Project Cost Management Under Contingency: An Effective Path Analysis of Fuzzy Set Qualitative Comparative Analysis

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Abstract. Construction projects under contingency are characterized by high uncertainty and difficulty in cost control. This study aims to analyze the impact of uncertainty on project cost management under contingency. By reviewing related literature, the influencing factors of construction cost management are identified. Cost data were collected for 6 projects under construction affected by COVID-19 from 2020 to 2022. On this basis, an analytical evaluation of the effective path for construction projects was performed using the fuzzy set qualitative comparative analysis (fsQCA) method to evaluate the influence of antecedent variables on explanatory variables in the combined state, which helps construction contractors to find solutions to cost management problems in unexpected situations. The result is valid non-Boolean configuration paths.

Keywords: Risk Project Cost Management · fsQCA · Configuration Analysis

1 Introduction

COVID-19 has harmed human life. Besides the recognized health problems, it also affects the production of the construction industry [1, 2]. And construction cost control is an important indicator of a project's success. Construction cost management deals with a broad range of functions such as estimating, scheduling, cost control, resource costing, and financial control [3]. Undoubtedly, contingencies such as COVID-19 disrupt the cost management plans of project managers. Therefore, it is crucial to analyze the impact of uncertainties on project cost management in contingency and develop strategies to deal with the negative impact.

Reviewing the experience of the construction industry, suffering from major contingencies is not unique to COVID-19, e.g. extreme weather [4], earthquakes [5], and floods [6] occur occasionally. The labor force for construction projects was affected. In some areas, there are no workers in construction projects, and some experienced construction technicians cannot work on time, which affects the project progress and increases the management cost. Therefore, although contingency is a minor probability event, it is

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necessary to study construction contractors to find solutions to cost management problems in contingency situations because it can be very costly for construction contractors and owners [7].

The research related to this study mainly includes the impact of COVID-19 on construction projects and construction project cost management.

Numerous researches have explored the impact of COVID-19 on construction projects through modeling, simulation, and questionnaires. For example, for projects under construction, Sierra [8] found that COVID-19 disrupted construction activities and required more time and money from the contractor. Li [9] analyze the impact of COVID-19 on different stages of the project life cycle and sort out the countermeasures taken by the project participants. Jamaludin [10] stated that most construction firms suspended construction and encouraged employees to work at home during the initial outbreak of COVID-19. This increases the project management cost but has little effect, as illustrated by the empirical transaction data of Lam [11]. Almohassen [12] explored the impact of COVID-19 on the importance of safety routines in the construction industry and found that to maintain work on construction projects, it is more necessary to prevent and control worker infections to adapt to safety measures. This inspired this paper to analyze the additional costs that managers face, such as contingency costs.

Researchers also explored the factors and strategies influencing cost management in projects. E.g. Sanchez [13] uses Bayesian networks to normalize the knowledge of project managers and extracts knowledge from a database of past projects to reduce the risk of project cost (or budget) overruns. Haaskjold [14] investigated the proportion of the total cost of a construction project spent on project management and quantified the size of the transaction costs in the head of a project in a construction project compared to the size of its body, the result was 18%. It can compare with our study of the change of project management costs in contingency. Other studies on engineering cost control are also closely related to this paper. For example, Liu [15] analyzed the cost management of marine engineering projects based on supply chain analysis and gave the corresponding cost control strategies for engineering projects. Liu [16] evaluated the cost management system of electric power engineering based on a fuzzy comprehensive evaluation model and established a complete cost control system of electric power engineering. This paper also uses fuzzy evaluation, but Liu's [16] study has a quantitative evaluation system while ours is a combination of quantitative and qualitative. The advantage of this study is the use of cost data from six construction-in-progress projects instead of one.

Based on the above research, Contingency situations have a significant impact on engineering project management. Using the fuzzy set qualitative comparative analysis (fsQCA) method, this paper investigates the core and auxiliary conditions affecting the cost objectives of construction contractors under contingency by identifying efficient cost control groups as a case study of six projects' cost data whit different types in Chengdu, China, to locate the mechanism of the role of different sets of influencing factor groups on cost control.

