Blast induced Ore Movement: The missing step in achieving realistic reconciliations

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ABSTRACT

At Tasiast Gold Mine, mine value chain (MVC) reconciliation was implemented using a similar approach to the one developed by Cook (2008). This hybrid approach is based on the widely used f_1 and f_2 denomination proposed by Parker (2012) and improved upon with the most recent developments found in the literature. MVC is a scientific and objective method to determine whether the assumptions built into our predictions are valid to increase the accuracy of forward planning, to enhance the knowledge of the orebody, to explain problems and be able to justify improvements to current practices.

Tasiast's MVC was missing a major step in the reconciliation process: dilution related to blast movement. While the blasts were monitored with Blast Movement Monitors (BMMs), it wasn't possible to determine the post-blast tonnage and grade per ore polygon. One of the major drawbacks is the representation of a blast by 2D displacements, when it is an inherently 3D phenomenon. This approach is a reasonable approximation to identify areas of potential dilution and misclassification, but is unable to re-evaluate the pre-blast grade and tonnage. In addition, reconciliation from mine to mill (f_2) doesn't take into account dilution related to blast movement.

OrePro 3D, a software package developed by OreControl Blasting Consultants (OBC) and financially supported by Kinross, takes 3D ore movement into account when creating a post-blast block model. It achieves this by generating a 3D vector field using blast displacements measured by markers in conjunction with the post-blast topography. The software computes the post-blast block model and determines the optimal ore polygons for each mining direction defined by the user. This approach is combined with turning band simulations to evaluate the probability of a polygon to be ore.

This paper will present this innovative software and how it is used at Tasiast in combination with geostatistical simulations, to enhance the final destination of the ore polygons and to refine f_2 reconciliations.

INTRODUCTION

Tasiast is an Archean gold deposit located in Mauritania, West Africa and 100% owned and operated by Kinross. Traditionally, *f*-factors (Parker, 2012) are used on a monthly, quarterly and yearly basis to report Tasiast performances. A new mine value chain (MVC) reconciliation tool was internally implemented to refine the existing performance indications and track each step of the mining process, from the resource model to the material fed to the mill, and identify where improvements were needed. A further analysis of this new MVC highlighted a gap between the pre-blast polygons, ie the material planned to be sent to the mill, and the material really mined and delivered to the mill. Undeniably, blast dilution impacts the well-known f_2 indicator used to compare the material delivered to the mill to the material received at the mill.

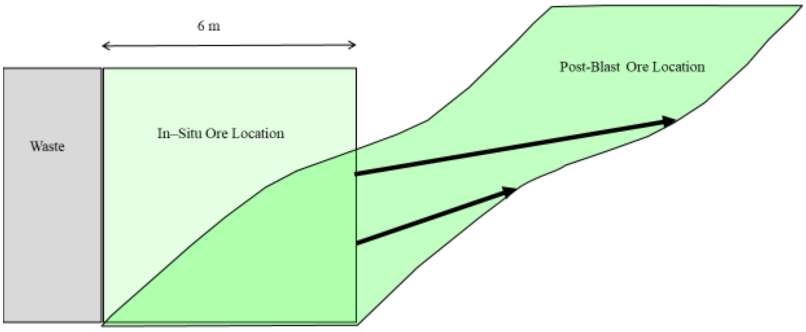
After a short review of the methods developed to mitigate ore dilution related to blasting, this paper describes an innovative approach using OrePro 3D to monitor and incorporate blast dilution into the MVC developed at Tasiast. Subsequently, geostatistical simulations are associated to OrePro 3D to assess the probability of a post-blast polygon to be above its reported grade and to compute its confidence interval in order to direct the ore to the right location (stockpile and blending strategy), delivering the best quality material to the mill.

INHERENT DILUTION RELATED TO BLASTING

Blast Movement and the Effect on Ore Control

Many studies have shown measured blast movement and the expected movement profiles in different regions of a blast (Hunt 2012, La Rosa 2011, Thornton 2009). Additionally, the effects of 3D movement and differential movement at depth have been measured (Hunt 2015, Hunt and La Rosa 2019).

From these, and other studies, it is understood that movement at depth may vary significantly throughout the bench. Therefore, a structure's dip and strike may change from in-situ to post-blast because of the movement induced by the blast. Consider the image shown in Figure 1. The mining method and dilution estimated by mining an in-situ structure dipping 90 degrees is not the same as mining the structure after it has moved. In some cases (such as this), the result is extremely different. In other words, what is achievable pre-blast is not always achievable post-blast.



We know from surrounding data that the floor is barely moving at this mine, if at all

Figure 1 - Pre-blast dip vs post-blast dip (Hunt and La Rosa 2019)

The phenomenon of differential movement at depth and extreme variation in heave has been well-known to the industry for some time. Anyone who has walked across blasted rock can attest that the surface is rarely flat after a blast, and sometimes undulates violently. But, a solution was difficult to achieve.

Since the size and shape of an in-situ ore zone changes during the blast, a simple two-dimensional polygon rarely contains the same tonnes, grade, or geochemistry. This creates a discontinuity in the mine's short-term plan, because it is created in advance of the blast, and any modifications to the forecasted ore are made pre-blast.

Due to the fourth dimension, time, operational reality varies from the short-term plan and the ore control plan. So, there is value in understanding the mechanisms for the change, and then measuring and planning for it.

Discussed in further sections are the methods developed by OreControl Blasting Consultants to mitigate losses from this pre-to-post change, and a method created by Kinross to apply the induced dilution to the mining plan.

Previous Tools Used to Mitigate Ore Movements

Blast Movement Monitors (BMMs)

Since the mid-2000's, Blast Movement Monitors (BMMs), manufactured and distributed by Blast Movement Technologies, have allowed mines around the world to measure displacement during blasts at various depths. The BMMs consist of directional transmitters that are installed in dedicated holes pre-blast, which are then located under the post-blast surface by walking on the muckpile with a specialized detector. The BMMs provide vectors of displacement by connecting pre and post-transmitter locations.

Polypipe (PVC)

Many mines have measured blast movement by inserting plastic pipe (PVC) of various thicknesses into dedicated holes pre-blast, and surveying their locations post-blast. In many cases, this provides surface displacement only. But, in some cases, mines have used different methods to survey sections of PVC placed at various depths to measure movement below the surface.

Other Methods

Other methods, including magnets, chains, paint cans, and painted sandbags have been used to measure movement with some degree of success. However, these methods tend to be cumbersome, labour intensive and difficult to locate before excavation of the blast commences.

How Previous Tools Use Data to Manage Blast Movement

To mitigate the effects of blast movement, the tools discussed above, including BMMs, PVC, and other methods, use the horizontal movement measured to displace ore control polygons (Figure 2). In order of operations, the mines:

1. Create Ore Control Polygons
    a. Usually by hand, which is subjective
2. Insert devices to measure blast movement
3. Connect the pre and post-locations of the devices to create horizontal vectors of movement
4. Displace the Ore Control Polygons using the horizontal vectors measured

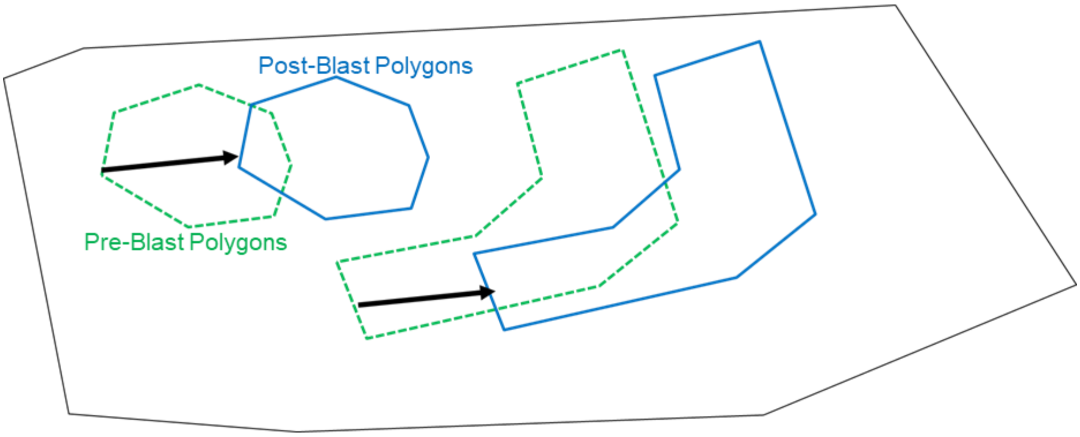


Figure 2 - Previous method for mitigating blast movement

Opportunity Presented by Previous Methods

Since none of the previous methods for measuring or mitigating blast movement displace anything in 3D, these are all, fundamentally, 2D solutions only. As has been thoroughly shown by the case studies referenced in this paper, blast movement is inherently a 3D problem. What is achievable pre-blast is not always achievable post-blast, which creates inconsistencies between pre-and post-blast ore control, including:

1. Tonnes in any polygon shape
2. Geochemistry, due to warping of the in-situ shapes
3. Intended material mined, due to mining direction and angle of the working face
4. Dilution, as the target shape has changed in dip and (frequently, in) strike
5. Flitch elevations, as material crosses initial flitch boundaries due to blast induced movement.

Additionally, the original shapes being moved in 2D are rarely optimised for value. If different geologists at the same mine are given the exact same grade control model and asked to draw polygons, there will oftentimes be different solutions offered by each. In the authors opinions, this is no surprise, because the human brain is incapable of designing complex geometric shapes for optimal value. Even if an optimiser is used pre-blast, the inconsistencies noted above render the pre-blast polygons inadequate for post-blast optimisation.

So, it should come as no surprise that mines using these existing methods, including Tasiast, frequently have experienced variation between what was planned and what was received at the mill. Tonnes, grade, and geochemistry sometimes have significant variation at great cost (Poupeau and Hunt, 2019). Without understanding the movement of the rock in 3D and accounting for this movement, it is unlikely that any 2D approach could solve these problems. Even if a 2D method could account for these differences, the material targeted would not be of the highest possible value if the in-situ polygons were translated into post-blast polygons, thanks to heave and differential movement.

