



Generación y Análisis de Planes Mineros Estratégicos Utilizando Algoritmos Evolutivos Genéticos

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Paper Original de Christie Myburgh y Steve Craig – Maptek
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- Los problemas reales de planificación, dada su complejidad, son difíciles de manejar en un tiempo razonable.
- Existen muchas herramientas buenas, pero son difíciles de configurar y demoran mucho tiempo en entregar resultados.
- El objetivo es generar y analizar diferentes planes mineros donde se maximice el valor presente neto a través de una política de leyes de corte y una secuencia de extracción para una mina a cielo abierto.
- Este trabajo muestra la innovadora forma en que los algoritmos evolutivos son combinados con los conceptos de búsqueda local y programación lineal para proponer una solución a lo anterior descrito, esta solución es Maptek Evolution Strategy.

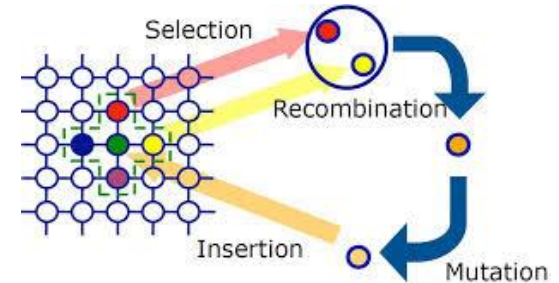
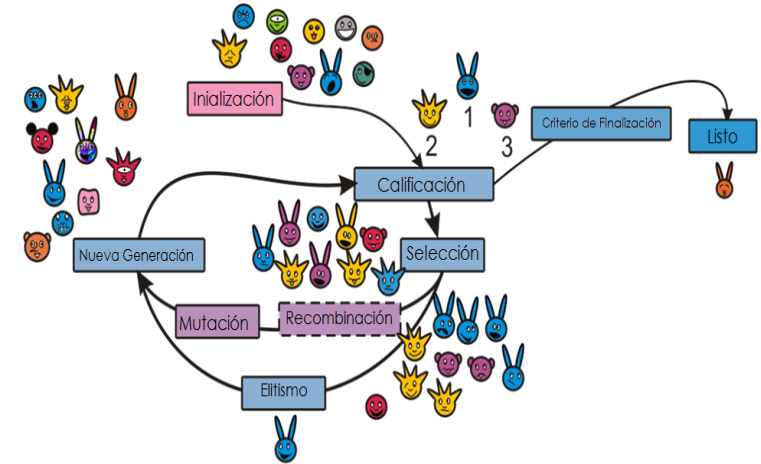
Optimización de Ley de Corte

- Kenneth Lane propuso un marco de referencia para modelar este problema.
- El algoritmo maximiza el VAN de un proyecto tomando en cuenta el valor del dinero bajo tres restricciones, Mina, Planta y Refinería.
- Objetivo: Max VAN

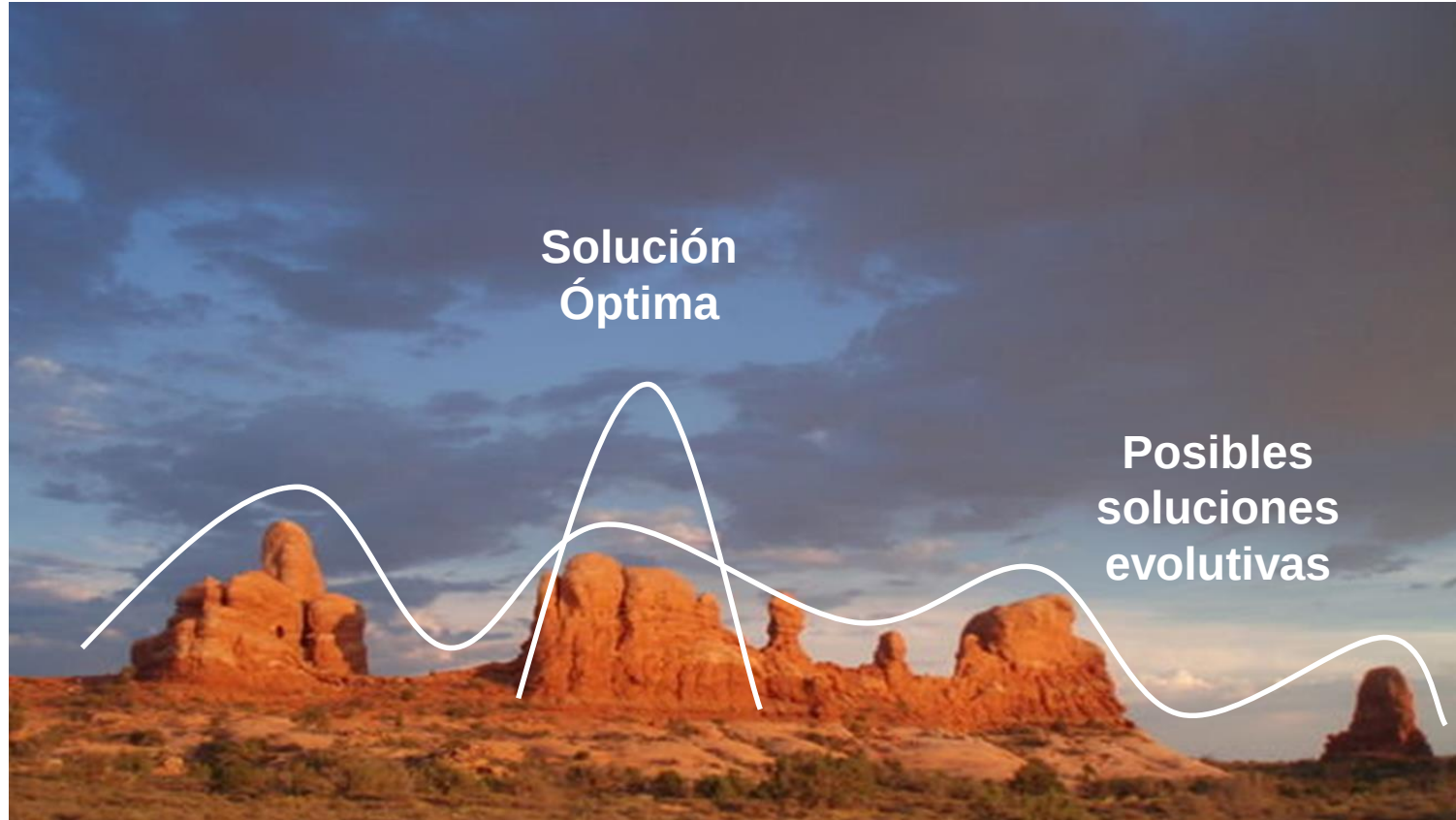


Algoritmos Evolutivos

- Los algoritmos evolutivos son métodos de optimización y búsqueda de soluciones basados en los postulados de la evolución biológica. En ellos se mantiene un conjunto de entidades que representan posibles soluciones, las cuales se mezclan, y compiten entre sí, de tal manera que las más aptas son capaces de prevalecer a lo largo del tiempo, evolucionando hacia mejores soluciones cada vez.
- Los algoritmos evolutivos, y la computación evolutiva, son una rama de la inteligencia artificial. Son utilizados principalmente en problemas con espacios de búsqueda extensos y no lineales, en donde otros métodos no son capaces de encontrar soluciones en un tiempo razonable.

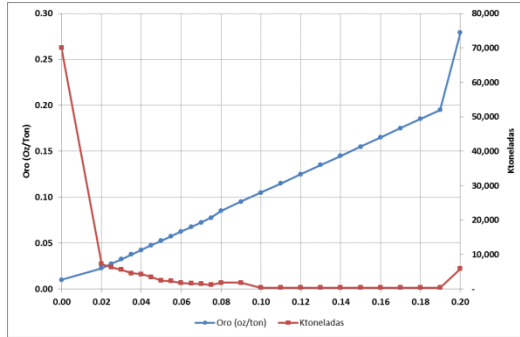


En busca del óptimo



- El objetivo de la optimización de ley de corte en Maptek Evolution - Strategy es maximizar el VAN bajo restricciones de capacidad, múltiples procesos, múltiples minas y secuencias de extracción.
- Información Base:
 - Fases de extracción
 - Capacidades (Mina, Planta, Refinería) por periodo.
 - Modelo Económico (Costos) y Precios.
 - Reservas Mineras.
 - Curva Tonelaje ley es calculada para cada mina/fase/banco/litología.

