Ranking Construction Project Alternatives with the Analytic Network Process Method

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Abstract

In evaluating construction investments, public or private sector owners often have several project alternatives, e.g. different sites for development and different types of building. Assessing each of them so as to identify the best for implementation is owners' most important decision in the project planning stage. The traditional net present worth method has difficulty in including intangible benefits and risks, so the result of it may not represent the overall value of an alternative. The multi-attribute utility theory method can include all factors in producing a total utility score for an alternative, but it has difficulty in determining criteria weights and utility functions. The analytic hierarchy process method can derive criteria weights and priority scores of alternatives from paired comparisons, but it cannot incorporate feedback relations between criteria and alternatives as it is done hierarchically in a top-down manner. This paper proposes an improved model for assessing project alternatives using the analytic network process method as the generalized analytic hierarchy process method to include the feedback impacts absent from the analytic hierarchy process. To illustrate the model, three recent housing projects in Kaohsiung, Taiwan were used as hypothetical alternatives being considered by a medium developer. A study of related factors that influenced their economics as well as feedback relations between factors and alternatives were conducted to determine the criteria and the dependency links in the network model. Based on company and project conditions, values of inputs for the model were set and were processed to produce the criteria weights and the relative scores of the alternatives for establishing their priority ordering. The ANP model results in changes in the ranking of the sites from those produced by the AHP method due to the additional relations.

Keywords: construction, project site selection, decision analysis, analytic hierarchy process, analytic network process.

1. Introduction

In evaluating construction investments, public or private sector owners often have several project alternatives, e.g. different sites for development and different types of building. Assessing each of them so as to identify the best for implementation is owners' most important decision in the project planning stage. The traditional net present worth method has difficulty in including intangible benefits and risks, so the result of it may not represent the overall value of an alternative (Lifson and Shaifer, 1982). The multi-attribute utility theory

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method can include all factors in producing a total utility score for an alternative, but it has difficulty in determining criteria weights and utility functions (Skibniewski and Chao, 1992). The analytic hierarchy process (AHP) method can derive criteria weights and priority scores of alternatives from paired comparisons, but it cannot incorporate feedback relations between criteria and alternatives as it is done hierarchically in a top-down manner. This paper proposes an improved model for assessing project alternatives using the analytic network process (ANP) method of Saaty (1996) as the generalized AHP method to include the feedback impacts absent from the analytic hierarchy process. The ANP method has found increasing application, e.g. Meade and Sarkis (1998), Meade and Presley (2002), Cheng and Li (2004). For illustration of our proposed model, three recent housing projects in Kaohsiung, Taiwan were used as hypothetical alternatives being considered by a medium developer. In the following, we start with the AHP model and then extend it into the ANP model; the assessments made by the two are compared.

2. The AHP model

Compared to traditional multi-attribute decision analysis techniques such as utility theory, the analytical hierarchy process of Saaty (1980) is a relatively informal approach to decision-making problems and has been applied to a variety of problems, e.g. Cheung et al (2001). The AHP helps decision makers to identify and set priorities on the basis of their objectives and their knowledge and experience. The AHP framework organizes their feelings and intuitive judgments as well as logic so that they can map out complex situations as per their perception. The AHP solution process begins with structuring a complex problem by decomposing it into a hierarchy to include all attribute elements reflecting the goals and concerns of the decision maker. Next, elements are compared in a systematic manner using the same 1-9 scale to measure their relative importance and the overall priorities among the elements within the hierarchy are established, while the relative standing of each alternative with respect to each criterion element is determined using the same scale. The overall score of each alternative can then be aggregated, while the consistency of comparison can be measured using Saaty's (1980) consistency ratio.

2.1 The hierarchy and comparison matrices

The proposed model for ranking construction project alternatives is a hierarchy of evaluation elements as shown in Figure 1, which is used as an illustrative example for site selection for terraced houses. The three criteria at level 2 of the hierarchy are surroundings conditions, plot conditions, and demand & competition. Reflecting a developer's goals and concerns for the site selection problem, they are generally regarded as essential factors in project success for commercial housing in the local area. Surroundings conditions refer to a site's external physical environments including completeness of transport systems, access to public transports, availability of public facilities such as schools, markets, and services, nearness to unfavourable places such as cemetery and landfills. A site's plot conditions refer to suitability of plot shape and terrain as well as ground conditions for housing development. Demand & competition refer to potential of, and threat to, respectively, sales for new housing in the considered area. Table 1 gives the comparison matrix for surroundings conditions, plot conditions, and demand & competition in their influence on overall assessment for site selection as perceived by the developer, with the eigenvector showing that surroundings conditions have the greatest weight (0.54), followed by demand & competition (0.297) and plot conditions (0.163).

