Simultaneous Pit and Waste Dump Schedule Optimization

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Overview

- Current Practice in Pit and Detailed Waste Dump Scheduling
- Problems with Current Practice
- Formulation for Joint Pit and Detailed Waste Dump Scheduling
- Examples (iGantt, Tempo, Minemax Scheduler)
- Extensions (Multiple Waste Dumps, Heap Leach, Reactive Waste)
- Conclusion

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Current Practice

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Accounting for Waste in Mining Schedule

- Basic Approach : Account for waste movement and dumping only through total material movement expressed in tonnes.
- Advanced Approach: Consider pit depth dependent trucking requirements on a per block basis

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Waste Accounting Basic Approach

- Total Material Movement upper limit can be based on digging and/or hauling capability in tonnes per period.
- However, trucking requirements for a given tonnage to be mined can actually vary depending on where the material is mined from. Basic approach does not account for trucking requirements which vary with depth of mined block in the pit.
- Trucking requirements for waste can vary depending on where it is placed on the waste dump. Does not account for trucking requirements associated with detailed waste dumping.

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Waste Accounting Advanced Approach

- Based on cycle-times and truck capacities, model truck-hours and set a limit on available truck hours.
- Accounts for depth dependent trucking requirements for ore out of pit and to crusher.
- Accounts for depth dependent trucking requirements for waste out of pit but **not** to final resting place in waste dump.

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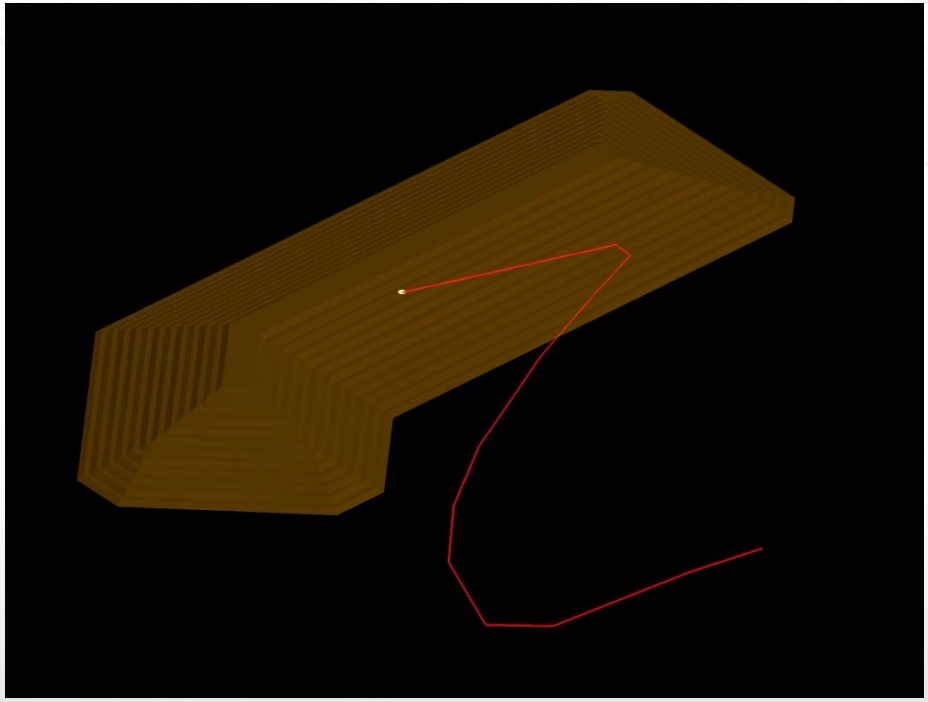
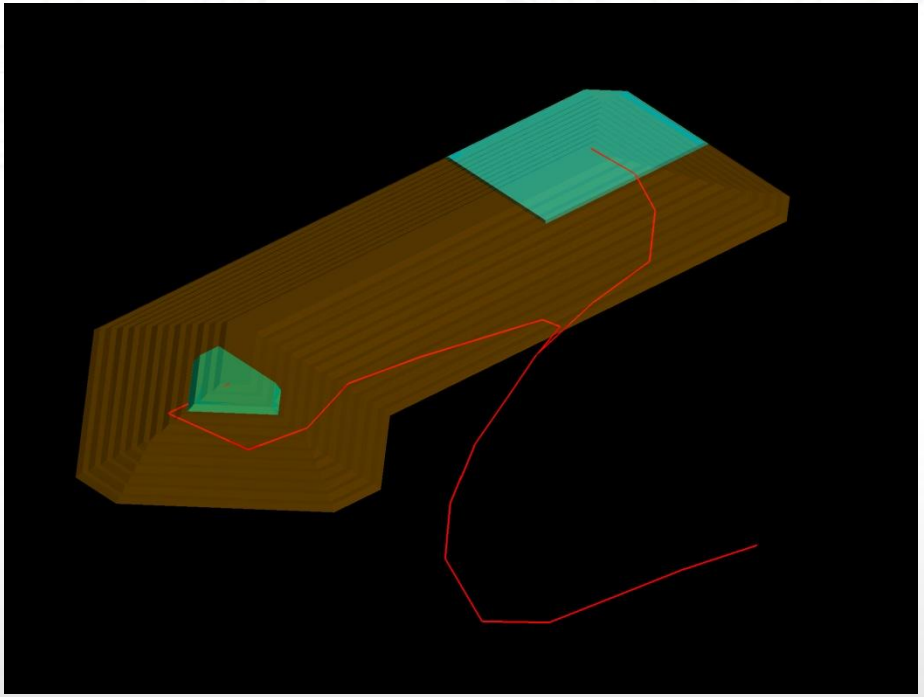
Waste Accounting Advanced Approach: Centroid Problem





- May use waste dump centroid as average distance for waste.
  - Results in over-estimating or under-estimating real trucking requirements.
  - With over-estimating there can be a loss in value
  - With under-estimating, the schedule is impractical

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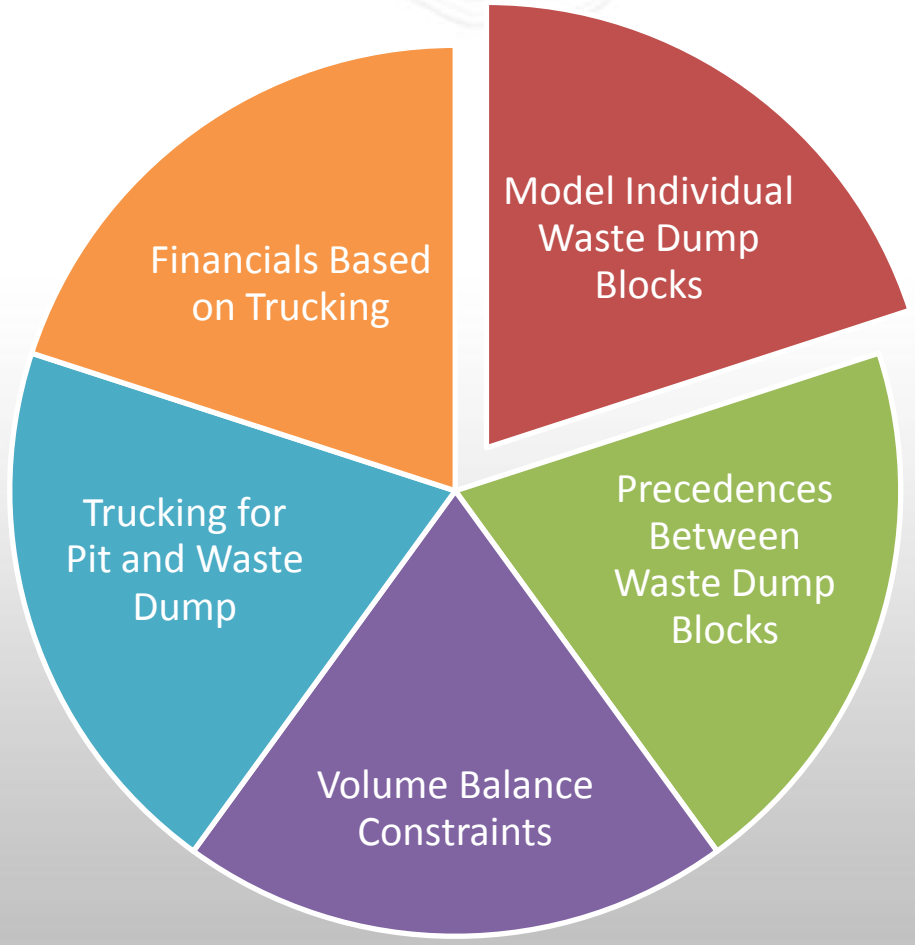
Pieces of the Puzzle for Proposed Formulation