Evolution vs Lane Optipit



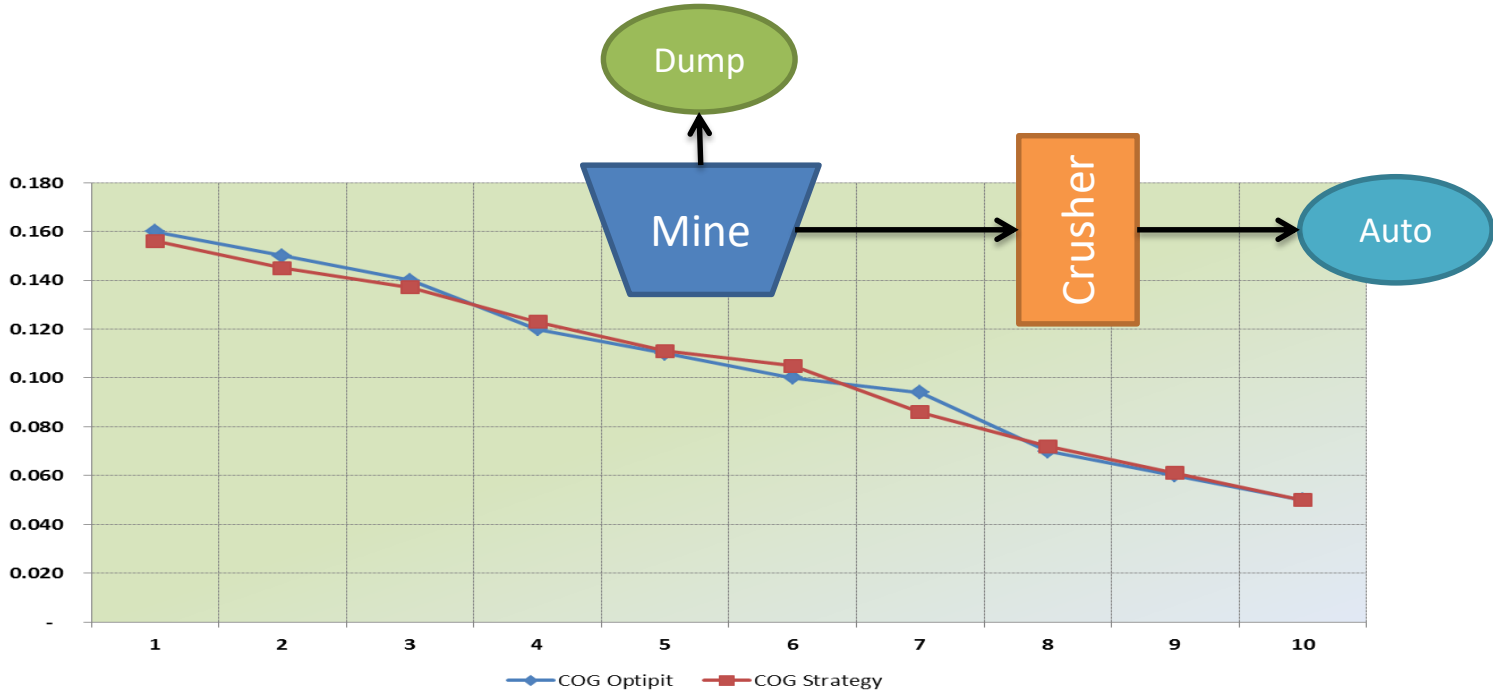
Parametros	Sigla	Valor	Unidad
Precio	(P)	600	\$/oz
Costo Venta	(s)	5	\$/oz
Costo Proceso	(c)	19	\$/ton Mineral
Recuperacion	(y)	0.9	
Costo Mina	(m)	1.2	\$/ton
Costos Fijos	(fa)	8.35	\$/año
Capacidad Mina	(M)	Unlimited	
Capacidad Proceso	(C)	1.05	tonnes
Tasa de Descuento	(d)	15	%

“Value Creation Through Strategic Mine Planning and Cutoff Grade Optimization”

SME Annual Meeting
K. Dagdelen CSM
K Kawahata CSM
Feb25-28, 2007
Denver Colorado

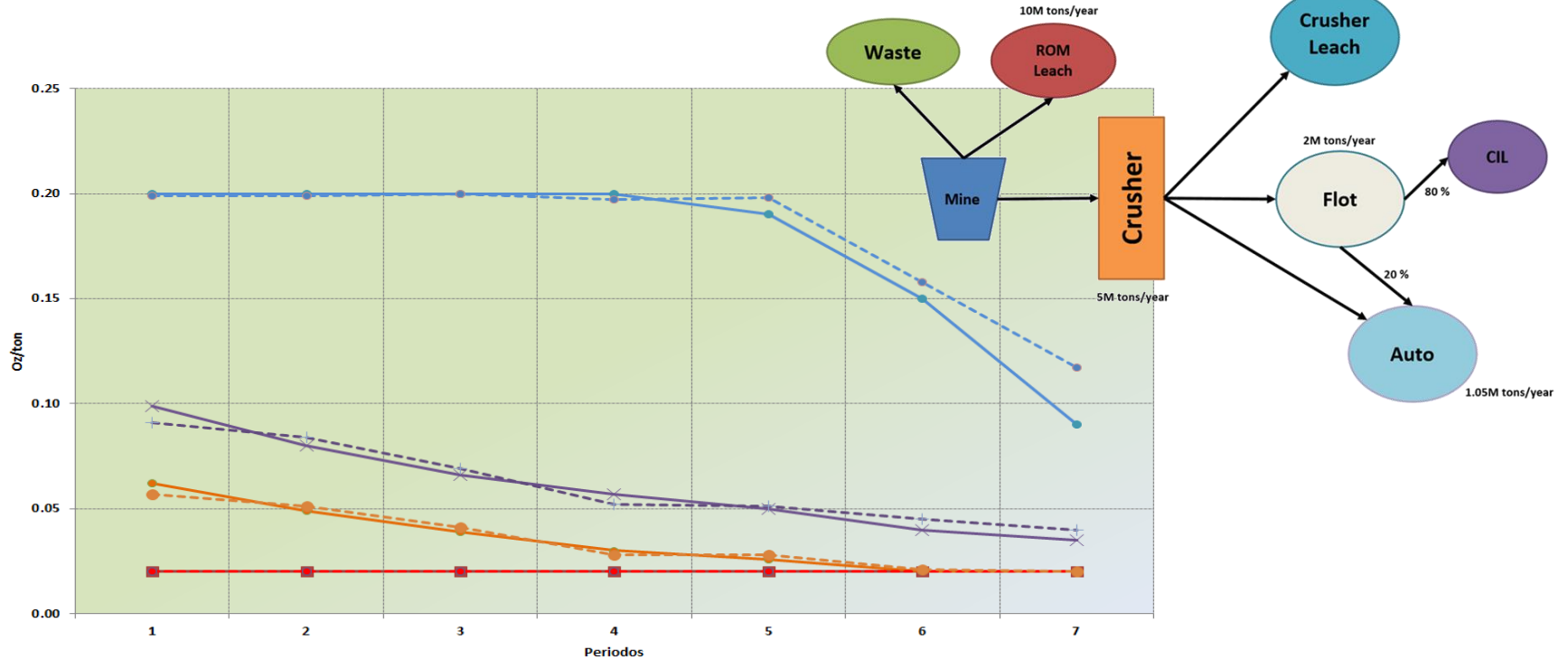
Caso 1

- Gráfico Ley de Corte (1 proceso)



Caso 2

- Gráfico Ley de Corte (múltiples procesos)



Esto es Evolution



The screenshot displays the MAPTEK Evolution software interface. The top menu bar includes options like New, Open, Save, Copy, Paste, Revert, Block Model, Schedule, Truck, Waste Utility, Strategy, Setup, Validate, Schedule, Go Online, and Download Jobs Automatically. The left sidebar shows a Project Manager tree with folders for Block Models, Transforms, Models, Utilities, Equipment, Strategy, Setups, Schedules, Origin, Analysis, and Report Formulas. The central workspace shows a 3D visualization of a block model with a color-coded surface. The right sidebar contains a Properties panel with a Model Summary, Schedule, and Block Detail sections. The bottom status bar shows the Job Manager.

