Development of a Risk Breakdown Structure in Mega Projects based on Different Case Studies

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ABSTRACT

Rapid urbanization, globalization, and population growth have led to an increase in megaprojects in recent decades. Consequently, as construction projects move forward, a wider range of risks arise. By looking into and managing risk factors in advance of their occurrence, it is vital to reduce their negative effects. In construction projects, risk management is seen as a critical procedure that helps meet project objectives in relation to schedule, budget, quality, safety, and sustainability concerns. This study aims to examine and gain a deeper understanding of project-related risks in mega projects. This study also develops a risk breakdown structure in mega projects based on a literature review. This will help project participants manage these risks in their projects properly. Another objective of this study is to examine the methodologies used in data collection for determining and categorizing risks in mega projects. Finally, it is concluded that the risk factors in mega projects can be divided into two categories: internal and external risks whereas the main risk factors in mega projects are categorized as execution, construction, technical, economic and financial, environmental, social, political, and other.

Keywords-risk management; mega projects; megaproject risk management

I. INTRODUCTION

Many nations view the mega-construction sector as their main source of income and as an engine of economic growth that generates jobs for a wide range of professionals and engineers. Large-scale engineering conveniences like water supply, communication, and transportation systems that provide a range of public services for people's livelihoods, social production, and economic development are regarded as mega construction projects [1]. Megaprojects are critical for social and economic growth, with infrastructure costs expected to exceed USD 94 trillion by 2040 [2]. Global megaproject spending is expected to be between USD 6 and 9 trillion per year, representing the greatest investment boom in human history [3]. However, because of their complexity, uncertainty, and reliance on multiple stakeholders, they face significant risks. The unpredictability of megaprojects can result in financial losses and project maintenance issues. However, mega projects require a strong risk management framework in order to overcome the many obstacles they may face. The PMBOK defined risk as an uncertain event or a condition that, if it occurs, has a positive or negative effect on one or more project objectives [4]. In the project management literature, risk management of building projects has been extensively studied [5]. Risk is a natural part of any construction project and can lead to significant time and cost overruns that are damaging to the project's goals. The negative impact of risks in the construction project could result in losses not only for the project owners, contractors, or society but also for the professionals involved in the project. It has never been easy to recognize inherent risks and take prompt action to avoid it, particularly in the case of megaprojects.

Construction megaprojects face political risks, which extend project completion time and impose significant financial risks because they are heavily dependent on local conditions, social acceptance, and government affirmation. Much research has been carried out to classify the sources of risk, however, none of the studies address every kind of risk [6].

The purpose of this study is to examine and gain a deeper understanding of project-related risks in mega projects as well this study also identifies the risk factors and their categories in mega projects based on a literature review.

II. METHODOLOGY

The fundamental components of a systematic review are similarities and differences [7-8]. This study reviewed different papers to determine risk factors and their categories in mega projects. The methodological procedures of [9, 10] were used and accordingly, the following steps were taken: The formulation of the research question, the study location, study selection, study evaluation, synthesis and analysis, and reporting and utilizing research findings.

Defining the study's location, involved determining the search terms and databases to consult. Risk management, mega project, and mega project risk management were the three keywords considered. These keywords were searched in various combinations. The following databases were consulted: Scopus, Taylor & Francis, Wiley, Springer, Science Direct, and Emerald Insight. The considered papers title, journal name, and published time are shown in Table I. The selected papers analyzed risk management in different aspects of mega projects and the types of the study were systematic review, case study, and data analysis. Risk management is crucial in megaprojects, as it helps mitigate environmental and social risks, and improve project success. Risk management tools and techniques in mega projects were the main objective of the reviewed papers, however, the risk factors and their categories were ranked based on the data collection and recorded data in case studies.

Each study had a specific methodology for conducting data collection to answer the objectives and research questions. Based on a critical review of each paper it can be concluded that the most useful data collection methods for determining risk probability and impact are questionnaire methods. The main steps of methodology can be summarized as follows:

The first step involved conducting a literature review to determine the risks associated with mega projects. This included books, journals, and articles that address risks generally and risks specific to mega projects. The second step is to design the questionnaire and distribute it. The questionnaire can be designed based on the risk categorization and factors obtained from the first step. Most papers used the Likert scale as a method for determining the risk impact and probability and the data was collected from case studies and interviews with experts. The final step is data analysis and tabulation of the results, whereas the discussion covers various statistical analysis methods, including the SHAMPU approach, system dynamics modeling, probability and impact assessment, bibliometric analysis, data analysis, matrix analysis, descriptive analysis, fuzzy set theory, and decision-making risk factor analysis. The methods and approaches of analysis for each reviewed paper are shown in Table I.

