First International Conference on Construction in the 21st Century (CITC2002)
"Challenges and Opportunities in Management and Technology"
25-26 April, 2002, Miami, Florida, USA

A CONCEPTUAL MODEL FOR HOLISTIC DECISION MAKING IN PROJECTS

Ali Jaafari
Professor of Project Management, The University of Sydney, NSW, Australia

David Gunaratnam
Senior Lecturer, The University of Sydney, NSW, Australia

Kitsana Kit Manivong
Postdoctoral Fellow, The University of Sydney, NSW, Australia

ABSTRACT
Decision models available in traditional project management systems are based mainly on quantitative data, such as resource quantities, rates, costs etc. Qualitative aspects of the projects, such as customer and stakeholders' satisfaction, quality, safety, statutory requirements and due diligence are not generally treated as variables but as constraints, even though these have major influence on all capital projects. The paper describes a multi-criteria decision model, with a hierarchical structure, that allows an optimum project plan to be determined based on a life cycle objective function, which takes into consideration both the quantitative and qualitative aspects of the project. The progression through the hierarchy is by a series of transformations that generate high-level attributes of project with reduced dimensionality, leading to a set of quantitative and qualitative criteria and finally to the single overall objective. The information and knowledge required for progression through the hierarchy are derived from case studies of projects, domain knowledge and the preferences of project managers.

KEYWORDS
Multi-criteria, Decision Model, Life Cycle, Project Management, Information System

1. INTRODUCTION

It is commonly known that projects often suffer serious set backs due to political, social, environmental and community challenges and through statutory processes. Despite their vital influence on the eventual fate of a project these factors are often managed informally, while the emphasis tends to be on the management of time, resources and capital expenditure. Project failures are not just related to delays or cost overruns as typically portrayed in the project management literature and the media. More significantly, failures tend to affect the relevant commercial and operational fundamentals, project fitness for purpose, adaptability and other vital characteristics. There is thus a need for a holistic decision-making framework that allows for the systematic inclusion of these different effects in the process of arriving at the optimum project plans. In this paper, we describe a decision framework developed to form the basis for an integrated project management information system, which is presently under development.

Procedures for evaluating projects based on economic criteria, which can be expressed in terms of quantitative monetary terms, are well developed (Rogers, 2001). Environmental impact assessment of project alternatives, involving non-monetary and qualitative attributes, has also been carried out using multi-criteria analysis (Janssen, 2001; Rogers and Bruen, 1995). In order to account for all aspects of the interactions between the project and its environment to ensure successful project outcomes, the model for holistic decision-making should include criteria relating not only to the project's financial status and its profitability, but also to the project's impact on the environment and community. The selection of an optimum project plan from a set of technically feasible alternative solutions is thus posed as a multi-criteria decision making problem, where the decision criteria are expressed both in terms of the quantitative and qualitative attributes, reflecting the economical, technical, environmental and social aspects of the project.

A number of methods are available for solving the multi-criteria decision making problems, which involve the selection of the best alternative from a solution set based on their performance on a set of decision criteria (Rogers, 2001; Rogers et al., 1999; and Saaty, 2000). These methods are usually based on a four-stage process that is made up of the definition of overall objective, formulation of criteria and sub-criteria, evaluation of the given alternatives and the selection of the preferred alternative. The decision framework usually has a hierarchical structure, with the overall objective at the top, the decision criteria at the next level followed by sub-criteria, if required, and finally the solution alternatives forming the lowest level, in some of the methods.

Evaluation of an alternative involves moving up the hierarchy to determine the degree to which the alternative satisfies the overall objective. In order to carry out the evaluation process a number of issues need to be resolved. These include the types of representation and performance measures to be used for the decision criteria, and information required to progress from one level of the hierarchy to the next. This information is usually elicited from the decision makers in the form of preferences and represented as weights that reflect the relative importance of the criteria at one level in the hierarchy in relation to the criteria at the next higher level. The preferences can also be expressed in different forms and can also include fuzzy relations (Cvetkovic, and Parmee, 1999; Fodor and Roubens, 1994; Lootsma, 1997; Slowinski, 1998).

