HOW AN OBJECT-ORIENTATED MODELLING APPROACH FOR A MINE OPTION STUDY CAN INCREASE THE QUALITY OF DECISION: A CASE STUDY

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Abstract

A large new underground platinum mining project required that all different mining options were investigated during an option study before proceeding to the prefeasibility stage of the project. The capital project team identified 21 different options requiring investigation. These options considered 10 different access methods and 4 different mining methods. Each of the 21 options required a mine design, a valid production schedule, and the associated economics in order to facilitate a comparison on project Net Present Value (NPV) and other metrics. The project sponsors required this work to be completed in 3 months and therefore the project team decided to adopt an object-oriented modelling approach as implemented by Cyest Corporation. This would allow all 21 options to be valuated within the tight time frame due to the generation and re-use of templates.

Standard objects were configured into templates containing the mine layout, design, and scheduling logic. These templates could then be assembled into a model to represent the option being investigated. The adoption of rules-based design and production scheduling then allowed for the rapid generation of a valid production schedule for each option with different iterations of varying production ramp-up and mining efficiency assumptions. The activity-based operating costs, labour, and capital were also linked to the standard templates such as a half level or barrel, which were then replicated to represent the overall mine structure for each option under consideration.

Using this approach for each option, a full production schedule was produced per mining activity, the operating costs were calculated using activity-based costing, an infrastructure capital expenditure estimate was determined, the development capital requirements costed, and an overall NPV determined. This options study was completed in an unprecedented 10 weeks and a recommendation was put through to the Business to take three of the options to the next study phase.

Introduction

Business decisions regarding the appropriate underground access method, mine layout, and configurations for capital study options are generally a challenge for project teams. The chosen access method, layout, and mining method determine the production schedule and resulting capital requirements and economics. The structural model and geology determine the feasible mining method and layout Therefore to have a true understanding of the dynamics associated with the layout, development rates required, and achievable mining rates and resulting economics, each option should have a mine design, production schedule, and associated economics.

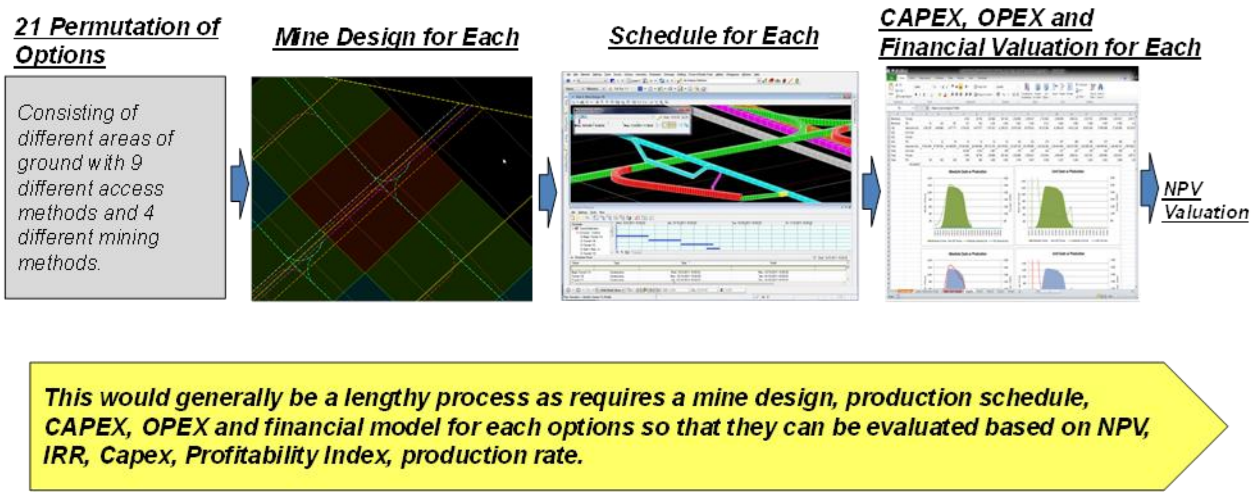

Figure 1-Evaluation steps required for each mining option under consideration

This is particularly challenging due to the time it takes to conduct a mine design and production schedule at the appropriate level of detail in the current graphical mine planning solutions (Figure 1). The result is often a high-level spreadsheet-based evaluation that does not pay attention to some of the critical aspects of the design and impact on the production schedule. Therefore chosen options do not pass detailed review, and in most instances some options are not considered based on subjective opinion or other bias.

This is indeed the case with the particular project in this case study, where a study at the feasibility phase was not approved, as it was not demonstrated to all partners involved that all reasonable options were considered. Furthermore, the considered options that were disregarded by the project team over the course of the study were disregarded in some instances without a full evaluation on a comparable basis.

To sufficiently quantify options, it is necessary to employ an economic model. Lane *et al.*[1] referred to an economic model as a mathematical representation of the real world. In the mining context it is a model of the complete business, operation, or shaft and integrates all production, labour, and financial metrics into a holistic representation. The reality of the situation is that it is not possible to exhaustively model the study options with the traditional procedural and resource study mindset.

An activity-based, object-orientated modelling approach allows for a rapid generation and analysis of study options, to an acceptable level of detail sufficient for technical review. This approach allows a mine to be viewed and modelled as an assembly of template components and mining activities that interrelate and interact.

What is object-orientated modelling?

Object orientation is moving away from the traditional software paradigm to that of modelling complex systems, as stated by Loos and Allweyer[2]. Loos and Allweyer state further that the application of the concept of object-orientated modelling (OOM) extends to business in the form of business process modelling, simulation and activity-based costing (ABC) modelling.

Object orientation, as per Fichman and Kemerer[3], is an abstraction approach to represent real-world objects that have the same characteristics, attributes, and behaviours. Essentially, object orientation allows the construction of mathematical building blocks that are able to be re-used, copied, and interacted with in a logical rules-based environment. The quintessential part of OOM is that the problem is not considered as a set of equations that can be solved, but rather as a set of related, interacting objects. These objects with their associated characteristics can be well understood, articulated, and defined not only according to their affect within the environment they operate in, but also the impact that the object has on other objects and the environment in totality.

This approach allowed for the configuration of templates that represent the main building blocks for the options and then assembly of a model that represents each option for evaluation.

