

**Workshop: Generating Risk Profiles for
Production Schedules of Mining
Complexes – The Risk Analysis Tool (RAT)**

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Workshop: Generating Risk Profiles for Production Schedules of Mining Complexes – The Risk Analysis Tool (RAT)

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Abstract: Mine scheduling requires input variables such as geological model and economic values in order to deliver an optimal production schedule. Geological uncertainty in grades, metal and material types cause a difference in the performance of forecasted long-term production scheduling. The risk analysis of a production schedule given geological uncertainty assists the potential performance of robust mine planning and risk management. The Risk Analysis Tool (RAT) uses as input the mine production schedule and the set of stochastic simulations of the mine deposits. The workshops show how the risk analysis is carried out using the available RAT in COSMO Stochastic Mine Planning Laboratory. Data from a copper Martian mine is used to describe the use of the software.

Key Words: Production schedule, materials, simulations, mine process, risk profiles.

1 Introduction

The purpose of the workshop is to show the use of Risk Analysis Tool v. 1.0.0 software (RAT) and perform risk analysis for a given mine design and production schedule. It is hoped that following the workshop, the user will be able to perform the risk analysis of any production schedule with multiple mines and multiple destinations, and will be able to customize the risk profiles according to their needs. To date, RAT has been tested successfully on 64-bit computers that have Windows XP or Windows 7 operating systems and Microsoft Excel 2007 or Microsoft Excel 2010. Note that RAT does not operate on a 32-bit machine and larger models with more than 20 orebody simulations will require a computer with more than 4GB RAM and 1 GB available hard drive space.

An executable file RATsetup.exe is included in the installation package of Risk Analysis Tool v. 1.0.0. The installation will start by simply double clicking **RATsetup.exe**. Click the **Next** button in the first copyright panel then choose in the second panel where the application will be installed (e.g., C:\McGill COSMO\Risk Analysis Tool\) and click the **Next** button. Confirm the installation by clicking the **Next** button once more and a final panel should appear with a message that the installation is completed, see Figure 1.

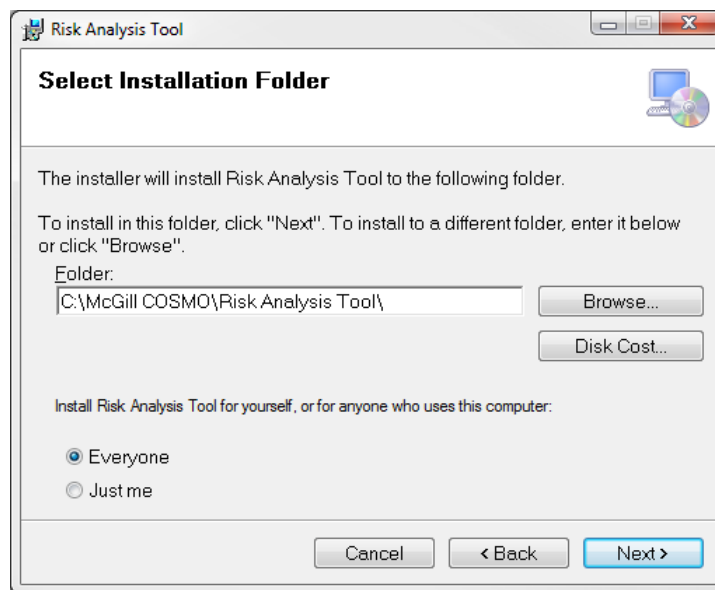
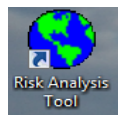


Figure 1: Second panel of the installation process

When the installation process finishes, a new icon will be added on the desktop and the software **Risk Analysis Tool** can be opened by double clicking this icon.

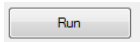


The workshop for the **Risk Analysis Tool** is divided into four sections. The first section describes the input files required; the second, the third and the fourth sections are the sequence that a user must follow to perform risk analysis using RAT.

- **Input data.** Explain the types of files and more specifically the information required for each input file.
- **Risk analysis model definition.** Configure the parameters that describe the orebody, material type and destinations. Define the objectives for the risk profiles to address and the types of profiles to be generated.

- **Generating risk profiles.** Read the previously defined parameters, generate risk profiles and save these risk profiles as output files.
- **Graphs of risk profiles.** Display graphs and interpretation of risk profiles.

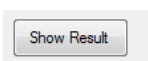
RAT requires a set of parameters that define the risk analyses model; these parameters can be defined from scratch or can be loaded and modified from a saved parameter file. The parameters must be saved as an ASCII XML file, then the risk analysis utility is run by pressing on the **Run** button in the main window, see Figure 2.



After clicking the **Run** button or executing the main routine, the parameters and the input data are read, the required risk profiles are generated and these risk profiles are saved.

Figure 2: Main window of Risk Analysis Tool v.1.0.0 software

Generating risk profiles is computer-intensive, particularly if the orebody are large with more than 20 stochastic simulations and the models involve multiple mines, that is, the main routine should be execute only one time unless additional risk profiles are required or an alternative mine design should be evaluated. Once the risk profiles are generated, the final step is to click the **Show Result** button in the main window.



The workshop uses data from a copper mine to illustrate how to set the required parameter by RAT. The data are referred to as the Martian mine and contain a set of five geological simulations. Each simulation contains the copper grades (%), block tonnage, recoveries and material type.

Given the type of material by block, there are a set of candidate destinations that the block can be sent to, see Figure 3. Each simulation also identifies the recovery (%) of the block if it is sent to the given destination. Along with the set of geological simulations, a production schedule file must be provided; this file contains the coordinates of each mined block and the period that the block belongs to. The Martian mine uses five material types, which are used to define the possible destinations. The material types are sulphide1, sulphide2, mixed, oxides and waste, see Figure 3.

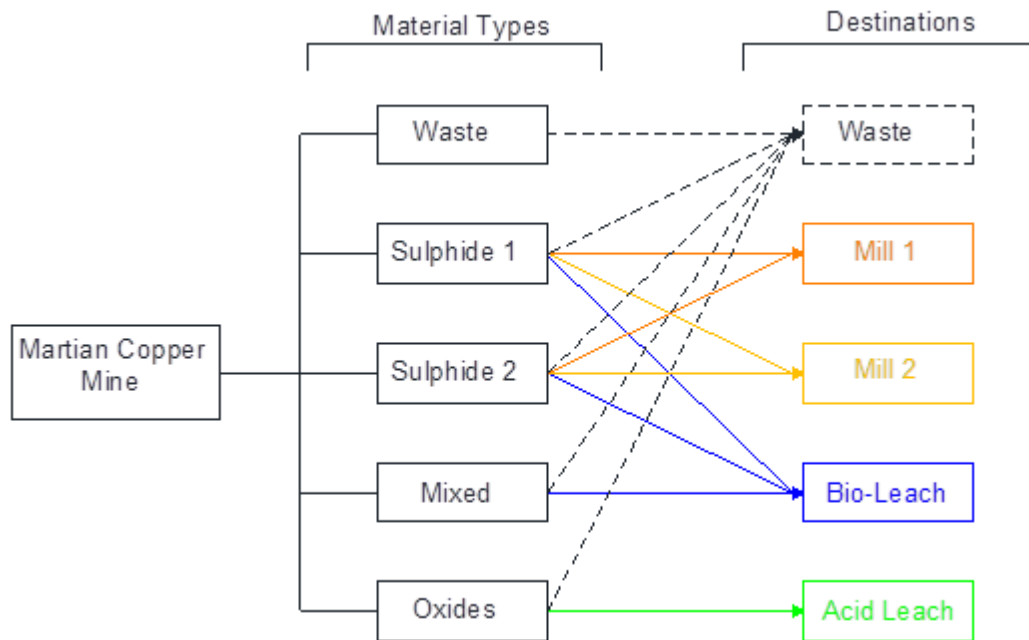


Figure 3: Material flow at Martian copper mine

All material types have the option of being sent to a waste dump, depending upon the value of the block. The two sulfide groups can be sent to either of two mills, to waste, or to bio-leach pad. The mixed material can either be sent to waste or to bio-leach pad and the oxide material can either be sent to waste or to acid leach plant.

The Risk Analysis Tool requires at least two types of input files. One is the set of simulation files and the second is a production schedule file. The installation package of RAT comes with five simulation files (*SimMartian1.txt* to *SimMartian5.txt*), a production schedule file (*MartianPhases.txt*), a mining cost adjustment factor file (*MartianMCAF.txt*) and an example of parameter configuration (*Martian_Mine.xml*) that is not essential when the parameters are set from scratch. These files can be found in the **Data** folder, located where the software was installed (e.g., C:\McGill COSMO\Risk Analysis Tool\RiskAnalysis Tools\Data).

2 Input Data

The input data is classified into two major categories: simulated and static. **Simulated data** is represented by a set of files, within each file contains information relevant to the simulation of an orebody (i.e. metal grade, material type, etc.) where the values for each block can vary from simulation-to-simulation. **Static data** is a single file that contains information that remains constant, regardless of the simulation's properties (e.g. mining cost adjustment factor, phase design and production schedule).

All the input data files must contain coordinates for each block in the ore body model. The input files must also have a header row that describes the information in each column. Each row in the data file should represent a different block (defined by its x, y, z coordinates). Note: The input data can not contain duplicates of blocks in the same file, and can be either tab or space delimited between the columns. The user should take the time to acquaint themselves with the data and classify the information before running the program.

2.1 EXERCISE 1: Data classification

The user should make a table that describes each column of the input file, see Table 1. The availability of this table and future tables around the workshop avoid mistakes through the model set. Also, a correct data classification reduces the amount of memory required for the software. The input data is classified according to the type of information it contains. The file is classified as Simulated or Static and each of its columns will be a property that is organized as follows:

- **Coordinates.** These can be in either xyz format that represent mid block coordinate location or ijk format that represent reference column, row and bench integer numbers. Once the format is chosen, the format must be consistent throughout all data files.
- **Material type.** There must be one column that describes material types by each block for each simulation file. The material type is described by integer numbers, e.g., 1 is waste, 2 is sulfide. The material types are simulated because and varies through all orebody simulation input files.
- **Important.** This is any information that should be used in the risk analysis model and does not match with existent property types. For example, element grades, simulated recoveries for each destination, cost adjustment factors and block tonnages. These values can vary from simulation-to-simulation or be static (remain constant) over all simulations.
- **Mine design:** only one mine design is evaluated with the provided risk analysis software. The mine design must be stored in a separate file and classified as static data. The mine design input file is mandatory to the software; otherwise, the risk profiles are not generated. If the user wants to evaluate multiple designs, the software must be run for each mine design and perform independent analyses. The user must figure out the time-scale for the mine design because the mine designs may be based on quarterly or annual designs. The user must maintain a consistent time-scale in a multiple-mine scenario. Note: The use of pushback for risk analysis of multiple-mine could be incorrect because one pushback for one mine might take longer time to mine than a pushback from another mine.

Martian mine contains 5 scenarios of the orebody or simulation files. Generally, if the input file column is not classified as coordinates property, material property or mine design property, the column is classified as an **Important** property. The fourth column in Table 1 informs that some columns could be part of file type simulated and others will be part of file type static; however, the coordinates are uploaded for both simulated file type and static file type because the software needs to link each property with the location of each block. Note: The coordinates of each block remain constant over all input files and only required columns from input files could be uploaded.

Table 1 describes the columns contained in each of the simulation files and their classification.

The second input data that contain Martian mine correspond to the mine design that was saved in an independent single file. The mine design or production schedule is stored in a file called *Martianphases.txt*. Table 2 gives an overview of the data contained in the schedule file. The production schedule file is always static data because the block will always be mined in the same period regardless of the geological scenario.

The third input data that contain Martian mine correspond to the mining cost adjustment factor that it is found in the file *MartianMACF.txt*. See Table 3.

The input files should be located in the **Data** subfolder of the installation folder e.g., C:\McGill COSMO Center\Risk Analysis Tool\RiskAnalysis Tools\Data. RAT assumes the **Data** folder as a working directory.