2 Method

2.1 Method Description

In this study, the fsQCA method is adopted to evaluate the influence of antecedent variables on explanatory variables in the combination state. On this basis, the effective path of construction projects is evaluated, which can help contractors find solutions to cost management problems in contingencies. Since the kind and degree of the set are combined, fsQCA is both qualitative and quantitative [17], compared with other evaluation methods. Therefore, fuzzy sets have many advantages of interval variables, especially the ability to distinguish accurately, while allowing for set operations [18], which are beyond the scope of traditional variable-oriented analysis. FsQCA is mainly aimed at continuous variables. According to practical experience and theoretical knowledge, the variable can be converted into a fuzzy set variable of continuous change in [0, 1]. Fuzzy sets are extended to clear sets by taking membership scores between 0 and 1. The essence of fuzzy sets is to allow scale variations of set scores and therefore partial membership is allowed. More importantly, QCA does not have high requirements for sample size, and therefore correlation analysis can also be carried out on small samples, which is not supported by other evaluation methods, such as DEA [19]. Since the cost data of contractors is their private information, it is difficult to obtain massive data, and as a result, fsQCA is more suitable for this study.

2.2 Indicators and Data

There are many indicators to judge the quality of project cost management, among which the most direct is the total cost. However, the choice of indicators should be more diverse, considering the project quality and duration, etc.

Under contingency, the cost of most construction projects will increase [20]. Therefore, under contingency, the indicators for evaluating project cost management should incorporate more efficiency indicators. In this study, Total Cost Deviation Rate (TCDR) and Owner Satisfaction (OS) are adopted to evaluate the results. The TCDR is defined by Eq. (1).

$$TCDR = \frac{ATC - PTC}{PTC} \times 100\% \tag{1}$$

where ATC is the actual total project costs, and PTC is the planned total costs, which is considered as the total contract price in this study. Because the total contract price is produced by the contractor based on the planned list as well as it is accessible. TCDR represents the management effect of the contractor. Owners' Satisfaction focuses more on indirect benefits. Total project costs include production costs and transaction costs associated with project management [14]. According to Waheeb's study [20], project costs increase suddenly under contingency. Therefore for this irreversible objective result, the owner has to accept it. However, the actions of a construction contractor can influence the impression of the owner. Therefore OS is used to define the owner's impression. In this study, OS is a subjective value, which is evaluated by the Delphi method following Elmousalami [21].

At the budget stage, the project cost is subject to many uncertainties [22]. Six factors (antecedent variables) that have a great influence on the evaluation indicators of project cost management are selected in this study, i.e., Labor Cost (LC), Machine Usage Cost (MUC), Material Cost (MC), Contingency Cost (CC), Number of Management Personnel (NMP) and Total Price of the contract (TP).

To eliminate the influence of the valuation quota of the bill of quantities in different regions, six actual projects under construction in Chengdu are selected, including parks, housing, infrastructure, and other types of projects. The six projects are referred to as A, B, C, D, E, and F, respectively. By analyzing their cost lists, the information on these six antecedent variables is extracted. On this basis, TCDR and OS are calculated. As shown in Table 1, there are 48 sets of processed data for fsQCA.

3 Case Study

3.1 Variable Assignment and Truth Table Construction

To convert regular-scale -variables and irregular spacing variables into standard fuzzy sets, it is necessary to calibrate the raw data with theoretical and substantive standards outside the data and to consider the conceptual issues, definitions, and labeling of the study. As a result, antecedent variables and explanatory indicators are kept consistent with external criteria. The result is the fine-grained calibration of degrees between sets of cases, with a score between 0 and 1.

Usually, the values of an interval scale variables are specified, which corresponds to the three qualitative breakpoints that make up the fuzzy set: (1) threshold of membership degree (fuzzy score = 0.95), (2) threshold of non-membership degree (fuzzy score = 0.05), (3) intersection points (fuzzy score = 0.5). The calibration of the raw data is shown in Table 2.

By using fsQCA 3.0, Boolean minimization is performed on the truth table, and then complex solutions, intermediate solutions, and parsimonious solutions are obtained, among which the intermediate solution is generally regarded as the most illustrative solution. Therefore, the core variable factors and the edge variable factors are identified in this study by comparing the intermediate solution and the reduced solution.

