

# MULTI- CRITERIA DECISION SUPPORT OF PROJECT RISK ASSESSMENT

Chaouki Moumeni<sup>1,2,\*</sup>, Kamel Tadjine<sup>1</sup>, Hamid Hamadache<sup>1</sup> and Mourad Nahal<sup>2</sup>

Received: October 04, 2019; Revised: October 26, 2020; Accepted: November 04, 2020

## Abstract

Risk is an inherent property of each project, because a project life cycle is subjected to different nature's risks, such as internal or external origins. The aim of this paper is to rank the pipeline installation project construction's risks in order of importance, taken into account the two multi-criteria approaches of decision support which are Analytic Hierarchy Process (AHP) and Weighted Product Model (WPM). The project construction's risks have been estimated using the cost, delay and quality criteria. The weighted criticality of each risk was determined according to the project characteristics, the probability of occurrence, aggregate impact and the non-detectability factor.

**Keywords:** Risk assessment, AHP, WPM, multi-criteria decision analysis, project Risks

## Introduction

Algeria's economy mainly depends on hydrocarbons exportation as many third world countries. Pipelines are often used to ensure the conveying of gas and oil from extraction wells to operating workshops. Thus, pipeline installation projects are necessary for effecting the transportation operation. Risk management is a very important task that is considered as an integral part of project management. Any new creation generates uncertainties and shadows. It is therefore important to master the potential threats to achieve the objectives set. The project risks become more important than the project during their life cycle which was increasingly complicated, either by their technical nature or by the multiplicity of project team (Marle, 2012; Jolanta *et al.*, 2013 and Nahal and Khelif, 2019).

Saaty has developed a structured technique for analyzing and organizing complex decisions, which Known as the Analytical Hierarchy Process, based on mathematics and psychology (Brebba, 2014; Kumar and Dash, 2016). The aim of AHP is to quantify the relative priorities of an alternative given set on a ratio scale, based on a decision-maker judgment, and emphasizes the importance of a decision-maker intuitive judgments as well as the consistency of comparing alternatives in decision-making process (Singh and Harwinder, 2018).

In fact, a decision maker judgment is based on knowledge and experience, and then the decisions can be made accordingly, the AHP approach fits well with a decision-maker behavior. The approach strength consists in organizing tangible and intangible

---

<sup>1</sup> Department of Mechanical Engineering, University of Badji Mokhtar of Annaba, P. O. Box 12, 23000 Annaba, Algeria. Tel. 213.550770622.

<sup>2</sup> Department of Mechanical Engineering, University of Mohamed Cherif Messaadia of Souk Ahras, P.O. Box 1553, 41000 Souk Ahras, Algeria. Tel. 213.776014763 ; E-mail: c.moumni@univ-soukahras.dz

\* Corresponding author

factors systematically and offers a structured solution to decision-making problems (Skibniewski and Chao, 1992).

Several authors have exploited the AHP approach and integrated it with other methods to achieve different objectives, we can mention:

Al-Subhi Al-Harbi (2001) applied AHP in the field of project management to select the best contractor. He constructed a hierarchical structure for the prequalification criteria, and the contractors who wish to qualify for the project. In all, five contractors were considered in the case study. Each of the contractors was compared pair-wise with the other for the different criteria "experience, financial stability, quality performance, manpower resources, equipment resources, and current workload".

Badri *et al.* (2012) propose a novel risk-factor-based approach comprising eight steps and allowing the integration of occupational health and safety (OHS) risks, based on identifying elements of risk and on a new concept of risk factor concentration weighted by multi-criteria comparison. The identification and assessment of OHS risks are integrated upstream in the risk analysis process in order to increase the effectiveness of the preventive measures taken at the start of the project.

The approach proposed by Ben Romdhane *et al.* (2007) consists in replacing the calculation of total criticality of the Failure Mode and Effects Analysis (FMEA) method by a fuzzy inference engine delivering five different criticalities which measure effectively and separately the impact of a failure on the personnel, the environment, the equipment, the production and management. In order to refine the relevance of the decision-making the authors used multi-criteria method AHP to build a matrix of criticality.

Wang *et al.* (2008) proposes a new integrated AHP - DEA methodology to evaluate the risks of hundreds of bridge structures.

The proposed AHP-DEA methodology uses only the AHP to determine the weights of criteria, linguistic terms such as High, Medium, Low and None to assess bridge risks under each criterion, DEA model with common weights to determine the values of the linguistic terms, and the simple additive weighting method to aggregate the bridge risks under different criteria into an overall risk score of each bridge structure.

Kanyarat *et al.* (2017) were conducted a study about the security factors of Human Resources Information System (HRIS) where Analytic Hierarchy Process (AHP) is used as a tool, also the importance of each factor influencing the work climate has been explored. The experimental result of this study shows that the most important found factor is the confidentiality followed by the non-repudiation and

privacy. However, the nature of organization can influenced the variability of the ranks of factors. Moreover, the most important aspect for supporting security is management followed by technology and organizational culture. The priority of each factor has been reflected by the obtained rankings for companies to achieve the open work climate. For giving insights into managerial concern, the organizational factors nurturing HRIS's security were ranked.