Table 1: The contents of the orebody simulations files

Column #	Column Name	Meaning	Files Type	Property Type
1	XC	Block's X coordinate	Static	Coordinate – xyz – x
2	YC	Block's Y coordinate	Static	Coordinate – xyz – y
3	ZC	Block-s Z coordinate	Static	Coordinate – xyz – z
4	MAT_TYPE	Material code	Simulated	Material
5	TONNES	Block tonnage	Simulated	Important
6	TOTCU	Block copper grade (%)	Simulated	Important
7	RECM1	Mill #1 recovery (%)	Simulated	Important
8	RECM2	Mill #2 recovery (%)	Simulated	Important
9	RECBL	Bio-leach recovery (%)	Simulated	Important
10	RECOX	Oxide leach recovery (%)	Simulated	Important

Table 2: The contents of the production schedule file

Column #	Column Name	Meaning	Files Type	Property Type
1	XC	Block's X coordinate	Static	Coordinate – xyz – x
2	YC	Block's Y coordinate	Static	Coordinate – xyz – y
3	ZC	Block-s Z coordinate	Static	Coordinate – xyz – z
4	Period	Year that the block is mined	Static	Mine design

Table 3: The contents of the mining cost adjustment factor file

Column #	Column Name	Meaning	Files Type	Property Type
1	XC	Block's X coordinate	Static	Coordinate – xyz – x
2	YC	Block's Y coordinate	Static	Coordinate – xyz – y
3	ZC	Block-s Z coordinate	Static	Coordinate – xyz – z
4	MCAF	Mining cost adjustment	Static	Important

3 Risk Analysis Parameters Definition

A mining sequence describes the life of the operation, the mines (ore bodies) involved and the processes that material can be sent to. The current version does not support stockpiles and blending operations. The mined material is sent to the destination that generates the highest possible value, or yields the lowest negative value if the block does not contain any profitable elements. In addition, RAT assumes that all the blocks of the mine schedule are mined. Prior to generating risk profiles, the variables to analyze must be defined. Risk could be associated with:

- Tonnage sent to Mill1, Mill2, Bio-leach, Oxides and/or to waste dump.
- Metal produced from Mill1, Mill2, Bio-leach or Acid-leach.
- Discounted Cash Flow produced by material sent to Mill1, Mill2, Bio-leach, or Acid-leach.
- Cumulative Net Present Value (NPV) of the production schedule.

The user is free to create other risk profiles according to their interests.

3.1 EXERCISE 2: Martian mine risk analysis parameters definition

The workshop will focus on Tonnage and Discounted Cash Flow produced by each destination of Martian mine during the setting of the risk analysis model. The RAT model is a set of parameters that the software needs to generate risk analysis profiles of a mine production scheduling. To set up the parameters the user must click the **Configure** button in the main window. A user interface window is opened; see Figure 4, where the **File** menu permits the creation of a new set of parameters from scratch or opening the predefined parameters.

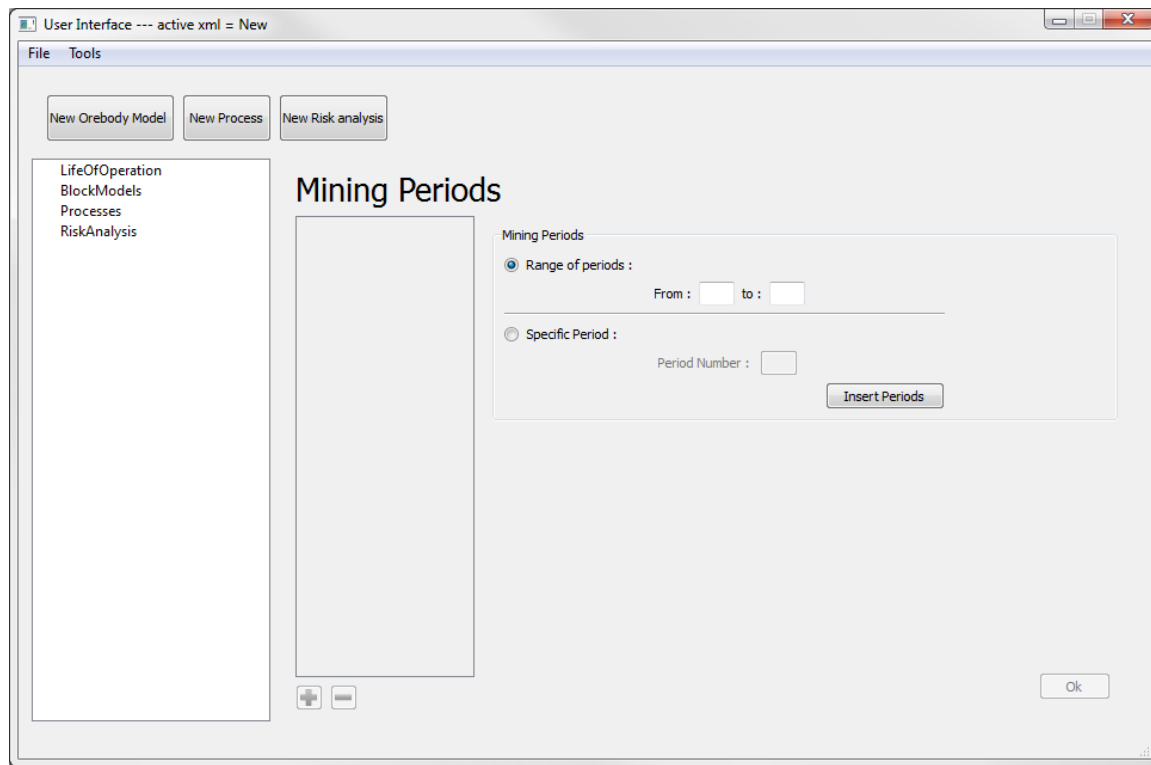


Figure 4: Empty risk analysis parameter set

Alternatively, the user can load the predefined parameter XML file by clicking the **Browse** button. The **User Interface** also permits verifying and modifying the predefined parameter file by selecting **File**→**Open** and saving the parameter file when the configuration is done, see Figure 5. The detail of the model configuration will be discussed in further sections.

3.2 Setting up the mine's life operation

The life of the operation refers to the periods in which the mines operate. A simple case is for a single mine, where the operation life is defined by the life of the single mine. More complex cases can consider multiple mines, where each mine can operate at different times and may have temporary shut-downs. The user will be asked to enter the mining operation periods to be considered: time period or phases. A risk analysis of pushbacks for multiple mines is not recommended when pushbacks are mined over different time periods (as is commonly the case).

Figure 6 shows the mining periods window displayed when creating a new risk analysis configuration. In this window, the user is asked to enter the mining periods for the life of the operation. By default, **Range of periods** radio button is checked and permits the user to enter a range of periods.

☒ Range of periods :

To input a range of periods, the user could enter the lowest period number in the **From** textbox and the final period in the **To** textbox, e.g., the life of Martian mine needs to be set from 3 period to 10 period. To insert the periods press **Insert Periods** button.

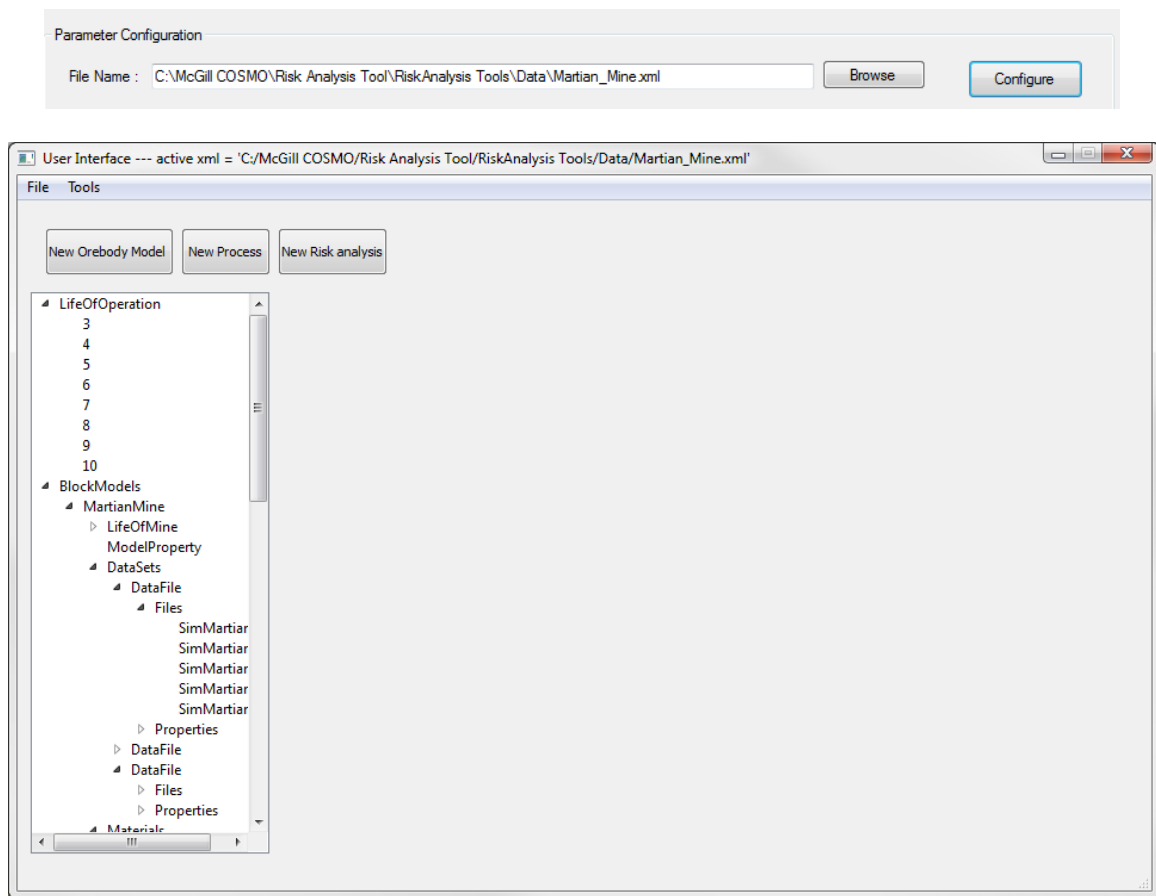


Figure 5: The upper box is part of the main window and the bottom panel shows the default parameter file *Martian_Mine.xml*

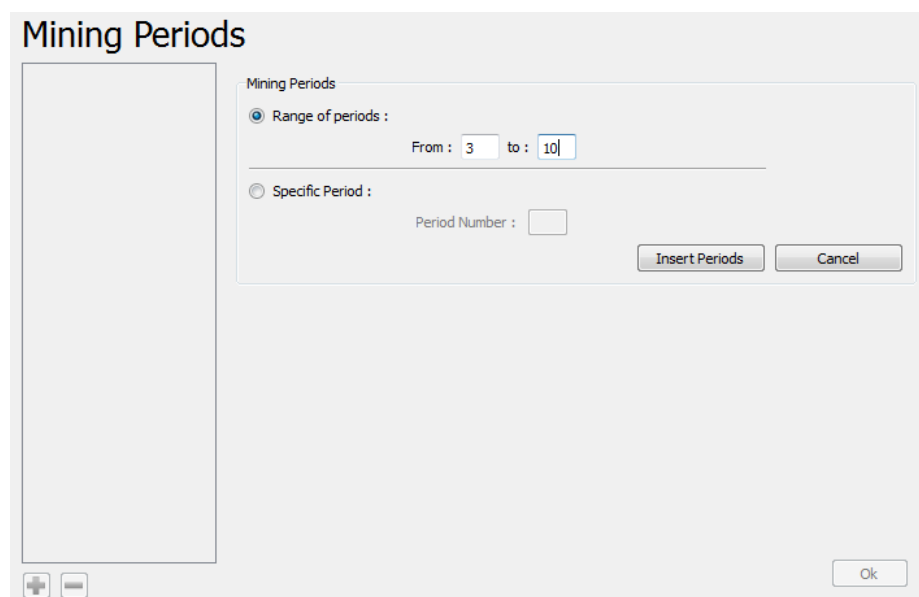


Figure 6: Initializing the periods of Martian mining operation

All changes should appear in the left hand list. To add periods individually, the user can check the **Specific Period** radio button, which permits the user to enter periods one at a time.