Barra de iconos

Interface Gráfica

Ventana de Proyecto - Objetos

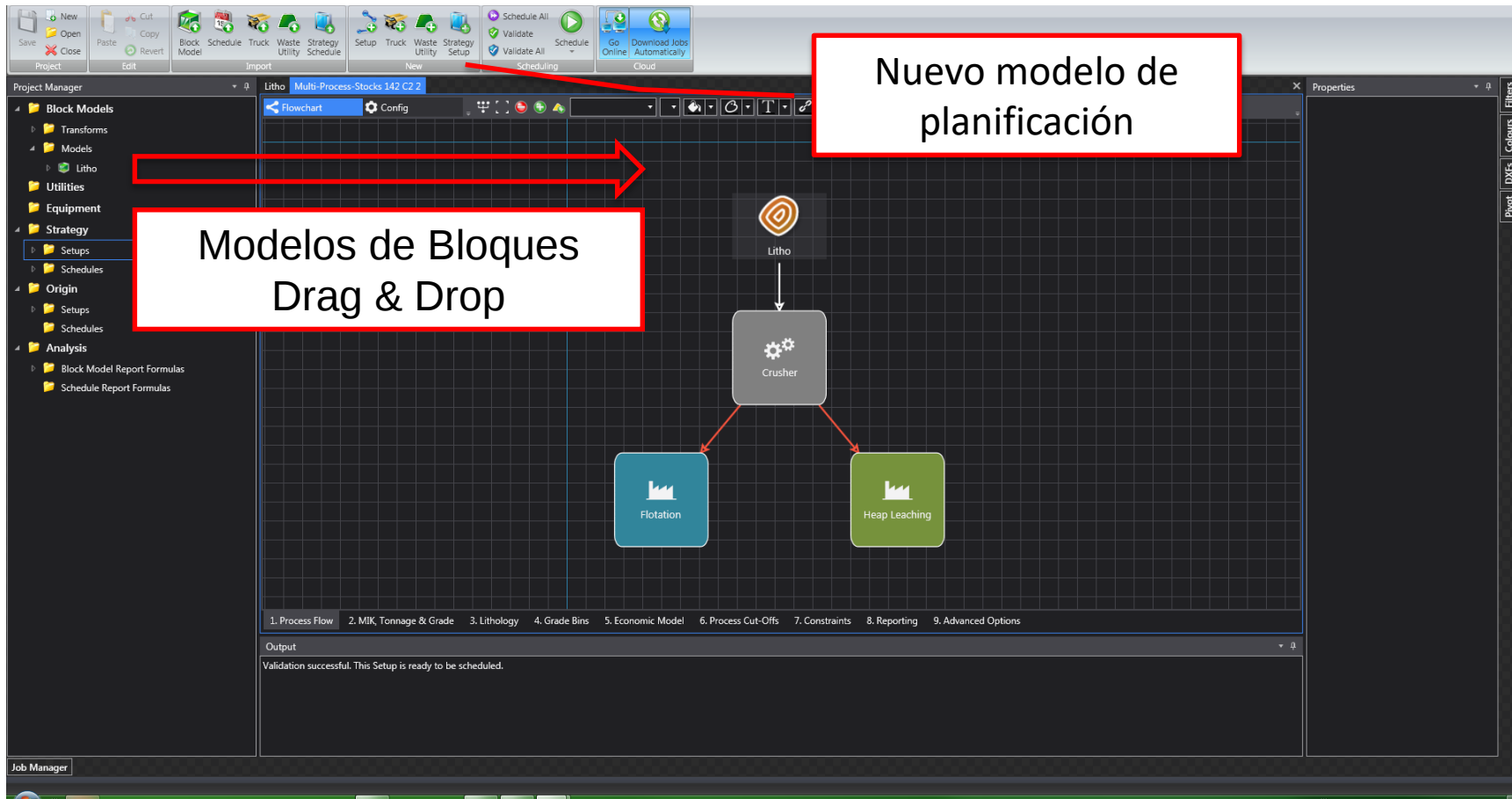
Barras de Propiedades, Colores, Tablas Pivote

Ventana de reportes

Model Summary	
Origin:	31353.5533 x 78586.44
Size:	135 x 131 x 63
Block Size:	20 x 20 x 15
Block Count:	285453
Toe Count:	0
Azimuth:	-45

Block Detail	
Position	30971.715638, 81216
stage	1.000
Toe	False
alter	6.000
an_4x	16.000
as	331.466
as_2001	549.587
aux	0.000
aux_3	2.420
aux2	1.000
auxiliar	0.000
caf_m	0.000
caf_p	0.000
categ	1.000
check	14,099.999
cus	0.002
cut	0.014
density	2.350
fases_prefs	2.000
id_x	80.000

Simple – Drag and Drop



The screenshot displays the MAPTEK software interface. On the left, the 'Project Manager' pane shows a tree view with folders like 'Block Models', 'Models', 'Litho', 'Utilities', 'Equipment', 'Strategy', 'Setups', 'Schedules', 'Origin', 'Analysis', 'Block Model Report Formulas', and 'Schedule Report Formulas'. A red arrow points from the 'Block Models' folder to the main workspace. In the center, a process flow diagram is shown on a grid background. It consists of four blocks: 'Litho' (top), 'Crusher' (middle), 'Flotation' (bottom left), and 'Heap Leaching' (bottom right). Arrows indicate the flow from 'Litho' to 'Crusher', and from 'Crusher' to both 'Flotation' and 'Heap Leaching'. A red box labeled 'Nuevo modelo de planificación' is positioned above the diagram. At the bottom, a status bar shows a sequence of steps: 1. Process Flow, 2. MIK, Tonnage & Grade, 3. Lithology, 4. Grade Bins, 5. Economic Model, 6. Process Cut-Offs, 7. Constraints, 8. Reporting, 9. Advanced Options. Below this, an 'Output' pane displays the message: 'Validation successful. This Setup is ready to be scheduled.'