TABLE I. CONSIDERED STUDIES, AND THEIR METHODS AND APPROACHES

Ref.	Methods	Analysis approach
[13]	Case study	SHAMPU approach
[14]	Case studies and interviews with megaproject experts.	System dynamics modeling
[16]	Case studies and review	Discussion
[17]	Systematic literature review	Qualitative analysis
[20]	Case study	Discussion
[19]	Door-to-door survey and an electronic survey	Probability and impact assessment
[18]	Systematic literature review	Bibliometric analysis
[21]	Case studies and interviews	Qualitative analysis
[3]	Case studies and review	Data analysis and discussion
[15]	Literature review	Matrix analysis
[23]	Qualitative and quantitative	Descriptive analysis
[25]	Expert interviews and questionnaires	Fuzzy set theory
[24]	Case study	Probability-impact matrix
[1]	Questionnaire	SPSS, statistics analysis
[2]	Case studies and review	Decision-making risk factor analysis and model development

III. RESULTS AND DISCUSSION

Globally, megaprojects have low efficiency due to missed deadlines and completion variances of more than 20% and even 85% in some cases. This is primarily due to increased risk levels caused by the lack of new forms of interaction between investors and implementers [11, 12]. The analysis of construction complexity showed that the fundamental components of complexity are the lengthy schedule, advanced technology, effective communication, and coordination amongst the various mega-project stakeholders. The majority of writers concurred that in order to recognize and control the rise in risks, more creative management approaches should be implemented [3]. Authors in [13] discussed the risk of optimistic overestimation in megaprojects during the planning phase, highlighting the common error of using biases to delineate favorable scenarios. Implementing a risk management methodology was recommended. This study adopted the SHAMPU methodology to deal with the risk of demand through a nine step procedure. Authors in [14] created the system dynamics risk assessment model in order to facilitate the more than 30 risk assessment methods included in the British Standards for Risk Management. The developed model described Social, Technological, Economic, Environmental, and Political (STEEP) risks and how they interact with the development of megaprojects. When these STEEP risks come together, they have an impact on and create unprecedented levels of complexity in risk environments. This study also indicated that the primary cause of cost and schedule overruns during the project's developmental stage is the inefficiency of conventional risk assessment methods in evaluating risks promptly and reliable data from the project's early phases.

In addition to qualitative analysis, an accurate quantitative analysis based on knowledge and experience is also required for megaproject. To enhance contractors' methods for quantitative risk assessments in the presence of uncertainty, authors in [15] analyzed the quantitative analysis literature for the construction of global megaprojects and considered quantitative methods such as earned value analysis, sensitivity analysis, and Monte Carlo analysis. The Monte Carlo analysis technique appeared to be the most effective and popular quantitative method for identifying deviations from schedules and budgets. Authors in [16] explored the fundamental components of multinational megaprojects, and the reasons behind inadequate outcomes, and offered managerial suggestions and a framework for risk management to raise the effectiveness and productivity of international joint projects. They proposed a comprehensive risk management methodology for large-scale projects. The suggested framework is a multidirectional, iterative process with numerous interactions between components rather than a step-by-step procedure. As such, the best way to describe this framework is as a cyclical process. This process begins before the project's initial stages and ends only when the project is finished. This study concluded that the developed risk management system can manage and control the risk in mega projects through the five steps as follows: define risks, risk evaluation and quantification, develop risk response strategies implement and monitor and update.

The first step in risk management is risk identification. Authors in [17-19] focused on this step in megaprojects and determined different risk types in different sectors. The proposed classification of risks is shown in Figure 1. Categorization includes every kind of risk that has been researched in the past. Other classifications are restricted because some risks are not included. The process of systematizing risks aids managers in identifying them within the megaproject and then initiating the next phases of the risk management process, which include risk response planning, qualitative and quantitative risk analysis, monitoring, and control. Cost and schedule overruns are the most frequently mentioned risks in project and megaproject management, according to [17]. Authors in [15] demonstrated that the most commonly recognized risks in project and megaproject management are those related to construction, which have the potential to result in significant cost and schedule overruns.

