Oil & Gas Projects Alternative Selection using Analytic Hierarchy Process - A Case Study.

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Abstract: During the feasibility phase of Oil & Gas projects, several solutions are developed and, before Board of Directors sanction, the Top Management needs to be informed about the most promising solution which could be selected to achieve the project goals. Considering that not for all the solutions the design can be fully developed, the alternative selection is normally carried out through a qualitative and relatively subjective analysis: typically the criticality ranking after the Hazard Identification (HAZID). To overcome the uncertainties of this analysis a more detailed and objective approach can be used: the Analytic Hierarchy Process (AHP). This paper describes how the best alternative against several offshore/onshore pipeline routes has been selected. The AHP has been applied just after the HAZID session to take advantage of the knowledge of design specialists belonging to different disciplines. This methodology allows to completely compare different solutions and to mathematically select the best project alternative from all the technical points of view, providing clear justifications for this choice. Finally, through a simple "benefits to costs ratios" analysis, also the costs, deliberately set aside until the benefits of the alternatives are assessed, are included in the analysis and the most promising solution can be identified.

Keywords: AHP, Decision Making, Safety Management, Pipeline Route Selection, Cost Benefit.

1. INTRODUCTION

During this recent stagnation of the economy, the Oil & Gas projects are suffering the decline of profits and the increase of costs. In this context, for the new projects, the selection among several options cannot be carried out after a complete basic design but has to be anticipated during the feasibility phase. At this stage not all the information are available: the uncertainties are high and the selection of the best option on the basis of a robust cost estimation is not possible. Moreover, selections based only on hazard identification or on simplified risk index methods can be affected by subjectivity.

For this reason, given the need of identifying the best alternative among very different options in the most accurate possible way even since the early design phase, the use of more objective and meticulous methodology, as the Analytic Hierarchy Process (AHP) developed in the 1970s by Thomas Saaty [1], has been attempted also in Oil & Gas field for the identification of the best pipeline route. The AHP is one of the best known and widely used mathematical decision making technique. The process uses human judgment to compare alternatives taking into account different criteria, on the basis of pairwise comparison (how important is A relative to B?). The AHP is a powerful and flexible decision making tool for complex, multi-criteria problems. It helps decision makers choose the best alternative, providing justifications for their choice.

2. CASE STUDY

The case study presented in this paper refers to pipeline route selection from a new offshore platform to an existing on-shore oil terminal. Several landfalls and onshore pipeline routes have been identified in order to assess the possibility of bringing the oil to the existing terminal by means of a pipeline (design pressure equal to 250 bar for offshore section and 150 bar for onshore section), instead of shuttle tankers.

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The aims of the whole project were

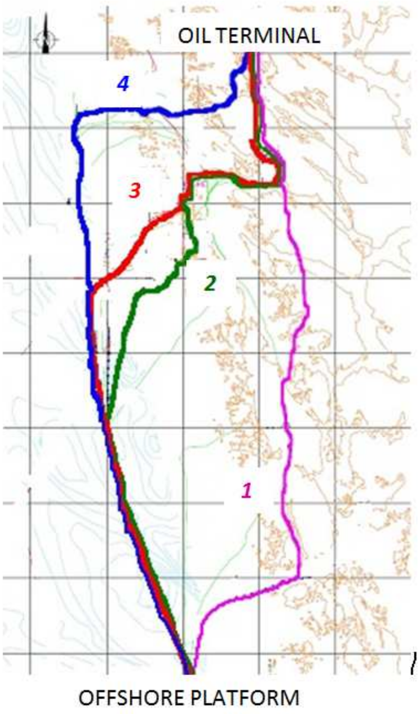
- ✓ to identify and characterize different feasible landfalls;
- ✓ to study possible pipeline routes from the identified landfalls to the oil terminal;
- ✓ to perform all the activities required to carry out cost estimates for the design, the construction and the laying of the pipeline;
- ✓ to point out areas where more detailed surveys were needed prior to the next design phase.

