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Halting decisions for gas pipeline construction projects using AHP: A case study

Tamer F. Abdelmaguid · Waleed Elrashidy

Abstract This paper considers a decision making problem encountered by a natural gas pipeline construction company having a set of ongoing projects and facing unpredictable risks that can result in large deviations from planned schedules. This situation forces the company to consider the decision of halting one or more projects to avoid future losses and to allow for possible reallocation of some of their resources to other ongoing projects. This decision making problem involves different factors and criteria that need to be combined in an organized structure that exploits assessments of experts managing such projects. The analytic hierarchy process (AHP) is found to be suitable for guiding decisions in this problem. A case study for a major natural gas pipeline construction company in Egypt is presented, where three ongoing projects are considered. The proposed AHP structure, along with collected pairwise comparison scores and calculated priorities, suggests halting one project. Sensitivity analysis is conducted to investigate the effect of changes in the pairwise comparison scores assigned to the main criteria on the final decision. The results and analysis provide some insights regarding the application of the AHP and the relative importance of the factors affecting decisions.

Keywords Project risk analysis · Project scheduling · Multicriteria decision making · Analytic Hierarchy Process

Mathematics Subject Classification (2000) MSC 90B50 · MSC 62C25

T.F. Abdelmaguid
Department of Mechanical Design and Production,
Faculty of Engineering, Cairo University,
Giza 12613, Egypt.
Tel.: +20106-268-9333
Fax: +202-35693025
E-mail: tabdelmaguid@alumni.usc.edu

W. Elrashidy
Department of Mechanical Design and Production,
Faculty of Engineering, Cairo University,
Giza 12613, Egypt.

1 Introduction

As natural gas is playing a very important role in the economic development program in Egypt, the construction of natural gas pipelines has recently experienced several risks due to some security problems and terrorist attacks, along with other force majeure problems (Eraky 2011). Moreover, the temporary political and economic instability that faced Egypt in recent years lead to increasing schedule delays due to unfulfilled commitments from suppliers and subcontractors, shortage in funds, and low labor productivity.

For the natural gas pipeline construction, there are different types of resources that need to be facilitated including manpower, equipment, tools, money and materials. Each of these resources has its own considerations in regard with reducing associated risks. Yet, in these projects, many activities depend on the completion of other external actions that are not controlled by the project manager such as obtaining permits and approvals from authorities and reaching agreements with landowners for compensation. Those external actions, which are considered as external dependencies (Kerzner 2009), are largely affected by the political and security conditions. Alongside the aforementioned causes of increasing schedule delay, not completing those external actions will delay project schedule for unforeseen period of time, and can eventually terminate the project. Therefore, a halting decision becomes a valid option for the decision maker as it will stop future unexpected costs and will possibly help reallocate some of the resources to other ongoing projects. A future decision of resuming a halted project is possible when the working environment improves.

This paper applies the analytic hierarchy process (AHP) to guide decisions on pursuing or halting ongoing gas pipeline construction projects under the effect of different external as well as internal factors. Among the different multiple criteria decision making tools (Figueira et al 2005), the AHP (Saaty 2008) is found to be suitable for the current application since it requires qualitative assessments based on personal experiences over the different criteria affecting the decision alternatives. The AHP provides a systematic method of combining such qualitative assessments, and does not require the calculation of a numerical utility or value function for each criterion, which suits the current application. Furthermore, the AHP utilizes simple pairwise comparisons that can be easily understood by local stakeholders, which facilitates their participation and acceptance of the final decision.

2 Literature Review

In construction project risk management, all risk factors associated with project activities are identified and mitigation plans are put forward to the best interest of the objectives of the project. In the literature, several contributions are made to analyze and identify the different types of risks that can be encountered in construction projects. The majority of those risks have a direct impact on project schedule. Early work on project risk analysis and management include Al-Bahar and Crandall (1990) who created a model entitled construction risk management system (CRMS) that provides an effective systematic framework for quantitatively identifying, evaluating, and responding to risk in construction projects.

Hsiao (1996) made a complete detailed analysis for risks in build-operate-transfer (BOT) projects, and concluded that the host government plays critical role of the risk allocation mechanism in BOT projects. Abdelgawad and Fayek (2010) combined fuzzy failure mode and effect analysis (FMEA) with fuzzy AHP for risk management in construction projects. The combined approach is intended to help project management team to establish corrective actions in a timely manner.

Dey (2002) proposed an integration of the AHP and decision tree analysis for project risk identification and selection of a response plan. That integrated approach was extended by Dey (2012) with an application in the construction of an Indian oil refinery. In addition, Dey (2010) proposed the integration of the AHP and risk map for managing project risks. Later, Buertey (2014) presented an approach based on FMEA and the theory of evidence to capture both quantitative and qualitative risk assessments which are gathered through structured questionnaires collected from built-environment professionals. Thaheem et al (2012) provided a literature review on the quantitative techniques developed for risk management of construction projects.

Due to the importance of project risk analysis and management strategies, Ryor (2013) conducted an explanatory analysis of risk management strategies by construction project managers in the USA. He asserted the importance of hiring an educated cadre aware of risk management strategies and to offer continuous training on them. Ashan and Sakale (2014) discussed general internal and external sources of risk in construction projects using risk analysis which could be either quantitative or qualitative in nature based on the amount of information available. They concluded that project risk analysis and management should not be viewed as a separate planning and response operation.

Some external risks are environmental. Dione et al (2005) suggested early identification of potential environmental risks so that a proper plan could be developed to mitigate their impact. Their study recommended the development and implementation of an environmental risk-management framework for construction projects. Other sorts of risk may be due to social and economic conditions. Odimabo and Oduoza (2013) suggested a risk management framework in order to improve performance of building construction projects in developing countries such as Nigeria.

For construction projects in Egypt, some research work addressed their associated risks. Eraky (2011) evaluated the most significant risk factors related to the construction projects in Egypt. El-Razek et al (2008) identified the main risk factors causing delay in construction projects in Egypt from the point of view of contractors, consultants, and owners and they found the most important cause was financing by contractor during construction. Ezeldin and Abdel-Ghany (2013) explained the main factors causing delays in Egyptian construction industry, and analyzed the results to rank and allocate the responsibility of causes of delays. That study focused on large engineering projects and the causes of delays were grouped into five main categories: construction, managerial, political, financial, and technical.