Based on Analytic Hierarchy Process approach, Anna and Wojciech (2019) in their paper entitled (Multi-criterial analysis of oversize cargo transport through the city, using the AHP method.) has confirmed the suitability of a multi-criterial method for determining the best transport route used in the city of Szczecin (Poland). Two parameters have been selected, the departure point and the destination point for the oversize cargo in the city of Szczecin based on the available data which concern the road condition and the infrastructure of tramway as well as the engineering projects underway. In accordance with these assumptions, three alternative routes have been selected for the transport of oversize cargo. The result of this research based on conducting AHP method and developing the tree of hierarchy shows that the highest general priority is given by route T3 (0.6750), which explain that route T3 is the most preferred for the transport. Therefore, the AHP method has shown its usefulness and objectivity in this study.

The paper of Devatha and Kumar (2019) presents a logical procedure that is used to manage a set of alternatives to achieve the rabi culture model through a multiple attribute decision making (MADM) approach. The study area concerns the akaltara branch canal banahil distributor of Hasdeo Bango Irrigation Command, Janjgir Champa district, Chattisgarh, India. It covers 8 villages of Akaltara block and 14 villages of Pamgarh block in Janjgir-Champa district. The results obtained by the MADM approach are evaluated and compared to the results of the LINGO standard optimization software package.

The summary of this research can be stated as follow:

1. Different attributes types such as. cultivated area, water use, crop selling price, cultivation cost, agricultural production were decided for each crop based on the importance of optimal cultivation pattern from the information collected.

2. Four methodologies namely: simple additive weighting (SAW), weighted product method (WPM), technique for order preference by similarity to ideal solution (TOPSIS) and preference ranking organization method for enrichment evaluations (PROMETEE) from MADM were used to make the culture model.

**Table 1. AHP measurement scale proposed by (Saaty and Kearns, 1991)**

| Numerical scale | Verbal scale                                                                               | Description                                                                     |
|-----------------|--------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| 1               | Equal importance of both criteria:<br><b>Also important</b>                                | Both criteria contribute as much to the father criterion.                       |
| 3               | Low importance of one criterion compared to another:<br><b>Slightly more important</b>     | Personal experience and appreciation slightly favor one element over another.   |
| 5               | Strong or determining importance of one criterion over another:<br><b>Highly important</b> | Personal experience and appreciation strongly favor one criterion over another. |
| 7               | Importance of one criterion over another:<br><b>Very strongly more important</b>           | A criterion is strongly favored and its dominance is attested in practice.      |
| 9               | Absolute importance of one criterion over another:<br><b>Absolutely more important</b>     | Evidence favoring one criterion over another is as convincing as possible.      |

3. The results obtained for SAW and WPM were slightly different, perhaps due to the weights assigned to each attribute, but not in comparison to the attributes.

4. The results obtained from TOPSIS and PROMETHEE showed good judgment in ranking the alternatives. These methods have been shown to be effective in acquiring various attribute information for comparison, ranking and selection of the optimal crop model. This method allows you to add or neglect any attribute depending on the importance of the criteria. It allows the decision maker to modify or select the importance of the criteria in relation to the objective of the study.

5. MADM's results have been evaluated against the results of the LINGO model and are satisfactory. Quick decisions can be made based on the MADM approach.

The objective of this paper is to provide a risk project manager using the two approaches AHP and WPM for assessing a pipeline project installation risks. A brief review of the multiple criteria decision analysis concepts, AHP's and WPM implementation steps, and also the paper demonstrate an AHP application for assessing problem of all kinds of project risks. The found results encourage its application in the whole field of risk management of different projects.

### The Analytic Hierarchy Process

The analytic hierarchy process, was developed by Saaty at Wharton School of Business, allows decision makers to model a complex problem in a hierarchical structure showing the relationships between goal, objectives (criteria), sub-objectives, and alternatives as presented in (Figure 1). Uncertainties and other influencing factors can also be included.

### The Method Steps

The AHP method has three phases:

### Hierarchies Construction

This phase consists of breaking down the decision problem in the main components. Then, the construction hierarchy can be operated according to top-down approach. This can lead to structuring the complex reality in a hierarchical tree (Forman and Selly, 2000).

### Priorities Establishment

The definition of priorities was done by binary comparisons between hierarchy's criteria of the same level.

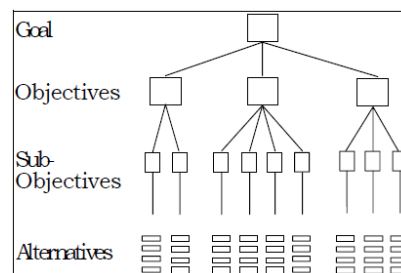
The notion of RIC (The Relative Importance of Criteria) or "Weight" applied to hierarchy can be found in this step, corresponding to decision-makers preference for a criterion compared to another using the rating scale presented in Table 1.

The pairwise comparisons were presented in a square matrix, reciprocal, of  $n$  dimension, denoted  $M = (m_{ij})$  where  $m_{ij}$ , represents the importance of  $g_i$  over relative to  $g_A$  and is such that:

$$m_{ij} > 0 \quad i, j = 1, \dots, n \quad (1)$$

The comparison of a criterion with itself gives unity:

$$m_{ii} = 1 \quad i = 1, \dots, n \quad (2)$$

**Figure 1. Decision Hierarchy (Forman, 2000)**

The matrix transposition positions are calculated according to reciprocity axiom (Forman and Selly, 2000):

$$m_{i,j} = \frac{1}{m_{j,i}} \quad i, j = 1, \dots, n \quad (3)$$

The summer step of appreciations allows to evaluating the RIC from the assessments formulated during the pairwise comparison process. The RIC form transformed to a vector :

$$W = (w_1, w_2 \dots w_n) \quad (4)$$

Where  $w_i$  is the relative importance of the criterion  $g_i$  in relation to its family of belonging. The vector  $W$  can be obtained by calculating the normalized matrix  $M$  average of each column (Saaty and Kearns, 1991).