The model for holistic decision-making in projects proposed in this paper also has a hierarchical structure, but differs from previous work in a number of aspects. It has the overall objective at the top level followed by three decision criteria, based on life cycle objective functions, which are used to determine the optimum project plan from a feasible set. The lowest level of the hierarchy consists of low-level attributes of the project and these attributes are provided by the integrated project management information system, within which the decision model is embedded as one of its modules. Progression through the hierarchy is by generating a series of transformation functions. Two types of information are required to generate these functions. At the lower levels the information required is non-preferential and is obtained from case studies, previous problem solving experiences and other available domain knowledge. At the higher levels the information required is derived from the preferences of the decision makers.

In the sections that follow, we initially describe a conceptual model for the project management information system, within which the holistic decision-making model is to be embedded, to identify the relationship of the model to the rest of the information system. Then sections that define the decision criteria and the structure of the decision model, identifying the different levels and the types of information and transformation functions required to move from one level to the next, are presented. The use of the decision criteria for selection of optimum project plan is then demonstrated through the analysis of four alternative solutions. Finally, issues in relation to the combining of the decision criteria values to arrive at the overall objective are considered, and a method for converting all the values to a common scale of measurement is described.

2. CONCEPTUAL MODEL FOR A PROJECT MANAGEMENT SYSTEM

The role of a project management information system is to facilitate the project manager and the relevant project teams in their task of planning and or implementing the project through rapid evaluation and real time holistic analysis of objective functions vis-à-vis target values set for these functions. The system must hence address the whole of life information, not just those relating to the implementation phase.

Figure 1 shows a broad view of an integrated project management system. The input variables and base information are both quantitative and qualitative; these are uncertain and tend to change with time. The information provided on the input side of the model defines the project environment's influence on the project outcomes. The project model is used to determine the project outcomes, in the form of performance measures, under the combined influence of the aforementioned quantitative and qualitative variables. These outcomes are of course dependent on the technical solution and managerial plan developed by the project teams vis-à-vis the pertinent variables. The decision criteria are expressed in terms of the performance measures and their values are evaluated for each of the project alternatives.

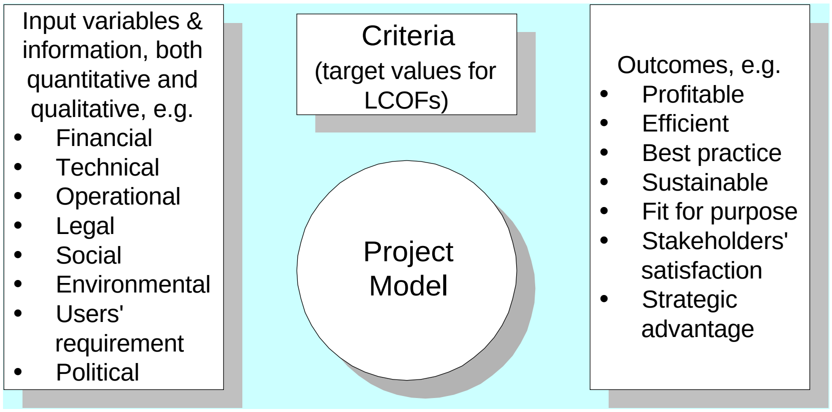

Figure 1: Broad view of an integrated project management system

The system has to operate in real time and when significant changes occur either in the input variables or in the base information. The project model must process the entire information available on the input side in a holistic manner and provide information, during the various phases of the project, which will assist the project manager to manage the project towards an optimal outcome.

The model for holistic decision-making described in this paper is to be embedded within the system. The model uses information generated by the project model during the project conceptualization stage for evaluating the alternative project plans to determine the optimum plan, and during the project implementation stage to monitor the optimality of the project plans due to changes in the project environment. The project model, in addition to providing descriptions of alternative project plans, also provides low-level attribute values and other non-preference information required for moving up the lower levels of the decision model to arrive at a set of performance values required for evaluating the decision criteria.

3. DECISION CRITERIA

The overall objective for holistic evaluation of projects is expressed in terms of the following 3 life cycle objective functions (LCOFs):

- the project's financial status and its profitability;
- the operability, quality or performance of the facility; and
- due diligence, including health and safety (H&S) and other statutory obligations throughout the life of the project, e.g. environment, community and stakeholders' obligations, and third party liabilities.

