A MULTIPLE ACCOUNTS ANALYSIS FOR TAILINGS SITE SELECTION.

A. MacG. ROBERTSON

and

S. C. SHAW*

* Robertson GeoConsultants Inc.
Suite 902, 580 Hornby Street
Vancouver, BC, V6C 3B6, Canada

Abstract

The project approval process has evolved so that, today, all stakeholders, including the proponent, regulatory agencies and community representatives, participate. Ultimate decision making, as to whether the project may proceed, and under which circumstances (which development and reclamation options are approved) requires collective understanding of the positive and negative impacts of the project. The range of impacts affect numerous stakeholders to varying degrees. For example, the migrant job seeker may endorse a particular project while the recreational fisherman may resent the loss of a recreational resource. Therefore, a framework is required under which stakeholders can express their concerns and communicate their assessments of the relative values of positive and negative impacts. The valuations and methodology of arriving at the compromises between the positive and negative impacts, or value 'tradeoffs', must be understood, transparent and easily communicated. This paper describes how the general methodology of "Multiple Accounts Analysis" may be adapted, specifically for tailings site selection, during mine planning and the project approval process.

To account for all substantive impacts, a comprehensive list (ledger) of 'accounts and 'sub-accounts' is prepared (e.g. cost, jobs, water quality, fisheries habitat etc.) to include all impacts identified as being of substantive concern by stakeholders. A measure or 'indicator value' of the impact applicable to each account is developed which describes the impacts in relevant terms (cost of haulage, number of jobs, metal concentrations in water, loss of fisheries etc.). Creation of this list of accounts, sub-accounts and indicators and the assignment of values to the indicators is often termed "Multiple Accounts Evaluation" in the literature. A basis for account list development is provided. The analysis and decision making for a preferred alternative (e.g. tailings impoundment site) based on this list can be done in one of two ways:

i) An arguments-based analysis whereby the analyst presents reasoned arguments of the relevant values of indicators in accounts and comparisons (tradeoffs) between accounts, and the reader must make a subjective selection of a preferred alternative; or
ii) A value-based analysis, in which the analyst assigns numerical values to the indicators in each account using ranking and scaling techniques. Tradeoffs are achieved by weighting each account prior to accumulating the numerical values in all accounts.

Both methods involve subjectivity in assigning values to indicators, and in the summation and tradeoffs needed to develop a 'cumulative' assessment of the net impact (from all accounts) for each alternative. Having clear and transparent methods and processes makes it easier for all stakeholders to share opinions and come up with a consensus agreement therefore simplifying the project approval process. The Multiple Accounts Analysis (MAA) method provides a sound basis for presenting, discussing and exploring differences of opinion (between stakeholders) in what is otherwise a complex value based alternatives selection process.

Key Words: Multiple Accounts Analysis, decision making, tailings site selection, alternatives, net impact, tradeoffs

Introduction

There are numerous stakeholders who are unequally affected by the range of positive and negative impacts associated with all aspects of mining projects, including location, design and management of mine waste. It is widely understood that mining in certain areas can result in long term and unforeseeable impacts. Making decisions on the best available designs and technologies to implement in order to minimize these unknown or uncertain impacts is, to say the least, difficult. The liabilities and economic and environmental consequences of making the wrong decisions can be extremely burdensome not only to the proponent but to society. It is therefore not surprising that the project approval process has evolved so that, today, all stakeholders, including the proponent, regulatory agencies and community representatives, participate in the project review process on many levels. Due to the multi-disciplinary and inter-agency involvement, the 'science' of decision theory is finding it's way into the mining industry and is being applied at various levels from Feasibility Studies to Closure Plan Designs.

Ultimate decision making, as to whether a particular option is acceptable and may proceed requires collective understanding of positive and negative impacts. It also requires a framework under which stakeholders can express their concerns and communicate their assessments of the relative values of positive and negative impacts. It is therefore important that not only the ultimate selection of the most suitable option be made, but that a clear, transparent and communicable selection and evaluation methodology be implemented in the decision making process.

The selection of a tailings storage site is perhaps the first stage in a mine's development in which stakeholders' opinions should be sought. Tailings impoundment are large, anthropogenic structures that are often susceptible to erosion, floods, earthquakes etc. Tailings storage sites rarely offer any economic return to the company and require monitoring and maintenance during and after mining operations. There are therefore, long-term risks, both environmental and economic, associated with any tailings storage facility. Maximizing environmental "safety" while minimizing cost most often involves evaluating "trade-offs". In order to select the most suitable, or advantageous, option from a list of alternatives for tailings site, design and management options the evaluator(s) must weigh the benefits and losses of each option. This involves three basic steps:

1. Identify the impacts (benefits and losses) to be included in the evaluation (assessment accounts and sub-accounts);
2. Quantify the impacts (benefits and losses) for each of the accounts and sub-accounts;
3. Assess the combined or accumulated impacts for each option and compare these with other options to develop a preference list (ranking, scaling and weighting) of the options.