### Logical Coherence

The AHP method suggests a consistency index (CI) calculated for measuring the gap between decision-makers responses and deemed consistent responses. According to (Saaty and Kearns, 1991) assessments are considered acceptable if the difference measure is less than 0.1, in the case of coherent appreciations, we have :

$$m_{i,j} = \frac{w_i}{w_j} \quad i, j = 1, \dots, n \quad (5)$$

$$\text{And } M.W = n.W \quad (6)$$

The matrix  $M$  has a unit rank (each matrix row can be obtained by multiplying the first row by a constant), all its eigenvalues  $\lambda_i$  are null, except one verify the following equality:

$$\sum_{i=1}^n \lambda_i = \text{trace}(M) = n \quad i = 1, \dots, n \quad (7)$$

Where, the trace is the matrix diagonal element sum,  $n$  is the matrix size.

The matrix maximum eigenvalue is  $\lambda_{max} = n$ . A simple method to approach  $\lambda_{max}$  is to consider:

$$W' = M.W = (w_i) \text{ so : } \lambda_{max} = \frac{1}{n} \sum_{i=1}^n \frac{w_i'}{w_i} \text{ where } i = 1, \dots, n \quad (8)$$

Thus, the matrix is coherent, when their maximum eigenvalue and dimension are equal.

Otherwise, an incoherent matrix for which:

$\exists i, j, k$  such as  $m_{i,j} \neq m_{j,k} \cdot m_{k,i}$ , we have  $\lambda_{max} > n$ . The consistency index  $CI$  is then obtained by calculating (Jolanta *et al.*, 2013):  $CI = \frac{\lambda_{max} - n}{n-1}$  (9)

If the matrix is coherent,  $CI = 0$ .

The consistency ratio is deduced by the formula :

$$CR = \frac{CI}{RI} \quad (10)$$

$RI$  is a random index which its value depends on the matrix size according to the values presented in Table 2 (Saaty and Kearns, 1991).

**Table 2. Average random consistency (Saaty and Kearns, 1991)**

| n  | RI   |
|----|------|
| 1  | 0    |
| 2  | 0    |
| 3  | 0.58 |
| 4  | 0.9  |
| 5  | 1.12 |
| 6  | 1.24 |
| 7  | 1.32 |
| 8  | 1.41 |
| 9  | 1.45 |
| 10 | 1.49 |

The hierarchy is considered consistent if  $CR$  respects the following values : if the size of the matrix is 3,  $CR = 0.05$

If the size of the matrix is 4,  $CR = 0.08$

If the size of the matrix is 5 or more,  $CR = 0.10$

### The WPM Method

WPM is a multi-criteria decision support method allows comparing alternatives against several criteria. This comparison is made by dividing the criteria value's by one of them, then performing reports multiplication. The equivalent power of each ratio is raised to the corresponding criterion weights. The method formula is described as :

$$P(A_K/A_L) = \prod_{j=1}^n (a_{Kj}/a_{Lj})^{w_j}, \quad K, L = 1, 2, 3, \dots, m \quad (11)$$

Where  $n$  is the criteria number,  $m$  the alternatives number,  $w_j$  the weight of  $j$  criterion,  $A_K$  and  $A_L$  two alternatives to compare and  $a_{Kj}$ ,  $a_{Lj}$  the weights of alternatives,  $A_K$  and  $A_L$  according to the  $j$  criterion.

The overall alternative weight can also be calculated according to equation 12 which represents an alternative to using WPM method (Kolios *et al.*, 2016).

$$P(A_K) = \prod_{j=1}^n (a_{Kj})^{w_j}, \quad K = 1, 2, 3, \dots, m \quad (12)$$

### The AHP / WPM Approach for Project Risk Assessment

The used approach can assess the construction project-risks of pipeline installation (CPRPI), through the "weighted criticality" notion. The

objective was to formulate a criterion prioritization defining the major risks that will be the subject of the treatment of actions.

This criticality will be calculated using AHP / WPM the multi-criteria methods in two phases:

- The each risk “aggregate impact” Calculate according to the three project characteristics: Delay, Cost and Quality.
- The weighted criticality definition of each risk according to three characteristics: the probability of occurrence, the aggregate impact and the non-detectability coefficient.

### The Risk Aggregate Impact Definition

To determine the risk aggregate impact, we have to apply binary comparisons between level 1 criterion (delay, cost, quality) of Figure 2 in order to build the corresponding performance matrix. Then, the sub criteria located at the second level of the same figure have to be performed as pairwise comparisons, in relation to three criteria located at the higher level either in relation to : delay, cost and quality.

The level 2 will be composed of N project risks.

By following the steps of implementation of the AHP method described above, we obtain the weight vector corresponding to these three parameters. Following AHP method steps described above, we obtain the vector weight corresponding to these three criteria.