The performance measures for these objectives are provided by three mutually exclusive decision criteria. The first is based on return on investment and is expressed in terms of internal rate of return. The second on the benefits that flow from the project and is expressed in terms of total benefit points, and third the overall satisfaction in the management of the interaction between the project and the project environment, and expressed in terms of an ordinal scale based on prevailing best practice. Whole of life financial modelling and analysis has already been successfully researched and developed at the University of Sydney (see Jaafari and Manivong, 1999; Manivong, 2000). Framework for combining all three criteria in the decision making process is described in the next section.

4. DECISION FRAMEWORK

Figure 2 shows the hierarchical decision framework proposed for the model for holistic decision-making in projects. The different levels of the hierarchy can be interpreted as project attributes that are defined at different levels of abstraction. The decision model requires both a description of the project solution to be evaluated and the values for the parameters that define aspects of the project environment that would impact on the project outcomes. This information is combined with other relevant information to progressively generate the attribute values for the different levels of the hierarchy.

The progression through the hierarchy can be interpreted as a dimensionality reduction process, to determine a single overall attribute, at the top of the hierarchy, which provides the basis for comparison of the technically feasible alternatives and for decision-making. The hierarchy can be divided into two stages based on the type of information required for progression from one level to the next. The first stage consists of all the levels except the top two levels and uses mainly non-preference information, and the second stage consists of the top two levels and uses the preference information of the decision makers. The hierarchy can also be partitioned vertically up to the decision criteria level, into those that can be expressed in quantitative terms, such as financial criteria, and those that are essentially qualitative in nature.