The routes of the pipeline have been selected having regard to the public safety, the pipeline integrity, the environmental impact and the consequences of escape of fluid, giving particular attention to the following items:

- topography and geology (seabed characteristics, soil properties, obstructions, seismic activity);
- environment (environmentally sensitive area, area of natural conservation interest, environmental conditions);
- constructability (accessibility, third party requirements, limited construction period, local constraints);
- proximity of on-shore sections to populated areas (present land use and expected change);
- third party activities (ship traffic, fishing activity, mining activities, military exercise areas);
- vicinity to existing facilities (plant, pipeline, cable) or future installations.

The four route options identified are shown in Figure 1.

Figure 1: Possible Pipeline Routes



3. ALTERNATIVE SELECTION

The activities performed by Loss Prevention Department of Saipem Fano premises were focused on the selection of the best alternative, in terms of landfall and route, for the pipeline that would have brought the oil from the new offshore platform to the existing oil terminal. These activities included the following steps:

- identification of the hazards related to a specific design choice, in terms of selected landfall, route or crossing method;
- assessment of the respective different risk levels;
- highlighting of the strong and weakness aspects of the possible alternatives;
- selection of the most promising pipeline route.

3.1. Hazard Identification

A multidisciplinary project team, led by a Chairman experienced in Hazard Identification and Risk Assessment process, has identified the potential hazards through a brainstorming analysis based on a guidewords approach, according to the technique described into the applicable international standard, i.e. ISO 17776 [2]. So, through a systematic review, all the critical health, safety, environmental, social related hazards have been identified and investigated, providing the necessary input to Project development decisions.

The guidewords list used during the analysis included threats related to design, fabrication, installation, hazardous material, fire hazards, corrosion, erosion, third party, natural hazard, environment and so on.

Since many of the hazards and Heath Safety Environment issues were common to the four alternatives, the brainstorming has been applied firstly to one of the alternatives (Route No. 3, which can be considered the base case in this analysis); then, the other alternatives have been analysed "by exception", on the basis of the worksheets developed for the first case, focusing on the risks typical of the alternative under study.

For any route, the procedure adopted during the meeting was the following:

- the Chairman nominated a category from the guidewords list and asked the team to consider each guideword belonging to the selected category;
- the team analysed each guideword to identify any credible hazard;
- the brainstorming process has been used to identify all the potential causes and effects of the hazard;
- the team analysed the appropriate controls or barriers that should be put in place to prevent or control each threat;
- the team assessed the risk corresponding to the hazard under study on the basis of the frequency of occurrence and the severity of the expected consequences of the event;
- finally, according to the calculated risk level, specific recommendations have been added in the worksheet, when required; since it is a feasibility phase, recommendations included both risk reduction measures to be implemented in the project and/or further detailed studies to be performed in the following design phases, considered necessary to address in detail the potential risk level related to some specific identified hazards (preventing the cause from occurring, detecting the cause before it develops into a hazard, mitigating consequences and alerting operators so that remedial actions may be taken).

The process has been completed once all the guidewords have been applied to all the routes. When a guideword has not been considered applicable to the node under analysis, it has not been included in the minute of the meeting (worksheets).

3.2. Risk Assessment

During the hazard identification meeting a semi-quantitative risk assessment has been performed in order to rank the risks associated to each pipeline route and to compare the alternatives with respect to risk level and possibility of risk reduction. The Risk Matrix used for the assessment is shown in Figure 2. The level of risk obtained for each hazard has been compared with the tolerability criteria defined by Client and international standards [3].

Three different colours classify the risk as:

1. Continuous improvement (CI, green): the level of risk is broadly acceptable and only generic control measures are required aimed at avoiding deterioration;
2. Risk reduction measure (RRM, yellow): the level of risk can be tolerable only once a structured review of risk-reduction measures has been carried out (for instance, by means of a cost and benefit analysis);
3. Intolerable Risk (IR, red): the level of risk is not acceptable; risk control measures are required to move the risk figure to the previous regions, otherwise the alternative shall be discarded.