For the risks associated with oil and natural gas pipeline construction projects, Zabaal (2007) identified the most significant risk factors related to pipeline construction projects in Egypt. Zand (2009) explained the different types of risk in oil and gas projects and introduced a framework for risk management for two projects of gas extraction complex at different legal regimes and how to cope with different risk types. Ruqaishi and Bashir (2014) made an investigation about the causes of delay in constructing oil and gas processing facilities in Oman.

Although risk management is an important element of construction project planning, and the presented literature discussed several types of risks both external and internal, some unpredictable risks may occur during project execution and can largely affect its schedule and objectives. Unpredictable risks are generally hard to identify and their effect may not be controllable by the project manager. In the field of natural gas pipeline construction, unpredictable risks can be a result of political and economic instability, terrorist attacks, security problems or natural disasters. Such unpredictable circumstances can intensify the effect of some risk factors resulting in large schedule delays. To the best of our knowledge, the literature of construction project management does not have any contribution in dealing with unpredictable risks as reactive actions during project execution. In the field of software project management, unpredictable risks are identified but nothing has been proposed for dealing with them (Pressman 2005).

This paper studies reactive actions in terms of deciding whether to pursue or halt ongoing natural gas pipeline construction projects facing unpredictable risks. This paper presents an approach based on the AHP for this decision making problem. Since the time of its introduction, the AHP has been used as a tool for selecting projects (Saaty 1980; Dey 2006; Kendrick and Saaty 2007; Palcic and Lalic 2009), for guiding inspection and maintenance decisions of oil pipelines (Dey 2004), for evaluating project performance (Wang et al 2012) as well as for construction delay risk assessment (Hossen et al 2015). However, to the best of our knowledge, it has never been used before to guide halting decisions for a group of ongoing projects. This paper investigates such an application in the field of natural gas construction projects through a case study.

3 Problem statement

The studied decision making problem involves a natural gas pipeline construction company that has several ongoing projects and faces unpredictable risks that necessitates an intervention with regard to decide to halt one or more projects. A gas pipeline construction project consists of four main phases: 1) Engineering studies phase which includes feasibility studies, project planning, sites surveys, pipeline designs and requirements preparation. 2) Procurement phase which includes issuing tenders, expediting purchase orders, and customs clearance. 3) Execution phase which includes excavations, welding, pipe landing, hydraulic test and inspections. 4) Commissioning and start-up phase. The unpredictable risks are not considered in project feasibility study and planning as they occur as a result of unexpected changes in the working environment due to political and/or economic instability or security problems. Those risks affect internal and external factors that have direct impact on project schedule, causing delays that cannot be controlled by project managers. Although the halting decision could be taken at any phase, this paper focuses on halting during the execution phase as it constitutes the main physical activities for which large expenditures are realized and the occurrence of unpredictable risks would have larger impact.

It is required to assess and analyze the effect of some critical factors influenced by unpredictable risks on delaying the schedules of a set of projects during the execution phase and accordingly make a suitable halting decision for some of them. Based on the assessment and analysis made, the pursuing decision usually bears the rescheduling of the unfinished activities to mitigate the effects of the unpredictable risks. Halting a project during its execution phase represents a big loss to the company, yet on the other hand it can save a rather large amount of expenditures, where some of them are unexpected, that could have been incurred without finally reaching the project's main goal. Furthermore, halting a project can help direct its equipment, resources and remaining budget to other company's projects. Therefore, a careful holistic view on the ongoing projects is needed.

4 Methodology

The AHP, developed by Thomas L. Saaty in the 1970s (Saaty 1980), is a tool used to organize and analyze complex decisions in a hierarchical structure that utilizes both mathematics and psychology. It helps decision makers to take best decision that suits their goal and their understanding of the problem. Based on Saaty (2008), the application of the AHP can be summarized in the following steps.

1. Define the problem and the kind of knowledge sought.
2. Build the decision hierarchy structure.
3. Conduct pairwise comparisons.
4. Priorotize elements at each level with respect to direct parent criteria.

The first step is covered in the previous section. The following subsections present the details of applying the remaining three steps, and comment on the adequacy of the AHP to the analysis in the current decision making problem.

4.1 Building the decision hierarchy structure

The application of the AHP in the second step involves the definition of the decision hierarchy structure. This structure contains at the top level, the goal of the decision, followed by one or more levels of criteria and sub-criteria on which subsequent decision elements depend, followed by the set of alternative decisions at the lowest level.

For the studied problem, the goal is to achieve the best possible performance for the company by selecting the best combination of pursuing and halting decisions of ongoing natural gas pipeline construction projects. In order to construct the decision hierarchy structure, 23 candidate factors that may result in delaying the natural gas pipeline construction projects are identified based on the previous work of Ezeldin and Abdel-Ghany (2013) for general engineering projects in Egypt and the specific conditions and information available from previous gas pipeline construction projects. Those delay factors and their classification are used here to form the criteria and sub-criteria in the decision hierarchy structure. It is important to note here that, the delay factors are actually risks that are normally taken care of during the project feasibility study and planning phase. However, the effect of those factors on project schedule recently increased due to the unpredictable risks resulting from the instability in political, economic and security conditions.

Table 1 Candidate factors causing delays in natural gas pipeline construction projects and average scores of survey results

Factor		Average score
Governmental		
1)	Conflict with governmental authorities	2.61
2)	Sovereign decisions	4.76
3)	Permits and Approvals	4.61
Financial		
4)	Increase of inflation rate	1.55
5)	Changes in cash flow	1.61
6)	Change in the exchange rate of the Egyptian Pound	1.58
7)	Increase in the cost of materials	1.18
8)	Increase in the cost of equipment	1.76
9)	Negotiations on compensation paid to landowners	4.42
10)	Shortage in funding from beneficiary institutions	4.76
Executional		
11)	Supplier delays	3.39
12)	Wrong means of material transportation to site	1.42
13)	Unproven or a complex technology to be implicated in site	1.79
14)	Difficult rerouting of pipelines in site	1.73
15)	Geotechnical issues and soil analysis troubles	1.15
16)	Labor productivity lower than required	3.79
17)	Bad weather conditions	2.42
18)	Catastrophic natural phenomena	1.36
19)	Terrorist attacks and security problems	4.58
20)	Energy and water supply troubles	1.15
21)	Site accessibility troubles	2.33
22)	Equipment productivity lower than required	3.88
23)	Contractor performance is lower than required	4.03

The halting decisions are the company's response to those intensified delay factors which is the main concern of this study.

