Use of Multi-Criteria Decision Analysis in Environmental Impact Assessment of Quarry

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Abstract
Environmental impact assessment for construction material extraction involves many uncertainties, complicated alternatives, and varied preferences, which make it hard for a decision maker to choose what to do in order to provide or meet on-going supply and future needs to its industry (consumers) while having minimal environmental effects. In this study, a decision support framework and a computer software package were developed to improve environmental optimisation and resource management for extractive industry. The framework uses a combination of scenario analysis, system optimisation, simulation, and decision analysis in a user-friendly decision support environment. The model, a hierarchical additive weighted value-function, was used as a part of a decision-making process to select the best alternative. A case study on Quarry Development (Brew Road, Tynong North) has shown that this approach can be used in obtaining better decisions balancing environmental and developmental needs and demands on behalf of the community.

Key words: alternative, construction material extraction, extractive industry, multi-attribute

Introduction
Making decisions is an important and integral part in environmental impact assessment of engineering projects. Often, decisions must be made on several choices without exactly knowing the outcome. This is especially true in long-term planning which involves many unforeseen factors and variable parameters. Generally, accommodation for future development and uncertainties is necessary in the analysis of most decision problems (Luce & Raiffa 1957). In fact, whenever there are many uncertainties, which may affect the views of the decision maker, decision theory offers a procedure for systematic analysis of problems in a rational manner designed to improve the decision-making process (Keeney 1971). This can be done by breaking up complex decision problems into a number of relatively smaller problems so that the quantification of the decision maker's preferences and judgment can be introduced. Smith (1972) has introduced the fundamentals of the decision theory through a presentation of a comprehensive problem and Carl and Zamora (1972) have the basic roles for analysis of decision alternatives and for decision analysis cycles.

The first stage in setting up a structure for decision-making is to express the outcome of any decision by a numerical value. This is what is known as the "utility theory" which has been developed by Luce and Raiffa (1957). The utility theory is a mathematical theory in which one attempts to measure the attitudes of the people or their preferences toward multiple objectives by means of numerical utility functions (Papp et al. 1974). This can be done by expressing the utility function in terms of monetized attributes (Swalm 1972) or intangibles (Hirschmann 1964).

Although decision theory is that procedure which accounts for all available information to give us the best possible logical decision, the usefulness of the decision analysis is limited by the lack of analytical
procedures for systematically assessing utilities for multidimensional functions. However, this is not a weakness of the decision theory but a current limitation on its implementation (Keeney 1971). The subjective nature of the utility functions or preferences is likely to vary with time and circumstances. However, the approach is expected to lead good decisions, which are not necessarily the same as good outcomes (North 1968).

In this paper the application of the multi-attribute utility theory/MCDA to decisions on selection of best quarry alternative where the decision-maker is faced with various uncertainties. The approach is applied in a case study of Quarry development (Environmental effects statement) Brew Road, Tynong North. Thus this paper describes the use of multi-criteria model as a decision aid in environmental impact assessment of quarry to choose the best alternative for its expansion. The total numbers of alternatives/options to be considered are three, which are as follows:

(a) Deeper Extraction/ Restrict Surface area ['GO DEEPER']
This option would entail the surface area used for extraction being limited to approximately 16 hectares (in general the eastern area of the site), and extracting below the 15.24-meter level, with the final depth being Radius Length (RL) 25. (The average surface currently is approximately RL 160 to RL 180).

(b) Continue As Is ['QUARRY WHOLE SITE']
This option would enable extraction to continue in stages over the entire licenced area of 43.7310 hectares, with the depth not exceeding 15.24 meters, and the site being progressively reclaimed by stages.

(c) Cessation ['CESSATION']
This option would involve cessation of extraction, and rehabilitation of the site on the assumption that Extractive Industry Licence was not renewed.

Fig. 1. Quarry development-Tynong North, Vic, Australia
Methodology

For this particular case study, the MCDA model was developed with the aid of information contained on its EIS report. As the task here (evaluating quarry alternatives) resembles to a typical multiple-criteria problem, the value of the performance measures were first converted to a common scale in the range of 0-1 (1 being best and 0 being worst) through user-defined utility functions. Each performance measure was then considered with respect to all scenarios, and an aggregated value for the performance measure was computed using user-defined weights. The aggregated performance measures were then combined to achieve best result. The multi-criteria decision analysis was achieved through LDW software, Logical Decisions 2001, which is integrated to the overall support program package.

