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Project Risk Management of EPC Based on Structural Equation Modeling

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Abstract:

This paper takes Zhijiang road EPC project as an example. By sorting out and analyzing relevant literature at home and abroad, EPC project risks are divided into five categories and 22 subcategories. The five categories are contract risk, design risk, procurement risk, construction risk and external environment risk. Data are collected by questionnaire. The structural equation model is established to make qualitative and quantitative analysis of Zhijiang road project. Research shows that contract risk is the most important. Then, the importance of risk decreases step by step, following the order of external environmental risk, design risk, construction risk and procurement risk.

Keywords: Risk assessment, *EPC*, Structural equation model.

I. INTRODUCTION

EPC is a project construction organization and implementation mode that is fully responsible for the quality, safety, cost and construction period of the project[1-2]. It refers to that the contractor signs a contract with the construction unit to implement general contracting for engineering design, procurement, construction and other stages. In terms of risk allocation, EPC mode allocates more risks to the general contractor. At present, most construction projects in China, especially large-scale investment projects, adopt the consortium model. This model can reduce costs, realize risk sharing, make enterprise resources complementary, and maximize benefits.

By searching the literature on EPC risk at home and abroad, it is found that most scholars use fuzzy evaluation method, analytic hierarchy process and other methods to conduct qualitative analysis on the risk of EPC project. Barbaros Yet [3] focused on the costs and benefits of the project and related risk factors, focusing on the planning and uncertainty of the project schedule. Mangla, S.K. [4] used ISM to explain the interaction and analyze the risk tolerance of the supply chain. Herui Cui [5] adopted the method of fuzzy comprehensive evaluation to analyze the Contractor's risk under the environment of economic crisis. The research on quantitative analysis needs to be further carried out. Firstly, this paper determines the risk evaluation index system of EPC project through literature search. Then the relevant data will be collected by questionnaire to establish structural equation model. Finally, the risk of Zhijiang road EPC project is

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analyzed qualitatively and quantitatively.

The design scope of Zhijiang Road water conveyance pipe gallery and road upgrading project is from Zhipu road to Fuxing Road. The total length is about 6.3 km. The planned construction period is 973 days. The estimated total investment of the project is 4.175 billion yuan. The project is contracted by a consortium composed of Design Institute, construction unit and procurement unit.

II. ANALYSIS OF PROJECT RISK FACTORS

At present, many scholars have systematically studied the risk of EPC project. Ning Yu [6] used ISM method to analyze the risk of EPC project. The 11 risks that the contractor needs to bear were summarized, and the risk structure diagram between the 11 risks was established. Antonio Rodríguez [7] used fuzzy analytic hierarchy process and fuzzy reasoning system to integrate various risk factors. The model considers the relationship between different degrees of uncertainty and risk factor groups. Victor A. Bañuls [8] used cross impact analysis and interpretative structural modeling to predict the risk of the whole life cycle of the project. Liu Yuming and others [9]analyzed the risks of EPC project by means of literature review and field research. The risk management indicators of railway construction projects under EPC mode were divided into 7 categories, with a total of 58. Zheng Shaoyu [10] applied RBS-RM-BN to analysis EPC project risk quantification and divided the risk into national level, market level and project level. Gao ran [11] analyzed the project risk from two aspects which were external risk and internal risk of the general contractor. External risks mainly included policy risks, economic risks, environmental risks, technical risks and safety risks, and internal risks included procurement risks, construction risks, design risks and etc. Duan Yonghui and others[12] established the risk evaluation index system of EPC project by using the method of structural equation. EPC project risks were divided into contract risks, design risks, procurement risks and construction risks.

In order to determine the risk evaluation index system of Zhijiang road EPC project, this paper adopts the methods of literature reading, brainstorming and expert consultation. In this paper, the risks of EPC project are preliminarily divided into five categories: contract risk, design risk, procurement risk, construction risk and external environment risk, with a total of 22 sub categories. See TABLE I for specific EPC project evaluation index system.

