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A Risk-based analysis of Engineering Geology Failures in Pipeline Corridors Investigations

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Pipelines are safe and environmentally friendly means for transportation of oil and gas over long distanced areas. The investigation of the terrestrial corridors within which the pipeline systems are developed is a multidisciplinary and multitasking process of high complexity. This process is iterative and starts with examinations in a wide '*corridor of interest'* and then narrows down to a more defined route at each engineering/design stage insofar more data is acquired to a final zone (also known as: '*Right of Way'*-ROW) that is finally identified as appropriate for the pipeline erection/construction. The scope of this process is the performing of an integrated assessment of various corridor alternatives by considering critical environmental, geological, geotechnical, social factors and natural hazards as well. For this reason, teams consisting of experts from various disciplines of science and technology (managers, geologists, environmentalists, archaeologists, sociologists, surveying engineers, piping designers, etc.) make all necessary evaluations to produce appropriate assessments from which the most advantageous corridor can be demonstrated and selected in relation to criteria of technical feasibility, constructability, safety, environmental compliance, cost effectiveness, public acceptance and permitting.

The Engineering Geology investigation constitutes a significant and sensitive part of that process. The objective of geological investigation is the analysis of the consistency of stratigraphic and soil formations, the geographic, terrain and landform features and the determination of soil geotechnical properties within the corridors under examination. The interpretation of geological layouts and laboratory results from tests performed on material collected from boreholes and site tests, constitute an instrument providing inputs valuable for the structural designs of the buried pipeline sections. These inputs derived from investigations of pipeline route encroachments of instable/loose formations, active faults, erosive or rocky sites, steep slope locations, soils prone to buoyancy or liquefaction and water crossings. Even important for the quality and efficiency of the pipeline design studies is the consideration of historical seismic data and determination of the seismic action parameters in determining the earthquake effects to the pipeline body at the wider areas where the alternative corridors are to be developed.

The investigation of pipeline corridors is a combination of desktop studies, extended field surveys as well as soil sampling and laboratory testing works. It is common practice the route corridor investigations to be performed in the early stage of the pipeline projects, where various supply chain scenarios are under examination and the technical philosophy of the pipeline system at hand has not yet come to a level of solid technical maturity. This fact combined with a number of other factors such as, managerial deficiencies, lack of appropriate expertise, low cost investigations, tight time schedules, non-completely developed project organization and planning schemes and low reliability baseline data/studies, might generate failures with potential effects to the quality of the engineering and design studies. In terms of the Engineering Geology, these failure risks represent any low quality/reliability data of surface/subsurface geology, hydrogeology, tectonics and seismicity, which, once they have inserted in the designs and calculations of other technical/technological studies, generate risks inserting the entire pipeline project time and cost overruns.

There are several types of Engineering Geology failure causes observed pipeline route corridors investigations with crucial impact in the elaboration of basic and detailed engineering studies (topographical, civil, mechanical, pipeline crossing design, structural and stress analysis). The main categories of risk generating failures are:

(a) Incomplete or low performance site surveys: refers to failures in field data collection, improper fieldworks logistics, omissions in visiting areas of geological/geotechnical/hydrogeological concern, inadvertent soil sampling and drilling works, insufficient experience of site personnel, inappropriate evaluation of crossings morphology, non-availability of field instrumentation/equipment, reactions of local communities, landowners or stakeholders reactions against the geotechnical research, permitting dysfunctions and weather conditions;

(b) Desktop Analysis failures: refers to failures related to inappropriate spatial analysis of baseline geographical data of the under evaluation corridors, lack of remotely sensed and satellite imagery/spectral data, limitations of GIS/software capabilities, IT equipment and hardware defects, time elapsing in transforming conventional mapping products to digital form, etc.;

(c) Poor scientific background and evidence: refers to non-availability of previous substantial geological studies and surveys, misuse/misinterpretation of baseline maps, satellite imagery and remote sensing products and ortho-photo-rectified maps, poor literature reviews and scientific knowledge acquisition;

(d) Managerial dysfunctions: refers to failures caused by budgetary limitations, lack of managerial capabilities, poor planning, organizational limitations, non-finalized project scope definition, unjustified delays in decision-making, uncontrolled delays in obtaining permissions, lack of interface management and poor quality controls;

In view of the above, some reasonable research questions are raising up: is there any method of analyzing the nature of Engineering Geology failures and quantifying the associated risks? Is there any instrument of representing those failures into an ontology enabling probabilistic estimation(s) of risk failures? Are there any methods of examining risk-based scenarios analysis developed as a tool for project management improvement in pipeline contexts?