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Linear Programming Context for Scheduling

- LP formulation can be viewed as a matrix with columns as decision variables and rows as constraints using decision variables
- In mine scheduling, use proportion of block to be mined in a period as decision variable : B_{ij} is a variable with a range between 0 and 1 representing the proportion of block i mined in period j
- Blocks can have multiple quantities associated with them
  - e.g. Mill tonnes, Mining tonnes, Metal Tonnes
  - denote Q_{ik} as the k^{th} quantity in block i
- For each quantity and in each time period, we can specify minimum and/or maximum total quantities denoted by row names of QC_{kj} indicating total quantity k in period j

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Linear Programming Matrix General Form

	B11	B12	B13	B14	B21	B22	B23	B24	.....	
	v	v	v	v	v	v	v	v		
QC11	Q11				Q21					QMAX11
QC12		Q11				Q21				QMax12
QC13			Q11				Q21			QMAX13
QC14				Q11				Q21		QMAX14
QC21	Q12				Q22					QMAX21
QC22		Q12				Q22				QMAX22
QC23			Q12				Q22			QMAX23
QC24				Q12				Q22		QMAX24

$$QMIN_{jk} <= \sum_{i} B_{ij} Q_{ik} <= QMAX_{jk}$$

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LPMatrix: Mining and Milling Example

	B11	B12	B13	B14	B21	B22	B23	B24	.....	
	150,000	130,000	100,000	60,000	-5,000	-4,700	-4,200	-3,500		
Mill1	2500									10,000,000
Mill2		2500								10,000,000
Mill3			2500							10,000,000
Mill4				2500						10,000,000
Mine1	2500				2500					80,000,000
Mine2		2500				2500				80,000,000
Mine3			2500				2500			80,000,000
Mine4				2500				2500		80,000,000

- B1 is 2500 tonnes of ore
- B2 is 2500 tonnes of waste

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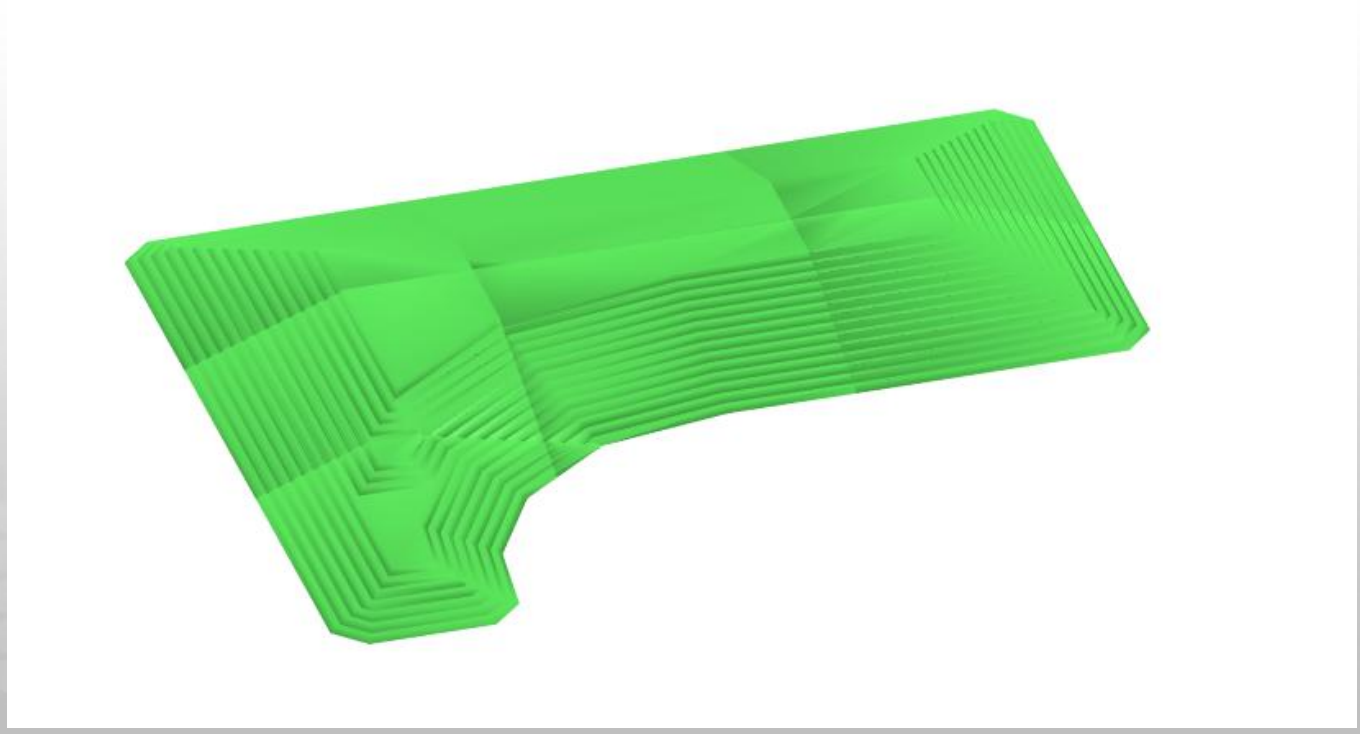
Model Individual Waste Dump Blocks

- A waste dump is divided into a number of horizontal lifts. Lifts are further divided into dump blocks.
- Include waste dump blocks into the LP similar to pit blocks



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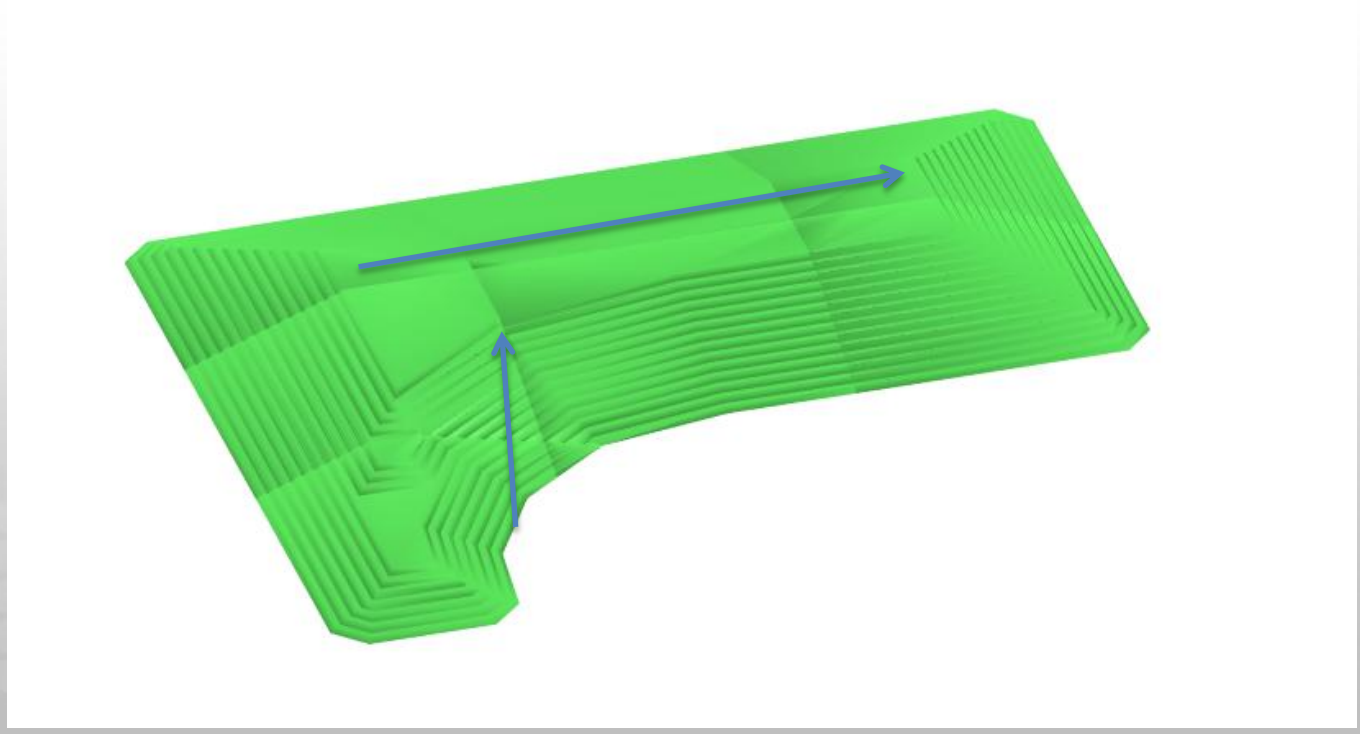
Precedences Between Waste Dump Cells