☐ Specific Period :

Once the period number is entered, the user should check the **Insert** button to insert the period. The operation mine's life is saved by pressing the **Ok** button in the bottom right corner of the application. Given that this is a single-mine scenario and we do not consider planned shutdowns, the mine will operate for all the 7 periods. This information is taken from the *MartianPhases.txt* file.

3.3 Setting up orebody models

The risk analysis requires several distinct and independent orebodies (or mines). To set up the parameters regarding orebody simulations and mine is required to create a new ore body model, click the **New Orebody Model** button at the top of the screen.

New Orebody Model

Alternatively, the user could select **Tools**→**Add orebody model**.

There are six steps to set up an ore body model for the risk analysis utility:

- **Basic information.** The user enters basic information about the ore body model, including mine name, coordinates, block dimensions and number of blocks.
- **Files.** The user defines information type of the input files, their type (static or simulated) and the relevant properties contained in the file.
- **Materials.** The user enters information related to the material types in the mine, their material ID (code) and the mining cost for the material.
- **Metals.** The user defines elements of interest in the mine that have an impact on the economic viability of a block. The user could create properties for each metal, for example the price (\$/lb) and a conversion factor to convert from (\$/lb) to (\$/t).
- **Expressions editor.** The user can make user-defined properties out of existing properties by creating expressions.
- **Constraints.** The user can use constraints to track relevant information (value, tonnages, metal) in the risk analysis, either for groups of materials or the mine as a whole.

3.3.1 Coordinates and basic model information

The basic information window, see Figure 7, allows the user to enter general information about the mine. The mine's name is entered in the **Mine Name** text box. In addition, the user must provide to RAT the coordinate system information as follows:

- The minimum x, y and z coordinates for the model, measured from the centre of a block with the lowest x, y and z coordinates.
- The block sizes in the x, y and z directions. The units are not important as long as they are consistent for each direction (i.e. meters in all directions or feet in all directions).
- The number of blocks in the x, y and z directions. This helps to define the size of the orebody model in each direction.

Table 4 gives the basic information of the input orebody model, the coordinates, the number of blocks, and dimensions of the blocks.

For Martian mine risk analysis model the dimensions are in meters; please remember to keep consistent units of measurements and apply the proper conversions when necessary. The **Life of Mine** list on the

Table 4: Basic information of Martian orebody model

	X	Y	Z
Minimum	2155	2455	1505
Dimension of Block	10	10	10
Number of Blocks	122	114	57

right of the Basic information window is set by default to be the entire life of the operation. The user could customize this list if there are planned shutdowns, or in a multi-mine scenario where one mine finishes before another. To de-select a period, the user can click on the period that should be removed. If the Life of Mine list is cleared (everything is deselected), the user may press the **CTRL** or **SHIFT** button on their keyboard to select multiple periods. Alternatively, the user can click and drag while holding the button to select or deselect multiple periods.

Enter the name of the ore body as the “Martian Mine” and provide the minimum coordinates of the model, the block dimensions and the number of blocks according to the information of Table 4, see Figure 7.

MartianMine

Basic Information :

Mine Name :

Coordinate System :

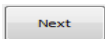
	x	y	z
Minimum Coordinate :	<input type="text" value="2155"/>	<input type="text" value="2455"/>	<input type="text" value="1505"/>
Block Size :	<input type="text" value="10"/>	<input type="text" value="10"/>	<input type="text" value="10"/>
Number of Blocks :	<input type="text" value="122"/>	<input type="text" value="114"/>	<input type="text" value="57"/>

Life of Mine

- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7
- ☐ 8
- ☐ 9
- ☐ 10

Figure 7: Setting up basic information for Martian mine

When finished entering the basic model information, press the **Next** button to continue to add data files and define model properties.



3.3.2 Data sets and files

The input data files contain information for each block, and can be classified as either static or simulated. These input files are loaded as a data set. A data set is an individual file or group of files that contain information for each block in the model. For a simulated data set, each input file must have the same header or column structure; however, the order of rows or blocks could be different amongst files.

To start creating data sets, press the **plus (+)** button below the left-hand tree.



The right-hand panel will be activated to permit upload information. The Martian mine require three datafiles to input the geological simulations files, the design mine file and the Mining Cost Adjustment Factor (MCAF) file. These are shown next.

DataFile of Geological Simulations

Each input file of the simulated data represents a different grade scenario

1. Select the **Type** of the file. There are only two options: **Simulated** and **Static**. The set of simulations of Martian mine are typified as **Simulated**, see Figure 8.
2. Select the **Property** tab to declare relevant information or properties for each block. Press the **plus (+)** button to add a new property. The user may specify three types of properties using the information of Table 5. After entering the properties, the user must press the **Add** button to save the changes.

- **Coordinates:** The user must specify the format, the direction and column.
- **Material:** Enter the name for the material and the material column.
- **Important:** The Martian mine require additional relevant properties that describe the block (e.g. Tonnage, Totcu, Recovery Mill1, Recovery Mill2, Recovery BL and Recovery OL) and must specify the property column in the simulation input files. Also, the user must specify a conversion factor, i.e., the metal grade as a %, require a decimal value 0.01 to use the grade in further calculations.

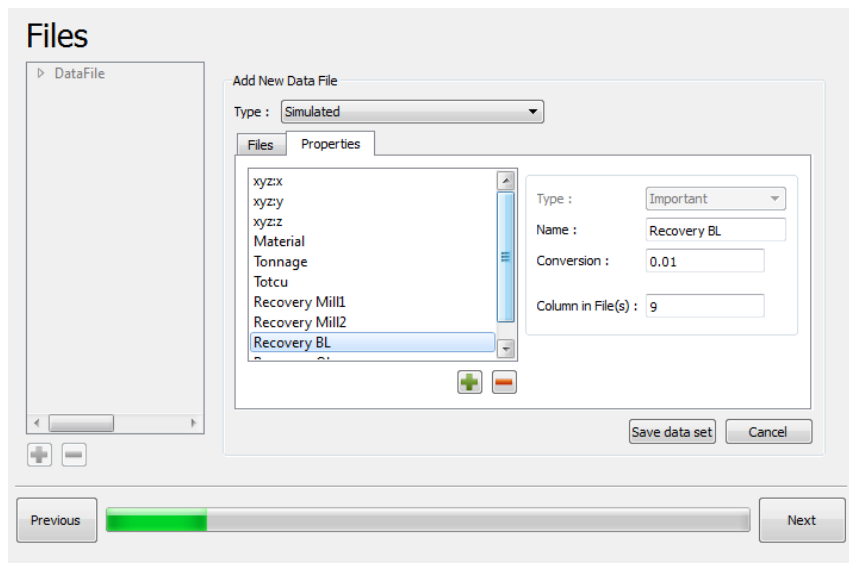


Figure 8: The properties set of simulation files

Table 5: Input parameters for loading geological simulations

Coordinates		
Direction	Format	Column in File
x	xyz	1
y	xyz	2
z	xyz	3
Material		
Name	Conversion	Column in File
Material	1	4
Important		
Name	Conversion	Column in File
Tonnage	1	5
CUGrade	0.01	6
Recovery Mill1	0.01	7
Recovery Mill2	0.01	8
Recovery BL	0.01	9
Recovery OL	0.01	10

The DataFile of Martian mine simulation was set as in Figure 8.

3. Select the **Files** tab and press **Datafile/Files**, see Figure 9, to add files. Press the **plus (+)** button to open the file browser. Navigate the **Data** subfolder of the installation folder to select the input data. If the data type is simulated, the user can select multiple files at once by pressing and holding **CTRL** or **SHIFT** on the keyboard while selecting the files with the mouse.

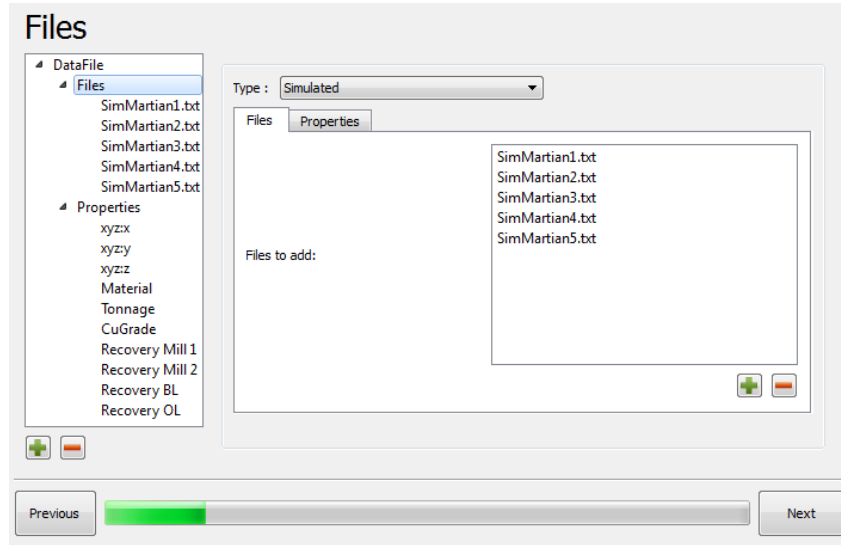


Figure 9: Loading the five grade scenarios of Martian mine

Please verify in the left list of the previous window if the simulation files were added correctly.

DataFile of Production Schedule

The second required input data file is the production schedule periods. This file must have a period column which is defined as **Mine Design** property in RAT.

1. Select the **Type** of the file. The production schedule file corresponds to a static data.
2. Select the **Property** tab to declare relevant information or properties for each block. Press the **plus (+)** button to add a new property. The user may set the mine design property using the information of Table 6.

Table 6: Input parameters for loading the mine production schedule

Coordinates		
Direction	Format	Column in File
x	xyz	1
y	xyz	2
z	xyz	3
Mine Design		
Name	Conversion	Column in File
Period	1	4

The mine design property will contain the mining periods. The user can export more than one mine design and select the one that will be used for the risk analysis. To select the mine design to evaluate, the user should check the box and save the property.

☒ This property is the current mine design

The DataFile of the production schedule of Martian mine should be set as in Figure 10.

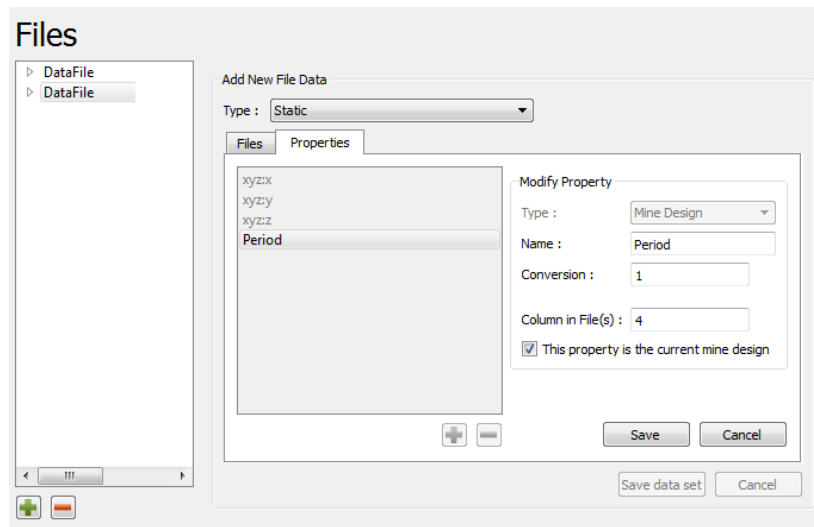


Figure 10: Set coordinates and mine design properties

3. Select the **File** tab and press **Datafile/Files**, see Figure 11, to add files. Press the **plus (+)** button to open the file browser. Navigate the **Data** subfolder of the installation folder to select the single *MartianPhases.txt* input data.

