From Volume to Value: The Strategic Case for Integrated Mine Planning

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And now for the slightly sillier title for this paper:

Nobody Expects the Integrated Planning! Our chief weapon is Skin Analysis... Skin Analysis and MILP... our two weapons are Skin Analysis, MILP, and ruthless efficiency... our three weapons are Skin Analysis, MILP, ruthless efficiency, and an almost fanatical devotion to Net Present Value…

- Monty Python (Spanish Inquisition), adapted

Summary

Siloed optimisation occurs when departments such as geology, mining, processing, and finance focus on their own KPIs and timelines. This functional isolation leads to misaligned interfaces, hidden assumptions, and outcomes that are often sub-optimal for the business. Integrated mine planning replaces these silos with a value-based planning framework that facilitates the transition from volume to value. It aligns mining, haulage, processing, capital decisions, and market constraints, using Net Present Value (NPV) as the primary directional guide for the enterprise.

Using a Mixed Integer Linear Programming (MILP) engine, IMC models the complete value chain on a single platform to make strategic trade-offs explicit. This methodology incorporates dynamic cut-off grade optimisation and skin analysis to ensure the "sins" of the final mining phase are not subsidised by the cash flow of earlier pushbacks.

The result is a realistic and risk-adjusted pathway to value: the foundational narrative required to achieve the best value from an asset. This paper outlines how to move beyond undiscounted pit shells toward an integrated plan that simultaneously considers cross-discipline value drivers from the pit to the market.

Why Optimisation Silos Destroy Value

Siloed optimisation is rarely a result of poor intent. It is the natural outcome of functional experts working within the confines of their own technical domains, timelines, and KPIs. In many mining businesses, departments such as mine operations, mine technical, processing, and finance operate independently, creating a series of local optimisations. Because mines are coupled systems, the interfaces between these functions are where value is either preserved or lost.

The failure modes resulting from a lack of integration are consistent across many operations:

- ***Conflicting Objectives:*** *Different teams often optimise for different metrics, such as total tonnes, head grade, mine operating cost, concentrate grade or metal recovery. Without a single value objective, the plan can lack a cohesive direction.*
- ***Hidden Assumptions at Interfaces:*** *The gaps between departments often result in diverging planning*

assumptions. Mismatches, such as mine planners using different recovery factors than the process plant, or throughputs being modelled as fixed rates rather than dynamic tonnes per hour, can undermine the entire plan.

- ***Static Constraints:*** *Operational constraints are frequently treated as fixed "givens" or historical habits. They are rarely viewed as limited capacity that should be allocated to the highest value use at any given time.*

Indicators of siloed planning include:

- ***Plan Instability:*** *The preferred plan changes significantly when minor adjustments are made to input assumptions.*
- ***Reverse Engineering:*** *Results are disputed because they challenge a pre-conceived idea. Inputs are subsequently "adjusted" to force the model to replicate a historical narrative or a specific budget target.*
- ***Frequent Rework:*** *Schedules require constant revision because a constraint, such as tailings capacity or a logistics bottleneck, is disputed late in the process.*
- ***Bolted-on Strategies:*** *Blending, haulage optimisation and stockpiling are post-processed after the mining sequence is defined rather than being central to the mine schedule optimisation.*
- ***Legacy Decision Triggers:*** *Major capital expansions are often linked to previous, perhaps outdated, decisions that have gained their own inertia. Instead of re-evaluating these projects against the current production plan and constraint environment, they are treated as "baked-in" milestones. In a truly integrated plan, every expansion is a decision variable that must be re-validated by the system's ability to monetise the new capacity.*

Ask for feedback early:

The planning process requires early and iterative collaboration with cross-discipline leadership (mine operations, plant and marketing). This feedback is essential to identify physical constraints, pain points or productivity "brakes", such as narrow mining phases, known haulage bottlenecks or vertical interaction between phases, which are often missed in purely mathematical models. Ensuring that the mine planning model is "aware" of these productivity issues from the start prevents *rework and maintains the credibility of the strategic plan.*

Integrated Mine Planning: Definition and Problem Solving

Integrated mine planning connects strategic design, scheduling, processing, and capital decisions in a single value-based framework. It typically uses a consistent set of inputs for loss/dilution, costs, recoveries, prices, and operational constraints to evaluate decisions based on discounted cash flow. By integrating these variables, the planning process moves beyond volume-based targets and instead focuses on value-based outcomes.