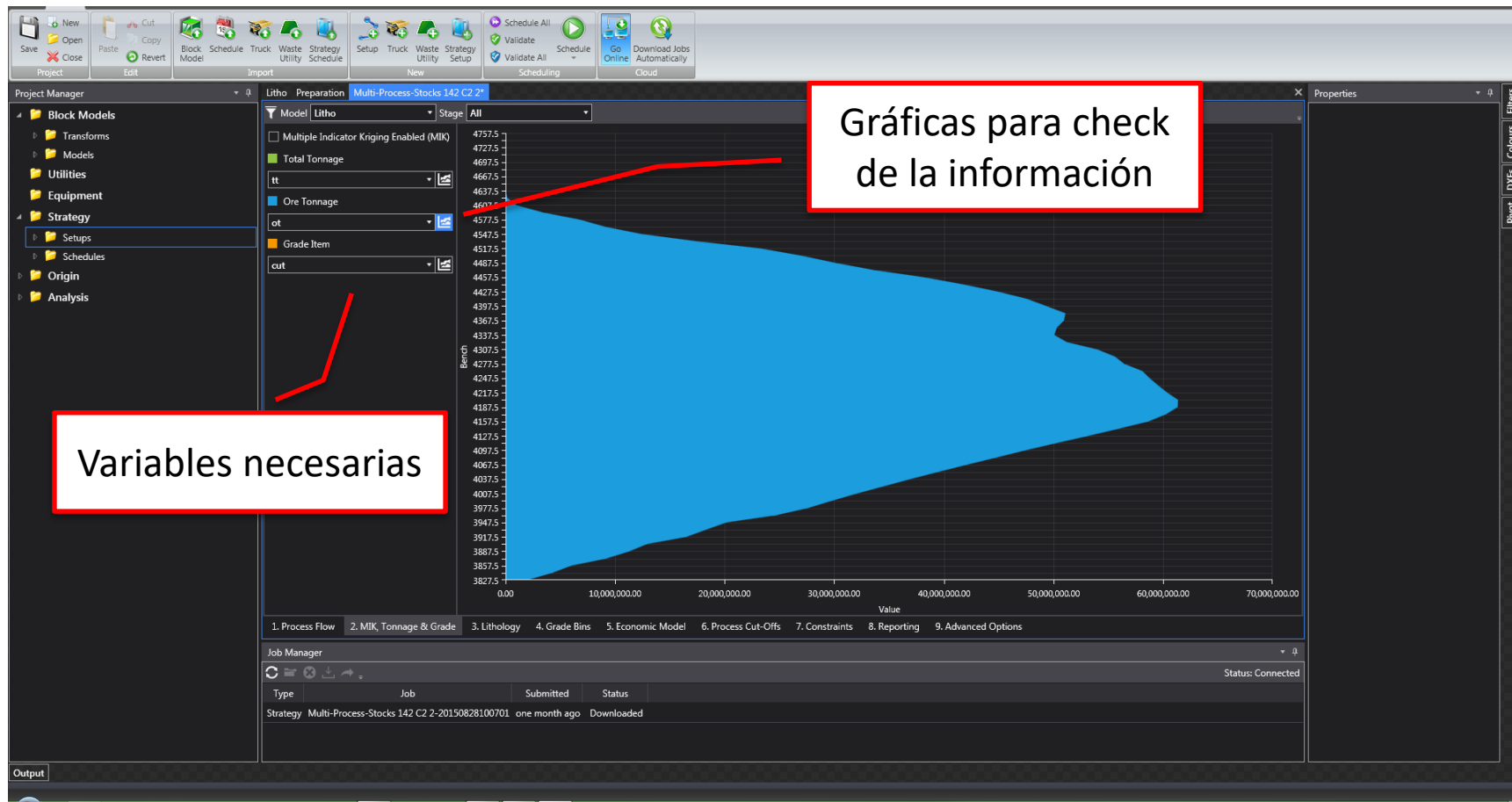
Nuevo modelo de planificación

Modelos de Bloques
Drag & Drop

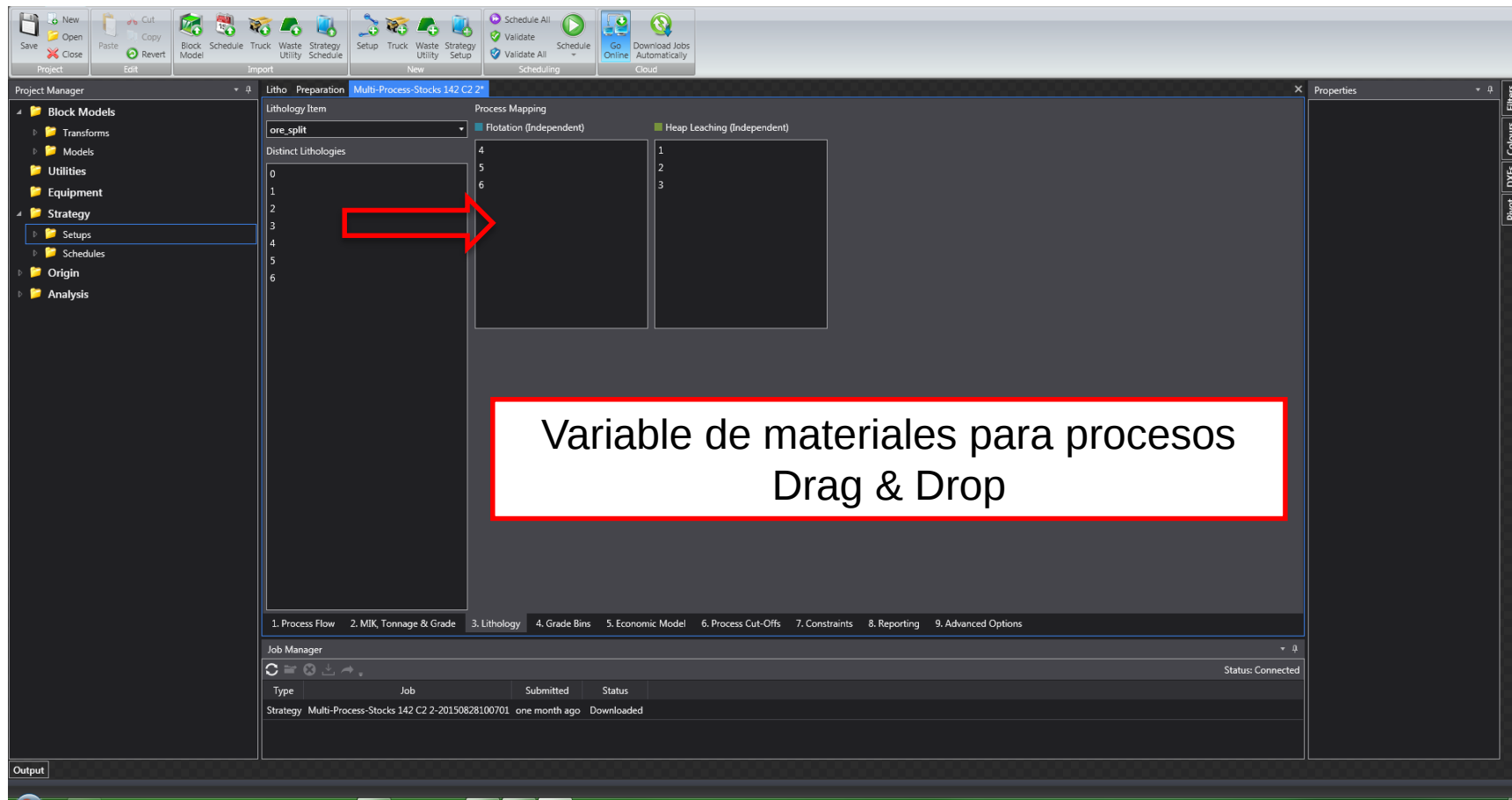
1. Process Flow 2. MIK, Tonnage & Grade 3. Lithology 4. Grade Bins 5. Economic Model 6. Process Cut-Offs 7. Constraints 8. Reporting 9. Advanced Options

Output
Validation successful. This Setup is ready to be scheduled.

Auditable



Litos - Directo desde el modelo de bloques



The screenshot displays the MAPTEK software interface, specifically the 'Litho Preparation' window. The 'ore_split' lithology item is selected in the 'Distinct Lithologies' list. A red arrow points from this list to the 'Process Mapping' area, which shows 'Flotation (Independent)' and 'Heap Leaching (Independent)' processes. A red box highlights the text 'Variable de materiales para procesos Drag & Drop'.

Variable de materiales para procesos
Drag & Drop

Bins – Directo desde el modelo de bloques

Save

Open

Close

Cut

Copy

Revert

Block Model

Schedule

Truck

Waste Utility

Strategy Schedule

Setup

Truck

Waste Utility

Strategy Setup

Schedule All

Validate

Validate All

Schedule

Go Online

Download Jobs Automatically

Project

Exit

Import

New

Scheduling

Cloud

Project Manager

Block Models

Transforms

Models

Utilities

Equipment

Strategy

Setups

Schedules

Origin

Analysis

Litho

Preparation

Multi-Process-Stocks 142 C2 2"

Grade Bins View

Config View

Lithology

Lower	Upper	Ore Units	Inc Metal Units	Cumulative Metal U						
0.000	0.300	2,406,314,278	4,716	1,688,165,588						
0.300	0.400	248,804,083	85,829,249	1,688,160,872						
0.400	0.500	157,771,208	70,382,288	1,602,331,623	0.446	1,655,366,983	0.968	4,310,485,345	1.604	0.0000
0.500	0.600	110,014,308	60,446,137	1,531,949,335	0.549	1,497,595,775	1.023	4,310,485,345	1.878	0.0000
0.600	0.700	125,307,811	81,663,855	1,471,503,198	0.652	1,387,581,468	1.060	4,310,485,345	2.106	0.0000
0.700	0.800	210,943,532	159,395,756	1,389,839,343	0.756	1,262,273,657	1.101	4,310,485,345	2.415	0.0000
0.800	0.900	226,762,930	191,976,376	1,230,443,587	0.847	1,051,330,125	1.170	4,310,485,345	3.100	0.0000
0.900	1.000	178,689,890	169,728,579	1,038,467,211	0.950	824,567,195	1.259	4,310,485,345	4.228	0.0000
1.000	1.100	177,882,709	186,664,713	868,738,632	1.049	645,877,305	1.345	4,310,485,345	5.674	0.0000
1.100	1.200	143,543,388	164,737,307	682,073,919	1.148	467,994,596	1.457	4,310,485,345	8.211	0.0000
1.200	1.300	110,524,783	137,830,325	517,336,612	1.247	324,451,208	1.594	4,310,485,345	12.285	0.0000
1.300	1.400	67,557,156	90,977,820	379,506,287	1.347	213,926,425	1.774	4,310,485,345	19.149	0.0000
1.400	1.500	44,626,733	64,504,035	288,528,467	1.445	146,369,269	1.971	4,310,485,345	28.449	0.0000
1.500	1.600	25,460,463	39,313,550	224,024,432	1.544	101,742,537	2.202	4,310,485,345	41.367	0.0000
2.421	75,783,074	0.471	4,310,485,345	66,807	0.0000					

Grade Bins

Directo del modelo de bloques

Grade Bins
Directo del modelo de bloques



Simple – Modelo Económico



Modelo Económico

- Precios
- Costos
- Capacidades
- etc.