- Define precedences between waste dump blocks corresponding to practical waste dump construction



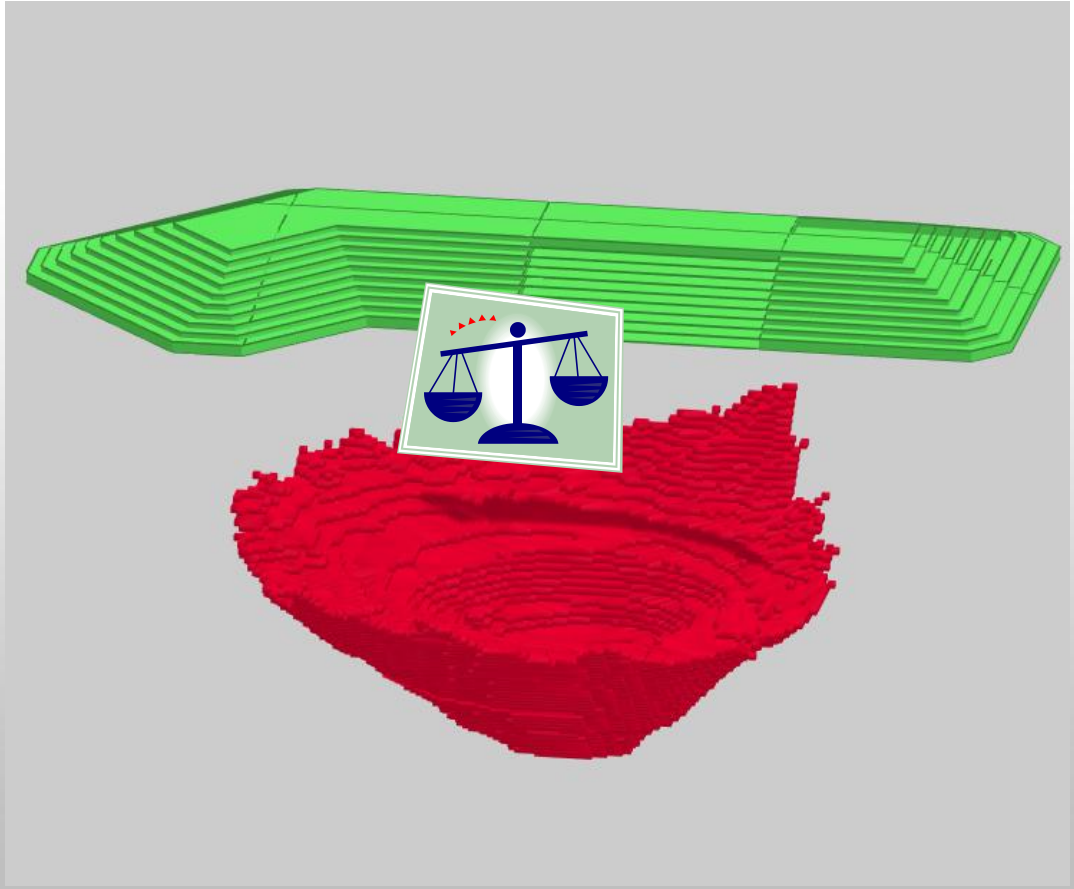
Detailed Waste Dump Modelling for Scheduling

- Introduce waste dump volume (wdv) as a positive quantity for waste dump blocks and a negative quantity for pit blocks

- Specify wdv balance constraints for each period.

$$\sum_i B_{ij} Q_{ik} = 0$$

- Where k is the waste dump volume quantity



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Detailed Waste Dump Modelling: Trucking

- Pit blocks use cycle times to calculate required truck hours to a common point of passage enroute to the waste dump
- Waste dump blocks use cycle times to calculate required truck hours from the common point of passage to the waste dump block
- Specify truck hours availability constraints for each period.

$$\sum_i B_{ij} Q_{ik} <= QMAX_k$$ Where k is the truck hours quantity

- Assign a cost/hour to trucking

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Examples

- Modelling approach can be applied to any lp-based mine scheduling solution which supports blocks with multiple quantities and constraints

- Example 1: iGantt

- Example 2: Minemax Scheduler

- Example 3: Tempo

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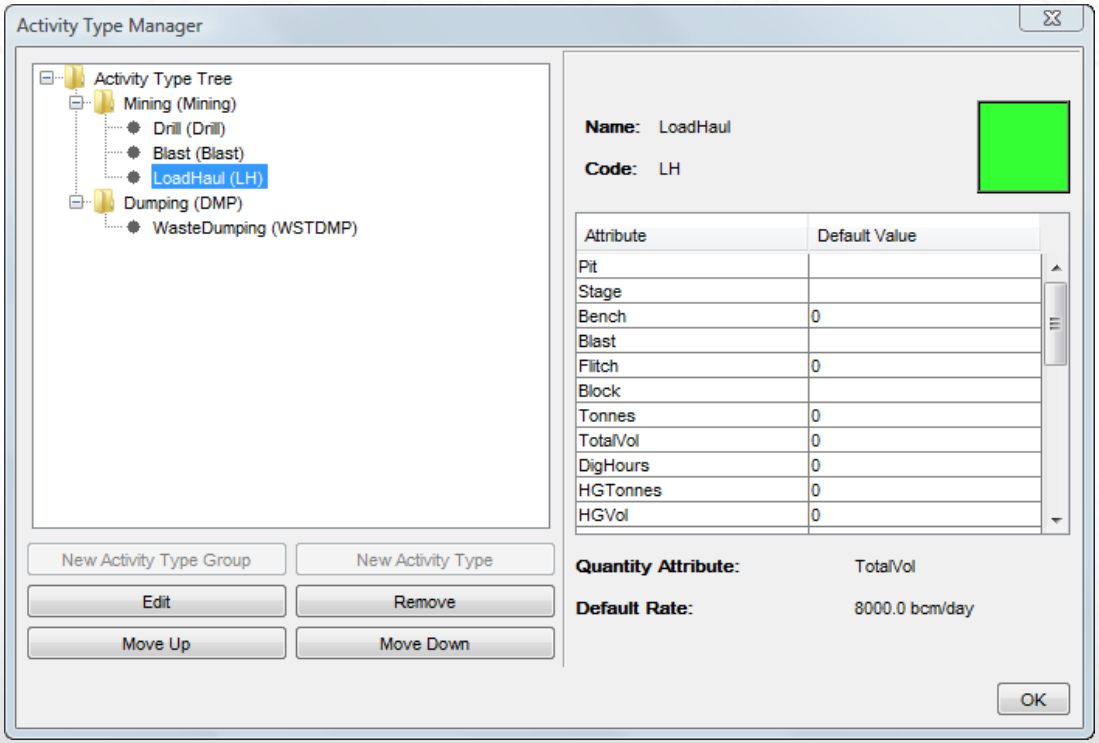
iGantt Example: Activity Types



