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The Application Fuzzy Delphi Method to Summarize Key Factors in the Education of Construction Engineers

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Abstract

In addition to the education of STEM (science, technology, engineering, and mathematics), this paper reviews the current relevant courses required in the field of construction projects from the practice point of view. The study summarizes the key courses in the education of construction engineers through document analysis, expert and scholar interviews, and subsequently establishes the key evaluation aspects and index reliability by Fuzzy Delphi Method. This study can provide the basis for the systematic curriculum design of construction engineering and management specialty in colleges and universities.

Keywords: Construction Engineers, Fuzzy Delphi Method, Project Management.

Introduction

Construction industry is vital to a country's infrastructure and is closely related to its economic development and the public life. A construction project involves many aspects of work, so the environment of the construction industry is more complicated than that of other industries. In recent years, STEM (Science, Technology, Engineering, Mathematics) is a new trend in the curriculum reform in international education; it is an interdisciplinary education that emphasizes practical experience in real-world situations. In addition, collaborative learning, inquiry-based teaching, science and technology teaching, multiple assessment techniques and other learning strategies can be used to encourage learners to investigate and integrate their understanding and application on science, technology, engineering and mathematics [1].

In the education of construction engineers, besides STEM education, the abilities on innovation, ethics and law, leadership and execution required for a construction project manager are also very important professional and technical abilities for students after they start working. In the harsh competition environment of the construction project industry, few people are concerned about the education orientation of construction engineers. The basic functions of teachers in colleges and universities have three major areas of teaching, research and service. But considering the promotion of a professor's position, etc. that affects a person's own rights and interests, they are mainly focusing on academic research. What is worrying is that the standards of good teachers in the academic circle are different from the standards of good engineers in the construction industry. On the campus, the teachers pay much attention to the theories and ignore the practice.

The students they taught not only must re-learn, but even don't care the importance of practice when they graduate from the universities and start working in the society. Therefore, the paper has not only summarized the STEM education of the construction engineering specialty, but also studied the relevant courses required by the industry. Through literature analysis, expert and scholar interviews, the key courses in the education of construction engineers are summarized, with the Fuzzy Delphi Method used consequently to establish the key indicators. This study can provide reference for the design of courses of Construction Engineering and Management discipline in colleges and universities.

Literature Review

From the project point of view, the construction industry shall involve such enterprises as the construction companies, specialized subcontractors, material suppliers, machinery leasing companies, testing and inspection units, architects and technicians firms, technical consulting companies, etc. Construction management is a technology integrating and management process for a specific construction project in a specific industrial environment. The scientific management and control of the entire project construction process requires diversified and complicated technical background and basis. It involves buildings projects, road and bridge tunnel projects, railway projects, port and waterway projects, etc. Construction management is an interdisciplinary subject of technology and management with complex characteristics.

Xiang, Yalan, & Yu (2017) compared the teaching objectives of China and other international construction management universities, and found that foreign countries pay more attention to cultivating the comprehensive quality of students in the international construction management environment. The students are not only trained on professional knowledge and ability, but also are required to receive an all-round and balanced education, professional awareness, self-learning ability and self-improvement ability. It emphasizes on students' meeting the basic qualification requirements for

working in the construction industry through learning, which will lay a good foundation for being the project managers in the future [2].

A. Requirements on Core Competencies of Construction Project Management Personnel

Spencer regards the core competencies to complete the work as the necessary qualities to get the work done properly. The core competence is the necessary skill to get the work done properly through the objective analysis of the work responsibilities and the work itself [3]. In this view, the three core management abilities required are: (1) execution; (2) the highly clean and efficient behavior; (3) systematic thinking. And the systematic thinking can make high-level executives have a global vision, cross-sectoral understanding and policy innovation ability when they plan policies.

B. STEM Education for Construction Engineers

The education system of each country is the basis for its progress and its future development. Since the education system is one of the largest and most complex systems in every society, it is impossible to change overnight. Therefore, education changes very slowly [4]. When curriculum reforms were carried out across Europe, there was another opportunity to increase learners' interest in science education, especially in the future career choices in the natural science and technology fields [5]. An integrated education of Science, Technology, Engineering, Mathematics, shorted as STEM education, has received many concerns and attention in recent years. In the United States, the trend of paying more and more attention to cultivating STEM talents has appeared [6].

However, the main purpose of the United States to promote STEM interdisciplinary integration education is to improve its national scientific and mathematics literacy. The proportion of graduates in STEM and other fields among the total graduates every year has become one of the commonly used evaluation indicators in the world. The science and technology education of the United States has changed from process education to science and technology education, and has been transformed into STEM education in recent years. The cultivation of students' abilities on engineering design, integration and problem solving is especially important.

C. Summary of Ability Courses of Construction Project Management Personnel

This paper proposes the the curriculum plan that can cultivate talents with both the engineering background and management expertise, aiming at enhancing the added value and consolidate profits in the era that construction projects are of low added value. Moreover, these talents should truly become professional managers of the construction industry with great potential in the future, and should be the high-level management personnel for the future integration of the construction industry. Seven areas are summarized in this study with combination of core courses in various literatures, which are: (1) Science; (2) Technology; (3) Engineering; (4) Mathematics; (5) Leadership and execution; (6) Innovation and (7) Ethics and law, as shown as figure 1.

