Analytic Network Process Applied to Project Selection

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Abstract: Owing to the complexity of a construction project, the analytic network process (ANP) is helpful to deal with interdependent relationships within a multicriteria decision-making model. This paper demonstrates an example to illustrate how to empirically prioritize a set of projects by using a five-level project selection model. A questionnaire was filled by a group of construction professionals of a medium-sized local developer and scores were computed for prioritizing the potential projects. The paper is relevant to both industry practitioners and researchers. Industry practitioners may adopt the weighted criteria for direct project selection or apply the ANP method to prioritize their own set of selection criteria. Researchers may rely on this paper as a point of departure for exploring other uses of ANP.

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Introduction

Construction clients are always faced with difficulties in selecting projects that offer return on investment. Due to scarce resources, they cannot undertake all projects simultaneously. Instead, they have to select the most viable projects, which not only maximize positive outcomes (e.g., profits, reputation, etc.) but also minimize any negative results (e.g., technical deficiency, environmental harm, etc.). This raises the need for relying on a set of selection criteria for prioritizing a number of projects. Those projects with most favorable scores are given the highest priorities for undertaking. However, the core question is how to select projects. Badri et al. (2001), after conducting a simple review, found that there are thirteen kinds of methods that are raised for IS project selection decision, including scoring, ranking, mathematical programming, fuzzy logic, and analytic hierarchy process (AHP). The authors of this study have also conducted a review of recent published papers and have identified another list of methods that have been developed to address project-selection problems in the construction field (as shown in Table 1).

Consistent with the view of Mohanty (1992), the field in general has progressed from the application of linear weighting, via linear programming and integer programming, to multicriteria decision making (MCDM) models. The AHP and analytic network process (ANP) are two analytical tools for MCDM. The AHP is employed to break down large unstructured decision problems into manageable and measurable components. The ANP, as the general form of AHP, is powerful to deal with complex decisions where interdependence exists in a decision model. As Molenaar and Songer (1998) suggested, such multicriteria (or multiattribute) analyses are suitable for the project selection process characterized by a large number of project variables and complex relationships. Despite the growing number of applications of AHP in various fields that involve decision-making, ANP has started to be employed in project selection in construction-related fields (e.g., Meade and Presley 2002). However, there is still a lack of papers presenting the use of ANP in typical construction project selection from the client's perspective. This paper is intended to apply the ANP process to select a number of projects that are plausibly undertaken. An example is demonstrated to prioritize a set of construction projects based on the identified and weighted criteria by means of ANP.

This paper proceeds as follows. The first section describes the major steps for ANP. The second section presents the project selection network model. Finally, an example is demonstrated to rank and select projects using ANP.

Analytic Network Process

The ANP incorporates both qualitative and quantitative approaches to a decision problem. The four major steps for the qualitative component are described below:

1. Identify the decision problem. Suppose a client would like to select the highest scored project from a number of potential construction projects, the decision problem will be to "select the highest scored construction project."
2. Ensure that the decision problem can be solved by ANP. The ANP is appropriate to solve decision problems with a network structure. Problems with a simple hierarchical model can be solved by AHP.
3. Decompose the unstructured problem to a set of manageable and measurable levels. The topmost level is the decision problem, while the lowest level is usually the scenario or alternative level (Saaty 1980).
4. Determine who should be responsible for making the decision (rater). Usually, a small group of top management or experts are sufficient to provide useful data. Sometimes, top management may assign weights to the top levels, while

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Table 1. Various Kinds of Project Selection

Decision method	Decision problem	Published papers
Cost analysis (e.g., NPV, DCF, and payback)	Construction project selection	Okpala (1991)
Ranking and nonweighted model	Project investment selection decision	Odusote and Fellows (1992)
Linear and integer programming	Construction project selection	Gori (1996)
AHP	Industrial project selection	Mohanty (1992), Alidi (1996)
Multiattribute utility theory in conjunction with PERT	Construction project selection	Moselhi and Deb (1993)
Multiattribute analysis in conjunction with regression models	Public sector design–build project selection	Molenaar and Songer (1998)
Mathematical programming	Vendor selection decision	Degraeve et al. (2000)
Fuzzy stochastic	Construction project selection	Wong et al. (2000)
Mixed 0-1 goal programming	IS project selection	Badri et al. (2001)
Possibility theory	Project investment decision	Mohamed and McCowan (2001)
ANP in conjunction with Delphi and 0-1 goal programming	IS project selection	Lee and Kim (2001)
Mathematical programming	Research and development project selection	Pillai et al. (2002)
ANP	Research and development project selection	Meade and Presley (2002)

middle to operational management may rate the lower levels.