OREPRO 3D

In early 2018, Kinross and OreControl Blasting Consultants (OBC) began working on a solution to the 3D problem. A solution was reached and with financial assistance from Kinross, a software application called “OrePro 3D” was created and commercialized.

Inputs

OrePro 3D takes some inputs from the mine, including the in-situ grade control model, the blast design, and a survey of the post-blast topographic surface (Figure 3).

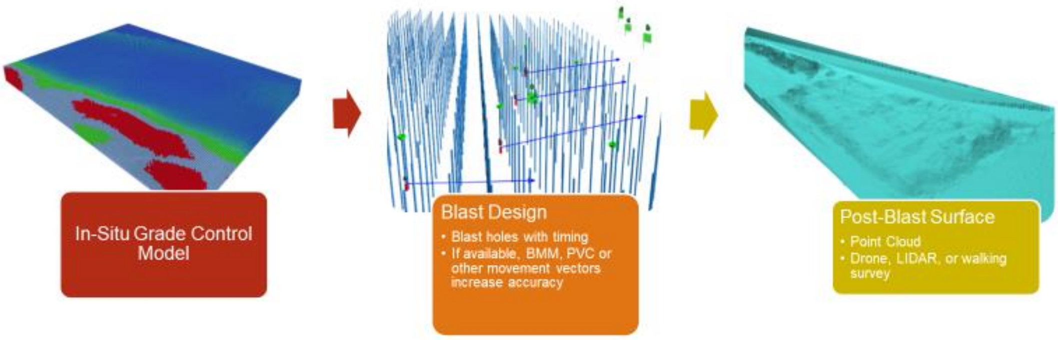


Figure 3 - OrePro 3D inputs

Utilising these inputs, a reactive movement model is created which allows the in-situ grade control model to be transformed into a post-blast grade control model. The model is 'reactive' because it starts with an underlying model that will translate the in-situ model without any measured movement vectors. If measured movement vectors are available, the model 'learns' from the inputs, giving a more accurate post-blast model.

Then, the operational considerations are entered, such as:

1. Single or Multiple Flitches;
2. Minimum ore polygon size;
3. Mining face angle;
4. Possible mining directions;
5. Cut-off grade;
6. Subclassification criteria.

Outputs and Calculations

The result yields suggested optimised grade control polygons on each flitch for each mining direction, with accurate tonnes that consider actual swell and geochemistry provided for each mining shape (Figure 4).

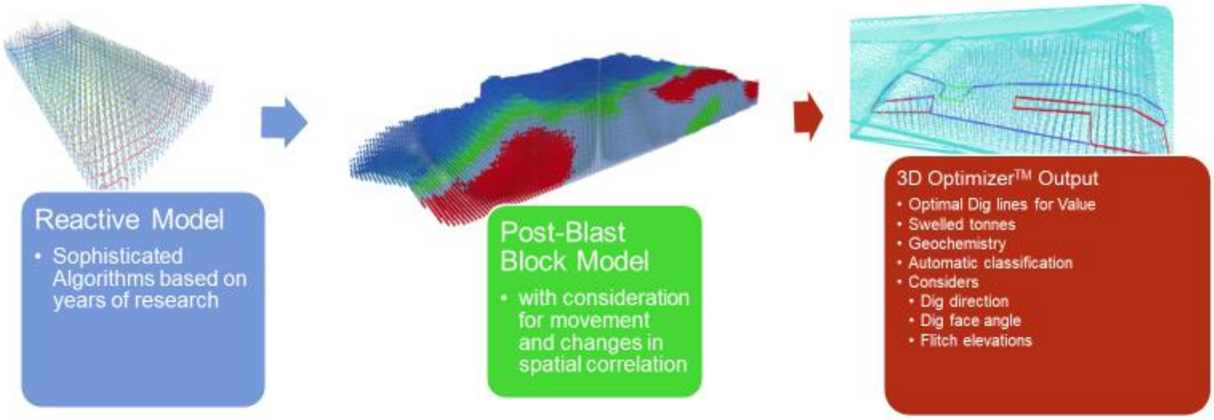
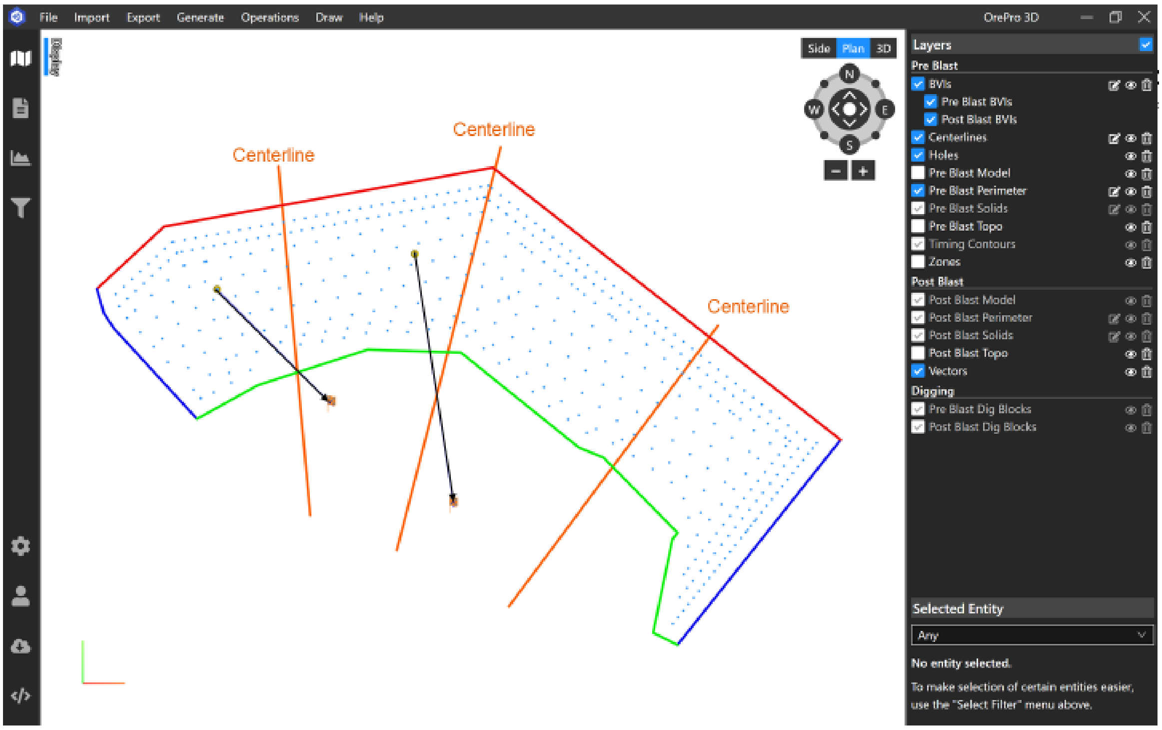


Figure 4 - OrePro 3D data processing and results

A Value-Add - QaQc

In addition to the optimisation benefits outlined, a significant value-add for the approach created is to provide quality assurance and control (QaQc) on measured movement. With the previously described monitoring methods, start and end points are connected to create displacement vectors. However, this method provides little, if any, assurance that the rock actually moved in the direction indicated by the movement vectors.

This problem is illustrated in a real blast shown in Figure 5. The vectors shown were provided by a mine (not Tasiast). The vectors appear to move across centerlines, something that violates normal blast dynamics. However, blast designs change, and blasts can be chaotic. So, without any reason to doubt the vectors, the mine elected to use them.



Layers ☑

Pre Blast
- ☑ BVIs
  - ☑ Pre Blast BVIs
  - ☑ Post Blast BVIs
- ☑ Centerlines
- ☑ Holes
- ☐ Pre Blast Model
- ☑ Pre Blast Perimeter
- ☑ Pre Blast Solids
- ☐ Pre Blast Topo
- ☑ Timing Contours
- ☐ Zones

Post Blast
- ☑ Post Blast Model
- ☑ Post Blast Perimeter
- ☑ Post Blast Solids
- ☐ Post Blast Topo
- ☑ Vectors

Digging
- ☑ Pre Blast Dig Blocks
- ☑ Post Blast Dig Blocks

Selected Entity

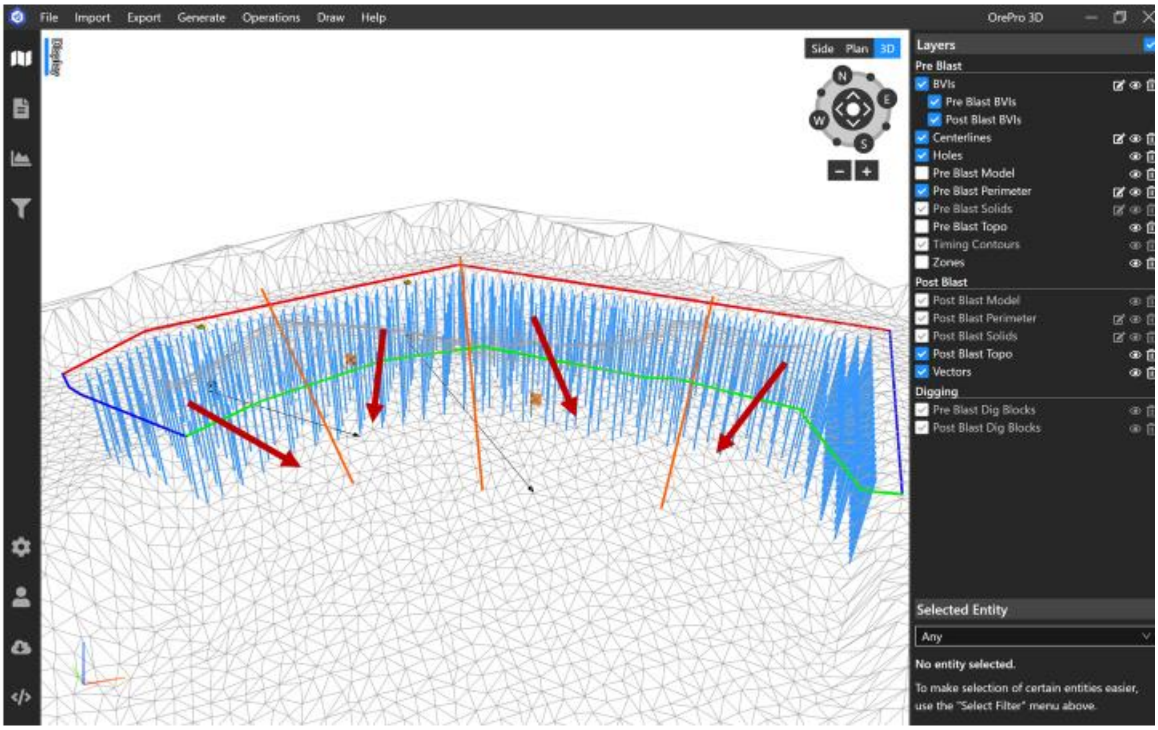
Any

No entity selected.