TABLE I. Risk evaluation index system of EPC project

LATENT VARIABLE	OBSERVATION VARIABLE	INDICATOR SOURCE
CONTRACT RISK (A)	RISK OF AMBIGUOUS CONTRACT TERMS (A1)	GUO WEI(2010)[13]; WANG LUWEI (2021); ZHAO ZHENG
	RISK OF UNREASONABLE RISK ALLOCATION (A2)	
	RISK OF CLAIMS AND DIAPUTES (A3)	

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	RISK OF CONTRACT CHANGE (A4)	(2019)[14] ET AL
DESIGN RISK (B)	RISK OF DESIGN CHANGE (B1)	ZHENG SHAOYU (2021); ZHAO ZHENG (2019) ET AL
	RISK OF DESIGN DEFECTS (B2)	
	RISK OF DESIGN DELAY (B3)	
	RISK OF DESIGN DEPTH (B4)	
	RISK OF INCREASED DESIGN COST (B5)	
PROCUREMENT RISK (C)	RISK OF MATERIAL AND EQUIPMENT PROCUREMENT QUALITY (C1)	LIU YANG(2020)[15]; ZHAO ZHENG (2019) ET AL
	RISK OF MATERIAL AND EQUIPMENT PRICE (C2)	
	RISK OF TRANSPORTATION (C3)	
	RISK OF PROCUREMENT PERSONNEL'S MISTAKES (C4)	
	RISK OF SUPPLIER CREDIT (C5)	
CONSTRUCTION RISK (D)	RISK OF CONSTRUCTION SAFETY (D1)	LIU YUMING (2020) YANG ZUXIAN (2020); LIU ZENGLIANG (2021)[16]ET AL
	RISK OF CONSTRUCTION PROGRESS (D2)	
	RISK OF CONSTRUCTION QUALITY (D3)	
	RISK OF CONSTRUCTION cost (D4)	
	RISK OF CONSTRUCTION ORGANIZATION MANAGEMENT (D5)	
EXTERNAL ENVIRONMENTAL RISK (F)	RISK OF POLITICAL ENVIRONMENT (F1)	LIU YUMING (2019)
	RISK OF HUMAN ENVIRONMENT (F2)	
	RISK OF ECONOMIC ENVIRONMENT (F3)	

III. QUESTIONNAIRE SURVEY AND DATA STATISTICS

3.1 Survey objects and methods

This questionnaire is conducted in two ways: online electronic questionnaire and offline questionnaire. As this paper mainly analyzes the influencing factors of the risk of Zhijiang road EPC project, the offline questionnaire is mainly distributed to the designers and constructors with EPC project experience, such as the Design Institute, the construction unit and the procurement unit. At the same time, online electronic questionnaires will be distributed to University experts, professors and researchers engaged in EPC project research.

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3.2 Purpose of investigation

Through questionnaire survey, study the importance of various risk factors of Zhijiang road EPC project on the project, and determine its key factors.

3.3 Questionnaire making

Refer to the questionnaire of relevant scholars to make the questionnaire of this survey. The questionnaire is mainly divided into two parts. The first part is the information collection of the respondents, including gender, education, EPC related work experience and work units (universities, design units, supervision units, construction units, suppliers and others). The second part is the main content of this survey. Likert 7 scale is used to score the importance of the impact of various risk factors on the EPC project, of which 7 is very important, 6 is important, 5 is relatively important, 4 is general, 3 is relatively unimportant, 2 is unimportant and 1 is very unimportant.

3.4 Questionnaire recovery

Because the online electronic questionnaire of this questionnaire survey is distributed to experts and professors in Colleges and universities. So the date has high authority. Offline questionnaires are distributed one-to-one at fixed points, so the questionnaire recovery rate is high. This time, 200 questionnaires were distributed offline and 100 questionnaires were distributed online. A total of 271 questionnaires were recovered, and the effective questionnaire rate was 90.3%.

