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Using sequential analysis procedures to rank the influencing factors of public work's quality

YANG Chau-ping

(*Department of Civil Engineering and Engineering Informatics, Chung-Hua University, Hsin Chu, Taiwan 30067, China*)

E-mail: ycp@chu.edu.tw

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Abstract: In order to improve the efficiency in management of public work projects, screening and controlling influencing factors affecting the quality of a public work project is essential. This study synthesized 9 influential categories including 91 factors related to quality management of public works in Taiwan using a sequential analysis procedure. According to the Borda-values of influencing factors obtained from a first stage questionnaire, the number of primary factors selected by the responsible entities and the design-supervisory entities were 44 and 45 respectively. A Fuzzy Analytic Hierarchy Process (FAHP) was used to prioritize and rank these factors. The top five factors ranked by the responsible entities were (1) introduction of the earned value analysis, (2) working efficiency, (3) environmental laws and regulations, (4) price-index fluctuation, and (5) on-site safety management. The top five factors ranked by the design-supervisory entities were (1) man power, (2) laws and regulations, (3) price-index fluctuation, (4) traffic conditions, and (5) faulty design.

Key words: FAHP, Public works, Quality management, Influencing factors
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INTRODUCTION

Based on the definition of quality in ISO-9000-1, the quality of public works is derived from the planning, design, tender, and construction phases. In recent years, the strategies that have been implemented to enhance the quality of public works in Taiwan since 1990 are: (1) the "Regular Supervision Meeting of the Public Building Committee" founded in 1991, (2) the "Quality Management System of Public Works" policy issued for enforcement in 1993, (3) the "Public Construction Commission" founded in 1995, (4) the "Procurement Act" passed in 1996, (5) the "Main Points for Quality Management Process of Public Works Act" passed in 1997, and (6) the "Review of Public Works Act" enacted in 2002 (Kuo, 2001).

There are many factors affecting the quality of public work projects, and these primary factors must be screened to ensure quality management of public work projects. By strengthening control of these factors, quality management can be assured. Therefore, this study used a sequential analysis procedure for tentatively ranking these quality management factors. The public transportation works (road, railway, airport and harbor) in Taiwan were the targeted work projects.

SEQUENTIAL ANALYSIS PROCEDURES

Synthesizing the influencing factors of the work's quality

Data were collected in order to gain understanding of the factors influencing quality management of public works. The data sources included the Control Yuan, the Public Construction Commission, and the Ministry of Transportation and Communication (Executive Yuan, Taiwan, 2002; Public Construction Commission, 2003; Review Meeting of Public Works, Ministry of Transportation and Communication, 2003). This study compiled 91 factors related to the quality management of public works. In order to systematically observe the weights of various factors, the systematical structure of the Analytic Hierarchy Process (AHP) was adopted (Saaty, 1986; Deng and Zeng, 1989). The 91 factors were placed into nine categories making each force in the same hierarchy independent from each other if possible. The nine categories included were policy (10 factors), technology (11 factors), economy (9 factors), environment (8 factors), management (9 factors), administration (8 factors), construction (16 factors), planning (11 factors), and supervision (11 factors).

Conducting first stage of the questionnaire survey

The first stage of the questionnaire survey was conducted to screen the primary factors from the nine categories. In each factors category, the participants chose the linguistic variables for each factor on a seven point scale (i.e. P_i=6, 5, 4, 3, 2, 1, 0) (Zadeh, 1975).

One hundred and fifty responsible entity officers and 150 design-supervisory entity staffs were surveyed. The responsible entities included the Taiwan Highway Bureau, the Taiwan Area National Expressway Bureau, the Taiwan Harbor Bureau, and the Taiwan Railway Reconstruction Bureau. The design-supervisory entities included consultants and project control management companies. Those who were surveyed included senior engineers with five years or more of experience whose work sites were distributed throughout Taiwan. A total of 300 questionnaires were issued in April of 2003, and 210 useable questionnaires were returned at a 70% return rate. One hundred and eight officers and 102 staffs returned useable surveys.

Screening primary influencing factors

Eq.(1) was used to calculate the Borda-value $f_{,a}(x)$ of the influencing factor x:

$$f_{,a}(x)=\sum_{i=0}^{6}(x:n_i\cdot P_i)\,, \tag{1}$$

where n_i is the number of questionnaires preferring P_i for influencing factor x.

In principle, the number of factors in each category were reduced to five primary factors according to the values of $f_{,a}(x)$. If, the $f_{,a}(x)$ value of factor was not more than 50% of the preceding one, it was not chosen (Bellman and Zadeh, 1970). The number of primary factors selected by the responsible entities was 44 while the number selected by the design-supervisory entities was 45.

Conducting second stage of the questionnaire survey

The second stage of the questionnaire was re-edited to include only the primary factors in the nine categories. In this questionnaire, the language variables among the primary factors were divided into nine grading scales. The value of the grading scale was one to nine. The same participants as those in the first stage questionnaire were surveyed. There were 210 questionnaires issued in June of 2003, and 191 questionnaires were returned at a return rate of 90%. Ninety-seven questionnaires were returned from the responsible entities, and 94 were returned from the design-supervisory entities.

