in bulk), which ones are generally 10 times less sensitive than NGL based products.

Bulk emulsion is now for more than 15 years all around the world, the reference were explosives are needed in construction work, bringing safety and high performance; and when country regulator considers matrix emulsion (raw material) as an oxidizer (class 5), it gives very positive solution for products storage on site.

Automatic drilling machine arrived early in the 90's, bringing new equipment which allow to drill blast holes with high accuracy, automatically and then with less workforces. In tunnel excavation using drill & blast method, automatic jumbos are the reference today.

Non-electric detonators replaced advantageously at the end of the 90's, electric initiation system, bringing more safety in tunnel.

Electronic detonators arrived in the market at the beginning of the 21th century, and in spite today of a pricing little bit more expensive compare to conventional initiating system, they could bring very interesting solutions in urban civil works (cities as Monaco, Hong Kong or Singapore encourage the use of such products to guaranty the timing for blasting works, mastering seismic effects on neighborhood structures).

### 2.2.2 *The best is yet to come*

Wireless electronic detonator is probably the most interesting thing to come soon. Most part of problems encountered during charging in underground come from wire, when using electronic detonators, as energy and communication is driven through the wires. In difficult geology and or with the use of fiber shotcrete, wires are often injured and could complicate communication with the detonator. By avoiding any wire, the use of electronic detonator will be safer and faster, and will open new windows, for a joint use with equipment, opening the way for a complete automation for explosives loading.

OnlineMWD (Measure While drilling) transfers drilling data in real time to the office to geologist's tablet by sing a WLAN connection. OnlineMWD is a great tool in order to know with high accuracy the rock behind the face. However, these data are never used for optimizing blast pattern and blast sequence in real time. New algorithms are arriving to transform all geological data in blast energy model needed to break the rock. And for sure, as for wireless electronic detonator, it will open windows for developing new generation of automatic charging equipments.

Photogrammetry is revolutionizing the way of realizing tunnel profile and, get in real time all information on excavated volume, over and under break, tunnel advance, granulometry, muck pile shape, etc…, with a simple camera (a smartphone for example) and a minimum light (car's lights for example).

When all these tools will work jointly or on a same equipment, it will be the time to have an automatic drilling and charging equipment. In this case, such technological breakthrough, will bring sufficient time savings on the tunnel excavation cycle, giving D&B method new reasons to be competitive compare to TBM excavation method. This time is coming soon.

## 3 Drilling AS THE FIRST LINK IN THE CHAIN, AND BLASTING, THE RELATED LINK

Whichever method is used (conventional or mechanized method), tunnel excavation is a permanent cycle with successive imbricated tasks: surveying, drilling, charging, blasting, ventilating, scaling, mucking, shotcreting, and bolting (sometimes heavy rock reinforcement is needed) and do over.


*Figure 1: tunnel cycle management*

As the first task on this cycle, drilling play an important role. If drilling is not performed well, whatever are the quality and the quantity of explosives that it will be used, the result of the blast will not be optimal; it's that expert called "as planned as drilled".

Which parameters are important to be managed? There are several parameters for drilling that it is important to be sure that they are well implemented: hole mark vs planned, hole length, burden and space at the bottom face, hole inclination and angle, hole missing.

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### 3.1 *Triptych of underground blasting*

There are 3 fundamentals elements to design a blast in underground: energy distribution in space and in time. These three elements work closely together and cannot be considered in theory separately.

As the 3D face geometry is responsible of the profile excavation (contour, soil and tunnel advance), the energy distribution play an important role in fragmentation, muck pile shape, and certainly, because it is closely link to 3D face geometry, in tunnel advance and contour quality control.

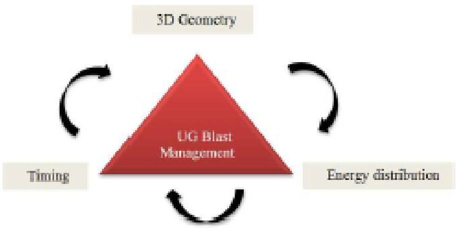


*Figure 2: triptych of UG blasting*

The timing (how the energy is deliver on time), play a role in fragmentation, muck pile spreading, contour quality control, ground vibration and air blast, and for sure in tunnel advance by giving optimal free face to the next series of blasting holes.

