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The whole process control of project cost based on bim in project implementation phase

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Abstract. In order to improve the reliability for project cost analysis, a kind of decision scheme on project cost at implementation phase of BIM project based on the fuzzy network analysis is proposed. Firstly, by utilizing the quantitative index on evaluation result of BIM model building evaluation, the judgment comparison matrix of hierarchical structure is established, to provide the model basis for decision-making analysis; next, for the indexes with restraint and coupling relationship, the hyper-matrix in un-weighted form is built according to the network structure, and is processed by utilizing the random way, to obtain the hyper-matrix in limiting form; and then, every obtained index weight can be synthesized to get the weight score of alternative scheme, so as to choose the optimal decision scheme. Finally, by carrying out the simulation test for the example, the effectiveness of proposed method in the project cost decision making at the implementation phase of BIM project is verified.

Key words. Engineering project Cost analysis; BIM project Network analysis Fuzzy plan.

1. Introduction

At present, the BIM technology has already accepted into the revolutionary technology of building industry by the international engineering circle, the comprehensive application of which is triggering the great revolution in the building industry, while it takes the project cost technology and information technology as the carrier, forms the complete engineering database, improves the project integration, largely enhancing the integration degree of construction works and work efficiency of participants and other parties, permanently changes the corporation way of project participants and profoundly changes the traditional cost management ways, to provide the comprehensive solution for the cost management and comprehensively promote

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the reform of cost management.

The application of BIM technology in the cost management aspect is mainly reflected in: (1) Prior control: The performed prior control by BIM technology can reach the obvious effect for controlling the project cost and so that to improve the economic benefit, to lay the solid foundation for the project cost control and play a role in the guidance of developer's capital estimate, allocation and quota design. (2) In-process control: BIM technology can create the considerable economic benefit and effectively control the cost for the developer and constructor. (3) Post-action control: BIM technology can increase the calculation efficiency and accuracy of quantities in the project settlement management, to guarantee the data completeness and normalization; and provide the data support for objectively and reasonably conducting the evaluation after the project.

At present, the BIM technology is slowly promoted and applied in the cost management industry. However, BIM technology is the digital representation to the project information and the direct application of digital technology in the building industry at the great data times, of which it represents the new direction of information technology in the building industry. BIM technology must become the core of building e-commerce, to achieve the standard transparent management of building industry. It is believed that, strived by all parties, the BIM technology will yield unusually brilliant results in our building industry.

2. Definition of refine project cost

2.1. Definition description

The refine management of cost is to carry out the refining management at every project phase, to achieve the phased strengthening management on cost. For all phases of project implementation, the optimization configuration shall be performed to the resource, to efficiently avoid the "three-excess" phenomena. The management links of refine project cost mainly are: the cost management and relevant subjects involved by five phases of design, decision making, construction, bidding and tender, and completion.

The cost management of refine project is the premise to reasonably determine and control the cost. In order to realize the reasonable evaluation of investment, it firstly shall be guaranteed to be within the control quota range of total costs. Especially at the designed cost evaluation phase, the cost evaluation value shall be guaranteed to be more reasonable to the cost evaluation value at the investment phase and affected by the cost estimation at the investment phase. As for the cost estimation at the design phase of construction drawing, the profound refine assessment shall be made according to the design thinking and data of the construction drawing. As for the building cost management, the key to cost evaluation is to handle with the bid and tender cost between the developer and constructor. For the management on the process building project schedule and advance fund item, two key links of construction practice and early-stage scheme design shall be combined. For the final settlement and settlement management of building project, not only the practical project cost shall be summarized, the cost at every project phase shall also be controlled.

2.2. BIM quantitative evaluation model

Taking the cost management process for scientific research building construction project of domestic university as the research object here, the cost analysis is made with cost management process of construction project as the research object. After determining the cost evaluation section, the model relation between the building materials and BIM elements shall be built, with the concrete types of building materials as shown in the Table 1.