Several common mining challenges are difficult to solve in isolation because they involve coupled decisions:

- ***Open Pit to Underground (OP/UG) Transitions:*** *These transitions involve complex decisions regarding capital timing, access development, and the lead time until first underground ore.*
  A locally optimal pit shell may lead to an unfavourable transition if it delays high-value underground production or forces inefficient use of capital.

In Figure 1, the optimal pit shell based on discounted value is at Revenue Factor (RF) 0.85. However, the optimal enterprise value (Figure 2) is based on a smaller pit (RF 0.75) and an earlier underground.

Identifying the optimal open pit on a standalone basis is rarely the correct answer when other production sources exist such as underground operations and other pit phases.

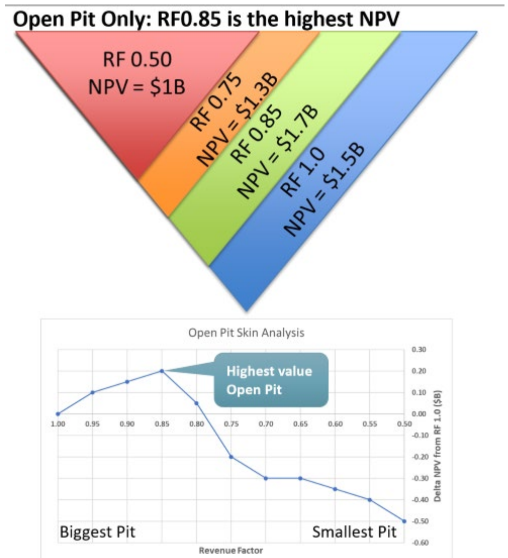

Figure 1 Standalone Open Pit Value

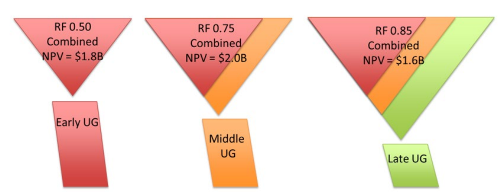

Figure 2 Integrated OP/UG Value

Solving for the 'optimal enterprise value' seen in Figure 2 is a multi-dimensional challenge. It requires a system-wide *evaluation of capital timing, open pit sequencing, ore delivery, cut-off grades, surface stockpiles and underground production ramp up simultaneously. This complexity is why traditional manual scheduling often falls short and necessitates a more robust mathematical approach.*

- ***Schedule Optimisation: Where the System Converges***
  Schedule optimisation is where the entire scheduling system comes together: spatial data, time-based logic, system capacities, and economic variables such time-based costs, revenue and discount rates. In tactical planning, throughputs and capacities are often treated as fixed maximums with pre-defined decisions on blending and cut-off grades. In the strategic space, however, nothing is "off the table".
  All potential solutions are judged equally based on their ability to deliver value. This process ensures that expansion timing and capital decisions are not treated as "baked-in" historical decisions, but as active choices validated against the current set of assumptions and constraints. Post-processing these decisions effectively hides the strategic trade-offs, resulting in enterprise value being left on the table.

- ***Expansion Timing and Scale:*** *Decisions regarding increases in primary fleet, crusher relocations, or plant debottlenecking cannot be evaluated in isolation. Integrated planning evaluates these options against the value of earlier metal production, lower operating cost, risk reduction, and future flexibility.*

Strategic Levers for Maximising Asset Value:
In practice, integrated planning is used to answer important questions that impact long-term asset or enterprise value:

- ***Constraint Identification:*** *Determining which constraints are truly value-limiting in the scheduling periods. Are these constraints impacted by seasonality? Is there a known expansion pathway to debottleneck these constraints?*
- ***Capacity Allocation:*** *Deciding where to allocate limited capacity, such as mining capacity, bench sink*

rates, mill hours, rail capacity or capital availability to achieve the highest return.