Alternativa de Costos y Recuperaciones desde modelo de bloques

Inyección Dinámica de Capital

Tasa de Descuento Definición de Stocks

Calendar View Config View Variable Costs Dynamic Capital

Discount Factor

The fraction by which cash flows for a period are multiplied to calculate the Net Present Value (NPV)

Discount Rate (%)

10.00

Cut-off Grade Optimisation

☐ Turn-off cut-off grade optimisation.

Global Minimum Cut-off

0.3000

Stockpiles

Allowing stockpiles will cause the schedule to auto-create stockpiles for each process defined in your process flow. You will also need to define stockpile rehandle and recovery values within the calendar.

☒ Allow Stockpiles

Process Stockpile Capacity

Name	Capacity (tonnes)	Fixed Cut-off
Flotation	999,999,999	0.0000
Heap Leaching	999,999,999	0.0000

Calendar View Config View Variable Costs Dynamic Capital

Optional. Select an item in the model to use as the cost. You will also need to define the cost escalation factor within the calendar.

Mining Cost

mcost

Rehabilitation Cost

Flotation

Processing Cost

pc_flot

Processing Cost Default

3.25

Recovery

rec_flot

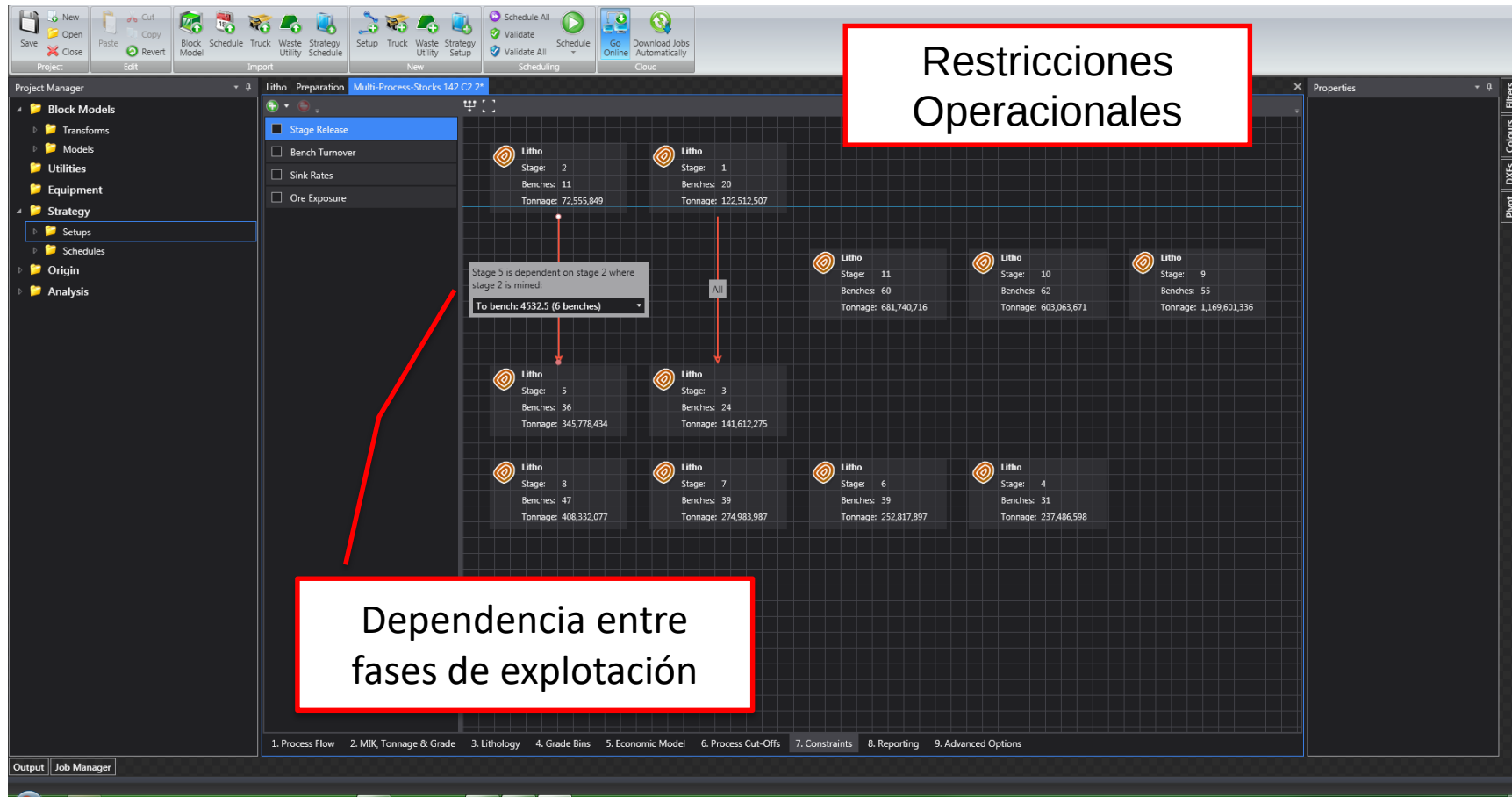
Recovery Default (%)

89.40

Calendar View Config View Variable Costs Dynamic Capital

Stage	Capital
Stage 1	\$0.00
Stage 2	\$0.00
Stage 3	\$0.00
Stage 4	\$0.00
Stage 5	\$10,000,000.00
Stage 6	\$0.00
Stage 7	\$0.00
Stage 8	\$0.00
Stage 9	\$0.00
Stage 10	\$0.00
Stage 11	\$0.00

Restricciones



Restricciones



Restricciones Operacionales

	Period 1	Period 2							
Litho									
Stage 1	10	9	8	8	8	8	8	8	
Stage 2	10	9	8	8	8	8	8	8	
Stage 3	10	9	8	8	8	8	8	8	
Stage 4	10	9	8	8	8	8	8	8	
Stage 5	10	9	8	8	8	8	8	8	
Stage 6	0	0	0	0	0	0	10	10	
Stage 7	0	0	0	0	0	0	10	10	
Stage 8	0	0	0	0	0	0	10	10	
Stage 9	0	0	0	0	0	0	10	10	
Stage 10	0	0	0	0	0	0	10	10	
Stage 11	0	0	0	0	0	0	10	10	

Numero de Bancos x Periodo

1. Process Flow 2. MIK, Tonnage & Grade 3. Lithology 4. Grade Bins 5. Economic Model 6. Process Cut-Offs 7. Constraints 8. Reporting 9. Advanced Options

Restricciones

Restricciones Operacionales

Multi-Process-Stocks 142 C2 24

☐ Stage Release
☐ Bench Turnover
☒ Sink Rates
☐ Ore Exposure

From (tonnes)	To (tonnes)	Rate (tonnes/year)
0	6,000,000	34,539,000
6,000,000	12,000,000	69,078,000
12,000,000	18,000,000	117,352,000
18,000,000	30,000,000	151,891,000
30,000,000	50,000,000	199,506,000

	Equipos	Pala	CF-Letour	CF-Cat	
TPD	94.627	37.632	20.000		
Ritmo Extracción	34.54	13.74	7.30	Mta	

Inferior	Superior	Pala	CF-Letour	CF-Cat	Ritmo Total (Mta)
30,000,000	50,000,000	5	2		199.506
24,000,000	30,000,000	4	1	1	159.191
18,000,000	24,000,000	4	1		151.891
12,000,000	18,000,000	3	1		117.352
6,000,000	12,000,000	2			69.078
-	6,000,000	1			34.539

Ritmo de extracción en función del tamaño de los bancos

1. Process Flow 2. MIK, Tonnage & Grade 3. Lithology 4. Grade Bins 5. Economic Model 6. Process Cut-Offs 7. Constraints 8. Reporting 9. Advanced Options

Restricciones



Restricciones Operacionales

Restricciones Operacionales Globales

Restricciones Operacionales x Fase

Restricciones Operacionales x Proceso

The screenshot displays the Martek software interface with several panels and settings related to operational constraints.