3.5 Analysis of validity and reliability of the questionnaire

Spss26.0 software was used to analyze the validity and reliability of the questionnaire. See TABLE II for the Alpha values of primary indicators. The Alpha values of the five dimensions are 0.802, 0.805, 0.888, 0.838 and 0.847 respectively, which are greater than 0.8, and the CITC values are greater than 0.3. It shows that the reliability of the questionnaire is high. KMO and Bartlett test were performed on the data of the questionnaire. The KMO value is 0.894, greater than 0.8, indicating good structural validity. The Bartlett value is less than 0.05, indicating that it is suitable for factor analysis.

TABLE II. Reliability statistics of primary index

PRIMARY INDEX	ALPHA	ALPHA VALUE BASED ON STANDARDIZED TERM
CONTRACT RISK (A)	0.801	0.802
DESIGN RISK (B)	0.803	0.805
PROCUREMENT RISK (C)	0.887	0.888
CONSTRUCTION RISK (D)	0.837	0.838
EXTERNAL ENVIRONMENTAL RISK (F)	0.847	0.847

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IV. STRUCTURAL EQUATION MODEL ANALYSIS

4.1 Basic idea of structural equation model

Structural equation model is a statistical method to analyze the relationship between variables based on the covariance matrix of variables. The standard structural equation model consists of two parts. The first part is the confirmatory factor analysis model, which is used to connect the potential variables with the corresponding observation variables, and consider the measurement error. The second part is the regression structural equation, which regresses the linear terms of several endogenous and exogenous potential variables from endogenous potential variables.

(1) Measurement model

$$\begin{cases} x = \Lambda_x \xi + \delta \\ y = \Lambda_y \eta + \varepsilon \end{cases} \tag{1}$$

(2) Structural model

$$\eta = \mathrm{B}\eta + \Gamma\xi + \zeta \tag{2}$$

In the above formula , "x" represents the vector composed of exogenous variables; "y" represents the vector composed of endogenous explicit variables; "ξ" represents the vector composed of exogenous latent variables; "η" represents the vector composed of endogenous latent variables; "Λ_x、 Λ_y" represents factor load matrix; "B" represents the relationship between endogenous latent variables; "Γ" represents the influence of exogenous latent variables on endogenous latent variables; "ζ" represents the residual term of the structural equation, and a represents the unexplained part of the equation.

4.2 Research hypothesis

In the previous section, the risks of EPC project are preliminarily divided into five categories and 22 sub categories. And the five categories are contract risk, design risk, procurement risk, construction risk and external environmental risk. Take the above five factors as latent variables. A total of 22 risk factors in Table 1 are used as observation variables. The structural equation model is established for analysis.

4.3 Analysis of model results

The data in SPSS 26.0 software were imported into Amos software for confirmatory factor analysis. Then draw the structural equation model diagram. And the results of the standardized model are shown in Fig 1. By looking at the non standardized p value, it is concluded that each parameter of the model is significantly different. According to the output data of the standardized model, the ratio of chi square to degree of freedom is 1.890, between 1 ~ 3, which meets the standard. The values of GFI, AGFI and CFI were 0.915, 0.902 and 0.936 respectively, which were greater than 0.9, meeting the standard. RMESA

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value is 0.057, less than 0.08, meeting the standard. See Table III for standardized fitting results and statistical test indicators. Therefore, the matching degree of the model is good and the model is reasonable. According to the structural equation model, the standardized regression path coefficients are 0.91, 0.73, 0.56, 0.57 and 0.87 respectively. The greater the value, the greater the influence on the project risk. Therefore, the contract risk has the greatest impact, followed by the external environment risk, then the design risk, construction risk, and finally the procurement risk.

Table III. Suggestions on structural equation fitting standard model

FITTING INDEX	GFI	AGFI	CFI	RMESA	CMIN/DF
FITTING RESULTS	0.915	0..902	0.936	0.057	1.890
RECOMMENDED VALUE	>0.9	>0.9	>0.9	<0.08	<2

V. RISK ASSESSMENT OF EPC PROJECT

According to the determined structural equation model, the weight settlement is carried out by using the structural path coefficient and factor load. The weights of primary indicators are 0.250, 0.201, 0.154, 0.157 and 0.239 respectively. The order of importance is: contract risk > external environment risk > design risk > construction risk > procurement risk. The specific weight calculation results are shown in Table 4.

