RISK MANAGEMENT IN THE DESIGN PHASE OF LARGE-SCALE CONSTRUCTION PROJECTS

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Abstract— The presented study considers the major potential risk events in the design phase of large construction projects in the developing countries. Based on the available literature and the experience of the authors and other practitioners, a list of the potential risks was developed. The risk events were categorized initially into technical, managerial, and external categories. The risks were evaluated by experienced practitioners in the field of construction projects. The evaluation included the expected probability of the event and its cost, time, and quality impact on the project. The study considered the distribution of the responsibility of each risk among the owner, engineer, contractor, and others. The collected data were analyzed qualitatively and quantitatively to assess the severity and effect of these events. The recommended responses for the major risks were introduced in the study.

Index Terms— Design, large projects, quantitative, qualitative, risk.

1. INTRODUCTION

INFRASTRUCTURE construction projects are typically large, uncertain, and complex in many aspects. Therefore, they are subject to more risks related to economical, social, political, and environmental conditions than other types of construction projects. Should these risks materialize, they may have an impact on the cost, schedule, and/or quality of the projects [1]-[3]. In order to prevent unexpected risks and thus disputes during construction, design process should pay close attention to project characteristics and contract practices [4]-[8]. In the developing countries, the international competitive design procedures will be the standard practice; then, government agencies will be subject to much stronger pressure from the international construction industry to prepare fair construction standards. This situation imposes bad need for the implementation of risk management approach in large-scale projects with major concentration on the initial phase including contract preparation and design aspects [9]-[14].

The current study handled the major common risks in the design phase of the large construction projects. Based on the collected data, the identified risks were evaluated to assess the severity of each event [15], [16]. The assessment included qualitative analysis based on the expected probability of each event and the corresponding impact. The impact of each event was divided into three major factors; cost, time, and quality. The qualitative analysis was followed by a quantitative analysis to define accurately the level of severity for the prime risks [17].

2. METHODOLOGY

The target of the study was to define and assess the major potential risks that affect the design phase of large-scale projects in Egypt. Initially, the information was collected from the previous research in the field of risk management of large-scale projects. The obtained information included common potential risks with little focus on the design phase. Most of the carried researches concentrated on the construction phase. The data obtained was discussed with senior engineers with experience more than 20 years in large construction projects (of more than 250 millions Egyptian Pounds that is about US$ 50 millions). The projects included infrastructure projects such as electrical plants, sanitary stations, and major road facilities. Other types of projects were also included in the study like universities, recreation areas, and residential complexes. Hence, the authors established the main list for the considered events in the form of a questionnaire. The list included 17 items correlated to the management processes in the design phase. The number of the participants in the questionnaire was chosen as fifty experts. The data obtained from the questionnaire was analyzed to find the priority of the potential risks and to determine the severity of these events. The possible responses for these risks were, also, considered.

3. POTENTIAL RISKS

The potential risks were identified by the authors based on the available published researches and the interviews carried out with experts. The final list was filtered by the authors and was concluded as shown in Table (1) regardless any ranking. The risks were categorized in three major groups; technical, managerial, and external risks. Most of the technical and managerial risks have links to the other category. Hence, the categorization was carried out based on the higher tendency of the risk event to either category. External risks included all events that most probably caused by reasons out of the project manager's control.

3.1. Technical risk events

The technical risk events are explained in the following section. Design errors and changes in the design due to performance enhancement, other discipline's requirement, or better constructability are common in the complex construction projects.

Delay of design and/or obtaining permits for the project is a risk that encounters many risk events. This risk includes delay

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that may occur due to delay in any discipline in the project. It also includes the delays in formal processes whether within the participating agencies (owner, engineer, contractor) or outside these agencies. This risk is placed in the technical category assuming that the frequency of the expected technical risk events are higher than the frequency of the managerial and external risk events in this respect.