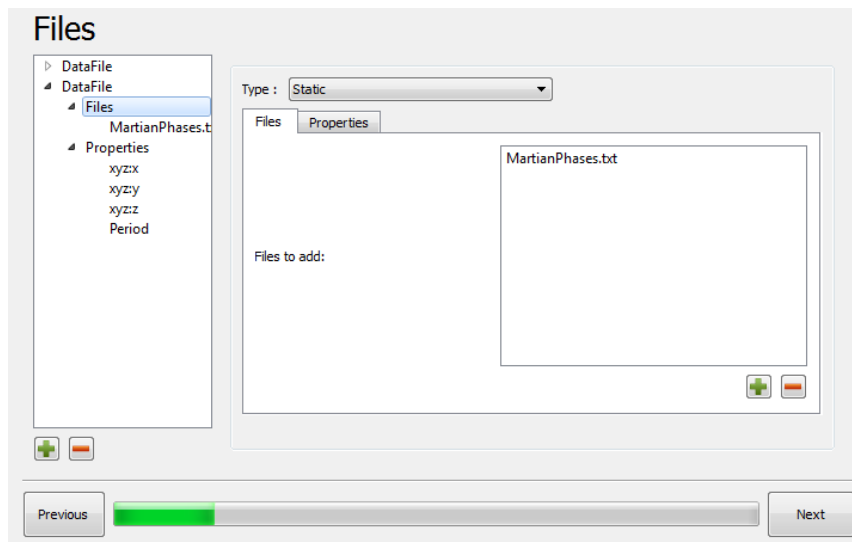


Figure 11: Adding mine design data file to the model

Note: If the static data (mining periods, MCAF) is distributed over multiple files. The user must create multiple data sets to read from the different files. Please verify in the left list of the previous window if the schedule file was added correctly.

DataFile of Mining Cost Adjustment Factor

The mining cost adjustment factor (MCAF) of Martian mine is given in file *MartianMCAF.txt*. The MCAF of each block are constant values among the five scenarios of the grade. The DataFile for MCAF is loaded as follow:

1. Select the **Type** of the file. The MCAF file corresponds to a static data.
2. Select the **Property** tab to declare relevant information or properties for each block, see Figure 12. Press the **plus (+)** button to add four new properties. The user may set the properties of the MCAF file using the information in Table 7.

Table 7: Input parameters for loading the mining cost adjustment factor

Coordinates		
Direction	Format	Column in File
x	xyz	1
y	xyz	2
z	xyz	3

Important		
Name	Conversion	Column in File
MCAF	1	4

The DataFile of the Martian mine MCAF static data should be set as in Figure 12.

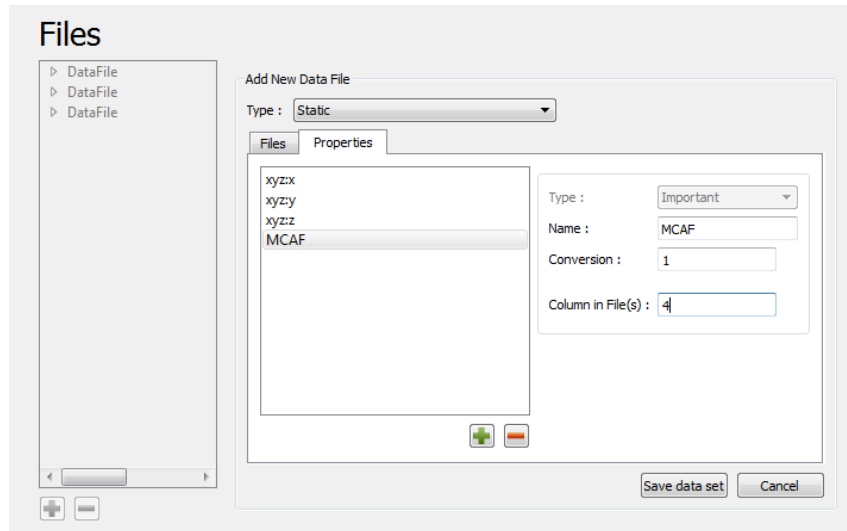


Figure 12: Set coordinates and important property (MCAF)

3. Select the **File** tab and press **Datafile/Files**, see Figure 13, to add files. Press the **plus (+)** button to open the file browser. Navigate the subfolder **Data** of the installation folder to select the single *MartianMCAF.txt* input file.

The MCAF factors are constant values read from important property that will be applied to each simulation. After entering all relevant information for the data sets, press the **Next** button to continue to define the Martian mine's material types.

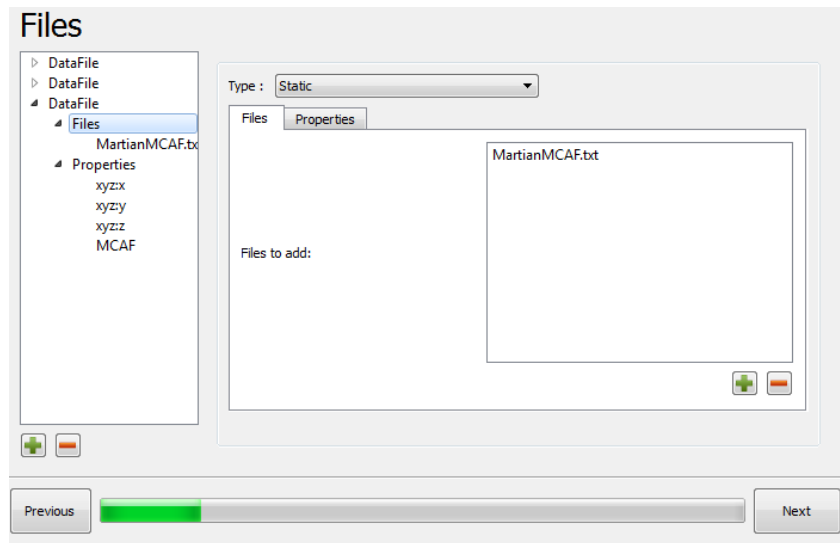


Figure 13: Adding MCAF data file to the model

3.3.3 Materials

A mine may have material types flagged by codes. The material window permits the user to associate the material names with material codes and mining costs. The material codes are integer values stored in **Material** property defined in the previous **DataSet** section.

Press the plus (+) button below the left hand list to add a new material, see Figure 14. Then, the **Add New Material** box on the right-hand side is enabled. Enter the name for the material (e.g. “Waste” or “SULF”), the material code and the mining cost. For Martian mine we have five material that are part of the simulation files as *Mat_Type* column. The summary of these codes and their respective mining cost are shown in Table 8.

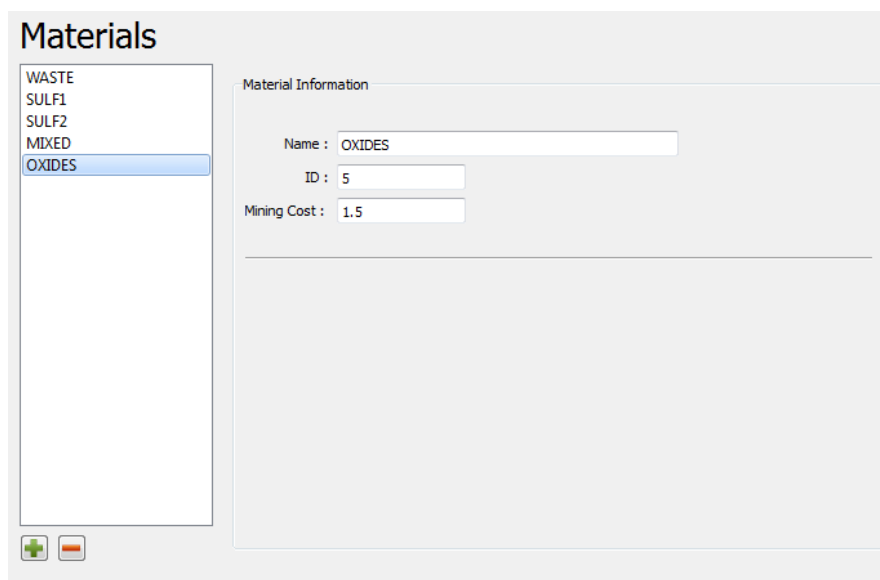


Figure 14: Adding materials and specifying mining cost for the Martian mine risk analysis model

Table 8: Input parameters for loading material of Martian mine to model

Material Name	Material Code	Mining Cost
Waste	1	1.5
SULF1	2	1.5
SULF2	3	1.5
MIXED	4	1.5
OXIDES	5	1.5

Press the **Add** button to save the material information and repeat the process for each material type using the information in Table 8 (see Figure 14).

Note: If some material requires extra drilling and blasting, the user could specify different mining costs for each material.

When finished, press the **Next** button to continue the setting of the Martian mine's metal types.

3.3.4 Metals

Metals are used to describe elements of interest in the blocks; the element could be a metal value and also some property that provides either a positive or negative economic value to a block. Figure 15 shows the window used to add metals to the ore body model. To add a metal (or element of interest), press the **plus (+)** button below the left-hand tree, enter a metal name (e.g. "Copper", "Au", etc.), and press the **Add** button. The properties that are relevant to include are the value of the metal (e.g. \$/lb metal) or a conversion factor to convert the metal value from \$/lb to \$/t. For Martian mine the metal "Cu" must contain one property called "Value" with the metal's projected price 1.76 as property value and another property called "ConvertPoundsToTonnes" with the conversion factor 2204.622 as property value.

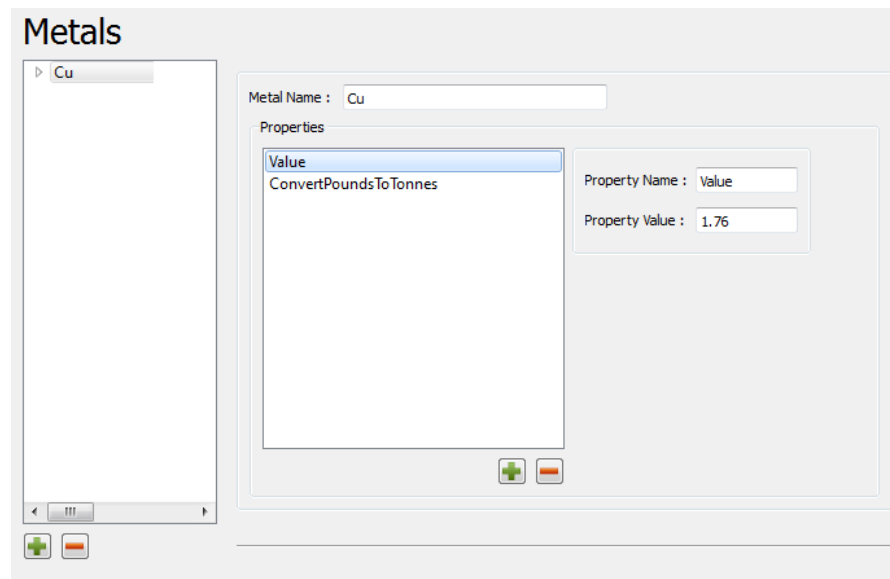


Figure 15: Adding metal and metal properties to the Martian mine risk analysis model

After all metals or elements have been declared, press **Next** to continue the setting of the Orebody Model parameters.

3.3.5 Expression

Expressions are processed by the software and treated as new properties, similar to the data file properties seen earlier. The expression editor is used for two primary purposes:

- To tell the software how to calculate the value of a block and permit a high-degree of complexity evaluations.
- To create new properties based on data file properties that were loaded. This avoids pre-processing steps.

To create an expression, press the **plus (+)** button on the bottom of the left-hand list. Give the expression a name, and specify whether or not the expression defines a block value or a property. The Martian mine require the creation of Metal Content expression and Value expression. To calculate the tonnage of metal in a block for a copper mine, the expression of metal content is set as in Table 9.

Table 9: Expression required to do the risk analysis evaluation of Martian mine

Name	Save As	Expression
MetalContent	Property	Block.CuGrade * Block.Tonnage
Value	Block Value	Block.MetalContent * Process.Recovery.Cu * (BlockModel.Metal.Cu.Value * BlockModel.metal.Cu.ConvertPoundsToTonnes) – BlockModel.MiningCost * Block.MCAF * Block.Tonnage – Process.ProcessingCost * Block.Tonnage

The value by block is calculated by the revenue of the block minus the mining and processing costs of the block. The two expression of Martian mine are set as in Figure 16; however, it is important to remark that the second expression in the previous table is calculated after the Process is set because the Process.ProcessingCost variable is defined in the Process section that follows.

All the defined properties of former sections appear as variables and are available to create expressions. The created expressions automatically are registered as additional variables (e.g., The Block.MetalContent variable, see Figure 16, corresponds to the first expression created for Martian mine). The Metal Content expression is used to create an expression to define the value of each block, that is, expressions are used in consecutive expressions as one variable more, see Figure 16.