To make selection of certain entities easier, use the "Select Filter" menu above.

Figure 5 - Measured movement provided for a blast

When the blast was inspected in OrePro 3D, it was immediately apparent that the vectors shown were not accurate. In fact, the easternmost vector is impossible. The likely movements given by the blast design and post-blast muck pile surface are shown in red in Figure 6.



Layers

Pre Blast
- ☑ BVIs
  - ☑ Pre Blast BVIs
  - ☑ Post Blast BVIs
- ☑ Centerlines
- ☑ Holes
- ☐ Pre Blast Model
- ☑ Pre Blast Perimeter
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- ☑ Post Blast Model
- ☑ Post Blast Perimeter
- ☑ Post Blast Solids
- ☑ Post Blast Topo
- ☑ Vectors

Digging
- ☑ Pre Blast Dig Blocks
- ☑ Post Blast Dig Blocks

Selected Entity

Any

No entity selected.

To make selection of certain entities easier, use the "Select Filter" menu above.

Figure 6 - Likely movement and post-blast heave (Red vectors)

There are several possible reasons for the incorrect vector(s), but the most probable explanation is an incorrect field procedure for installing/detecting blast movement measuring devices. Without the situational awareness provided by the OrePro 3D process, this error would have never been known, and it would have likely persisted in many blasts at great cost to the mine.

Value-Add - Mining Direction

Optimising dig direction frequently creates conflict between tech services and operations departments, because changing dig directions can be cumbersome. In porphyry or disseminated deposits, dig directions typically have a small effect. However, in structurally-controlled operations, changing dig direction can prevent serious dilution and increase grades (Figure 7 and Figure 8). At Tasiast, the mining constraint size and the post-blast dip of the ore structures play a large role in the value achieved by different directions. To maximize value, polygons should be created to consider the post-blast structures and shapes with respect to constraints.

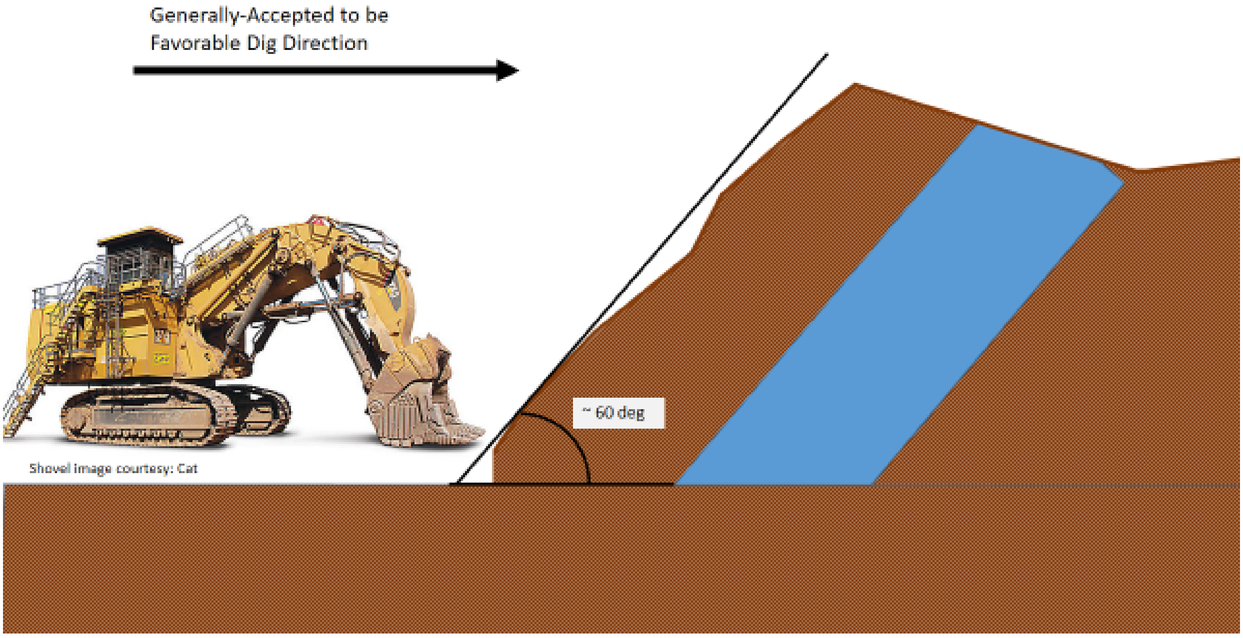


Figure 7 – Generally accepted best dig direction in narrow vein orebody

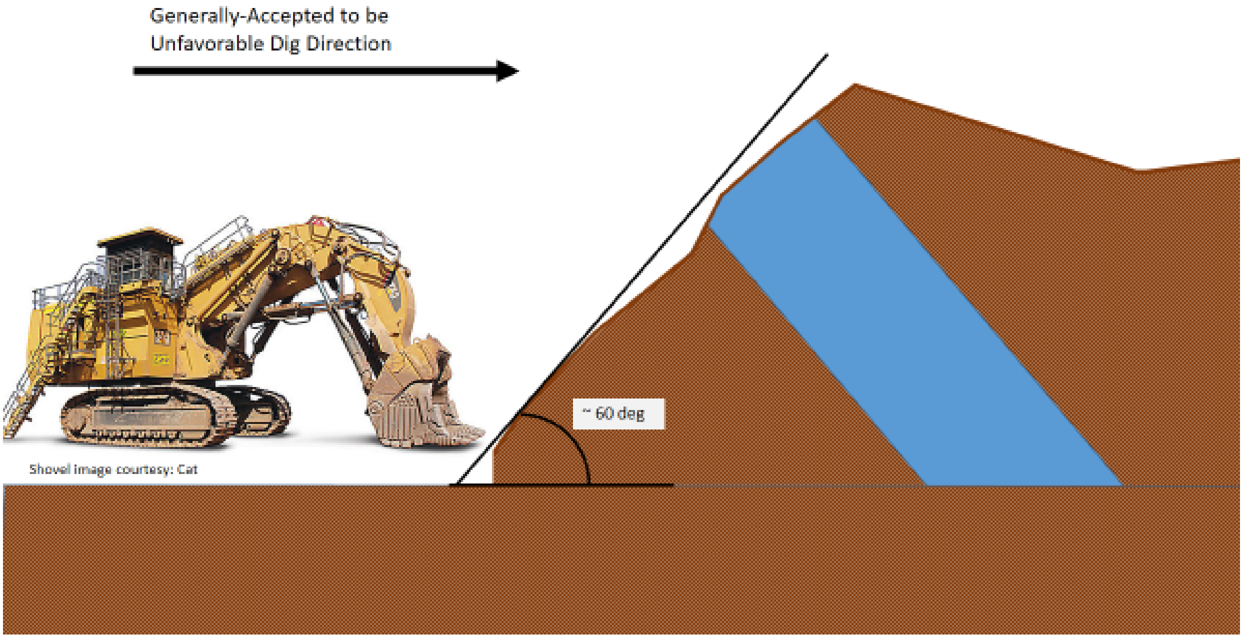


Figure 8 - Poor dig direction in narrow vein orebody

Value-Add - Dilution Caused by Equipment Size

Unlike traditional SMU methods, OrePro 3D creates the most value when models with the highest resolution possible are imported. Then, after the models have been moved and a post-blast block model has been created, the equipment and mining constraints are added in the form of minimum polygon size.

Minimum polygon size is a constraint used in OrePro 3D to determine optimal ore control polygons. However, ore control geologists sometimes violate this constraint when drawing polygons freehand. The results may be shapes that are higher in grade and lower in dilution, but these freehand polygons can be problematic or impossible to dig.

Consider the OrePro 3D ore control polygons generated for another mine in Figure 9 and Figure 10, one with a minimum size constraint of 4x4 m and the other with 8x8 m. The results are significantly different, because in the 8x8 scenario, the polygons must include more dilution in order to create an 8x8 shape. The area circled in Figure 9 contains waste, but an ore shape is still created because the net is an increase in overall value and the constraint demands it. But, a more selective shape would be ideal, and this is achieved when the constraint is lowered to 4x4 m.

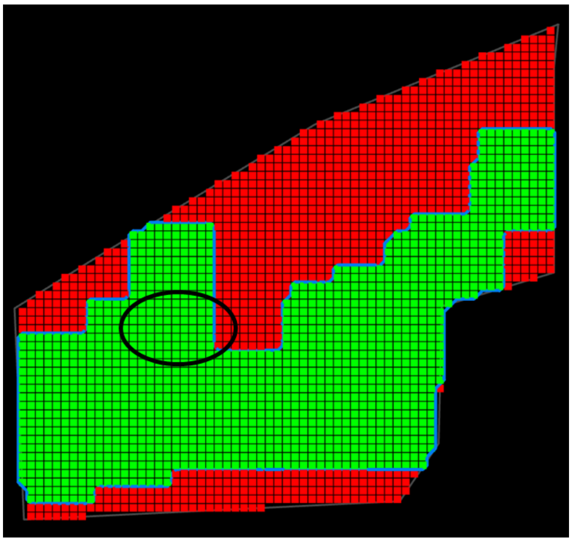


Figure 9 – Example blast with 8x8 minimum size ore block

Figure 10 – Example blast with 4x4 minimum size ore block

It is recommended to find a constraint size that minimizes dilution, and that is feasible to mine post-blast, considering a variable surface. Smaller block constraints lead to higher grades and lower dilution (selective mining), but there is a point where the blocks aren't mineable. Optimised ore polygons rely on rigid rules that will not be violated, whereas a geologist may violate a size constraint in certain operational settings. So, the best solution is a combination of the two:

optimised polygons slightly altered by an experienced ore control geologist. The time it takes to run this analysis is seconds per iteration, allowing for expedient decision-making.