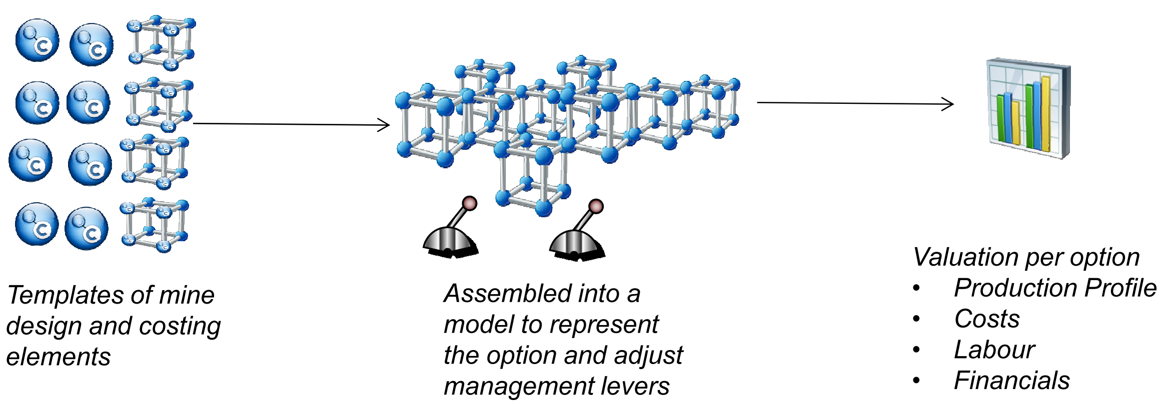

Figure 2-Object-oriented modelling approach allows rapid assembly of representative models

Case study: object-oriented modelling approach for an option study

The project in this case study is for a new underground platinum mine. This case study shows how through the use of object-oriented modelling principles an option study can be performed to a higher level of accuracy in a shorter space of time, allowing for a more rigorous decision by investigating all viable options.

The business challenge

Wooldridge[4] stated that capital budgeting follows the process through which a business determines the long-term financial viability of a capital investment through various financial instruments. Corporate capital budgeting and cost of capital estimation are among the most important decisions made, as stated by Ryan and Ryan[5], particularly in relation to the impact they may have on the business. From this it can be assumed that the decision made from the outcome of a capital mining project's financial evaluation lies essentially in what is shown by the options NPV trade-offs, as stated by Ryan and Ryan[5], Bhappu and Guzman[6], and Gilbert[7].

The business environment in which the project in this case study was to be performed presented its own challenges. The fact that the project was an equal partnership between two large competing mining companies ensured that the review and approval was more rigorous than if the project was owned by a single entity. The differences in the organisations' cost reporting structures, global assumptions, risk appetite, and strategic outlook contributed to the challenge. The corporate governance of both companies, different as they are, needed to be satisfied for a successful hurdling of the project. The very tight deadline for the study was not arbitrary, but enforced, as production from this mine is necessary to augment the declining output from other mining areas. The project team had developed the study to feasibility level over a number of years, only for it to be rejected at the final review stage.

The lessons learnt from this process prompted a high-level decision to workshop all the possible options to be considered, so that a due diligence could be demonstrated in the selection of the mine access and mining methods.

The technical review team believed there could be a more viable mining option and therefore wanted a detailed evaluation of all viable options. Therefore 21 different options were identified that required evaluation. These options considered 10 distinct access methods and 4 different mining methods. For each of the 21 options, the following was required; a mine design, a valid production schedule and the associated economics in order to facilitate a comparison of project NPV, capital required, mining rate, unit costs, and technical risk. The project sponsors required this work to be completed in three months, an unprecedented tight time frame considering the level of detail required.

Although the study was classified as a concept study, the economic evaluation needed to be at a high level of confidence, as the options potentially had relatively small differences between them from a design and scheduling point of view. A further implication was that a more intense technical review was going to be conducted by both partners to understand the merits and trade-offs of the different options.

The approach taken

The project team made the decision to utilize the object-oriented modelling solutions developed by Cyest to undertake this option study, as this was seen as the only means to deliver the project to the level of detail and in the time frame of 10 weeks required.

The object-oriented Carbon14 Mine Scheduler solution would be utilized for the rules-based mine design and production scheduling, and the Carbon Economics solution for the rules-based economic modelling.

Each option required a mine design, production schedule, capital estimate, and all economics to calculate a NPV and other output metrics. A technical risk assessment was also done by the project team on each option so that a risk 'measure' could be included in the evaluation criteria for the options (Figure 3).

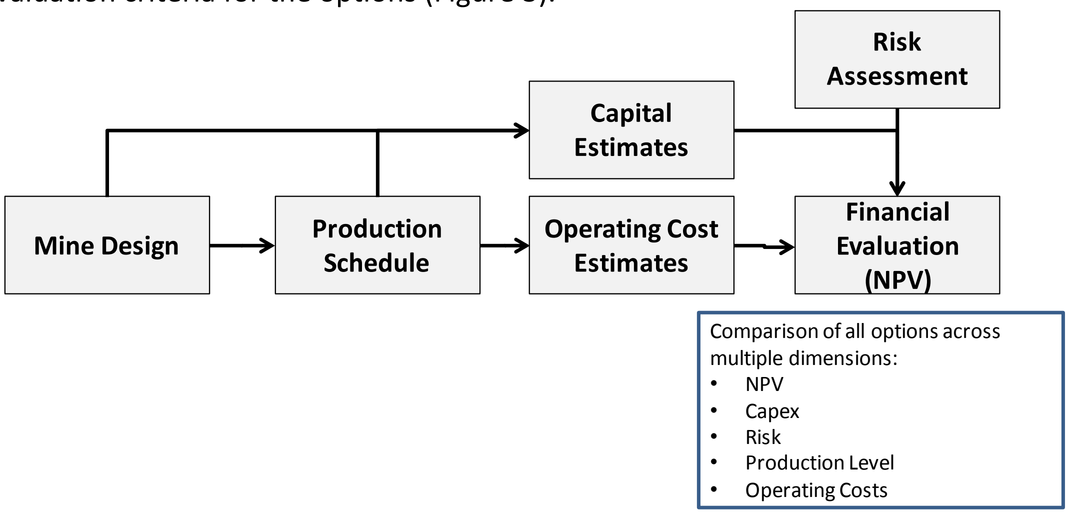

Figure 3-The process taken to evaluate each option

Owing to the fact that both companies have fundamentally different cost reporting structures, and therefore different methods of cost benchmarking and evaluation, a modelling approach had to be adopted that accommodated both review teams. This included the physical mine structure, the infrastructure of the mining activities, and the relationship between them. By modelling these aspects at a low resolution, the cost allocation differences could be understood, and the common mining conversation could be engaged. The proviso to this, though, was that the modelling granularity needed to be a level lower than that normally expected for a concept level of study. The level of detail was in fact closer to that of a feasibility study. The accuracy associated with higher study levels was also required, as the differences in the options were especially sensitive to capital outlay and operating cost.