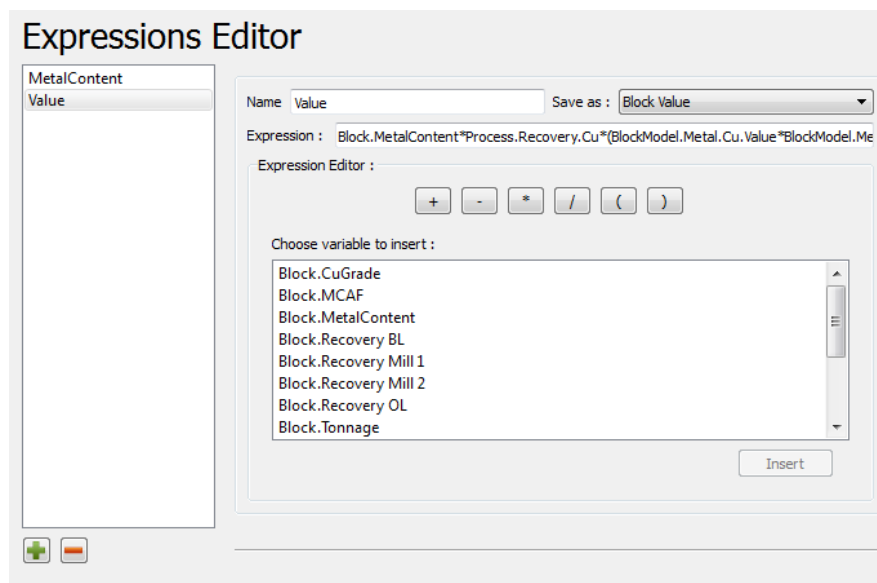


Figure 16: Adding expression to the Martian mine risk analysis model

Under the Expression panel, each **variable** is defined by one of three major categories and their respective sub-properties. The BlockModel category and Block category are explained in this section and the Process category will be explained in the Process section.

- **OrebodyModel.** Parameters that apply to the whole orebody model.

MiningCost – mining cost for the block because the software considers that these costs may change depending on what material the block is classified as, e.g., OrebodyModel.MiningCost.

Metal – the software search for the metals added and each respective sub-properties (Orebody-Model.Metal. (*Metal Name*).(*Metal Property*)), e.g., OrebodyModel.Metal.Cu.Value.

- **Block.** Properties can change from block-to-block and between each simulation.

(*Property name*) – the properties loaded from the data files, e.g., Block.CuGrade.

(*Expression name*) – a new expression can be evaluated from previously defined expressions. As you add more expressions to the model, these expressions will be added to the variable list, e.g., Block.MetalContent.

Note: The expression editor panel is displayed only in this Orebody Model section and some expressions may require variables from the next Process section, that is, the user must return to this Orebody Model section to finish the setting of expressions that use Process variables when the next Process section has been set.

To save the expression to the model, press the **Add** button. After the expressions have been entered, press the **Next** button to continue with the setting of constraints.

3.3.6 Constraints

The constraints are used to track relevant information. **Constraints** can be used to track the tonnage mined from the orebody over the entire life of a mine, over only specific periods and over specific materials. The constraint can be customized for specific properties, periods and materials. The Martian mine constraints are set as in Figure 17.

Figure 17: Adding constraints to define which variables RAT should use to calculate a risk profile

Press the **plus (+)** button found in the lower left of the **Constraints** window to create conditions, see Figure 17. Enter a description of the constraint (e.g., “Tonnage”). Select the **Block.Tonnage** property from the drop-down combo box; all block properties and expressions are listed in this box, that is, the user can select which periods to track the property in or which property to track by selecting the period(s) or/and material(s) from the appropriate lists. After all metals or elements have been declared, press the **Next** button to continue the setting of the risk analysis model. Also, the user should save the progress of the parameter configuration by clicking **Save** in the **File** menu.

3.4 Setting up processes

Processes are destinations that extracted material can be sent to. RAT assumes that the specify process is the final destination for the material and the saleable product is evaluated unless the destination is waste, where recovery is 0.0. Five consecutive steps define each process and are as follows:

- Basic information: name of the process.
- Processing costs: defines which incoming materials the process accepts. Costs can be changed depending on the material being processed.
- Recovery: different recoveries can be applied to the various metals and materials from each of the simulations and mines.
- Properties: information that applies to each process; values can vary depending on the process (e.g. refining charges).
- Constraints: methods to track the relevant information on material sent to the process over time.

The number of processes required will depend on the mine. To create a process, press the **New Process** button or select **Tools**→**Add Process**.



Each process is set following the previous five steps. The Martian mine require to add waste process, Mill1 process, Mill2 process, Bio-leach process and Oxide process to the risk analysis model, that is, these processes are added and set one after the other.

3.4.1 Basic information

Unlike the ore body model, the basic information for a process should be fairly straightforward and only the name of the process is required, see Figure 18.

Figure 18: Setting up the basic information for waste process

Enter the name in the **Process Name** textbox. When finished, press the **Save** button.

3.4.2 Processing costs

Processing costs are used to charge a monetary value to the incoming material from the mine and the user must define which materials can be sent to the process being created. All materials from the orebodies are loaded in the left-hand list. The Martian mine presents five materials that should be linked with each process, see Table 10.

By defining a processing cost for a material in the left-hand pane, the user decides if the process accepts that incoming material type. When there is no cost associated, the user can select all materials with default cost of \$0. (e.g., waste dump without associated treatment charges). The Process Cost window should be set using the information in Table 10 for each process of Martian mine.

When a material is selected and a processing cost is entered, the information can be saved by pressing the **Ok** button on the right-hand side of the screen. Any materials that are not saved with a cost will not be evaluated. For Martian mine, it was assumed that all materials will have the same processing cost for a given destination.

Table 10: The material of each Martian mine process and the associated processing cost

Material Name	Processing Waste	Cost	Processing Mill1	Cost	Processing Mill2	Cost	Bio-leach	Processing Cost	Oxide Leach	Processing Cost
Waste	Selected	0								
SULF1	Selected	0	Selected	6	Selected	6	Selected	1.5		
SULF2	Selected	0	Selected	6	Selected	6	Selected	1.5		
MIXED	Selected	0					Selected	1.5		
OXIDES	Selected	0							Selected	4

Figure 19: Setting up the processing cost for Martian mine input materials

3.4.3 Recovery

Recoveries define how effective the process is at extracting the metals (elements) of interest from the incoming material. Recoveries can either be stored in a file or not. The user must select which ore body model and metal the process recovers, and the associated input property that relates to the recovery for that metal. Since RAT considers only which materials are permitted to be sent to the given process, all recoveries for material without cost are ignored. Once the recovery form is filled out then press the **Add** button to save the recovery. Be sure to repeat the process for each ore body and each metal that the process treats.

Rather than storing recoveries in input files, there is also the option to apply a “blanket” recovery for a given metal and material. This is the case for a waste dump where it is not necessary to store the block’s recovery. Select **No** from the drop-down list and enter 0 because no metal is recovered from waste.

The user can specify a blank recovery value by entering it as a blanket value (Note: this is assumed to be a decimal value and not in percentage, %, format). The user can then select which mine, metal and materials the blanket factor applies to. The user should be cautious and ensure that a recovery is given for each mine, metal and material type. This can be verified by looking at the left-hand panel in Figure 20.

The recovery for Mill1, Mill2, Bio-leach and Oxides process are set with a unique Orebody Model Martian Mine and a Metal Cu; otherwise happen with the set of the recovery property.

The recovery property changes for each process. The Mill1 process is linked with **Recovery Mill1** property, the Mill2 process is linked with **Recovery Mill2** property, the Bio-leach process is linked with **Recovery BL** property and the Oxide process is linked with **Recovery OL** property, see Figure 21.

The defining recoveries for metals are stored as a model property and when all recoveries have been entered for the process, press the **Next** button to continue on to define process properties.

3.4.4 Properties

Properties can be defined for each process and can differ for each of the processes (destinations). As long as the property name remains the same from process to process, RAT will apply the correct property value when evaluating ore body model expressions. For example, a refining charge may apply to milled material,

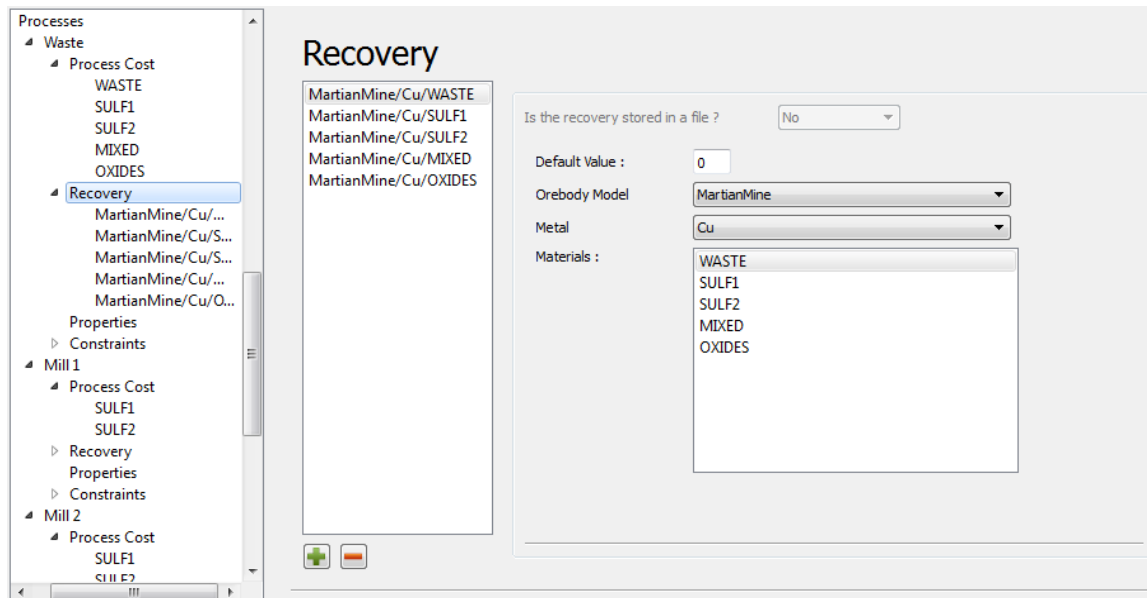


Figure 20: Add recovery for each material in Waste process

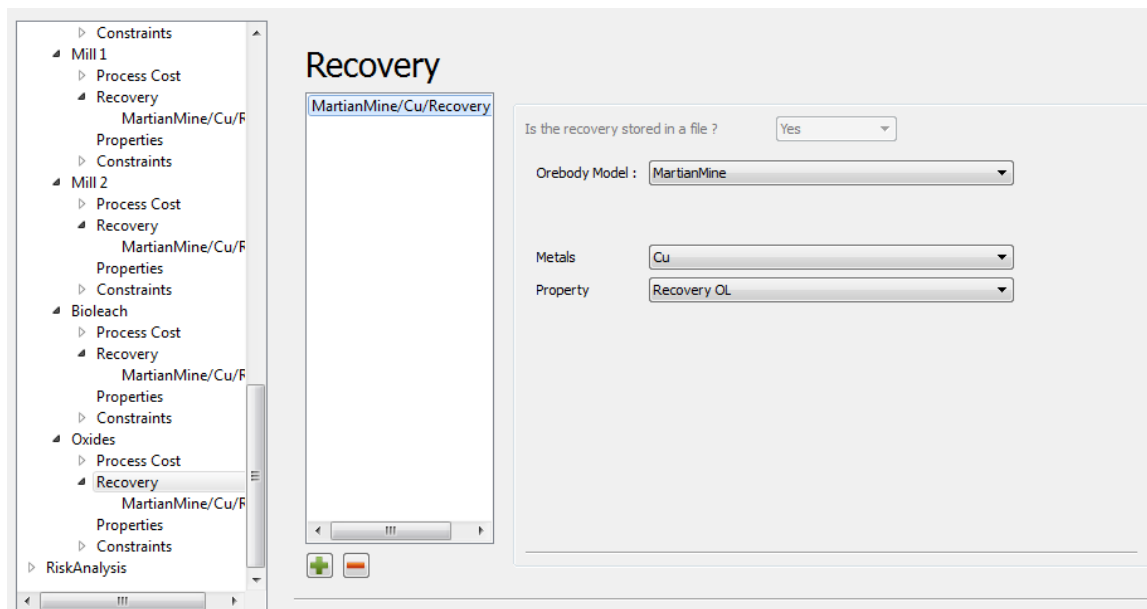


Figure 21: Set recovery for a metal Cu whether recovery is read from simulations files

which is different than a refining charge applied to materials from an oxide leach. To accommodate this, a “charge” property can be created for each of the processes, and different values are supplied for the mills and the leached material. The property can then be included in the ore body model expression for calculating block values; if a property is not specified for the process (e.g. a “charge” property for the waste), the default value will be 0 and no charge will be applied at all.