The delay factors are classified under three main categories: governmental, financial and executional. In order to determine the most significant factors among the 23 candidates, survey forms are prepared and 33 project managers are asked to provide their assessments. The experiences of the participating project managers in the field of natural gas pipeline construction range from 5 to 20 years. A 5-point Likert scale is used for each candidate factor to measure its level of significance on delaying project activities. A score of 1 indicates insignificant factor, a score of 2 indicates little significance, a score of 3 indicates moderate significance, a score of 4 indicates significant factor, and a score of 5 means very significant factor. In the survey forms, it is stated clearly that higher significance scores are commensurate with longer delays. Table 1 lists the candidate factors considered in the survey, and the averages of the collected scores.

The top-level criteria in the AHP structure are defined as governmental procedures, financial procedures and execution environment. The survey results identifying the significance of the delay factors in Table 1 are used in selecting the sub-criteria in the AHP structure. The rule used here is to consider only delay factors receiving an average score of more than 3. Accordingly, beneath the top-level criteria, sub-criteria are selected as follows.

– Beneath governmental procedures:

  - Sovereign decisions: Getting permits for working on a region that is dedicated to military defense takes long time. This refers to factor 2 in Table 1.
  - Permits and approvals: Governmental procedures for getting necessary legal permits may take longer than expected. This refers to factor 3 in Table 1.
- Beneath financial procedures:
  - Compensation: This is related to time consumed in negotiations on the rental value to be paid to farmers or landowners in exchange for the passage of the gas pipeline in their land. These negotiations consume a lot of time and effort, which can affect the project schedule. This refers to factor 9 in Table 1.
  - Funds: Shortages in funds from the beneficiary company or institution may affect the execution of project activities. This refers to factor 10 in Table 1.
- Beneath execution environment:
  - Security conditions: security threats during project execution due to terrorist attacks may delay its activities for unforeseen length of time. This refers to factor 19 in Table 1.
  - Suppliers and contractors commitments: commitments of suppliers and contractors to contractual dates are sometimes not respected. This sub-criteria combines the two factors 11 and 23 referenced in Table 1 as they both represent relationship with third parties whose performance affects the project.
  - Productivity of labor and equipment: This sub-criteria combines the two factors 16 and 22 referenced in Table 1 as they both refer to the effect of low productivity on the project.

At the bottom level of the decision hierarchy structure, all possible combinations of pursuing and halting decisions of the selected set of ongoing projects exist. That is, for n selected projects, there will be 2^n decision alternatives to select from. For instance, if there are two ongoing projects, the decision alternatives will be: 1) pursue both projects, 2) halt both projects, 3) pursue the first project and halt the second one, and 4) halt the first project and pursue the second one. Since the number of decision alternatives grows exponentially with the number of selected projects, the application of the AHP is limited to a certain manageable number of projects that ensures the consistency of the score matrices. As recommended by Saaty and Ozdemir (2003), the number of elements being compared must not exceed 9 in order to improve the consistency and accuracy of the assigned scores. This may require a pre-election of a subset of ongoing projects to be considered if the total number of ongoing projects is relatively large. Alternatively, projects may be clustered into groups as explained by Saaty (1990).

The main reason behind considering the decisions for a set of projects together in the decision hierarchy structure instead of studying each project individually is that we are concerned with the overall performance of the company. Since the resources allocated to all projects belong to the same organization, their reallocation between projects is possible. Therefore, the decision of halting one project may be affected by how much resources can the company benefit from their reallocation to the other projects. In addition to that, the actions taken by the company regarding the deals with suppliers and subcontractors or negotiations with authorities can be affected by the collective halting/pursuing decisions for a set of projects.

4.2 Conducting pairwise comparisons

After defining the decision hierarchy structure of the studied problem, a set of pairwise comparison matrices is constructed in the third step. In the comparison matrices, each element in the upper level of the decision hierarchy structure is taken as a reference for comparing the relative importance of the elements that are beneath it. Such comparisons are conveyed through numerical scale depending on the intensity of importance between compared elements. In this paper, the importance scale from 1 to 9 (Saaty 1990) is adopted. In that scale, a score of 1 indicates equal importance; and a score of 9 indicates that an element is extremely important than the other. Meanwhile, reciprocals to these scores (i.e. 1/2, 1/3,...1/9) represent the counter importance relationships. For assigning numerical scale values, survey forms are prepared and a selected pool of 12 project managers and engineers who are participating in the set of ongoing projects are asked to provide their assessments separately.

The geometric means of the collected individual scores are evaluated as explained by Forman and Peniwati (1998) using uniform weights, resulting in the comparison matrices which are used in the next step of the AHP application. It is important to note here that arithmetic means can alternatively be used to aggregate individual scores. As indicated by Forman and Peniwati (1998), both aggregation methods can be employed when group members act as individuals and we are concerned with aggregating their individual priorities. However, when we are concerned with both individual judgments and priorities, the geometric mean is more consistent. Saaty and Vargas (2012) specify four conditions that need to be satisfied by the aggregation method including separability, unanimity, homogeneity and power conditions. They assert that only geometric mean satisfies them.

4.3 Prioritizing elements in the decision hierarchy structure

In the last step of the AHP application, the comparison matrices are used to calculate the local priorities of the elements at each level in the hierarchy structure with respect to direct parent item(s). Local priorities are propagated from the goal down to the decision alternatives in a top-down approach via simple multiplications and additions, ending up with weights for decision alternatives which represent their priorities with respect to the goal. Finally, the alternatives can be ranked according to their weights which provide an order of preference for the decision maker. The decision alternative with the highest weight is recommended to the decision maker. More details about the computations in the AHP and its theoretical background can be found in Saaty (1990).

As a method of verifying the consistency of the assigned scores in the matrices, Saaty (1980) suggested utilizing a consistency index (CI^h), which is calculated as $CI^h = (\lambda^h_{max} - n^h)/(n^h - 1)$, where λ^h_{max} is the largest eigenvalue of the pairwise comparison matrix with respect to a higher element h in the hierarchy structure and n^h is the size of this matrix. Based on CI^h, a consistency ratio (CR^h) is evaluated, which is defined as the ratio between CI^h and an average index, denoted $RI(n^h)$, of randomly generated score matrices of size n^h. As suggested by Saaty (1980), the pairwise comparison matrix is said to be consistent whenever its consistency ratio is found to be less than or equal to 10%. Several revisions have been proposed in the literature on the values of $RI(n^h)$ (Tummala and Ling 1998).