Performing consistency's test

Pair-wise comparisons were first conducted for the primary influencing factors in the same category. Then, the pair-wise comparisons were extended to all the primary factors in the nine categories. Eq.(2) is the pair-wise comparison matrix $\boldsymbol{A}$.

$$\boldsymbol{A}=[a_{ij}]=\begin{bmatrix} w_1/w_1 & w_1/w_2 & \dots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \dots & w_2/w_n \\ \vdots & \vdots & \dots & \vdots \\ w_n/w_1 & w_n/w_2 & \dots & w_n/w_n \end{bmatrix}, \tag{2}$$

where i, j=1,2,…,n, n is the number of primary influencing factors in a hierarchy. $a_{ij}=w_i/w_j$ is the value of grading scale for primary influencing factor F_i to F_j. a_{ij}=1, $a_{ij}=1/a_{ji}$, $a_{ij}>0$.

The value of $C.I.$ can be calculated from Eq.(3), where $\lambda_{\max}$ is a maximum eigenvalue. $C.I.>0$ represents matrix $\boldsymbol{A}$ as inconsistent, but if $C.I.<0.1$ the consistency of matrix $\boldsymbol{A}$ is acceptable (Saaty, 1980; Chang and Cheng, 1989).

$$C.I.=(\lambda_{\max}-n)/(n-1)\,. \tag{3}$$

The key of this sequential analysis procedure is the second stage of the questionnaire survey. In order to increase the number of useable samples, a participant whose questionnaire failed to pass the consistence test was asked by mail, phone call, or personal interview to fill in the questionnaire again. The consistency test means of the responsible entities and the design-supervisory entities were only 62.8% and 66.4%, respectively.

Ranking priority orders of primary influencing factors

The weights of each factor passing the consistency test were calculated with a Fuzzy Analytic Hierarchy Process (FAHP). If the triangular fuzzy function and fuzzy arithmetic were introduced into the AHP, then the common sense of all the interviewees could be integrated. That is the concept of FAHP analysis (Laarhoven and Pedrycz, 1983; Buckley, 1985; Seo *et al*., 2004).

To successfully integrate the participants' questionnaires, the positive reciprocal matrix $\boldsymbol{A}$ is first changed into a fuzzy positive reciprocal matrix $\boldsymbol{E}$ with the triangular fuzzy numbers obtained from Eq.(4). Where Le_{ij} is the left value of the triangular fuzzy function, Me_{ij} is the middle value of the triangular fuzzy function, and Ue_{ij} is the right value of the triangular fuzzy function.

$$\boldsymbol{E}=[Le_{ij}, Me_{ij}, Ue_{ij}]. \quad (4)$$

Next, matrix $\boldsymbol{E}$ is integrated into matrix $\boldsymbol{X}$ calculated by using Eqs.(5)~(8), where m is the number of participants surveyed.

$$\boldsymbol{X}=[Lx_{ij}, Mx_{ij}, Ux_{ij}], \quad (5)$$

$$Lx_{ij}=(1/m)\odot(Le_{ij}^{1}\oplus Le_{ij}^{2}\oplus\ldots\oplus Le_{ij}^{m}), \quad (6)$$

$$Mx_{ij}=(1/m)\odot(Me_{ij}^{1}\oplus Me_{ij}^{2}\oplus\ldots\oplus Me_{ij}^{m}), \quad (7)$$

$$Ux_{ij}=(1/m)\odot(Ue_{ij}^{1}\oplus Ue_{ij}^{2}\oplus\ldots\oplus Ue_{ij}^{m}). \quad (8)$$

Furthermore, a group's fuzzy synthetic judgment matrix $\boldsymbol{R}$ is calculated by using Eqs.(9)~(12).

$$\boldsymbol{R}=[Lr_i, Mr_i, Ur_i], \quad (9)$$

$$Lr_i=\sum_{j=1}^{n} Lx_{ij}\times w_j, \quad (10)$$

$$Mr_i=\sum_{j=1}^{n} Mx_{ij}\times w_j, \quad (11)$$

$$Ur_i=\sum_{j=1}^{n} Ux_{ij}\times w_j. \quad (12)$$

Finally, a de-fuzzy operation is implemented on matrix $\boldsymbol{R}$ in order to determine its best non-fuzzy performance BNP-value to facilitate sorting. The values of BNP_i for the primary factors were calculated according to Eq.(13). Eventually, the priority orders of the primary factors could be ranked according to the BNP-values.

$$BNP_i=[(Ur_i-Lr_i)+(Mr_i-Lr_i)]/3+Lr_i. \quad (13)$$

RESULTS

Table 1 lists both the priority order of the primary influencing factors ranked by the responsible entities and the design-supervisory entities. In order to validate the analyzed results, this research team sent Table 1 to the 210 persons surveyed in the second stage and asked for their opinions. There were 174 questionnaires returned for a return rate of 82.8%. The results of this survey were strongly agree at 63%, agree at 21% and no comment at 16%.