METHODS AVAILABLE TO INCORPORATE BLAST DILUTION INTO RECONCILIATION PROCESSES

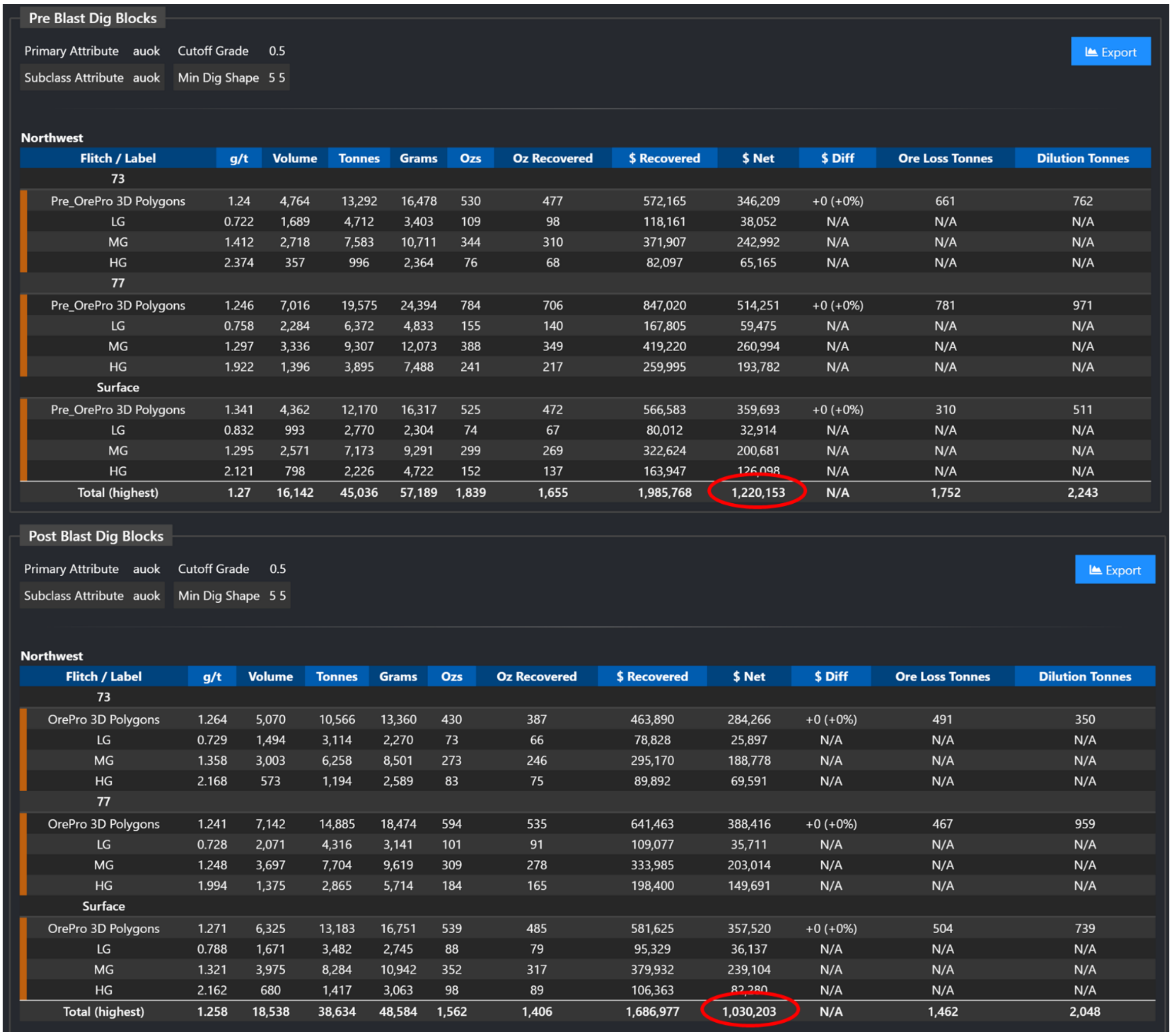
It is important to understand that a relationship must exist to tie together the polygons mined in the field with the ore control plan that exists long before the blast is ever fired. This complicates the reconciliation process because of the changes in the ore shapes, tonnages, and grades through the blast. Remember, swell, differential blast movement, mining direction, and the angle of mining cannot be considered in the planning stages because they are all unknowns at that point (though sometimes mining direction and angle are known pre-blast). If the mining method incorporates multiple flitches, this process becomes impossible because ore and waste have travelled upwards and downwards across flitch boundaries, thereby changing the value and dilution on each flitch.

While accounting for differences pre- and post-blast is important, it is arguably more important to optimise the value gained from each blast. If the question is asked, *"Which would you rather have 1) an accurate reconciliation, or 2) highest value achievable from the blast?"*, any acceptable methodology must answer *"both, at the same time"*.

In the authors' experiences, mines that have attempted to 'chase tonnes' so that their pre and post-blast tonnages agree end up suffering in value. In other cases, mines that strictly mine value and never attempt to reconcile pre and post-blast planned polygons inevitably are always trying to explain differences in tonnes, grade, and geochemistry. This process can become challenging when stockpiling or delays in processing are introduced, or when the mine is constrained by NPV or processing requirements instead of economic cut-off.

In some cases, achieving highest value and providing reconciliation between pre and post-blast is relatively simple. If a mine is hand-to-mouth and does not rely on strict planning requirements, two processes can be run in OrePro 3D simultaneously to determine losses due to blasting in a specific blast: automatic creation of pre-blast optimised polygons and comparison with optimised post-blast polygons. This provides the value lost (or gained) through the blasting process for a specific blast, given a defined mining direction. In Table 1, a real blast (multi-flitch) is optimised pre and post-blast using the exact same algorithms and constraints. In this blast, approximately USD190,000 is lost during the blast. The planned dilution (economically-justified) and planned ore loss (because it's not financially-feasible to take it) are also given, so the effect is easily measured. All tonnes in each layer and shape are assigned with calculated swelled density. The tonnes in the post-blast ore polygons shown in this spreadsheet are less than pre-blast because this process targets value, not tonnes.

Table 1 - Simple method to calculate losses in blasting



Pre Blast Dig Blocks

Primary Attribute auok | Cutoff Grade 0.5
Subclass Attribute auok | Min Dig Shape 5 5

Northwest

Flitch / Label	g/t	Volume	Tonnes	Grams	Ozs	Oz Recovered	$ Recovered	$ Net	$ Diff	Ore Loss Tonnes	Dilution Tonnes
73											
Pre_OrePro 3D Polygons	1.24	4,764	13,292	16,478	530	477	572,165	346,209	+0 (+0%)	661	762
LG	0.722	1,689	4,712	3,403	109	98	118,161	38,052	N/A	N/A	N/A
MG	1.412	2,718	7,583	10,711	344	310	371,907	242,992	N/A	N/A	N/A
HG	2.374	357	996	2,364	76	68	82,097	65,165	N/A	N/A	N/A
77											
Pre_OrePro 3D Polygons	1.246	7,016	19,575	24,394	784	706	847,020	514,251	+0 (+0%)	781	971
LG	0.758	2,284	6,372	4,833	155	140	167,805	59,475	N/A	N/A	N/A
MG	1.297	3,336	9,307	12,073	388	349	419,220	260,994	N/A	N/A	N/A
HG	1.922	1,396	3,895	7,488	241	217	259,995	193,782	N/A	N/A	N/A
Surface											
Pre_OrePro 3D Polygons	1.341	4,362	12,170	16,317	525	472	566,583	359,693	+0 (+0%)	310	511
LG	0.832	993	2,770	2,304	74	67	80,012	32,914	N/A	N/A	N/A
MG	1.295	2,571	7,173	9,291	299	269	322,624	200,681	N/A	N/A	N/A
HG	2.121	798	2,226	4,722	152	137	163,947	126,098	N/A	N/A	N/A
Total (highest)	**1.27**	**16,142**	**45,036**	**57,189**	**1,839**	**1,655**	**1,985,768**	**1,220,153**	**N/A**	**1,752**	**2,243**

Post Blast Dig Blocks

Primary Attribute auok | Cutoff Grade 0.5
Subclass Attribute auok | Min Dig Shape 5 5

Northwest

Flitch / Label	g/t	Volume	Tonnes	Grams	Ozs	Oz Recovered	$ Recovered	$ Net	$ Diff	Ore Loss Tonnes	Dilution Tonnes
73											
OrePro 3D Polygons	1.264	5,070	10,566	13,360	430	387	463,890	284,266	+0 (+0%)	491	350
LG	0.729	1,494	3,114	2,270	73	66	78,828	25,897	N/A	N/A	N/A
MG	1.358	3,003	6,258	8,501	273	246	295,170	188,778	N/A	N/A	N/A
HG	2.168	573	1,194	2,589	83	75	89,892	69,591	N/A	N/A	N/A
77											
OrePro 3D Polygons	1.241	7,142	14,885	18,474	594	535	641,463	388,416	+0 (+0%)	467	959
LG	0.728	2,071	4,316	3,141	101	91	109,077	35,711	N/A	N/A	N/A
MG	1.248	3,697	7,704	9,619	309	278	333,985	203,014	N/A	N/A	N/A
HG	1.994	1,375	2,865	5,714	184	165	198,400	149,691	N/A	N/A	N/A
Surface											
OrePro 3D Polygons	1.271	6,325	13,183	16,751	539	485	581,625	357,520	+0 (+0%)	504	739
LG	0.788	1,671	3,482	2,745	88	79	95,329	36,137	N/A	N/A	N/A
MG	1.321	3,975	8,284	10,942	352	317	379,932	239,104	N/A	N/A	N/A
HG	2.162	680	1,417	3,063	98	89	106,363	82,280	N/A	N/A	N/A
Total (highest)	**1.258**	**18,538**	**38,634**	**48,584**	**1,562**	**1,406**	**1,686,977**	**1,030,203**	**N/A**	**1,462**	**2,048**

THE RECONCILIATION PROCESS AT TASIAST

The Previous Approach

The official reconciliations conducted at Tasiast followed the **f-factor** approach (Figure 11) developed by Parker (2012) to compare, in terms of grade, tonnage and ounces, the long-range model to the short-range model (f_1), the material delivered-to-mill versus the material received at mill (f_2) and the mill to the long-range model (f3). This high-level approach is helpful to highlight issues along the Mine Value Chain (MVC) but a degree of refinement might be missing to identify and evaluate the impact of each factor through the MVC and be able to explain the reconciliation figures (on a monthly, quarterly or yearly basis).