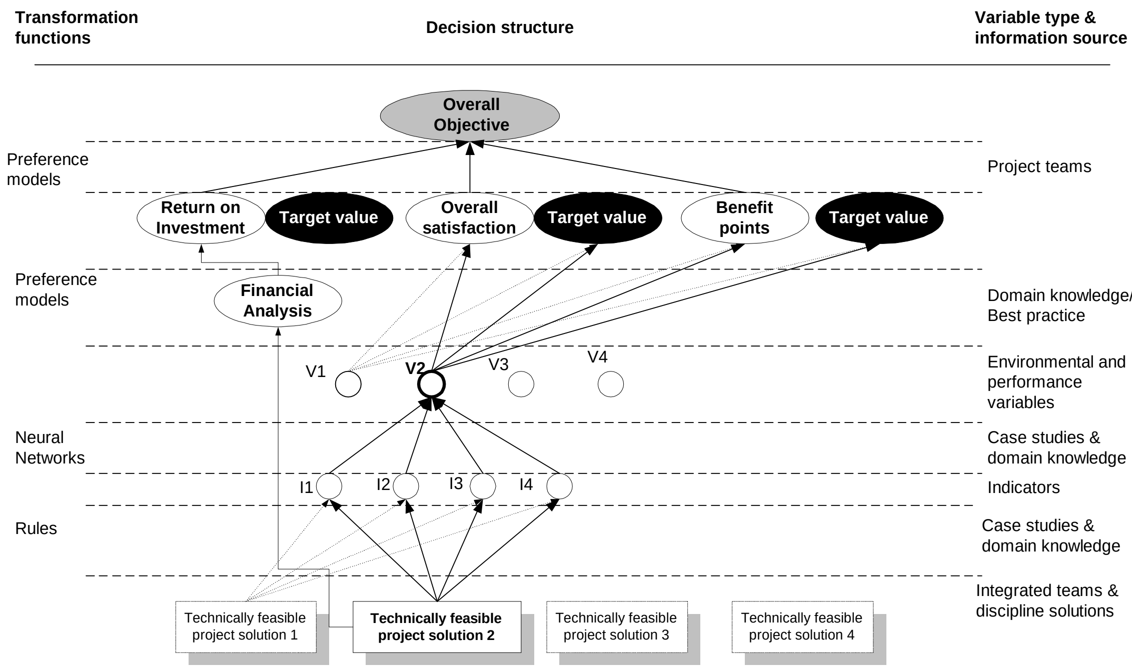

Figure 2. Project Decision Model Hierarchy and Information Sources

Thus in order for holistic decision-making, the hierarchy needs to be first defined, that is the number of levels, the attributes to be considered at each level, and the information and the transformation functions required to progress from one level to the next. The top level of the hierarchy defines the overall objective, performance on which forms the basis for ordering or ranking of the project alternatives. The overall objective is determined by combining, using a suitable transformation function, the performances of the project alternative on the three decision criteria – internal rate of return, overall satisfaction and total benefit points - that form the next level of the hierarchy, as shown in figure 2. The number of levels of attributes leading to each of the decision criteria can be different and depends on the types of information and transformation functions available.

In order to generate the different levels of the hierarchy below the decision criteria level, the high-level attributes influencing each decision criterion are initially identified. The attributes required to define each of these high-level attributes form the next level of the hierarchy and other lower levels, if required, are progressively generated till the lowest level is reached. The attributes at the lowest level of the hierarchy are those, whose values can be determined readily or are available for the project solutions to be evaluated. It is possible, in the case of complex projects, for the number of low-level attributes to be large.

Figure 2 also identifies the attribute types that occur at each level of the hierarchy and the sources from which information required to define the attributes and to achieve dimensionality reduction are derived. The transformation functions are implemented in the form of rules, neural networks and preference models, depending on the types of information available. The information required for the lower levels are derived mainly from case studies and previous problem solving experiences of experts. The lower level attributes, such as indicators and environmental and performance variables, are represented on nine point and six point ordinal scales respectively, with values for best practice at the top end of the scale.

The performances of alternatives on the three decision criteria are measured using different scales. The financial criterion, which is quantitative, is expressed in terms of the internal rate of return. The present project management system has the functions required to determine this value for a given alternative from the project description and relevant parameters. The overall satisfaction level is measured as an index from a scale of 0 for no satisfaction to 6 for best practice solution in the management of non-quantitative variables, such a environmental variables. Total benefit points are both direct and indirect benefit points, expressed as a percentage of the total project value, where project value is its present value at a specified discount rate.

The performances of a project alternative on the three decision criteria are then combined to arrive at the performance value for the overall objective. The transformation function to achieve this is derived from preferences of the decision makers. There are a number of methods available for elicitation of the decision makers' preferences (Rogers, 2001; Rogers et al., 1999; and Saaty, 2000; Fodor and Roubens, 1994, Cvetkovic and Parmee, 1999). The preferences are usually represented as weights, by which the values of each of the criteria are modified and then aggregated to arrive at the performance value for the overall objective. The project alternatives to be ranked must satisfy the target values set for each of the decision criteria, based on policy and derived for each project. Even though some alternatives may not meet the targets set, their performance on the decision criteria provides useful information and can form the basis for generating a modified/hybrid solution with better performance characteristics. These possibilities are further explored in the next section.

Given the hierarchical structure of the decision model, and by adopting the view that the decision making process involves a series of dimensionality reduction stages, the decision framework can be developed in the form of neural networks with modular structure. The parameters of the networks, such as connection weights, can be determined using approaches appropriate to the type of information available. Thus if case studies and previous problem solving experiences are used to determine the parameters of the network, then a multi-layer perceptron (MLP) network would be appropriate. Where the connection weights are determined using preference modelling techniques, then a linear network can be used. More details in the use of neural networks for developing the decision framework are given in the companion paper titled Tools and Techniques for Intelligent Project Management Information System: Heralding a New Project Management Paradigm.

5. SELECTION OF PROJECT PLAN

This section illustrates the use of the decision criteria and the trade-off to be made, within the decision process, in selecting the best project plan from a set of alternatives. The alternatives can fall into three categories: those that do not attain one or more of the targets set; those that have superior performance values for all three decision criteria; and those that have superior performance values for only some of the decision criteria. It is the third category that is of main concern, where the decision makers' preferences determine the level of trade-off that needs to be made.

Though the overall objective is defined by the three decision criteria, the decision model also includes incremental cost values – defined as additional cost in each solution expressed as a percentage of some base life cycle project cost. This gives an indication of the consequences of the decision makers' preferences on the life cycle project cost and can form an additional constraint to the solutions.