Drilling pattern, charging and firing pattern give all theoretical parameters of a blast. If these documents are done generally by blasting engineers, they are implemented on field by experienced operators. It is very important that no frontier exists between the theory and the reality: field controls are very important to be certain that parameters are correctly implemented, and, to link blast results to those parameters as an iterative process.

But for sure, to be efficient, tools and time are needed to process all measurements, control and analysis. It's the price to pay to have efficient blasting, and finally save money.

To be honest, in tunneling excavation, time is essential, and the main goal is to reduce cycle time as short as possible. In this frame of mind, project managers are not predisposed to spend time in measurement and analysis, as there are not considered their project as a laboratory. In this case, efficient and easy tools are the only answer to give to them, and proven added value is the key.

### 3.2 *3D face geometry management*

It is important to well mange the 3D face geometry, but it exists different way depending which type of equipment is used.

The figure at the opposite shows how a drilling pattern should be considered on the field.

The important thing is to understand that a drill plan should be designed by considering it in three dimensions (3D).

By avoiding that, a lot of blast dysfunctions may occur.

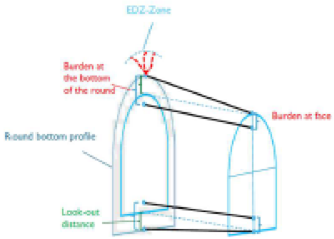


*Figure 3: theoretical drill plan design*

### 3.2.1 *Using automatic drilling machine*

When automatic drilling machine is used, drill pattern is memorized into the machine, and jumbo operator should drill more than 80% in automatic mode (bottom holes and some contour holes need to be carefully done in semi-automatic mode to avoid damage on the boom, or to take account of rock face reality).

When automatic jumbo is used, the accuracy of drilling is very high, around a centimeter, and if the blast plan is properly planned, the blast result shouldn't be affected by drilling.

In semi-automatic mode, the jumbo should correct automatically length, inclination and angles when the operator moves the boom from its original mark, assuring to a certain extent, that drilling pattern is well performed at the bottom face.

In manual mode, there is no help from robotic or electronic tools; the experience and feeling of drilling operator is essential, but not a guarantee.

*Figure 4: computerized drilling*

### 3.2.2 *Using manual drilling machine*

Unfortunately, automatic drilling machine are not always used, because of availability on the country, project budget, or other reasons.

Manual drilling machine is often used is small to medium underground mines, small tunneling projects, or bigger projects in remote and exotic area. In this case it is important to control the implementation of drill holes on face, quality of holes drilled (angles, inclination) and length, and compare it to drill pattern planed.

*Figure 5: grid paint of face (left) --- laser system projecting hole mark according to drilling pattern (center) --- drill plan projected directly on the face with a digital projector (right)*

The main problem is this case is how to mark the drilling pattern on the face to give references for drillers. Sometimes, drillers don't use any mark on face and drill with their own feeling and experience, other times a grid is painting on the face helping drillers to have some references, or hole mark is painting (with as a reference of the axis of the tunnel or not) or projected with the help of a laser or a projector (see Figure 5).

Whatever the system is used, it's better than nothing, but not a guarantee that the drill plan is correctly done. In this case the drilling accuracy is relatively poor, adding errors from the drill plan implementation to its achievement.

By measuring the accuracy, it's then possible to better manage.

### 3.2.3 *The importance of measuring drilling accuracy*

All those parameters affect the drilling advance per blast. The drilling advance is a percentage of meters of tunnel effectively blasted, compare to tunnel drilled. Normally, a good productivity should be at least more than 92 to 95%, a very good one reach 100%. Below 90%, something should be analyzed and done, if not over costs will affect the whole excavation budget.

*Figure 6: measurement for efficient management*

There is a famous proverb saying, 'you can't manage what you can't measure". At the time of a precise management on project construction, measuring to better understand, act and master the costs, this proverb was never so true.

*Figure 7: view of as planned (green point) and as drilled (red point) with a semi-automatic drilling machine*

Hopefully, automatic drilling machine record all parameters effectively done and it is possible to check the quality of drilling accuracy (but this job is not however done in real time) after job is realized.

By importing drilling data from jumbo, and by overlaying these data on a 3D model obtained from photogrammetry for example, it's possible then to compare with the theoretical drilling pattern, to appreciate the work quality (see Figure 7).