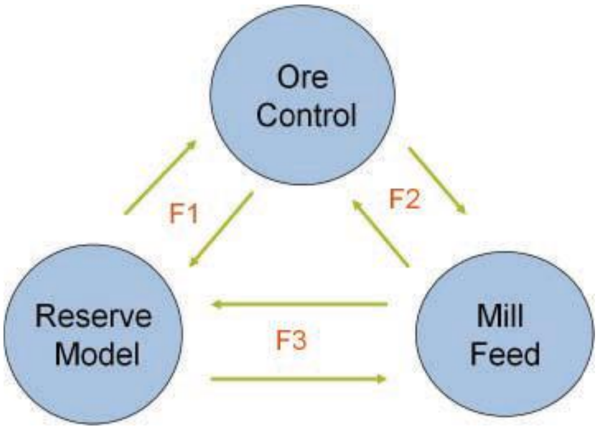


Figure 11 - Summary relationships between factors (Parker, 2012)

Over the past twenty years, reconciliations have been very topical, and many authors (Morley, 2003; Cook, 2008; Bray, 2009; Burns and Savory, 20; Fouet *et al*, 2009; Macfarlane, 2013; Shawn *et al*, 2013; Richard and Sulemana, 2015; Chamberlain, 2016; Morley and Arvidson, 2017) proposed complementary views to address this topic. The definition of reconciliation given by Shaw *et al* (2013), as a scientific and objective method to determine whether the assumptions built into predictions are valid, guided the way the MVC was adapted to Tasiast's needs. As mentioned by Shaw *et al* (2013), reconciliations can be used to:

1. increase the accuracy of forward planning;
2. improve knowledge of the ore body;
3. explain problems; and
4. justify improvements to current practice

In the previous process, Tasiast created in-situ ore polygons, slid them horizontally using the methodology detailed previously, and mined the moved 2D shapes. The in-situ calculated tonnes and grade were assumed to be the same post-blast as pre-blast, and mining angle and direction were ignored.

New Approach for Tasiast

Tasiast has much larger blasts than the blast shown in Table 1, and a much more complex process, making reconciliation to a specific polygon in time very difficult. When reconciliation is performed, many blasts may be partially-mined, making estimation of the dilution in a single blast very difficult to pinpoint. Since the mine has mill and operational constraints tied to pre-blast planning, it is also important to relate the plan to what was actually-mined and targeted post-blast.

This process allows for dilution to be estimated in each step of the process. Additionally, in order to incorporate risk mitigation, simulations can be performed to evaluate the effect of grade probabilities on the reported dilution. This process will not fit every mine, but was designed to manage Tasiast's specific needs.

Description of the new Mine Value Chain (MVC)

Recently, a new MVC was built internally at Tasiast to capture potential discrepancies between the main factors (geology, planning, operations and mill). It has been sub-divided into 3 main groups of indicators (Figure 12 below):

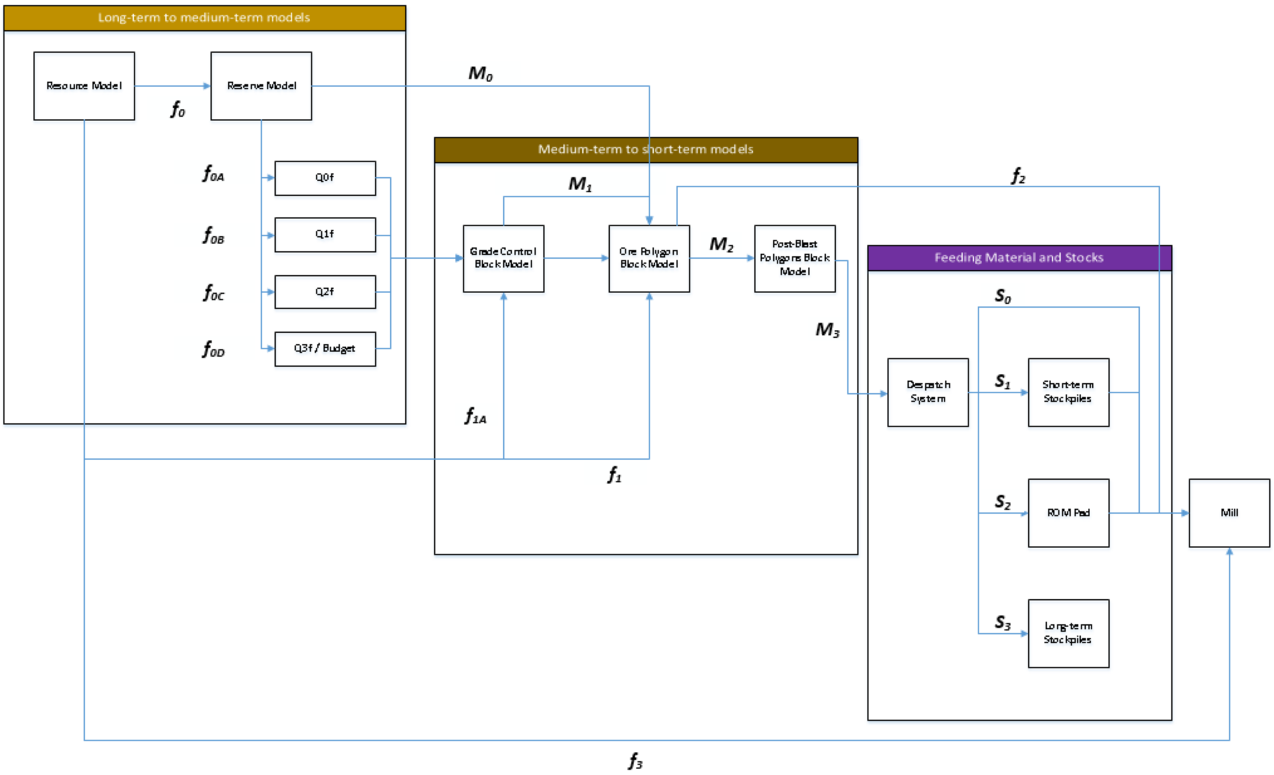


Figure 12 - Mine Value Chain implemented at Tasiast

1. The first set of indicators is related to **long-term and medium-term models (**Figure 13**)**. The comparisons of the resource model to the reserve model (f_0) and the reserve model to the different models prepared for forecasts (Q0f, Q1f, and Q2f) and budgets (f_{0A}, f_{0B}, f_{0C}, f_{0D}) highlight the impact of the expected dilution on the resource model; the differences between what's budgeted versus forecasted ore tonnage and grade, etc.

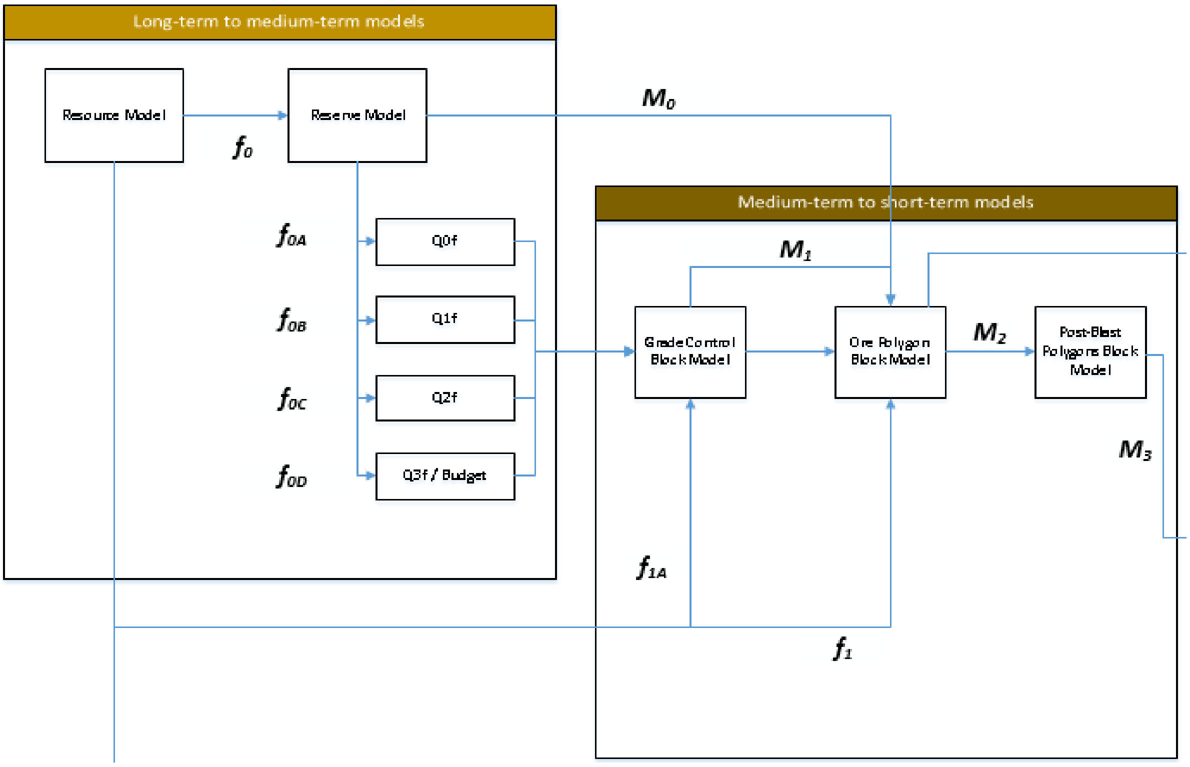


Figure 13 - First set of indicators

2. The second group of indicators focuses on **medium-term to short-term models (**Figure 14**)**. At Tasiast, grade control is performed on 10m benches with Reverse Circulation (RC) drills.
    a. Between 5-10 benches are designed ahead of production and give a medium-term model to the planners. This information is used to estimate[1] a "grade control block model" (GCBM) from which pre-blast ore polygons are designed.
    b. Then, an "ore polygon block model" (OPBM) can be generated where ore polygons assign their grade to the blocks they contain.
    c. Finally, a "post-blast polygon model" (PPBM) is generated (the detail is explained below) to recalculate the dilution related to each blast.