The steps followed in developing this MCDA model were:

- **Identifying Alternatives**
  - Go Deeper
  - Quarry Whole site
  - Cessation

- **Clarify Goals**: Assess alternative
  - Sub goals: Minimize impacts
    - Physical, Biological and Socio-economic

- **Define Measures (Scoring)**
  - Impact on mammals: High, Medium and Low
  - Cost: in dollars (A$) etc.

- **Quantify Preferences/Weightings**
  - Convert the measures to common units
  - Establish the relative importance of the measures

- **Examine Results**

- **Do Sensitivity analysis**

Fig. 2. The steps followed in developing MCDA model for Quarry-Tynong North

Result Of The Multi-Criteria Analysis

A program written by Gary R. Smith -LDW 2001 was used to analyze the information on Tynong north Quarry options. The initial result upon inserting data from its EIS report showed that “GO DEEPER” option/alternative ranked the first with highest Utility 0.682 followed by “CESSATION” and “QUARRY WHOLE SITE” with Utility 0.630 and 0.449 respectively (fig 3).

Ranking for Overall Goal

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Utility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cessation</td>
<td>0.940</td>
</tr>
<tr>
<td>Go Deeper</td>
<td>0.647</td>
</tr>
<tr>
<td>Quarry Whole site</td>
<td>0.218</td>
</tr>
</tbody>
</table>

Note: 0 utility = the worst, 1 utility = the best

Fig. 3. Ranking result of Quarry Alternatives/Option based on Overall Utility

A thorough sensitivity analysis was carried out between “GO DEEPER” and “QUARRY WHOLE SITE” option/alternative and in almost all cases ‘GO DEEPER’ option proved to be good (see figure 4).

Ranking for Biological Impact Goal

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Utility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cessation</td>
<td>1.000</td>
</tr>
<tr>
<td>Go Deeper</td>
<td>0.741</td>
</tr>
<tr>
<td>Quarry Whole site</td>
<td>0.315</td>
</tr>
</tbody>
</table>

Fig. 4. Selected display results of multi-criteria analysis for Quarry-Tynong North

Findings

The application of the multi-attribute utility theory/MCDA to decisions on selection of best quarry alternative on Tynong North shows:
The MCDA model can simultaneously produce a wide variety of specialized displays, including overall ranking, stack bar ranking, alternatives graphs, sensitivity graphs, alternatives tables, sensitivity tables, scatter diagrams, ranking result graphs, ranking result matrices, assessment summary reports etc. in traditional text form. With such a graduated series of displays which trade off depth of explanation (credibility) for simplification (ease of interpretation), almost any decision-maker can locate a display form which suits his interpretative abilities and through which he can build an understanding and belief in more or less complex forms of assessment.

MCDA (as a common communication package) provides grounds for two or more decision-makers with differing interpretative abilities from which they can achieve an understanding of each other's view. This feature of the MCDA model is of great value (especially where decision-making process involves many decision making groups) as it enables any decision making group to change the choice of objectives and criteria/measures if required.

MCDA provides a means whereby qualitative and quantitative criteria/measures can receive equal attention, without the necessity for reduction to a monetary scale. This is because every measure is converted to utility.

MCDA is an open, consultative process.

Conclusion
This work reported here has shown that multi-criteria model can successfully be applied in environmental impact assessment of quarry to choose the best alternative for its expansion. The application was perhaps a bit unusual in that the decision process was not developed with that framework from the beginning; however, there is no doubt that the model served the purpose of allowing the decision-making group to explore and learn about the problem and their preferences.

Acknowledgements
The author wishes to acknowledge the assistance given by Dr. John V. Smith (RMIT University, Austral)ia) and Deepa Shree Rawal (RONAST, Kathmandu) for conducting this research. The views and ideas expressed in this paper are solely of author and have nothing to do with any environmental assessment bodies.

References


