BLAST OFF

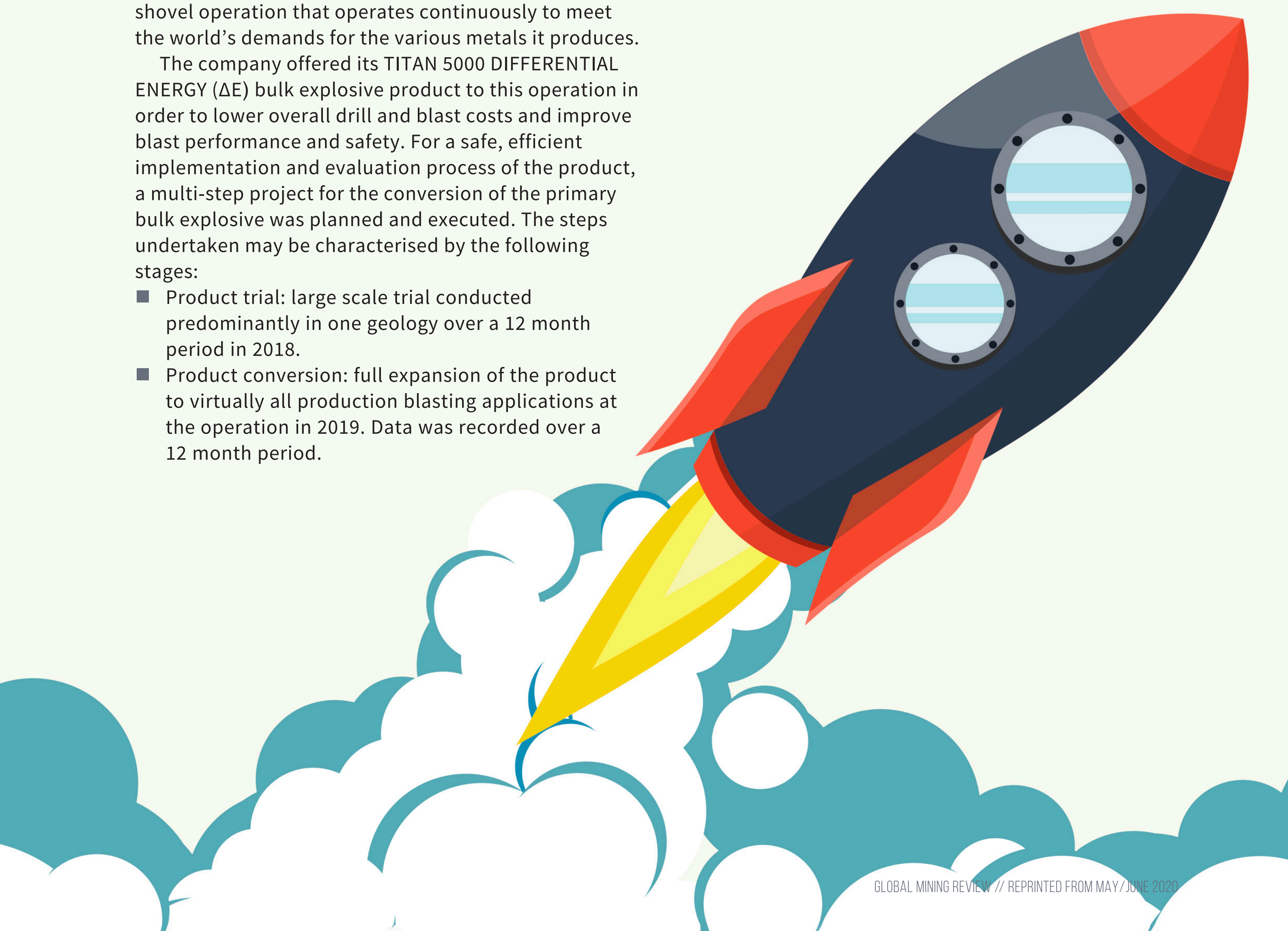
Russell Lamont, Miguel Valenzuela and Jim Kennedy, Dyno Nobel, the Americas, detail how the company helped a large opencast mining operation in North America.