How to define the frequency of occurrence and the consequence of hazard to be used in the risk matrix is described in the following subparagraphs.

Figure 2: Risk Matrix and Risk Acceptance Criteria

RISK MATRIX		*Hazard Frequency*				
		A Negligible	**B** Rarely	**C** Individually not expected	**D** Can occur once	**E** Can occur more than once
Consequence Severity	**1** Negligible	**A1**	**B1**	**C1**	**D1**	**E1**
	2 Minor	**A2**	**B2**	**C2**	**D2**	**E2**
	3 Moderate	**A3**	**B3**	**C3**	**D3**	**E3**
	4 Severe	**A4**	**B4**	**C4**	**D4**	**E4**
	5 Major	**A5**	**B5**	**C5**	**D5**	**E5**

The risk ranking performed for each identified potential hazard allowed understanding if the foreseen risk reduction measures and further studies were sufficient to guarantee a low enough risk level or if any additional recommendation was required.

3.2.1. Hazard Frequency

The following table shows the five frequency categories used in the risk matrix, shown in Figure 2. The assessment has been based on the Team consensus on the basis of qualitative definitions shown in Table 1.

Table 1: Frequency Classes

Frequency Class	Hazard Frequency in Quantitative terms	Hazard Frequency in Qualitative Terms
A	$< 10^{-5}$ occ/y	Negligible event
B	$10^{-5} \div 10^{-4}$ occ/y	Rarely expected to occur
C	$10^{-4} \div 10^{-3}$ occ/y	Individually not expected to happen, but when summarized over a large number of pipelines have the credibility to happen once a year
D	$10^{-3} \div 10^{-2}$ occ/y	Individually may be expected to occur during the lifetime of the pipeline
E	$> 10^{-2}$ occ/y	Individually may be expected to occur more than once during lifetime

3.2.2. Consequence Severity

The different consequence categories have been addressed separately, i.e. people/personnel safety, environmental and asset. For any hazard, the most severe consequence class assessed for the different targets has been used in order to define the associated risk level. Table 2 shows for each target the consequence categories used in the Risk Matrix shown in Figure 2.

Table 2: Consequence Severity Classes

Consequence Severity Class	People - Personnel	Environment	Asset
1. Negligible	No or superficial injuries	Non, small or insignificant release on the environment < 10 ton	< 0.01 million Euro
2. Minor	Slightly injury, a few lost work days	Minor release that will be neutralized rapidly, 10 ÷ 100 tonnes	0.01 – 0.1 million Euro
3. Moderate	Major injury, long term absence	Moderate release that can easily be removed, 100 ÷ 1,000 tonnes	0.1 – 1 million Euro
4.Severe	Single fatality or permanent disability	Large release that can be removed 1,000 ÷ 10,000 tonnes	1 – 10 million Euro
5.Major	Multiple fatalities	Large release that cannot be removed and will use long time to be neutralized. > 10,000 tonnes	> 10 million Euro

3.2.3. Risk Assessment Results

The main results of Risk Assessment, starting point for AHP application aimed to best route selection, are shown in this subparagraph.

Route No. 3, selected as base case, as shown in Figure 3, was characterized by

- six recommendations;
- twelve hazard issues having an acceptable risk level (Continuous Improvement);
- four hazards belonging to Risk Reduction Measure area of Risk Matrix;
- one hazard with an Intolerable risk level.

Route No. 1, as shown in Figure 3, was characterized by

- six recommendations;
- twelve hazard issues having an acceptable risk level (Continuous Improvement);
- five hazards belonging to Risk Reduction Measure area of Risk Matrix; the additional hazard (in respect of base case) was related to the interface with several local authorities;
- two hazards with an Intolerable risk level; the additional one related to the presence of populated area.