Table (1) Potential risk in large-scale projects

Symbol	Potential Risk Event
	Technical risk events
R/DSN/01	Design errors and changes
R/DSN/02	Delay of Design and permits
R/DSN/03	Innovative and new technology design
R/DSN/04	Complicated design and not sufficient details
	***Managerial* risk events**
R/MNG/01	Lack of communication planning
R/MNG/02	Lack of coordination among different disciplines
R/MNG/03	Poor organizational structure and definition of roles and responsibilities
R/MNG/04	Impact of Value Engineering (VE) Process
R/MNG/05	No Consultant for specific discipline
R/MNG/06	No quality control system
R/MNG/07	Roles and responsibilities map is not clear
	External risk events
R/EXT/01	Changing the engineer
R/EXT/02	Owner's frequent change orders
R/EXT/03	No Project Management Office
R/EXT/04	Overseas Engineer's Headquarter
R/EXT/05	Overseas Contractor's Headquarter
R/EXT/06	Suitability of available skills with the project

Innovative and/or new technology design is one of the events that usually have relatively high impact and high probability due to encountered high uncertainty in the design and in the constructability of the project.

Complicated design and insufficient details is concerned with the insufficiency of the required details. This risk has higher probability and higher impact as the project becomes more complicated and more innovative. This risk includes the low engineering capability with respect to the required innovative engineering level.

3.2. Managerial risk events

Managerial risk events are presented in the following section. Lack of communication planning among the key persons of the project is a common problem in the developing countries. Usually, there is no detailed plan for the project communication. Most of the projects accounts for periodical meetings in addition to as needed meetings that take place after the trigger of the risk [18].

Lack of coordination among different disciplines within the design process depends on the capacity of the project manager or the project management office.

Poor organizational structure and definition of roles and responsibilities within the whole project could result with any stakeholder in the project. A common source of this problem is the incompatibility between the organization breakdown structure (OBS) of the client and the OBS of the engineer's firm. This event could be of higher risk if the project manager has low level of authority or low level of capability.

Impact of value engineering process depends on the accepted recommendations of the value engineering process. The more the accepted changes the higher the severity of the resulting risks. This event may encounter technical as well as managerial risk events based on the nature of the required changes [19]. This risk is placed in the managerial category since the value engineering process as a whole could be considered as a managerial process.

Lacking a consultant for specific discipline can be of considerable risk. This risk takes place if the project manager or the main engineer lessens the importance of a specific discipline that has a little stake in the project.

Lacking quality control system in the design phase may cause many troubles to the project. Technical and managerial quality control is necessary in the design phase as well as it is in the construction phase. Quality control includes having a consistent system among all disciplines participating in the project such as in using consistent specifications and integrated documentation system for archiving and retrieving the documents.

If the roles and responsibilities' map is not clear in any participating firm it will be a source of trouble for the project. This risk usually caused by mismatching between the organization breakdown structure (OBS) and the work breakdown structure (WBS). It, also, could arise from unclear definition for the job description with one the main stakeholders in the project.

3.3. External risk events

External risk events are enlightened in following section. Changing the engineer is a prime risk in the design phase of any project. Most of the cases for changing the engineer are referred to the failure to satisfy the requirements of the client. Either this could be because of severe delay in fulfilling the required time schedule or the technical capacity of the engineer is less than the target level.

Owner's change orders in the design phase constitute major obstacles to the success of the required tasks. If the scope of the client is not well defined, the changes are expected to be frequent and the impact on the productivity of the engineer is likely to be much lower than the predicted productivity.

Lacking project management office leads to reduction in the coordination among the stakeholders of the project. In complex projects with multiple disciplines and many links to contractors and suppliers, the need for perfect communication control is an essence. This risk is likely to appear when the client prefers to reduce the cost of the project management in the design phase by omitting the project management office relying on the engineer only.

Having an overseas engineer's headquarter is another logistical risk that is common to arise in the mega projects in the developing countries. This is usually due to employing design firms with headquarters in the United State, Europe, or the Far East countries. Despite the new developed communication technology, the need to physical interviews is required in many situations.

Overseas contractor's headquarter is similar to the previous point but with less severity in the design phase and higher severity in the construction phase.

Suitability of available skills with the project is usually leads to severe delay in the project or changing the engineer. The inappropriateness of the required skills could be referred to the need to employ local human resources with certain ratio as required by the local authority or because of disgrace in appointing the engineer’s firm that is not technically qualified to have the project.

