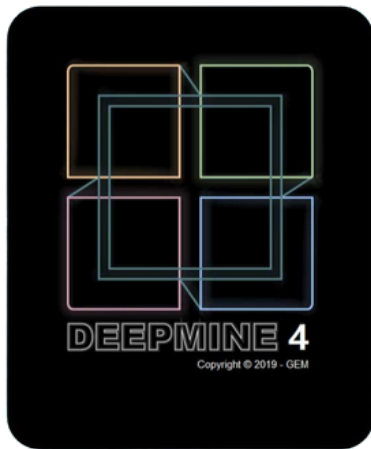




DEEPMINE

State of the Art Mine Planning Software to
Maximize the Value of Mining



DeepMine: State of the Art Mine Planning Software to Maximize the Value of Mining

Since its origins, mining has gone hand in hand with the development of humanity. Throughout history, multiple algorithms have been generated in relation to mine planning and methodologies for the exploitation of deposits. Many have been beneficial and therefore perpetuated. In recent years, however, there has been a tendency to question some of the most traditional mining paradigms, in search of optimizing processes and making them increasingly automatic and efficient. In this line, GEM Mining Consulting has developed DeepMine, the state of the art mine planning software to maximize value, paving the way for the future of mine planning.

DeepMine is a knowledge and technological leap in mine planning, providing new concepts such as the automatic generation of phases, holistic risk analysis and management, the ability to establish a dynamic objective function that allows to prioritize cash flows in the short term and Net Present Value (NPV) in the long term, among other innovations. All these methodological and technological improvements allow DeepMine to increase a project's NPV up to 20%.

Regarding the short and medium term, we are experiencing an economic scenario marked by high inflation and low growth, following the trend endorsed by history, a slowdown in demand could be expected. This will force the industry to be more efficient and innovative to

face the medium and short term, and for the same reason, having a tool like DeepMine is a game changer.

The focus of DeepMine is to automate the mine planning process from start to finish, adding value to the entire chain and all its participants. From the geologist who makes the first samples to the investor who decides to contribute capital to the project, each can benefit from the powerful DeepMine engine.

Three concepts that characterize and distinguish DeepMine from competition are developed in this document:

I. Robust: Automatic Phases Generation, this functionality starts addressing the mining problem and how mine planning has been carried out until today with the corresponding manual phase design. Subsequently, the DeepMine algorithm is described and the main improvements it brings are highlighted, making this crucial stage of mine planning more objective and efficient. The automatic phase generation solves the mine problem in its spatial and temporal dimension simultaneously maximizing the value of the business.

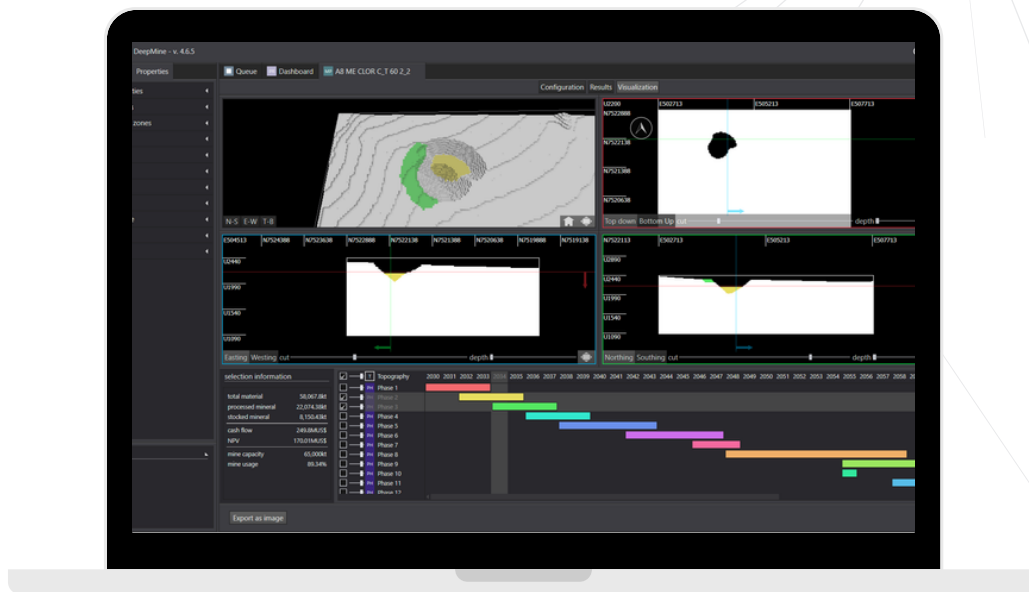
II. Holistic: Stochastic Risk Analysis and Management, DeepMine contributes new concepts to mine planning. First, the change from the traditional concept of Revenue Factor to Risk Factor is explained, which can be summarized as a better measure of the directional trend of the economic envelope, considering in