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[1] The estimation method used to run grade control block model at Tasiast is usually ordinary kriging. Sometimes, if RC grade control data is missing, exploration data is included and ordinary kriging with variance of measurement error (KVME) is preferred to take into account samples with different quality/support.

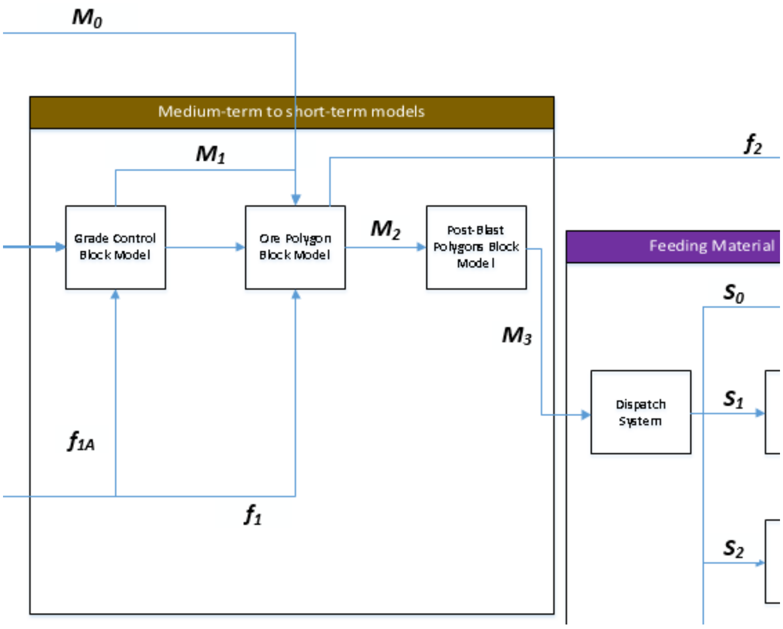

Figure 14 - Second set of indicators

The factor M_1, is the ratio of “ore polygon block model” versus “grade control block model”, describes the dilution included into the designed polygons. The factor M_2 indicates the impact of the dilution resulting from the blast process. The factor M_3 indicates the impact of the mining direction on recovered value.

This group pertains to the performance analysis of the **medium-term to short-term models**, and is linked to the **long-term to medium-term models** group via three (3) indicators (Figure 13):

- f_{1A} that measures the performance of the resource model against the grade control model;
- f_1 that compares the resource model to the pre-blast polygon block model;
- M_0 that analyses the reserve model to the pre-blast polygon block model.

3. The last group of indicators concentrates on the **tonnage comparison** of the material delivered to the mill or to the different stockpiles **between the survey method and the dispatch system** implemented at Tasiast. The S_x KPIs compare the tonnage reported by the dispatch system, from the pit to the mill or the stockpiles (short-term/long-term) to the surveyed material balance for each destination.

This final group is tied to the previous groups by two indicators (After Parker, 2012):

- f_2 that evaluates the ratio: Received-at-mill versus Delivered-to-mill;
- f_3 that compares the f_1 (Short-range model depletions versus Long-range model depletions) against the f_2 (Received-at-mill versus Delivered-to-mill);

At the time this MVC was established, the M_2 and M_3 factors were only mentioned and a gap was left and roughly filled by comparing the designed polygons to the dispatch system. This blurred area hides most of the operational dilution and raises some questions about the validity of the f_2 factor. How is it possible to get a f_2 factor close to 100%; except by applying experimental factors[2], when:

1. the designed polygons are not the mined polygons (usually translated or distorted in 2D to take into account the blast movement) in terms of grade, tonnage and ounces;

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[2] The application of factors on polygons is questionable as it usually results in comparing the depleted polygons to the mill feed and implying the figures reported by the mill of what it has been processed in terms of tonnes, grade and ounces are accurate.

2. dilution, inherent to each blast, and the impact of the mining direction is not estimated.

A methodology was developed to fill, at least partially, the reconciliation gap between the designed polygons and the mill feed. It is mainly based on the use of OrePro 3D and the use of a post-processing script.

Proposed Steps in MVC Process for Reconciling Dilution in Blasting and Operations

The proposed methodology (relating to Figure 15 and Figure 16) is as follows:

1. The first step remains. The “grade control block model” (GCBM) and ore polygons are created in-situ. These polygons are created without consideration to mining direction or angle of mining.
2. The second step assigns the average grade from each polygon as an attribute into each block that resides in it.
    a. For example, all blocks inside an ore polygon with average grade of 1.0 g/t will contain an attribute of that value, while the waste blocks outside the ore polygon may contain an attribute of 0.2 g/t (average waste grade).
    b. This provides an “ore polygon block model” (OPBM).
    c. At this stage, the first indicator performance, called M_1, can be computed to determine dilution inside the planned ore shapes.

$$M_1 = \left(\frac{Ore\ Polygon\ Block\ Model}{Grade\ Control\ Block\ Model}\right) = Planned\ Dilution\ inside\ in\ situ\ polygons$$

3. Then, OrePro 3D is used to move the GCBM according to blast dynamics.
4. OrePro 3D creates suggested optimised ore polygons for value post-blast for each available mining direction based on the translated GCBM. When a mining direction is selected, the grades for each block that reside in the optimised ore polygons and the calculated swelled tonnes are sent to the shovels via the fleet management system.
    a. These are the ore polygons **TO BE MINED**.
5. In certain areas of a blast, convergence, stretching, and vertical mixing can occur. When this happens, these regions may have slightly different grades than they did in-situ, depending upon where they fall in the post-blast muck pile. If an in-situ block is diluted during the blasting process, the post-blast grade is sent back to the in-situ model where it started. It is now referred to as “diluted grade”, and the script to estimate the pre-blast polygon is re-run, yielding a “post-blast polygon model” (PBPM).
    a. A second indicator, M_2, can be computed by comparing the OPBM to the PBPM. This indicator describes the overall dilution caused by the blast (Figure 15).

$$M_2 = \left(\frac{Post\ Bast\ Polygon\ Model}{Ore\ Polygon\ Block\ Model}\right) = Dilution\ caused\ by\ blasting$$

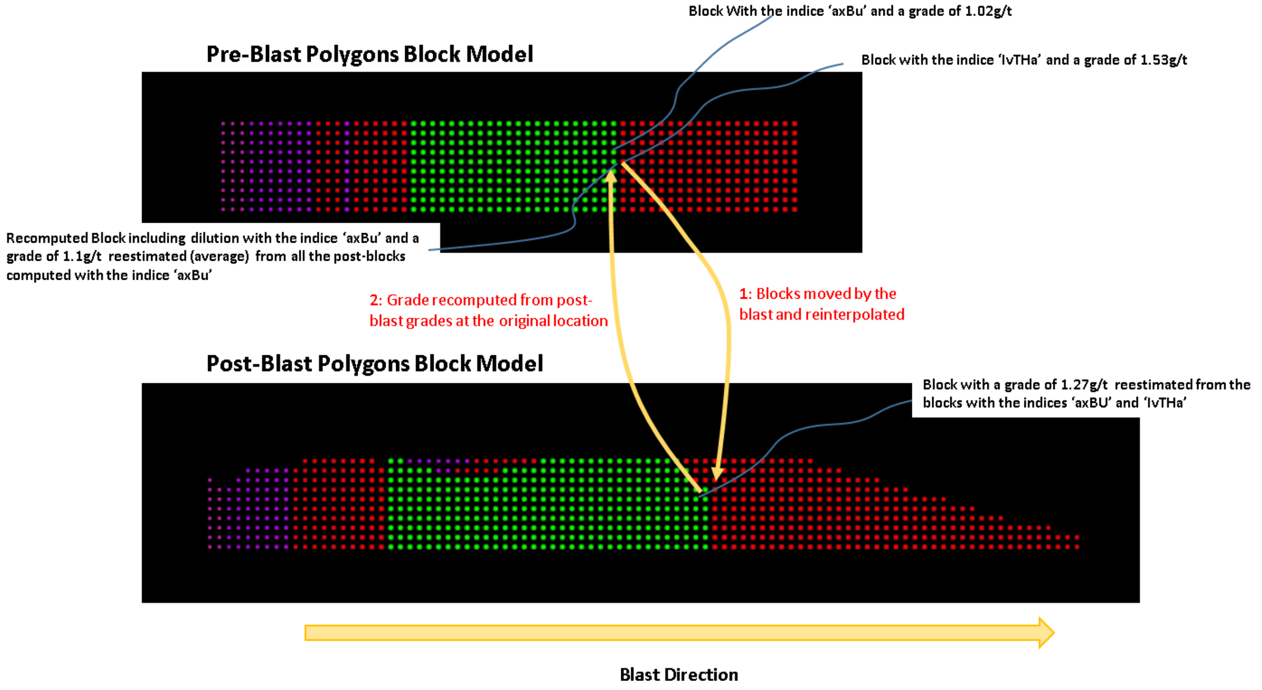


Figure 15 - Illustration of how M_2 is calculated

6. A last indicator, M_3, is defined to compare, in terms of grade, tonnage and ounces, the OrePro 3D optimised polygons for each possible mining direction. This indicator shows the impact of the mining direction on the diluted block model. This indicator is used as a decision-making tool, to determine the best mining direction if operational constraints allow. If possible, the best possible mining direction will be sent to the shovel via the Fleet Management System.

$$M_3 = \left(\frac{Post\ Blast\ Polygon\ Model}{Mining\ Direction\ Selected}\right) = Effect\ of\ Mining\ Direction$$

Then, the mined material reported by the dispatch system is compared, through the **S-factors**, to:

1. The OrePro 3D polygons to identify any potential modelling issue with the ore polygons or a dispatch problem (mis-declared material for example).
2. The depleted PBPM, to evaluate the survey or dispatch discrepancies and the impact of the mining direction;
3. The surveyed balanced material for each stockpile and toward the mill.