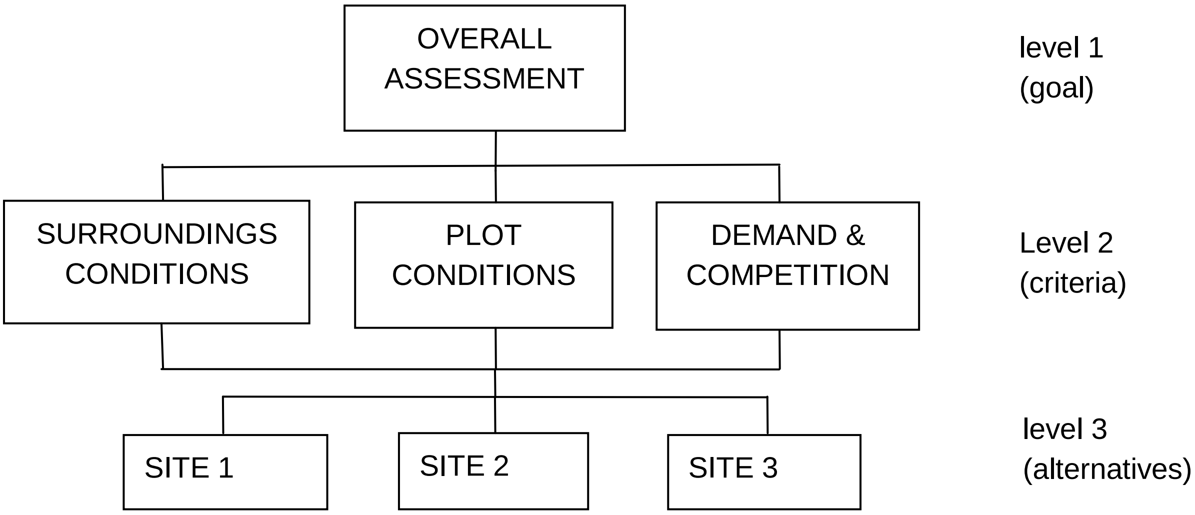

Figure 1. Decision attribute hierarchy for the example site selection problem

The three sites at level 3 of the hierarchy are the alternatives being considered for constructing terraced houses. Based on the data collected, site 1 is assessed as above-average in all three aspects: the surroundings, the plot itself, and the demand & competition in the nearby area. Situated in an area of intense construction activity, site 2 is assessed as excellent in surrounding conditions, but it is assessed as poor in plot conditions and in demand & competition, because of its shape making efficient land use difficult and the risk of over-supply in the area, respectively. Site 3 is located at a far-flung corner of the city with high potential for future housing developments and so it is assessed as poor in surrounding conditions, but good to excellent in plot conditions and in demand & competition. Tables 2, 3, and 4 gives the comparison matrices for the three sites in their performance on surroundings conditions, plot conditions, and demand & competition, respectively, as per the opinions of the developer; the obtained eigenvectors show their differences in scores as stated above.

Table 1: Comparison of surroundings conditions, plot conditions, and demand & competition in their influence on overall assessment

Attributes	Surroundings Conditions	Plot Conditions	Demand & Competition	Principal Eigenvector
Surroundings Conditions	1	3	2	0.540
Plot Conditions	1/3	1	1/2	0.163
Demand & Competition	1/2	2	1	0.297

Table 2: Comparison of alternative project sites in their performance on surroundings conditions

Alternatives	Site 1	Site 2	Site 3	Principal Eigenvector
Site 1	1	1/2	3	0.309
Site 2	2	1	5	0.581
Site 3	1/3	1/5	1	0.110

Table 3: Comparison of alternative project sites in their performance on plot conditions