4.4 Adequacy of the AHP

It is worth mentioning here that there is an alternative tool called analytic network process (ANP) which is considered as a generalization of the AHP (Saaty 2005). The main difference between the AHP and the ANP is that the elements within any level of the decision hierarchy structure of the latter can depend on each other; meaning that pairwise comparisons are needed between them. In the current application, the criteria, the sub-criteria and the alternatives are mutually exclusive and independent. For instance, the governmental procedures, which are related to obtaining either permits for working in a region dedicated for military defense or legal governmental approvals, are by no means affected by financial procedures, which are related to negotiations for compensations to land owners or receiving funds from the beneficiary institution. Therefore, both criteria are independent and there is no mutual effect between them. Similar relationship exists between these two criteria and the execution environment criteria, as the latter is concerned with the factors that are directly related to project execution. For instance the productivity of labor and equipment which is a sub-criterion of the execution environment is totally independent and not affected by any of the governmental or financial procedures. Similar relationships can be easily seen among the different sub-criteria. For the decision alternatives at the lowest level of the decision hierarchy, their formulation enforces their independence. Therefore, we can conclude that the utilization of the AHP is adequate and sufficient for the studied decision making problem.

5 Case study

In this paper, the AHP approach is applied to a case in which there are three ongoing projects, labeled A, B and C. These three pipeline construction projects are respectively intended to supply natural gas for domestic use, for generating electrical power and for exportation to a neighboring country. Fig. 1 depicts the current status of the three projects in terms of their percentage completion of governmental permits and approvals, compensations and supplier and contractor commitments in addition to the labor and equipment productivity level.

Project A is set to extend the national gas domestic grid by connecting an additional city. The overall budget of the project is 140 million Egyptian pounds. It was launched on October, 2012 and its conceptual and feasibility studies phase finished on June, 2013. The planned deadline for finishing the project was set on June, 2014. The project schedule was modified and delayed five times to cope with the effects of the uncontrollable external factors. At the time when this study was conducted, there was a clear delay in governmental procedures for obtaining permits and approvals due to some conflicts with governmental authorities. Furthermore, there were delays due to execution environment as the productivity of the vendors and contractors was lower than planned.

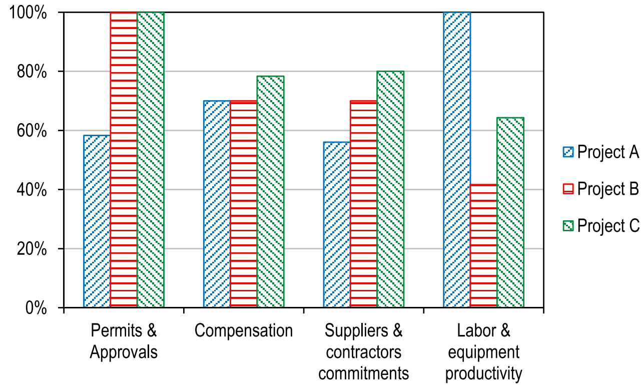

Fig. 1 Status of studied projects at time of study

Project B is another extension to the national gas grid which is set to feed natural gas to a large power station. The overall budget of the project is 692 million Egyptian pounds. This gas pipeline construction project began on November, 2012 in its conceptual and feasibility studies phase which was finished on December, 2013. It was planned that the gas will be available in the pipes by June, 2015. The schedule was modified and delayed twice to cope with the effects of the uncontrollable external factors. At the time when this study was conducted, there was a delay in financial procedures and execution environment. For financial procedures, the project faced high fees for purchasing necessary land. For execution environment, the project faced security problems, low vendor and contractor performance and low labor and equipment productivity.

Project C aims to export natural gas to a neighboring country. The overall budget of the project is 370 million Egyptian pounds. This project began on June, 2011 in its conceptual and feasibility studies phase, which was completed on April, 2012. Commissioning and start-up phase was planned such that the gas in the pipeline will be available by January, 2015. The schedule was modified and delayed three times to cope with the effects of the uncontrollable external factors which are mainly due to delays in financial procedures and execution environment. For financial procedures, the land owners refused compensation for the passage of the pipeline. For execution environment, the project faced security problems as a result of terrorist attacks, in addition to low vendor and supplier performance and low labor productivity.

At the time when this study was conducted, the decision maker had to consider the possibility of halting one or more projects in order to free some of the resources tied to them which can be reallocated to other current or new projects. Furthermore, in spite of the large investments that have been made, the halting decision can save unforeseen future costs that will be needed to just maintain the finished tasks of the projects without guaranteeing their final completion. Due to the complex nature of such decisions which involves the consideration of different factors simultaneously and the different inclinations of the stake holders, the AHP is found to be suitable for providing a systematic method for taking appropriate decisions.

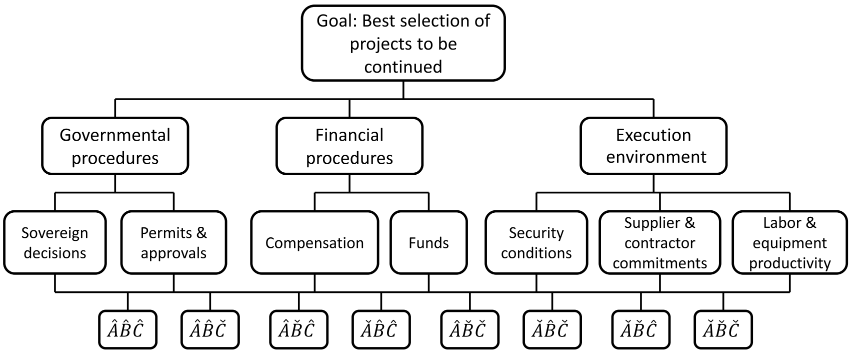

Fig. 2 AHP hierarchy for the studied case

In the current AHP application, let $\hat{x}$ and $\check{x}$ denote respectively the decisions of pursuing and halting a project labeled using the letter x. Accordingly, for the three projects A, B and C, the set of alternative decisions are represented as $\hat{A}\hat{B}\hat{C}$, $\hat{A}\hat{B}\check{C}$, $\hat{A}\check{B}\hat{C}$, $\check{A}\hat{B}\hat{C}$, $\hat{A}\check{B}\check{C}$, $\check{A}\hat{B}\check{C}$, $\check{A}\check{B}\hat{C}$ and $\check{A}\check{B}\check{C}$, forming a total number of eight mutually exclusive decision alternatives. Accordingly, Fig. 2 shows the structure of the AHP hierarchy for the studied case.