The following describes the five major steps for the quantitative component:

1. Set up a quantitative questionnaire for collecting data from those who should respond. Saaty (1980) suggested the use of a nine-point priority scale and pair-wise comparison.
2. Estimate the relative importance between two elements (when pairwise comparison is used) of the elements in each matrix and calculate the eigenvector of each of the developed matrices. Refer to the existing literature having suggested the necessary algorithms for calculating the eigenvector of each matrix, such as Saaty (1980) and Cheng and Li (2001).
3. Measure the inconsistency of each of the matrices (when pairwise comparison is used) by employing the consistency ratio (CR). Refer to the existing literature having suggested the necessary algorithms to calculate CR, such as Saaty (1980) and Cheng and Li (2001). Alternatively, commercial software packages that compute eigenvectors and CRs are available (e.g., *Expert Choice for Windows*, 2003). Saaty (1994) set three acceptable levels for CR (i.e., 0.05 for 3 by 3 matrix, 0.08 for 4 by 4 matrix, and 0.1 for other matrices). Matrices that are inconsistent should be excluded or rerated by the raters.
4. Place the eigenvectors of the individual matrices (also known as submatrices) to form the supermatrix (Saaty 1996). Refer to the later illustrative example of how to construct the supermatrix.
5. Ensure the supermatrix is column stochastic and raise the supermatrix to high power until the weights have been converged and remain stable (Sarkis 1999). For the purpose of mathematical computation of matrices, the authors of this paper created a program in the popular *Microsoft Excel*. Alternatively, a commercial software tool, *SuperDecisions*, developed by William J. Adams of Embry Riddle Aeronautical University and Rozann W. Saaty is appropriate to solve decision problems with a network model (Saaty 2003). Despite the availability of user-friendly software, users must have a thorough understanding of the ANP concepts before attempting to use the software. This will reduce unnecessary mistakes that hamper the making of good decisions. In a later section, we reveal a paper exhibiting wrong results from using ANP.

Project Selection Network Model

Project selection is also known as the preinvestment phase of a project life cycle (Alidi 1996). This phase has four core stages: (1) identification of investment opportunities; (2) analysis of project alternatives and preliminary project selection (prefeasibility study); (3) project preparation (feasibility study); and (4) project appraisal and investment decisions (Behrens and Hawranek 1991). Prior to a decision for preparing a detailed feasibility study for the selected industrial projects, a prefeasibility study is required to determine the viability of a pool of industrial projects (Alidi 1996).

Mohanty (1992), when developing a decision model, raised the four core characteristics of an attractive project, which are: (1) minimum investment; (2) a low degree of skills and techniques; (3) a short time horizon; and (4) highest return potential. This mix is almost impossible in real world practices when taking quality, reputation, continuous improvement, and social responsibility into consideration. Therefore, a selection decision is expected to be dependent on a number of criteria to ensure that the decision is practicable to the company. Using ANP to project selection involves a decision model that specifies relationships among elements within a hierarchical structure. To build up such a decision problem hierarchy, we have to know what elements should be incorporated.