This feature may not be necessary in many cases; however, it is available to provide some flexibility when modeling the user-defined properties and block values for the ore body models. To add a property to the process, press the plus (+) button below the left-hand list. When the name and value have been entered,

Figure 22: Creating process properties

press the **Add** button to save the changes. The Martian Mine did not require the use of property by process. Then, we can leave empty this window for all the process and press the **Next** button to continue to enter the process constraints.

3.4.5 Constraints

Similar to ore body model constraints, the process constraints are used to track relevant incoming material over the life of the mine, which ultimately are used to generate risk profiles. Note that this form is slightly different from the mine constraint form; however, the operation is quite similar.

To add a constraint, press the **plus (+)** button below the left-hand list and provide a description of the constraint, for example Mill1 Tonnage. The **Apply to Properties** box will list all properties and user-defined expressions for all of the ore bodies. If the user wishes to track incoming tonnages from multiple mines, press and hold **CTRL** or **SHIFT** while selecting items from the list. The software will add the values for each production period (e.g. tonnages or value from two mines). Select the production periods that should be tracked, along with the material types that should be tracked. If only certain incoming materials should be tracked, select the relevant materials by holding **CTRL** or **SHIFT**.

The software has a specific method for parsing user-defined expressions; each **variable** is defined by one of three major categories and their respective sub-properties. The **Process** category is related to the destinations that material can be sent to (including a waste dump).

- **ProcessingCost** – processing costs are similar to mining costs in the essence that they can be customized or changed depending on the material type. The software will automatically apply the correct cost to the block depending on which material is selected.
- **Recovery.(Metal name)** – a given destination may attain various recoveries for different metals, which can differ from one process to the next.
- **(Property name)** – a process property can be applied for each process and used in the software. An example of this is a deduction per pound of metal; the deduction may be lower when the final metal product comes from a smelter rather than, for example, an oxide leach pad. If the same property name is applied for each process, the software will apply the appropriate deduction when calculating the value for the block.

For Martian mine we need to create Value constraints and Tonnage constraints that will be linked to MartianMine.Value and MartianMine.Tonnage property respectively and select all the period and material. These processing constraints are set as in Figure 23.

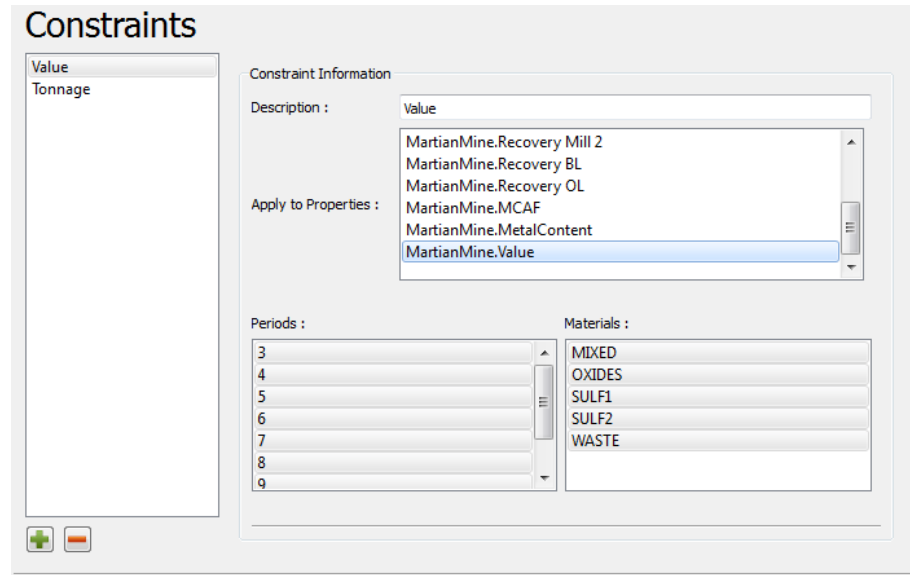
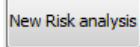


Figure 23: Creating constraints to track information about incoming material to a process

The process constraints are created in the same way for all the processes.

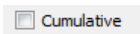
3.5 Defining risk analysis outputs

At the final step, the user defines the risk analysis output where is evaluated the performance of a mine design given several scenarios of the grade. To create a new risk analysis output, press the **New Risk analysis** button, or alternatively select **Tools**→**Risk Analysis** from menu.

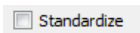


The constraint drop-down menu will allow the user to select any of the ore body model or process constraints previously defined. The output data of the risk analysis will be saved to the **Output File** – for example, the user could enter “*mill1_value.txt*” as an output file name.

A discount rate can be entered to gradually decrease the impact of values in the future. This is particularly useful for Net Present Value (NPV) analyses where a discount rate is typically used. A discount rate of 0 will yield no discounting at all. The values should lie between 0 and 1. To plot a cumulative distribution, check the **Cumulative** checkbox.



If the values should be standardized in terms of the average over all simulations for each period, check the **Standardize** checkbox.



When we have more than 20 simulations, the risk analysis graph can become cluttered. The **Risk Analysis** window gives the option of selecting only the minimum, maximum and averages for each period. The Martian mine risk analysis output files is set as in Figure 24.

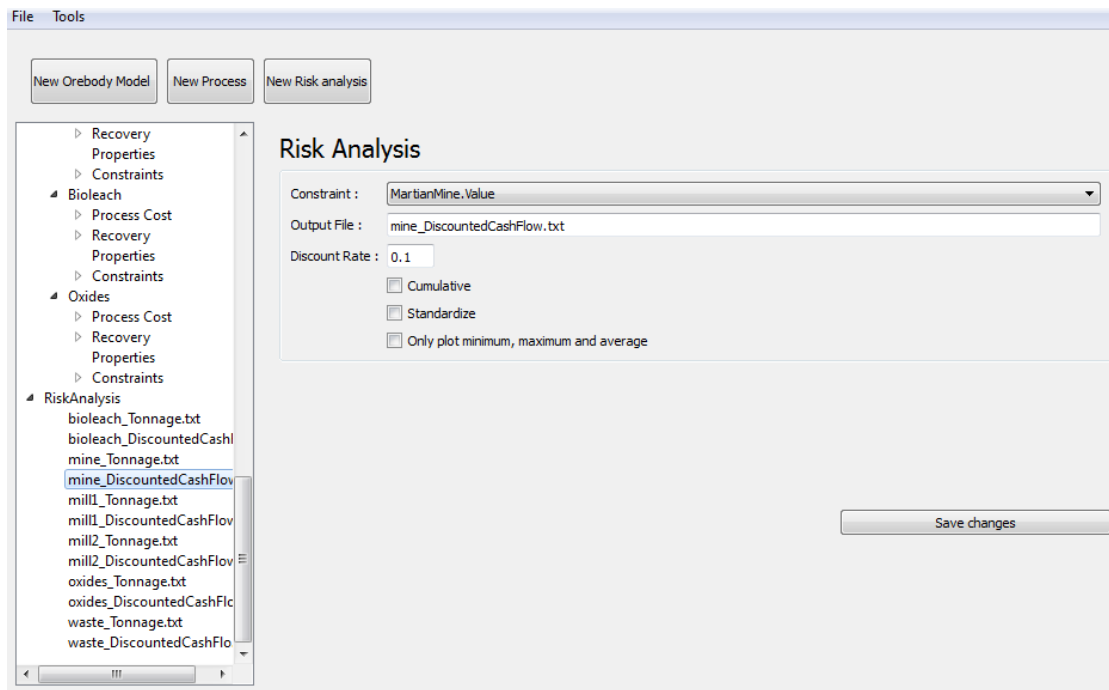
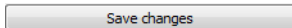


Figure 24: Preparing the risk analysis outputs

The changes must be saved by pressing the **Save changes** button after filling out the form.



When the preparation of the risk analysis output is completed, the whole parameter must be saved by selecting **File**→**Save** from menu.

4 Generating Risk Profiles

After the parameter file has been loaded or set, the user may press **Run** button to perform the risk analysis tool.



The progress of the evaluation is reported in the **Process Status** box and any errors encountered will be reported as well. The utility progresses through six main stages:

- Load the ore body models into memory.
- Initialize the process or destinations.
- Remove unnecessary information (filtering).
- Evaluate the mine constraints.
- Evaluate the process constraints.
- Save the risk analysis outputs to a set of files.

The output is a set of risk analysis files that store the period and value for the parameter of interest for each simulation (or combination of simulations, in the case of multiple mines), see Figure 25.

The risk profiles are generated and saved in hard disk. The risk analysis graphic could be done directly in the RA software or by using Microsoft Excel.

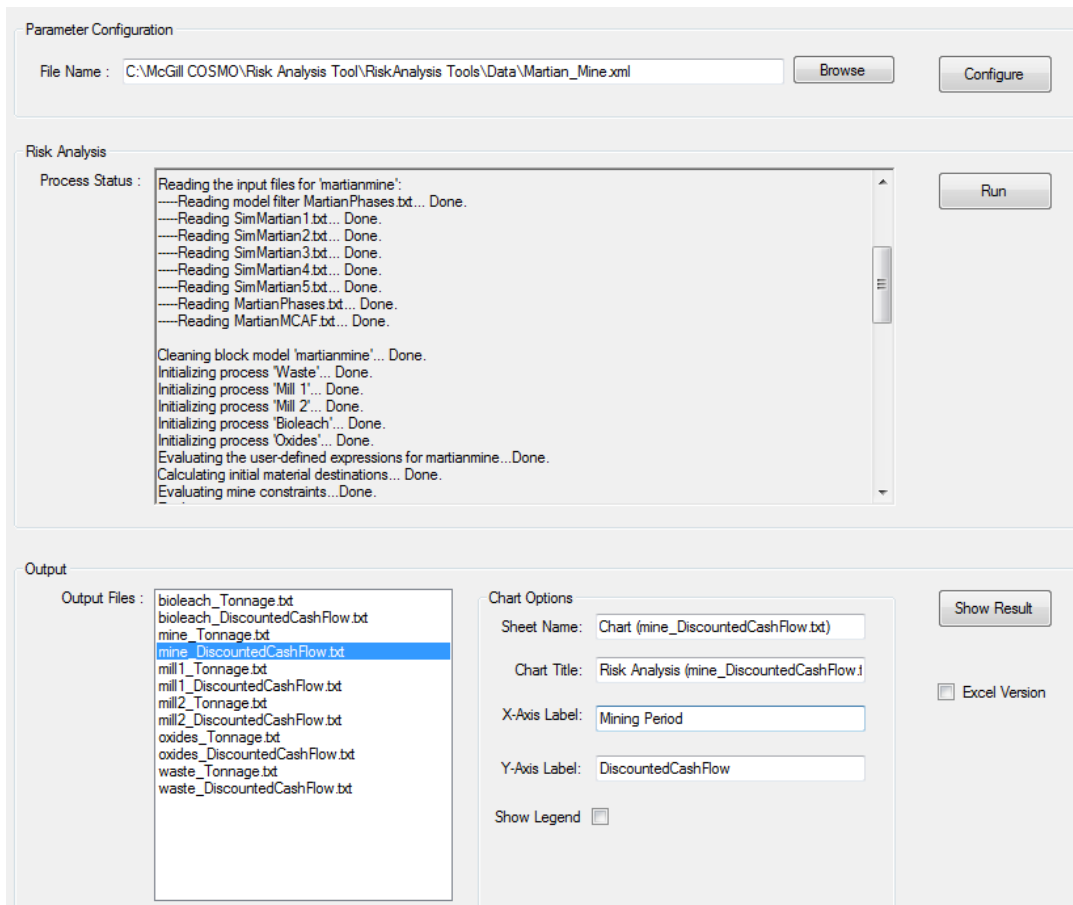


Figure 25: Generating the risk analysis outputs

5 Graphs of Risk Profiles

When the risk analysis process is completed, RAT provides two alternatives to display the risk analysis profiles: one option is to display the graphs directly from the RA software and the other is to use Microsoft Excel. To display in the software we select the required profile from the output list and then click **Show Result**, see Figure 26.