Top Panel: Contains icons for New, Open, Close, Save, Paste, Copy, Revert, Block Model, Schedule, Truck, Waste Utility, Strategy, Setup, and Schedule All. It also includes buttons for Validate, Schedule, Go Online, and Download Jobs Automatically.

Project Manager: A tree view on the left showing the project structure. The 'Strategy' folder is expanded, showing sub-folders like 'Setups', 'Schedules', 'Origin', and 'Analysis'.

Accumulation Constraints: A panel on the right showing constraints for 'Global Accumulation', 'Stage Accumulation', and 'Process Accumulation'. The 'Global Accumulation' checkbox is checked.

Accumulation Table: A table showing accumulation data for 'Period 1' through 'Period 7'. The table has columns for 'Period 1', 'Period 2', 'Period 3', 'Period 4', 'Period 5', 'Period 6', and 'Period 7'. The 'Units' column is empty.

Stage Accumulation Table: A table showing stage accumulation data for 'Period 1' through 'Period 5'. The table has columns for 'Period 1', 'Period 2', 'Period 3', 'Period 4', and 'Period 5'. The 'Units' column is empty.

Process Accumulation Table: A table showing process accumulation data for 'Period 1' through 'Period 5'. The table has columns for 'Period 1', 'Period 2', 'Period 3', 'Period 4', and 'Period 5'. The 'Units' column is empty.

Properties Panel: A panel on the right showing properties for the selected item, including 'Filters', 'Colours', 'Pivot', and 'DXFs'.

Reportabilidad



Project Manager

Block Models

- Transforms
- Models
- Utilities
- Equipment
- Strategy
- Setups
- Schedules
- Origin
- Analysis

Report Items

- alter
- an_4x
- as
- as_2001
- aux
- aux_3
- aux2
- auxliar
- caf_m
- caf_p
- categ
- check
- cus
- cut
- cut
- density
- fases_prefs
- id_x
- id_y
- id_z
- mcost
- mcost2
- minzn
- nueva
- nueva2
- ore_split
- ot
- ot_flot
- ot_hl
- ot2
- pc_flot
- pc_hl
- pit
- rec
- rec_flot
- rec_hl

Additional Grade Items

- Flotation (Independent)
- Heap Leaching (Independent)

as

- cus
- rec_flot

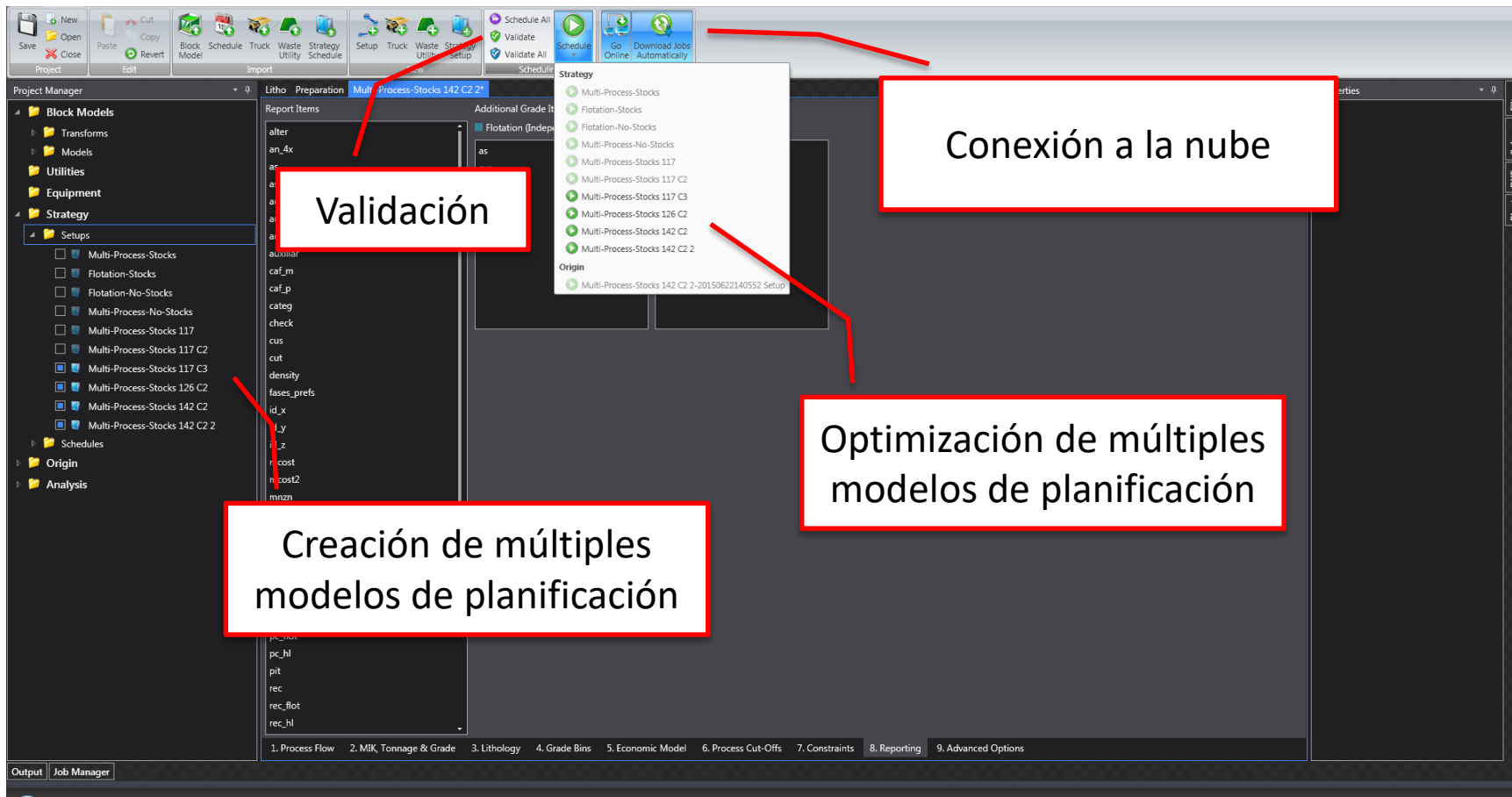
as

- cus
- rec_hl

Reportabilidad desde el modelo de bloques

1. Process Flow 2. Mill, Tonnage & Grade 3. Lithology 4. Grade Bins 5. Economic Model 6. Process Cut-Offs 7. Constraints 8. Reporting 9. Advanced Options

Optimización



The screenshot displays the MAPTEK software interface with several key components highlighted by red boxes and arrows:

- Validation:** A red box highlights the 'Validate' button in the top toolbar and the 'Multi-Process-Stocks 142 C2 2' item in the 'Setups' list on the left. An arrow points from this box to the 'Strategy' dropdown menu.
- Conexión a la nube:** A red box highlights the 'Go Online' button in the top toolbar, with an arrow pointing to the 'Download Jobs Automatically' button.
- Optimización de múltiples modelos de planificación:** A red box highlights the 'Multi-Process-Stocks 142 C2 2' item in the 'Setups' list, with an arrow pointing to the 'Strategy' dropdown menu.
- Creación de múltiples modelos de planificación:** A red box highlights the 'Multi-Process-Stocks 142 C2 2' item in the 'Setups' list, with an arrow pointing to the 'Strategy' dropdown menu.

The 'Strategy' dropdown menu is open, showing a list of optimization strategies including 'Multi-Process-Stocks', 'Flotation-Stocks', 'Flotation-No-Stocks', 'Multi-Process-No-Stocks', 'Multi-Process-Stocks 117', 'Multi-Process-Stocks 117 C2', 'Multi-Process-Stocks 117 C3', 'Multi-Process-Stocks 126 C2', 'Multi-Process-Stocks 142 C2', and 'Multi-Process-Stocks 142 C2 2'. The 'Origin' section shows 'Multi-Process-Stocks 142 C2 2-20150622140552 Setup'.