The options identified for study

Through a series of workshops the project team identified 21 different options that required investigation. These consisted of permutations of 10 distinct access methods and 4 different mining methods. The team required each of the options to have a mine design, production schedule, capital estimate, and full economics so that a comparison could be done and a recommendation put forward to the partners on which options to take forward to the next study phase.

Table I-Permutation of 21 options with 10 different access methods

	Access Methods									
Option	*Footwall Decline With Dog Leg*	*Straight Footwall Decline*	*Single Secondary Footwall decline*	*Two Secondary Footwall declines*	*Vertical Shaft*	*On-reef decline*	*Extend from existing decline*	*Approach from current mining area*	*Addits from re-habilitated Open cast mine*	*Open Cast Section*
1	x									
2	x									x
3						x				
4		x								
5		x				x			x	
6						x				
7		x				x				
8								x		
9							x			
10				x			x			
11			x				x			
12					x					
13			x					x		
14			x				x			
15			x							
16			x				x			
17			x				x			
18					x			x		
19					x					
20					x			x		
21					x					

Table II-Mining method chosen for each option

	Mining Methods			
Option	*Conventional Breast*	*Opencast*	*Board & Pillar*	*Conventional stope, conveyor HL tramming*
1	x			
2		x		
3				x
4	x			
5	x			
6			x	
7	x		x	
8	x			
9	x			
10	x			
11	x			
12	x			
13	x			
14	x			
15	x			
16	x			
17	x			
18	x			
19	x			
20	x			
21	x			

Rules based mine design and scheduling

An object-oriented modelling approach allowed for a detailed mine design and production schedule to be produced for each of the 21 options. The Carbon14 Mine Scheduler is an object-oriented solution and allows for a rules-based mine design and production schedule to be produced in a short time.

A wireframe graphical mine layout was done for each of the possible mining methods as well as the 10 access methods. From this the standard common 'templates' were identified that could be used across the options, and were then configured in Carbon14 Mine Scheduler as the building blocks of the options under investigation. The templates would consist of the excavations parameters (width, height, and position in stratigraphy) and scheduling logic that would be applied. For example, templates of a decline station layout, secondary decline and raise bore, and breast mining layout would consist of all the excavations and the scheduling logic relevant (Figures 4, 5, and 6). The geological parameters consisting of each geozone; the stratigraphy and grades were also obtained from the resource model and a template made for each area of ground to be mined.