Alternatives	Site 1	Site 2	Site 3	Principal Eigenvector
Site 1	1	3	1	0.429
Site 2	1/3	1	1/3	0.143
Site 3	1	3	1	0.429

Table 4: Comparison of alternative project sites in their performance on demand & competition

Alternatives	Site 1	Site 2	Site 3	Principal Eigenvector
Site 1	1	3	1/2	0.309
Site 2	1/3	1	1/5	0.110
Site 3	2	5	1	0.581

2.2 Aggregation of comparison results

The aggregation of comparison results, i.e. eigenvectors, can be accomplished by means of vector multiplication as below.

$$S_j = \sum_{i=1}^{3} w_i s_{ji} \qquad \text{……………….(1)}$$

where S_j=site j's total score; w_i=criterion I's weight; sji=site j's score on criterion i.

However, aggregation of AHP results can also be done by means of the limit matrix method used in analytic network process, as introduced next. First, create a 7 by 7 matrix in which each row (and column) corresponds to each of the seven attributes in the hierarchy in Figure 1, and then insert all the four eigenvectors obtained above into their corresponding columns and insert zeros where there is no dependency relation between the attributes, resulting in an initial super-matrix, *W*, as shown in Table 5. Notice that at the right-bottom area, there is an identity sub-matrix for the three sites, making sure that the matrix is so-called column stochastic, i.e. the sum of every column is one. Then, to obtain the sites' total scores, raise the power of the matrix until the product of multiplication converges, i.e. no change occurs. For more details, see Saaty (1996) and Saaty (2005). The limit matrix is represented as:

$$\lim_{k \to \infty} W^k \qquad \text{………………(2)}$$

Since there is no feedback relation in the hierarchy in Figure 1, convergence occurs at *k*=2. Table 6 (W^2) contains the three's total scores in the overall assessment column, showing that site 2 is rated the highest at 0.3697, because of its superior score in the most important criterion, surroundings conditions, which more than compensate for its shortcomings in plot conditions and demand & competition.

Table 5: Initial super-matrix for the AHP example, W

Attributes	Overall Assessment	Surroundings Conditions	Plot Conditions	Demand & Competition	Site 1	Site 2	Site 3
Overall Assessment	0	0	0	0	0	0	0
Surroundings Conditions	0.540	0	0	0	0	0	0
Plot Conditions	0.163	0	0	0	0	0	0
Demand & Competition	0.297	0	0	0	0	0	0
Site 1	0	0.309	0.429	0.309	1	0	0
Site 2	0	0.581	0.143	0.110	0	1	0
Site 3	0	0.110	0.429	0.581	0	0	1

Table 6: Limit super-matrix for the AHP example, W^2

Attributes	Overall Assessment	Surroundings Conditions	Plot Conditions	Demand & Competition	Site 1	Site 2	Site 3
Overall Assessment	0	0	0	0	0	0	0
Surroundings Conditions	0	0	0	0	0	0	0
Plot Conditions	0	0	0	0	0	0	0
Demand & Competition	0	0	0	0	0	0	0
Site 1	0.3286	0.309	0.429	0.309	1	0	0
Site 2	0.3697	0.581	0.143	0.11	0	1	0
Site 3	0.3019	0.11	0.429	0.581	0	0	1

3. The ANP model

The above analysis is lop-sided due to domination of one criterion, namely surroundings conditions, - in other words, the so called location effect. Not satisfied with the result, the developer re-considers the characteristics of the three sites and decides to incorporate feedback relations in the model thus making it an ANP model.

3.1 Additional comparison matrices

Besides comparison of surroundings conditions, plot conditions, and demand & competition in their influence on overall assessment in Table 1, three more comparison matrices are produced for evaluating the relative importance of the three criteria with respect to site 1 (Table 7), site 2 (Table 8), and site 3 (Table 9). Since the site alternatives occupy the bottom level of the hierarchy in Figure 1, these three more matrices define the feedback relations between the criteria and the alternatives in addition to the dependency relations between the criteria and the alternatives defined previously in Tables 2, 3, and 4. As shown in the obtained principal eigenvectors in Tables 7, 8, 9, varying weights for surroundings conditions, plot conditions, and demand & competition are generated, reflecting the developer's concerns for the weaknesses of each site. When the three eigenvectors are added to the model, they represent challenges to the superiority of each site and will influence the resulting scores.