Route No. 2, as shown in Figure 3, was characterized by

- seven recommendations;
- twelve hazard issues having an acceptable risk level (Continuous Improvement); the hazard characterized by a severity lower than that of the base case is the environmental pollution in case of pipeline leak: due to the different profile of the pipeline, in fact, the expected amount of oil release is lower than oil spill of base case;
- five hazards belonging to Risk Reduction Measure area of Risk Matrix; the additional hazard comparing with the base case is due to the presence of populated area;
- one hazard with an Intolerable risk level.

Route No. 4, as shown in Figure 3, was characterized by

- six recommendations;
- thirteen hazard issues having an acceptable risk level (Continuous Improvement); the additional hazard is due to the presence of three slopes near the shore approach requiring specific intervention works; the hazard with a severity lower than that of base case is the environmental pollution in case of pipeline leak;
- four hazards belonging to Risk Reduction Measure area of Risk Matrix;
- one hazard with an Intolerable risk level.

The risk associated to the hazards identified has been assessed as the risk before the implementation of recommendations. For the hazards characterized by medium (Risk Reduction Measure, RRM) or high (Intolerable, IR) risk level, adequate recommendations have been given, in order to reduce it.

Figure 3: Risk Levels of Hazards Identified for all the Routes (Route No. 3 is the base case; differences between other routes and base case are highlighted using different symbols)

Route No. 3		Hazard Frequency				
		A Negligible	**B** Rarely	**C** Individually not expected	**D** Can occur once	**E** Can occur more than once
Consequence Severity	**1** Negligible			□		
	2 Minor			□		□
	3 Moderate	□□□	□□□	□	□	□
	4 Severe	□□□□		□		
	5 Major					

Route No. 1		Hazard Frequency				
		A Negligible	**B** Rarely	**C** Individually not expected	**D** Can occur once	**E** Can occur more than once
Consequence Severity	**1** Negligible			□		
	2 Minor			□		□
	3 Moderate	□□□	□□□	□	□X	□X
	4 Severe	□□□□		□		
	5 Major					

Route No. 2		Hazard Frequency				
		A Negligible	B Rarely	C Individually not expected	D Can occur once	E Can occur more than once
Consequence Severity	1 Negligible			□		
	2 Minor			□		□
	3 Moderate	□□□◊	□□□	□	□◊	□
	4 Severe	□□□		□		
	5 Major					

Route No. 4		Hazard Frequency				
		A Negligible	B Rarely	C Individually not expected	D Can occur once	E Can occur more than once
Consequence Severity	1 Negligible			□		
	2 Minor			□		□
	3 Moderate	□□□●	□□□●	□	□	□
	4 Severe	□□□		□		
	5 Major					

3.3. Analytic Hierarchy Process Application

As a part of the HAZID meeting (to take advantage of the knowledge of design specialists belonging to different disciplines in order to rank the different alternatives under study), a dedicated analysis has been performed on the basis of the results of the hazard identification and risk assessment themselves and on the basis of the AHP theory.

The possible route alternatives have been compared each other considering the impact of the identified hazards on the following aspects (criteria):

- people safety,
- environment,
- technical challenge,
- impact on schedule.

The criteria ranking has been performed on the basis of the Client's opinions. The relative importance of one criterion over another has been determined by comparing all the criteria in pairs: the more important the criterion, the greater its influence on the selection of the best route is.

The relative priority of the criteria has been established by assigning a weight between 1 (equal importance) and 9 (extreme importance); the reciprocal of this value has been assigned to the other criterion in the pair. The scores given by the Client Representatives have been then normalized and averaged in order to obtain the weight for each criterion.

For all the criteria defined above, the possible alternatives have been compared each other considering the impact of the identified hazards. During the analysis, the rank of the alternatives has been defined individually by each HAZID meeting participant on the basis of his/her personal experience. For any pairing of alternatives, within each criterion, every alternative is awarded a score (again, on a scale between 1 – equally good - and 9 – absolutely better; for the scale of numbers please refer to [1]) according to how well one alternative meets the criterion under study compared to the other alternative. Then, the ratings of all the Alternative Ranking Meeting attendants have been normalized and averaged, once again.