this process the main risks associated with mining. The concept of stochastic mine planning is also presented, characterized by evaluating and mitigating mining's main risks during mine planning. This approach is considerably more robust than traditional deterministic mine planning, which is biased by only considering the risk associated with commodity price. DeepMine incorporates both concepts that allows risk management since the earliest stage, improving strategic decision making.

III. Agile: Prioritize Cash Flow in the Short Term and then Maximize Value, understanding that we are facing an unstable economic scenario, it is useful to have a tool that has the ability to adapt its objective function to the contingency. DeepMine can establish three objective functions when running a mine plan:

(1) the standard method of maximizing NPV, (2) maximizing cash flow for a certain period of years and thereafter maximizing NPV and (3) maximizing the use of some specific plant(s). This agility and versatility allow generating a value contribution in the evaluation of a project.

The vast experience of GEM in Mining Consulting and Engineering, has generated value beyond DeepMine, with contributions in risk analysis, project evaluation, technical studies and other advisory tasks that can be reviewed in more details at the website <https://www.gem-mining-consulting.com/>.



I. ROBUST: AUTOMATIC PHASES GENERATION

A strategic mine plan is a fundamental part of any mining operation. It must provide a realistic and operative extraction and processing schedule, and yield the highest value for the business. For open-pit mines, the problem can be modelled as a set of blocks representing the deposit, for each of which we need to decide if it is going to be mined, if so, when and where it will be sent (process, stock or dump).

This problem can be proven to be of NP-Hard complexity. The traditional approach used by mining engineers to tackle this complexity is to separate the problem into more tractable components, solving each separately.

The first step is to use the Lerchs-Grossman (LG) or Pseudoflow algorithms to obtain the final pit limit, as well as a set of optimized pit shells (nested pits), using different input prices. Then, using this input, operational phases are designed.

Third, the set of phases can be used as

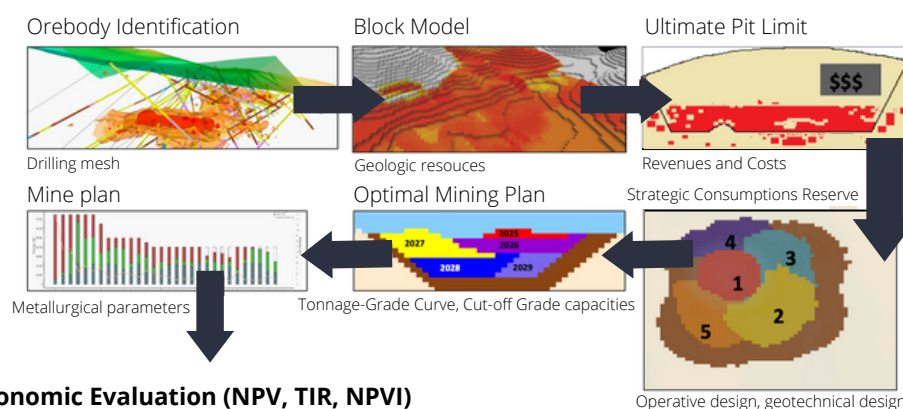
an input for a phase-bench style optimisation, usually using a mathematical programming based algorithm.

There are, however, several problems with this approach. First, dividing the problem into simpler parts has the consequence that any compromise made at early stages limits the potential value left for the following steps. Second, LG is a static algorithm, with no concept of the time-value of money, capacity limits, opportunity costs, etc. Phase design is essentially a manual step, and therefore the quality of the result in terms of potential NPV strongly depends on the experience and expertise of the designer.

This means that key input data such as commodity prices, different processes capacities and mine movement limits, are considered only at scheduling, when there is little room for optimisation. This sequential approach limits the potential value in each step, where a simplified problem is addressed, instead of addressing the real, and more complex problem, which is dynamic and should be solved as a whole.

Figure 1. Stages of Current Mine Planning

Suboptimal process and poor automation of its stages



Understanding the suboptimal presented above, the need to optimize this process is evident. In this context, GEM Mining Consulting has developed the software DeepMine, which uses a unique and innovative algorithm based on an approximate dynamic programming approach to create and explore several development possibilities for the mine. DeepMine's logic solves the mine problem in its spatial and temporal dimension simultaneously, and therefore maximizing the business value, reaching up to 20% increase in NPV over traditional industry software. An objective and automatic phases design process, in contrast to the current methodology that strongly depends on the mine planner experience, improves the efficiency and profits of mining.