- ***Sequencing Logic:*** *Identifying mining sequences that bring high-value material forward without making the plan fragile or overly sensitive to change.*
- ***Model Coherence:*** *Ensuring the model responds logically when key assumptions, such as commodity prices or metallurgical recoveries, are adjusted.*
- ***Tactical Guidance:*** *Providing fast evaluation of alternative mining and processing scenarios to guide tactical mine plans, as it is much faster to evaluate 20 scenarios in a strategic tool than in a tactical scheduler.*

  Guidance is a two-way street: strategic plans are not designed to evaluate minute tactical decisions. A robust strategic plan relies on guidance from the tactical plan for short-term constraints to ensure the initial years of the strategic plan are grounded in reality.

Explainer: MILP for Mine Planners

Mixed Integer Linear Programming (MILP) is a mathematical method for choosing the best combination of decisions when many interacting constraints are present. It is particularly effective for mining because our business involves discrete choices, such as which phase to mine, which processing path to use and what ore should be blended to achieve throughput constraints.

The "Head Chef" Analogy

To understand how MILP functions without the math, imagine your mineral resource and stockpiles are a fridge and pantry full of ingredients. Each ingredient has attributes like grade, contaminants, or hardness. Your goal is to produce the most profitable "recipes" (saleable products) possible while managing the physical limits of your kitchen.

The optimiser acts as the head chef, making decisions based on the total system:

- ***Ingredients (Resources):*** *You must decide which ingredients (ore) to use now and which to save in the pantry (stockpiles) for later based on value.*

  Using all the "butter" (high-grade ore) early can make later years more complicated!

- ***Kitchen Size (Claim Space):*** *The kitchen can only fit a head chef and a sous-chef (a large rope shovel and a smaller excavator on each bench). This physical limit dictates the maximum number of meals you can prep simultaneously (maximum production per day).*
- ***Washing Up (Sink Rate):*** *You cannot start the next service until the dishes are done. In an open pit, you must drill/blast, scale, and prep for the next bench (washing up) to keep the kitchen safe and functional. These ancillary activities limit how many "services" (benches) you can achieve/sink in a year.*
- ***The Oven and Burners (System Constraints):*** *You are limited by the size of your oven (the mill) or the number of burners (rail and logistics capacity). Even if the chefs prep faster, the system can only "cook" at its bottleneck capacity.*
- ***Market Orders (The Objective):*** *You aren't just using up food; you are creating the most profitable combination of recipes over time that the customers actually ordered.*

The Building Blocks

While the underlying mathematics is complex, the structure of a MILP model is straightforward. The model is built from four primary components:

- ***Decision Variables:*** *These are the choices the optimiser can change, such as the tonnes mined from a specific unit in each period, destination splits for blending, and variables that represent "on/off" project choices.*
- ***Objective Function (linear):*** *The model optimises a single measure of value. In strategic planning, this is typically to maximise Net Present Value (NPV).*
- ***Constraints (linear):*** *These are the rules the model must follow. This includes physical limits such as mining, processing and rail capacity, mill hours and blending requirements, and business requirements like capital spend restrictions.*
- ***Integrality (integer and binary variables):*** *Some variables are restricted to integer values, including "yes/no" (binary) choices. This is what allows logical dependencies, such as only activating Phase B after Phase A has reached a specific trigger depth, or deciding which year to build a plant expansion.*

Why MILP is Useful in Integrated Planning

The power of MILP lies in its ability to model the mine as a fully integrated system. Instead of optimising one department at a time, the optimiser evaluates every component of the value chain simultaneously. Each period is defined by a set of capacity limits, such as equipment hours, plant throughput, milling capacity, development metres, or market requirements.

The optimiser then allocates this available capacity across all possible mining, processing, and project decisions across multiple years (often 10 to 15 years at a time) to maximise the objective while honouring all defined constraints.

This approach makes all assumptions and constraints explicit. If the model selects a specific pathway, the displacement or cost elsewhere in the system becomes visible. This visibility supports clearer plan communication, robust scenario testing, and alignment on the factors that truly drive value for the asset.