We proceed in the same way for the second level elements by comparing two out of two risks in terms of cost, delay and quality in order to obtain the weights of each risk for each parameter.

The method result is presented in Table 3.

Where  $P_d$ ,  $P_c$  and  $P_q$  respectively denote the weights of Delay, Cost and Quality parameters.  $[P_{R1d} P_{R2d} \dots P_{RNd}]$  the risk weight vector  $R_i, i=1 \dots N$  relative to the Delay parameter.

Then, we classify the risks according to their weight for each parameter by assigning each weighted criterion according to its classification and following the values specified in Table 4.

From Equation 12, we calculate the risk aggregate impact (Equation 13):

$$I_{Ri} = (P_{Rid})^{P_d} \cdot (P_{Ric})^{P_c} \cdot (P_{Riq})^{P_q} \quad (13)$$

### The Weighted Criticality Definition of Each Risk

We check the consistency of the three criteria: probability of occurrence ( $P$ ), aggregate impact ( $I$ ), and non-detectability coefficient ( $ND$ ) for hierarchy verification (Figure 3).

Figure 3 represents the hierarchy of risks criticality, to determine the criticality via a comparison between the criteria of this level such

as: the occurrence probability, aggregate impact and nondetectability coefficient, then deduce the vector corresponding  $[P_p P_i P_{Nd}]$  to the weights relating the three characteristics  $P, I, ND$ .

Using equation, the weighted criticality notion is defined as (Equation 14):

$$C = (P)^{P_p} \cdot (I)^{P_i} \cdot (ND)^{P_{ND}} \quad (14)$$

Where:

$C$  : weighted criticality,  $P$  : occurrence probability,  $I$  : aggregate impact,  $ND$  : Non-detectability,  $P_p$  : weight of occurrence probability,  $P_i$  : weight aggregate impact,  $P_{ND}$  : non-detectability weight.

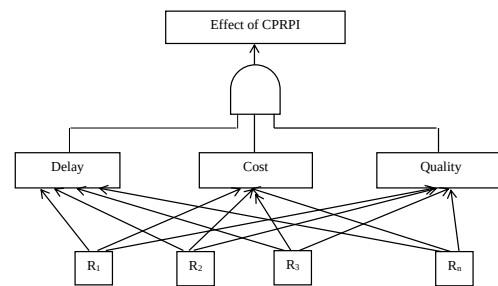


Figure 2. Hierarchical structure of the overall risk effect

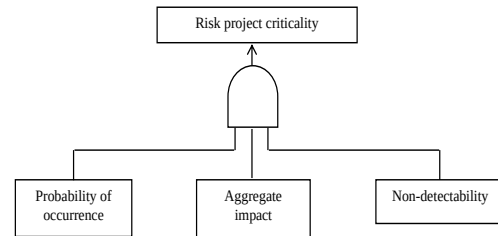


Figure 3. The risks criticality hierarchy

Table 3. Decision matrix to calculate the impact

|       | Delay     | Cost      | Quality   |
|-------|-----------|-----------|-----------|
|       | $P_d$     | $P_c$     | $P_q$     |
| $R_1$ | $P_{R1d}$ | $P_{R1c}$ | $P_{R1q}$ |
| $R_2$ | $P_{R2d}$ | $P_{R2c}$ | $P_{R2q}$ |
| $R_3$ | $P_{R3d}$ | $P_{R3c}$ | $P_{R3q}$ |
| ...   |           |           |           |
| $R_N$ | $P_{RNd}$ | $P_{RNc}$ | $P_{RNq}$ |

Table 4. Definition of standard risk weighting (Forman, and Selly, 2000)

| Risk ranking | Weighting assigned |
|--------------|--------------------|
| 1            | N                  |
| 2            | N-1                |
| 3            | N-2                |
| ...          | ...                |
| N            | 1                  |

## Case Study: Construction of a Pipeline Installation Project

### The Project Presentation

The studied project is related to a pipeline facility construction by Sonatrach, this Algerian state-owned is a company setup for research, exploitation, transportation, processing and marketing of hydrocarbons and their derivatives. It is also involved in other sectors such as power generation, new and renewable energy and desalination of sea water (Company Blog, 2018).

In this study, we will be interested in inherent risks during the project execution phases, which proceeds according to the steps presented in Figure 4.

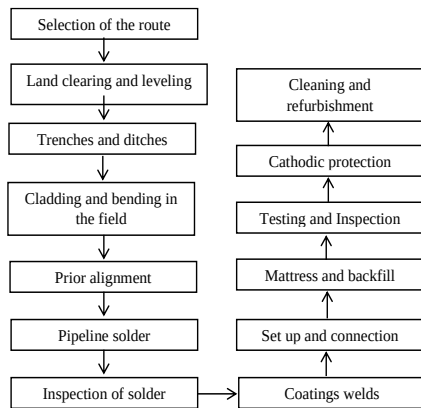


Figure 4. The steps in construction of a pipeline installation project

The aim of this study is to assess and prioritize the various risks that may affect the stages of project execution using the AHP / WPM approaches.

### Risk Identification

The identification phase consists of identifying risks which can be defeating the project objectives. Table 5 lists the 7 identified risks.

### Risk Assessment

This involves doing a risk analysis related to positions and prescribed work methods. All risks identified in Table 5 are considered.

The probability rating model is based on the approach developed by (Lichtenstein and Newman, 1967) evaluates occurrence probabilities. Table 6 shows the used values.