After a review of the existing literature, this paper establishes five levels in the ANP network (as shown in Fig. 1). The first level is the decision problem, which prioritize the projects. This level is decomposed into the actor level composed of three parties exerting influence into the project. These parties, referred to as groups' objectives (Alidi 1996), are the management of the company, the public and other pressure groups, and the company's Board of Directors. These three parties play different roles in viewing the

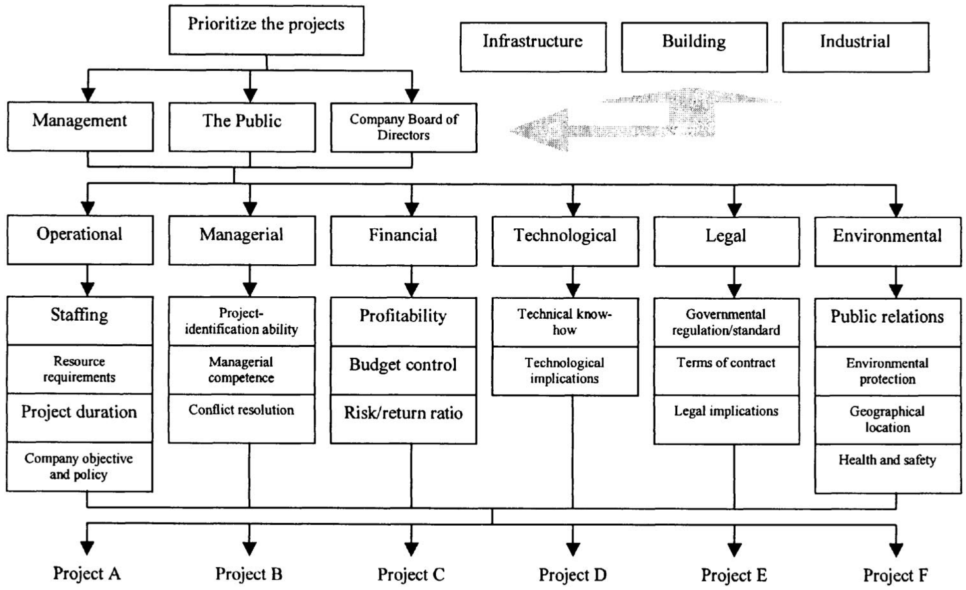

Fig. 1. Project selection decision model

project criteria. For example, pressure groups may be more interested in whether the company offers good wages for workers, violates the governmental regulations, or damages the environment. The company's board of directors may have objectives that maximize profits and increase the company's goodwill, while the management of the company may be concerned about most of the project criteria. Following Mohanty (1992), the actor level is further decomposed into six criteria categories (operational, managerial, financial, technological, legal, and environmental). It is noted that the three parties may have different expectations on these criteria categories. Thus, ANP helps integrate their expectations to form the composite category weights after taking into account their various interests.

There are corresponding criteria of the six categories (Mohanty 1992), which form the fourth level. Specifically, criteria for the operational category are staffing, raw materials (resources requirements and availabilities), equipment, project duration, and company objective, and policy. Criteria for the managerial category are project-identification ability, managerial competence (plus past experience), and conflict resolution. Criteria for the financial category are profitability (plus market demand), budget control, and risk/return ratio. Criteria for the technological category are technical know-how (plus project complexity) and technological implications. Criteria for the legal category are governmental regulations and standards, terms of contract, and legal implications. Criteria for the environmental category are public relations, environmental protection, geographical location, and health and safety. These criteria are described more in Table 2. Finally, the projects that are going to be selected form the fifth level. In the present study, there are six projects having to be selected.

As shown in Fig. 1, interdependence or feedback occurs between the actors (second level of the hierarchy) and the types of project (infrastructure, building, and industrial), indicated by the two-headed arrow. The impact of project type on project cost estimate has been proposed in the existing literature (e.g., Oberlender and Trost 2001). Also, Meade and Presley (2002) suggested the interdependence between actors and research phase in their research and development (R&D) project selection. However, they put the phase of research as part of the formal hierarchy, while actors are external elements. Conversely, in this paper, these types of projects are not included in the formal hierarchy because they should have individual sets of criteria ratings. Since they may have some degree of interdependence with the three actors, they should affix to the hierarchy as an external cluster.