4. PROBABILITY OF RISK EVENTS

The probability of each risk event was evaluated by the participants on a five-point scale. Choosing the value of one means that this event has the lowest probability and choosing five means that this event has the highest probability. Fig. (1) shows the results of the evaluation as calculated from the following equation;

$$E_{p_i} = 0.05*n_{pi_1}*1 + 0.10*n_{pi_2}*2 + 0.2*n_{pi_3}*3 + 0.4*n_{pi_4}*4 + 0.8*n_{pi_5}*5 \quad (1)$$

where; E_{pi} is the expected weighted probability of the risk (i). The value of n_{pi1} is provided by the number of the participants who chose (1), lowest probability, for the expected probability of the considered risk event. The values of n_{pi2} to n_{pi5} are calculated in the same manner for the other expected probability levels. Equation (1) considers higher impact for the number of the participants who assign higher probability. The nonlinear relationship of the weighting system was chosen to magnify the effect of the risk events that attract the attention of more construction practitioners.

The values of the weighted probability of each risk event as obtained by using Equation (1) show that lacking project management office (PMO) is the most probable risk event among all considered events. This proves that the awareness of PMO in construction projects in Egypt is way below the needed level. The following risk is lacking quality system in the design phase of the project. Lack of coordination among different disciplines comes third in expected frequency. The similarity among the three events is that all events are referred to the lack of project management awareness. The following risk is the changes from the client that comes in the fourth place based on probability. The first technical risk in this ranking is the errors and changes from the different engineering disciplines. Note that the highest weighted probability is slightly less than 20 and the lowest weighted average which is for the changing the engineer risk is about 11. The narrow range of choice can be referred to the importance of the risk events enclosed in the explored short list of events.

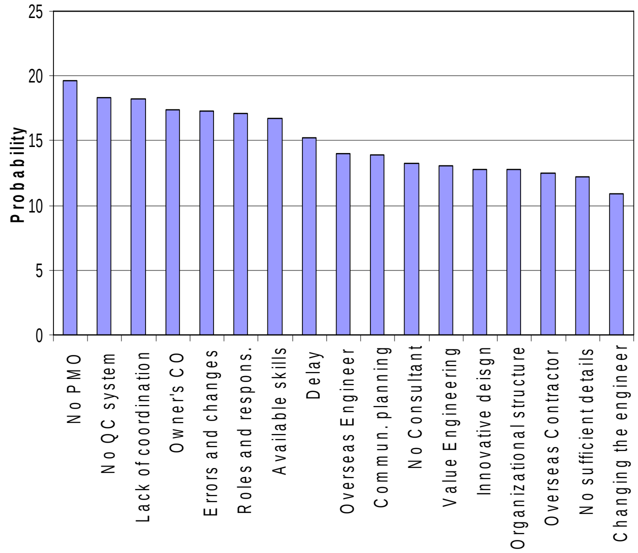

Fig. 1 - Probability of potential risks (Equation 1)

5. IMPACT OF RISK EVENTS

5.1. Cost impact of risk events

The data collected from the participants was weighted using Equation (2) in the same way as for the calculation of the weighted probability. The expected weighted impact of the risk (i) on the cost is calculated as;

$$E_{c_i} = 0.05*n_{ci1}*1 + 0.10*n_{ci2}*2 + 0.2*n_{ci3}*3 + 0.4*n_{ci4}*4 + 0.8*n_{ci5}*5 \quad (2)$$

The weighted expected cost impact is shown in Fig. (2). Four risk events are having noticeably higher values than the others are. Lack of coordination among different engineering disciplines has the highest weighted impact on the cost of the projects. This problem points to the common losses in the Egyptian construction due to coordination problems. The problems arising from innovative designs and adopting new technology in the design come in the second category. This risk takes place when specific engineering trend applies a new technology while other trends do not have the required experience to deal with the new requirements. For example, the need for specific openings or heights to acquire specific machinery system or communication ducts. In third place, comes the clients’ change that is a traditional risk in all types of projects. The lack of the required skills and capability has a great effect on the cost of the project as a whole and on the cost of the design phase as well. Insufficient skills and knowledge leads to excessive repetitions and uneconomic engineering design.