Tables 4 through 14 in the Appendix report the aggregated pairwise comparison matrices using geometric means along with their corresponding calculated local priorities and maximum eigenvalues with their consistency ratios. The consistency ratios are found to be below 10% for all matrices, except for the permits & approvals sub-criteria for which an original consistency ratio of 16.1% is found. Based on the recommendations of Saaty and Ozdemir (2003), the most inconsistent judgments in the matrix are determined, and experts are asked to reconsider their evaluations. The reported final matrix is found to have a consistency ratio of 4.9% as given in Table 9.

The weights of the main criteria, which are their local priorities with respect to the goal shown in Table 4, indicate that governmental procedures have large effect on the decision which exceeds the collective effect of the other two criteria by almost 6%. In order to represent the influence of each sub-criterion on the weights of the decision alternatives, the weights of the seven sub-criteria are evaluated and illustrated in Fig. 3. Each of those weights is the result of multiplying the calculated local priority of the sub-criterion with respect to the parent main criterion (Tables 5 to 7) by the weight of the parent main criterion. Based on Fig. 3, it is evident that the weight of sovereign decisions is almost double the weight of permits & approvals, funds and security conditions individually. Meanwhile, the influences of the remaining sub-criteria are comparatively small.

The calculated weights of the decision alternatives are presented in Fig. 4. The horizontal bars in Fig. 4 are divided into sections that represent the contributions of the sub-criteria on the weights of the decision alternatives. They suggest that the decision of halting project A and pursuing both projects B and C has the highest priority in achieving the goal as it received the highest weight of 37.21%. The major contributor to that weight is sovereign decisions with about 13.5%. This is followed by security conditions of about 7% contribution, and permits & approvals and funds with contributions of about 6% each. The second highest

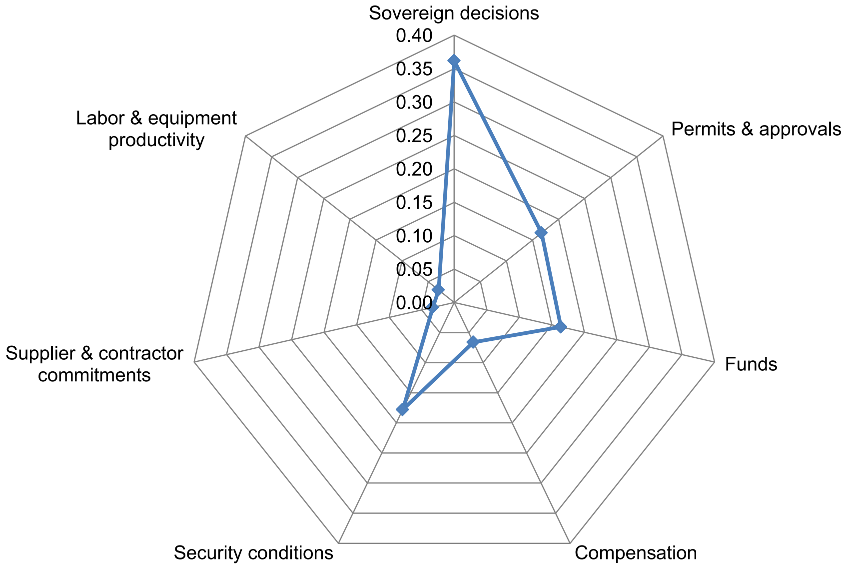

Fig. 3 Weights of sub-criteria for the studied case

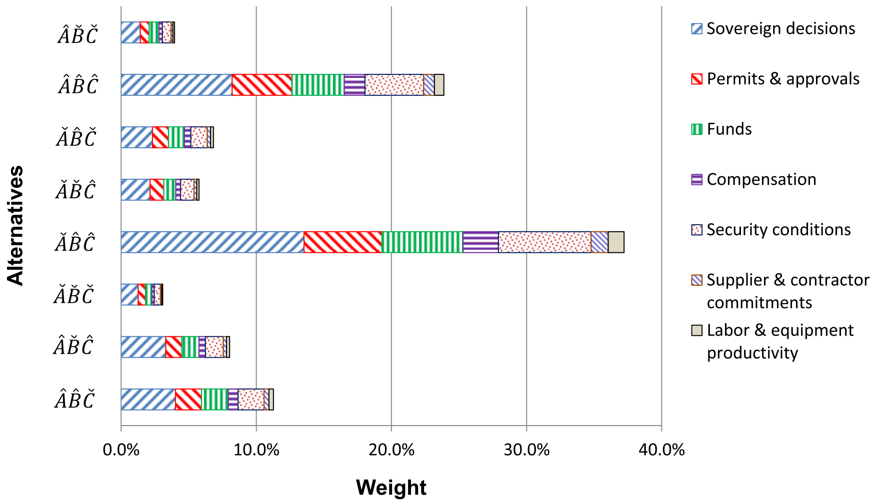

Fig. 4 Calculated weights of the decision alternatives for the studied case

weight alternative is to pursue all three projects with a weight of 23.88%. The rest of alternative decisions received close weights of less than 12%. These results point out the significance of the four factors, namely sovereign decisions, permits & approvals, funds and security conditions, on the decision of halting project A.

Table 2 Weights of the main criteria generated for sensitivity analysis

		Weights for sensitivity analysis					
	Original	Governmental		Financial		Execution	
Criteria	weights	highest	lowest	highest	lowest	highest	lowest
Governmental	0.529	0.647	0.37	0.1	0.38	0.1	0.271
Financial	0.23	0.15	0.313	0.81	0.224	0.09	0.538
Execution	0.241	0.203	0.317	0.09	0.396	0.81	0.191

6 Sensitivity analysis

Sensitivity analysis is necessary to study the effect of variations to the assigned scores on the final decision recommended. In this study, the main focus is on changes to the scores assigned to main criteria with respect to the goal as they have larger impact on the final decision compared to changes in the scores assigned to lower levels in the hierarchy structure as can be concluded from the computational structure provided in Saaty (1990). Participants in the conducted surveys are separately asked to reconsider their pairwise comparison scores such that each main criterion is assigned both the highest and the lowest possible scores according to their opinion with respect to the other two criteria, while the remaining comparisons are kept fixed. For instance, a participant who originally assigned a score of 5 for governmental procedures compared to financial procedures might give a maximum score of 7 and a minimum score of 3 to that specific pairwise comparison. Similar change is made to the comparison of governmental procedures with execution environment; while the comparison of financial procedures with execution environment remains unchanged. Here, we consider a change in the level of importance of governmental versus the other two criteria, not a reversal of the relative importance relationship. This means that, for instance, if a score in the original analysis is greater than 1, it will remain as such in the sensitivity analysis.