Truth table construction and analysis involve two steps. Firstly, a truth table spreadsheet from raw data is created, which mainly involves specifying the results and antecedents in the analysis. Secondly, frequency thresholds and consistency thresholds are selected to analyze the truth table spreadsheet, as shown in Table 3.

The result shows that all raw consist is greater than 0.7, which means that OS need not be corrected. In this case, there is a necessary condition (~TP), which is set to absent in the Intermediate solution analysis. Therefore, the four nonboolean paths of the Intermediate solution for this case are shown in Table 4.

Then the complex solution, parsimonious solution, and intermediate solution are performed. The results of the parsimonious solution and intermediate solution in the four models of complex solutions are shown in Table 5. It can be seen from the calculation that the consistency of the solution is greater than 0.8, and the coverage of the solution is greater than 0.5, which indicates that the fsQCA model is applicable.

Table 1. Raw cost data for 6 construction projects

Projects	LC	MC	MUC	NMP	TP	CC	TCDR	OS
A	1556000	1983000	1415	10	3928000	91816	0.052453613	0.9
B	2709146.58	8745069.87	1960025.41	15	30213701.3	610759.11	0.530841958	0.5
C	2463144.6	6958595.28	976690.8	10	16881597.5	524822.2	0.246324119	0.7
D	12717921.91	35861862.17	2070151.97	10	63083855.6	932475.6	0.138548001	0.9
E	18529623.17	3828775.2	43531004.71	8	79423785.8	603260.894	0.243360003	0.8
F	6014486.751	876999.632	30679922.87	8	61019215.2	1847670.22	0.214564999	0.85

Table 2. Calibration data for 6 construction projects

Projects	TCDR	OS	LC	MC	MUC	NMP	TP	CC
A	5%	0.9	0.94	0.95	0.97	0.25	0.06	0.95
B	53%	0.5	0.91	0.85	0.95	0.03	0.32	0.76
C	25%	0.7	0.92	0.88	0.96	0.25	0.14	0.81
D	14%	0.9	0.22	0.03	0.95	0.25	0.12	0.49
E	24%	0.8	0.03	0.93	0.03	0.44	0.03	0.76
F	21%	0.85	0.76	0.96	0.2	0.44	0.14	0.03

Table 3. The truth table for this case

LC	MC	MUC	NMP	TP	CC	TCDR	OS	raw consist	PRI consist	SYM consist
1	1	0	0	0	0	1	1	1	1	1
0	0	1	0	0	0	1	1	1	1	1
0	1	0	0	0	1	1	1	1	1	1
1	1	1	0	0	1	3	1	0.89867	0.82031	1

Table 4. The four nonboolean configuration paths of the Intermediate solution

Frequency cutoff: 1 Consistency cutoff: 0.898678	Assumption: ~ P (absent)		
	raw coverage	unique coverage	consistency
~LC*~MU*MUC*~NMP*~TP*~CC	0.172043	0.103226	1
LC*MU*~MUC*~NMP*~TP*~CC	0.15914	0.111828	1
~LC*MU*~MUC*~NMP*~TP*CC	0.15914	0.113979	1
LC*MU*MUC*~NMP*~TP*CC	0.43871	0.372043	0.898678
Solution coverage: 0.769892			
Solution consistency: 0.939633			
ERROR (Quine-McCluskey): The 1 Matrix Contains All Configurations.			

3.2 Necessity Analysis of a Single Variable Condition

Table 6 shows the necessity test of fsQCA. From Table 3, it is found that ~ TP is necessary with our explanatory variables (output results) (evaluation score > 0.9 [9]). It can be seen that the Total Price of the contract will have a necessary influence on the results, among the cost management factors of projects under contingency. Referring to the meaning of antecedent variables, the TP represents the scale and construction area of the project

Table 5. Consistency and coverage of solutions

Core Conditions	Model 1	Model 2	Model 3	Model 4
LC	○	○	○	●
MC	○	●	●	●
MUC	●	○	○	●
NMP	○	○	○	○
TP	○	○	○	○
CC	○	○	●	●
Original coverage	0.172043	0.15914	0.15914	0.43871
Unique coverage	0.103226	0.111828	0.113979	0.372043
Consistency of the solution	0.9396			
Solution coverage	0.7698			

Note: ● indicates that the core condition exists; ○ indicates that the core condition is absent

and estimates the total cost of the construction project, that is, the higher the TP is, the more disadvantageous it is to the cost management under contingency.