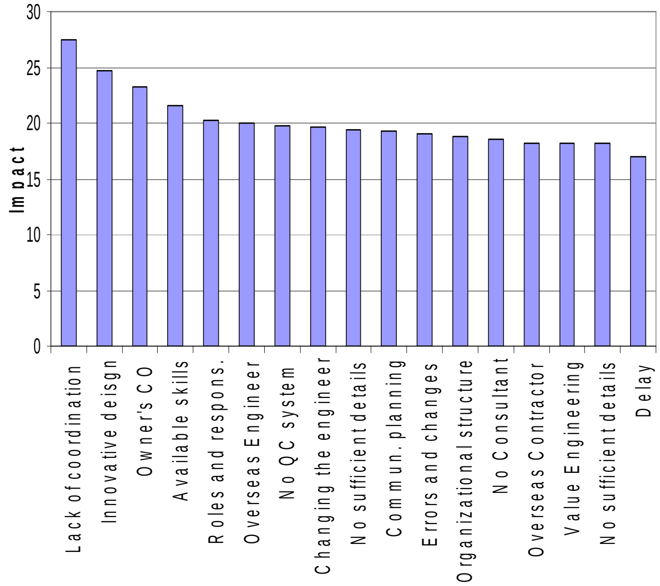

Fig. 2 – Impact of potential risks on projects' cost (Equation 2)

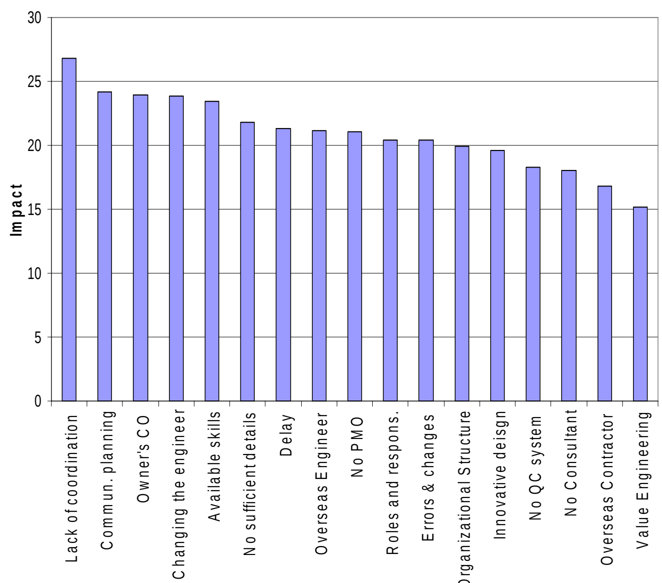

Fig. 3 – Impact of potential risks on projects' time (Equation 3)

5.2. Time impact of risk

The expected weighted value for the impact of the risk events on the time schedule was quantified using Equation (3). The equation has the same weighting system as before. The expected weighted impact on time (E_{ti}) of each risk (i) is calculated as follows;

$$E_{t_i} = 0.05*n_{ti1}*1 + 0.10*n_{ti2}*2 + 0.2*n_{ti3}*3 + 0.4*n_{ti4}*4 + 0.8*n_{ti5}*5 \quad (3)$$

The impact of the risk events on the schedule of the design phase of the project is illustrated in Fig. (3). The figure shows the weighted value of the time impact for each risk event. It could be noticed that the variability of the time impact of the different events is greater than the variability of the same events with respect to cost impact. Lacking of coordination among the different engineering disciplines has remarkably the highest weighted time impact, the same as for cost impact. Four risks with little interval are following the coordination problem. Weakness of the communication plan for the design phase could affect the duration of this phase dramatically. The client's change orders are common sources of trouble for the design phase. Changing the engineer in the design phase is a prime factor in causing the project behind schedule. The low capacity of the engineering team reduces the overall productivity in the design process especially in complex or innovative projects.

5.3. Quality Impact of risk events

The impact of risk events on the quality of the project's design was quantified in the same manner as for the above-mentioned parameters. Equation (4) shows the calculation of the expected weighted impact of the risk (i) on the quality;

$$E_{q_i} = 0.05*n_{qi_1}*1 + 0.10*n_{qi_2}*2 + 0.2*n_{qi_3}*3 + 0.4*n_{qi_4}*4 + 0.8*n_{qi_5}*5 \quad (4)$$