### The Non-Detectability Weights Definition

In some extreme environments where activities are dangerous for humans, detectability is a major parameter in risk characterization; Table 7 presents a rating scale of the non-detection probability on 5 levels.

Table 8 identifies the each risk occurrence probability values (P) and the non-detectability (ND).

### The Risks Impact Definition

Applying the implementation steps of AHP method, binary comparisons were made between the

Table 5. List of identified risks (Company Blog, 2018)

| Code | Risk identification                           |
|------|-----------------------------------------------|
| R1   | gear failure on site                          |
| R2   | Hardness of the ground                        |
| R3   | Opposition of passage in a proprietary ground |
| R4   | Incorrect operation                           |
| R5   | Flash fire                                    |
| R6   | Ground movement                               |
| R7   | Non-compliance with the Delay                 |

Table 6. Correspondence between declarative estimation and probabilistic

| Probability of appearance | Average probability |
|---------------------------|---------------------|
| Highly probable           | 0.89                |
| Probable                  | 0.79                |
| likeliest                 | 0.71                |
| Possible                  | 0.37                |
| Impossible                | 0.12                |
| unlikely                  | 0.11                |
| Highly unlikely           | 0.06                |

Table 7. Rating grid of non-detection probability

| Weight | Designation                        |
|--------|------------------------------------|
| 1      | Risk totally detectable very early |
| 2      | detectable risk early              |
| 3      | Moderately detectable risk         |
| 4      | weakly detectable risk             |
| 5      | Undetectable risk                  |

Table 8. Risks probability of occurrence and non-detectability

| code | Risk designation                                         | P    | ND |
|------|----------------------------------------------------------|------|----|
| R1   | gear failure on site (G.F.S.)                            | 0.71 | 3  |
| R2   | Hardness of the ground (H.G.)                            | 0.79 | 4  |
| R3   | Opposition of passage in a proprietary ground (O.P.P.G.) | 0.71 | 2  |
| R4   | Incorrect operation (I.O.)                               | 0.37 | 2  |
| R5   | Flash fire (F.F.)                                        | 0.71 | 3  |
| R6   | Ground movement (G.M.)                                   | 0.71 | 4  |
| R7   | Non-compliance with the Delay (N.C.W.D.)                 | 0.37 | 4  |

**Table 9. Standardized coherent matrix**

|                | Delay     | Cost | Quality | Sum of line | Weight (W)  |
|----------------|-----------|------|---------|-------------|-------------|
| <b>Delay</b>   | ½.33      | 3/6  | ½.5     | 1.33        | <b>0.44</b> |
| <b>Cost</b>    | 0.33/2.33 | 1/6  | 0.5/2.5 | 0.50        | <b>0.16</b> |
| <b>Quality</b> | ½.33      | 2/6  | ½.5     | 1.16        | <b>0.38</b> |

level 1 hierarchy criteria, then the weight (W) for each project objective was defined (Table 9).

The weighting of each criterion with weight (W) is to give for the decision maker the relative importance of a criterion in relation to its affiliation family (or in relation to another).

For example in Table 9 to determine the value of W, each row sum is divided based on the matrix size (n = 3).

So, a presentation model of a square matrix of order  $n \times n$  as following:

$$M = (m_{ij}) = \begin{bmatrix} 1 & 3 & 1 \\ 1/3 & 1 & 1/2 \\ 1 & 2 & 1 \end{bmatrix}$$

Consistency ratio determination CR: from Equation 9,  $CI = \frac{\lambda_{max} - n}{n-1}$

We calculate the maximum eigenvalue  $\lambda_{max}$ :

We multiply the matrix  $m_{ij}$  by the weight vector elements (W), then we calculate the found values average:

$$(0.44 \ 0.16 \ 0.38) \times \begin{bmatrix} 1 & 3 & 1 \\ 1/3 & 1 & 1/2 \\ 1 & 2 & 1 \end{bmatrix} = \begin{pmatrix} 1.30 \\ 0.49 \\ 1.14 \end{pmatrix}$$

The vector elements are divided by the weight corresponding to each criterion.

$$\begin{aligned} \text{Delay :} & \quad 1.30 / 0.44 = 2.95 \\ \text{Cost :} & \quad 0.49 / 0.16 = 3.06 \\ \text{Quality :} & \quad 1.14 / 0.38 = 3 \end{aligned}$$

We calculate  $\lambda_{max}$  according to Equation 7.

$$\lambda_{max} = \frac{1}{3} (2.95 + 3.06 + 3) = 3.003$$

So the consistency index :  $CI = \frac{3.003-3}{2} = 0.0015$

And the consistency ratio according to Equation 10:

$$CR = \frac{0.0015}{0.58} = 0.0025 \text{ or } 0.25\%$$

$CR < 0.05$  the consistency degree of comparison is acceptable.