NPV: The Main Character, Not the Whole Show

Net Present Value should be viewed as a directional guide rather than an absolute success metric. A successful plan must align corporate objectives with operational practicality. While NPV identifies the strategic direction, it is important to distinguish between enterprise-level value drivers and minor tactical value compromises.

To quote a former client, a sub-optimal tactical detail is "not a hill I'm willing to die on" if it distracts from the broader enterprise objective. The goal is a plan where the mathematics is tempered by the practical capability of the site.

Why Whittle and Pseudoflow Do Not Provide the Full Answer

Lerchs-Grossman (Whittle) and Pseudoflow remain valuable algorithms for solving the initial value optimisation problem: defining the economic limits of the deposit whilst honouring slope geometry.

However, the limitation lies in the algorithm itself: Pseudoflow is designed to find a static limit based on <u>undiscounted</u> values; it cannot schedule or account for the time value of money. Instead, integrated planning focuses on the sequence and timing that delivers the best <u>discounted</u> value for the entire system (mine, plant and market).

Pit Shells are Undiscounted Value Contours

We often see technical teams assert that their mine plan is "optimised" because they have created pit shells in Whittle or Pseudoflow. This is only step one.
Pit optimisation outputs represent undiscounted value under a specific set of costs, revenues, and slope constraints. While these are useful for defining the economic limits of a deposit, they do not optimise for timing, cut-off grade, capital allocation, or operational interactions. It is a common misconception to treat these shells as an "optimised" final design. Because Pseudoflow shells represent undiscounted cash flow contours, they require a subsequent schedule to evaluate their discounted value using a DCF analysis.

Revenue Factor 1 is Rarely the Maximum NPV

Revenue factor (RF) shells are a useful way to explore the sensitivity of a pit to changes in revenue. Mining the shells that are "optimal" at lower revenue factors first usually brings high-margin ore forward, which results in a higher NPV.

However, selecting RF 1 as a default final shell often ignores the timing of costs and revenues. The RF 1 pit shell is designed to provide the highest total undiscounted cash flow. Because NPV is driven by the timing of those cash flows, the highest NPV pit shell is almost always smaller than the RF 1 shell.

Consider a scenario where a final phase requires five years of waste stripping before reaching the first ore in year 6. In this case, the waste mining costs are spent early (years 1-5), but the value of the ore is effectively discounted by 6 years. At a 10% discount rate, year 6 revenue has a discount factor of approximately 0.56. This means the ore only delivers 56% of its value when discounted back to the start of the waste stripping for the final phase. If the cost of the early waste stripping exceeds the overall value of the ore, the final phase is value-destructive regardless of its undiscounted value (Figure 3).

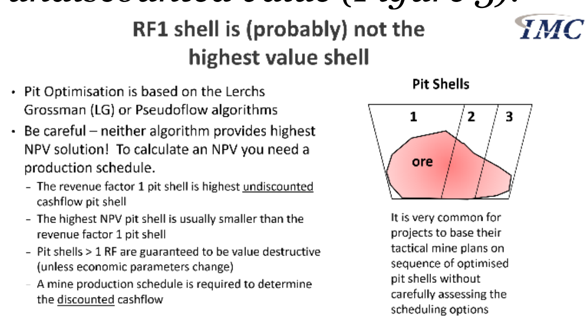

Figure 3 Revenue Factor 1 Pit Shell

The Need for Scheduling

To calculate a Net Present Value (NPV), a production schedule is required. Strategic planning rarely monetises all mineralised material; it instead focuses on which material should be prioritised to maximise value within the current system limits.
Strategic scheduling of mining phases is critical to unpack complex product blending

requirements. Consider an iron ore project: the product specifications are often driven by shipping contaminants such as phosphorus (P) and alumina (Al2O3) rather than iron (Fe) grade alone. Without a production schedule that considers these contaminants over time, pit shells defined by Fe revenue risk ignoring the impact of blending on overall system value.

The practical takeaway is to treat optimised pit shells as spatially compliant mining phases that the schedule optimiser can choose to mine, process, stockpile or leave in the ground, based on the total system value.