Illustrative Example

In order to demonstrate the use of ANP in project selection, an example is provided in this paper. During the process that we designed this experimental study, we had reviewed a number of ANP papers and found that the decision model of Meade and Presley (2002) was appropriate for us to develop our model. However, when we replicated their quantitative component of the ANP process, we produced different results. The discrepancies might originate from the following mistakes:

1. They specified the interdependence between the actor level and the phase of research level. Yet, there were three sets of relative importance values of the three categories with respect to the three phases of research (as shown in their Fig. 1). These three sets of values should have been incorporated into the supermatrix. This is a kind of serious mistake since it involves misconception. Cheng et al. (2002) described one possible misconception of using AHP in their paper.
2. After comparing between their Tables IV and VII, we found that the data of the actor level mistakenly replaced those of the category level (by comparing between their Tables IV and VII). Although this small mistake may be due to carelessness (may not involve misconception), this is detrimental to the interpretation of the results, totally destroying the decision having been made.
3. After comparing the results of the last two columns of their Table VII and ours (by using their formula for calculating the desirability index for an alterative), we found that their results were wrong. It is likely that they used a wrong spreadsheet formula to calculate the final scores for the two choices

Table 2. Description of Selection Criteria

Criterion	Description
Staffing	Staffing means the hiring of the right people for jobs. A project is said to be feasible if the company has the right people (e.g., skills and knowledge) to perform the duties and if the company is able to pay for the wages and welfare to staff and workers. Staffing, thus, has an important bearing on project choice (Mohanty 1992).
Resource requirements	The availability of required resource (including capital, raw materials and equipment) is a constraint that limits the alternatives under consideration (Okpala 1991, Mohanty 1992).
Project duration	Project duration affects the time for the return on investment (ROI) (Mohanty 1992). This would be critical to companies looking for a fast ROI.
Company objective and policy	The project must match the company's objectives and policies (Mohanty 1992). If the company aims at infrastructure projects, commercial and industrial projects are of little concern.
Project-identification ability	Project identification is probably the first step in project selection to identify a number of potential projects (Mohanty 1992). So, the management should be able to perform this duty.
Managerial competence	Management competence includes capability, attitudes, and past experience (Mohanty 1992). Managers must be able to manage properly, should have positive attitudes to project management, and has experience to deal with the project. It is noted that the higher the management competence to a specific type of project, the more is the client's willingness to select that type of project.
Conflict resolution	Managerial skills in conflict resolution are particularly crucial for a construction project since there are a number of parties involved (Cheng and Li 2001). If a client has strong conflict resolution skills, it may be more favorable in undertaking complicated projects that are perceived to have more conflicts at work when more parties are involved.
Profitability	Profit is the motive for most of the construction projects. A project is said to be profitable when there is net market demand and a positive profit/cost ratio (e.g., NPV, IRR). Profitability is inevitably a criterion for project selection (Alidi 1996)
Budget control	Budget control is essential to every kind of project (Alidi 1996; Oberlender and Trost 2001). Out of budget may cause the reduction of profit margin or even a deficit.
Risk/return ratio	Project that anticipates higher return usually entails a higher risk. Thus, an assessment of the risk/return ratio for each project stands a promise to determining the feasibility of a project (Mohanty 1992).
Technical know-how	Ensuring that technology is available locally or can be obtained from foreign sources is essential to project choice (Mohanty 1992).
Technological implications	This refers to technical interdependencies as mentioned by Lee and Kim (2001) where the technology gained in one project can extend to other projects.
Governmental regulations and standards	Projects must conform to governmental regulations and standards. As Mohanty (1992) was aware, policy considerations may have bearing on the choice of project.
Terms of contract	This is related to the procurement methods adopted for different projects (Cheung et al. 2001). The terms of contract are thus expected to affect the choice of projects (Mohanty 1992).
Legal implications	Each project has its own unique legal implications that must be studied in depth, such as the prediction of any consequence for the project resulted from the likely changes in the legal framework of a country or state (Mohanty 1992).
Public relations	A project must be acceptable in terms of the public interest. Without good relations to the public, the project is not feasible to undertake (Alidi 1996).
Environmental protection	Protecting the environment is a kind of social responsibility. Other than the environmental legislation, pressure from other interest groups may increase the need for additional environmental protection (Chin et al. 1999). Environment is expected to be a criterion to project selection (Meade and Presley 2002).
Geographical location	If a potential project is located on a site with inherent construction problems, the project may not be feasible. Geographical location is important as perceived by individual investors and client companies (Okpala 1991).
Health and safety	Occupational health and safety (OHS) is a key measure for protecting workers health on site (e.g., Lingard 2002). Project to be undertaken must be able to conform to the measure without compromise.