LoadHaul and WasteDumping as Activity Types

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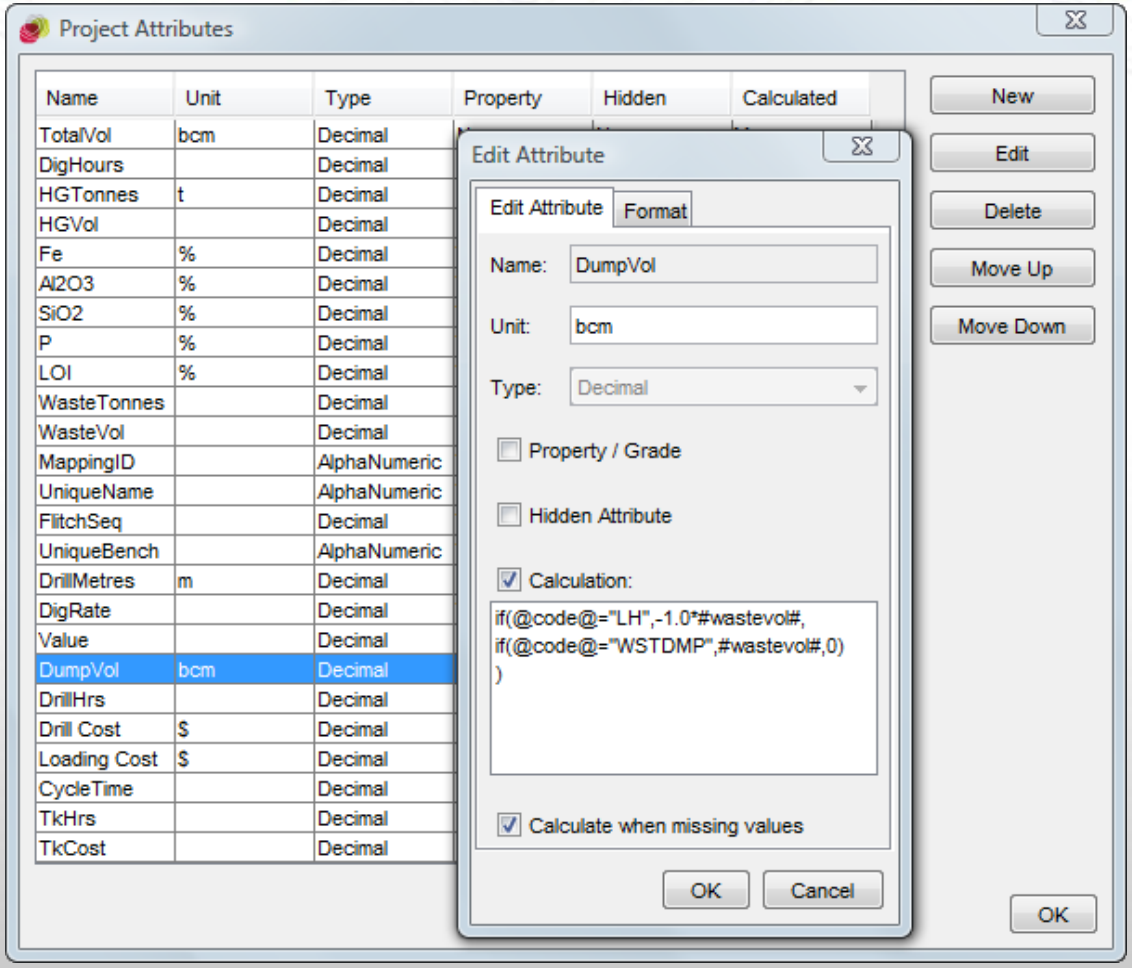
iGantt Example: DumpVol Quantity



DumpVol Quantity
LoadHaul takes –ve values
WasteDumping takes +ve values

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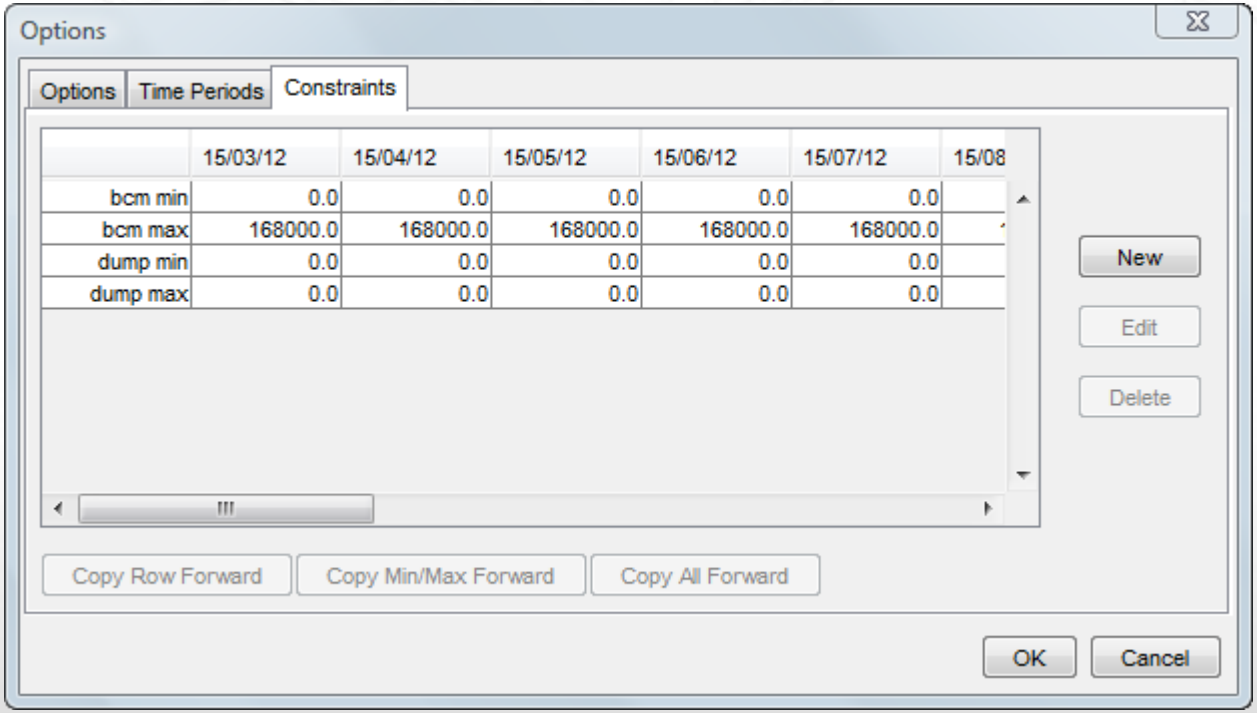
iGantt Example: DumpVol Constraint



Total DumpVol balance set to be exactly zero

(-ve from LoadHaul, +ve from WasteDumping)

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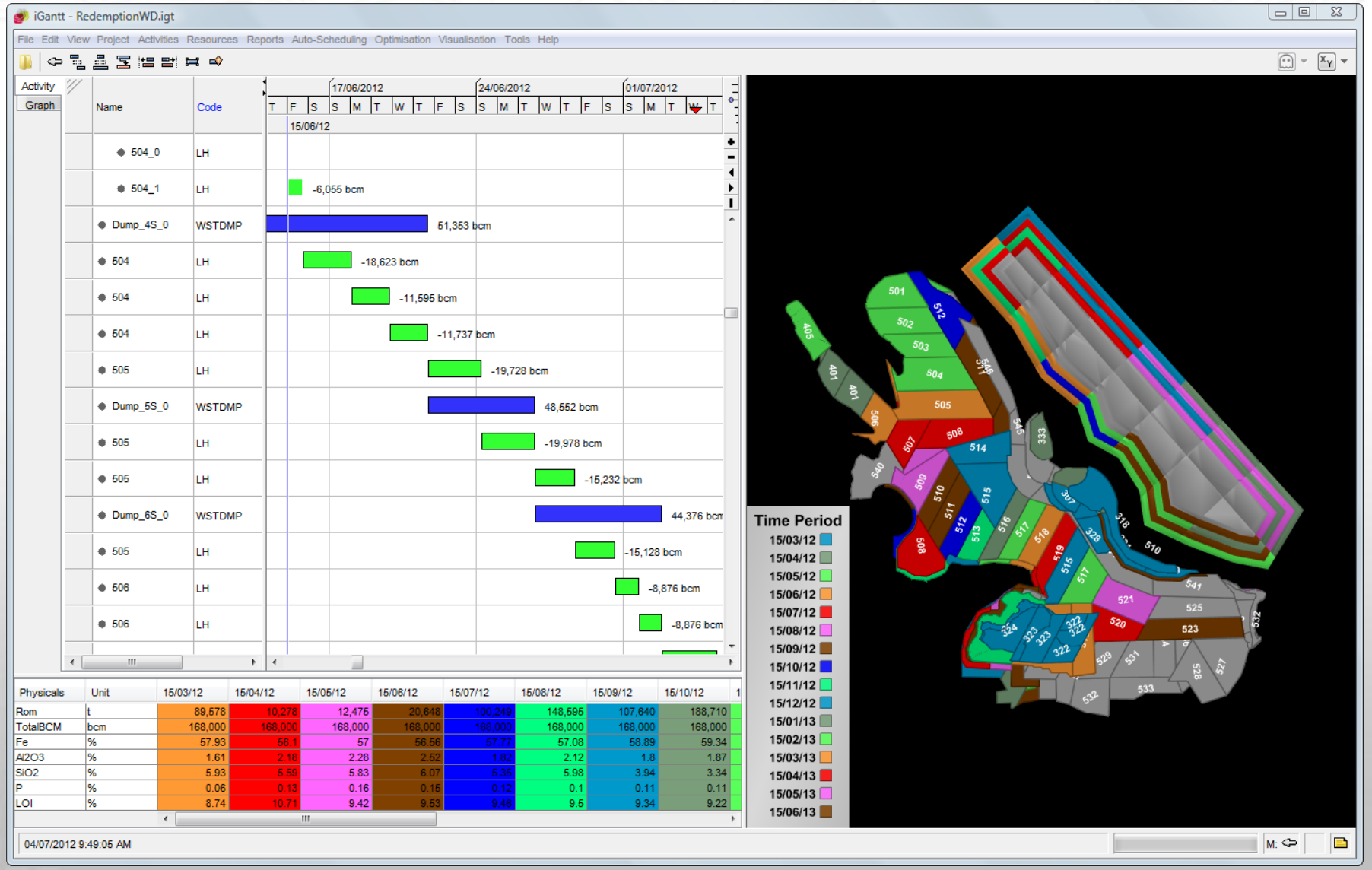
iGantt Example: Activities in Gantt Chart