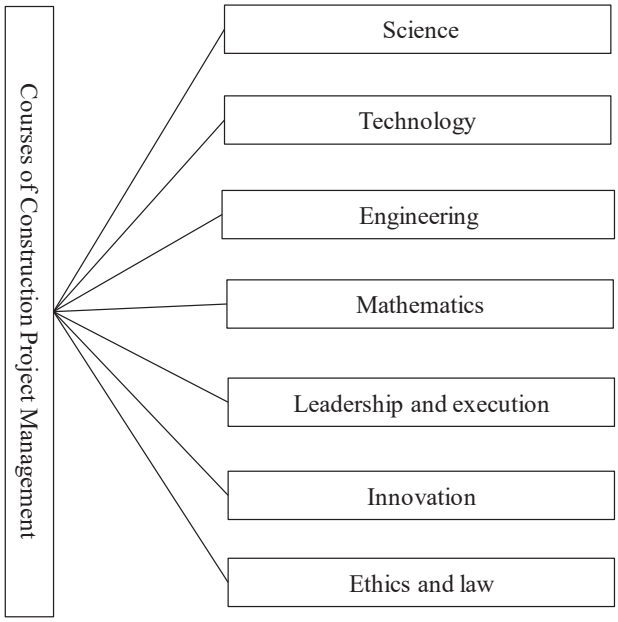

Fig. 1 Ability Courses of Construction Project Management Personnel

Multi-objective decision-making method

The multi-objective decision-making analysis method has two major research directions, which are Multiple Objective Programming and Multiple Criteria Decision Making, respectively. Regarding the practical application, Multiple Objective Programming is used for solving the "design-level" issues; Multiple Criteria Decision Making is used to solve the "choice-level" or "assessment-level" issues [7]. In this paper, the concept of membership function being added based on Delphi Method is used to replace the conventional crisp number [8], and a Fuzzy Delphi Method for fuzzy evaluation recognized by the experts is used. The following is a discussion of conventional Delphi Method, Fuzzy Mathematics and Fuzzy Delphi method.

A. Delphi Method

Delphi Method began to be widely applied in various subject areas, including science & technology forecast and future trend forecast [9, 10]. The studies by Murry Jr & Hammons suggest that Delphi Method is an anonymous type (Anonymous) collective expert decision-making technique. The technique, where the experts are the investigation objectives for a certain problem or future event, aims at reaching a consistent and stable consensus among experts (in the way of special investigation and group members are anonymous each other) under the environment of no interference through specific programs and repeated procedures and combining with the experts' knowledge, opinions and predictive ability in this field, in order to infer events that may occur, predict future trends effectively or obtain an agreed conclusions on an issue [11].

B. Combined Application of Fuzzy Theory

The Delphi Method is an expert forecasting method and a kind of group decision-making method. It has the advantages of both questionnaires and meetings [12, 13]. Ishikawa et al.

(1993) used the concept of cumulative number distribution and fuzzy integral to integrate experts' opinions into fuzzy numbers, which is called Fuzzy Delphi Method [14]. Chang et al. 's study of the Fuzzy Delphi Method is a study of using the Fuzzy Delphi Method on large-scale project planning [15]. In their study, based on the triangular fuzzy number, the Fuzzy Delphi Method was used to estimate the reasonable time of each work, and then a fuzzy project completion time and its Degree of Criticality were obtained correspondingly. This study has developed an improved Double-triangle Fuzzy Algorithm by applying the mathematical model modified by Jeng (2001) to quickly integrate the opinions of experts and reduce the number of repeated investigations of the questionnaire algorithm [16].

Discussions

According to Jeng (2001), the "Double-triangle Fuzzy Numbers" is used to integrate experts' opinions, and the "Grey Area Verification Method" is used to check whether experts' cognition has reached convergence[16] . The implementation steps of the Fuzzy Delphi Method are as follows:

Step 1: Design an expert questionnaire for the evaluation items, and the experts are asked to give a possible value range to each evaluation item. The "minimum value" in the value range indicates the "most conservative cognitive value" of the expert's quantitative score for the evaluation item. However, the "maximum value" indicates the "most optimistic cognitive value" of the quantitative score of the evaluation item.

Step 2: For each evaluation item *i*, the "most conservative cognition value" and the "most optimistic cognition value" given by all experts are counted respectively, and the extreme values beyond the "double standard deviation" are eliminated. Then, calculate the minimum value C_L^i, geometric mean and maximum value C_U^i of the remaining"most conservative cognitive values", and the minimum value O_L^i , geometric mean O_M^i and maximum value O_U^i of the remaining "most optimistic cognitive values" respectively.

Step 3: Establish the triangular fuzzy number C^i =(C_L^i , C_M^i , C_U^i) of the "most conservative cognitive values" of each evaluation item *i* calculated by step 2 and the triangular fuzzy number O^i = (O_L^i , O_M^i , O_U^i) of the "most optimistic cognitive values".