The methodology consists in creating many possible states in which the mine might be at a particular period. Then, for each of these possible scenarios, develop several possible new states, and so forth. After a great number of possible paths have been explored, the path that leads to the highest NPV can be selected.

Since the raw number of combinations of how to select which blocks to mine on a given period is too large for any attempt of solution in a reasonable time, two important strategies are used to reduce the solution space, while guiding the solution.

First, in order to comply with operational constraints and the requirement of having to translate the results into phases or pushbacks, blocks will only be extracted in cohesive volumes (mimicking phases). There is a maximum number of

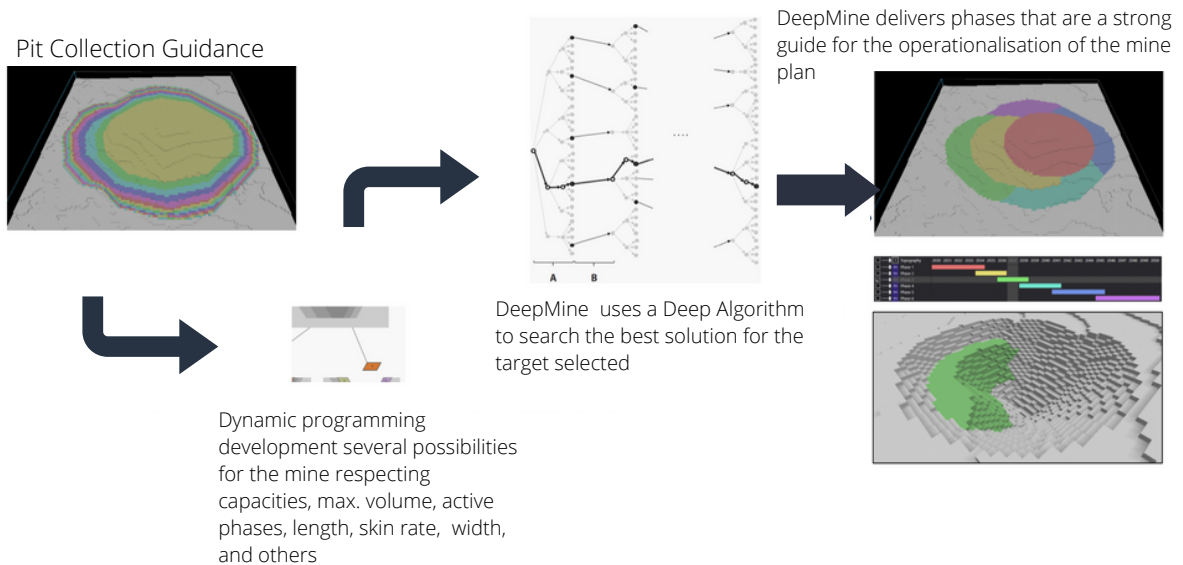
such volumes, or active phases, which can be extracted each period, given by the number of shovels and other machinery required to do so. There are also constraints for the dimensions of these volumes, such as the maximum length, maximum sinking rate and minimum width. A key feature of these volumes is that they are not predefined. They must be formed dynamically, responding to all variables of the problem, considering past extractions and future consequences of each analysed path.

Another technique to restrict the solution space is to use the results from the LG or Pseudoflow algorithms to guide exploration. First, only blocks within the ultimate pit are extractable. This is a reasonable assumption to make without losing generality of the solution, since the ultimate pit problem is unconstrained by time and process capacities, it establishes an upper limit for the solution of the more general problem. The algorithm also uses intermediate pits as temporary bounds for pushbacks as a way to guide the solution into the final pit.

The way in which their information is considered allows for solutions that are much more flexible than just assuming phases will follow pit exact boundaries, as is the case with optimisations that use pit shells in place of phases to do bench scheduling.

Figure 2. DeepMine Mine Plan

DeepMine algorithm addresses the dynamic problem as a whole, simultaneously and automatically creating a high value strategic mine plan



As represented in Figure 2, the algorithm uses a combination of heuristics and clustering methods to find several possible locations for an extraction zone.

Some possible zones may be limited by the boundary of the current Pseudoflow pit shell, while others might be only limited by width and length parameters. Using these alternative extractions for each period, the algorithm can then create many different states for the mine, depending on which zone or combination of zones is chosen to be mined. Depending on the available mining capacity, not all zones might be fully mined.