Mine production equipment operates in three main geologies, principally comprising of quartzites, monzonites and limestones. Each of these geologies possess its own unique set of characteristics that present different challenges to the successful execution of blasting goals. Significant changes to blast designs are often implemented in each geology individually and then evaluated for possible wider application.

Dyno Nobel partnered with a large opencast metal mining operation in North America to deliver high value solutions and cost savings. The mine is a large truck and shovel operation that operates continuously to meet the world's demands for the various metals it produces.

The company offered its TITAN 5000 DIFFERENTIAL ENERGY (ΔE) bulk explosive product to this operation in order to lower overall drill and blast costs and improve blast performance and safety. For a safe, efficient implementation and evaluation process of the product, a multi-step project for the conversion of the primary bulk explosive was planned and executed. The steps undertaken may be characterised by the following stages:

- Product trial: large scale trial conducted predominantly in one geology over a 12 month period in 2018.
- Product conversion: full expansion of the product to virtually all production blasting applications at the operation in 2019. Data was recorded over a 12 month period.



Product technology overview

Historically, ANFO and slurry formulations were the bulk explosives of choice at this operation. More recently, the operation has moved to Dyno Nobel's TITAN 5000ΔE emulsion to assist with reactive ground and the mitigation of effects from harder rock types. The company's drill and blast product is formulated to inhibit exothermic reactions in sulfide-bearing ore

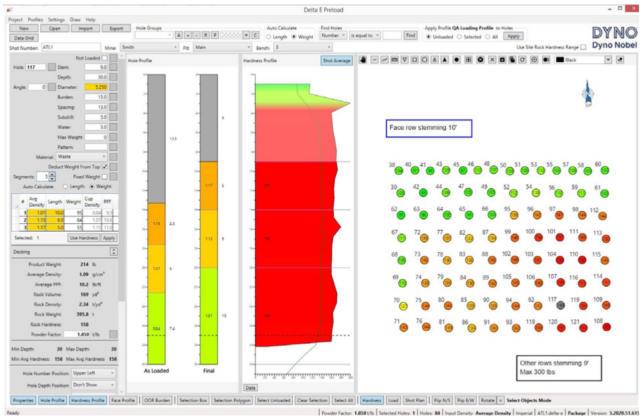


Figure 1. ΔE^2 Preload application demonstrating the TITAN loading profiles for individual blastholes that are automatically predetermined using the hardness profile shown in the centre pane.

Figure 2. A TITAN jumbo mobile production unit with ΔE^2 capability when loading a blasthole.

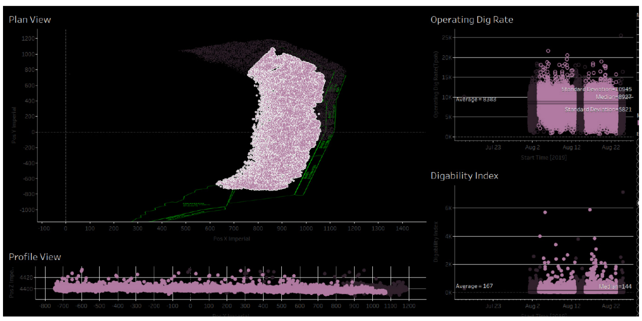


Figure 3. Example output from a shovel monitoring system measuring the dig rate and dig-ability index. Multiple sensors that are installed on the shovel allow for detailed data packages to be gathered for each discrete loading unit (in this case, shovel buckets) which are then 'placed' at real coordinates in the mine using GPS.

bodies, and is sensitised during the loading process using its ΔE technology. Like all TITAN bulk products, the process used to manufacture the product formulation enhances water resistance and detonation performance while improving loading characteristics. ΔE is a system that utilises the latest in bulk explosive technology to deliver enhanced explosive product performance while improving safety and protection of the environment.

The ΔE system uses chemical gassing to allow the density of the emulsion to be varied in order to optimise the desired blast performance. Density may be varied in response to geologic conditions and blast design factors. This system utilises data obtained via sensors installed on various manufacturer smart drill packages, including GPS data related to borehole location, down pressure, rotation speed, engine RPMS, etc. The data is then uploaded to the ΔE^2 Preload application (Figure 1), allowing the customer to build simple to complex loading profiles to match the energy requirements of the geology being blasted. These loading profiles may be generated automatically using algorithms that incorporate the smart drill data, resulting in each blasthole being loaded with a unique explosive profile.