Skin Analysis for Open Pits

Skin analysis is a process used to evaluate the incremental value of alternative widths for mining phases using a discounted cash flow (DCF) analysis. The goal is to select and sequence phase widths that maximise discounted value, rather than simply choosing shells based on an inflection point on a Whittle size vs. value chart or a "threshold" amount of metal.

This process ensures that the "sins of the last phase" are not subsidised by the cash flow of the preceding phases. Without this incremental evaluation, it is easy to select a phase that increases total undiscounted value while actually destroying NPV by delaying high-value ore or increasing pre-strip at the wrong time.

By focusing on the incremental margin of increasing final phase widths, we can identify the point of diminishing returns. This prevents the "over-mining" of low-value material that occurs when teams rely solely on undiscounted pit shells.

A practical example is the comparison between a Revenue Factor (RF) 1.0 shell and an NPV-optimised shell. While RF 1 contains the most metal, it often requires a massive final waste-stripping campaign that occurs too late in the life-of-mine to be offset by the discounted value of the remaining ore at depth. By using skin analysis to evaluate the incremental margin of each pushback, we normally find that a smaller pit shell delivers higher enterprise value than the RF 1 shell.

Communicating the Strategic Plan

A strategic plan only creates value if stakeholders can understand it, leaders can commit to it and operations can execute it. Communication must make the underlying logic visible: what decisions were made, why they were made, and what must be true for the plan to succeed.

Pathway to Value

The "Pathway to Value" is the foundational narrative required to achieve the best value from an asset. This chart (Figure 4) or narrative summarises the sequence of key decisions and constraint relaxation required to deliver the highest risk-adjusted value mine plan from the current central case. It links phases, expansions, and operating policies directly to value outcomes and risks, providing a clear pathway from the central case to the full-value mine plan with intermediate steps (or decisions) along the way.