Table 1. BIM-Tally correspondence

No.	Material name	Model family name	Volume
1	concrete-fine stone concrete	100+150	74.168
2	concrete-rebar	100+150	18.532
3	concrete-fine stone concrete	100+200	19.918
4	concrete-rebar	100+200	5.974
5	concrete-rebar	150	0.218
6	concrete-rebar	FW-150	118.156
7	concrete-rebar	JT-150	15.142
8	concrete-rebar	SH-150	290.128

After determining the concrete reinforcement building material, the calculation shall be made on the cost influence of building material to the building project, mainly involved in following three phases:

(1) Project construction phase. During the project construction process, various kinds of influence factors of building cost shall be ordered as per the size. For the building during the construction phase, because the consumption of primary energy and non-renewable energy resource occupies more than 80% in the total project cost, selecting the rebar, refine concrete stone and other materials with lower costs is good for lowering the process cost of whole project. (2) Project cost decision making and operation phase. At this phase, the recycling and reuse of waste water and other raw materials in the project construction process shall be strengthened to further reduce the project cost. (3) Recycling phase of building material. This process mainly contains the recycling of waste steel, and reasonably recycles the floor waste to carry out the new building construction and make a big significance to lower the project cost.

3. Decision making of FANP maintenance mode

3.1. Fuzzy planning

When in decision making, the qualitative and quantitative ways shall be applied to compare the factor relevance. In the past literatures, the analytic hierarchy process (AHP) or analytic network process (ANP) are made for decision making. While in evaluation, because of the imprecise information, the precise valuation way applied in the past will cause the deemed excessive participation and not objective decision, therefore, the fuzzy way is adopted here to make decision and improve the impartiality of decision making.

The common triangular fuzzy number can be represented as (l, m, u) and satisfy the $l \leq m \leq u$. The parameters l, m, u in the formula are the probable values of minimum probability, normal probability and maximum probability of fuzzy decision degree.

$$\mu_M(x) = \begin{cases} (x-l)/(m-l), \ l \leq x \leq m \\ (\mu - x)/(\mu - m), \ m \leq x \leq \mu \\ 0, \ otherwise \end{cases} \tag{1}$$

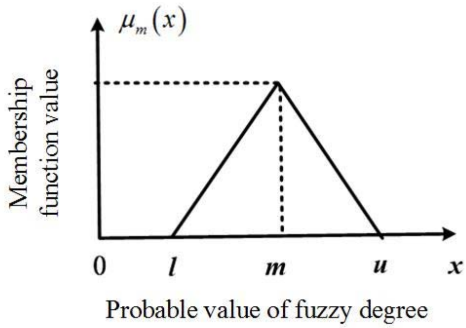

Fig. 1. Triangular Fuzzy Number

Take $A = (l_{ij}, u_{ij})$ as the discriminant vector of index n range, l_{ij} as the lower bound of expert discriminant value, and u_{ij} as the upper bound of expert discriminant. The range discriminant vector and weight vector $w = (w_1, w_2, \cdots, w_n)^T$ can be calculated by utilizing the fuzzy planning method, under the consistency condition, which can satisfy:

$$l_{ij} \leq \frac{\omega_i}{\omega_j} \leq \mu_{ij}\,. \tag{2}$$

In the Formula (2), $i = 1, 2, \cdots, n-1$, $j = 2, 3, \cdots, n$ and $j > i$.

Under the inconsistent condition, satisfy:

$$l_{ij} \tilde{\leq} \frac{\omega_i}{\omega_j} \tilde{\leq} \mu_{ij}\,. \tag{3}$$

The operational character $\tilde{\leq}$ is the fuzzy operation identification, and the inequation showed in the Formula (3) means that the weight vector shall satisfy the upper and lower bounds of expert discriminant value as much as possible.