Finally, after the meeting, the alternatives ratings have been combined with the criteria weights to obtain an overall score for each alternative: the extent to which the alternatives satisfied the criteria has been weighted according to the relative importance of the criteria.

In order to get the ranking of priorities from a pairwise matrix, as Dr. Thomas L. Saaty mathematically demonstrated, the eigenvector solution is calculated through the following steps:

1. the pairwise matrix is raised to powers;

2. the row sums are calculated and normalized;
3. these steps are iterated until the difference between the row sums in two consecutive calculations is smaller than a prescribed value.

These steps have been implemented in an in-house software, in order to speed-up the processing of the results of the Alternative Ranking Meeting.

3.3.1. Criteria Weights

The criteria ranking performed on the basis of the Client's opinions is shown in Table 3.

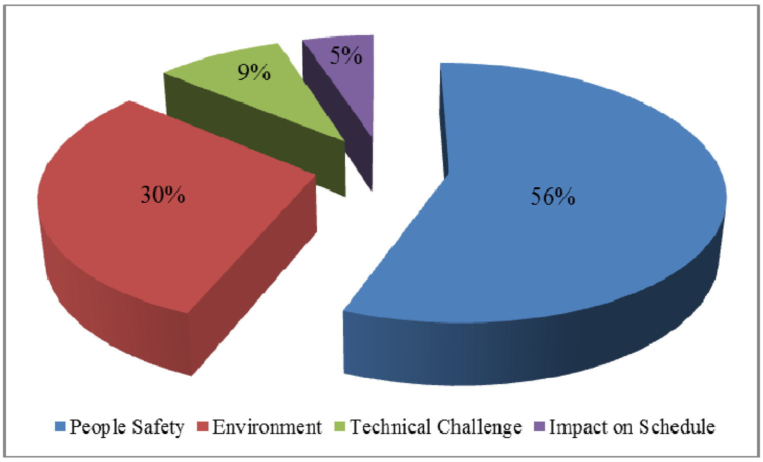
Table 3: Criteria Ranking – Pairwise Comparison

Criteria Ranking	People Safety	Environment	Technical Challenge	Impact on Schedule
People Safety	1.00	**3.00**	**6.00**	**7.00**
Environment	0.33	1.00	**5.00**	**6.00**
Technical Challenge	0.17	0.20	1.00	**3.00**
Impact on Schedule	0.14	0.17	0.33	1.00

For instance, the "People Safety" criterion has been assessed by the Client to be slightly more important than "Environment" criterion (value equal to 3), strongly more important than "Technical Challenge" criterion (value of 6) and very strongly more important than "Impact on Schedule" criterion (value of 7) for the selection of the best pipeline route.

Applying the Analytic Hierarchy Process, the resulting relevance of criteria is shown in Figure 4.

Figure 4: Criteria Weights



The most important criterion for route selection was to guarantee people safety, the second one to avoid environment pollution, the third one to select easy design and construction methods and the last one to minimize schedule delay.

3.3.2. Alternatives Ratings

The processed rank of the alternatives performed by the Project Team is shown in Table 4.