Finally, the software reviews all the branches generated in the DeepMine algorithm and selects the best solution, which meets all the imposed restrictions and maximizes the pit value.

Some of the benefits of using DeepMine for strategic mine planning are that the spatial and temporal problems of mining are faced simultaneously, in contrast to other alternatives that solve these problems separately.

DeepMine improves the phase design process reducing reliance on mine planner expertise.

Multiple scenarios can be evaluated quickly without having to go through the traditional stages on every variant, another advantage is that the traditional gap problem is avoided by reducing reliance on nested pits as a planning guide. All of this resulting in maximising the value of the mining operation.

II. HOLISTIC: STOCHASTIC RISK ANALYSIS AND MANAGEMENT

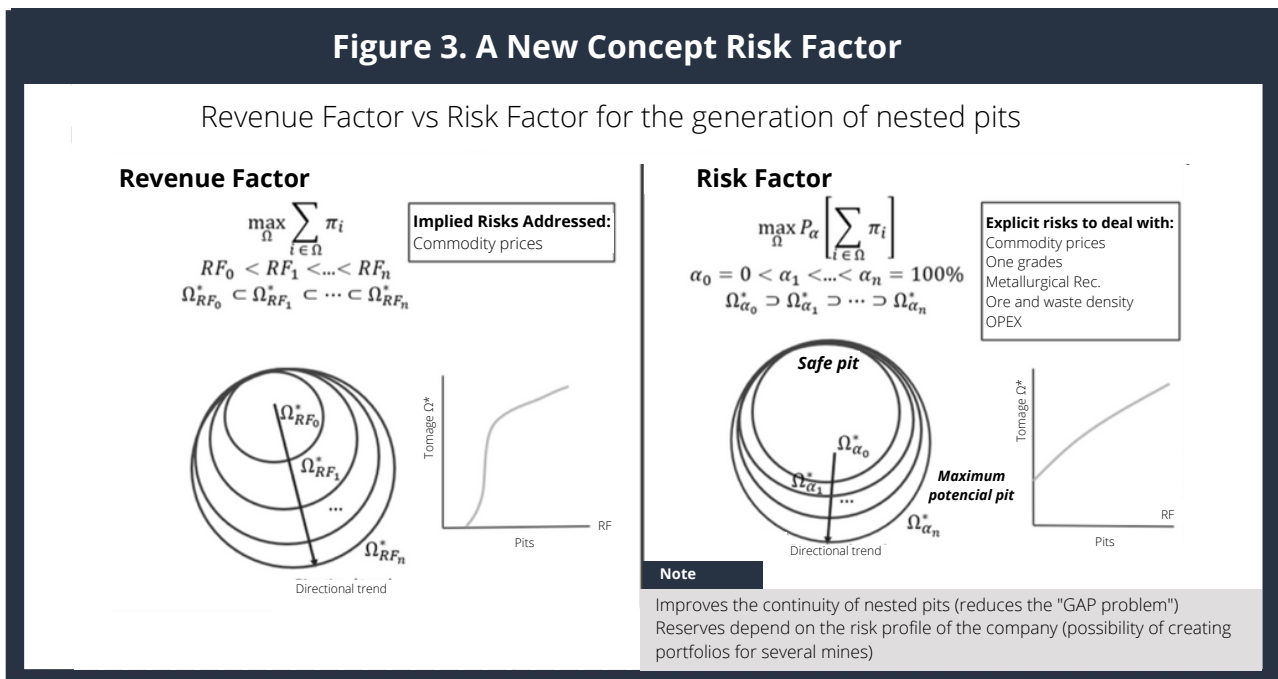
Mining is characterized as a problem with many associated uncertainties. Those that can be internal such as geology, geotechnics, metallurgy, operations, recovery and organizational, among others. This can also be due to external factors such as market, financial, political, legal, social, environmental, commercial, industrial, and technological causes. For this reason, its resolution is based on multiple assumptions that configure the scenario to be optimized.

With every new assumption added to the problem, its resolution becomes more and more complex.

since there is very little probability the values of the variables will be the expected ones. DeepMine proposes a risk analysis with a holistic view that allows incorporating these uncertainties since the earliest stage of the mine planning process, which results in considerable improvements of the NPV and robustness of the mine planning solution.