The expert discriminant value represented by the triangular fuzzy rule can be calculated by utilizing the weight vector, with form as follows:

$$\mu_{ij}\left(\frac{\omega_i}{\omega_j}\right) = \begin{cases} \dfrac{(\omega_i/\omega_j) - l_{ij}}{m_{ij} - l_{ij}}, \dfrac{\omega_i}{\omega_j} \leq m_{ij} \\ \dfrac{\mu_{ij} - (\omega_i/\omega_j)}{\mu_{ij} - m_{ij}}, \dfrac{\omega_i}{\omega_j} \geq m_{ij} \end{cases} \tag{4}$$

The value range of membership shown in the Formula (4) is $(-\infty, m_{ij})$, which can satisfy the linear decreasing feature within the value range (m_{ij}, ∞). If satisfying $w_i/w_j < l_{ij}$ or $w_i/w_j > u_{ij}$, then $u_{ij} < 0$; if satisfying $w_i/w_j = m_{ij}$, then u_{ij} can obtain the maximum value as 1. At the value range (l_{ij}, u_{ij}), then, there are following forms:

$$Q^{n-1} = \{(w_1, w_2, \cdots w_n)|w_i > 0, \sum_{i=1}^{n} w_i = 1\}\,. \tag{5}$$

The fuzzy membership on the feasible value region can be defined as:

$$u_p(w) = \min_{ij}\left\{u_{ij}\left(w\right)|i = 1, 2, \cdots, n-1;\ j = 2, 3, \cdots, n;\ j > i\right\}\,. \tag{6}$$

After fuzzy planning of weight vector $w \in Q^{n-1}$, if the discriminate matrix is inconsistent, then $u_p(w)$ is valued in negative. The above assumption 2 can determine that the maximum membership value of Formula (6) is the selection rule of weight vector, and $u_p(w)$ can be proofed as the convexity collection. Therefore, the maximum membership value of weight vector $w^* \in Q^{n-1}$ always exists:

$$\lambda^* = u_P(w^*) = \max_{w \in Q^{n-1}} \min_{ij}\left\{u_{ij}\left(w\right)\right\}\,. \tag{7}$$

Above problem for solving the weight vector can be transformed to be the following planning problem:

$\max \lambda$

$$\lambda \leq u_{ij}\left(w\right), i = 1, 2, \cdots, n-1;\ j = 2, 3, \cdots, n;\ j > i\,, \tag{8}$$

$$\sum_{k=1}^{n} w_k = 1, w_k > 0, k = 1, 2, \cdots, n\,.$$

According to the Formula (4), the Formula (8) can be transformed to be the nonlinear planning form as follows:

$\max \lambda$

$$(m_{ij} - l_{ij})\lambda w_j - w_i + l_{ij} w_j \leq 0\,.$$

$$(u_{ij} - m_{ij})\lambda w_j + w_i - u_{ij} w_j \le 0\,. \tag{9}$$

$\sum_{k=1}^{n} w_k = 1, w_k > 0$

In the Formula (9), $k = 1, 2, \cdots, n$, $i = 1, 2, \cdots, n-1$ and $j = 2, 3, \cdots, n$, so $j > i$. Its optimal scheme is (w^*, λ^*), of which w^* is the weight vector in correspondence with the maximum membership value; λ^* is the consistency characteristic index. The bigger the λ^* is valued, the higher the decision-making uniformity is. If satisfying $\lambda^* > 0$, then $l_{ij} \le \left(w_i^*/w_j^*\right) \le u_{ij}$ is correct, representing the better uniformity of discriminant matrix; if $\lambda^* \le 0$, it means that $\left(w_i^*/w_j^*\right)$ is carried out the equivalence with in-equation, representing the poor discriminant matrix.

As for the fuzzy planning problem shown by the Formula (9), the weight can be calculated based on the least square algorithm, with concrete process referring to what states in the Literature [9].

3.2. FANP decision-making weight calculation

The selection for decision-making way on traction power supply cost is taken as the control layer criterion $p_1, p_2, \cdots, p_m$ of the FANP network, and the element attributes of cost decision-making factor set constitutes the network element group $C_1, C_2, \cdots, C_n$, of which contains the elements $e_{i1}, e_{i2}, \cdots, e_{in_i}$, with $i = 1, 2, \cdots, N$. Firstly, for the control criterion $p_s\ (s = 1, 2, \cdots, m)$, the un-weighted hyper-matrix W_s is built.