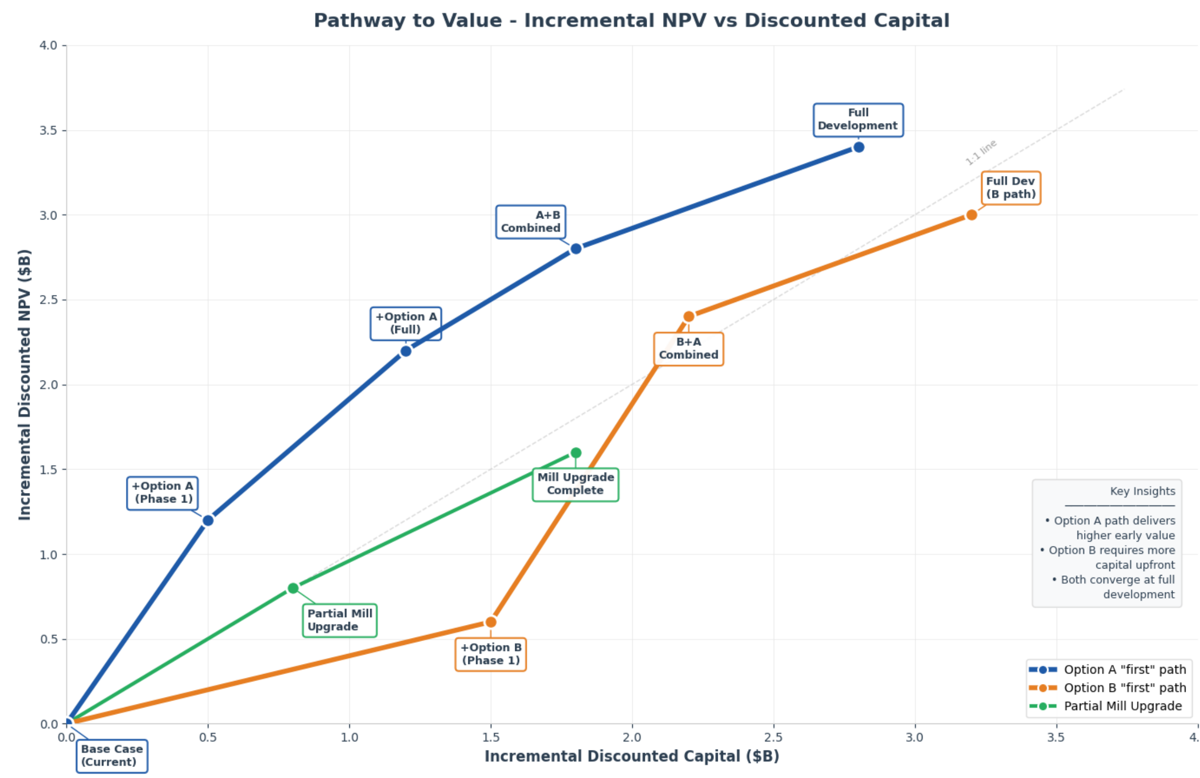

Figure 4 Pathway to Value – Describing the Value Journey

Key Development Milestones

A key output from the mine plan will typically include the timing of specific milestones that turn scheduling outcomes into a clear narrative. These include:

- ***Mining Phases**: The start and finish times for each phase or pushback.*
- ***Active Constraints**: A clear identification of which constraints are active in each period.*
- ***Dynamic Cut-Off Grade**: The evolution of the stockpiling and processing cut-over grades for each period.*
- ***Fleet Management**: The timing for primary mining fleet replacement or major fleet expansions.*

- ***Infrastructure Support***: *The schedule for tailings dam raises and other civil works.*
- ***Processing Levers***: *The optimal time for mill upgrades, additional milling capacity, or changes in grind size.*

Post-Planning Cycle Debrief: *Effective communication includes acknowledging that no plan is perfect. Documenting a roadmap for "Future Work" allows teams to highlight known compromises or areas for technical refinement in the next iteration. This transparency ensures that even when a preferred plan must move forward "as-is", the business has a clear record of what can be improved in the next planning cycle.*

Case Studies

While the mathematical principles provide the foundation, the practical value of an integrated approach is best seen when applied to real operations. These case study summaries highlight how the "nothing off the table" philosophy was used to navigate strategic challenges that standard, siloed planning often struggles to resolve.

Diamonds: Portfolio vs. Asset Optimisation

For these Tier-1 diamond assets, local optimisation at the mine level was a threat to broader business value. The strategic challenge was not just about tonnes and carats: it required the staging of open-pit and underground transitions within a narrow window of marketing limits and product mix requirements.

- ***The Problem:*** *Staging major open-pit phases against underground development and satellite sources created a large number of development pathways. If one pit over-produced, it risked flooding specific marketing categories or exceeding processing capacity elsewhere in the portfolio.*
- ***The Intervention:*** *IMC built an integrated MILP model that linked every mine production unit directly to downstream marketing constraints. This allowed us to evaluate larger open-pit phases against various underground production rates simultaneously, ensuring the mines never produced more than the market could accept.*
- ***The Outcome:*** *We made the opportunity cost of each sequence explicit, showing that increasing production at one operation could actively reduce value at another. This defined the*

strategic triggers for plant upgrades and underground development, ensuring capital was deployed only when it protected the total enterprise NPV.

Iron Ore: Product quality, Permitting and Tailings

In this iron ore system, the plan was dictated by the intersection of product strategy, milling capacity and tailings capacity.

- ***The Problem:*** *Constraints were moving targets: tailings capacity was critical, and increased ore hardness was impacting the throughput of both crushing and flotation circuits. The business needed to decide whether to permit an adjacent greenfield mine or invest in brownfield plant debottlenecking.*
- ***The Intervention:*** *We focused on decision timing, using the MILP engine to test whether a new mine should feed the existing plant or if the value case supported an independent concentrate stream. We assessed separate front-end and back-end upgrades to demonstrate capital optionality.*
- ***The Outcome:*** *We replaced the traditional volume-based plan with a "Pathway to Value" that ranked options by incremental NPV versus incremental capital. This provided a direct comparison between disparate projects and gave leadership a clear, capital-efficient route to de-risked and increased production.*

Platinum: Optimising a Behemoth

This complex platinum system, involving multiple concentrators and numerous payable metals, represents one of the most significant integrated mine planning challenges in the industry.