Figure 3 shows one of the strongest biases of traditional mine planning, where the economic envelope is built from the Revenue Factor concept, generating a vector of prices, and using the Lerchs & Grossman algorithm or its updated version called Pseudoflow in each one of those prices. This methodology is insufficient because although it considers the most important risk, it leaves out of

Figure 3. A New Concept Risk Factor



The traditional way to incorporate this uncertainty during mine planning is taking the expected values for each of the variables. Such as the expected price of the commodity or an estimate CAPEX. The experience has proven that following this methodology is unrealistic,

the equation multiple risks such as those listed above, and that can have major repercussions downstream in the mine planning process, and finally on the value of the operation.

Therefore, GEM with its close ties to academia, has generated an improved algorithm called Stochastic Pseudoflow that allows unifying the traditional methodology for determining economic envelopes with risk analysis. Some of the risks considered may be commodity prices, grades, recoveries, ore and waste density, and operational costs. Giving rise to a new concept called Risk Factor that highlights generating economic envelopes that are grouped from those with greater confidence to those with less confidence and with a new directional trend. Thus, improving the continuity of the nested pits and helping to reduce the impact of the GAP problem (considerable gap volume between a pit and the next one). With this new methodology, reserves depend on the company's risk profile, generating the possibility of creating portfolios for multiple mines. The Stochastic Pseudoflow algorithm and the risk analysis that this entails allow for better risk management, making DeepMine a fundamental decision-making tool.

In fact, the concept of Risk Factor and the new directional trend of the economic

envelopes is not the only contribution that DeepMine provides to the mining industry. The software can also use the risks contemplated on the analysis and generate a stochastic mine plan.

Like other mine planning software, DeepMine generates deterministic mine plans that are calculated by the traditional methodology based on expected values for mining and economic parameters. But its

great differentiator with respect to its competition is that DeepMine can also use probability function distributions of the values as inputs for these parameters. It is also possible to associate these values with each other by a correlation matrix.

Consequently, a paradigm shift is generated. DeepMine is capable of producing more robust mine plans, delivering fundamental valuable insights, and is therefore an essential tool enabling strategic decision making for the various participants in the mining business.

Figure 4. Stochastic Mine Plan

The stochastic mine planning return a histogram with the NPV values simulate in the iterations

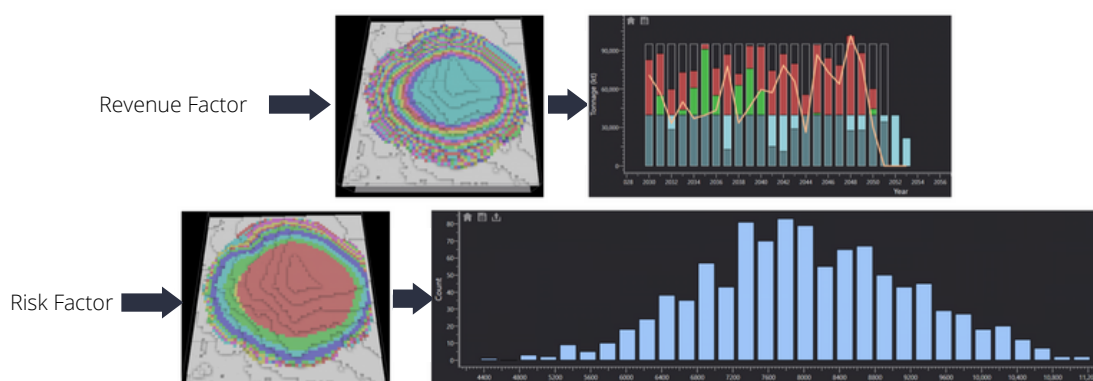


Figure 4 shows, in the first sequence, a deterministic mine plan that is the vision widely spread in the industry and used by the largest mining companies in the world. While in the second sequence, a stochastic mine plan is shown, and instead of returning a single mine plan with its respective NPV, it reports a distribution of possible NPV values that the mine can reach according to when the contemplated risks materialize.

DeepMine reports the expected value of the project, its maximum potential, as well as its worst-case scenario. Obviously, this information are key insights to allow strategic decisions with greater backing and support, based on the holistic risk analysis performed. Proper risk management and mitigation is fundamental, especially in early stages where there is a greater margin of possible scenarios.

As such, incorporating risks during the mine planning process is a great innovation that hasn't been done by any other mine planning software, but that DeepMine has begun to incorporate, such as flexible plans based on the concept of real options, which will greatly help decision making, like whether to expand a plant in a certain period based on the behaviour of the price of the commodity.