(1) With respect to PRI

	MGT	PUB	CBD	EV
MGT	1	2	1/2	0.297
PUB	1/2	1	1/3	0.164
CBD	2	3	1	0.539
			CR =	0.008

(2) With respect to INF

	MGT	PUB	CBD	EV
MGT	1	1/3	1	0.2
PUB	3	1	3	0.6
CBD	1	1/3	1	0.2
			CR =	0

(3) With respect to BUI

	MGT	PUB	CBD	EV
MGT	1	7	1	0.467
PUB	1/7	1	1/7	0.067
CBD	1	7	1	0.467
			CR =	0

(4) With respect to IND

	MGT	PUB	CBD	EV
MGT	1	1/2	2	0.286
PUB	2	1	4	0.571
CBD	1/2	1/4	1	0.143
			CR =	0

(5) With respect to MGT

	INF	BUI	IND	EV
INF	1	1/7	1/3	0.085
BUI	7	1	4	0.701
IND	3	1/4	1	0.213
			CR =	0.028

(6) With respect to PUB

	INF	BUI	IND	EV
INF	1	7	2	0.615
BUI	1/7	1	1/3	0.093
IND	1/2	3	1	0.292
			CR =	0.002

(7) With respect to CBD

	INF	BUI	IND	EV
INF	1	1/7	1	0.111
BUI	7	1	7	0.778
IND	1	1/7	1	0.111
			CR =	0

Fig. 2. Relative weights of actor level and type of project level (Note: PRI = prioritize projects; MGT = management; PUB = Public; CBD = Company Board of Director; INF = infrastructure; BUI = building; IND = industrial)

(8) With respect to MGT

	OPE	MGL	FIN	TEC	LEG	ENV	EV
OPE	1	1/2	1/3	1	1/3	1	0.091
MGL	2	1	1/2	1	1/2	2	0.149
FIN	3	2	1	3	1	3	0.284
TEC	1	1	1/3	1	1/3	1	0.103
LEG	3	2	1	3	1	3	0.284
ENV	1	1/2	1/3	1	1/3	1	0.091
						CR =	0.007

(9) With respect to PUB

	OPE	MGL	FIN	TEC	LEG	ENV	EV
OPE	1	3	3	3	1	1/3	0.187
MGL	1/3	1	1	1	1/3	1/5	0.069
FIN	1/3	1	1	1	1/3	1/5	0.069
TEC	1/3	1	1	1	1/3	1/5	0.069
LEG	1	3	3	3	1	1/3	0.187
ENV	3	5	5	5	3	1	0.419
						CR =	0.009

(10) With respect to CBD

	OPE	MGL	FIN	TEC	LEG	ENV	EV
OPE	1	1	1/7	1	1/5	1/2	0.059
MGL	1	1	1/7	1	1/5	1/2	0.059
FIN	7	7	1	7	4	2	0.446
TEC	1	1	1/7	1	1/4	1/2	0.061
LEG	5	5	1/4	4	1	2	0.237
ENV	2	2	1/2	2	1/2	1	0.138
						CR =	0.028

Fig. 3. Relative weights of category level (Note: OPE = operational; MGL = managerial; FIN = financial; TEC = technological; LEG = legal; ENV = environmental)

(new system or upgrade) in their alternative level. This is also a small mistake but is definitely detrimental to the interpretation of the results. Our calculations indicate that new system score (0.517) is larger than upgrade score (0.509). In other words, we have had opposite results. They therefore wrongly suggested upgrading the system.

Although they provided a robust decision model (qualitative component of ANP), mistakes with respect to the quantitative component due to misconception or carelessness would devalue their work. Academic researchers had no excuse of not paying attention to every detail of their research. Therefore, we urge that researchers should focus not only on the decision model development but also the quantitative steps of ANP. Crosschecking is crucial in the ANP process since a large number of variables, data, and calculations are involved. It is certain that a simple mistake would lead to a harmful effect to the decision being made. With this in mind, we have taken every precaution to prevent the creation of similar mistakes in our study.