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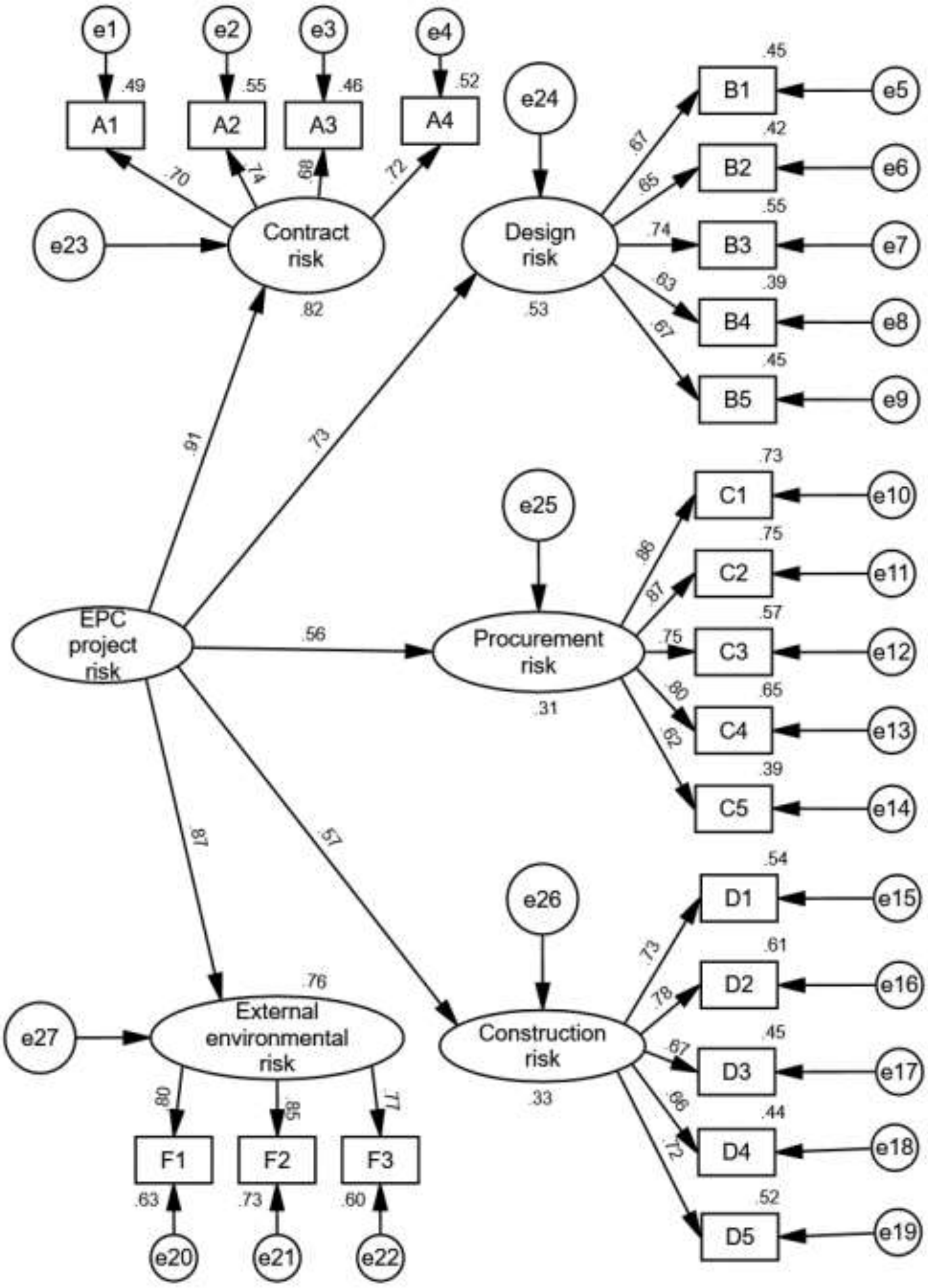