The S-factors are only used as a quality control from the pit(s) to the mill to check the accuracy of the survey of the pit(s) and stockpiles.

This methodology integrates the blast dilution into a block model and tracks, step by step, through several performance indicators, the evolution of the ore from a grade control block model to the material fed to the mill.

It proposes to compute an improved f_2 which doesn't compare, for a period of time, the depleted (OPBM) "ore polygon block model" and the stockpile movements to the received-at-mill material. But, it compares the depleted PBPM to the mill. By removing a source of error to the f_2 analysis, this approach tends to give a more realistic view of what is really fed and reduces the number of actors having an impact on the mine to mill reconciliation. It will highlight poor estimation, poor mining methods or issues with the mill without conflating the inherent blast dilution with operational dilution.

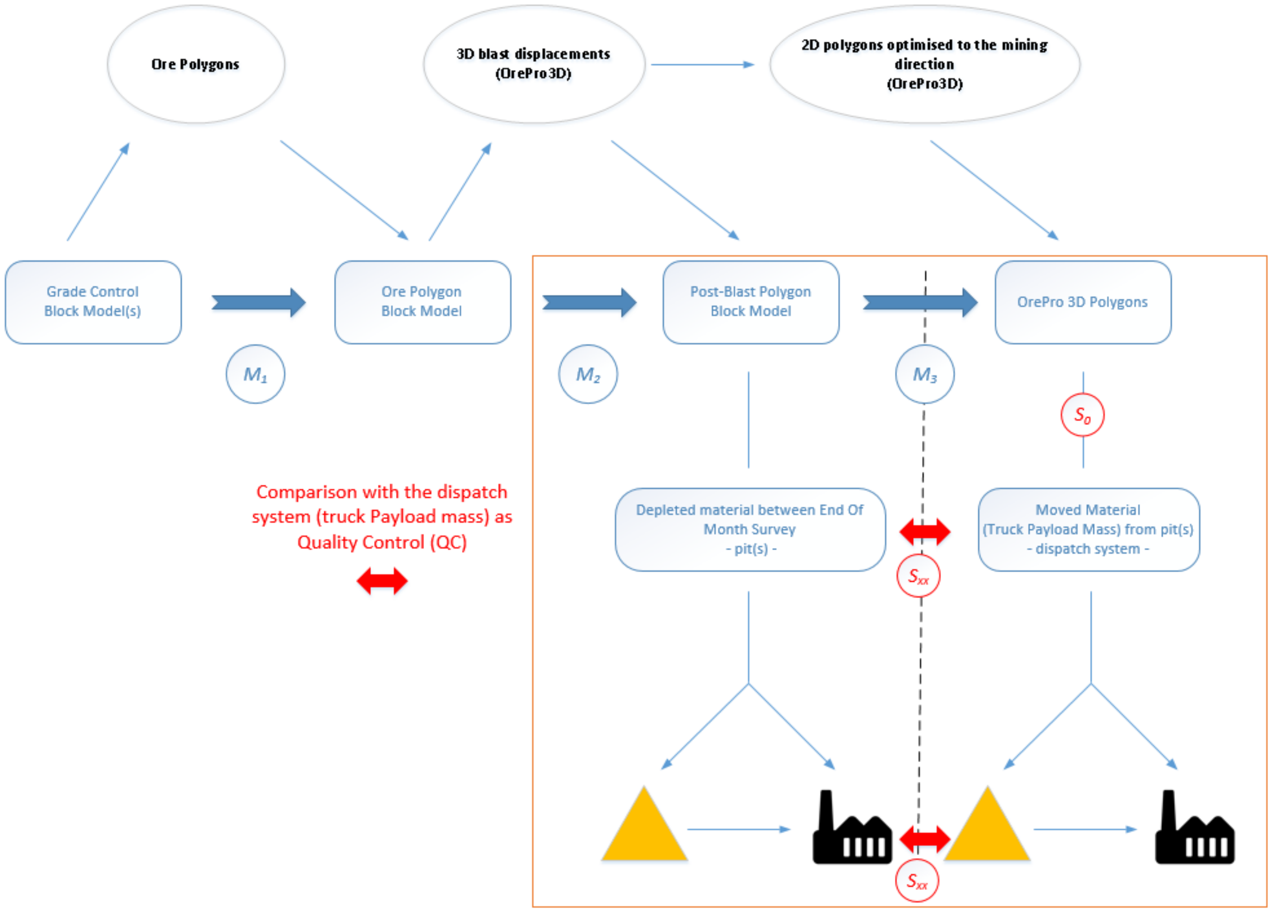


Figure 16 – Methodology to incorporate blast dilution

Use of Simulations to Mitigate Risks and Optimise the Final Destination for Ore

While the previously discussed process attempts to account for dilution caused in various processes, the confidence of the grade computed from an ore polygon redesigned after a blast should be considered as well. If this is done properly, it could add value to the blending strategy and aid in delivering the best quality material, ie a material with a relatively low variability, to the mill. In other words, if a polygon has a grade considered as high grade but with a low probability to contain this grade, it could be stockpiled or mixed with a better quality material to mitigate the risk associated with the low probability.

In order to improve the confidence in the material sent to the mill, between 100 to 500 simulation realisations are usually generated from RC grade control data with the turning bands algorithm (Matheron, 1975; Lantuéjoul, 2002). Each realisation is imported as an attribute, along with the grade control model, into OrePro 3D and moved by blast displacement. Optimised polygons are created with each realisation. Then, for each post-blast polygon, the grade of each realisation is computed and compared to the grade of the post-blast polygon (reference grade). This is useful to define a confidence interval for each moved polygon, giving the probability, by the number of realisations above the grade of the post-blast polygon, for a polygon to be above its reference (Figure 17 and Figure 18).

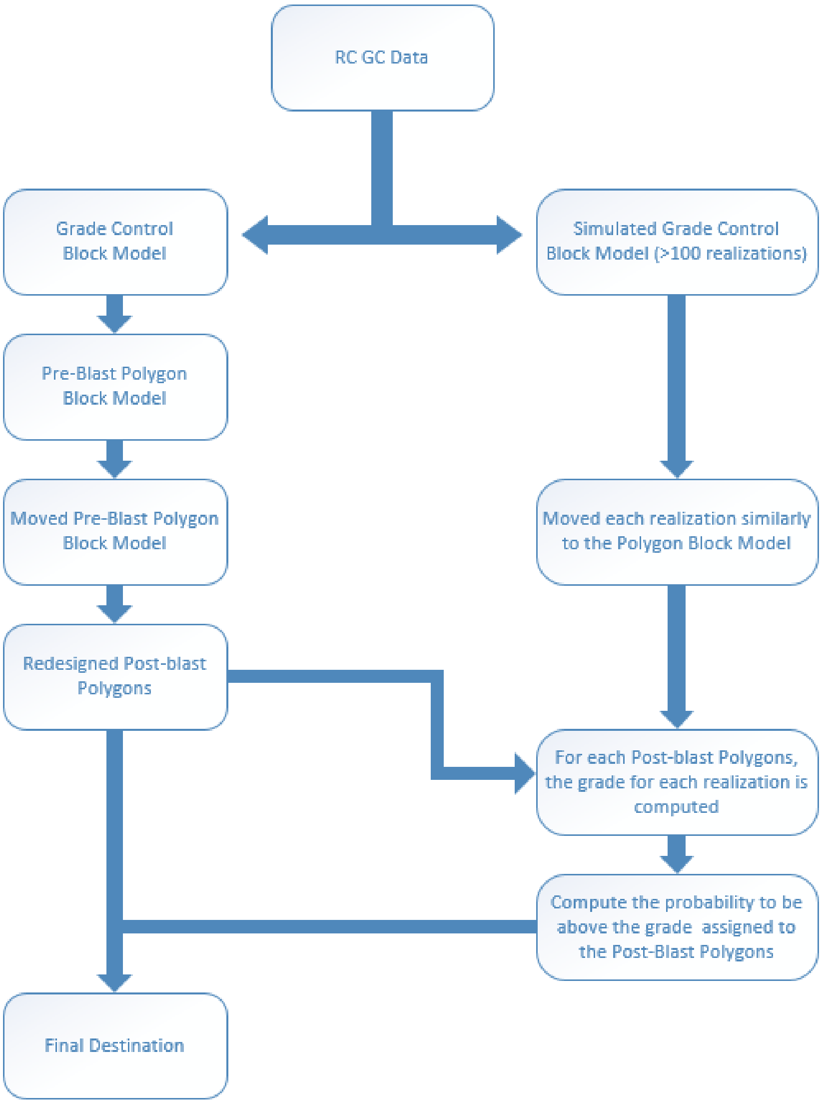
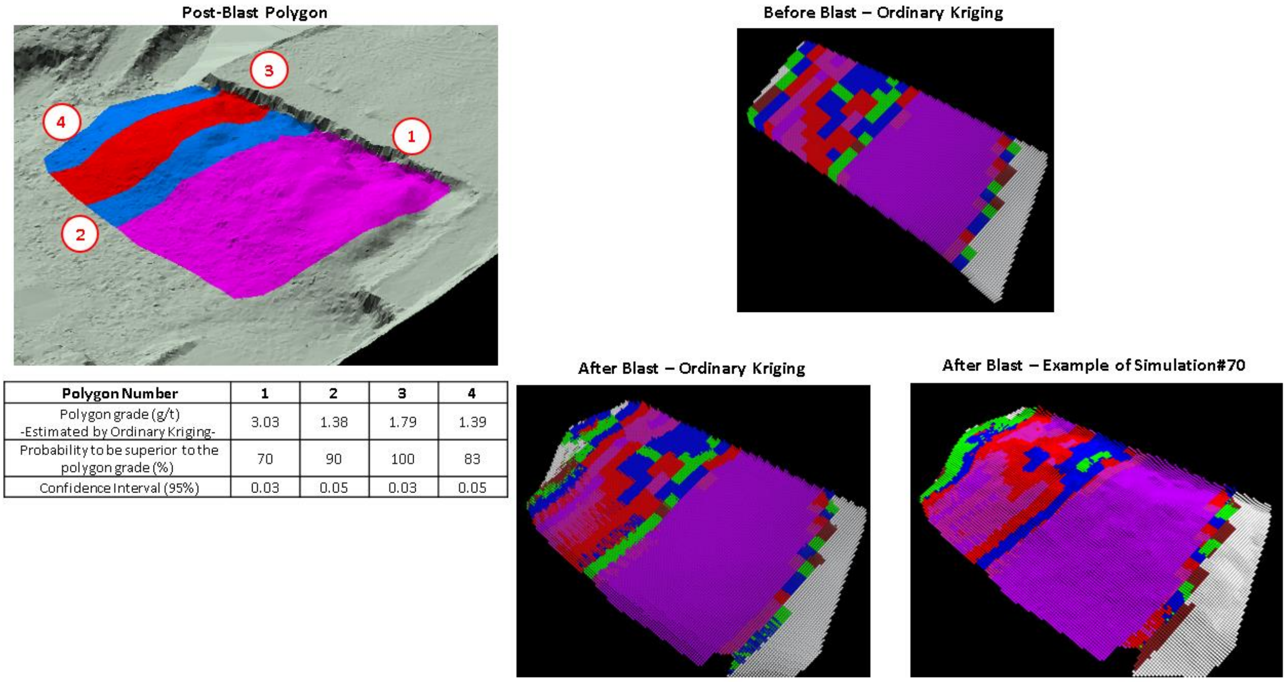