In this paper, we designed a questionnaire that used the nine-point priority scale developed by Saaty (1980), appropriating it for pairwise comparison. A group of construction professionals of a medium-sized local developer, a subsidiary of a local public-listed company, is responsible for filling in the questionnaire collectively. Their company mainly invests in commercial and residential building projects. Their ratings are for experimental purpose. Figs. 2–4 illustrate the 16 matrices and the resulting ratings. The CR values are all acceptable and the eigenvectors displayed are appropriate to enter into the supermatrix. It is noteworthy that companies may be inclined to use objective measures for some criteria to replace the subjective scale we used in this experimental example. Nevertheless criteria, such as management competence and conflict resolution, are difficult to measure ob-

(11) With respect to OPE

	STA	RES	PDU	COP	EV
STA	1	1/3	1/2	1	0.141
RES	3	1	2	3	0.455
PDU	2	1/2	1	2	0.263
COP	1	1/3	1/2	1	0.141
				CR =	0.004

(12) With respect to MGL

	PIA	MCO	CON	EV
PIA	1	1/3	1/3	0.143
MCO	3	1	1	0.429
CON	3	1	1	0.429
			CR =	0

(13) With respect to FIN

	PRO	BUD	RRR	EV
PRO	1	1/3	1/2	0.164
BUD	3	1	2	0.539
RRR	2	1/2	1	0.297
			CR =	0.008

(14) With respect to TEC

	TKH	TIM	EV
TKH	1	2	0.67
TIM	1/2	1	0.33
		CR =	n.a.

(15) With respect to LEG

	GRS	TER	LIM	EV
GRS	1	2	3	0.539
TER	1/2	1	2	0.297
LIM	1/3	1/2	1	0.164
			CR =	0.008

(16) With respect to ENV

	PRE	EPR	GEO	HAS	EV
PRE	1	1/2	1	1/2	0.167
EPR	2	1	2	1	0.333
GEO	1	1/2	1	1/2	0.167
HAS	2	1	2	1	0.333
				CR =	0

Fig. 4. Relative weights of the criterion level (Note: STA = staffing; RES = resource requirements; PDU = project duration; COP = company objectives and policies; PIA = project-identification ability; MCO = managerial competence; CON = conflict resolution; PRO = profitability; BUD = budget control; RRR = risk/return ratio; TKH = technical know-how; TIM = technological implications; GRS = governmental regulations and standards; TER = terms of contract; LIM = legal implications; PRE = public relations; EPR = environmental protection; GEO = geographical location; HAS = health and safety)

Table 3. Initial Supermatrix (Major Components)

		Actor of project			Type of project			Selection Criteria category					
	PRI	MGT	PUB	CBD	INF	BUI	IND	OPE	MGL	FIN	TEC	LEG	ENV
MGT	0.297	0	0	0	0.2	0.467	0.286	0	0	0	0	0	0
PUB	0.164	0	0	0	0.6	0.067	0.571	0	0	0	0	0	0
CBD	0.539	0	0	0	0.2	0.467	0.143	0	0	0	0	0	0
INF	0	0.085	0.615	0.111	0	0	0	0	0	0	0	0	0
BUI	0	0.701	0.093	0.778	0	0	0	0	0	0	0	0	0
IND	0	0.213	0.292	0.111	0	0	0	0	0	0	0	0	0
OPE	0	0.091	0.187	0.059	0	0	0	0	0	0	0	0	0
MGL	0	0.149	0.069	0.059	0	0	0	0	0	0	0	0	0
FIN	0	0.284	0.069	0.446	0	0	0	0	0	0	0	0	0
TEC	0	0.103	0.069	0.061	0	0	0	0	0	0	0	0	0
LEG	0	0.284	0.187	0.237	0	0	0	0	0	0	0	0	0
ENV	0	0.091	0.419	0.138	0	0	0	0	0	0	0	0	0
STA	0	0	0	0	0	0	0	0.141	0	0	0	0	0
RES	0	0	0	0	0	0	0	0.455	0	0	0	0	0
PDU	0	0	0	0	0	0	0	0.263	0	0	0	0	0
COP	0	0	0	0	0	0	0	0.141	0	0	0	0	0
PIA	0	0	0	0	0	0	0	0	0.143	0	0	0	0
MCO	0	0	0	0	0	0	0	0	0.429	0	0	0	0
CON	0	0	0	0	0	0	0	0	0.429	0	0	0	0
PRO	0	0	0	0	0	0	0	0	0	0.164	0	0	0
BUD	0	0	0	0	0	0	0	0	0	0.539	0	0	0
RRR	0	0	0	0	0	0	0	0	0	0.297	0	0	0
TKH	0	0	0	0	0	0	0	0	0	0	0.67	0	0
TIM	0	0	0	0	0	0	0	0	0	0	0.33	0	0
GRS	0	0	0	0	0	0	0	0	0	0	0	0.539	0
TER	0	0	0	0	0	0	0	0	0	0	0	0.297	0
LIM	0	0	0	0	0	0	0	0	0	0	0	0.164	0
PRE	0	0	0	0	0	0	0	0	0	0	0	0	0.167
EPR	0	0	0	0	0	0	0	0	0	0	0	0	0.333
GEO	0	0	0	0	0	0	0	0	0	0	0	0	0.167
HAS	0	0	0	0	0	0	0	0	0	0	0	0	0.333