The solutions in Table 1 are all assumed technically feasible (generated by the project teams), each has an estimated incremental cost and a corresponding level of overall satisfaction and total benefit points. Both 3 and 4 satisfy all the expected target values set as criteria, though Solution 4 has a higher incremental cost while 3 has a higher return on investment. Solution 1 is rejected, as it does not meet any of the criteria, while Solution 2 is financially superior but will not meet the targets set for the overall satisfaction level and the total benefit points. Selection is therefore confined to either 3 or 4. The question is whether or not the additional investment of 1.20 percentage points of total life cycle cost is worth making, or whether or not the drop in the IRR value by 2 percentage points in Solution 4 relative to Solution 3 is acceptable, given that the latter has an increased overall satisfaction level by 0.5 and additional benefits (accruable to the stakeholders and the community) of 4 percentage points of the project base value. The sponsors and the teams considering the merits of each case (decision makers) normally make this type of decision. The decision made by the relevant players ultimately reflects the perception of the parties concerned and the worth they place on the benefits gained versus the drop in the return on investment, and hence their preferences.

Table 1. Holistic analysis of alternative project plans for a given project

Solution (plan) number	Incremental cost	Return on investment (IRR value, in % pa)		Overall satisfaction level (index)		Total benefit points (% points)	
		Target	Expected	Target	Expected	Target	Expected
1.	0.75	25	20	4.0	3.4	20	11
2.	3.92	25	31	4.0	4.1	20	17
3.	5.55	25	27	4.0	5.0	20	21
4.	6.75	25	25	4.0	5.5	20	25

While Solutions 1 and 2 appear to be outside the initial selection, these will nevertheless prompt the project teams to look further to see if they can be enhanced or if the targets set as criteria beforehand can be somewhat lowered. So the real benefit is the feedback that the system will provide, and the clarity of how solutions meet the relevant targets and whether or not a hybrid solution that embodies elements of all the aforementioned solutions can be synthesized with superior performance all around. Thus, targets set for the criteria in Table 1 are not necessarily the minimum levels, indeed it is far better to set "stretched" targets to challenge the project teams and the project manager to come up with innovative and creative solutions meeting all the technical, social and financial goals.

The selection of a solution from feasible alternatives via this approach is valid at the time that the analysis is conducted. Should there be changes in the project environment, resulting in changes to the input variables at some future point in time, the analysis needs to be repeated with the revised solutions (devised by the teams and the PM) used as the basis. Indeed, over the life of a significant project one might expect to undertake repeated cycles of analysis and re-planning, given the dynamic environment typical on most projects.

In order to arrive at the level of the decision criteria and to determine their values, similar to those shown in Table 1, the decision maker needs to progress through the lower levels of the hierarchy using techniques discussed in the previous section. There are three aspects that need to be considered at the decision criteria level. The first relates to the scales of measurements to be used to determine the values of the criteria. Those relating to the financial criteria are well covered in the literature. The next section will thus discuss the issues relating to the other two criteria – overall satisfaction and total benefit points. The second is the weighting to be applied to each of the criteria values, and the literature on preference modelling offers a number of possibilities, mostly based on pair-wise comparison of the decision criteria. The third is the transformations to be applied to the decision criteria values, to account for the different scales of measurement. One approach is to normalize the values to be within the same range and to then combine them along with the weights. This is similar to pre-processing of input variables in neural networks and can thus be used.

6. DETERMINING SATISFACTION LEVELS

Satisfaction level relates to how well a particular variable is managed on a given project. The highest satisfaction stems from applying the best practice that the relevant industry sector has developed for management of that particular variable. Thus, it is necessary to construct a domain knowledge base for each industry sector (such as commercial building, process plant, industrial projects and so on) in each region.