Table 2 lists the original and resultant weights or priorities of the main criteria with respect to the goal that are generated for sensitivity analysis. The columns that list the generated weights for sensitivity analysis correspond to the highest and lowest input scores of the main criteria specified in the heading of each column with respect to the other two criteria. It is important to note that the method used for sensitivity analysis does not change the weights directly since they are not direct inputs to the AHP, they rather depend on the collected scores. Therefore, a weight for a given criterion generated using the highest (lowest) scores is not necessarily the highest (lowest) weight generated for all sensitivity analysis cases.

Table 3 reports the summary of the sensitivity analysis results. The listed numbers are the final percentage weights of the eight alternatives calculated for the originally assigned scores and the highest and lowest scores assigned to each criteria. The alternative $\check{A}\hat{B}\hat{C}$ receives the highest percentage weight in all situations considered. This indicates that the decision of halting project A and pursuing projects B and C is insensitive to changes in the assigned scores of the main criteria with respect to the goal.

Table 3 Sensitivity analysis results

	Original	Governmental		Financial		Execution	
	weights	highest	lowest	highest	lowest	highest	lowest
$\hat{A}\check{B}\check{C}$	3.95	4.52	4.30	4.27	4.27	3.82	4.31
$\hat{A}\hat{B}\hat{C}$	23.88	23.60	23.71	23.59	23.76	24.07	23.64
$\check{A}\hat{B}\check{C}$	6.83	6.73	6.87	7.09	6.85	6.95	6.96
$\check{A}\check{B}\hat{C}$	5.77	5.81	5.70	5.50	5.73	5.70	5.61
$\check{A}\hat{B}\hat{C}$	37.21	36.24	37.00	37.33	37.06	38.17	37.08
$\check{A}\check{B}\check{C}$	3.08	3.13	2.95	2.84	2.94	2.69	2.92
$\hat{A}\check{B}\hat{C}$	8.02	8.52	8.07	7.71	8.07	7.58	7.95
$\hat{A}\hat{B}\check{C}$	11.26	11.45	11.40	11.67	11.32	11.02	11.53

7 Conclusions

This paper presented an application of the AHP in guiding pursuing and halting decisions on a group of ongoing natural gas pipeline construction projects facing unpredictable risks. Due to the complex nature of the considered decision making problem and its significant impact on the overall performance of the company managing the projects, careful analysis of the factors involved and their constituent elements is needed. The AHP is found to provide a well-structured approach of integrating such factors and decision making elements in a decision hierarchy structure that facilitates pairwise assessments of their relative importance and effectiveness which is conducted via soliciting personal judgments of experts involved in natural gas pipeline construction.

The application of the AHP to the studied decision making problem is demonstrated through a case study of a major natural gas pipeline construction company in Egypt, which involved three different ongoing projects. All different combinations of pursuing and halting decisions of the three projects formed eight different mutually exclusive alternative decisions which are evaluated via pairwise comparisons with respect to each sub-criterion. The calculated weights resulted in assigning the highest priority to the decision of halting one project and pursuing the other two. This result remained unchanged when changes to the assigned pairwise comparison scores of the main criteria with respect to the goal are made in the sensitivity analysis.

The calculated priorities in the studied case not only provide preference regarding the best decision to make; they also provide insights to the decision and policy makers on how to improve the current situation. The influence of both sovereign decisions and permits & approvals on the halting or pursuing decision is evident as shown in Fig. 3. This recommends that the governing authorities should facilitate such procedures. The results also show the importance of political and economic stability for gas pipeline construction projects, which improves security conditions and funding capabilities.

The presented case study demonstrated the effectiveness of the AHP in providing rational decisions in a structured approach that is derived by expert judgments. However, one shortcoming of the AHP is its ability to deal only with limited number of decision alternatives in order to be able to manage a reasonable number of pairwise comparisons. For the studied decision making problem, the number of decision alternatives grows exponentially with the number of ongoing projects as indicated in the methodology section of this paper. Therefore, a direct application of the proposed methodology is limited to only three projects which result in eight alternatives. However, the AHP allows for adding more layers to the structure which can help in partially mitigating this issue by adding one layer for clustered projects. For instance, beneath the sub-criteria layer, three clusters can be added; the first one for projects that target domestic consumption, the second one for projects that target industrial consumption and the third one for projects that target exportation. This allows for adding more projects beneath each cluster.

It is important to note that depending on the circumstances that affect ongoing natural gas pipeline construction projects, experts may opt to exclude some alternative decisions from the AHP structure. For instance, it may not be acceptable to halt all ongoing projects or a subset of them. This requires a former assessment of the enumerated decision alternatives to rule out unacceptable ones.

Based on the results obtained from the application of the AHP to the studied case, future extension will include the study of another resultant decision making problem looking into how to reallocated resources from the halted project to the other two ongoing projects. This extension will require detailed information about the resources that can possibly be reallocated and the current and future scheduled activities in the other two projects. Different objectives can be considered including both cost and time elements of the reallocation decisions.

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A Pairwise comparison matrices

This appendix contains all aggregated pairwise comparison matrices for the presented case study.