Often there is a threshold value for a particular impact which, if not achieved, constitutes a critical flaw. A critical flaw is one which, of itself, renders the option under evaluation unacceptable. Thus failure to meet a mandatory water quality standard may be a critical flaw. Thus, step 2 includes a screening out of all options which fail to meet threshold values for all accounts or sub-accounts. All options which survive the threshold test at step 2 must be included in the integrated (combined and cumulative) impact assessment of step 3.

The diversity of impacts that must be considered makes integrated (combined and accumulative impacts) assessment difficult. How does one compare the 'apples and oranges' in one fruit basket with the 'plums and bananas' in another to decide which is the preferable. To a large extent any comparison is subjective and depends on the flavor preference (value basis) of the analyst. It is not possible, and probably not desirable, to remove this subjectivity as each analyst seeks to have his/her value basis applied in the analysis. It is therefore an advantage if the evaluation methodology (analysis) is systemized and transparent allowing the various analysts to clearly indicate their value basis and results. If the results of analyses from two analysts are similar, despite differences in value basis, then there is likely to be consensus on the option selected. If results are materially different then the root cause of the difference can be identified and discussions focused on the material, value basis, issues to determine if a consensus resolution can be reached.

Some alternatives evaluations can reach conclusion or agreement after completion of step 2. This is typically referred to as Multiple Accounts Evaluation.[1,2,3] Some evaluations, in particular those involving multidisciplinary problems and numerous stakeholders with differing viewpoints, must be taken to the end of step 3. This is termed a Value-Based Decision Process similar to other studies found in the literature.[4,5] Together, the Multiple Accounts Evaluation and the Value-Based Decision Process have been defined here as a Multiple Accounts Analysis (MAA).

Details of the analysis extent, complexity and stakeholder interaction must be developed jointly between the proponent and regulatory agency representatives. The process should be kept as simple as possible (the KISS principle) maintaining focus on the major issues. Maintaining simplicity is itself an issue of communication and negotiation with the stakeholders. This method of analysis is illustrated here by using an example for the assessment of alternatives for a tailings storage site.

Methodology

The Multiple Accounts Analysis is a two staged process. The first stage consists of the development of a multiple accounts ledger, an explicit list of accounts (and sub-accounts) of the impacts from various development alternatives, and, for each sub-account, indicators which give a clear understandable description of those impacts. This stage allows the determination of alternatives that are critically flawed (do not meet threshold values). The second stage constitutes the Value-Based Decision Process applied to the remaining alternatives. It involves ranking, scaling and weighting the indicator values in the sub-accounts in a systematic transparent manner such that the value basis for the combination or accumulation of effects is readily apparent. In this manner, all the 'fruit in a basket' can be compared equally, amongst themselves and with 'fruit in other baskets'.

The various impacts, particularly environmental and socioeconomic impacts, during development, operations, closure and post closure for a tailings storage facility are sometimes difficult to accurately describe or quantify without an enormous amount of investigation and analysis. This makes the early quantification of accounts, and hence the evaluation and selection of the most advantageous of alternatives more difficult. Therefore, much of the assessment is necessarily based on judgement rather than deterministic analysis. The anticipation and assessment of the performance of the engineered structures, natural processes at work and environmental impact requires a sound understanding of the current technologies as well as considerable experience on a wide variety of similar projects in order to recognize and identify potential impacts, issues and risks. It is important therefore that the meetings and negotiations with stakeholders be lead by credible, experienced specialists who can assist in the establishment of appropriate indicators and the associated ranking, scaling and weighting factors. Fortunately the 80/20 rule (20% of the effort often gets you 80% of the result) usually applies. Since the accuracy of quantification as well as the ability to rank, scale and weigh alternatives all have some uncertainty, it is appropriate to use a fairly coarse classification methods.

Framework for Assessment

The framework for the assessment of various alternatives, in this case for tailings storage options, involves a MAA for the assessment of each of the specific alternatives for site selection, design alternatives, such as construction methods and materials, and management options, such as water balance and treatment options. The specific alternatives for the development of each of these components can be assessed based on four fundamental categories, or accounts, namely Technical, Project Economics, Environmental and Socio-Economic accounts (Figure 1). These main accounts are then broken down into a list of sub-accounts on which the assessments are based. The sub-accounts are described in the following section.