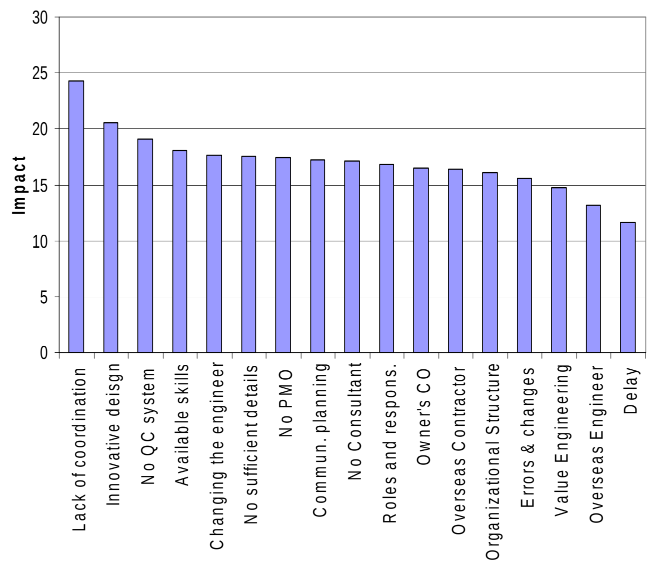

Fig. 4 – Impact of risks on projects' quality (Equation 4)

Again, lacking the communication among the different engineering disciplines has the highest weighted impact with respect to the quality of the design. Innovative design and employing new technology in the project comes as the second risk with respect to quality. Importing new technology or methodology makes a lot of trouble in the developing countries because of the insufficient knowledge and skills that are required to adopt the new aspect. The third risk with respect to quality is the lack of quality system for the design process. When there is no clear set of specification for the designed elements and the design process, the expected quality of the project's design would be less than that it should be.

6. SEVERITY OF RISK

Severity of risk was obtained in the study considering the probability of the risk event combined with its effect on the cost, time, and quality of the project. The following equation was utilized to calculate the quantified severity of the risks under investigation;

$$S_i = E_{pi} * (E_{ci} + E_{ti} + E_{qi}) \quad (5)$$

where; S_i is the severity index for the risk (i), E_{pi} is the expected weighted probability of the risk (i) (Equation 1), and E_{ci}, E_{ti}, and E_{qi} are the expected weighted impacts of the risk (i) on the cost, time, and quality; respectively (Equations 2-4).

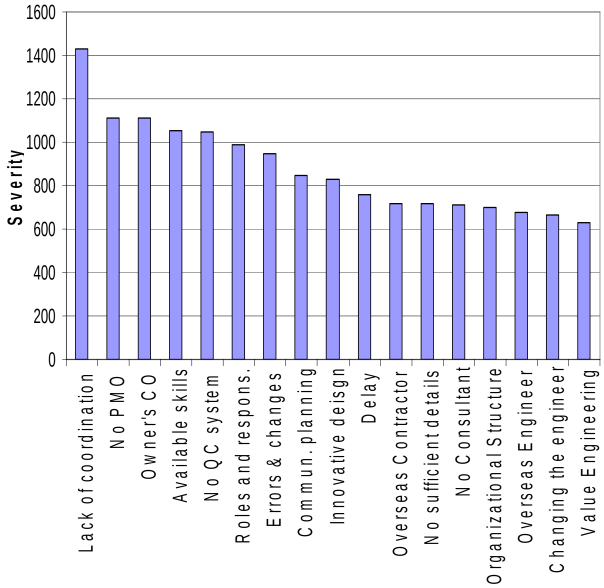

Fig. 5 – Severity of risk (Equation 5)

It is easily noticed from Fig. (5) that lack of coordination has the highest risk severity with expected weighted severity of 1430 that is considerably higher than the weighted severity of any other risk. Next is the lack of project management office, which is strongly correlated to the lack of communication among different engineering trends in the project. The changes from the owner during the design phase have a weighted severity that is very close to that of the owner's changes. In the following category come two risks with very close weighted severity. These two risks are insufficient engineering and managerial skills and knowledge and lacking comprehensive quality system.

7. RESPONSIBILITY OF RISK

The study included investigation of the responsibility of the risk source. Five parties are considered for responsibility of each risk event. These are namely; engineer, owner, shared between engineer and owner, contractor, and not well defines responsibility. The data collected from the participant practitioners is demonstrated in percentages in Fig. (6). The results of the collected data could be summarized in that there is a set of risks with the engineer is the prime responsible for and another set where the owner is the prime responsible, as noticed from the figure.