Process 1: Take p_s as the control matrix and the elements $e_{jk}\ (k = 1, 2, \cdots, n_j)$ within $C_j\ (j = 1, 2, \cdots, N)$ as the control sub-matrix, carry out the dominance comparison according to the influence of C_i elements to e_{jk} or the influence of e_{jk} to the elements in C_i, obtain the discriminant matrix with its characteristic normalization being carried out, and then get $(w_{i1}^{(jk)}, w_{i2}^{(jk)}, \cdots, w_{in_i}^{(jk)})^T$ according to the ordering.

Process 2: Compare the sub-criterion dominances of elements $e_{j1}, e_{j2}, \cdots, e_{jn_j}$ in C_i as per the method as shown in the Process 1, obtain the discriminant matrix with its characteristic normalization being carried out, and then summarize the obtained normalized characteristic vector, with the form of obtained matrix W_{ij} as:

$$W_{ij} = \begin{bmatrix} w_{i1}^{(j1)} & w_{i1}^{(j2)} & \cdots & w_{i1}^{(jn_j)} \\ w_{i2}^{(j1)} & w_{i2}^{(j2)} & \cdots & w_{i2}^{(jn_j)} \\ \vdots & \vdots & \ddots & \vdots \\ w_{in_i}^{(j1)} & w_{in_i}^{(j2)} & \cdots & w_{in_i}^{(jn_j)} \end{bmatrix}. \tag{10}$$

In the Formula (10), W_{ij} represents the influence degree of element group C_i to C_j. If there is no relation between the elements in C_j and the elements in C_i, then, $W_{ij} = 0$ can be obtained.

Process 3: According to the methods as shown in the Process 1 and Process 2, build the un-weighted hyper-matrix of control criterion p_s:

$$W_s = \begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1j} & \cdots & W_{1N} \\ W_{21} & W_{22} & \cdots & W_{2j} & \cdots & W_{2N} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ W_{i1} & W_{i2} & \cdots & W_{ij} & \cdots & W_{iN} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ W_{N1} & W_{N2} & \cdots & W_{Nj} & \cdots & W_{NN} \end{bmatrix}. \tag{11}$$

In the Formula (11), the hyper-matrix element can be solved in accordance with the Formula (2). The dominance comparison among the elements in the hyper-matrix can reflect the preference and emphasis degree of decision maker to the cost decision-making way.

In a similar way, as for the $p_1, p_2, \cdots, p_m$ and other control criteria, m un-weighted hyper-matrixes can be built, all of which are the nonnegative matrixes. The normalization operation, in overall, will not be carried out for the hyper-matrix, while the column normalization operation will be carried out for all sub-block W_{ij}. In this case, the hyper-matrix cannot represent the priority among the elements, so the dominance of different element groups shall be compared to transform it into the weighted hyper-matrix.

As for the p_s control criterion, take the element group C_j as the sub-criterion as the control layer, obtain the indirect dominance comparison data according to the relational degree of $C_1, C_2, \cdots, C_N$ to C_j or the relational degree of C_j to $C_1, C_2, \cdots, C_N$, and obtain the discriminant matrix with its normalization characteristic ordering $(a_1^{(j)}, a_2^{(j)}, \cdots, a_N^{(j)})^T$. Compared successively, the weighted matrix of column summary characteristic ordering can be obtained, with form as:

$$A_s = \begin{bmatrix} a_1^{(1)} & a_1^{(2)} & \cdots & a_1^{(N)} \\ a_1^{(1)} & a_2^{(2)} & \cdots & a_2^{(N)} \\ \vdots & \vdots & \ddots & \vdots \\ a_N^{(1)} & a_N^{(2)} & \cdots & a_N^{(N)} \end{bmatrix}. \tag{12}$$

In the Formula (12), the element of weighted matrix A_s is the indirect dominance comparison data of element group toward the criterion p_s. For the sub-criterion C_j, the vector ordering result of element group irrelevant to it is 0. Then, the number of weight matrixes in correspondence with m groups of criteria is m.