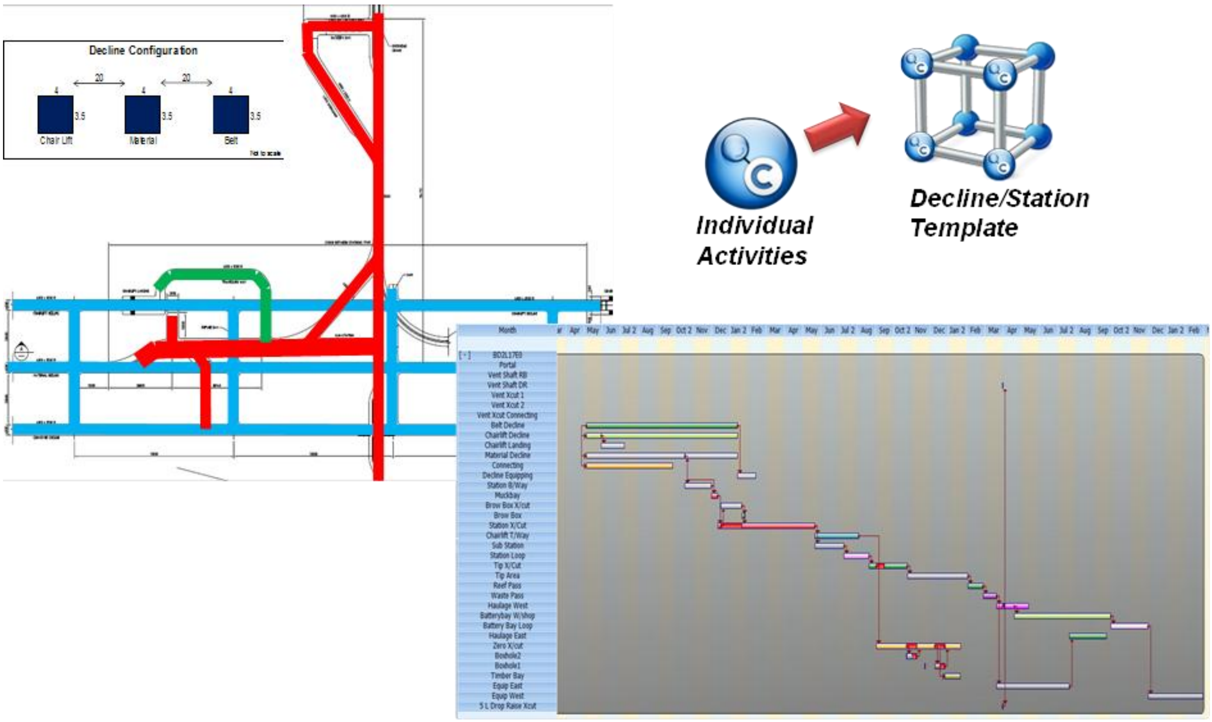

Figure 4-Decline station layout template

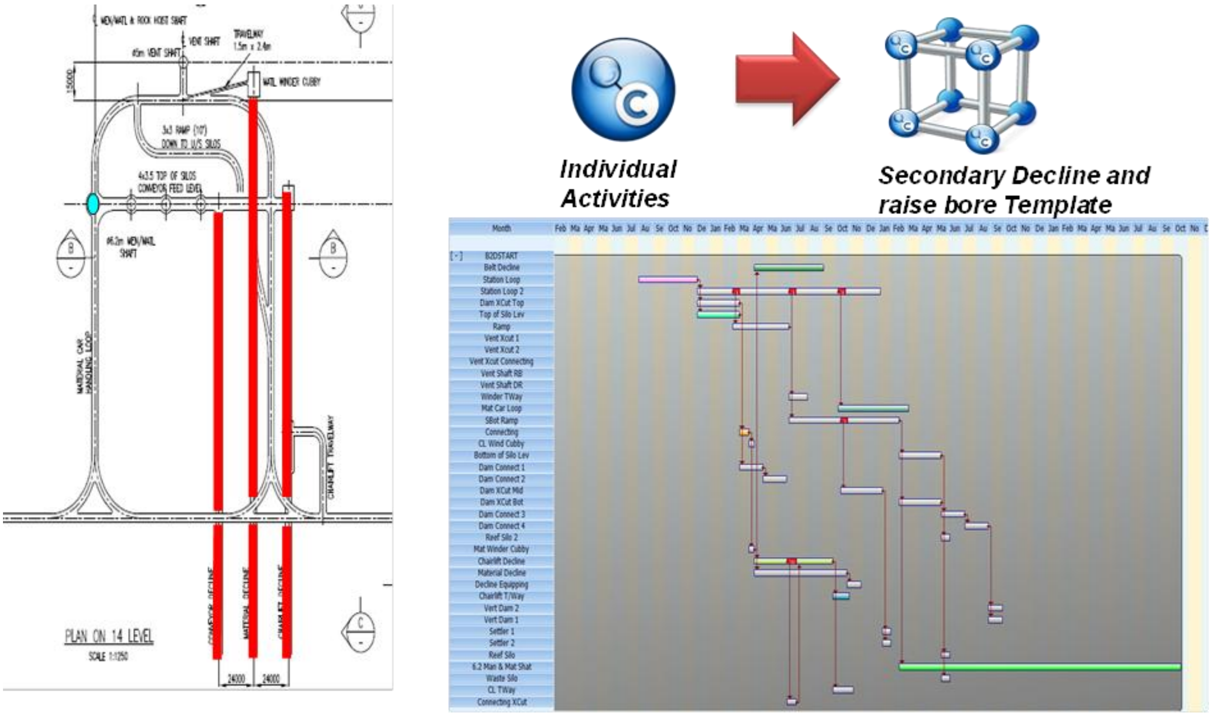

Figure 5-Secondary decline and raise bore template

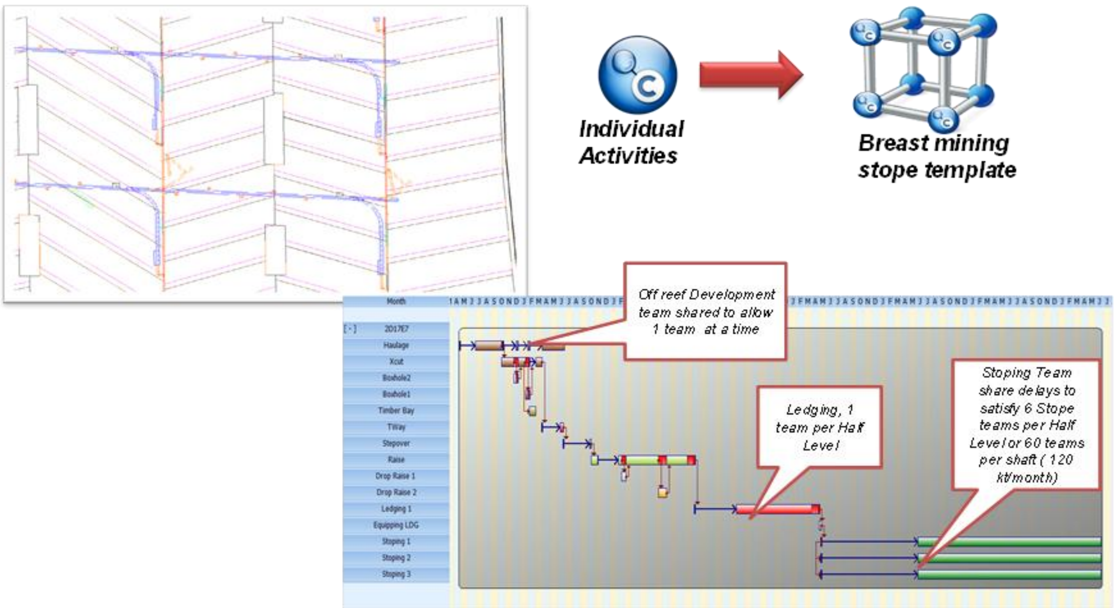

Figure 6-Scattered mining template

These individual templates could then be assembled into a model, all the actual excavation lengths updated based on the overall layout for that option, the scheduling assumptions around efficiencies added, and a final production schedule produced (Figures 7 and 8).