Physicals	Unit	15/03/12	15/04/12	15/05/12	15/06/12	15/07/12	15/08/12	15/09/12	15/10/12
Rom	t	89,578	10,278	12,475	20,648	100,249	148,595	107,640	188,710
TotalBCM	bcm	168,000	168,000	168,000	168,000	168,000	168,000	168,000	168,000
Fe	%	57.93	56.1	57	56.56	57.77	57.08	58.89	59.34
Al2O3	%	1.61	2.18	2.28	2.52	1.82	2.12	1.8	1.87
SiO2	%	5.93	5.59	5.83	6.07	5.35	5.98	3.94	3.34
P	%	0.06	0.13	0.16	0.15	0.12	0.1	0.11	0.11
LOI	%	8.74	10.71	9.42	9.53	9.48	9.5	9.34	9.22

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Minemax Scheduler Example

Minemax Scheduler Enterprise

SAVE SETTINGS | HELP

Joint Pit Waste Dump Model

home project **model** scenario reports

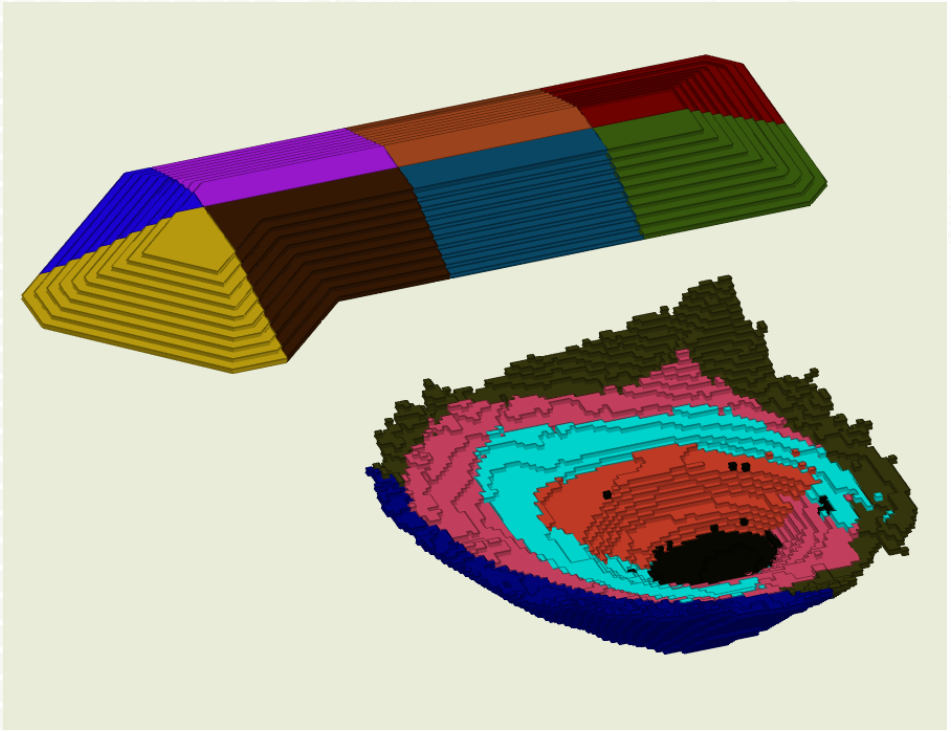
overview define import stockpiles pits **reserves**

Optimize

scenario DumpBalanced

add clone

filter by (none) colour by Pit Export



show blocks show attributes Export

name	quantity	InsituOre	DumpVol	Mill	Leach	WasteDump	WasteTrucking
Total	1,301,377,310.06	449,804,291.2186	-694,149.1316	449,804,291.2186	449,804,291.2186	449,804,291.2186	3,558,554.3625
1	15,851,276	14,941,231.9961	343,412.8396	14,941,231.9961	14,941,231.9961	14,941,231.9961	52,837.584
2	43,927,116	35,055,971.7358	3,347,601.84	35,055,971.7358	35,055,971.7358	35,055,971.7358	146,423.731
2543.000000	17,816	0	6,723.019	0	0	0	59.3867
2526.000000	1,837,496	1,155,251.9814	257,450.5605	1,155,251.9814	1,155,251.9814	1,155,251.9814	6,124.987
2509.000000	6,887,856	4,091,083.7918	1,055,385.4867	4,091,083.7918	4,091,083.7918	4,091,083.7918	22,959.5257
2492.000000	5,954,624	4,358,119.9747	602,454.581	4,358,119.9747	4,358,119.9747	4,358,119.9747	19,848.746
2475.000000	5,409,400	4,215,115.9891	450,673.4063	4,215,115.9891	4,215,115.9891	4,215,115.9891	18,031.3342
2458.000000	4,887,772	4,136,372.0067	283,547.161	4,136,372.0067	4,136,372.0067	4,136,372.0067	16,292.5726
2441.000000	4,210,560	4,033,351.998	66,870.9438	4,033,351.998	4,033,351.998	4,033,351.998	14,035.2011
2424.000000	4,020,772	3,846,759.9967	65,664.9094	3,846,759.9967	3,846,759.9967	3,846,759.9967	13,402.5747
2407.000000	4,212,940	3,806,980.0099	153,192.4581	3,806,980.0099	3,806,980.0099	3,806,980.0099	14,043.1343
2390.000000	3,739,320	3,266,040	178,596.2309	3,266,040	3,266,040	3,266,040	12,464.4018
2373.000000	2,748,560	2,146,895.9875	227,043.0832	2,146,895.9875	2,146,895.9875	2,146,895.9875	9,161.8668
3	173,636,428	104,454,256.0315	26,106,464.661	104,454,256.0315	104,454,256.0315	104,454,256.0315	578,788.0669
4	334,328,326	147,178,315.724	70,622,528.8851	147,178,315.724	147,178,315.724	147,178,315.724	1,114,428.1054
5	266,331,316	64,463,251.814	76,176,490.4031	64,463,251.814	64,463,251.814	64,463,251.814	887,771.5624
6	233,491,464	83,711,263.9172	56,520,736.2997	83,711,263.9172	83,711,263.9172	83,711,263.9172	778,305.3127
DumpCell_1_1	10,322,513.66	0	-10,322,513.66	0	0	0	0
DumpCell_1_2	33,128,457	0	-33,128,457	0	0	0	0
2935.000000	1,472,014	0	-1,472,014	0	0	0	0
2920.000000	1,887,481	0	-1,887,481	0	0	0	0
2905.000000	2,299,104	0	-2,299,104	0	0	0	0
2890.000000	2,706,900	0	-2,706,900	0	0	0	0
2875.000000	3,112,709	0	-3,112,709	0	0	0	0
2860.000000	3,518,489	0	-3,518,489	0	0	0	0
2845.000000	3,924,270	0	-3,924,270	0	0	0	0

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Minemax Scheduler: DumpVol Constraint