The next step consist of perform the seven (07) sub-criteria pairwise comparisons, located at the second level, against three (3) criteria located at the next level, or in relation to : delay, cost and quality. Starting with the criteria delay:

$$M = \begin{bmatrix} 1 & 1/3 & 1/3 & 3 & 1 & 3 & 3 \\ 3 & 1 & 2 & 3 & 3 & 1 & 1 \\ 3 & 1/2 & 1 & 3 & 3 & 2 & 3 \\ 1/3 & 1/3 & 1/3 & 1 & 1/3 & 1/3 & 2 \\ 1 & 1/3 & 1/3 & 3 & 1 & 2 & 3 \\ 1/3 & 1 & 2 & 3 & 1/2 & 1 & 3 \\ 1/3 & 1 & 1/3 & 1/2 & 1/2 & 1/2 & 1 \end{bmatrix}$$

Consistency ratio determination (CR):

The matrix  $m_{ij}$  will be multiplying by vector elements weight's W (Table 10) then, the found values average will be calculated as:

$$(0.14 \ 0.22 \ 0.21 \ 0.06 \ 0.13 \ 0.16 \ 0.08) \times \begin{bmatrix} 1 & 1/3 & 1/3 & 3 & 1 & 3 & 3 \\ 3 & 1 & 2 & 3 & 3 & 1 & 1 \\ 3 & 1/2 & 1 & 3 & 3 & 2 & 3 \\ 1/3 & 1/3 & 1/3 & 1 & 1/3 & 1/3 & 2 \\ 1 & 1/3 & 1/3 & 3 & 1 & 2 & 3 \\ 1/3 & 1 & 2 & 3 & 1/2 & 1 & 3 \\ 1/3 & 1 & 1/3 & 1/2 & 1/2 & 1/2 & 1 \end{bmatrix} = \begin{pmatrix} 1.3 \\ 1.78 \\ 1.76 \\ 0.4 \\ 1.04 \\ 1.24 \\ 0.5 \end{pmatrix}$$

The vector elements are divided by the corresponding weight to each criterion.

$$\begin{aligned} \text{G.F.S.:} & \quad 1.3 / 0.14 = 9.28 \\ \text{H.G.:} & \quad 1.78 / 0.22 = 8.09 \\ \text{O.P.P.G.:} & \quad 1.76 / 0.21 = 8.3 \\ \text{I.O.:} & \quad 0.4 / 0.06 = 6.66 \\ \text{F.F.:} & \quad 1.04 / 0.13 = 08 \\ \text{G.M.:} & \quad 1.24 / 0.16 = 7.75 \\ \text{N.C.W.D.:} & \quad 0.5 / 0.08 = 6.25 \end{aligned}$$

We calculate  $\lambda_{max}$ :

$$\lambda_{max} = \frac{1}{7} (9.28 + 8.09 + 8.3 + 6.66 + 08 + 7.75 + 6.25) = 7.76$$

$$\text{So the consistency index: } CI = \frac{7.76-7}{6} = 0.12$$

$$\text{The consistency ratio: } CR = \frac{0.12}{1.32} = 0.09 \text{ or } 09\%$$

$CR = 09\% < 10\%$  the consistency degree of comparison is acceptable. Even steps to calculate

**Table 10. Standardized coherent matrix for delay**

| Delay    | G.F.S.    | H.G.      | O.P.P.G.  | I.O.      | F.F.      | G.M.      | N.C.W.D. | Sum of line | W           |
|----------|-----------|-----------|-----------|-----------|-----------|-----------|----------|-------------|-------------|
| G.F.S.   | 1/8.99    | 0.33/4.49 | 0.33/6.32 | 3/16.50   | 1/9.33    | 3/9.83    | 3/16     | 0.99        | <b>0.14</b> |
| H.G.     | 3/8.99    | 1/4.49    | 2/6.32    | 3/16.50   | 3/9.33    | 1/9.83    | 1/16     | 1.54        | <b>0.22</b> |
| O.P.P.G. | 3/8.99    | 0.5/4.49  | 1/6.32    | 3/16.50   | 3/9.33    | 2/9.83    | 3/16     | 1.47        | <b>0.21</b> |
| I.O.     | 0.33/8.99 | 0.33/4.49 | 0.33/6.32 | 1/16.50   | 0.33/9.33 | 0.33/9.83 | 2/16     | 0.42        | <b>0.06</b> |
| F.F.     | 1/8.99    | 0.33/4.49 | 0.33/6.32 | 3/16.50   | 1/9.33    | 2/9.83    | 3/16     | 0.89        | <b>0.13</b> |
| G.M.     | 0.33/8.99 | 1/4.49    | 2/6.32    | 3/16.50   | 0.5/9.33  | 1/9.83    | 3/16     | 1.13        | <b>0.16</b> |
| N.C.W.D. | 0.33/8.99 | 1/4.49    | 0.33/6.32 | 0.5/16.50 | 0.5/9.33  | 0.5/9.83  | 1/16     | 0.56        | <b>0.08</b> |

**Table 11. The Cost Pair-wise comparison matrix**

| Cost     | G.F.S.    | H.G.       | O.P.P.G.  | I.O.     | F.F.       | G.M.     | N.C.W.D.   |
|----------|-----------|------------|-----------|----------|------------|----------|------------|
| G.F.S.   | 1/9.56    | 5/14.66    | 0.14/2.87 | 3/20.5   | 5/11.86    | 3/13.2   | 2/13.83    |
| H.G.     | 0.2/9.56  | 1/14.66    | 0.2/2.87  | 3/20.5   | 3/11.86    | 1/13.2   | 0.5/13.83  |
| O.P.     | 7/9.56    | 5/14.66    | ½.87      | 5/20.5   | 2/11.86    | 2/13.2   | 3/13.83    |
| P.G.     |           |            |           |          |            |          |            |
| I.O.     | 0.33/9.56 | 0.33/14.66 | 0.2/2.87  | 1/20.5   | 0.33/11.86 | 0.2/13.2 | 2/13.83    |
| F.F.     | 0.2/9.56  | 0.33/14.66 | 0.5/2.87  | 3/20.5   | 1/11.86    | 3/13.2   | 5/13.83    |
| G.M.     | 0.33/9.56 | 1/14.66    | 0.5/2.87  | 5/20.5   | 0.33/11.86 | 1/13.2   | 0.33/13.83 |
| N.C.W.D. | 0.5/9.56  | 2/14.66    | 0.33/2.87 | 0.5/20.5 | 0.2/11.86  | 3/13.2   | 1/13.83    |