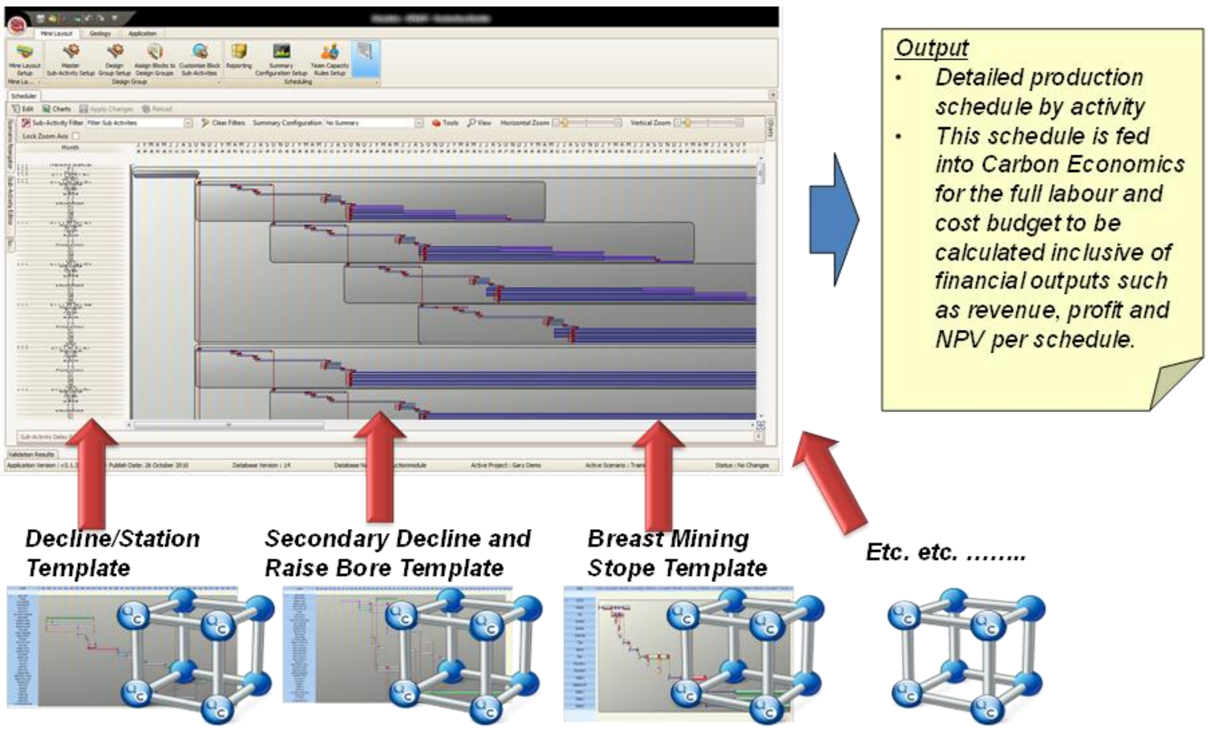

Figure 7-Templates assembled to represent each option

For each of the options under investigation, a full detailed production schedule was produced at a half level and for each activity (haulage, breakaway, cross-cut, travelling way, stopover, timber bay, stoping panel etc.). In addition, resource levelling was done on the schedule to take into account the configuration of the resources on each half level and therefore constrain the schedule to the available teams. For example, the activities would be constrained by the number of stoping teams, ledging teams, and development teams per half level.

The outputs from the model for each option included:

- Production schedule for each activity per half level
- The output in ounces for each activity per half level over time
- The grade per half level over time.

An example output is shown in Figure 8. This schedule and associated information could then be used in the economic model to calculate all costs, labour, and financial outputs for each option.

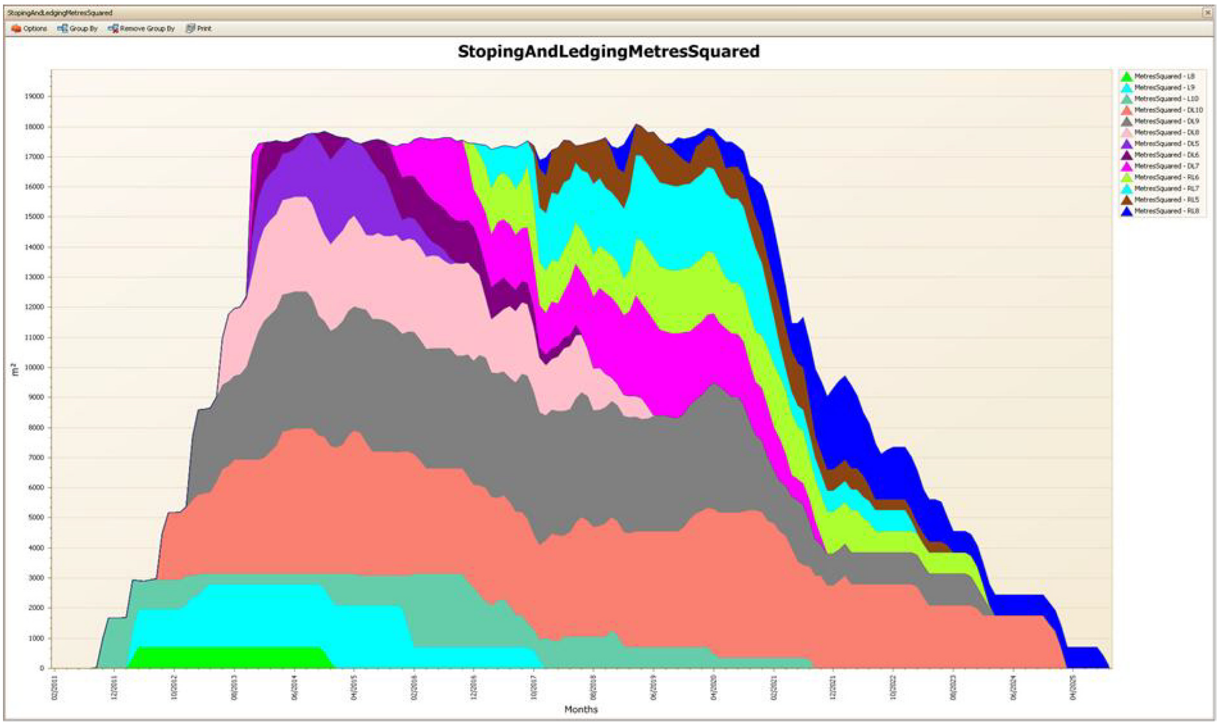

Figure 8-Example output showing production (m^2 per half level)

Object-oriented economic modelling

According to Turney[8] and Cooper and Kaplan[9], activity-based costing (ABC) has emerged from the accounting discipline to calculate, articulate, and detail the costs and higher degree of profits that emerge from the analysis and employment of ABC models. ABC is a technique in which costs from all activities and sub-activities that constitute a process or business operation, instead of the organizational elements or departments, are employed in articulating cost and profits as per Briciu and Capusneanu[10].