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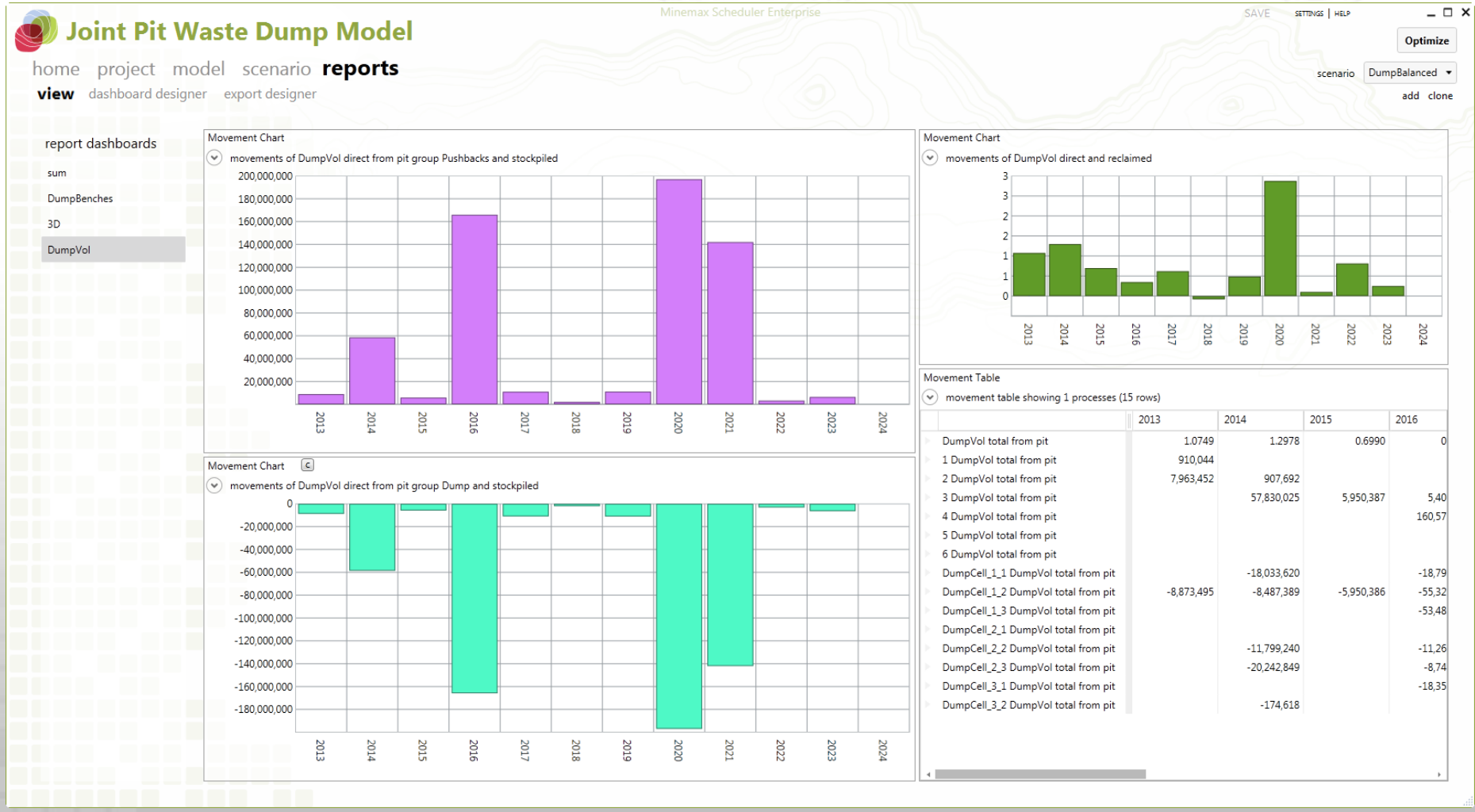
Minemax Scheduler: DumpVol Report



	2013	2014	2015	2016
DumpVol total from pit	1.0749	1.2978	0.6990	0
1 DumpVol total from pit	910,044			
2 DumpVol total from pit	7,963,452	907,692		
3 DumpVol total from pit		57,830,025	5,950,387	5,40
4 DumpVol total from pit				160,57
5 DumpVol total from pit				
6 DumpVol total from pit				
DumpCell_1_1 DumpVol total from pit		-18,033,620		-18,79
DumpCell_1_2 DumpVol total from pit	-8,873,495	-8,487,389	-5,950,386	-55,32
DumpCell_1_3 DumpVol total from pit				-53,48
DumpCell_2_1 DumpVol total from pit				
DumpCell_2_2 DumpVol total from pit		-11,799,240		-11,26
DumpCell_2_3 DumpVol total from pit		-20,242,849		-8,74
DumpCell_3_1 DumpVol total from pit				-18,35
DumpCell_3_2 DumpVol total from pit		-174,618		

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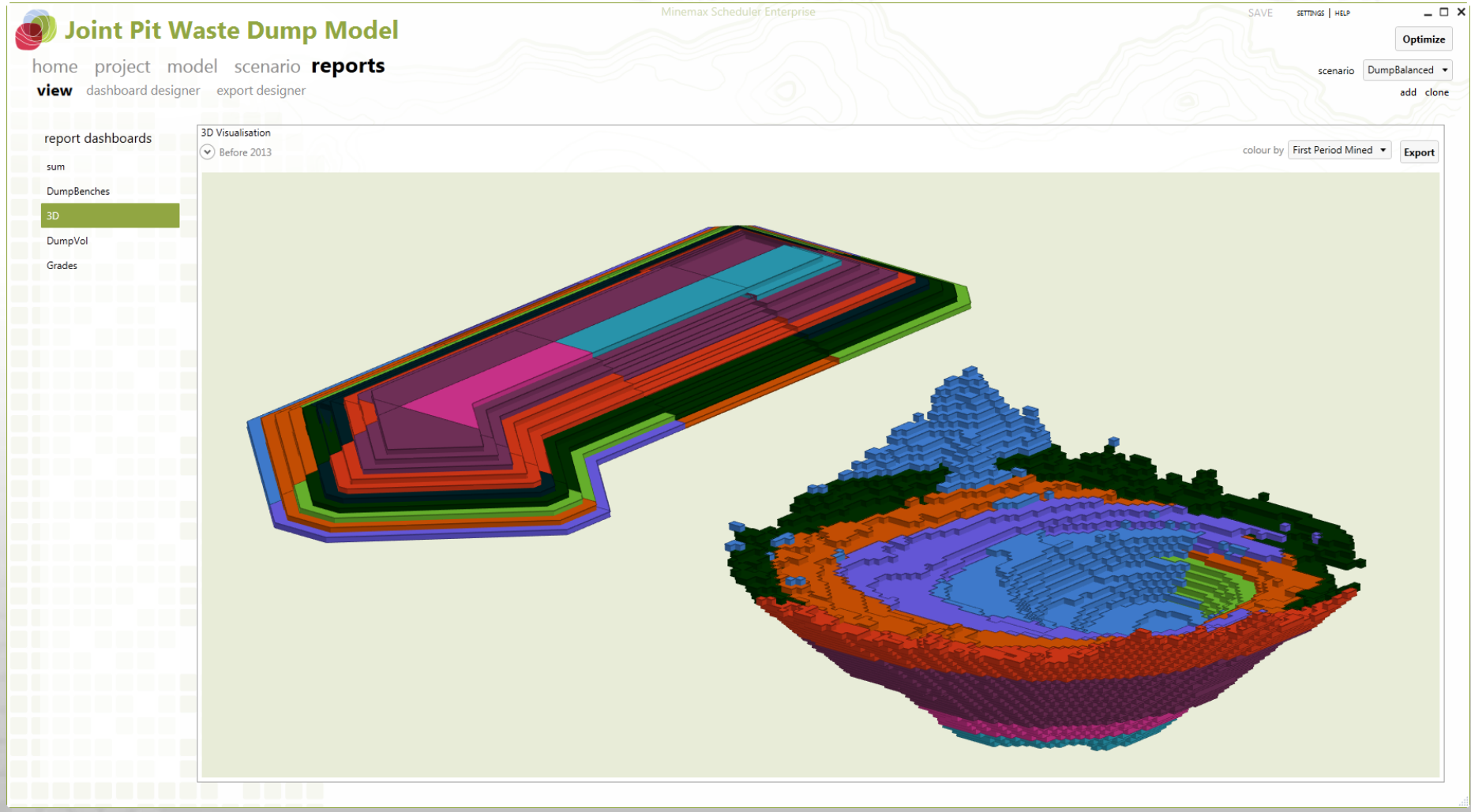
Minemax Scheduler: 3D by Time