This software application includes several tools to evaluate rock hardness, face burdens and other key design parameters to ensure the loading schemes reflect the actual conditions experienced in the field. Once completed, loading designs can be exported directly to the DYNOLOGIX control system on the TITAN Mobile Production Unit (MPU) for easy on-pattern implementation (Figure 2).

Product trial

A large-scale trial of TITAN was conducted at this open pit operation in 2018. Approximately 7 million lbs of the product were used over a 5 month period to conduct 129 blast events in a wide range of geologies, hole diameters, pattern sizes and applications. Two TITAN MPUs were used in conjunction with the mine's existing fleet of Heavy ANFO and 'Triple Threat' (capable of delivering ANFO, emulsion/ANFO blends, or straight emulsion) MPUs.

Without changing pattern dimensions, sub-drill, or stem heights, TITAN was loaded side-by-side in patterns with emulsion/ANFO blends. Patterns were split between the two products, and the density of the TITAN product was varied from pattern-to-pattern based on geology and desired blast results. Blasting performance during the trial was measured using several key metrics, including post-blast NO_X, dig-ability index, fragmentation and MPU blasthole load times.

Using shovel monitoring system outputs (Figure 3), instantaneous dig rates (measured using unit mass per unit time) and dig-ability index were shown to be comparable in patterns loaded with both TITAN and blends. Dig-ability index represents the excavation equipment's performance in the given ground conditions based on resistance of material to excavation. These results are considered important as powder factors in the patterns loaded with Dyno Nobel's product were, on average, less than those loaded with blends.

Qualitatively, mine personnel reported a noticeable improvement in the mine's fragmentation during the trial. Quantitatively, fragmentation was evaluated by the percentage of blasted tons segregated for secondary breakage. In one trial blast loaded exclusively with blends, over 10% of the blasted tons were separated for secondary breakage. In a second trial blast, 70% of the pattern was loaded with TITAN, resulting in less than 1% of the material being separated for secondary breakage.

Visible NO_X emissions are evaluated and reported at the mine using a visual, colorimetric method. Baseline data showed that over a third of all blasts loaded with the blends produced appreciable levels of NO_X. This represented a serious concern to the operation as these NO_X events often resulted in production delays corresponding to the additional time required to clear the blast site and release mine traffic. During the trial, there were no significant reports of post-blast NO_X and the improved results have continued since completely converting, with post-blast NO_X nearly being eliminated.

Prior to and during the trial, operational management expressed concern that TITAN MPUs would be unable to load blastholes as quickly as the existing MPU fleet. These concerns were based largely on the fact that the TITAN loading process requires the loading hose to be lowered into each blasthole. However, time study results shown in Table 1 demonstrates that the company's MPUs were able to load blastholes at comparable or faster cycle times than the traditional MPUs. The loading times were aided largely by a pump rate of 1700 lbs/min. on the TITAN MPUs, which is higher than the existing fleet pump rate of 1200 lbs/min. Additionally, the customised blasthole loading profiles are uploaded into the DYNOLOGIX control system, ensuring minimal required input from the MPU operator.

TITAN is a 100% emulsion product, and thus is capable of loading in both wet and dry holes. The mine found these MPUs to be faster and more effective in loading wet holes than the existing fleet. Additionally, mine management discovered that TITAN MPUs enabled an earlier loading start time, as blast crews no longer needed to determine the ratio of wet and dry holes on the pattern prior to beginning loading. Furthermore, the larger capacity of these MPUs, paired with their variable density capability, resulted in reduced bench-to-bin transits.

By using the variable density capabilities of TITAN over the duration of the trial, the mine was able to achieve the following key results:

- 8.4% average reduction in powder factor.
- US$0.005/t of mined ore explosives savings.
- 4.8% overall reduction in drill and blast costs.
- NO_X generation reduced and often almost eliminated.
- Significantly improved fragmentation.
- Decreased blasthole loading times.