With reference to Popesko[11], Briciu and Capusneanu[10], and Amir *et al.*[12], when applying ABC the following stages can be drawn; (i) identification of all the activities, (ii) identification of the activity cost drivers, (iii) identification of the costs associated to the activity, (iv) defining the rules-based behaviour of the cost with the specified activity, and (v) applying the cost to the activity.

As an illustration, (i) an activity in an underground mining environment is stoping, (ii) the cost driver for the stoping activity is stoping area in square metres, (iii) the costs associated with that is *x* Rand per stoping square metre, (iv) the rules defined are that the cost is 100 per cent variable on the work conducted, and (v) applying the cost as defined in Equation 1.

$$\frac{\text{Cost Rate}}{\text{t}} = \frac{\left(\frac{\text{HistoricalCost}*\text{VariablePercent}}{\text{HistoricalProduction}}*\text{CostDriver}\right)+(\text{HistoricalCost}*\text{FixedPercent})}{\text{ReefTonne}} \qquad [1]$$

The Carbon Economics solution was utilized for the rules-based economic modelling using ABC principles to calculate all the activity costs and labour required for each option, as well as the financial outputs such as revenue, profit, cash flow, NPV, and Internal Rate of Return (IRR). This solution has the same object-oriented modelling approach, and therefore this could be leveraged to build the common templates for all the options and rapidly assemble a model to represent each option for the valuation.

For example, the standard objects that make up an ABC methodology and are inherent in the Carbon Economics solution are:

- Cost element – a cost line item such as explosives or drill steel
- Resource – a resource is consumed by an activity in production of work –examples of resources include stores or labour
- Activity – an activity is a unit of work such as stoping.
- Entity – this is the physical location of the where the activity is being performed, such as half level or shaft.

These standard objects are assembled into the templates that make up each option. For example, the activities and underlying business logic and rules that makes up a conventional breast mining half level, or decline shaft or vertical shaft.

The templates can then be assembled to represent the mining option to be evaluated (Figure 9). The production schedule is imported into the model and all the costs and labour numbers calculated at an activity level, as well as the financial outputs relevant to that option.

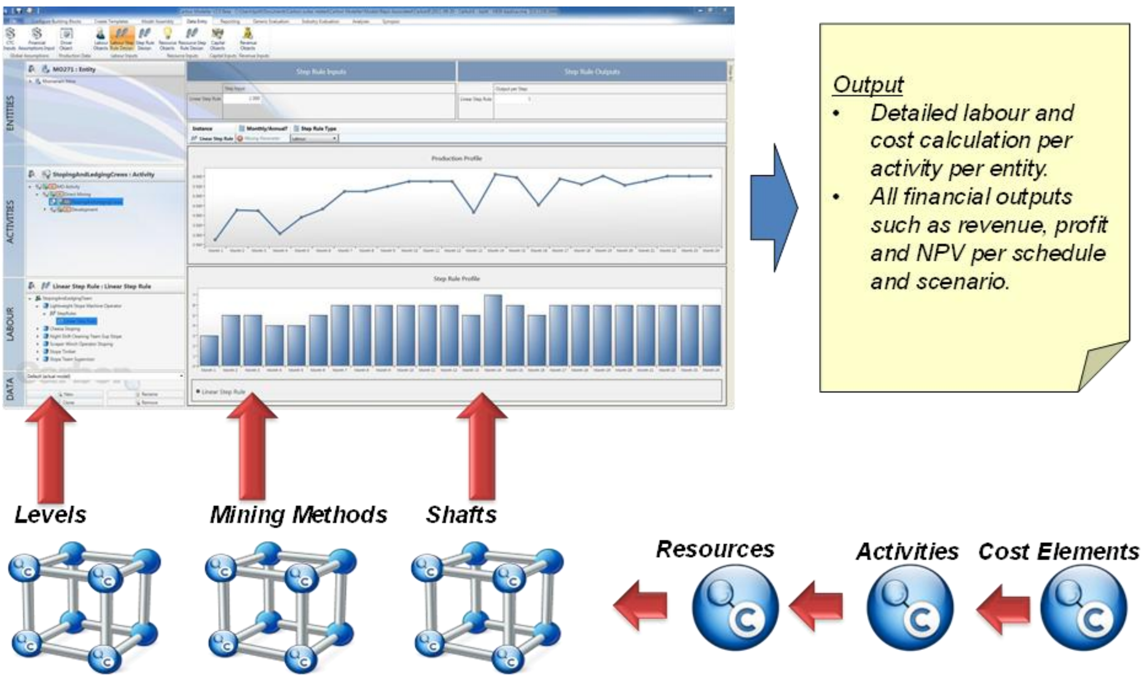

Figure 9-Assembling the standard ABC building blocks into a model to represent each option

From the activity-based object-orientated modelling approach thus far described, the ability to generate multiple economic relationship profiles has been made possible. In addition to the mining, engineering, labour, and accounting objects defined thus far, the evaluation took into account global assumptions in terms of escalation factors, consumer price index (CPI) and producer price index (PPI), metal prices, NPV discount factors, taxation factors, royalty factors, and intra-company ore sales agreements.

Application in practice

It is evident that the different options considered were unique in the combinations of mining access method, mining method' and production profile timing. These access methods and mining methods have specific activities uniquely associated to them, with these activities and their associated relationships remaining consistent across the various options with the same mining method. This ensures that the cost input rates, the associated production modelling drivers, and the modelling relationships and rules stay consistent for the same mining method. Qualifying the assessment as such was the key in being able to analyse the required options in the tight timelines required, using the object-oriented modelling approach.

All the relevant costing input information was constructed and sourced from actual mine costs and associated production outputs as a proxy for costs for similar activities in the same mining method. The date from four different mining operations data was sourced at a detailed level, representing the different mining access methods and the mining methods. These costs were adjusted where required to take into account differences – for example, if different support or blasting was used, then this was taken into account to ensure the costs are an accurate reflection.

Utilizing actual achieved activity costs for similar activities for the same mining method for similar operations was adopted instead of first-principle costing, as this was deemed a far more realistic and credible view of the actual costs that would be achieved. This was deemed the worst-case cost scenario and would pass the technical review.