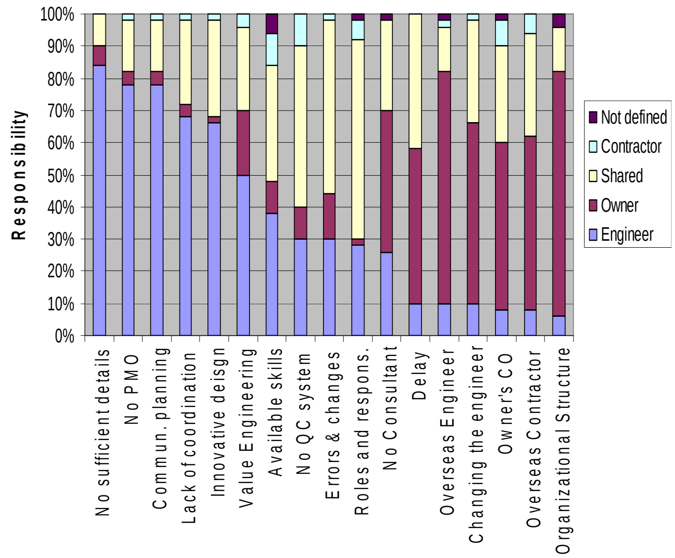

Fig. 6 – Responsibility of risks

8. RISK RESPONSES

The study investigated the possible responses for the mentioned risk events. The participating practitioners proposed different responses for each risk. The collected responses are summarized in the Table (2).

9. SUMMARY AND CONCLUSIONS

- The study investigated the prime potential risks that affect the design phase of mega construction project in Egypt and similar developing countries.
- The study considered the cost, time, and quality of the projects as well as the responsibility of the risk.
- The risk events were sorted according to the probability as expected by the response of the participants.
- The risks were ranked also according to its impact on cost, time, and quality.
- The severity of the risks was quantified considering the probability of the risk and its impact on the project.
- The following risks had the highest severity with respect to the design phase:
  - Lack of coordination among different disciplines
  - Lack of Project Management Office
  - Owner's frequent change orders
  - Inappropriateness of available skills with the project
  - Lack of quality control system
- The study investigated the responses for each risk event and the concluded responses were stated.

Table (2) Risk responses

Potential Risk Event	Risk Response
Technical risk events	
Design errors and changes	▪ Enforce a change control system for all changes in the design process
Delay of design and permits	▪ Have well-organized responsibility matrix for the owner and engineer. ▪ Each design item or permit should be tracked through the responsible person.
Innovative and new technology design	▪ Conduct detailed study for the methodology and its application. ▪ Employ personnel with high knowledge and skills to the required level. ▪ Prepare all the needed level to ensure clearance for all parties.
Complicated design and not sufficient details	▪ Make the required details with comprehensive communication with all disciplines. ▪ Make mock-ups or models if needed
***Managerial* risk events**	
Lack of communication planning	▪ Use Computer Aided Design (CAD) system that collect all the design documents and distribute them according to specific access and need basis.
Lack of coordination among different disciplines	▪ Have communication plan ▪ Prepare full checklists for all engineering trends ▪ Follow communication control requirements according to standards
Poor organizational structure and definition of roles and responsibilities	▪ Prepare comprehensive organizational structure with well-defined roles and responsibilities for the contributing firms.
Impact of value engineering process	▪ Apply VE analysis (positive risk)
No Consultant for specific discipline	▪ Choose an appropriate consultant with the matching knowledge, skills, staff, experience, and managerial and financial capabilities.
No quality control system	▪ Employ electronic remote CAD system with full standards and reviewers.
Roles and responsibilities are not clear	▪ Have well-organized responsibility matrix for the owner and engineer.
External risk events	
Changing the engineer	▪ Choose the engineer with the matching knowledge, skills, staff, experience, and managerial and financial capabilities.
Owner's frequent change orders	▪ Enforce a change control system for all changes in the design process
No Project Management Office	▪ Enforce having a qualified local or international (if needed) PMO for the project
Overseas Engineer's Headquarter	▪ Have a fully authorized representative in the country of the project
Overseas Contractor's Headquarter	▪ Have a fully authorized representative in the country of the project
Suitability of available skills with the project	▪ Choose the engineer with the matching knowledge, skills, staff, experience, and managerial and financial capabilities.

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