Step 4: The following method can be used for verification:

1. If the two triangular fuzzy numbers have no overlap, that is $C_U^i < O_L^i$, it indicates that the experts' opinion range values have a consensus section, and the opinions tend to be within the consensus section. Therefore, the "importance degree value of consensus" G^i of the evaluation item *i* is equal to the arithmetic mean value of C_M^i and O_M^i, expressed as

$$\text{Ci} = (C_M^i + O_M^i)/2 \circ \quad (1)$$

2. If the two triangular fuzzy numbers overlap, that is $C_U^i > O_L^i$, and the gray area of the fuzzy relationship $Z^i = C_U^i - O_L^i$ is less than the range value $M^i = O_M^i - C_M^i$ between the "geometric mean value of optimistic cognition values" and "geometric mean value of conservative cognition values" of the expert evaluation items, it indicates that there is no consensus section for each expert opinion's value ranges, but there is less difference between the extreme value opinions (the most conservative in the optimistic and the most optimistic in the conservative) given by two experts and the opinions of other experts, which will not result in divergence of opinions. Therefore, the "Importance Degree Value of Consensus" G^i is equivalent to the fuzzy set obtained by the intersection (*min*) to the fuzzy relations between two triangular fuzzy numbers, and then the quantitative score of the fuzzy set with the maximum membership degree is obtained.

$$F^i(x_j) = \left\{ \int_x \left\{ \min\left[C^i(x_j), O^i(x_j) \right] \right\} dx \right\} \quad (2)$$

$$F^i(x_j) = \left\{ \int_x \left\{ \min\left[C^i(x_j), O^i(x_j) \right] \right\} dx \right\} \quad (3)$$

3. If the double-triangle fuzzy numbers overlap, that is $C_U^i > O_L^i$, and the gray area of the fuzzy relationship $Z^i = C_U^i - O_L^i$ is greater than the range value $M^i = O_M^i - C_M^i$ between the "geometric mean value of optimistic cognition values" and "geometric mean value of conservative cognition values" of the expert evaluation items, it indicates that there is no common consensus section for each expert opinion's value ranges, and the difference between the two experts who give extreme value opinions (the most conservative in the optimistic and the most optimistic in the conservative) and the opinions of other experts is too big, resulting in divergence of opinions. Therefore, the unconverged evaluation items are provided to the experts for reference, and steps 1 to 4 are repeated, and the questionnaire is again performed until all the evaluation items have reached convergence to obtain the consensus value G^i.

In this study, the depth interviews were conducted for the 9 experts engaged in the construction management education and training field. The three senior engineers and education and training experts of the work decision-making group are from relevant government authorities, three professors from the construction project management departments in the academic circle are invited, and construction management lecturers on education and training of construction practice also participate. All these experts and scholars have a considerable understanding of the evaluating methods of the study theme. Combining with the previous information and literature, the training courses and subject abilities in the 7 areas mentioned in the previous section are constructed. Then, the questionnaire is prepared, and the questionnaire are filled out in the way of one-on-one answer. The expert evaluation value analysis is shown in Table 1.

Table I
Expert Evaluation Value Analysis Table

No.	Competency training course	Conservative value		Optimistic value		Single value		Geometric mean M			Test value			Consensus value	Ranking
		Min	*Max*	*Min*	*Max*	*Min*	*Max*	C^i	O^i	a^i	M^i	Z^i	M^i-Z^i	G^i	
S1	Science	4	7	7	9	6	8	5.17	8.18	6.85	3.01	0.00	3.01	6.68	6
S2	Technology	2	9	7	9	5	8	4.72	8.06	6.60	3.34	2.00	1.34	7.40	4
S3	Engineering	4	8	7	9	6	8	4.87	8.29	6.52	3.42	1.00	2.42	7.29	5
S4	Mathematics	4	7	6	10	5	9	5.02	8.15	6.22	3.13	1.00	2.13	6.52	7
S5	Leadership and execution	5	9	8	10	6	9	6.29	9.20	7.40	2.91	1.00	1.91	8.31	1
S6	Innovation	5	9	9	10	7	9	6.89	9.54	7.87	2.65	0.00	2.65	8.22	2
S7	Ethics and law	5	9	9	10	7	9	6.39	9.43	7.64	3.04	0.00	3.04	7.91	3

Conclusion

Seven training courses in the field are analyzed in Table 2, where S5 - leadership and execution ability course is the most important (8.31), followed by S6 - innovation ability course (8.22), and ethics and law course (7.91) ranks the third. The on-the-job training of construction project management staff should focus on the abilities of leadership execution, innovation, ethics and law. Among them, the leadership execution ability and innovation ability courses emphasize the importance of project management, while construction project management staff need to pay attention to the quality and safety of related construction projects and prevent corruption because of the huge budget of the undertaking projects. This study can provide a reference for the systematic curriculum design of construction engineering and management specialty in colleges and universities.

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