Carry out the weight valuation to the elements in W_s with A_s, the weight hyper-matrix $\bar{W}_s$ can be obtained:

$$\left(\bar{W}_s\right) = (A_s) \cdot (W_s)\,, s = 1, 2, \cdots, m\,. \tag{13}$$

In the Formula (13), $(\cdot)$ represents the selection operation of matrix element. The normalization operation is carried out for the matrix $\bar{W}_s$, representing the relative priority among the elements.

As there is the relevance and feedback relation among the elements in the ANP decision-making, it is very difficult to determine the element grade. As for the element e_i and e_j, the grade determination can be calculated on the strength of the weight hyper-matrix $\bar{W}_s$ (one-step grade determination), or be represented based on the elements $\sum_{l=1}^{N} w_{il}w_{lj}$ within $\bar{W}_s^2$ (two-step grade determination), or be represented on the basis of elements within the $\bar{W}_s^n$ matrix (n-step grade determination). In order to accurately represent the relevance and feedback existed among the elements, the stabilizing treatment shall be carried out for the weighted hyper-matrix.

$$\bar{W}_s^{\infty} = \lim_{t\to\infty} \bar{W}_s^t \,. \tag{14}$$

If the limit value as shown in the Formula (14), then the column j within the matrix $\bar{W}_s^{\infty}$ is the limit grade relative value of every element under the criterion p_s to e_j. As for all control layers, obtain the limit grade relative value among the elements according to the above criterion steps, and then get ANP comprehensive weighted result in accordance with criterion weight, so as to get the comprehensive weight value of all cost decision-making forms and obtain the grade ordering of cost decision-making way.

4. Experimental analysis

4.1. Index analysis

BIM project cost of Thsware, Glodon and Luban is selected for the modeling of project cost. The index analysis is conducted based on the algorithm proposed in the Paper. The evaluation indexes include installation project cost, safety evaluation and function universality. Compared with decision algorithm, the algorithm in Literature [11] is selected.

According to the requirement for decision evaluation process, the judgment standards are divided into such five judgment grades as “very poor” “poor”, “ordinary”, “well” “excellent”. Based on this, the comment set is acquired: $V = \{v_1, v_2, v_3, v_4, v_5\}$ = {very poor, poor, ordinary, well, excellent}. The score of the worst grade v_1 is 50 points and the score of the best grade is 100 points. The quantitative rating vector is:

$$B = \{50, 60, 80, 90, 100\} \,. \tag{15}$$

Literature [11] is about the analysis of project cost based on the expert evaluation. Firstly, the expert evaluation is made according to the grade defined by the comment. The statistic analysis of evaluation data is realized based on the mathematical statistics to acquire its membership value. For example, 10 experts from different fields assess the project cost index. If no one selects V_1 and V_2 evaluation grade, two experts select V_3 evaluation grade, five experts select V_4 evaluation grade and three experts select V_5 evaluation grade, the fuzzy evaluation value of such project cost index is (0,0,0.2,0.5,0.3).

4.2. Results analysis

The index fuzzy evaluation scores of the algorithm in the Paper + (Thsware, Glodon and Luban) and Literature [11] + (Thsware, Glodon and Luban) are shown as Table 2.

Table 2. Fuzzy Evaluation

Evaluation index	Project cost	Algorithm	Numerical value
Project installation	Glodon	Algorithm in the Paper	91.2
		Literature [11]	89.8
	Thsware	Algorithm in the Paper	89.7
		Literature [11]	88.6
	Luban	Algorithm in the Paper	88.3
		Literature [11]	86.2
Safety evaluation	Glodon	Algorithm in the Paper	82.36
		Literature [11]	80.1
	Thsware	Algorithm in the Paper	89.4
		Literature [11]	86.3
	Luban	Algorithm in the Paper	92.7
		Literature [11]	89.2
Function applicability	Glodon	Algorithm in the Paper	86.9
		Literature [11]	84.3
	Thsware	Algorithm in the Paper	88.2
		Literature [11]	85.4
	Luban	Algorithm in the Paper	89.9
		Literature [11]	86.7
Comprehensive evaluation	Luban	Algorithm in the Paper	88.2
		Literature [11]	84.9
	Glodon	Algorithm in the Paper	89.4
		Literature [11]	86.2
	Thsware	Algorithm in the Paper	89.5
		Literature [11]	84.3