Table 4 Pairwise comparison matrix for main criteria with respect to the goal ($\lambda_{max}^{Goal} = 3.031, CR^{Goal} = 3.6\%$)

	Governmental	Financial	Execution	Priorities
Governmental	1	2.75	1.83	0.529
Financial	0.36	1	1.14	0.23
Execution	0.55	0.88	1	0.241

Table 5 Pairwise comparison matrix for the sub-criteria with respect to the criteria governmental procedures ($\lambda_{max}^{Governmental} = 1.999, CR^{Governmental} = 0.1\%$)

	Sovereign decisions	Permits & Approvals	Priorities
Sovereign decisions	1	2.16	0.684
Permits & Approvals	0.46	1	0.316

Table 6 Pairwise comparison matrix for the sub-criteria with respect to the criteria commercial procedures ($\lambda_{max}^{Commercial} = 1.999, CR^{Commercial} = 0.1\%$)

	Funds	Compensation	Priorities
Funds	1	2.49	0.713
Compensation	0.4	1	0.287

Table 7 Pairwise comparison matrix for the sub-criteria with respect to the criteria execution environment ($\lambda_{max}^{Execution} = 3.002, CR^{Execution} = 0.2\%$)

	Security conditions	Suppliers & contractors commitments	Labor & equipment productivity	Priorities
Security conditions	1	5.6	5.65	0.738
Suppliers & contractors commitments	0.18	1	1.16	0.137
Labor & equipment productivity	0.18	0.86	1	0.125

Table 8 Pairwise comparison matrix for the alternatives with respect to sub-criteria Sovereign decisions ($\lambda_{max}^{Sovereign} = 8.593, CR^{Sovereign} = 6.0\%$)

	$\hat{A}\breve{B}\breve{C}$	$\hat{A}\hat{B}\hat{C}$	$\breve{A}\hat{B}\breve{C}$	$\breve{A}\breve{B}\hat{C}$	$\breve{A}\hat{B}\hat{C}$	$\breve{A}\breve{B}\breve{C}$	$\hat{A}\breve{B}\hat{C}$	$\hat{A}\hat{B}\breve{C}$	Priorities
$\hat{A}\breve{B}\breve{C}$	1	0.22	0.36	0.38	0.17	1.94	0.33	0.35	0.039
$\hat{A}\hat{B}\hat{C}$	4.55	1	4.13	4.21	0.29	4.48	3.7	3.83	0.227
$\breve{A}\hat{B}\breve{C}$	2.8	0.24	1	1.27	0.18	2.83	0.5	0.33	0.064
$\breve{A}\breve{B}\hat{C}$	2.64	0.24	0.79	1	0.21	2.43	0.4	0.4	0.059
$\breve{A}\hat{B}\hat{C}$	5.74	3.4	5.65	4.78	1	5.18	4.99	5.09	0.374
$\breve{A}\breve{B}\breve{C}$	0.51	0.22	0.35	0.41	0.19	1	0.36	0.36	0.035
$\hat{A}\breve{B}\hat{C}$	3.07	0.27	2.02	2.51	0.2	2.82	1	0.56	0.091
$\hat{A}\hat{B}\breve{C}$	2.87	0.26	3.04	2.51	0.2	2.75	1.77	1	0.111

Table 9 Pairwise comparison matrix for the alternatives with respect to sub-criteria Permits & approvals ($\lambda_{max}^{Permits} = 8.483, CR^{Permits} = 4.9\%$)

	$\hat{A}\breve{B}\breve{C}$	$\hat{A}\hat{B}\hat{C}$	$\breve{A}\hat{B}\breve{C}$	$\breve{A}\breve{B}\hat{C}$	$\breve{A}\hat{B}\hat{C}$	$\breve{A}\breve{B}\breve{C}$	$\hat{A}\breve{B}\hat{C}$	$\hat{A}\hat{B}\breve{C}$	Priorities
$\hat{A}\breve{B}\breve{C}$	1	0.25	0.38	0.38	0.17	1.46	0.4	0.33	0.039
$\hat{A}\hat{B}\hat{C}$	3.94	1	3.91	4.67	0.47	5.36	5.12	4.78	0.264
$\breve{A}\hat{B}\breve{C}$	2.60	0.26	1	1.46	0.19	2.86	0.89	0.43	0.071
$\breve{A}\breve{B}\hat{C}$	2.65	0.21	0.68	1	0.24	2.63	0.57	0.32	0.061
$\breve{A}\hat{B}\hat{C}$	5.92	2.11	5.29	4.15	1	5.91	5.65	4.94	0.345
$\breve{A}\breve{B}\breve{C}$	0.68	0.19	0.35	0.38	0.17	1	0.34	0.30	0.032
$\hat{A}\breve{B}\hat{C}$	2.49	0.20	1.13	1.74	0.18	2.95	1	0.43	0.072
$\hat{A}\hat{B}\breve{C}$	3.04	0.21	2.31	3.11	0.20	3.37	2.33	1	0.116

Table 10 Pair-wise comparison matrix for the alternatives with respect to sub-criteria Funds ($\lambda_{max}^{Funds} = 8.32, CR^{Funds} = 3.3\%$)

	$\hat{A}\check{B}\check{C}$	$\hat{A}\hat{B}\hat{C}$	$\check{A}\hat{B}\check{C}$	$\check{A}\check{B}\hat{C}$	$\check{A}\hat{B}\hat{C}$	$\check{A}\check{B}\check{C}$	$\hat{A}\check{B}\hat{C}$	$\hat{A}\hat{B}\check{C}$	Priorities
$\hat{A}\check{B}\check{C}$	1	0.25	0.49	0.76	0.17	1.76	0.44	0.38	0.045
$\hat{A}\hat{B}\hat{C}$	4.08	1	4.38	4.24	0.47	6.25	4.25	2.72	0.237
$\check{A}\hat{B}\check{C}$	2.04	0.23	1	1.52	0.21	2.64	1.27	0.39	0.072
$\check{A}\check{B}\hat{C}$	1.32	0.24	0.66	1	0.15	3.57	0.40	0.39	0.054
$\check{A}\hat{B}\hat{C}$	5.85	2.14	4.75	6.60	1	7.54	6.27	4.23	0.366
$\check{A}\check{B}\check{C}$	0.57	0.16	0.38	0.28	0.13	1	0.29	0.29	0.029
$\hat{A}\check{B}\hat{C}$	2.25	0.24	0.79	2.48	0.16	3.39	1	0.46	0.077
$\hat{A}\hat{B}\check{C}$	2.62	0.37	2.59	2.57	0.24	3.51	2.16	1	0.120

Table 11 Pairwise comparison matrix for the alternatives with respect to sub-criteria Compensation ($\lambda_{max}^{Compensation} = 8.495, CR^{Compensation} = 5.0\%$)