The bottom status bar displays the following workflow steps: 1. Process Flow, 2. MIK, Tonnage & Grade, 3. Lithology, 4. Grade Bins, 5. Economic Model, 6. Process Cut-Offs, 7. Constraints, 8. Reporting, 9. Advanced Options.

Feedback



Reportabilidad



Project Manager

Block Models

- Transforms
- Models
- Utilities
- Equipment
- Strategy
 - Setups
 - Multi-Process-Stocks
 - Flotation-Stocks
 - Flotation-No-Stocks
 - Multi-Process-No-Stocks
 - Multi-Process-Stocks 117
 - Multi-Process-Stocks 117 C2
 - Multi-Process-Stocks 117 C3
 - Multi-Process-Stocks 126 C2
 - Multi-Process-Stocks 142 C2
 - Multi-Process-Stocks 142 C2 2
 - Schedules
 - Multi-Process-Stocks-201412300356...
 - Flotation-No-Stocks-20141230041529
 - Multi-Process-No-Stocks-201412300...
 - Multi-Process-Stocks-201502110033...
 - Multi-Process-Stocks-201504291402...
 - Multi-Process-Stocks 117 C2-201505...
 - Multi-Process-Stocks 117-20150505...
 - Multi-Process-Stocks 117 C3-201505...
 - Multi-Process-Stocks 117 C3-201505...
 - Multi-Process-Stocks 117 C2-201505...
 - Multi-Process-Stocks 126 C2-201505...
 - Multi-Process-Stocks 142 C2-201506...
 - Multi-Process-Stocks 142 C2 2-2015...
 - Flotation-No-Stocks-20150619122505
 - Flotation-No-Stocks-20150619123320
 - Flotation-No-Stocks-20150619124812

Multi-Process-Stocks 142 C2 2-20150828100701 - Standard Reports

	Totals	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8
Overall Schedule Totals									
Discount Factor		1.00	1.10	1.21	1.33				
Mined Tonnes	4,310,485,345	97,632,044	173,350,000	173,350,000	166,905,836				
Mill-Feed Tonnes	1,196,581,268	15,000,000	30,000,000	40,000,000	45,000,000				
MCost	\$2,586,291,207	\$58,579,226	\$104,010,000	\$104,010,000	\$100,143,502				
PCost	\$3,849,558,354	\$45,250,000	\$93,999,999	\$126,500,000	\$142,750,000				
Rehandle	\$188,771,706	\$0	\$667,523	\$910,366	\$0				
Rehabilitation	\$0	\$0	\$0	\$0	\$0				
Closure Cost	\$0	\$0	\$0	\$0	\$0				
Admin/Fixed	\$1,249,600,000	\$44,000,000	\$44,000,000	\$44,000,000	\$44,000,000	\$44,000,000	\$44,000,000	\$44,000,000	\$44,000,000
Capital	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Revenue	\$15,039,749,899	\$297,288,647	\$520,618,108	\$604,361,766	\$756,962,033	\$874,451,077	\$673,682,348	\$542,488,904	\$928,687,098
Profit	\$7,165,528,632	\$149,459,421	\$277,940,585	\$328,941,400	\$470,068,531	\$583,590,950	\$381,994,059	\$242,886,192	\$636,967,098
Incremental NPV	\$3,161,534,006	\$3,161,534,006	\$3,313,282,044	\$3,338,875,604	\$3,310,927,625	\$3,124,945,003	\$2,795,489,458	\$2,654,844,939	\$2,653,154,621
Litho									
Crusher									
WASTE									
Flotation									
Cut-off		0.79	0.84	0.71	0.78	0.71	0.92	0.78	1.00
Total Tonnes	1,174,106,544	13,000,000	28,000,000	38,000,000	43,000,000	43,000,000	43,000,000	43,000,000	43,000,000
Total Grade (Wavg)		1.520	1.341	1.146	1.280	1.454	1.132	0.986	1.571
Total in situ Metal	1,190,527,606	19,758,503	37,545,219	43,534,189	55,029,933	62,500,916	48,657,168	42,396,149	67,543,247
Total Recovered Metal	981,679,253	17,664,101	33,358,003	38,919,565	49,196,760	55,875,819	43,499,509	34,728,924	60,383,663
Global Recovery (Avg)		89.40 %	88.85 %	89.40 %	89.40 %	89.40 %	89.40 %	81.92 %	89.40 %

Schedule Overview | Charts | Stages | Accumulation | Process/Litho | Stockpile Reclaim | Stockpile State at Start of Period | Grades | Process Constraints

Job Manager

Status: Connected

Type	Job	Submitted	Status
Strategy	Multi-Process-Stocks 142 C2 2-20150828100701	one month ago	Downloaded

Output

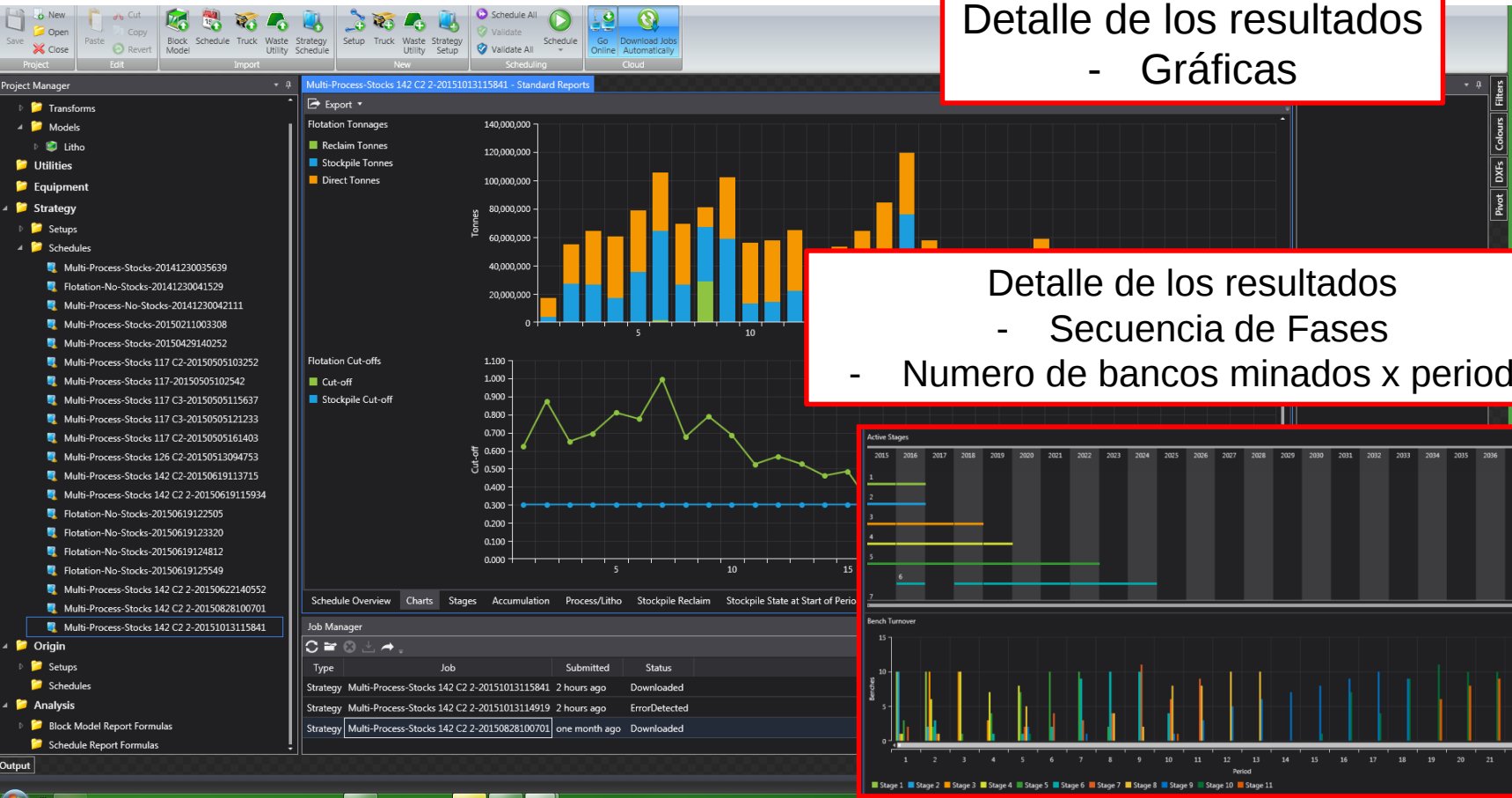
Detalle de los resultados

- Flujos de caja
- Movimientos x Rajo
- Movimiento x Proceso
- Leyes de Corte x proceso y stock

