Whole Life Cycle Risk Assessment of Prefabricated Construction: A Structural Equation Modeling

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Abstract. With the rapid development of urbanization in China, prefabricated construction (PC) has attracted the attention of the public but PC is still in their infancy. Therefore, it is necessary to identify the risk factors of whole life cycle of PC. This paper adopts the structural equation modeling to analyze the data of the questionnaire and calculates the weight of each risk index. The research results provide decision makers with reference to the PC cycle risk, and also lay the foundation for the PC risk index system.

1. Introduction

PC is a manufacturing process, generally taking place at a specialized facility where various materials are joined to form a component part of the final installation[1]. Compared with the traditional construction method of cast-in-place concrete, it has the advantages of high production efficiency, high construction quality, low labor demand, saving resources and reducing environmental pollution. At present, Chinese government attaches great importance to resource environmental protection, and relevant policies have also been introduced. Under this background, PC has gradually become an important component in the development of industrial buildings in China. Due to the late start of PC in China, great risks and challenges remain on the road to the development of PC.

Sang Peidong[2] identified 18 key indexes to build a risk assessment system for the investment risk of PC project and used the structural equation modeling to obtain that consumer cognitive and project management model were important risk factors. Meng Tao[3] evaluated the risk of PC from five stages through the analytic hierarchy process and the entropy method. Meanwhile, based on the extension theory, a full life cycle risk extension evaluation model for PC was constructed. Shi Yufang[4] constructed the SWOT matrix of PC and concluded that the great difficulty of construction was the primary factor to the development of PC. Qi Baoku[5] used the entropy method to identify 27 key risk factors in practical cases based on the perspective of whole life cycle of PC and provided an effective reference for the research of deuterian risk assessment. Gan Xiaolong[6] used ISM to study the factors that hindered the development of PC, and found that inadequate policies and regulations and lack of knowledge and expertise were the first causes.

Based on the characteristics of PC, this paper constructs the whole life cycle risk assessment system of PC in view of the development status and practical problems of PC in China. The structural equation modeling is introduced to quantify qualitative factors, which can scientifically analyze the uncertainty of the multilevel index and provide certain reference basis for risk assessment of PC.
2. Index system establishment

By summarizing and analyzing the research situation of domestic and foreign scholars in PC, this paper divides the whole life cycle of PC into five stages, which are decision stage, design stage, production transportation stage, construction stage, operation maintenance stage. Combined with the present situation of Chinese PC and the problems it faces, the whole life cycle risk index system of PC is established through expert interviews. As shown in Table 1.

Table 1. Risk evaluation index system.

| Latent variables          | Observation variables                                      |
|---------------------------|------------------------------------------------------------|
| Decision                  | lack of effective financing channels                       |
|                           | large upfront investment                                   |
|                           | inadequate policy and regulations                          |
|                           | lack of professional consultants                           |
|                           | long investment payback period                             |
|                           | inaccurate market estimate                                 |
| Design                    | nonstandard design                                         |
|                           | lack of experience in PC integration design                 |
|                           | poor design workability                                    |
|                           | Not Considering the Local Conditions                       |
|                           | Failure to comply with modular coordination principle       |
|                           | Not considering civil engineering, decoration, equipment integration |
| Production transportation | unqualified production qualification                        |
|                           | insufficient concrete strength                             |
|                           | component stacking loss                                    |
|                           | the limited size and load of transport vehicles             |
|                           | lack of special plans for lifting and transporting          |
|                           | lack of personnel with experience in lifting                |
| Construction              | lack of site managers for PC                               |
|                           | inaccurate contractor quotes                               |
|                           | lack of complete technical conditions                      |
|                           | PC component structure processing                           |
|                           | insufficient industrialization and mechanization            |
| Operation maintenance     | insufficient consumer awareness                            |
|                           | short of expected return                                   |
|                           | Low level of cooperation among the participants             |
|                           | lack of scientific maintenance                             |
|                           | insufficient level of property management company           |