As the source data was gathered from well-understood, existing operations, the relational aspects of cost and drivers could be derived, and tested and calibrated, for each resource for each activity. For example, taking the total consolidated cost for the cost element such as stoping stores and dividing it by the consolidated production information for that activity over the same period in time will result in the following cost rate per for ton for stores, according to Equation2:

$$\frac{\text{Cost Rate}}{\text{t}} = \frac{(\text{R }3\,000\,000)}{(666\,666.67\text{ t})} = \mathbf{R4.50/t} \qquad [2]$$

This cost rate will be used as input to drive the costs of stoping stores for a particular mining method in the OPEX estimation model, based on the production schedules used as input into the OPEX estimation model. For example, if the production is 300 000 tons in a specific period, the driven cost would be R1 350 000, for that period, expressed in Equation 3 and illustrated through the OOM approach in Figure 10.

$$\frac{R4.50}{t} * 300\,000\,t = R1\,350\,000 \qquad [3]$$

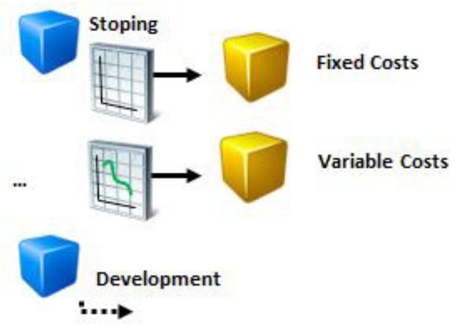

Figure 10-Stoping activity object cost element addition

Using the labour rules that have also been defined and driven by a production driver, labour complements and labour costs can be determined. An example of such a rule is the modelling of the complement and costs of a stoping team. The rule could conceivably be that one stoping team is required for an efficiency of 400 stoping metres squared per month.

The cost of a single stoping team will be associated to its labour grade allocation of each of the members required in the stoping team. Therefore the cost of a stoping team consisting of 16 people can be expressed by Equation 4 and illustrated through the OOM approach in Figure 11.

$$\frac{Stoping\ metres\ squared/month}{400\ metres\ squared/month} * \frac{cost}{team} = monthly\ team\ Cost \qquad [4]$$

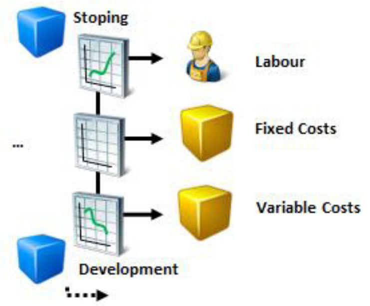

Figure 11-Stoping activity object labour addition

Armed with the applicable information as discussed above, the objects with associated activities could be defined, and options constructed, and modelled, in a manner represented by Figure 12.

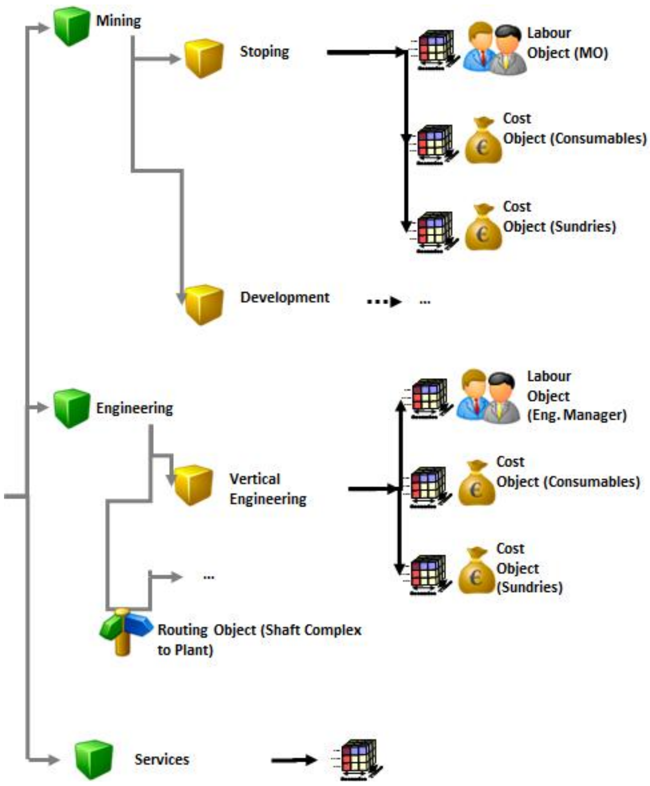

Figure 12-ABC model representation with all objects

Scenario analysis

An evaluation of the different options was conducted using the project's managing partner's valuation techniques. This required a high level of transparency, in both the figures and techniques used. The model needed to be robust enough for the non-managing partner to carry out an independent valuation to satisfy its own internal governance requirements.

Additionally, a technical risk analysis was performed on the different options by the project team, incorporating safety, mine access, and mining technique considerations. The final project decisions incorporated both risk and economic factors to provide a holistic option analysis.

The evaluation process was completed, and results summarized to be used in the larger ranking exercise. The options were compared across multiple dimensions to obtain a holistic view on the best options to put forward for the next phase of study. Options could be compared on the basis of NPV, risk, capital spend, profitability index, mining rate, and final reserve size. Below are two examples of such analysis that was done to assist the decision-makers.

For example Figure 13 compares all the options along the dimension NPV on the y-axis, risk measure on the x-axis, and bubble size representing the project capital. This allowed the decision-makers to understand the risk/reward trade-off between the different options as well as the capital required for the project.

Figure 14 compares profitability index (rand return for each rand capital investment) on the y-axis and risk measure on the x-axis, while the size of the bubble indicates the reserve size in terms of available ounces. The risk percentage is defined in a manner such that a high percentage is more favourable than a lower percentage.
This analysis allowed the decision-makers to understand the least-risk options and also those that were the most capital efficient (i.e. high profitability index).