Reportabilidad

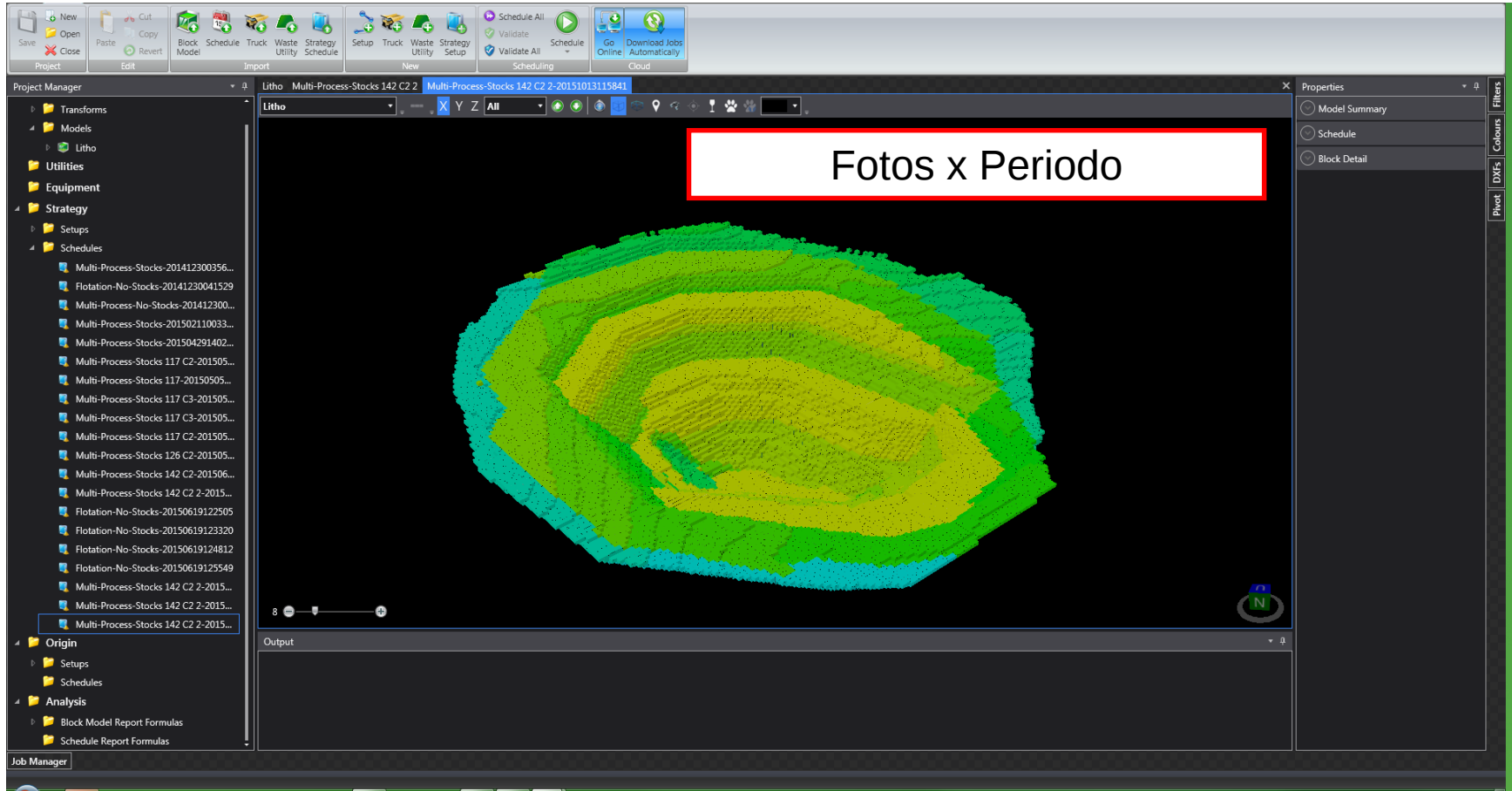


Detalle de los resultados
- Gráficas

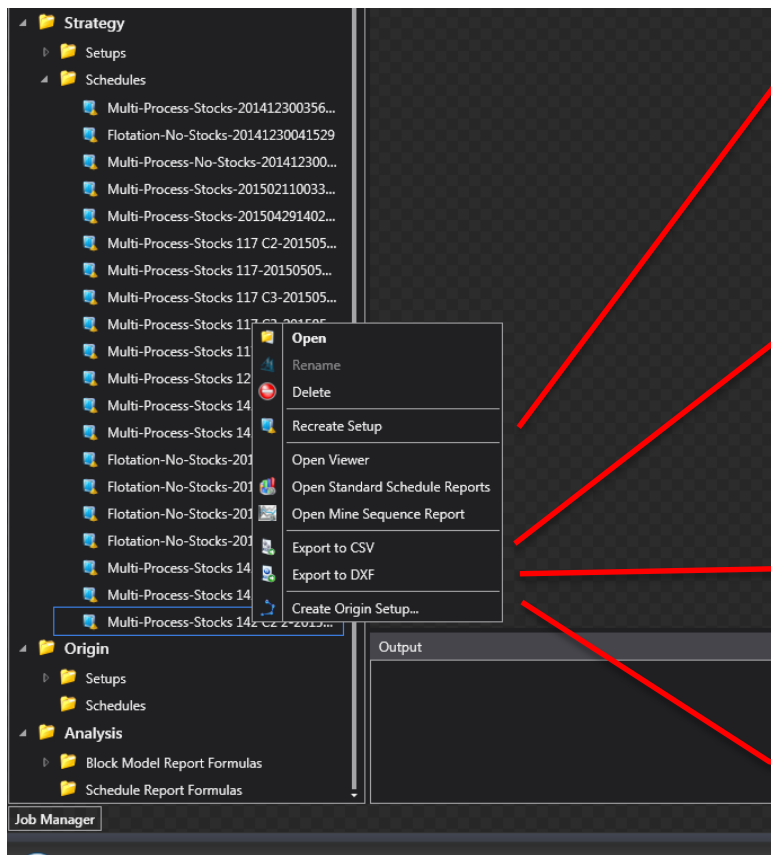


Detalle de los resultados
- Secuencia de Fases
- Numero de bancos minados x periodo

Fotos x Periodo



Otras Características



Reconstruir configuración
desde el resultado

Exportar modelo de bloques
con variables del plan minero

Exportar

- Sólidos x periodo
- Fotos x Periodo

Crear desde el resultado de Strategy
una configuración de Origin

Conclusiones



- Genera plan mineros
- Optimiza la ley de corte por periodo
- Interface orientada a objetos
- No requiere manejar cubicaciones o bases de datos adicionales (Excel, Access, etc.) ya que trabaja directo sobre modelo de bloques
- La configuración se hace de manera local, lo que permite utilizar los recursos del computador en otras tareas
- La optimización se realiza en la nube permitiendo una muy rápida obtención de resultados (solo minutos)

Conclusiones



- Incorpora conceptos económicos para agregar valor al proyecto (NPV, Inyección Dinámica de Capital, Precios y Costos variables en el tiempo, etc.)
- Incorpora conceptos mineros para generar planes operativos y factibles (numero de bancos por periodo, Sinking Rate, blending, etc.)
- Si el usuario pierde la configuración que realizó la puede recuperar desde el resultado
- No es solo datos numéricos (o planilla Excel), también hay gráficas que apoyan el entendimiento y desarrollo de los problemas
- Una gran variedad de reportes y animaciones
- Muy fácil de configurar
- Muy fácil de aprender
- Directa interacción con Vulcan

Conclusiones



- LO MÁS IMPORTANTE es que al ser fácil de configurar y rápido al obtener resultados **permite al usuario gastar su tiempo en el análisis de múltiples resultados** y no en la configuración del modelo



Gracias!!!

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