There were nine primary influencing factors ranked in the top five by the two entities. The primary factors enhancing the quality of public works are as follows.

1. Introduction of earned value analysis

Earned value analysis is necessary for lowering the risks related to the cost of the construction, and also enhances the flexibility to respond to unforeseen difficulties in the construction work. Responsible entities ranked earned value analysis as the most important factor.

2. Price-index fluctuation

The rise in the cost of construction materials impacts profit and the ability of contractors to fulfill the contracts. For example, the price of reinforcement steel in Taiwan rose from 230 US$/t in the fourth quarter of 2003 to 510 US$/t in the second quarter of 2004. Although the responsible entity could provide contractors with additional funds, its administrative procedures are troublesome and fell behind schedule.

3. Environmental laws and regulations

Responsible entities and design-supervisory entities will be fined if pollution problems become seri-

Table 1 The priority order of primary influencing factors

Item	Priority order		Item	Priority order	
	RE	DE		RE	DE
Policy's category			Management's category		
Labor's safety and health system	8	38	Qualified system for the subcontractor	38	33
Quality management system	43	24	Self-audit on the management system	15	29
Review system	40	36	Administration's category		
Tender system	29	32	Self-audit on documents	7	27
Govern	25		Engineer's attitude toward their responsibility	28	17
Certification of qualifier		28	Corrective and preventive actions for document's defects	14	18
Technology's category			Plan of work	37	
Special knowledge of the engineers	32	45	Man power	20	1
Self-inspection on the technology	34	34	Related codes		21
Quality surveillance on the technology	41	40	Construction's category		
Technology of the contractor	26	43	Ability of the qualifier	18	25
Audit by professional qualifier		37	Experience of the workers	12	14
Economy's category			Skill of workers	21	16
Introduction of earned value analysis	1	6	Corrective and preventive actions for construction's defects	24	12
Price-index fluctuation	4	3	Safety actions in construction	13	13
Violation of the agreement by the contractor	19	26	Planning's category		
Bidding price	39	30	Design review	6	44
Scope of the contractor	44	35	Faulty design	9	5
Environment's category			Defects of the contract	10	7
Environmental laws and regulations	3	22	Construction interfaces	31	41
Coordination of the pipeline entity	27	39	Ability of the consultants	42	11
Disposal of the residual soil	30	31	Supervision's category		
Land acquisition for the construction	35	23	Working efficiency	2	19
Traffic conditions	23	4	Crowd protest	11	
Management's category			Casualties of personnel	16	8
On-site safety management	5	20	Laws and regulations	36	2
Corrective and preventive actions for management's defects	22	10	Damages of the permanent structure	33	15
Self-inspection on management actions	17	42	Damages from disaster		9

RE: Responsible entities; DE: Design-supervisory entities

ous enough to break the law. Serious problems regarding environmental protection will even cause public protest and delay the progress of the work.

4. Traffic conditions

Traffic conditions on the roads to the job site influence transportation costs because of the need to transport materials or residual soil.

5. On-site safety management

Workers are asked to stop working immediately when serious injuries or death of a worker happens. On-site safety management is an important issue, and must be thoroughly addressed because injuries and death impact the construction schedule negatively.

6. Manpower

Lack of manpower is a common problem for responsible entities and design-supervisory entities in Taiwan. An over-worked worker tends to make mistakes and cause delays in the work schedule.

7. Faulty design

Reduction of faults and mistakes could reduce the risks of construction. For example, in the flood of August of 2004, because the exit culvert of the MRT construction along the river was not designed and constructed properly, the flood flowed into San

Chung City, Taipei County through the culvert. It was estimated that about 14000 households were flooded and suffered heavy loss. The incident has entered the legal process, and related entities will have to take responsibility for compensation of the flood victims.

8. Working efficiency

Low work efficiency causes poor strategic planning because of the emotional stress on strategy planners. Although working efficiency is not one of the items included in the current review and supervisory system, the analysis of results in this study showed that working efficiency is considered important.

9. Laws and regulations

The details of a contract are regulated by the Construction Law which is not completely understood even by some of the officers. The number of arguments, arbitration meetings, or lawsuits related to the contract could be prevented when the contracts are clearly written.

CONCLUSION

Responsible entities are supposed to insure the quality of public work projects. Responsible entities should entrust project designs to design-supervisory entities tasked to supervise the project during the construction period according to the "Government Procurement Act". Responsible entities and design-supervisory entities have varying ability to identify the quality of a work project because of differences in their responsibilities, experience, and training. Sometimes these differences cause a delay in the work project schedule, and even lawsuits because of these differences in quality management.

In order to improve quality management between the different entities, the differences in the responsibilities of these two entities must first be understood clearly. The priority order of the primary influencing factors was ranked in this study so that this result could provide the two entities with insight into the primary factors influencing quality management of public works.

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