	$\hat{A}\check{B}\check{C}$	$\hat{A}\hat{B}\hat{C}$	$\check{A}\hat{B}\check{C}$	$\check{A}\check{B}\hat{C}$	$\check{A}\hat{B}\hat{C}$	$\check{A}\check{B}\check{C}$	$\hat{A}\check{B}\hat{C}$	$\hat{A}\hat{B}\check{C}$	Priorities
$\hat{A}\check{B}\check{C}$	1	0.24	0.32	0.42	0.16	1.90	0.38	0.33	0.037
$\hat{A}\hat{B}\hat{C}$	4.18	1	4.52	4.78	0.37	6.17	4.48	3.29	0.232
$\check{A}\hat{B}\check{C}$	3.10	0.22	1	1.41	0.22	3.00	1.13	0.39	0.071
$\check{A}\check{B}\hat{C}$	2.39	0.21	0.71	1	0.16	3.57	0.40	0.33	0.055
$\check{A}\hat{B}\hat{C}$	6.43	2.69	4.54	6.28	1	8.39	7.89	5.89	0.396
$\check{A}\check{B}\check{C}$	0.53	0.16	0.33	0.28	0.12	1	0.29	0.29	0.026
$\hat{A}\check{B}\hat{C}$	2.62	0.22	0.88	2.48	0.13	3.46	1	0.56	0.073
$\hat{A}\hat{B}\check{C}$	3.04	0.30	2.59	3.06	0.17	3.41	1.77	1	0.110

Table 12 Pairwise comparison matrix for the alternatives with respect to sub-criteria Security conditions ($\lambda_{max}^{Security} = 8.397, CR^{Security} = 4.0\%$)

	$\hat{A}\check{B}\check{C}$	$\hat{A}\hat{B}\hat{C}$	$\check{A}\hat{B}\check{C}$	$\check{A}\check{B}\hat{C}$	$\check{A}\hat{B}\hat{C}$	$\check{A}\check{B}\check{C}$	$\hat{A}\check{B}\hat{C}$	$\hat{A}\hat{B}\check{C}$	Priorities
$\hat{A}\check{B}\check{C}$	1	0.22	0.35	0.41	0.16	1.79	0.36	0.36	0.037
$\hat{A}\hat{B}\hat{C}$	4.51	1	4.45	4.83	0.45	6.99	4.23	3.61	0.244
$\check{A}\hat{B}\check{C}$	2.87	0.22	1	1.33	0.21	2.90	1.01	0.45	0.069
$\check{A}\check{B}\hat{C}$	2.46	0.21	0.75	1	0.17	3.31	0.48	0.36	0.056
$\check{A}\hat{B}\hat{C}$	6.45	2.24	4.86	5.74	1	8.47	7.89	5.64	0.386
$\check{A}\check{B}\check{C}$	0.56	0.14	0.34	0.30	0.12	1	0.27	0.27	0.026
$\hat{A}\check{B}\hat{C}$	2.77	0.24	0.99	2.09	0.13	3.75	1	0.49	0.074
$\hat{A}\hat{B}\check{C}$	2.77	0.28	2.23	2.79	0.18	3.69	2.04	1	0.108

Table 13 Pairwise comparison matrix for the alternatives with respect to sub-criteria Suppliers & contractors commitments ($\lambda_{max}^{Supplier} = 8.437, CR^{Supplier} = 4.5\%$)

	$\hat{A}\check{B}\check{C}$	$\hat{A}\hat{B}\hat{C}$	$\check{A}\hat{B}\check{C}$	$\check{A}\check{B}\hat{C}$	$\check{A}\hat{B}\hat{C}$	$\check{A}\check{B}\check{C}$	$\hat{A}\check{B}\hat{C}$	$\hat{A}\hat{B}\check{C}$	Priorities
$\hat{A}\check{B}\check{C}$	1	0.24	0.33	0.44	0.16	1.96	0.42	0.32	0.038
$\hat{A}\hat{B}\hat{C}$	4.19	1	4.63	4.64	0.46	6.62	4.09	3.61	0.242
$\check{A}\hat{B}\check{C}$	3.01	0.22	1	1.25	0.22	3.43	0.99	0.40	0.071
$\check{A}\check{B}\hat{C}$	2.29	0.22	0.80	1	0.16	3.70	0.45	0.38	0.058
$\check{A}\hat{B}\hat{C}$	6.35	2.17	4.54	6.12	1	8.39	7.80	5.56	0.382
$\check{A}\check{B}\check{C}$	0.51	0.15	0.29	0.27	0.12	1	0.28	0.29	0.026
$\hat{A}\check{B}\hat{C}$	2.39	0.24	1.01	2.21	0.13	3.53	1	0.47	0.073
$\hat{A}\hat{B}\check{C}$	3.11	0.28	2.51	2.66	0.18	3.41	2.11	1	0.11

Table 14 Pairwise comparison matrix for the alternatives with respect to sub-criteria Labor & equipment productivity ($\lambda_{max}^{Productivity} = 8.422, CR^{Productivity} = 4.3\%$)

	$\hat{A}\check{B}\check{C}$	$\hat{A}\hat{B}\hat{C}$	$\check{A}\hat{B}\check{C}$	$\check{A}\check{B}\hat{C}$	$\check{A}\hat{B}\hat{C}$	$\check{A}\check{B}\check{C}$	$\hat{A}\check{B}\hat{C}$	$\hat{A}\hat{B}\check{C}$	Priorities
$\hat{A}\check{B}\check{C}$	1	0.24	0.33	0.45	0.15	2.26	0.47	0.38	0.041
$\hat{A}\hat{B}\hat{C}$	4.12	1	4.12	4.72	0.45	6.25	4.13	2.93	0.23
$\check{A}\hat{B}\check{C}$	3.02	0.24	1	1.10	0.24	3.04	0.98	0.45	0.072
$\check{A}\check{B}\hat{C}$	2.20	0.21	0.91	1	0.16	3.49	0.40	0.34	0.058
$\check{A}\hat{B}\hat{C}$	6.48	2.24	4.25	6.11	1	8.57	7.98	5.75	0.389
$\check{A}\check{B}\check{C}$	0.44	0.16	0.33	0.29	0.12	1	0.31	0.30	0.026
$\hat{A}\check{B}\hat{C}$	2.13	0.24	1.02	2.48	0.13	3.27	1	0.52	0.074
$\hat{A}\hat{B}\check{C}$	2.62	0.34	2.23	2.98	0.17	3.33	1.91	1	0.11