jectively. The criteria that use objective measures do not need to calculate the consistency ratio since no paired comparisons and matrices formed for them. Only normalized values of these criteria are needed to enter into the supermatrix.

Table 3 shows the supermatrix after entering the prioritized values. The supermatrix was column stochastic. It was then raised to sufficiently large power until convergence occurred (Saaty 1996; Meade and Sarkis 1998). More specifically, given that the supermatrix is irreducible, this involves raising the supermatrix to the power $2k+1$ and converges if $k\rightarrow\infty$ (Saaty 1996; Meade and Sarkis 1998). Table 4 exhibits the weighted values of the 19 criteria in the final limit matrix.

As shown in Table 4, the highest weight is 0.08, while the lowest weight is 0.039. This implies that the ANP method proves its utility by bringing specific loadings to bear on the criteria. The criterion with the highest weight is budget control (0.08), followed by governmental regulations and standards (0.076), technical know-how (0.063), risk/return ratio (0.058), resource requirements (0.057), environmental protection (0.057), health and safety (0.057), and terms of contract (0.056). This is somewhat consistent with other studies. For example, Mohanty (1992) found that governmental regulations and standards rank first, while social environment ranks third. Alidi (1996), on the other hand, found that budget has the highest weight. Nevertheless, attempting to draw implications from comparing among these studies is impracticable since these studies used different groups of raters.

In order to rate a set of projects based on the weighted selection criteria, the normal linear weighting method was used, in which each project was rated based on a score (using a ten-point scale) on each of these criteria and in which the products of the rating and weighting scores of the criteria were combined into a single final score. In mathematical expression, the final score of each project, $P_i=\Sigma_j W_j S_{ij}$ (where P_i is the project i, W_j is the weighted value on criterion j, and S_j is the score on criterion j, and where $j=1,\ldots,19$). For example, the final score of Project A, $P_A=W_1S_{A1}+W_2S_{A2}+\ldots+W_{19}S_{A19}$.

For prioritizing a set of projects, the raters chose six projects from their company for this study (see Table 5). The raters rated these projects based on the 19 criteria. They did not know the weights of the criteria and only recorded their collective scores for each criterion on a project scorecard, resulting in the completion of six scorecards. Due to confidentiality, detailed information about the six projects was not provided. Table 4 exhibits the individual scores of the criteria on each project and the final scores of the projects.