For manual drilling machine, it exists equipment to added in order to track and trace every essential hole parameters (inclination, angle and length, drilling parameters). Without these equipments, it is difficult then and it takes time to measure drilling parameters.

Drilling accuracy is certainly responsible to a half part for a minimum to contour quality, tunnel advance, soil flatness, and in a certain measure rock fragmentation, and ground vibration.

It's the reason why, it is so important to have a continuous view along the excavation project, about this essential parameter.

*Figure 8: additional equipment installed on manual drilling machine (Bever Control AG)*

### 3.3 *Some blast malfunctioning*

As Drilling and blasting should represents at least 20 to 25% of the total excavation costs (see Figure 9: typical costs repartition in D&B tunnel excavationFigure 9), to take care of these direct costs is not a harmless thing. But we can see that consequences on the downstream operations, which costs for some represents between 15% to more than 30% of the total excavation costs, could be enormous.

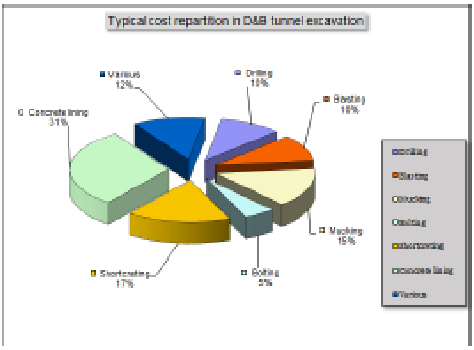


*Figure 9: typical costs repartition in D&B tunnel excavation*

There is a lot of examples of malfunctioning it could occur in tunneling or underground mining blast:

- Some are related to the management of tunnel profile (under and over break, soil quality and altitude, advance),
- Some are related to fragmentation (poor or excessive blast fragmentation),
- Some are related to muck pile spreading,
- Others are related to blast nuisances (over ground vibration and air blast, excessive blast fumes),
- In underground mining, problems related to blast ore dilution are also mentioned,

All these problems have a common link: over costs generated directly or, indirectly on down-stream operations. We can talk about:

- Augmentation of cycle time due to poor charging productivity (muck pile spreading, over size etc…), over time spending in scaling or reboring tunnel profile, decrease of tunnel round advance due to excessive ground vibrations,
- Augmentation of concrete volume used in the whole project,
- Loss of ore due to bad management drilling and blasting in ore body,
- Poor tunnel advance (increase about 10 to 30% of drilling and blasting costs)

The chart above (see Figure 10) shows how quality of contour combined with efficiency of tunnel round advance, influence jointly overall costs in tunnel construction.

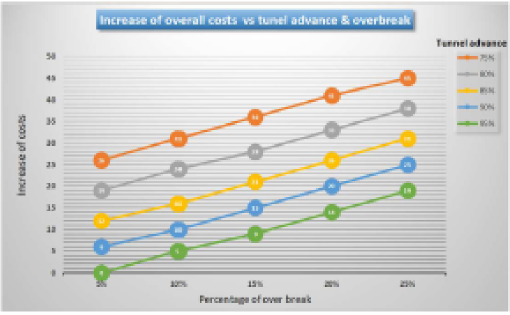


*Figure 10: over costs function of drill advance and over break*

## 4 EXPERTIR® UG – A NEW MODERN TOOLS TO QUANTIFY AND QUALIFY BLASTING WORKS

### 4.1 *Users's requirements*

Today, to design a drilling and blasting pattern, it exists some tools using most of the time theoretical models (JKSIM blast® for example) or a combination of theoretical and experienced model (in house software provided by computerized jumbo manufacturers).

More generally, these software give a theoretical pattern to be done without taking in account the reality of the face (geology, geometry etc…).

User's requirement is exactly the same of what was developed for open pit blast design: from laser scanning or pictures taken from a drone, the blasting software is taking in account the reality of field to make the design efficient and safe.

### 4.2 *Software concept*

Expertir UG© had been developed from scratch with at least two goals in mind. First it provides tooling for visualization and measurements of 3D geometric data. It can be a gallery shapes obtained by photogrammetry or laser survey as well as drilling plans or reports with bore holes data.