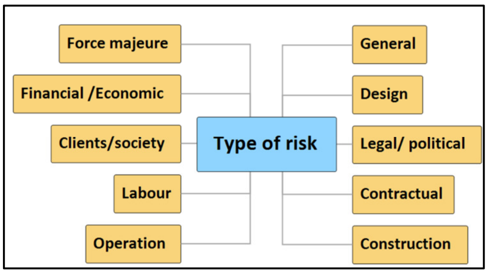

Fig. 1. Main types of risks in mega projects

The Gomal Zam Dam Multi-Purpose project comprises a hydropower generating station and Pakistan's tallest roller-compacted concrete gravity dam. Started in 2007, the project was officially inaugurated in 2013. Throughout the construction process, the contractor's construction management level encountered numerous risks and challenges that were not previously known. Schedule, cost, and finance control were just a few of the ways that these risks affected the construction process. Authors in [20] gave background information on the project, project details, and challenges encountered. Gomal Zam Dam faced numerous risks and challenges as a result of contract limitations, the natural environment, erratic security concerns, and employer payment delays. As a result, the project's actual cost exceeded the original budget by more than 16%, and the project's contract fulfillment was extremely challenging. In Gomal Zam Dam different risks were recorded and affected the project status, the risks encountered include harsh natural and inclement weather conditions and spacing, risks associated with currency variations, inflation, political uncertainty and military situations, contract disputes, and financial issues.

Authors in [1, 21] investigated the uncertainty and risk management in oil and gas mega projects. Studies regarding the iron triangle (time, cost, and scope) have shown that high levels of uncertainty are frequently the cause of low performance in megaproject management. Authors in [21] examined ways to maximize the added value in megaprojects by defining best practices and implementing proven methods to understand megaproject success from a value management perspective. This will help to narrow down the prevailing iron triangle perspective, which refers to project management success rather than project success. Authors in [1] considered three types of risks which include internal risks, external risks, and major risks to find the statistical correlation with the performance of mega projects. The risk factors considered in [1] for the evaluation of the performance of oil and gas Mega projects are shown in Figure 2.

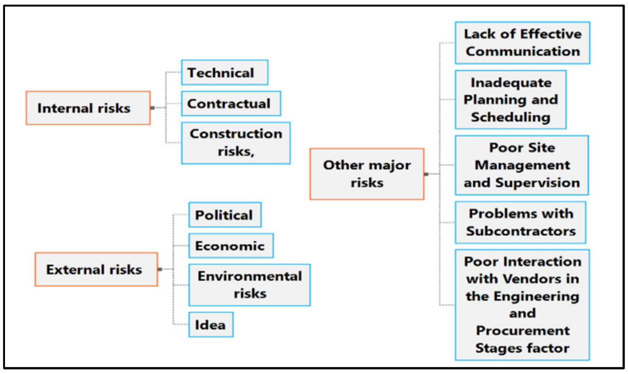

Fig. 2. Risk types in the mega project based on internal and external risks.

Throughout the whole project life cycle, a construction project faces a variety of risks [22]. The two most crucial aspects of managing a construction project are identifying and managing risks. Enhancing risk management may help anticipate future events, even though recognizing possible risk factors affects the process both directly and indirectly [23]. Different risk factors have been determined through a wide view of the study conducted on risk management in mega projects. Scholars have conducted multiple studies to identify and categorize megaproject risk factors, acknowledging the difficulty of accurately quantifying these factors. The risk framework system for China's mega infrastructure projects was analyzed and summarized in [2]. The multiple risk indicators before developing a complete framework with 22 elements to evaluate the risk framework system for China's mega infrastructure projects is shown in Figure 3.

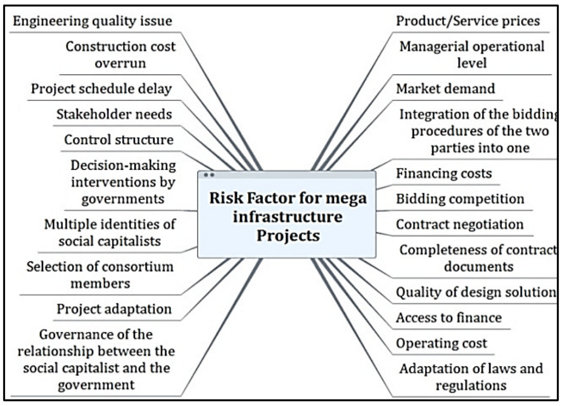

Fig. 3. Risk systems for mega infrastructure projects.