GEM Mining Consulting is expanding the knowledge of mining and is pushing the frontiers of knowledge of mine planning with DeepMine. We are convinced that its innovations are paving the way for the future of an increasingly technological and efficient mining. GEM expects that stochastic mine plans will be the norm of mine planning in a few years, and advises to adopt this practice as soon as possible in order to continually improve efficiency and gain a strong competitive advantage.



III. AGILE: BALANCE CASH FLOW VS MAXIMIZE NPV

The forecast for the economic cycle in the medium and short term is strongly marked by high inflation and low growth. Based on the history and behaviour of the commodity markets in scenarios such as the described, a slowdown in demand could be expected, which could end up translating into strong prices variations. As for mine planning cycles, there are short-term commitments such as the pre-established and determined phases with an economic scenario different from the one described above, probably a more optimistic scenario. Therefore, if the economic evaluation of these phases is made in the medium term, a suboptimal case should be reached with possible negative flows that can affect the commitments with investors.

Given these omens, future investments and business decisions will

be strongly conditioned by the contingency and worldwide events. Depending on the risk profile of each company or entity involved, it could be decided to update or search for new objective functions and KPIs in the business evaluation.

The widespread practice in western culture over the last decades has been to value new projects using the NPV as a measure of their value, a tendency repeated in mine planning software on the market. Understanding the highly volatile scenario that awaits us in the short and medium term, it is attractive to be able to rather maximize cash flows in this temporary lapse, and then for the long-term return go back to the criteria of maximizing NPV. The idea is to have the option of evaluating a trade-off between earning higher cash flows in the short and medium term, in order to face these difficult years at the expense of some long-term value of the project.

Figure 5. Importance of Cash Flow

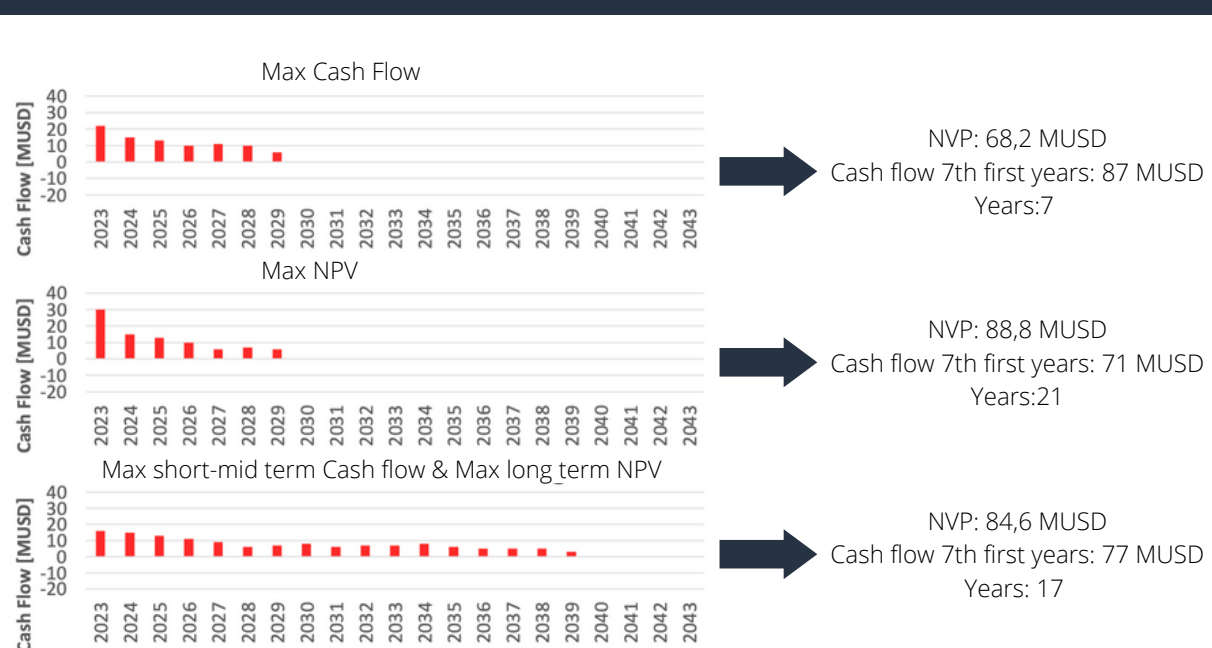


Figure 5 represents a theoretical scheme of three different behaviour of cash flow. If only cash flow is maximized, value is lost with a lower NPV in comparison with the scenario where the focus is on maximizing value in the long term, with its respective loss of resources and life of the mine. Otherwise, the case that maximizes the NPV has a great disadvantage in the current world context, because although it generates the greatest value in the long term, its cash flow in the short term is negative, which is not ideal for the reasons described above.