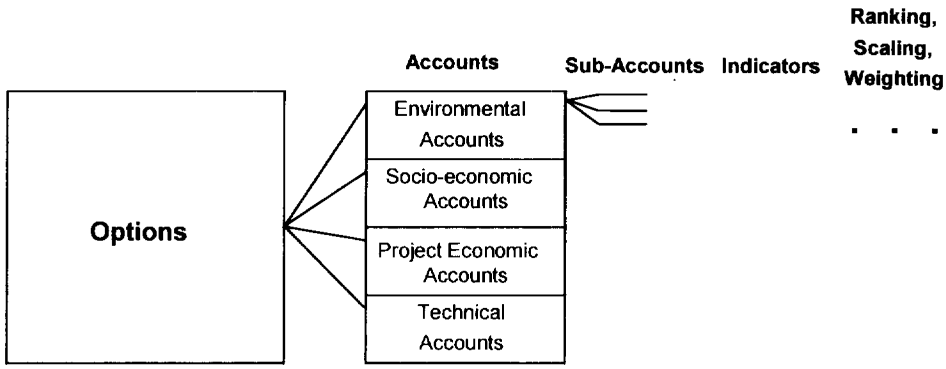

Figure 1. Fundamental Accounts for Options Selection using MAA methodology.

Sub-Accounts

Because most projects involves local, State or Provincial, Federal and multidisciplinary issues, advice and input should be sought from a variety of stakeholders, to be identified jointly by the proponent and regulatory authorities, on the identification and selection of sub-accounts. Sub-accounts can be defined as any material impact (benefit or loss) by any of the alternatives being evaluated. Initial identification of a comprehensive list of sub-accounts ensures that no a priori judgements have been made regarding the selection of any alternatives. However, this comprehensive list can be carefully scrutinized and those impact accounts which are either similar for all alternatives or not materially influential in selecting between options, can be dropped from the evaluation 'Ledger' or list (Figure 2). Care should be taken to ensure that no redundancy or double counting of sub-accounts is done. However, some accounts must consider only impacts not accounted for in other accounts (i.e. 4.14 must exclude what is considered in 4.13). It becomes apparent upon first inspection of Figure 2 that certain sub-accounts will have variable impacts based on the various alternatives and others will have similar impacts regardless of the alternatives chosen. For instance, a tailings storage facility located 2 km from the mill would have a significantly less tailings delivery cost associated with it than one located 15 km from the mill, however, both sites would have a similar impact on community services. Therefore, from the general list of sub-accounts given in Figure 2, a list of fundamental (high value) sub-accounts can be defined (Figure 3). These fundamental sub-accounts are those which may vary with different alternatives being considered.

Indicators

Each sub-account may have one or more indicators with which to measure, either qualitatively or quantitatively, the impact (benefit or loss) of each option. For example, the sub-account of water quality may have a list of indicators including pH, concentration of Total Dissolved Solids (TDS), sulfate concentration etc. These indicators are likely different at different stages of mining and therefore should be divided into time periods (construction, operation, post closure). Sub-accounts such as water quality, or capital costs etc. that can be expressed in parametric terms that can be readily measured are relatively straightforward with respect to the assignment of indicators. It is more difficult to measure and assign values to the impacts on sub-accounts such as aesthetics or outdoor recreation and tourism. Figure 4 is presented as a template for listing the indicators of each of the fundamental sub-accounts using the example of outdoor recreation, fishing and tourism.

It is at this point of the MAA that the Multiple Accounts Evaluation concludes and the Value-Based Decision Process begins. The Value-Based Decision Process takes this list of indicators, sub-accounts and accounts and assesses the combined impacts for each of the alternatives being evaluated (i.e. allows the 'apples' and 'oranges' to be compared).

Accounts	Sub-Accounts	Indicators
1.0 Technical	1.1 Dams 1.2 Mine 1.3 Diversions 1.4 Covers 1.5 Water Treatment 1.6 Access Road	1.1.1 ...
2.0 Environmental	2.1 Climate 2.2 Air Quality 2.3 Hydrology & Water Management 2.4 Water Quality 2.5 Aquatic Ecology 2.6 ARD/ML 2.7 Fish & Fish Habitat 2.8 Terrain & Soils 2.9 Vegetation 2.10 Wildlife	
3.0 Project Economics	3.1 Capital Cost 3.2 Operational Cost 3.3 Closure Cost 3.4 Profitability/Taxes 3.5 Economic Risk	
4.0 Socio-economics	4.1 Income (direct/indirect) 4.2 Taxes (direct/indirect) 4.3 Regional Government Development 4.4 Government Expenditures 4.5 Labour Market Analysis 4.6 Population 4.7 Housing 4.8 Transportation & Traffic 4.9 Navigable waters (recreational) 4.10 Community Services 4.11 Health & Safety 4.12 Land Tenure 4.13 Fishing 4.14 Outdoor Recreation & Tourism 4.15 Aesthetics 4.16 Archaeological resources 4.17 Sacred/Traditional Sites	