2.1. Data collection

In this study, a questionnaire was designed based on whole life-cycle risk index system of PC, and the variables were measured using the Likert 5-level scale. In order to ensure the quality of the questionnaire, the survey conducted online and offline paper questionnaires for project developers, design enterprise, construction enterprise, engineering consulting enterprise, equipment supply enterprise, scientific research academy and other units in the construction industry. 284 questionnaires were issued, and the effective questionnaire was 250, with a recovery rate of 88.02%.
2.2. Reliability analysis
Using the Cronbach's alpha to analyze the reliability of the scale, Normally Cronbach's alpha has a good reliability when it is above 0.6. From the results of SPSS24.0, the Cronbach's alpha of the subscale of the five potential variables is more than 0.6, and the overall Cronbach's alpha is 0.946, indicating that the scale has good reliability. The specific Cronbach's alpha of the scale is shown in Table 2.

| Latent variables       | Number of measurable variables | Cronbach's alpha |
|------------------------|---------------------------------|------------------|
| Decision               | 6                               | 0.961            |
| Design                 | 6                               | 0.959            |
| Production transportation| 6                              | 0.960            |
| Construction           | 5                               | 0.952            |
| Operation maintenance  | 5                               | 0.956            |

2.3. Validity analysis
The KMO test and Bartlett's test were used to do effectiveness degree test of the scale. As the statistical analysis software SPSS24.0 calculation shows, the KMO value of the questionnaire is 0.875. The Sig value of the Bartlett's test is 0, which is less than 0.01, indicating that the sample data is highly correlated. Therefore, the scale has good convergence validity.

3. Discussion and analysis
Combined with the above data, the whole life cycle risk of PC is analysed from five stages: decision, design, production transportation, construction, operation maintenance. In order to make data support more reliable, this study uses structural equation modeling to analyse the relationship among variables. Among them, the ellipse represents the latent variable, and the rectangle represents the observed variable. Taking five stages of whole life cycle of PC as the latent variable of the model and investigating each index as the observation variable of the model, the whole life cycle risk assessment model of PC is constructed.

3.1. First-order model confirmatory factor analysis
Before evaluating the model-fitting degree, it is necessary to conduct an "Offending Estimates" to determine whether estimation coefficient is within the acceptable level[7]. Hair[8] believe that the Offending Estimates follows three rules: The first is that the Negative error term has variation, the second is that the standardization coefficient is too close to or exceeds 1 (generally 0.95 is the threshold), and the third is that the standard error is too large. If the detection results of the construction model do not have the above-mentioned Offending Estimates phenomenon, then the matched degree of the overall model can be tested. The first-order model is calculated by Amos22.0. It is shown in Figure 1.

3.2. Second-order model confirmatory factor analysis
It can be found from the study of 3.2 that the first-order theoretical model can be adapted to the sample data, and there may be a medium and high correlation between the original first-order factors, so it can be assumed that there is a higher-order factor construct that measures the five first-order factors. Combined with the questionnaire design, this higher-order potential factor is named as whole life cycle risk of PC. Based on this, the second-order confirmatory factor analysis model of life cycle risk is drawn. After substituting the questionnaire data into the model, it was found that most of the indexes in the model can measure up to standard through AMOS22.0 analysis, but there are still a few fitting indexes that do not measure up to standard. Thus, the model needs to be modified. With reference to the correction index MI value, the relevant path of the residual variable is added to the
model until the final model is obtained which is shown in Fig. 2. The model test results are shown in Table 3