From here arises the idea of rescuing the best of both worlds through a hybrid objective function that in the short and medium term seeks to maximize cash flows and return to maximizing the NPV in the long term. On one hand this scenario allows a slight reduction of the LOM, compared to the case of only maximizing NPV, and on the other hand it doesn't reduce as much value as the case that only maximizes cash flow on the short and medium term.

DeepMine is unique by being able to adapt to scenarios like the expected for the coming years and being able to define a hybrid objective function where in the first years cash flow is prioritized and in the long term the value of the project is maximized. So, a case like the one described in the last example in Figure 5 can be configured in DeepMine.

This allows mine planning executed with DeepMine to be more flexible and agile. More specifically and returning to the last case shown in Figure 5, positive cash flows are generated in the short term

that can satisfy and provide security to the investors and consequently attract the necessary resources and capital to execute the project. That may otherwise not be obtained if the case in Figure 5 that maximize NPV would have been selected because of the respective negative cash flows.

The option to change priorities delivers value and this characterizes DeepMine precisely, always seeking the maximum revenue for projects, ensuring optimal execution during the mine planning process, and at the same time adapting to the needs of the project owner.

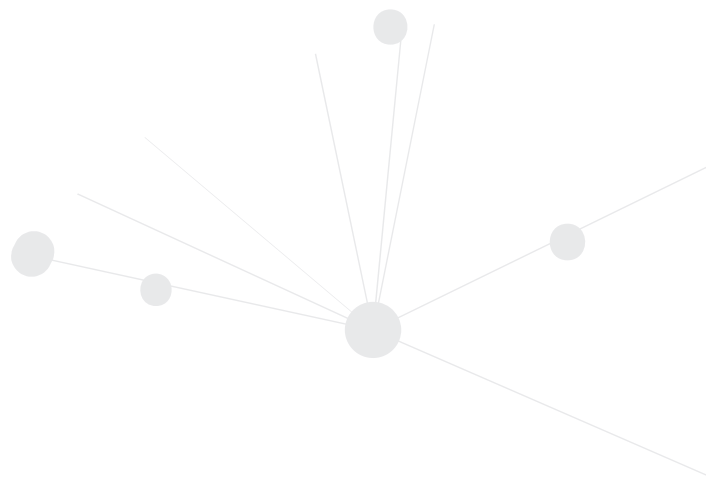


Figure 6. How DeepMine Incorporated the Logic

DeepMine has three objective functions: maximize NPV, maximize cash flow and maximize plant usage

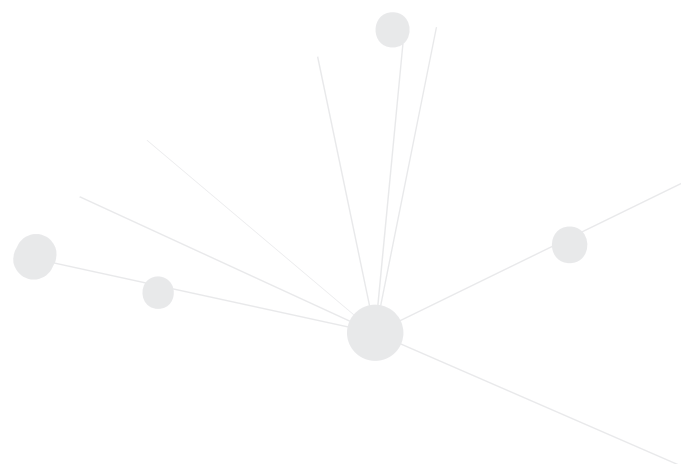


As seen in Figure 6, there are three objective functions in DeepMine that can be established when running a mine plan. It can be (1) the traditional method of maximizing NPV, (2) maximizing the cash flow for a certain period of years and then return to maximizing NPV and finally (3) maximizing the use of some specific plant(s).

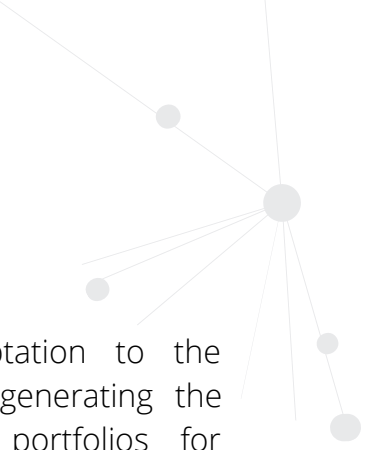
DeepMine marks a milestone in how the mining problem is faced, because the experience has shown us that the case with the best NPV is not always the one that is executed, it is rather the one that best adapts to its environment. And that is precisely the approach that DeepMine provides.