Table 7: Comparison of surroundings conditions, plot conditions, and demand & competition in their importance with respect to site 1

Attributes	Surroundings Conditions	Plot Conditions	Demand & Competition	Principal Eigenvector
Surroundings Conditions	1	3	3	0.600
Plot Conditions	1/3	1	1	0.200
Demand & Competition	1/3	1	1	0.200

Table 8: Comparison of surroundings conditions, plot conditions, and demand & competition in their importance with respect to site 2

Attributes	Surroundings Conditions	Plot Conditions	Demand & Competition	Principal Eigenvector
Surroundings Conditions	1	1/2	1/2	0.200
Plot Conditions	2	1	1	0.400
Demand & Competition	2	1	1	0.400

Table 9: Comparison of surroundings conditions, plot conditions, and demand & competition in their importance with respect to site 3

Attributes	Surroundings Conditions	Plot Conditions	Demand & Competition	Principal Eigenvector
Surroundings Conditions	1	2	2	0.500
Plot Conditions	1/2	1	1	0.250
Demand & Competition	1/2	1	1	0.250

3.2 Super-matrices and final ranking

As shown in Table 10, the eigenvectors from Tables 7, 8, and 9 are inserted into their corresponding columns of the initial super-matrix, while the previous identity sub-matrix is deleted and everything else is retained. Then, the power of the matrix is raised until the product of multiplication converges at k=10. Now the ranking of the three sites has changed to site 1 (rated at 0.3431), site 3 (rated at 0.3328), and site 2 (rated at 0.3254), as shown in Table 11, as a result of the feedback relations added. The changes in the three sites' scores are due to changes in the criteria weights, as a result of the feedback relations added. Compared to the previous criteria weights of 0.540, 0.163, and 0.297, the final criteria weights of 0.437, 0.282, and 0.282 show moderated differences among them, also as a result of the feedback relations.

Table 10: Initial super-matrix for the ANP example, W

Attributes	Overall Assessment	Surroundings Conditions	Plot Conditions	Demand & Competition	Site 1	Site 2	Site 3
Overall Assessment	0	0	0	0	0	0	0
Surroundings Conditions	0.54	0	0	0	0.6	0.2	0.5
Plot Conditions	0.163	0	0	0	0.2	0.4	0.25
Demand & Competition	0.297	0	0	0	0.2	0.4	0.25
Site 1	0	0.309	0.429	0.309	0	0	0
Site 2	0	0.581	0.143	0.11	0	0	0
Site 3	0	0.11	0.429	0.581	0	0	0

Table 11: Limit super-matrix for the ANP example, W^{10}

Attributes	Overall Assessment	Surroundings Conditions	Plot Conditions	Demand & Competition	Site 1	Site 2	Site 3
Overall Assessment	0	0	0	0	0	0	0
Surroundings Conditions	0	0.4373	0.4377	0.4373	0	0	0
Plot Conditions	0	0.2819	0.2822	0.2819	0	0	0
Demand & Competition	0	0.2819	0.2822	0.2819	0	0	0
Site 1	0.3431	0	0	0	0.3432	0.3432	0.3432
Site 2	0.3254	0	0	0	0.3254	0.3254	0.3254
Site 3	0.3328	0	0	0	0.3328	0.3329	0.3328

4. Conclusions

Although the AHP method is used widely in decision analysis, it allows only bottom-up, one-way influences in the hierarchy since it cannot incorporate feedback and other dependency relations among the criteria and alternatives. On the other hand, as the generalized AHP method, the ANP method allows multi-direction relations among the elements and evaluates the impacts of all relations on the final assessment. In our study of project site selection, the hierarchical relations between adjacent levels as well as the feedback relations between the criteria and alternatives are included in the proposed model to determine the ranking of alternative sites for housing development. The ANP model results in changes in the ranking of the sites from those produced by the AHP method due to the additional relations. However, because of the increased complexity, use of ANP for the site selection problem is only justified by situations where it is important to include such extra links in the analysis. Further validation of the model by comparison of assessments from the model with those from other methods is required.

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