= 7.61, CI = 0.1, CR = 0.09 < 0.1

**Table 12. The Quality Pair-wise comparison matrix**

| Quality   | G.F.S.    | H.G.     | O.P.P.G.  | I.O.      | F.F.      | G.M.   | N.C.W.D. |
|-----------|-----------|----------|-----------|-----------|-----------|--------|----------|
| G.F.S.    | 1/9.66    | 3/12.7   | 0.5/13.83 | 0.5/3.06  | 2/6.36    | 3/12   | 2/20     |
| H.G.      | 0.33/9.66 | 1/12.7   | 5/13.83   | 0.2/3.06  | 0.33/6.36 | 1/12   | 2/20     |
| O.P.P.G.  | 2/9.66    | 0.2/12.7 | 1/13.83   | 0.33/3.06 | 0.5/6.36  | 0.5/12 | 3/20     |
| I.O.      | 5/9.66    | 5/12.7   | 3/13.83   | 1/3.06    | 2/6.36    | 3/12   | 5/20     |
| F.F.      | 0.5/9.66  | 3/12.7   | 2/13.83   | 0.5/3.06  | 1/6.36    | 3/12   | 5/20     |
| G.M.      | 0.33/9.66 | 1/12.7   | 2/13.83   | 0.33/3.06 | 0.33/6.36 | 1/12   | 2/20     |
| N.C.W. D. | 0.5/9.66  | 0.5/12.7 | 0.3/13.83 | 0.2/3.06  | 0.2/6.36  | 0.5/12 | 1/20     |

= 7.8, CI = 0.13, CR = 0.098 < 0.1

**Table 13. Risk weight according to delay, cost and quality parameters**

|    | Delay | Cost  | Quality |
|----|-------|-------|---------|
| R1 | 0,14  | 0,25  | 0,17    |
| R2 | 0,22  | 0,094 | 0,11    |
| R3 | 0,21  | 0,31  | 0,09    |
| R4 | 0,06  | 0,04  | 0,32    |
| R5 | 0,13  | 0,14  | 0,175   |
| R6 | 0,16  | 0,05  | 0,08    |
| R7 | 0,08  | 0,09  | 0,04    |

**Table 14. The risk impact decision matrix and the aggregate impact**

|    | Delay | Cost | Quality | Aggregate impact |
|----|-------|------|---------|------------------|
|    | 0,44  | 0,16 | 0,38    |                  |
| R1 | 4     | 6    | 5       | 4,5              |
| R2 | 7     | 4    | 4       | 4,9              |
| R3 | 6     | 7    | 3       | 4,5              |
| R4 | 1     | 1    | 7       | 2,1              |
| R5 | 3     | 5    | 6       | 4,1              |
| R6 | 5     | 2    | 2       | 2,9              |
| R7 | 2     | 3    | 1       | 1,6              |

the parameters of cost (Table 11) and quality (Table 12) criterion.

The weights of each identified risk according to the three characteristics : delay, cost and quality are presented in Table 13.

The risk weights were classified according to each parameter, a standard weight was assigned according to values in Table 6. Table 14 presents the impact risks decision matrix and the aggregate risk impacts were obtained by using Equation 12.

The relative weights to occurrence probability, the aggregate impact and the non-detectability are defined.

**Table 15. Standardized coherent matrix**

|    | PO        | I         | ND  | Sum of line | w           |
|----|-----------|-----------|-----|-------------|-------------|
| PO | ½,33      | ½,25      | 3/8 | 1,24        | <b>0,41</b> |
| I  | ½,33      | ½,25      | 4/8 | 1,37        | <b>0,46</b> |
| ND | 0,33/2,33 | 0,25/2,25 | 1/8 | 0,38        | <b>0,13</b> |

= 3.003, CI = 0.015, CR = 0.0025 < 0.05

**Table 16. Identified risks prioritization**

|    | PO   | I    | ND   | Weighted Criticality | Rank |
|----|------|------|------|----------------------|------|
|    | 0,41 | 0,46 | 0,13 |                      |      |
| R1 | 0,71 | 4,5  | 3    | 1,96                 | 2    |
| R2 | 0,79 | 4,9  | 4    | 2,21                 | 1    |
| R3 | 0,71 | 4,5  | 2    | 1,86                 | 4    |
| R4 | 0,37 | 2,1  | 2    | 1                    | 6    |
| R5 | 0,71 | 4,1  | 3    | 1,88                 | 3    |
| R6 | 0,71 | 2,9  | 4    | 1,66                 | 5    |
| R7 | 0,37 | 1,6  | 4    | 0,97                 | 7    |

$$M = (m_{i,j}) = \begin{bmatrix} 1 & 1 & 3 \\ 1 & 1 & 4 \\ 1/3 & 1/4 & 1 \end{bmatrix}$$

Table 15 presents the standardized coherent matrix.