Figure 2. Ledger of Accounts and Sub-Accounts

Accounts		Fundamental Sub-accounts (e.g. Tailings Options)	Indicators
1.0 Technical	1.1	Constructability with local access, materials, permafrost	1.1.1 ...
	1.2	Achieve Stability of Dams, Dykes and Diversions	
	1.3	Maintain 'Zero' Discharge	
	1.4	Minimize Contaminated Seepage (control pore water quality or prevent seepage)	
	1.5	Maintain Covers (ARD control)	
	1.6	Minimize Post Closure Operating and Maintenance Requirements	
2.0 Environmental	2.1	Water Quality (preserve)	
	2.2	Fish and Fish Habitat (minimize disturbance and achieve mitigation/compensation)	
	2.3	Wildlife (minimize disturbance and achieve mitigation/compensation)	
	2.4	Permafrost Degradation/Agradation (control)	
	2.5	Post Mining Land Use (self-sustaining, appropriate use)	
3.0 Project Economics	3.1	Capital Cost (minimize)	
	3.2	Operational Cost (minimize)	
	3.3	Closure Cost (minimize)	
	3.4	Construction Schedule	
4.0 Socio-economics	4.1	Outdoor Recreation, Fishing and Tourism during Operations (minimize loss)	
	4.2	Post Closure Outdoor Recreation, Fishing and Tourism (minimize loss, maximize recovery)	
	4.3	Traffic Disturbance (minimize with routing, type and quantity)	

Figure 3. High Value Sub-Accounts.

Account: 4.0 Socio-economic								
Sub-account: 4.1 Outdoor Recreation Fishing and Tourism During Operations								
Multiple Accounts Evaluation ← →						**Value-Based Decision Process** ← →		
	Indicators	**Indicator parameter**	**unit**	**critical flaw threshold**	**Indicator Quantity**	**Indicator Value (S)**	**Weight (W)**	**S x W**
4.1.1	Hiking trails lost	Length	km	None	0.5 km	9	3	27
4.1.2	Tailings impoundment visible from trails	Length	km	None	15 km	7	1	7
4.1.3	River within 300 m of mine development	Length	km	None	1.5 km	3	5	15
4.1.4	Visual impact	Value		None		5	2	10
					Sub-account Merit Score	**Σ(S x W)**		**59**
					Sub-account Merit Rating	**(SxW)/ΣW**		**5.4**

Figure 4. Example of Indicators for a High-Value Sub-Account.

Ranking, Scaling and Weighting

For each tailings storage site option being assessed, the options are **ranked** in order from best to worst with respect to the indicators for each sub-account. Ranking is a simple ordered list and makes no attempt to distinguish how great the difference in impact is between alternatives on the list. In practice there may be very little difference in the impact from the best to the worst.

Since the separation of the best option from the worst may be either very slight or very significant, a **scaled** value (S) can then be assigned to each option for each of the indicators using a nine point scale. The three and five point scales often used by other workers are simple subsets or lesser subdivisions of the original nine point scale as illustrated in Figure 5. The authors have found a nine point scale is readily understood and provides a range and discretion suited to this type of analysis. The 'best' option in the ranking is always given a value of 9 merit points. If the 'worst' option is considered to be half as good as the best, it would be given a value of 5 merit points and the other options distributed between these values. An example is the sub-account 'distance from mill to tailings impoundment' that accounts for the potential impacts of long tailings and return water pipelines, the potential for leaks and spills, impoundment inspection and management constraints, etc. If all the impoundments are at a similar distance from the mill then the scaled effect of the 'worst' option may not be very different from the 'best' option and may be made in proportion to the actual tailings pipeline distance. An example is provided in Figure 6.

Scale Factor		
	9	**BEST**
	8	*very good*
	7	GOOD
	6	*good 'ish*
	5	**INTERMEDIATE**
	4	*poor 'ish*
	3	POOR
	2	*very poor*
	1	**WORST**

Figure 5. Subdivisions of Scaling System

Scale Factor		
	9	**Option A** (e.g. 4.5 km from mill to tailings)
	8	
	7	
	6	**Option C** (e.g. 8 km from mill to tailings)
	5	**Option B** (e.g. 9 km from mill to tailings)
	4	
	3	
	2	
	1	

Figure 6. Example of scaling and positioning of "ranked" options.