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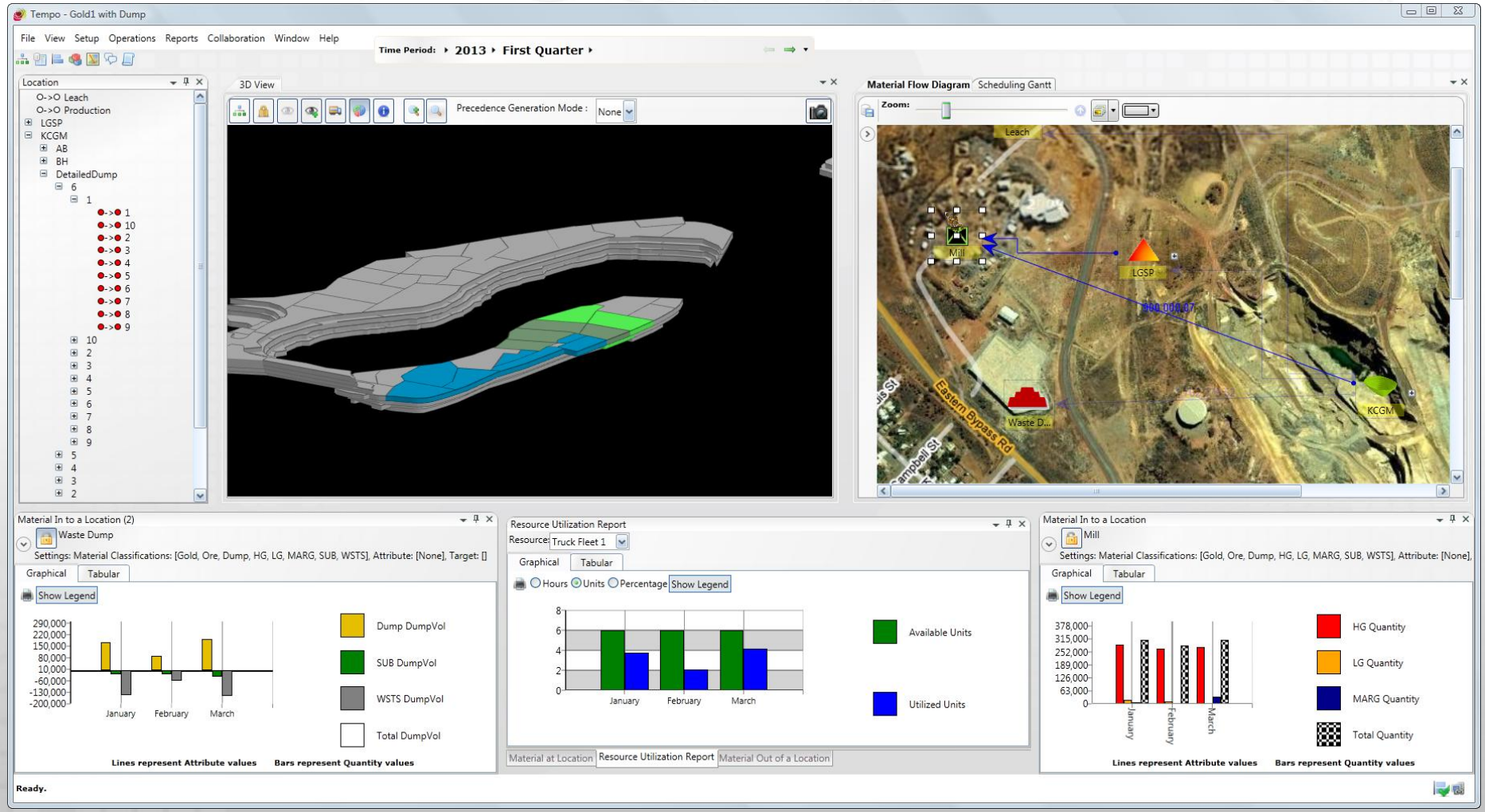
Tempo Example



Tempo Example : Dump Constraints

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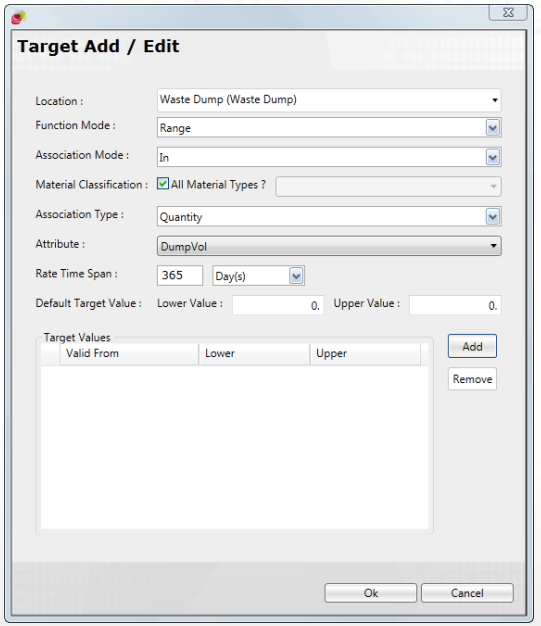
Targets | Material Flow Diagram | Scheduling Gantt

Location	Function Mode	Association Mode	Material Classification	Association Type
Mill	Range	In	All Classifications	Quantity
KCGM->AB	Maximum	Out	All Classifications	Quantity
KCGM->BH	Maximum	Out	All Classifications	Quantity
Mill	Minimum	In	All Classifications	Attribute - Au
Production	Minimum	In	Gold	Quantity
Leach	Range	In	All Classifications	Quantity
Waste Dump	Range	In	All Classifications	Quantity - DumpVol

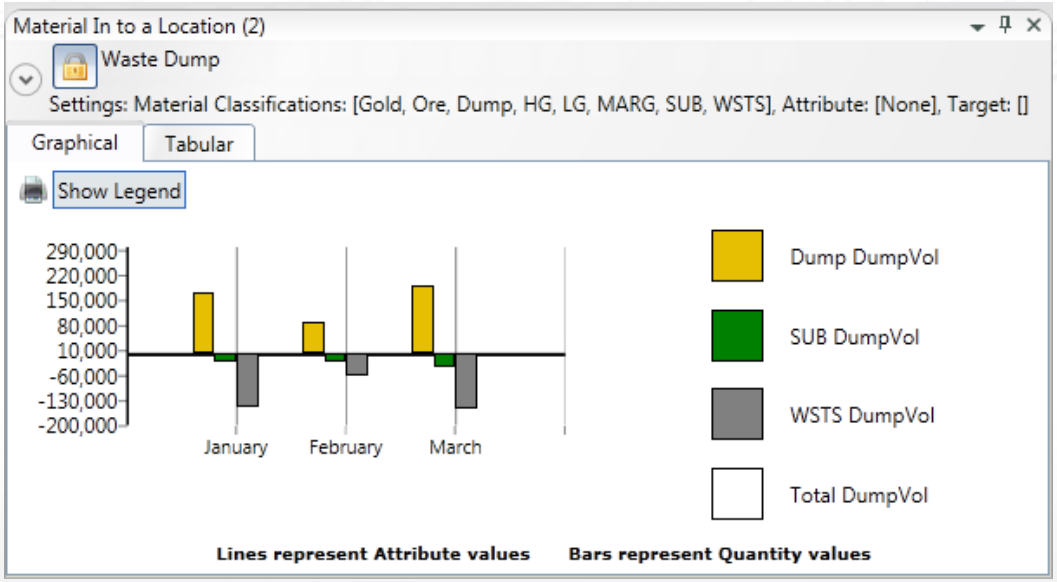
Resource Availabilities | **Resource Transfer Rates** | Targets | Material Flow Diagram | Scheduling Gantt