The weighted criticality for each risk was calculated by using Equation 14, which will be the hierarchy basis. The found results are presented in Table 16.

This classification allows the decision maker to judge that the most critical risk is R2, the ground's hardness, due to high values of: probability of occurrence, aggregate impact and coefficient of non-detectability. This risk affects more the project smooth running; therefore it requires rigorous treatment and control compared to risks R1 and R5.

## Conclusions

The two approaches AHP and WPM were integrated for assessing a pipeline construction project risks. The proposed approach is a decision-making method allows multiple criteria consideration. The work novelty is given by integrating the two approaches which allows the decision maker to select the risks in order of importance and also can dealing with the case of risks dependencies.

The definition of weighted criticality notion was used for risks prioritization. This approach is used to remedy the limits of the classical criticality notion, as used in the FMECA method. The ability of this approach to structure a complex and multidimensional problem in a hierarchical manner, reduces waste of time and improves the decision making precision, which is not the case in the SAW method adapt for one-dimensional problems, and even for the VIKOR method (Compromise Ranking method) where in case of contradictory criteria, a decision maker have also to take into account imprecise or ambiguous data.

The practical use of the method has been tested on a real construction project of a pipeline installation in order to determine the critical risks threatening the achievement of project objectives.

## Acknowledgment

The authors would like to express their greatest gratitude to the Algerian General Direction of Scientific Research and Technological Development for supporting this project (A01L09UN410120200 001) without forgetting Sonatrach company people for their help.

## References

- Al-Subhi Al-Harbi, K.M. (2001). Application of AHP in project management. *Int. J. Project Manag.*, 19(1):19-27.
- Anna, E.W. and Wojciech, K. (2019). Multi-criterial analysis of oversize cargo transport through the city, using the AHP method. *Trans. Res. Proc.*, 39:614-623.
- Badri, A., Nadeau, S., and Gbodossou, A. (2012). Proposal of a risk-factor-based analytical approach for integrating occupational health and safety into project risk evaluation. *Acc. Anal. Prev.*, 48:223-234.
- Ben Romdhane, T., Ben Ammar, F., and Badreddine, A. (2007). Une approche par la logique floue pour l'optimisation multicritère de la prise de décision appliquée à l'AMDEC. *J. Dec. Sys.*, 16(4):505-544.
- Brebbia, C.A. (2014). *Risk analysis IX*. WIT press., ISBN: 978-1-84564-792-6.
- Company Blog. (2018). Sonatrach Business Blog. Available from: [www.sonatrach-dz.com/sonatrach-business-blog](http://www.sonatrach-dz.com/sonatrach-business-blog). Accessed date: Feb 18, 2018.
- Devatha, C.P. and Kumar T.A. (2019). Prioritizing cropping alternatives based on attribute specification and comparison using MADM models. *J. Saudi Soc. Agricul. Sci.*, 18:337-343.
- Forman, E.H. and Selly, M.A. (2000). *Decision by Objectives: How to Convince Others that you are Right*, Pre-publication book.
- Jolanta, T., Edmundas, K.Z., and Zenonas, T. (2013). Multi-criteria risk assessment of a construction project. *Procedia Comp. Sci.*, 17:129-133.
- Kanyarat, Ph., Bunthit, W., Worarat, K., and Suree, F. (2017). Rankings of the security factors of human resources information system (HRIS) influencing the open climate of work: using analytic hierarchy process (AHP). *Procedia Comp. Sci.*, 111:287-293.
- Kolios, A., Mytilinou, V., Minguez, E.L., and Saloni K. (2016). A comparative study of multiple-criteria decision-making methods under stochastic inputs. *Ener.*, 9:566.
- Kumar, A. and Dash, M.K. (2016). *Fuzzy optimization and multi-criteria decision making in digital marketing*. Business science reference., ISBN : 978-1-14666-8808-7.
- Lichtenstein, S. and Newman, J.R. (1967). Empirical scaling of common verbal phrases associated with numerical probabilities. *Psychon. Sci.*, 9(10):563-564.
- Marle, F. (2012). A multi-criteria decision-making process for project risk management method selection. *Int. J. Multicri. Dec. Mak.*, 2(2).
- Nahal, M. and Khelif, R. (2019). Numerical model for estimating time-dependent reliability of a corroding pipeline over its lifetime. *Int. J. Adv. Struct. Eng.*, 11:1-7.
- Saaty, T.L. and Kearns, K.P. (1991). *Analytical planning: the organization of systems. The analytic hierarchy process series, vol. 4*, RWS Publications Pittsburgh, USA.
- Singh, J. and Harwinder, S. (2018). *Strategic implementation of continuous improvement approach, improving the performance of small and medium- sized enterprises*. Springer Brief in Operations Management., ISBN: 978-3-319-93120-3.
- Skibniewski, M.J. and Chao, L. (1992). Evaluation of advanced construction technology with AHP method. *J. Construc. Eng. Manage.*, ASCE, 118(3):577-593.
- Wang, Y.M., Liu, J., and Elhag, M.S. (2008). An integrate AHP-DEA methodology for bridge risk assessment. *Comp. Indus. Eng.*, 54:513-525.