To determine the risk factors associated with megaprojects, a review of recently released articles that compares and specifically presents risk factors was conducted. Choosing risk factors for building projects where complexity and expansion are progressively expected required a review of literature concentrating on mixed-use development projects. A total of 92 risk factors were identified under 8 categories in mega projects as shown in Table II. The main risk categories of mega projects are execution, construction, technical, economic and financial, environmental, social, political, and other major risks. Challenges that megaprojects face increase the risks to sustainability goals significantly [24]. Additionally, as public awareness of sustainable development has grown, the impact of megaprojects on sustainability has drawn attention from academics, posing a variety of new risks that need to be taken into account. Thus, the characteristics found in sustainable development principles need to be incorporated into megaproject risk identification to improve it [25]. This study's other aspect will be determining the risk factors of mega projects from an extended sustainable perspective. As a result, this study determined 9 risk categories. Risk factors of mega projects from an extended sustainable perspective are categorized into 9 types of risks which include: economy and financial, environment, society cultural, coordination, technology, physical, client, technical, and contractual. Each category has different types of risk factors as shown in Figure 4.

TABLE II. RISK BREAK-DOWN STRUCTURE IN MEGA PROJECTS

	Risk Factors in Mega Projects
1.1	**Execution Risk Factors**
1.1.1	Utility diversion
1.1.2	Inappropriate equipment and material quality
1.1.3	Schedule delays
1.1.4	Schedule delay caused by changed orders
1.1.5	Permits and licenses
1.1.6	Poor equipment performance
1.1.7	Machinery failure/breakdown
1.1.8	Unforeseen site conditions
1.1.9	Incorrect take-off calculation
1.1.10	Delayed supply of material and equipment
1.1.11	Delay in obtaining working drawings/reports/designs
1.1.12	Low-skilled/incompetent workforce
1.1.13	Unavailability of materials, equipment, and labor
1.1.14	Delay of commissioning
1.1.15	Delay in obtaining temporary traffic regulation orders
1.2	**Construction Risk Factors**
1.2.1	Delay of construction start and dinish dates
1.2.2	Additional construction
1.2.3	Poor site coordination/work organization
1.2.4	Construction failure
1.2.5	Land acquisition for ROW
1.2.6	Inadequate preliminary survey and site information
1.2.7	Unrecognized soil structure/unforeseen ground condition
1.2.8	Delay in the transport of Ready-Mix Concrete (RMC)
1.2.9	Construction and implementation errors from faulty design
1.2.10	Changes in material during construction
1.2.11	Deviations between specification and implementation
1.2.12	Supply chain breakdown/improper equipment and material quality
1.2.13	Site inaccessibility
1.2.14	Lack of site security for personnel and assets
1.3	**Technical Risk Factors**
1.3.1	Contractor selection problem
1.3.2	Faults in plans for facility and scale
1.3.3	Design error and omission problem
1.3.4	Incompetency of designers
1.3.5	Design changes
1.3.6	Inadequate design and design errors
1.3.7	Modification to drawing/design
1.3.8	Unforeseen multiple modifications to the project scope
1.3.9	Delay in obtaining preliminary drawings/reports
1.3.10	Revision in design standard
1.3.11	Inadequate project complexity analysis
1.3.12	Error of project cost and project schedule estimation
1.4	**Economic and Financial Risk Factors**
1.4.1	Change of cash flow
1.4.2	Errors of the preliminary feasibility study
1.4.3	Probability of financial risk occurrence
1.4.4	Inappropriate budget and financing plan
1.4.5	Errors of the feasibility study
1.4.6	Increase in financial and construction
1.4.7	Inflation
1.4.8	Foreign exchange rate and interest rate fluctuation
1.4.9	Changes in market conditions
1.4.10	Changes in taxes
1.4.11	Incorrect cost estimate
1.4.12	Financial difficulties/failure of subcontractor
1.4.13	Cost overrun
1.5	**Environmental Risk Factors**
1.5.1	Natural disasters
1.5.2	Adverse weather conditions
1.5.3	Pollution and vibration
1.5.4	Geology, soil, and topography
1.5.5	Drainage pattern
1.5.6	Inadequate environmental analysis
1.5.7	Land cover (grass, asphalt, trees, water bodies)
1.5.8	Presence of quarries and mines
1.6	**Social Risk Factors**
1.6.1	Demands of locals
1.6.2	Public objections
1.6.3	Social issues (tree cutting, shrine removal)
1.6.4	Cultural and heritage sights
1.6.5	New stakeholders with changed requests
1.6.6	Damage to property and persons
1.6.7	Multilevel decision-making bodies
1.7	**Political Risk Factors**
1.7.1	Conflicts between Government agencies and local governments
1.7.2	Inconsistency and changes in law, institution, and policy
1.7.3	Changing government regulations/funding policy
1.7.4	Lack of moderators
1.7.5	Legal disputes
1.7.6	Political instability
1.7.7	Changes in local laws and standards (tax imposition)