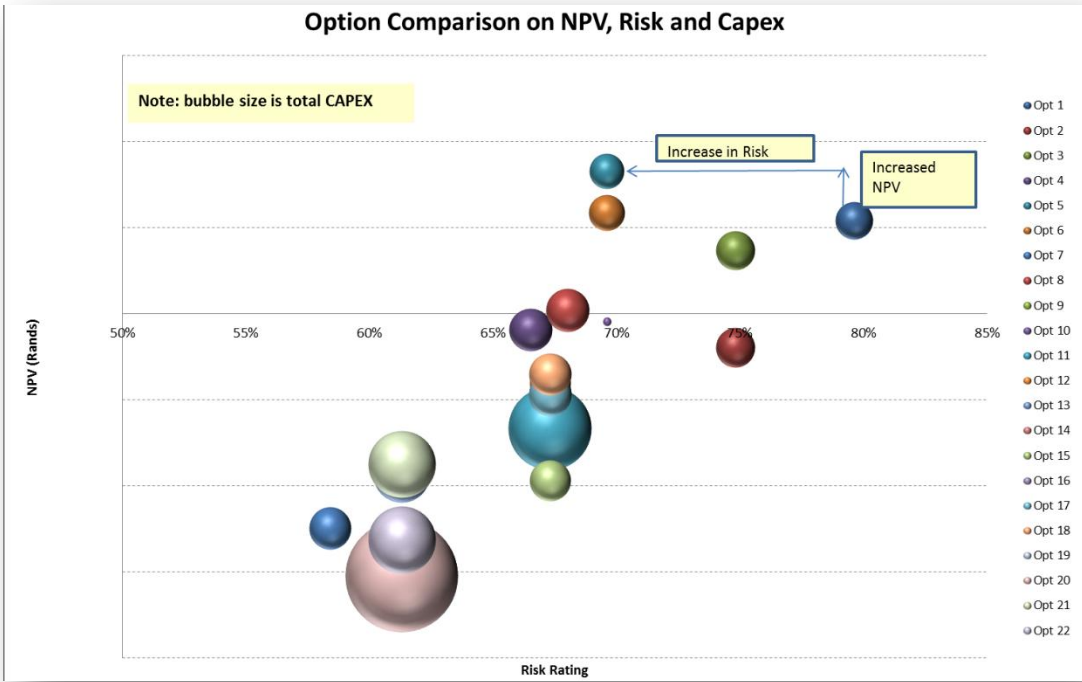

Figure 13-Inter-option comparison of NPV, risk, and capital

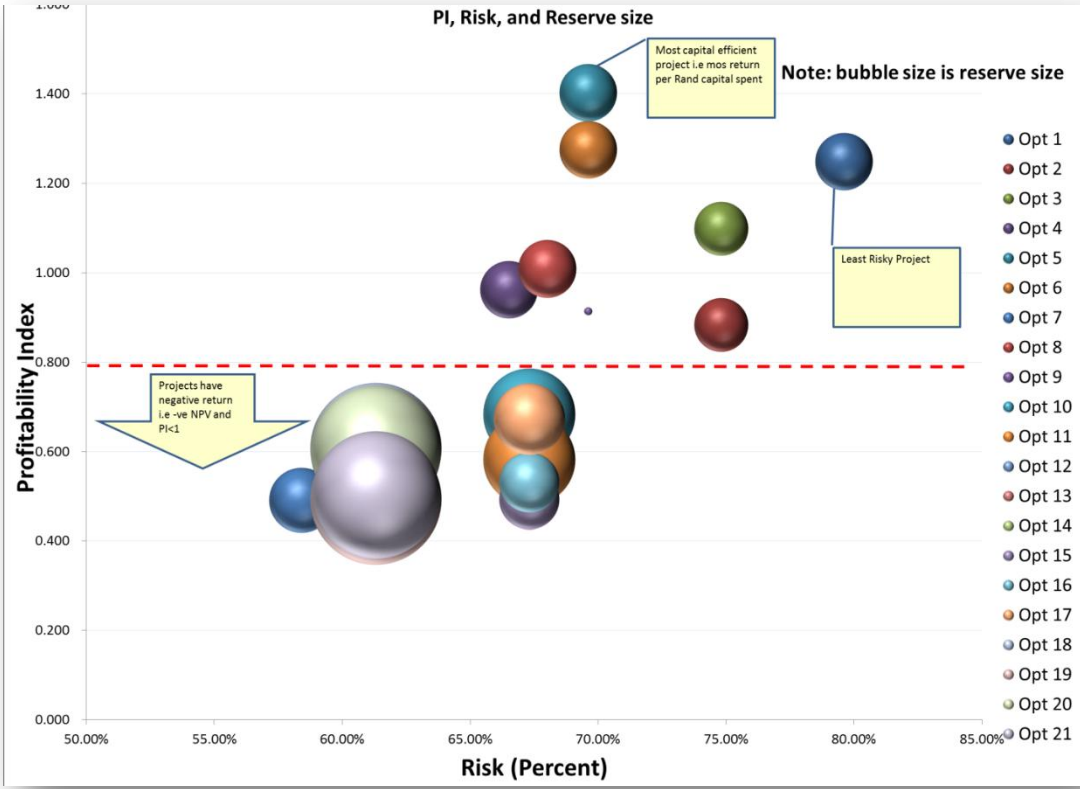

Figure 14-Inter-option analysis comparison of PI, risk, and reserve

As can be seen, the strongest project options are manifest by their relative positions on the graph. The options occurring on the top right of the graph are preferable, while options occurring in the bottom left hand side of the graph should most likely be discarded under current assumptions.

Depending on the overriding priorities, executives were sufficiently armed to make decisions regarding options with a bias to maximizing profitability or minimizing risk.

Final result

The option study went through a detailed technical review by both partners, and three options were recommended for carrying through to the next phase of study.

Conclusion

All the options and option iterations were completed within a 10-week period with the focus on production schedule and mine layout optimization. For each option a full production schedule was produced per mining activity, the operating costs were calculated using activity-based costing, an infrastructure capital expenditure estimate was determined, the development capital requirements costed, and an overall project NPV calculated.

A risk assessment was completed to ascertain the technical risk of each option to be used in the ranking criteria. The options were then compared across multiple dimensions such as NPV, risk, capital required, production level, and operating costs. The project team was able to complete the study in the required deadline of 10 weeks and recommend to the partners three options that could be considered for the next phase of study. This options study was completed in an unprecedented time-frame that was made possible by adopting an object-oriented modelling approach.

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