The final weighted scores of the projects indicate that Project A (6.714) should be undertaken first, followed by F (6.586), C (6.161), E (5.682), B (4.642), and D (3.778). In general, the

Table 4. Prioritization of Six Projects

	Weight (Wi)	Project (Pi) (Ten-point scale) A	B	C	D	E	F
Staffing	0.039	5	8	6	7	6	5
Resource requirements	0.057	5	8	5	6	5	5
Project duration	0.046	5	6	7	3	4	5
Company objective and policy	0.039	8	5	7	5	5	8
Project-identification ability	0.039	6	4	6	4	5	6
Managerial competence	0.053	8	3	7	3	8	8
Conflict resolution	0.053	8	2	7	2	4	8
Profitability	0.046	6	3	4	7	4	4
Budget control	0.080	8	3	7	2	5	8
Risk/return ratio	0.058	7	3	7	2	5	8
Technical know-how	0.063	8	9	6	2	6	8
Technological implications	0.047	4	7	6	9	6	2
Governmental regulations and standards	0.076	6	2	5	2	5	6
Terms of contract	0.056	7	3	6	3	6	7
Legal implications	0.045	8	2	7	2	7	8
Public relations	0.044	8	6	7	6	8	8
Environmental protection	0.057	6	7	4	4	6	6
Geographical location	0.044	8	4	8	3	8	8
Health and safety	0.057	6	5	6	4	6	6
Mean score (nonweighted)=		6.684	4.737	6.211	4	5.737	6.526
Project final score (weighted)=		6.714	4.642	6.161	3.778	5.682	6.586

Notes: (1) The weight column is the final limit matrix, a ten-point scale from the lowest (=1) to the highest (=10) was used to measure the extent to which the company rated the importance level of the criterion.

higher the score, the lower the risk that the project will be harmful to the company. The results are consistent with their company's usual practice that is to undertake building projects. The non-weighted mean scores of the projects had also been calculated (see Table 4). It is observed that the two sets of results are similar, while the rank of projects is the same. This is not necessary to be a common situation if the weighted results are dominantly influenced by interdependent relationships. Other ANP studies have resulted in significant differences between weighted and non-weighted results (e.g., Cheng and Li 2004).

Relevance to Researchers and Industry Practitioners

The ANP is an innovative tool for multicriteria decision making. Both researchers and industry practitioners should find it useful in

Table 5. Description of Six Projects

	Project A	B	C	D	E	F
Project type	Building	Building	Industrial	Infrastructure	Building	Building
Project specific	International office building	Low-rise residential complex	Depot	Fee-paying infrastructure	High-rise residential complex	Commerical building
Location	Local prime area	Prime area in Guangdong province	Local industrial area	Guangdong province	Local prime area	Local suburban area
Size of the project in terms of capital investment	Medium sized	Medium sized	Medium sized	Large	Large	Medium sized
Project duration (Expected)	3 years	2 years	2 years	6 years	4 years	3 years
Projected profit (10-point scale)	6	3	3	8	5	4
Risk/return ratio (10-point scale)	2	8	3	5	5	2
Partners involved	No	Yes	No	Yes	Yes	No

different ways. Researchers may rely on this study as a point of departure for exploring other uses of ANP. For example, it can be employed to select the appropriate construction method for a project or to evaluate project performance. With respect to industry practitioners, ANP is useful to determine the initial viability of construction projects, helping to select a smaller number of projects from a larger pool. A detailed feasibility study would be conducted for the selected projects. With a cautiously designed decision model and rigorous ratings, ANP can act as the detailed feasibility study and the results can be the best solution for the company. Companies should take further work to be geared toward improving the lower scored criteria. However, the company may not plan to undertake all the projects or follow the order of the selection priority. The selection of project may sometimes depend on other factors, such as intuitive preference of the management, net profit margin of the projects, risk taking behavior, etc. In such cases, the final score on each project together with the individual scores on the criteria would give the company a reliable signal. For example, if the company insists on embarking on the lowest scored project (i.e., the infrastructure project), it should be aware of the associated high risk and should pay particular attention to those selection criteria with lower scores.

Conclusions

The concept of ANP has evolved to deal with interdependent relationships in a multicriteria decision model. Despite a number of publications applying AHP in construction project selection, this is probably the first time that an attempt has been made to apply ANP in project selection. This paper has demonstrated an example to illustrate the steps of ANP in project selection. However, we take the view that companies should develop their individual sets of selection criteria, especially when they have to put further effort into examining the complex nature of a construction project. In this regard, our decision model is a reference point for them. It should be noted that an effective project selection method helps to ensure optimal resource utilization and greater contribution of projects toward company's missions and goals.

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