The versatility provided by the software allows it to adapt to the project's risk profile in the short and medium term horizon. Understanding that not all projects or all companies have the same business philosophies. The key is that the advanced tool has the ability to adapt to the owner of the project and in line with its purposes, to get the most out of the deposit.

At GEM we believe that it is important to question the traditional paradigms and understand them, with their pros and cons, to take them as a basis and build from them the future of mining. Ensuring in this way a greater return on investment and efficiency in each of the projects we execute.



DeepMine is a Game Changer



In this document, three examples have been presented that describe how DeepMine is reformulating the great concepts of mine planning to take them to the next level, using the latest in mining knowledge with a strong connection with the academy and the considerable improvement of the computational capacity experienced in recent years.

Regarding Automatic Phases Generation & Value Maximization, this incorporation allows to solve and face the spatial and temporal problems of mining simultaneously, in contrast to the alternative that solves these problems separately. DeepMine improve the phase design process by reducing reliance on a mine planner expertise. Multiple scenarios can be evaluated quickly without having to go through the traditional stages on every variant, another advantage is that the traditional gap problem is avoided by reducing reliance on nested pits as a planning guide.

On the Holistic Risk Analysis and Management, DeepMine has generated two important concepts such as the Risk Factor and stochastic mine planning. The first concept highlights for generating economic envelopes that are grouped from those with the highest confidence to those with the least confidence, thus improving the continuity of the nested pits and helping to reduce the impact of the GAP problem. In addition, this new methodology for determining economic

envelopes, allows adaptation to the company's risk profile, generating the possibility of creating portfolios for multiple mines. The second concept provides a distribution of possible NPV values that the pit can reach when the contemplated risks materialize. Managing these insights allows decisions to be made with greater support and confidence based on a holistic analysis of the main risks.

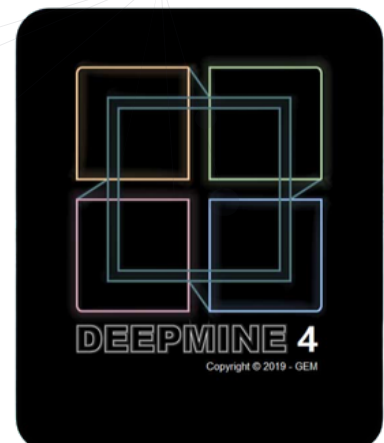
For the concept of Prioritizing Cash Flow in the Short Term and then Maximizing NPV, being able to change priorities of the objective function in the evaluation of the project is a characteristic of DeepMine, always looking for the maximum value, agility and flexibility, by ensuring the mine planning optimal execution. The versatility provided by the software allows it to adapt to the project's risk profile in the short / medium / long term horizon. Understanding that not all projects or all companies have the same business philosophies. The key is that the tool has the ability to adapt to the owner of the project and in line with their purpose, to get the most out of the deposit.

It is important to note that the previous examples are just a sample of the improvements that DeepMine incorporates. Another feature to highlight is its powerful 3D visualization engine that allows an overview of the block model and main plans that give a better understanding of the deposit to be studied. Another feature of DeepMine

is its great ability to recreate real scenarios through its multiple restrictions and filter options. The software also stands out for its versatility when configuring its environments that allow different scenarios to be created from combinations of them, being able to explore different alternatives quickly and efficiently such as price scenarios, capacities, and technologies, among other functions. The software is constantly evolving and incorporating the cutting edge of knowledge in mine planning and deep algorithms. To learn more about other features of DeepMine you can visit [our website](#).

DeepMine is a tool that covers the mining problem transversally to the planning process and for this reason it is essential to make strategic decisions in areas such as geology, planning, plant, and investments.

GEM Mining Consulting provides solutions for the industry, such as DeepMine. GEM Mining Consulting also stands out as the major and most innovative consultancy in mining, working with the largest mining companies in the world. With extensive knowledge in risk analysis, analytics, project evaluation, technical studies, ESG, machine learning and other consulting assignments that enable maximizing value in mining. GEM Mining Consulting is Paving the Way for the Future of Mining.



CONTACT

JEAN MASSENEZ

Chief Business Development Officer

jmassenez@gem-mc.com



www.gem-mining-consulting.com



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