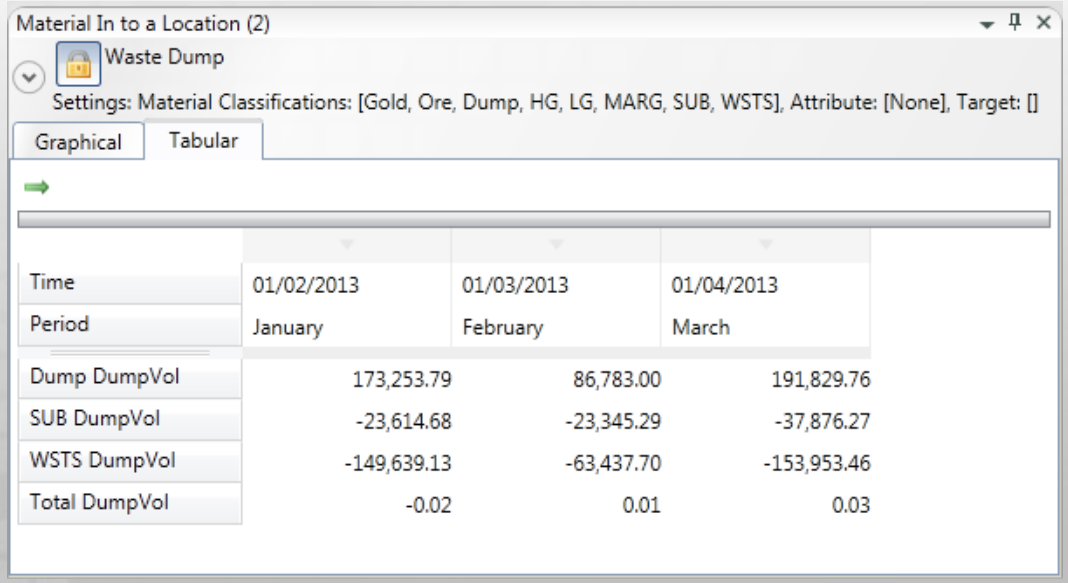
Source Location	Destination Location	Resource Name	Rate Per Unit	Material Classification
KCGM->AB->-100	Waste Dump	Truck Fleet 1	7,000.00	All Classifications
KCGM->AB->-90	Waste Dump	Truck Fleet 1	6,800.00	All Classifications
KCGM->BH->-100	Waste Dump	Truck Fleet 1	7,000.00	All Classifications
KCGM->BH->-90	Waste Dump	Truck Fleet 1	6,800.00	All Classifications
KCGM->OY->-330	Waste Dump	Truck Fleet 1	7,000.00	All Classifications
KCGM->OY->-340	Waste Dump	Truck Fleet 1	6,800.00	All Classifications
KCGM->OY->-350	Waste Dump	Truck Fleet 1	6,600.00	All Classifications
KCGM->OY->-360	Waste Dump	Truck Fleet 1	6,400.00	All Classifications
KCGM->ST->-230	Waste Dump	Truck Fleet 1	7,000.00	All Classifications
KCGM->ST->-240	Waste Dump	Truck Fleet 1	6,800.00	All Classifications
KCGM->ST->-250	Waste Dump	Truck Fleet 1	6,600.00	All Classifications
KCGM->ST->-260	Waste Dump	Truck Fleet 1	6,400.00	All Classifications
DetailedDump->1	Waste Dump	Truck Fleet 1	4,000.00	All Classifications
DetailedDump->2	Waste Dump	Truck Fleet 1	4,500.00	All Classifications
DetailedDump->3	Waste Dump	Truck Fleet 1	5,000.00	All Classifications
DetailedDump->4	Waste Dump	Truck Fleet 1	5,500.00	All Classifications
DetailedDump->5	Waste Dump	Truck Fleet 1	6,000.00	All Classifications
DetailedDump->6	Waste Dump	Truck Fleet 1	6,500.00	All Classifications



- Dump volume balance constraint included together with processing constraints
- Trucking requirements dependent upon detailed dump location

Tempo Example : Dump Results





Time	01/02/2013	01/03/2013	01/04/2013
Period	January	February	March
Dump DumpVol	173,253.79	86,783.00	191,829.76
SUB DumpVol	-23,614.68	-23,345.29	-37,876.27
WSTS DumpVol	-149,639.13	-63,437.70	-153,953.46
Total DumpVol	-0.02	0.01	0.03

- Volume of sub-grade and waste classification material from pit balances with waste volume provided from dump

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Multiple Waste Dumps

- Any number of waste dumps (e.g. short haul, long haul) can be set up
- Each waste dump uses a common waste dump volume quantity
- Single multi-period optimization will choose alternative waste dumps to balance trucking over life of mine

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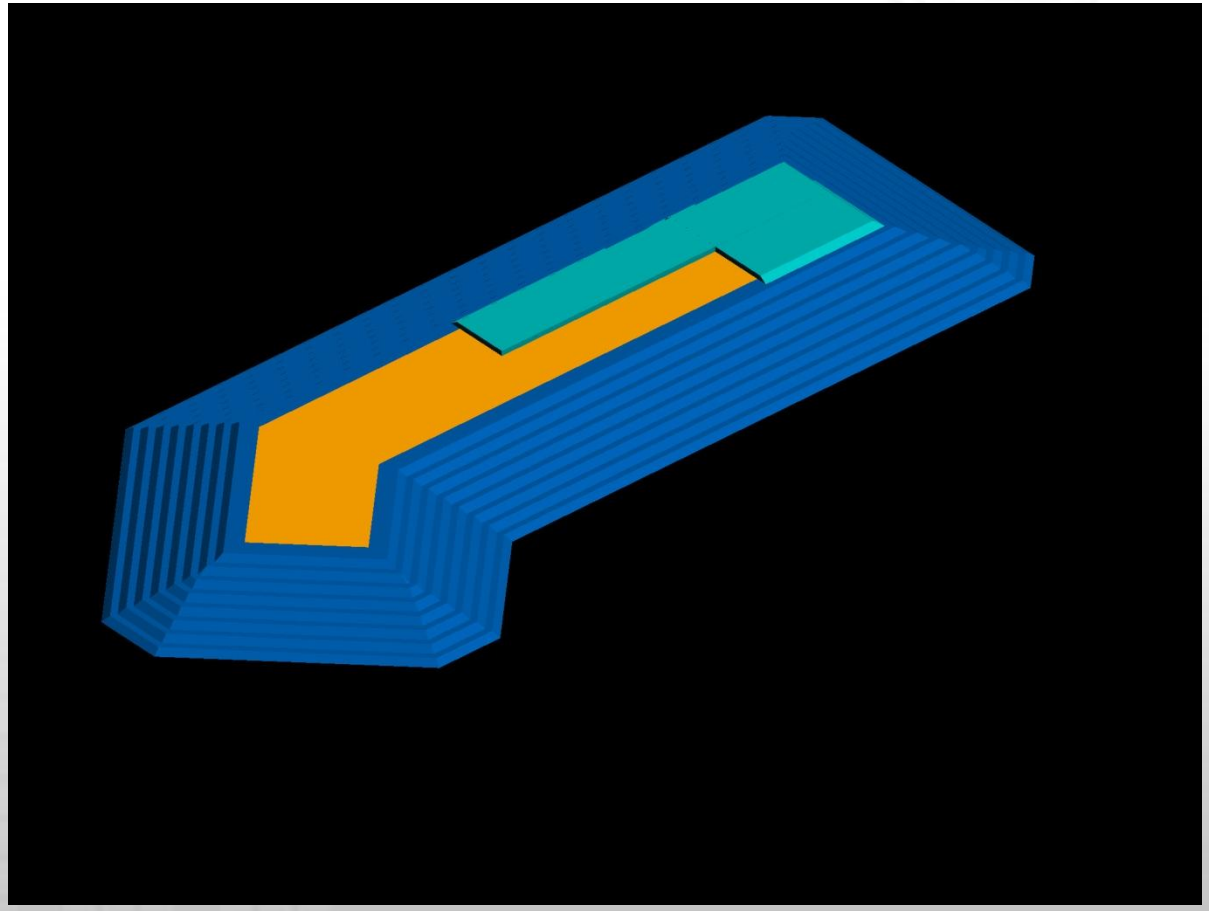
Heap Leach

- Introduce a heap leach dump volume quantity in addition to the heap leach ore tonnes quantity
- Define heap leach locations as lifts or blocks similar to a waste dump
- Heap leach locations contribute to heap leach dump volume quantity
- Blocks scheduled to heap leach contribute to both heap leach ore quantity and heap leach dump volume quantity
- Define volume balance constraints for heap leach dump volume quantity

Containing Reactive Waste



- Introduce reactive and non-reactive wdv quantities which each have their own volume balance constraints
- Internal dump blocks and in-pit reactive waste blocks contribute to reactive wdv quantity
- External dump blocks and in-pit non-reactive waste blocks contribute to non-reactive wdv quantity

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Conclusion

- Introduced a generic way to model joint pit and detailed waste dump schedule optimization
- Implemented modelling technique in 3 of Minemax's schedule optimization solutions
- Outlined extensions for multiple waste dumps, heap leach and reactive waste
- Modelling technique can be applied to any lp-based mine schedule optimizer that models multiple quantities on a block