Then it is also a solution to aggregate those data and more in a single place thus allowing the extraction of relevant Key Performance Indicators (KPI's) like advance, over break volumes, explosives quantities…

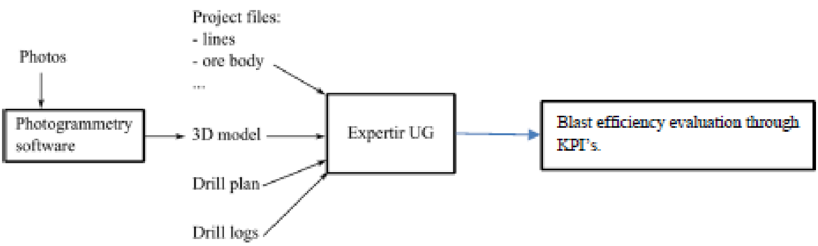


*Figure 11: software overview*

This tool allows both to analyze the detail as well as view the big picture on a complete gallery scale. To achieve this, Expertir UG© accepts various input files coming from other software or equipment. But the core feature remains 3D visualization and analysis.

*Figure 12: 3D model computed from pictures get with a classic camera (smartphone)*

The main input is the 3D model upon which other geometric data are related. Photogrammetry yields a good accuracy (sub centimeter compared to laser) with the advantage over laser to offer both position and color information. Another software is used to produce a 3D model from the photos taken underground. The quality of the produced model is inherent to the quality of the picture. Unlike the laser photogrammetry doesn't work in complete darkness and descent amount of light is required. Tests have been successful using a vehicle headlight.

The Figure 12 shows a 3D tunnel displayed in Expertir UG®. Displaying the texture allows the user to better understand the model and the geology (water, rock structure…).

By importing drilling data and overlaying with planned data, the 3D model can easily shows potential quality deviation.

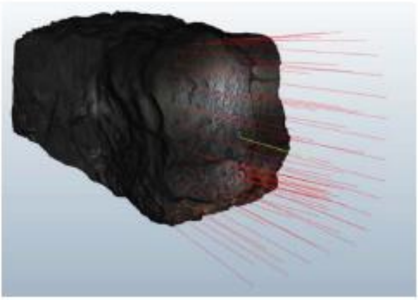

*Figure 13: import drilled data in 3D model*

### 4.3 *Advance following*

The measurement of blast advance is automated when models are imported. A mean distance between closed face is computed between each model. A 2D view of the gallery shows a symbolic advance along the gallery line, whatever its path. The 3D model still must be georeferenced before import.

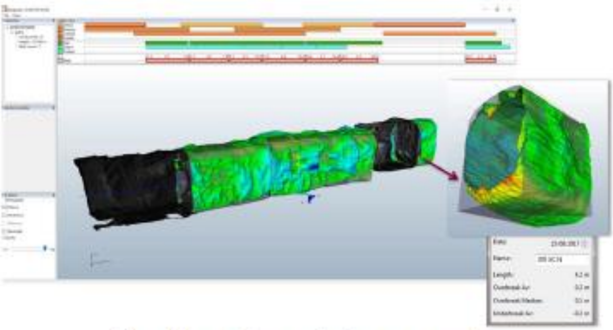

Figure 14: round advance and volumes measurement

### 4.4 Over/underbreak measurements

There are different ways of defining the over break and underbreak figures. Since contour holes are not bored exactly parallel to the gallery desired axis (due to drill rig mechanical constraints), the software considers both cases:

- Over break/under break with drilled geometry: allowing to access the efficiency of the blast only
- Over break/under break with project contour geometry: to access global quality of the drill and blast process.

The software allows to view the evolution of these values along the blast as well as provides numerical values for both volumes.

In addition, the imported 3D model can be seen in fake color to show the distance from the planned contour thus allowing a quick highlight of problematic areas.

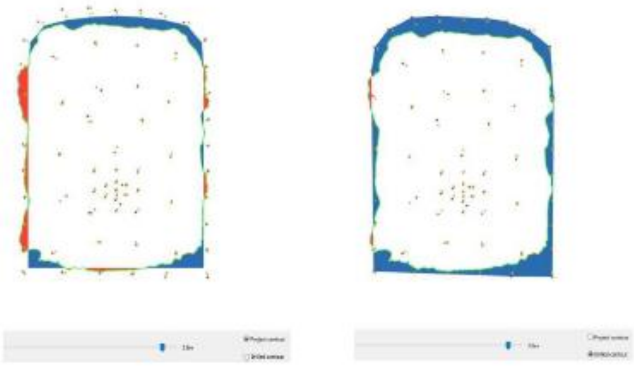

Figure 15: over break and under break measurement as planned vs drilled

### 4.5 *Production hole and ore body*

In underground mining blast production (sub level stopping, sub level caving), it is very important to control drilling quality along the ore body shape.