Table 4: Alternatives Ratings

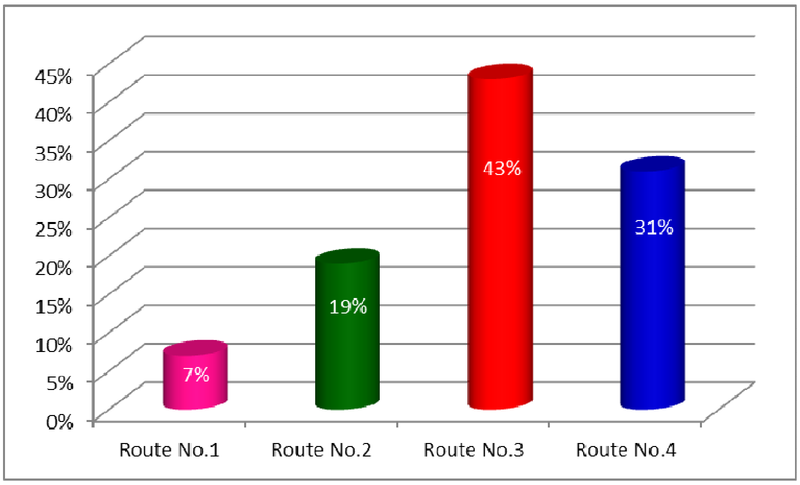
Alternatives Ratings	People Safety	Environment	Technical Challenge	Impact on Schedule
Route No. 1	6	8	13	6
Route No. 2	13	27	24	26
Route No. 3	**57**	9	**57**	**56**
Route No. 4	24	**56**	6	12

Route No. 3 was the best route from each point of view, except for the environment. From the point of view of the environment the best alternative was the Route No. 4. From this table can be inferred not only which one is the best route, but also the reasons why it is the most promising alternative, especially if it is read jointly with HAZID Worksheet.

3.3.3. Pipeline Route Scores

Finally, the scores calculated by means of AHP for each pipeline route is shown in Figure 5. As above, for convenience in this paper these scores (and all the priorities), usually summing to 1 (since they are normalized), have been indicated as per cents (i.e. they have been multiplied by 100). Nevertheless, as usual, the higher the value, the more promising the route is.

Figure 5: Resulted Scores of Pipeline Route



Route No. 3 was confirmed to be the best option among the four alternatives under study from all the technical points of view. Therefore, it should be taken into account in the next design phases.

3.3.4. Consistency Ratio

The consistency of all the judgments collected during the Alternative Ranking Meeting have been verified by means of the calculation of Consistency Ratio and Consistency Index [4]. The maximum found Consistency Ratio was equal to 0.08, lower than the threshold value of 0.1.

3.4. Benefit to cost ratios analysis

To finish, through a simple "benefit to cost ratios" analysis, also the costs, deliberately set aside until the benefits of the alternatives have been assessed, have been included in the analysis in order to identify the most promising solution, without politically influencing the choice.

The benefit to cost ratios calculated for the different route alternatives are shown in Table 5. They have been obtained dividing the benefits (i.e. the score calculated for each pipeline route, see Figure 5) by the normalized costs.

Table 5: Benefit to Cost Ratios

Alternative	Benefit to Cost Ratios
Route No. 1	1.23
Route No. 2	0.89
Route No. 3	**1.36**
Route No. 4	0.33

The greater the benefit to cost ratios value, the more attractive the project is.
In this case, also according to the benefit to cost ratios analysis the most promising alternative is route No. 3.

4. CONCLUSION

To perform an Alternative Ranking Meeting based on the Analytic Hierarchy Process just after the Hazard Identification session has been disclosed to be a very powerful approach to select the best alternative when several solutions and different criteria are concerned.

The possibility to collect the opinions of many specialists having very different background, already gathered for performing the HAZID, allows to perform a "broad-spectrum" selection, optimizing the schedule, minimizing the costs and, above all, taking advantage to the full of the experience of many several specialists involved in the Project.

AHP methodology applied to the judgments collected during the Alternative Ranking Meeting, followed by a simple "benefits to costs ratios" analysis, allows to have a complete picture of the situation under analysis, given not only indications on which is the best solution, but also explaining the reasons why it is the most promising one and how another solution can overpass the goodness of the alternative which at the moment seems to be the best one.

Especially, during the feasibility phase of Oil & Gas Projects, when HAZID session is usually already foreseen, to plan the Alternative Ranking Meeting as the final section of HAZID session is extremely suggested and useful to facilitate the right selection of which solution to be developed during the following design phases, on the basis of an objective and full analysis.

References

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