The objective of this paper is to suggest a methodology aiming to the better understanding/management of Engineering Geology failures based on application of quantitative methods and structured according to the following main tasks:

(i) Understanding, identification and classification of Engineering Geology Failures that insert risks in multidisciplinary investigations of pipeline route assessments;

(ii) Developing a Risk-based analysis of Engineering Geology failures using the Analytical Hierarchy Process (AHP) technique for obtaining the probability of occurrence of failure risk factors/sub-factors based on knowledge aggregation and empirical evidence of pipeline route experts and engineering geologists (see Table-1);

(iii) To represent the identified failure causes in a Fault Tree Analysis (FTA) ontology enabling a top-down and bottom-up probabilistic analysis (see Figue-1);

The methodology is supported by a Case Study showing how the results of probabilistic analysis produced by the AHP and the FTA ontology provides an integrated approach of estimating time and cost overruns using the Expected Value (EV) function in engineering geology investigations. The methodology is advised as a low cost and soft computing solution, however, its techno-economic views and limitations have to be considered.

Table-1: Probabilities of Failure Risks - AHP results

Reciprocal Matrix

Main Failure Risks		*R1*	*R2*	*R3*	*R4*
SITE SURVEY FAILURES	*R1*	**1,00**	3,50	1,50	3,00
DESKTOP FAILURES	*R2*	0,29	**1,00**	0,50	0,43
POOR EVIDENCE FAILURES	*R3*	0,67	2,00	**1,00**	1,67
MANAGERIAL DEFICIENCIES	*R4*	0,33	2,33	0,60	**1,00**

Normalized Matrix

Main Failure Risks		*R1*	*R2*	*R3*	*R4*	*WRi*
SITE SURVEY FAILURES	WR_1	0,44	0,40	0,42	0,49	***0,436***
DESKTOP FAILURES	WR_2	0,13	0,11	0,14	0,07	***0,112***
POOR EVIDENCE FAILURES	WR_3	0,29	0,23	0,28	0,27	***0,267***
MANAGERIAL DEFICIENCIES	WR_4	0,15	0,26	0,17	0,16	***0,185***
		1,00	**1,00**	**1,00**	**1,00**	**1,000**

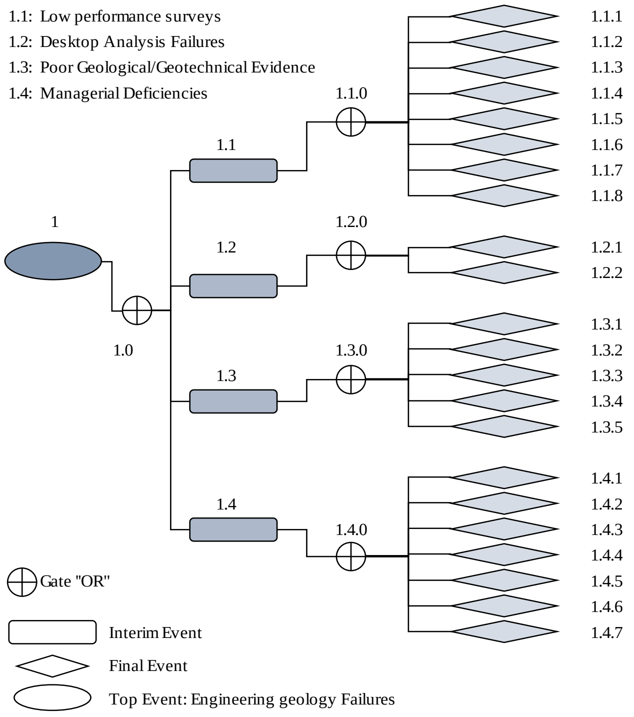
WR_i: Weight of Risk Factors $\sum WR_i = 1;\ 0 < WR_i < 1$

Consistency control

CI =	0,086	RI =	0,9	CR =	0,023	< 0,10

CI: Consistency index
RI: Random Index
CR: Consistency Ratio

Figure-1: FTA Ontology



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