By importing data from multiple source, Expertir UG® lets the user visualize within the software the position of production holes relative to the ore body.

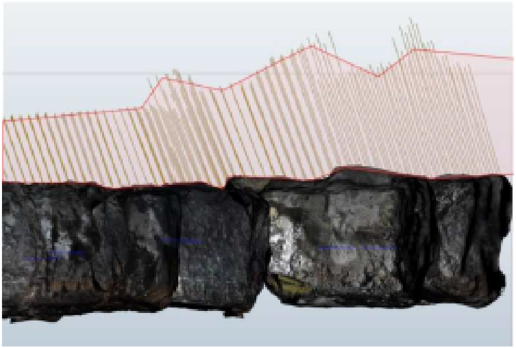

*Figure 16: position of drilled hole in ore body in production blasting*

### 4.6 *KPIs*

In addition to informations extracted from the geometry analysis, users can input other blast related values of interest. Clients having different needs the user interface is flexible to adapt to various input types.

Finally, all theses Key Performance Indicator (KPI) may be exported in an open format for further specific manipulation.

A KPI could be tunnel advance (% of tunnel blasted/tunnel drilled), accuracy of contour blasted (% of over break or underbreak), shape of the muck pile (related to wheel loader efficiency), fragmentation (related to wheel loader efficiency), seismic impact, air pressure impact etc… Depending the main objective chosen by the user, it becomes "easy" to qualify a blast within these KPI's.

KPI's is the only way to prove the positive or negative influence of drilling & blasting parameters changes.

## 5 CASE STUDY

In Sweden we experienced this tool and some view of the results are given here after:

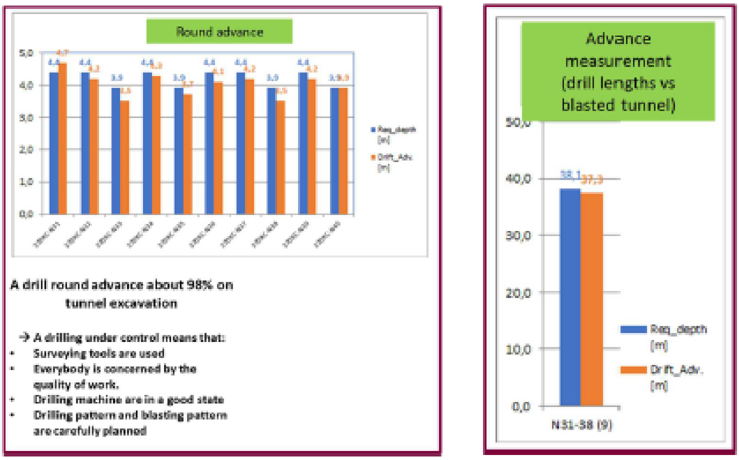


*Figure 17: using EXPERTIR UG® for advance measurement in a project in Sweden*

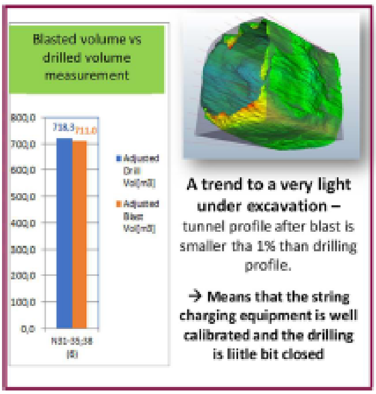


*Figure 18: blasted volume vs drilled volume measurement*

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## 6 CONCLUSION

To manage correctly rock excavation using drill&blast method, it's necessary to input some key measured data during drilling and blasting cycle time, and link those ones to downstream operation to evaluate their negative or positive impact on them.

This is the only way to evaluate any changes on drilling and blasting pattern on operations, and potential money savings could be important.

To achieve that, EPC groupe had developed EXPERTIR UG®, a 3D data base object in which one all rounds are collected (with measured or input data), for fine analysis, with one objective, save money on the whole excavation cycle. With the help of new numeric tools, it's now easier to collect data for better management.

Now the famous proverb could be "we can manage as we are measuring".