1.7.8	Lack of political support
1.7.9	Political indecision
1.7.10	Change in government
1.7.11	Multilevel decision-making by government bodies for consent and approvals
1.7.12	Government intervention
1.8	**Other Major Risks**
1.8.1	Risks in lotting-out, rent, and selling
1.8.2	Civil appeals
1.8.3	Error of business process
1.8.4	Conflict of consortium (contractor)
1.8.5	Occurrence of claim by stakeholders
1.8.6	Occurrence of some items not reflected on the project plan
1.8.7	Delay of contract implementation
1.8.8	Various authorization and permission procedure delays
1.8.9	Conflicts among association members and lack of resident opinion collection
1.8.10	Risk according to investor change
1.8.11	Lack of risk Management expert

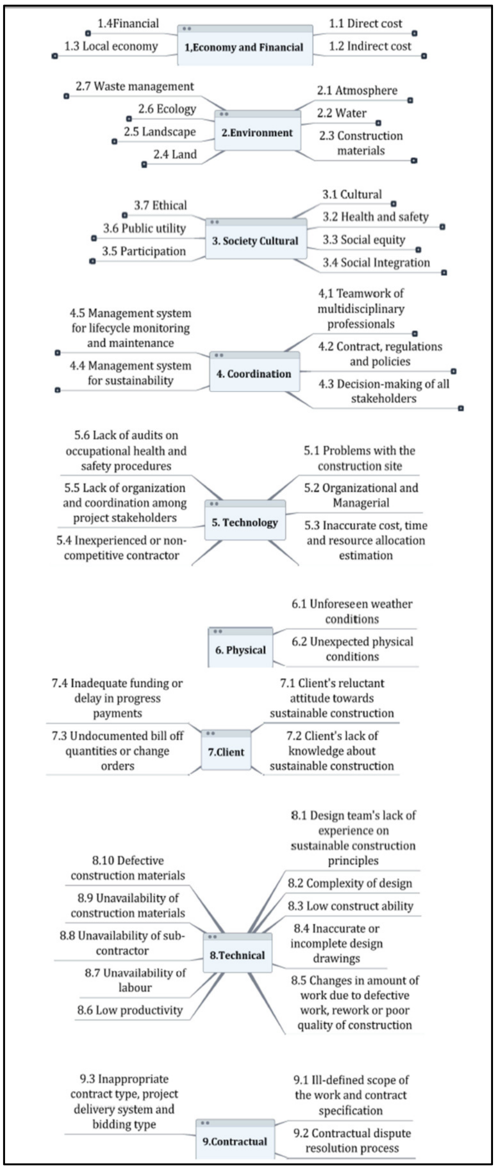

Fig. 4. Risk category of mega projects from an extended sustainable perspective.

IV. CONCLUSIONS

The management of risk is crucial for all projects, especially sustainable projects, due to their unique challenges and uncertainties. Many mega-projects have failed to finish on time and within budget due to the various risks they face. This study aimed to develop a risk breakdown structure based on a review to help project participants properly manage and control mega-project risk. From another perspective, this study showed the methods that can be used to define risks and their analysis, which can help those who plan to study risk management in mega-projects. Generally, the risk factors in mega-projects can be determined based on considering or non-considering the sustainability perspective. In this study, 92 risk factors in mega-projects from a non-sustainability perspective were identified, covering areas such as execution, construction, technical, economic and financial, environmental, social, political, and other major risks. Additionally, it identified risk factors related to sustainability in mega-projects, which were divided into nine types, including economy and finance, environment, society and culture, coordination, technology, physical, client, technical, and contractual risks.

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