To enable the analyst to introduce their value bias between individual indicators, a **weighting** factor (W) is applied to each indicator. If the analyst considers the relative "importance" (on his value scale) of one indicator is twice that of another then the relative weightings would be 2 to 1. Weighting is the factor most likely to reflect the analysts' bias or value basis. The sum of weightings for indicators must add up to the weighting for the sub-account they represent and similarly the sum of the weightings for the sub-accounts must add up to the weighting of the account they represent.

For the sub-account considered in Figure 4 (Outdoor recreation, fishing and tourism during operations) the key indicators were identified as the length of trails lost (through the wooded landscape in which the facility was being located), the length of trails and roads from which the tailings facility was visible, the visual impact, and the length of river within 300 m of the tailings site (zone over which recreational fishermen would be disturbed by the presence of the tailings impoundment). The length of hiking trails lost (or replaced) would be 0.5 km. This was the least impact of all tailings sites so it had a numerical value of 9 assigned to it. The relative weight of "hiking trails lost" compared to "visibility of tailings impoundment" and the "disturbance to fishermen" (river within 300 m of tailings impoundment) was judged to be 3, 1 and 5 respectively. The total merit score for this particular tailings impoundment site (Tailings Impoundment Site Option 1) is 59. This score can be compared with scores for other site options for the same sub-account. However, to be able to compare this value against values for other sub-accounts, it is necessary to "normalize" the score on the same 1 to 9 scale used to rate each indicator value. This is achieved by dividing the sub-account merit score by the sum of the weightings to yield the sub-account merit rating (a value in the range of 1 to 9).

For certain sub-accounts the impacts may be similar for the various options. For example the socio-economic impacts do not change with the tailings pond locations. For the selection of the most advantageous option for tailings pond location the socio-economics are not a distinguishing account and the socio-economics can be assigned a neutral value ("N"), or be dropped from the ledger of accounts.

The process of adding together the sub-account merit ratings to obtain the overall rating for the account follows the same procedure of weighting and normalization. Figure 7 illustrates the summation of the sub-accounts for the socio-economic factors defined in Figure 3. The weighting for post closure outdoor recreation, operational recreation and traffic disturbance were assessed to be 3:2:1. The resulting account merit score is 39.4 and the normalized account merit rating is 6.6.

	Sub-account	**Sub-account Merit Rating (R)**	**Weight (W)**	**R x W**
4.1	Outdoor recreation, fishing and tourism during operations	5.4	2	10.8
4.2	Post Closure outdoor recreation, fishing and tourism	6.8	3	20.4
4.3	Traffic disturbance	8.2	1	8.2
		Account Merit Score	**Σ(R x W)**	**39.4**
		Account Merit Rating	**(RxW)/ΣW**	**6.6**

Figure 7. Example of Account Value-Based Decision Process Rating Determination.

Preferred Options Selection

A similar process is used to add together the four main accounts to develop an option merit rating for Tailings Impoundment Option 1. The higher the merit points the more favorable the option. It is now possible to compare the option merit ratings for all tailings impoundment siting options (all values between 1 and 9) and the Preferred Option (or options) identified as the option with the highest merit rating(s). Caution should however be exercised in coming to the conclusion that the option with the most merit points is the 'best' option. At the feasibility stage of mine development, the Multiple Accounts Analysis is crude, particularly because of the limited information on impacts available at this stage of project investigation. It is the authors' opinion that, for the current level of engineering and data, it may be used to distinguish between alternatives of high merit and those of intermediate or low merit. On this basis alternatives worthy of detailed study can be identified and those of low or intermediate merit eliminated from detailed study requirements. The selection and/or approval of the final preferred option requires additional more detailed options design, investigations and impact analysis.

The tedium of setting up tables and their completion is well handled by spreadsheets. The spreadsheet incorporates the mathematics to allow the combined and cumulative assessment calculations to be performed. Using the spreadsheet it is possible to perform sensitivity analyses to changes in both scaling and weighting values. This allows the sensitivity of the merit ratings to individual preferences to be evaluated. It makes apparent the root cause of disagreement between parties and which sub-accounts need to be further investigated. The Multiple Accounts Analysis method therefore provides a sound basis for presenting, discussing and exploring differences of opinion (between stakeholders) in what is otherwise a complex value based options selection process.

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