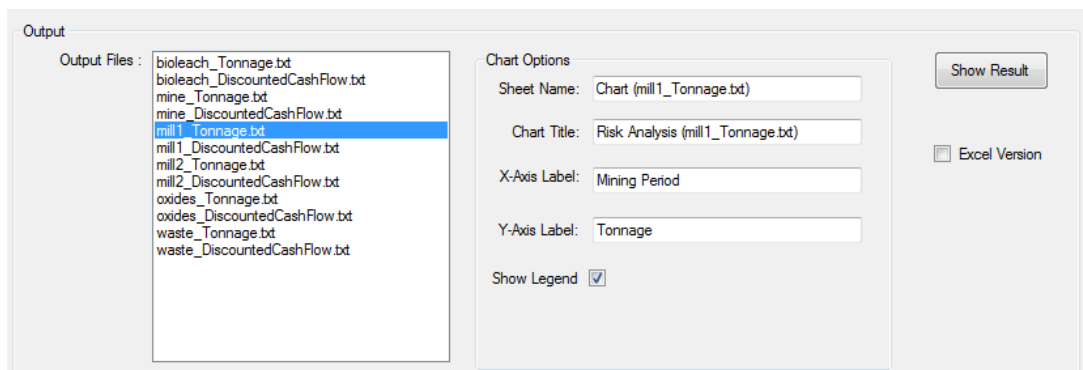


Figure 26: Section of risk analysis' main window used to display risk profile graphs

A window with two tabs is opened: the first tab contains the profile graph and the second tab contains the profile data in a table, see Figure 27.

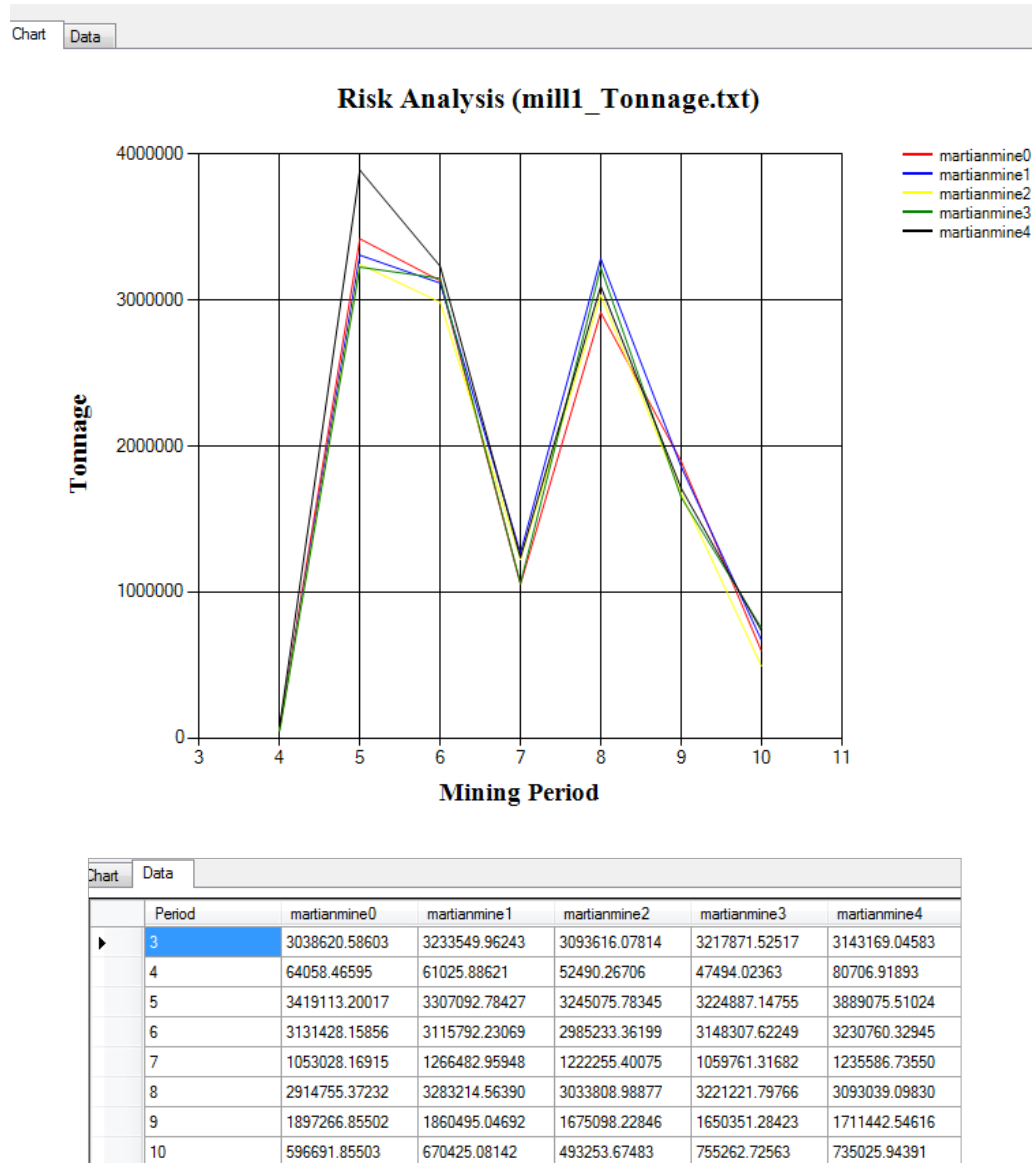
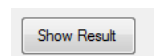


Figure 27: The chart and data of treated tonnages in Mill1 given 5 realizations

Once the graph is displayed, the profile selected disappears from the list. This option will work only once for each risk profile; however, the risk profiles output are stored in the working folder and the user could produce graphic representations again in the software that he/she prefers.

To load directly the risk data in Microsoft and visualize the risk profiles, press the **Show Result** button in the main window of the risk analysis tool and make sure to check the **Excel Version** radio button, see Figure 28.



The software will automatically load a table and create a chart into a new Excel sheet, see Figure 29.

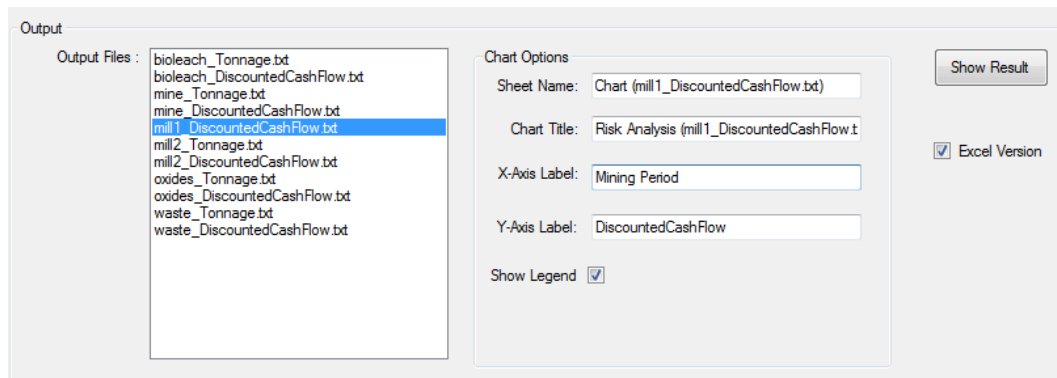


Figure 28: Section of risk analysis main window used to display risk profiles in Excel

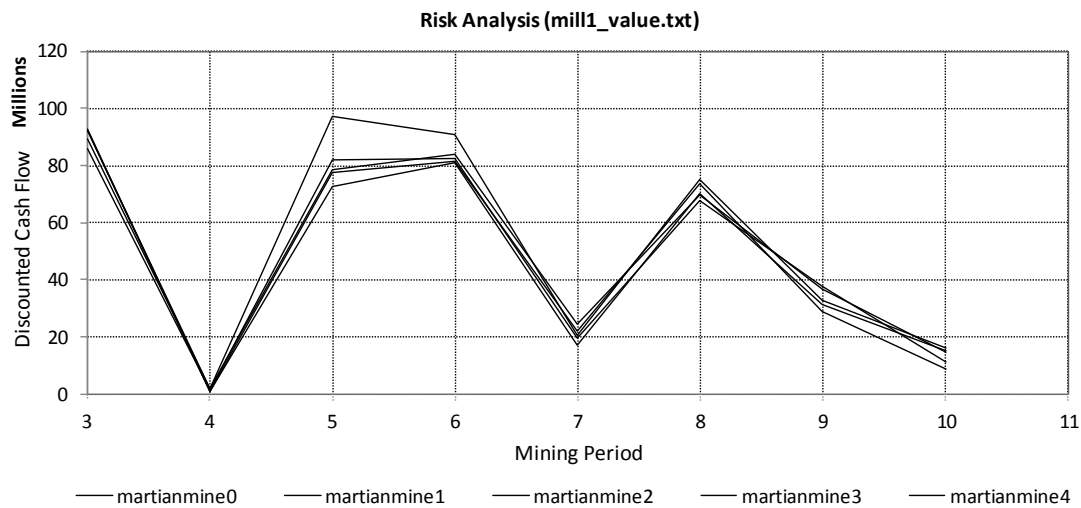


Figure 29: Risk analysis profiles displayed in Excel

The Excel chart shows a risk profile graph similar to the graph in RA software. The user could use Excel tools to better customize the graphs.

5.1 EXERCISE 3: Graph Martian mine risk analysis profiles

The Martian mine presents 5 material types and 5 destinations. The tones sent to each destination and the values that produce this decision were evaluated. Twelve risk profiles were generated and will be displayed in Microsoft Excel, 5 profiles are linked with tones sent to each destination, 1 profile considers all the tones produced, 5 profiles are linked to the value that produced the 5 destinations and 1 profile considers the total value for the Martian mine. The risk analysis of the total production and expected value is show in Figure 30.

The production schedule plan considers 7 periods to mine the Martian copper deposit. The risk analysis of the total production given 5 scenarios of the grade show that the first 3 periods has low risk; meanwhile, the next 4 periods show a considerable high risk to accomplish the proposed plan. Particularly, the period eight has a space of uncertainty from 200 million to 350 million. On the other hand, the total tonnage remains invariable through the 7 periods because the risk analysis is performed into a static mine design. As expected, the total tonnage mined given variable scenarios of the grade does not change.

The next risk analysis evaluates the waste extracted, see Figure 31.