Table 6. Analysis of Necessary Condition

Factors	**Outcome variable: TCDR**		**Outcome variable: OS**	
	Consistency	Coverage	Consistency	Coverage
LC	0.664198	0.711640	0.668817	0.822751
~LC	0.471605	0.860360	0.440860	0.923423
MC	0.785185	0.691304	0.812903	0.821739
~MC	0.303704	0.878572	0.286021	0.950000
MUC	0.711111	0.709360	0.694624	0.795566
~MUC	0.387654	0.809278	0.380645	0.912371
NMP	0.409877	1.000000	0.356989	1.000000
~NMP	0.844444	0.788018	0.821505	0.880184
TP	0.133333	0.666667	0.174194	1.000000
~TP	0.992593	0.774566	0.995699	0.892100
CC	0.733333	0.781579	0.726882	0.889474
~CC	0.429630	0.790909	0.447312	0.945454

Note: “ ~” means the variable is missing or non-existent

Before the QCA comparative analysis, whether a single antecedent variable factor is the necessary condition of an outcome variable should be analyzed, which is often measured by the Consistency indicator. In the necessary condition test, the setting standard adopted in this paper sets the consistency threshold as 0.9.

3.3 Adequacy Analysis of Conditional Configuration

The conditional configuration analysis of the effective path is one of the most important ideas of the QCA analysis method. It mainly analyzes the adequacy of the configuration results of the effective path formed by the combination of different antecedent variable conditions. In this study, the clear truth table algorithm of fsQCA 3.0 is adopted for qualitative comparative analysis. Since there are only 6 projects in this study, the frequency threshold for cases is set to 1, the threshold for raw consistency (raw consist) is set to 0.7, and the threshold for PRI is set to 0.75. Finally, the antecedent condition structure of conditional configuration on explanatory variables is shown in Table 7.

The results shown in Table 7. The antecedent condition structure of conditional configuration on explanatory variables are as follows. (1) When the outcome variable is Owner Satisfaction, the overall consistency is 0.9396, greater than the threshold value of 0.8, and the coverage is 0.7698. In this result, there are four paths to high owner satisfaction, i.e., X1, X2, X3, and X4. (2) When the outcome variable is the Total Cost Deviation Rate, the overall consistency is 0.978, which is greater than the selected threshold. There are three paths to achieve excellent TCDR, i.e., Z1, Z2, and Z3.

Table 7. The antecedent condition structure of conditional configuration on explanatory variables

Conditional Configuration	Outcome variable: OS				Outcome variable: TCDR		
	X1	X2	X3	X4	Z1	Z2	Z3
LC	○	●	○	●	○	●	○
MC	○	●	●	●	○	●	●
MUC	●	○	○	●	●	●	○
NMP	○	○	○	○	○	○	○
TP	○	○	○	○	○	○	○
CC	○	○	●	●	○	○	●
Original coverage	0.172043	0.15914	0.15914	0.43871	0.1877	0.1827	0.1827
Unique coverage	0.103226	0.111828	0.113979	0.372043	0.1333	0.1284	0.1309
Consistency of solution	0.9396				0.978		
Solution coverage	0.7698				0.447		

The robustness of the model is tested by changing each threshold and observing whether the result changes significantly. For example, the threshold of the raw consistency is raised to 0.85 (from 0.8), and the PRI is raised to 0.8 (from 0.75). The results show that the interpretation of each variable does not change fundamentally. Therefore, the configuration obtained by fsQCA3.0 is reliable.

4 Configuration Analysis Results and Discussion

This study examines the effect of six antecedent variables of fsQCA on two explanatory variables. Configuration Analysis is performed separately for OS implementation and TCDR implementation based on case channel count and PRI settings in Sect. 3.