Data collected during the trial focused only on direct cost impacts to mining operations without considering additional downstream benefits. The enhanced detonation characteristics of TITAN provide potential for higher levels of savings in downstream stages such as crushing, grinding, milling, beneficiation, and leaching. Future work will include plans to capture and quantify these benefits. A number of benefits were realised, including:

- Improved explosive product consistency.
- Enhanced buffering capabilities.
- Reduced risk of nitrates leaching into groundwater.
- Reduced risk of theft and foul play.

These benefits, both direct and indirect, led to the decision to convert the entire operation over to the TITAN product.

Product conversion

Upon completion of the trial, Dyno Nobel and the mine management began the process of converting completely over to TITAN. Data was collected over a 12 month period to track effects of this conversion. As part of the transition, the following methodology was proposed to optimise blast patterns for use with the new product:

Stage 1

Realise the lower overall powder factor achieved during the trial by varying the TITAN density based on geology and pattern type, while holding pattern dimensions constant. Despite encountering increasingly hard geology, the mine was able to deliver significant total explosive product savings through powder factor reduction, including:

- 6.8% powder factor reduction.
- US$0.002/t of mined ore explosives savings.

Table 1. Results of a TITAN 5000*ΔE* trial

Explosive product	NO_X Incidents	Dig rates and dig-ability	Fragmentation	Loading Time per Hole (s)
TITAN 5000ΔE	0 Incidents	Comparable with lower PF	<1% in hard ore	147
Emulsion/ANFO blends	>33% of blasts	Comparable with higher PF	>10% in hard ore	142

Table 2. Scope of product conversion changes

Key metric	TITAN trial	TITAN conversion	
	Powder factor reduction	Stage 1: Powder factor reduction	Stage 2: Pattern expansion
Powder factor reduction (%)	8.42	6.8	--
Explosives savings (US$/t of ore)	0.005	0.002	--
Reduction in drilling (%)	--	--	8.00
Drill and blast savings (US$/t of ore)	0.005	0.002	0.025

Stage 2

Where possible, expand drill patterns based on the new, lower, powder factor to alleviate drilling constraints and take advantage of TITAN's detonation characteristics.

Dig rates and dig-ability were monitored during this time period to ensure no negative impact to operations. Quartzites were the primary geology targeted for pattern expansion. The quartzites tend to be highly laminated and cross-bedded, and thus blast easily. Key results achieved include:

- 12 - 18% average reduction in powder factor.
- 8.0% reduction in drilling demand.
- US$0.025/t of mined ore overall reduction in drill and blast costs.

Stage 3

After expanding patterns, utilise the mine's drill data and Dyno Nobel's ΔE^2 technology to custom load each blasthole based on drilling characteristics, achieving lower drill and blast costs with improved blast results.

The results have been achieved primarily by varying the TITAN density from pattern-to-pattern. Full integration of drilling data with the ΔE^2 technology to create customised loading profiles for individual blastholes have been used and proven on a limited basis, and is moving toward full-scale implementation. Drill data consistency and quality are primary concerns that are being actively addressed.

Continued product expansion and the next steps

The introduction of the TITAN 5000ΔE at this operation was undertaken with the primary goals of reducing drill and blast costs and improving blast performance and safety. Data was collected throughout the process to track and prove the results (Table 2). The results indicate the success in delivering on all primary goals. This success has firmly established intentions to continue the use of TITAN 5000ΔE. Priorities for 2020 include further pattern expansions and implementation of the ΔE^2 technology with continued monitoring to ensure the required performance and desired cost savings.

Operational benefits covered in this case study focus on direct mine operations such as drilling, blasting and shovel loading. Dyno Nobel is partnered with the mining operation to widen the scope of data collection and monitoring, with the goals of quantifying benefits realised by optimising mill throughput and reducing energy consumption. A more detailed case study will be carried out to demonstrate the full value of TITAN 5000ΔE and other blasting technologies as they relate to downstream processes such as crushing, grinding, milling and further processing. Downstream processing costs are understood to represent levels of cost at 7 - 15 (and sometimes more) times the cost of drilling and blasting. The principles discussed in this case study have been implemented for other customers and have demonstrated significant cost savings. GMR