Fig 1: Risk structure model of EPC project

5.1 Contract risk assessment

Compared with other risk factors, the primary index weight of contract risk is the largest. In other words, contract risk is the main influencing factor of Zhijiang road EPC project. According to TABLE IV, the secondary index weight of the risk with unreasonable risk distribution is the largest in the contract risk,

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which is 0.261. Zhijiang road project adopts EPC general contracting mode, and the general contractor has more initiative. It can effectively control the progress and cost, but at the same time, the general contractor will bear greater risks. Therefore, when signing the contract, the risk allocation of each contractor in the consortium shall be clearly agreed in the contract terms. If the contract does not reasonably allocate the risks, it is easy to generate disputes, resulting in unbalanced distribution of interests and serious consequences. The risk of claim and dispute, the risk of ambiguous contract terms and the risk of contract change have similar secondary index weights. They are 0.239, 0.246 and 0.254 respectively. It shows that the impact of these three risks on contract risk can not be ignored. In engineering practice, risks should be allocated reasonably, especially the commitment or sharing of special risks or proprietary risks of specific projects should be agreed in combination with specific conditions. Establishing a perfect contract management mechanism and improving contract management are of great significance to prevent contract risks. The Contractor's rights and obligations under the contract need to be respected by the contractor. It provides advice to project managers and engineering teams. And it can make profitable modifications to the contract or change request[18].

5.2 Design risk assessment

The weight of secondary index of design delay is the largest, which is 0.220. It shows that design delay is the main factor affecting design risk. The secondary index weights of design defect risk and design depth risk are similar, which are 0.193 and 0.188 respectively. Both of these risks will lead to the delay of design progress. If the design period increases, it will increase the construction period of the whole project. The most serious consequence is that the owner claims for the construction period against the contractor or increases the additional cost for speeding up the construction. To prevent design risk, we need to establish a perfect design risk evaluation system. It is necessary to accurately identify the risk, evaluate the risk and give corresponding risk response measures to minimize the loss caused by the risk as much as possible. During the construction process, the design unit shall timely follow up the progress of the construction unit, pay close attention to the dynamics of all parties, and timely deal with the design problems reflected by the construction, supervision and other units. Only in this way can we effectively prevent risks and reduce the probability of risk occurrence.

TABLE IV. Risk evaluation index weight of EPC project

LATENT VARIABLE	PRIMARY INDEX WEIGHT	OBSERVATION VARIABLE	SECON-DARY INDEX WEIGHT
CONTRACT RISK (A)	0.250	RISK OF AMBIGUOUS CONTRACT TERMS (A1)	0.246
		RISK OF UNREASONABLE RISK ALLOCATION (A2)	0.261
		RISK OF CLAIMS AND DIAPUTES (A3)	0.239

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		RISK OF CONTRACT CHANGE (A4)	0.254
DESIGN RISK (B)	0.201	RISK OF DESIGN CHANGE (B1)	0.199
		RISK OF DESIGN DEFECTS (B2)	0.193
		RISK OF DESIGN DELAY (B3)	0.220
		RISK OF DESIGN DEPTH (B4)	0.188
		RISK OF INCREASED DESIGN COST (B5)	0.199
PROCURE-MENT RISK (C)	0.154	RISK OF MATERIAL AND EQUIPMENT PROCUREMENT QUALITY (C1)	0.221
		RISK OF MATERIAL AND EQUIPMENT PRICE (C2)	0.223
		RISK OF TRANSPORTATION (C3)	0.192
		RISK OF PROCUREMENT PERSONNEL'S MISTAKES (C4)	0.205
		RISK OF SUPPLIER CREDIT (C5)	0.159
CONSTRUC-TION RISK (D)	0.157	RISK OF CONSTRUCTION SAFETY (D1)	0.205
		RISK OF CONSTRUCTION PROGRESS (D2)	0.219
		RISK OF CONSTRUCTION QUALITY (D3)	0.188
		RISK OF CONSTRUCTION cost (D4)	0.185
		RISK OF CONSTRUCTION ORGANIZATION MANAGEMENT (D5)	0.202
EXTERNAL ENVIRON-MENTAL RISK (F)	0.239	RISK OF POLITICAL ENVIRONMENT (F1)	0.331
		RISK OF HUMAN ENVIRONMENT (F2)	0.351
		RISK OF ECONOMIC ENVIRONMENT (F3)	0.318