Figure 17 – Use of simulations to optimise the final ore destination



Polygon Number	1	2	3	4
Polygon grade (g/t) -Estimated by Ordinary Kriging-	3.03	1.38	1.79	1.39
Probability to be superior to the polygon grade (%)	70	90	100	83
Confidence Interval (95%)	0.03	0.05	0.03	0.05

Figure 18– Example of simulations used to assign a probability and a confidence interval for each polygon – Blast WB3-4890-5

FIRST RESULTS AND CONCLUSIONS

Since this new reconciliation approach was implemented in parallel with the use of OrePro 3D, two major improvements were noticed:

1. The variation in tonnage between ore polygons sent to dispatch and the reported tonnes in each polygon is now down to nearly 1% compared to over 18% average with the old 2D methodology.
2. The grade and ounces received by dispatch are nearly identical to the predicted diluted grades and ounces given in OrePro 3D.

Previous attempts to reconcile polygons which were moved horizontally to mitigate blast movement varied wildly from their in-situ tonnes. Figure 19 shows a comparison between those translated 2D polygons and the truck scales which report every tonne hauled from the post-blast location of the polygons.

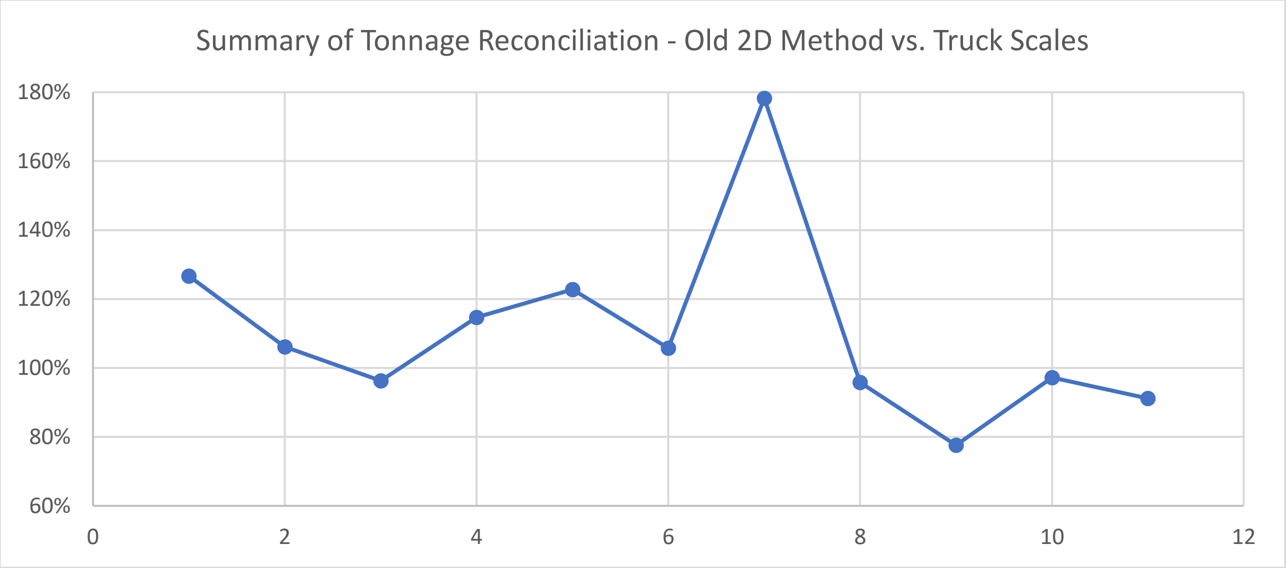


Figure 19 - Previous attempts at reconciling 2D methodology (tonnes)

A larger comparison is shown below in Table 2. This metric is described as S_0 in the MVC. The difference in tonnes between the blasted high-grade ore material, with a grade superior to 1.5g/t and expected to be mined with minimal operational losses, and the material declared as mined by the dispatch represents less than 1% so far this year. It is a huge improvement compared to the former method used at Tasiast which represents a difference of 18%. As with any new process, it is best to run potential changes in tandem with existing practices. Table 2 shows the new approach using OrePro 3D side-by-side to the old 2D approach. The reduction in variance is clearly evident.

Table 2 - Comparison of dispatch to OrePro 3D polygons YTD

Polygons	In-Situ Polygons	Previous 2D Blast Mitigation Process	OrePro 3D Polygons	Dispatch
Tonnage (t)	962,088	880,647	1,035,838	1,030,994
Grade (g/t)	2.69	2.71	2.63	2.61
Ounces (Oz)	83,254	76,795	87,688	86,435

The second improvement, given when the blast dilution is incorporated into the block model, is the ability to explain a deficient f_2 factor and the effect of the blast on this deficiency. Recently, the reported monthly f_2 grade was only 88% (by using the Kinross guidance for a monthly basis) but the M_2 factor above 1.5g/t (material sent to the mill) shows a potential dilution of 10% related to the blasts during the month (Table 3). The material sent to the mill had a diluted grade close to 2.54g/t instead of 2.74g/t as originally-reported.

Table 3 - M_2 reconciliation

	Pre-Blast Polygon Block Model			Post-Blast Polygon Block Model			M2		
CutOff Grade	Grade	Tonnage	Ounces	Grade	Tonnage	Ounces	Grade	Tonnage	Ounces
(g/t)	(g/t)	(t)	(Oz)	(g/t)	(t)	(Oz)	(%)	(%)	(%)
0	1.89	466,000	28,347	1.89	466,000	27,615	100%	100%	103%
0.1	1.89	466,000	28,347	2.01	427,500	27,595	94%	109%	103%
0.2	2.03	433,750	28,329	2.01	427,250	27,594	101%	102%	103%
0.3	2.07	423,500	28,248	2.05	416,875	27,512	101%	102%	103%
0.4	2.10	417,500	28,186	2.08	409,875	27,438	101%	102%	103%
0.5	2.10	417,500	28,186	2.08	409,500	27,433	101%	102%	103%
0.6	2.10	417,500	28,186	2.09	407,125	27,384	100%	103%	103%
0.7	2.11	415,250	28,141	2.25	364,500	26,333	94%	114%	107%
0.8	2.27	369,750	27,019	2.28	357,125	26,133	100%	104%	103%
0.9	2.29	366,000	26,920	2.31	348,875	25,890	99%	105%	104%
1	2.32	358,250	26,695	2.38	329,750	25,241	97%	109%	106%
1.1	2.40	337,000	25,974	2.44	314,625	24,696	98%	107%	105%
1.2	2.45	324,250	25,518	2.55	287,750	23,606	96%	113%	108%
1.3	2.56	296,750	24,405	2.62	271,875	22,915	98%	109%	107%
1.4	2.63	280,500	23,696	2.73	249,500	21,863	96%	112%	108%
1.5	2.74	255,500	22,519	2.82	231,125	20,954	97%	111%	107%
1.6	2.83	238,500	21,679	2.83	229,750	20,881	100%	104%	104%
1.7	2.83	237,500	21,626	2.89	217,875	20,214	98%	109%	107%
1.8	2.89	225,250	20,936	2.89	216,125	20,109	100%	104%	104%
1.9	2.89	225,250	20,936	2.95	204,625	19,397	98%	110%	108%
2	2.94	215,250	20,321	3.01	191,500	18,521	98%	112%	110%
2.1	2.98	204,000	19,569	3.17	162,375	16,548	94%	126%	118%
2.2	3.15	171,000	17,334	3.17	161,875	16,512	99%	106%	105%
2.3	3.15	171,000	17,334	3.19	158,250	16,234	99%	108%	107%
2.4	3.17	166,750	17,008	3.20	157,250	16,155	99%	106%	105%
2.5	3.17	166,750	17,008	3.22	151,125	15,656	98%	110%	109%
2.6	3.21	158,000	16,295	3.22	150,875	15,635	100%	105%	104%
2.7	3.21	158,000	16,295	3.30	129,625	13,737	97%	122%	119%
2.8	3.30	129,875	13,783	3.30	128,875	13,669	100%	101%	101%
2.9	3.30	129,250	13,726	3.30	128,625	13,645	100%	100%	101%
3	3.30	129,250	13,726	3.30	128,625	13,645	100%	100%	101%

The joint use of simulations and OrePro 3D gives more confidence to the final destination of the ore and allows Tasiast to develop strategies (blending, stockpiling) to deliver a more homogeneous material to the mill.

FUTURE WORK

When reconciliation is possible during batch testing, or other hand-to-mouth situations, the simple method for applying grade and tonnage changes could be compared to this methodology, which may enable a simpler method to be used. Additionally, it is possible that changes in the reporting process for reconciliation could place less emphasis on tying planned polygon names, tonnes, and grade to mined polygons, freeing the operational and geology staff to target value without the constraints this process places on post-blast ore control.

It is possible that simulations could be performed on the post-blast model in OrePro 3D, but this requires a very detailed investigation into spatial-correlations after the rock has moved and swelled.

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