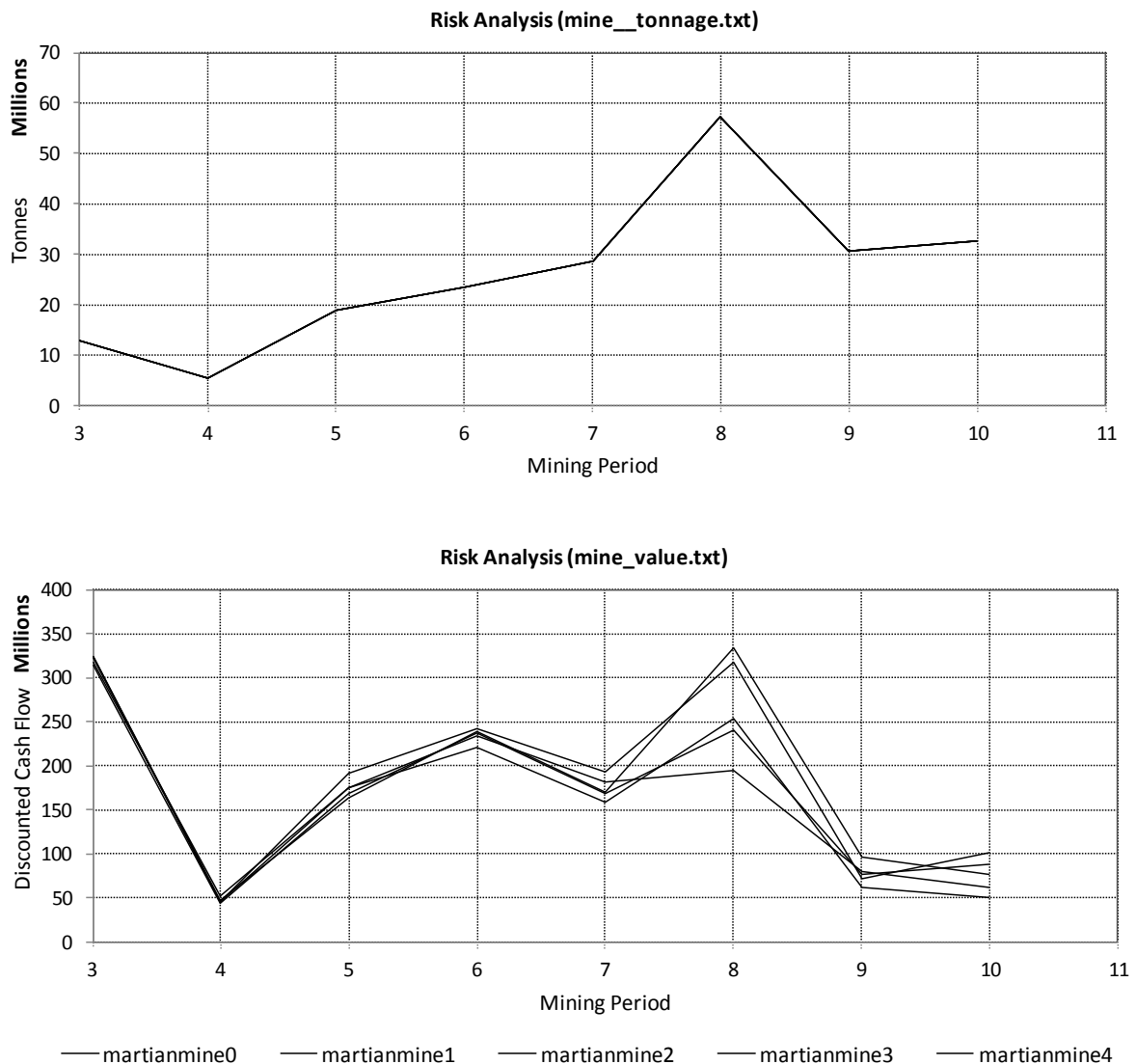


Figure 30: Risk analysis of the expected Discounted Cash Flow of Martian mine and total tonnage mined

The tonnage of the waste fluctuates given 5 geological simulations because the material type changes among the different scenarios of the grade. A considerable risk is associated with the periods from 8 to 10 for both cost and tonnage.

The next risk analysis graph corresponds to the process that contributes most to the total expected values of Martian mine.

The tonnage planned for Mill2 process show considerable fluctuations from period 8 to 10 and the values expected show the same periods plus period 7 with high fluctuation.

6 Conclusions

Exercise one contains tables that describe the header for each column and the corresponding column number from the input files. The availability of tables around the workshop avoids mistakes through the model set. Also, the correct data classification reduces the amount of memory required for the software. The input data is also classified according to the type of information it contains. The input data is classified into two major

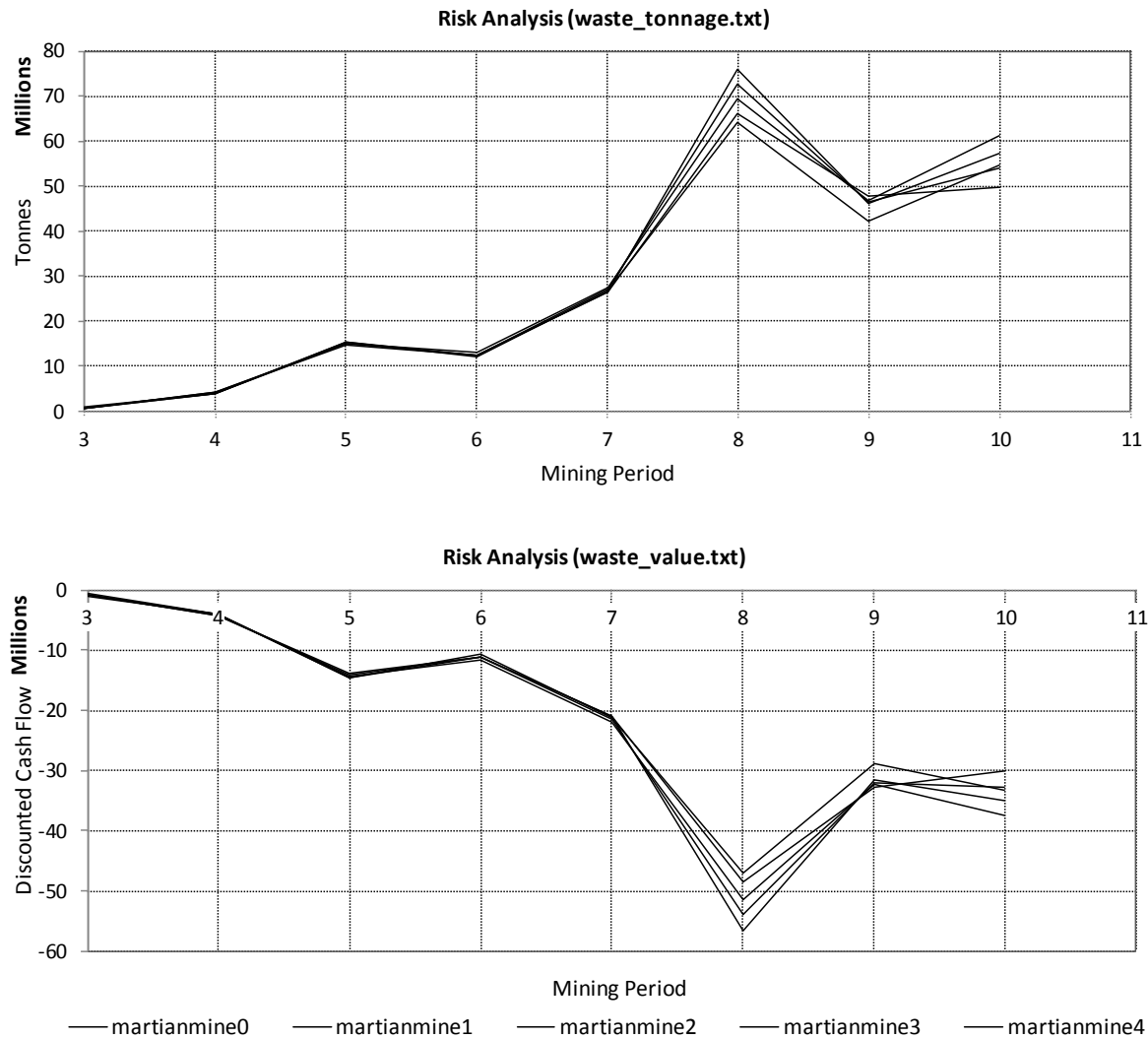


Figure 31: Risk analysis of the waste tonnage mined and the cost associated

categories: simulated and static. The simulated data is represented by a set of files simulated data and the static data lies in a single file that contains information that remains constant, regardless of the simulation's properties.

Exercise two describes how the risk analysis model is set. The risk analysis model contains the set of parameters that the software needs to generate risk analysis profiles of a mine design. The workshop has a focus on tonnage and value by each destination of Martian mine during the setting of the risk analysis model. The Martian mine data help to illustrate the four steps required to perform the configuration. To set up the parameters, the user must click the **Configure** button in the main window. A user interface permits creating new sets of parameters from scratch or opening the predefined parameters.

Exercise three explains how the risk profiles are displayed as graphs. When the risk analysis process is finished, the software provides two alternatives to display the risk analysis profiles: one option is to display graphs directly from the software and the other option is the use of Microsoft Excel. The risk analysis was performed for the software data. The Martian mine contain 5 material types and 5 destinations. The tones sent to each destination and the discounted cash flow that produces this decision was evaluated. Twelve risk profiles were generated, and there were displayed in Microsoft Excel.

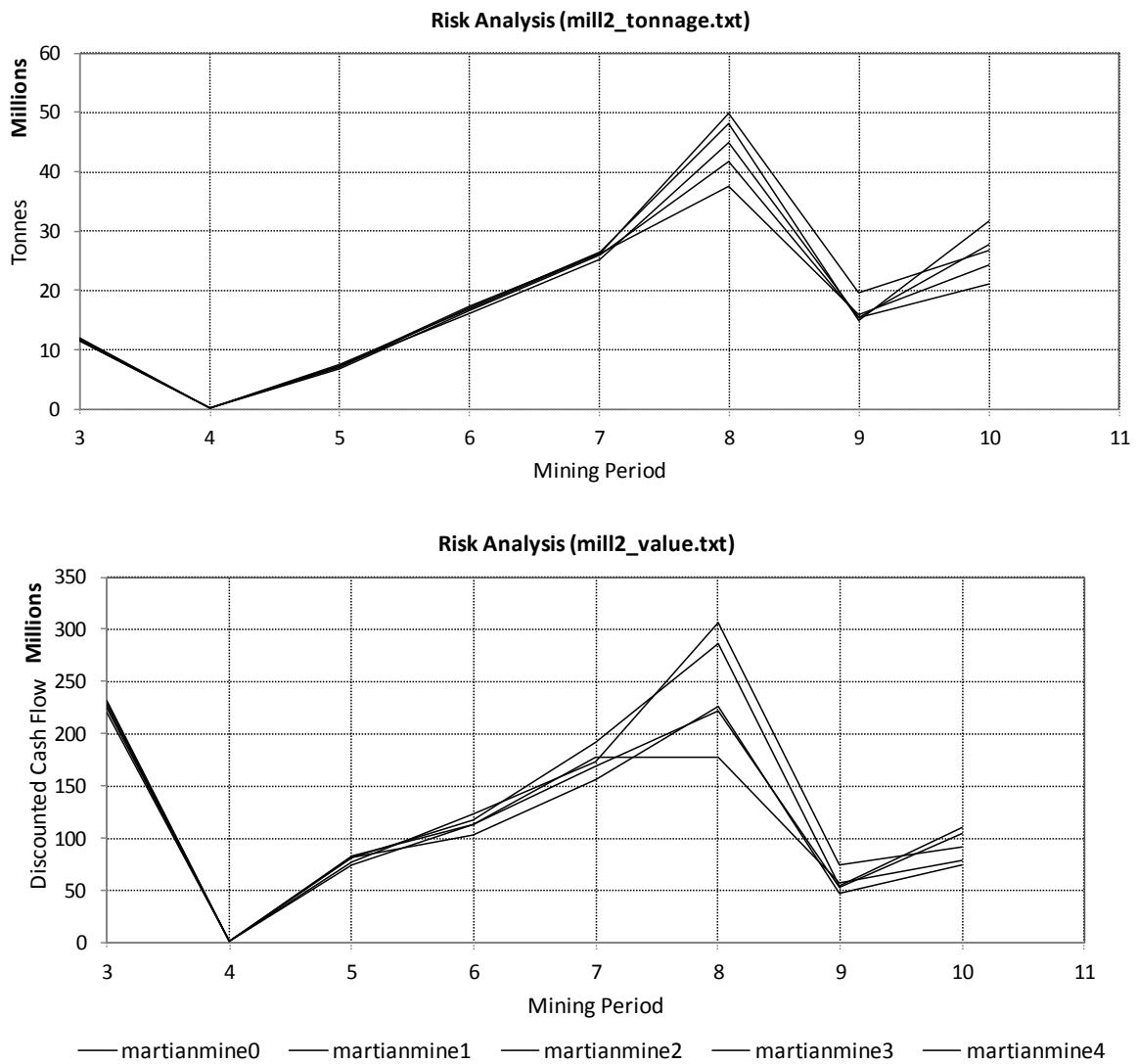


Figure 32: Risk analysis of the Discounted Cash Flow and tonnage treated in Mill2 process

References

Dimitrakopoulos, R. (2011). Ore Reserve Risk and Mine Planning Optimization: Course Notes MIME 525. Montreal: McGill University, Cosmo.