5.3 Procurement risk evaluation

The quality and price of material and equipment procurement are the main factors affecting the procurement risk. The weights of the two secondary indicators are similar, which are 0.221 and 0.223 respectively. The purchase price directly affects the cost of the whole project, and the purchase quality will also affect the quality of the whole project. Unqualified material quality will bring hidden dangers to construction. The risk weight of procurement personnel's work error is 0.205. The professional ability and sense of responsibility of procurement personnel are the key to the smooth progress of procurement. The material procurement department needs a strict supervision system. It is necessary to carefully review and accept all purchased materials and equipment, send special principals to sign for all materials and confirm the quantity and quality of materials. Only in this way can we comprehensively reduce the probability of

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risk and realize the standardized management of procurement process. The EPC contractor must strengthen the effective communication with each other in the procurement process of the project. Project procurement involves many aspects and fields. We must strengthen the control of details to ensure that the probability of procurement risk is reduced.

5.4 Construction risk assessment

EPC projects generally have the characteristics of large quantities and long construction period. In the construction stage, due to the complexity of the project, the risk factors will increase accordingly. From TABLE IV, the weight of secondary indicators of construction schedule risk is the largest, indicating that schedule risk has the greatest impact on construction risk. If the construction period is delayed due to uncertain factors, it will have serious consequences for the whole Zhijiang road EPC project, which will also have a serious impact on the income of the project. In order to prevent construction risks, the construction unit shall establish a strict and standardized construction organization and management system, introduce advanced construction technology, enhance the awareness of safe construction, and make the whole construction process compliant and reasonable.

5.5 External environmental risk assessment

Political environment, cultural environment, economic environment and other risk factors have similar weight to the secondary indicators of external environmental risk, and their impact on external environmental risk is equally important. Among them, the secondary index of human environment has the largest weight and the greatest impact. The outbreak of COVID-19 has a major impact on the construction industry. The pandemic may exacerbate the already severe safety and health conditions in the industry and have a negative impact on construction workers and employers[19].Adverse weather conditions, COVID-19 and other natural environmental factors will affect the normal construction of the project. The construction unit shall earnestly do a good job in epidemic prevention requirements and take countermeasures against adverse climatic conditions. Zhijiang road EPC project is mainly to upgrade the water transmission pipeline corridor and road from Zhipu road to Fuxing Road. The whole project is located in Hangzhou City, Zhejiang Province. It passes through cultural relics scenic spots such as white pagoda and Qiantang River Bridge. The impact of construction on the scenic spot should also be considered in the construction process.

VI. CONCLUSION

This paper determines the risk index system of EPC project through literature search The risk factors of Zhijiang road EPC project are divided into five categories, with a total of 22 sub categories. The five categories are contract risk, design risk, procurement risk, construction risk and external environment risk. After that, a questionnaire was issued to collect relevant data. The structural equation model is established to calculate the weight of each risk factor. It is concluded that the first-class index weight of EPC project risk is contract risk, external environment risk, design risk, construction risk and procurement risk from large to small.

The research shows that contract risk is the main influencing factor of Zhijiang road project. The Contractor shall establish a perfect contract management mechanism and make clear provisions on risk allocation in the contract terms. External environmental risk is a secondary influencing factor. The general contractor shall timely follow up national policies, do a good job in epidemic prevention requirements, and strengthen the formulation of response measures to adverse climate. The design unit shall follow up with the construction unit in time and pay close attention to the dynamics of all parties. Timely respond to the design problems raised by the construction unit and the supervision unit. During the construction process, the construction progress shall be strictly controlled to ensure the completion of the project with quality and quantity within the specified construction period. In the process of project procurement, the control of details should be strengthened, and all parties should supervise each other to reduce the probability of risk.

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