The domain knowledge, derived from previous cases and problem solving experiences, is used to determine the relationship between a given qualitative variable's satisfaction level versus the incremental cost (expressed as percentage points of the total life cycle). Satisfaction levels can be classified using a numeric scale of 0 to 6, where 0 represents worst practice and 6 best practice. To avoid confusion, it may be desirable to use the following equivalent linguistic scale: 0=non-existent, 1=poor, 2=below average, 3=average, 4=good, 5=very good, 6=excellent. One needs to define a series of appropriate indicators for each qualitative variable so that through assessing the status of these indicators it is possible to assign a numeric value (or an equivalent linguistic term) to it to assess the corresponding satisfaction level. For example, in the case of air quality, the concentrations of particulate matter, carbon dioxide, carbon monoxide, hydrocarbons and oxides of nitrogen in the air can be defined as indicators. Domain knowledge is used to generate the transformation function required for determining the satisfaction levels for the variables from indicators.

To construct the initial domain knowledge, a sample of at least 50 projects will need to be studied for each industry sector. The information from these case projects will have to be augmented by the input from the experts in the sector under consideration. Using the relevant indicators and the scale of practice from the domain knowledge, it is possible to estimate the satisfaction level for each qualitative variable afforded by each of the alternative project solutions. The corresponding incremental costs can also be estimated by the teams. The domain knowledge may be held in the system as the reference basis for guiding the project teams and for setting of stretch targets to challenge the teams to come up with optimal solutions. As an example, the relationship could be in the form of a plot containing the practice envelope as typified in Figure 3. The curve in this Figure represents the industry average practice.

Solutions S1 and S2 in Figure 3 are as devised for a given project versus the relevant practice curve. S1 is less efficient compared to S2. This is because, other things being equal, S2 has a lower incremental cost with a higher satisfaction level compared to S1. However, the temptation to select a solution based only on a single qualitative variable response must be resisted, as the final decision may well be different depending how each solution responds to the relevant set of qualitative variables as a whole, and depending on the total benefit points attributable to each solution. An interesting point evident from Figure 3 is the exponential rise in the incremental cost with rise in the satisfaction level. The fact is that achieving the best practice may mean investing substantially more resources on the project (hence incurring an order of magnitude higher incremental cost) than achieving an acceptable level of practice.

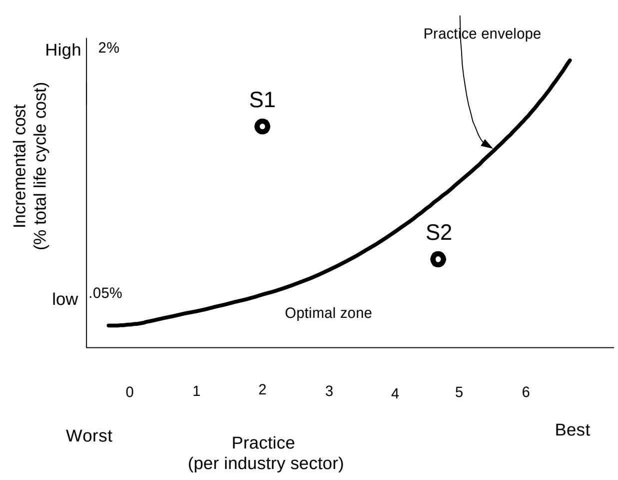

Figure 3. Schematic representation of using the domain knowledge and alternative solutions

Best practice can only be justified if the total benefit points are considerable, and if the scale and complexity of the project demands a best practice approach to the variable under consideration. Otherwise there is a trade off between these, and the optimum overall solution is located after results are combined as in Table 1, and compared to the corresponding criteria. As stated already, preference models and multi-objective evaluation may be used to combine all the relevant variable values and thus derive single values for overall satisfaction and total benefit points for each solution.

7. CONCLUSIONS

It has been demonstrated that a holistic decision model, with a hierarchical structure, can be developed for evaluating the performance of project solutions on decision criteria that are based on life cycle objective functions, which include the project's impact on the environment and the community. Such a model could be embedded into a project management information system and can be used not only at the conceptualisation stage of the project to evaluate project alternatives, but also for dynamic decision-making over the life of the project by being responsive to changes in the project environment. By considering the different levels of the hierarchy as attributes of the project, and progression through the hierarchy as a dimensionality reduction process, it is possible to implement the decision model as a set of neural networks with modular structure. The dimensionality reduction process leads to a single high-level attribute that permits the simple ordering or ranking of project alternatives.

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