Table 3. The model fitting indices results

| index name     | Adapted standard or threshold | initial model | Model adaptation judgment | corrected model | Model adaptation judgment |
|----------------|-------------------------------|---------------|---------------------------|-----------------|--------------------------|
| RMSEA          | <0.08                         | 0.083         | NO                        | 0.027           | YES                      |
| GFI            | >0.9                          | 0.819         | NO                        | 0.903           | YES                      |
| PNFI           | >0.5                          | 0.815         | YES                       | 0.827           | YES                      |
| CFI            | >0.9                          | 0.929         | YES                       | 0.993           | YES                      |
| TLI            | >0.9                          | 0.922         | YES                       | 0.992           | YES                      |
| NFI            | >0.9                          | 0.893         | NO                        | 0.956           | YES                      |
| CMIN/DF        | <3                            | 2.72          | YES                       | 1.184           | YES                      |

Through the analysis of the integrated model fitting degree and the measurement equation estimate parameters, it can be considered that the correction model has a good internal structure fitting degree, so the model constructed by the article shows better adaptability. In summary, the model overall is ideal.

Figure 1. First-order model confirmatory factor analysis

Figure 2. Second-order model confirmatory factor analysis
3.3. Risk weight determination
According to the evaluation of the above fitting effect, the weight coefficient of whole life cycle risk assessment index of PC is further calculated. The calculation method is as follows: Firstly, assume that the path coefficients of the five latent variables are $H_1, H_2, H_3, H_4, H_5$, then the index weights of the five latent variables are calculated by the formula $H_i = \frac{H_i}{\sum_{i=1}^{5} H_i}$. Similarly, the index weights of the observation variables can be calculated. The results are shown in Table 4.

| latent variables | The weight of the first grade indexes | observation variable | The weight of the second indexes of the grade |
|------------------|--------------------------------------|-----------------------|------------------------------------------|
| decision         | 0.222                                | lack of effective financing channels 0.176 |
|                  |                                      | large upfront investment 0.152 |
|                  |                                      | inadequate policy and regulations 0.172 |
|                  |                                      | lack of professional consultants 0.165 |
|                  |                                      | long investment payback period 0.165 |
|                  |                                      | inaccurate market estimate 0.170 |
| design           | 0.198                                | nonstandard design 0.167 |
|                  |                                      | lack of experience in PC integration design 0.163 |
|                  |                                      | poor design workability 0.169 |
|                  |                                      | Not Considering the Local Conditions 0.179 |
|                  |                                      | Failure to comply with modular coordination principle 0.148 |
|                  |                                      | Not considering civil engineering, decoration, equipment integration 0.174 |
| Production       | 0.191                                | unqualified production qualification 0.171 |
| transportation   |                                      | insufficient concrete strength 0.179 |
|                  |                                      | component stacking loss 0.177 |
|                  |                                      | the limited size and load of transport vehicles 0.171 |
|                  |                                      | lack of special plans for lifting and transporting 0.150 |
|                  |                                      | lack of personnel with experience in lifting 0.152 |
| construction     | 0.198                                | lack of site managers for PC 0.203 |
|                  |                                      | inaccurate contractor quotes 0.184 |
|                  |                                      | lack of complete technical conditions 0.205 |
|                  |                                      | PC component structure processing 0.203 |
|                  |                                      | insufficient industrialization and mechanization 0.205 |
| operation        | 0.191                                | insufficient consumer awareness 0.207 |
| maintenance      |                                      | short of expected return 0.202 |
|                  |                                      | Low level of cooperation among the participants 0.189 |
|                  |                                      | lack of scientific maintenance 0.200 |
|                  |                                      | insufficient level of property management company 0.202 |

4. Conclusions
Structural equations are mainly used to analyze theoretical models made up of causes and results. In this paper, structural equations are applied to the study of whole life cycle risk of PC, the results show that the structural equation modeling can be used to analyze whole life cycle risk of PC, and the reliability of the established risk index system can be verified. At the same time, this paper improves the domestic research on whole life cycle risk assessment method of PC, which can help stakeholders to effectively judge and avoid risks. In addition, there are still some shortcomings in this paper. Future research can combine the data with the successful cases of PC at home and abroad for risk analysis and program selection. With the continuous development of PC in China, it is necessary to screen and optimize the whole life cycle index of PC.
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