It is shown from the data in Table 4 that in each evaluation index, the evaluation score obtained by the model of algorithm in the Paper +(Thsware, Glodon and Luban) is superior to that of Literature [8] +(Thsware, Glodon and Luban). It shows the effectiveness of the algorithm proposed. Meanwhile, as for such three BIM project cost of Thsware, Glodon and Luban, the score of Glodon is the lowest, the scores of Thsware and Luban are relatively better. In general, the cost quality of Thsware and Luban is much better.

5. Conclusion

BIM project cost analysis algorithm based on fuzzy network analysis is put forward to improve the reliability of project cost analysis. The quantitative index of project evaluation results is constructed based on BIM model and the hierarchical structure is established to judge the comparative matrix. As for the index with restriction and coupling relation, unweighted hypermatrix is constructed according to network structure and the weight of each index acquired is combined to obtain the weight score of candidate scheme so that the optimal solution could be selected. The research emphasis of next step will be placed on the development of application system of the algorithm.

References

[1] Winn M D, Ballard C C, Cowtan K D, et al.: (2011) *Overview of the CCP4 suite and current developments*[J]. Acta Crystallographica, 67(4):235–242.

[2] Mayaux P, Holmgren P, Achard F, et al.: (2011) *Tropical forest cover change in the 1990s and options for future monitoring*[J]. Philos Trans R Soc Lond B Biol Sci, 360(1454):373-384.

[3] Singh V, Gu N, Wang X: (2011) *A theoretical framework of a BIM-based multi-disciplinary collaboration platform*[J]. Automation in Construction, 20(2):134-144.

[4] Xia Y, Mitchell K, Ek M, et al.: (2012) *Continental-scale water and energy flux analysis and validation for North American Land Data Assimilation System project phase 2 (NLDAS-2): 2. Validation of model-simulated streamflow*[J]. Journal of Geophysical Research Atmospheres, 117(D3):3109.

[5] Arayici Y, Coates P, Koskela L, et al. : (2011) *Technology adoption in the BIM implementation for lean architectural practice*[J]. Automation in Construction, 20(2):189-195.

[6] Jin G, Song L, Zhang W, et al.: (2011) *Automated atomicity-violation fixing*[C]// ACM Sigplan Conference on Programming Language Design and Implementation, PLDI 2011, San Jose, Ca, Usa, June. DBLP, 2011:389-400.

[7] Shek D T, Yu L: (2011) *Prevention of adolescent problem behavior: longitudinal impact of the Project P.A.T.H.S. in Hong Kong.*[J]. Scientific World Journal, 11(11):546-567.

[8] Sreenath K, Park H W, Poulakakis I, et al.: (2011) *A Compliant Hybrid Zero Dynamics Controller for Stable, Efficient and Fast Bipedal Walking on MABEL*[J]. International Journal of Robotics Research, 30(9):1170-1193.

[9] Blaschke T F, Osterberg L, Vrijens B, et al.: (2012) *Adherence to Medications: Insights Arising from Studies on the Unreliable Link Between Prescribed and Actual Drug Dosing Histories*[J]. Annual Review of Pharmacology, 52(1):275-301.

[10] Deller A T, Brisken W F, Phillips C J, et al.: (2011) *DiFX-2: A More Flexible, Efficient, Robust, and Powerful Software Correlator*[J]. Publications of the Astronomical Society of the Pacific, 123(901):275-287.

[11] Low S H: (2014) *Convex Relaxation of Optimal Power Flow, Part II: Exactness*[J]. IEEE Transactions on Control of Network Systems, 1(2):177-189.

[12] Wheeler H E, Maitland M L, Dolan M E, et al.: (2013) *Cancer pharmacogenomics: strategies and challenges*[J]. Nature Reviews Genetics, 14(1):23-34.

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