- ***The Problem:*** *With 40 open-pit options and 150 underground alternatives feeding multiple concentrators and off-site refineries, the sheer number of permutations made manual sequencing impossible. A key requirement of the strategic mine plan was to determine the optimal transition point between the open pits and the underground, which were both competing for the same ore.*
- ***The Intervention:*** *We integrated the open-pit to underground transition with alternative stope cut-off grade strategies. We modelled concentrator and refinery expansions as well*

as mining fleet in the total system.

- ***The Outcome:*** *By optimising mass pull in the concentrators alongside long-term stockpiling strategies, we identified an OP/UG transition strategy that protected downstream value. This prevented the "bolted-on" transition error, ensuring the open-pit strategy and underground development were synchronised for the life-of-mine.*

Laterite Nickel: A Blending and Logistics Challenge

For this laterite nickel project, the mine plan was essentially a logistics and chemistry puzzle involving five mining centres and 150 pits.

- ***The Problem:*** *The mountainous terrain made logistics difficult, while the offshore refinery required strict adherence to specific blending windows for Ni grade, Fe:Ni ratios, and MgO:SiO2 (basicity). Without a dynamic schedule, the variability in ore from the various mining centres risked exceeding these plant specifications or incurring significant demurrage costs at the port.*

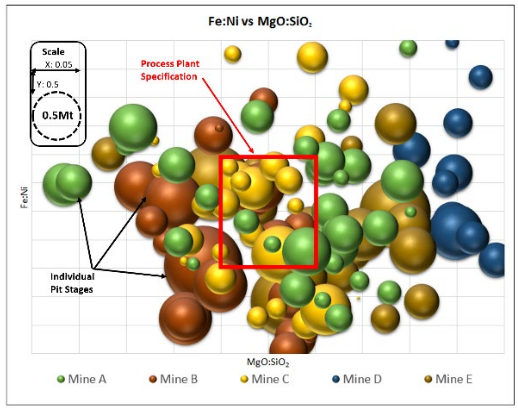

Figure 5 Inventory vs Plant Specification

- ***The Intervention:*** *Because several mining areas were waste dump constrained, we integrated backfilling sequences and haulage route optimisation directly into the value optimisation. This ensured the plan was operationally deliverable in the steep terrain while respecting the available mining space on each bench.*
- ***The Outcome:*** *The model provided guidance on period-by-period cut-off grades and blending strategies across the portfolio. This ensured the mine plan honoured the plant's specific window of acceptance while maximising the enterprise NPV and the overall saleability of the saprolite resource.*

Conclusion: Value Based Planning

*Optimisation is more than a departmental function; it is a consistent value objective. While advanced platforms such as **Minemax Scheduler** allow the entire system to be modelled on a single platform, the true power of this approach lies in the disciplined allocation of limited capacity across the value chain. While pit optimisation defines useful geometric shells, integrated production planning is the orchestra leader that coordinates the final performance.*

The goal of integrated planning is not simply to produce a bigger number or thousands of iterations; it is to provide a foundational narrative for the asset. It is a story of how the mine will transition through its phases, navigate its bottlenecks, and ultimately deliver cash flow that is resilient to risk.

To move beyond static, siloed planning, we must focus on these five pillars:

- ***Establish a Single Truth:** Agree on one value objective and a single set of assumptions across functional teams to eliminate conflicting goals.*
- ***Manage Capacity, Not Tonnes:** Identify binding constraints, such as mill hours, tailings capacity, or transport logistics, and treat them as allocatable maximums rather than fixed "givens".*
- ***Integrate Early:** Bring blending, stockpiling, and downstream constraints into the optimisation scope before the mine production sequence is locked in.*
- ***Incremental Value:** Use skin analysis and discounted cash flow to ensure that current cash flows are not being used to subsidise the "sins" of the final mining phases.*
- ***Communicate the Narrative:** Tell the story of the plan through its key development milestones and its roadmap for future refinement.*

Integrated strategic planning converts technical complexity into strategic clarity, ensuring capital is deployed only where it improves enterprise value. Rapidly evaluating 10 to 20 NPV-guided scenarios provides the strategic direction required by the business and provides context for the tactical plans and budgets. Integrated strategic planning ensures that every decision made is in the context of long-term business value.