4.1 Configuration Analysis of OS Implementation

Configuration X1 focuses on the construction project material cost to facilitate OS realization when the contingency occurs, while the construction project labor cost, construction project machinery cost, number of managers, total contract price, and contingency cost negatively affect the OS realization. From Configuration X1, under contingency (e.g., COVID-19), the rapid rise of material cost (including raw material price and transportation cost) is one of the key factors affecting the cost management of construction projects. The production of raw materials has stagnated due to COVID-19, while the demand for raw materials has soared since the resumption of construction work in April 2020, which has jointly contributed to the increase in material price. In addition, the transportation cost has also risen due to the control policy of COVID-19. Therefore, construction contractors need to contract with material suppliers to control price risk before construction. Moreover, in terms of responding to contingency, e.g., COVID-19, stakeholders of the construction project, such as the owner, the construction party, the supervisor, and the supplier, should maintain a cooperative relationship and work together to achieve the goal of the project cost management.

Configuration X2 focuses on the combined effect of construction project labor cost and construction project machinery usage cost to facilitate OS realization during contingency, while construction project material cost, the number of management staff, total project contract price, and contingency cost negatively affect OS realization. The X2 path shows that the rapid increase in the cost of machinery and labor during contingency is a key factor affecting project cost management. The main reason for this is the staff factor, when the contingency occurs, the demand for labor at the construction site is greater than the supply, and the labor cost is elevated.

Configuration X3 focuses on construction project machinery cost and contingency cost to promote OS during contingency, while construction project labor cost, material cost, number of managers, and total contract price negatively affect OS realization.

Configuration X4 focuses on construction project labor cost, material cost, machinery cost, and contingency cost to promote OS achievement while the number of managers and total contract price negatively affect OS realization.

4.2 Configuration Analysis of TCDR Implementation

Configuration Z1 focuses on construction project material costs contributing to TCDR realization and the remaining factors negatively contribute to TCDR realization. Z1 is similar to X1. The size of the entire project, the overall area of the project under construction, and the total cost directly affect the indicator conditions for cost management when the project is under contingency. This indicates that the smaller the project size and the smaller the area under construction, the smaller the total cost and the easier it is to control the cost when the project is under contingency. The regression analysis shows that the total contract price is almost negatively correlated with the explanatory indicators, which shows that the experience of the project manager is crucial for cost control.

Configuration Z2 focuses on construction project labor costs and construction project machinery costs to facilitate TCDR achievement. Construction project material cost, number of managers, total contract price, and contingency cost will inhibit TCDR achievement. Similar to configuration X3.

Configuration Z3 focuses on construction project mechanical cost and contingency cost to promote TCDR achievement, while the others negatively on TCDR achievement.

In either case, there is a reluctance to increase the number of managers and total contract price. The essential reason for reducing the number of managers is to reduce overhead costs, such as overheads, for projects under construction. And the total contract price indicates that small projects are more likely to reach management goals in a contingency situation. For machinery usage costs, most of the paths have a positive effect on the results of project cost management. This suggests that in more cases cost managers should pay more attention to the use of machinery to reduce other costs.

5 Conclusion

This paper discusses the relationship between six antecedent variables and two explanatory variables by analyzing the cost data of six construction projects under contingency (COVID-19) and uses fsQCA for a combination of quantitative and qualitative methods to evaluate the effective path of construction project cost management. Based on the evaluation model established by field research, this paper touches on the actuality of construction projects and finds 7 sets of nonBoolean variable configuration paths to reveal the reasons for cost control of construction projects being affected under contingency conditions, to help construction contractors find solutions to cost management problems under contingency.

Finally, by calculating the original and unique solutions, the best cost management strategy (configuration path X4) is increasing the labor cost, material cost, machinery cost, and contingency cost by reducing the number of managers and lowering the total contract price for the project cost management achieved under contingency. The Original coverage and Unique coverage of this path reached 0.43871 and 0.372043, respectively. Minimizing overhead costs and small-scale engineering projects are more likely to achieve cost management objectives under contingency. This is similar to the impact of cost overruns studied by Waheeb [20] and is in line with the laws of economics.

The application of fsQCA to project management is not new (e.g., [23, 24]). This study applies fsQCA to construction project cost control, combining the quantitative and qualitative advantages of QCA with construction cost forecasting, control, and analysis for project cost management. This is in line with the needs of construction contractors for construction cost analysis and evaluation.

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