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Fiabilist and Economic Approaches to Optimization of the Renewal of Hydrocarbons Transporting Pipelines.

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Problems of hydrocarbons transporting pipelines aging and rehabilitation are currently a major concern for operators of such installations. Rehabilitating and insuring hydrocarbons transporting pipelines, require interventions, such as the renovation of existing lines, the replacement of some pipelines with new ones, in order to meet the growing demand of consumers and improve the supply reliability. In this context, a decision to repair or replace a section of pipe must combine both a technical analysis of failures and sound economic analysis of the choice of possible interventions, which is the purpose of this study, dedicated to research and policy determination of repair and replacement of aged pipe sections, taking into account the factors mentioned above, and based on significant feedback.

1. Introduction

Hydrocarbons transport pipelines are high-risk facilities that require to be designed, constructed, operated, monitored and maintained with the utmost rigour. The control of the risks associated with hydrocarbons transport pipelines is concerned with all stages of the artwork from its design stage to its final (decommissioning) stoppage. Conduct procedures, maintenance and monitoring of these structures are to maintain a high level of security over the years. Following the leaks taking place in hydrocarbons transport pipelines, monitoring and maintenance rules must be strengthened to account better for aging phenomena that affects some installations in operation. A pipeline is designed of a finite number of pipes whose geometric and strength characteristics differ in a random manner. Factors having overriding influence on the behaviour of pipes in a pipeline are external aggression and internal constraints related to operating conditions. After decades of operation, the pipes are subjected to internal and external corrosion phenomenon, cracking and others. Internal and external corrosion are the main cause of leakage and rupture of aging pipelines, sometimes resulting in catastrophic damage (human damage, pollution of the natural environment, additional repair costs, and extended shutdown). Evidently, identified events, including the most recent ones, justify better attention to be given to the control of ageing structures and their renewal. To control hydrocarbons transport pipelines aging, it is essential to identify, detect, assess and prioritise the main aging vectors, and to take the necessary measures for their removal; in other words, operation or maintenance technical measures should be taken to manage aging, aiming to keep aging degradation, within acceptable limits.

The aging leads inevitably into sensitive increases in failures (Abdelbaki et al., 2008), which incurs significant additional costs coupled with the risk of having to urgently renew pipeline sections in a State of advanced degradation (Kermani et al., 1996). On the other hand ageing hydrocarbons transport pipelines is manifested over time by a decrease in their hydraulic performance, by water loss of metal pipes, and by a reduction of the maximum allowable service pressure, leading to the decrease in their ability to transport (Bettayeb et al., 2012). The increase in failures at the aging stage is a characteristic of any mechanical

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system including hydrocarbons transport pipelines. This increase in failures is related to the deterioration of their condition under the influence of the wear process, of corrosion and fatigue defects accumulation during operation. The most serious failures are gas explosions and fires resulting from oil inflammation, especially during the execution of repair work. Such failures may be due to, naked lights during repair works, during metal welding, electrical short circuits and other causes.

When failures occur besides human victims, there appear negative consequences of economical and ecological nature. Economic losses are mainly related to the transported products losses and are determined by the importance of the leaks. These losses reach sometimes tens of millions of dollars, depending on the scale of the damage. The ecological consequences resulting from damage, sometimes exceed many times the economic consequences and may be irreversible, with a catastrophic character, particularly when oil flow into lakes and seas takes place. An oil transport pipeline consists of a number of pumping or compression stations depending on the nature of the product being transported. These stations are separated by a hundred kilometers from each other, having as a main function, the supply of energy as well as the flow rate desired. There is the flow, which is a known constant characterizing the performance of a pipeline in perfect condition. Aging of the pipe reduces its performance which can be determined using the hydraulic relationships describing the flow of the transported product and the characteristics of the pumping (or compression) stations equipment (Tiratsoo et al. 1992).

The problems of integrity of hydrocarbons transport pipelines are very important (API 2007) and (Wilkowski 2000), including studies of the influence of corrosion on their strength and integrity (Choi et al. 2003).

The issue of hydrocarbons transport pipelines renewal involves a set of quantitative and qualitative, endogenous and exogenous variables. The first attempts to approach the problem of pipelines renewal have involved statistical patterns describing the evolution of failures in time (Mecker et Escobar, 1998). It is introduced in these models cost function to estimate the future in service pipes maintenance costs, and compare it with replacement cost. Such models are designed to determine an optimal date of renewal. Subsequently, other statistical models have been used (Lonnoy et al. 2005). These describe pipes deterioration using an aging law; the interest was to identify the most critical pipelines in terms of pipe corrosion (Worthingham et al. 2002) and for rehabilitation analysis (Abdelbaki et al 2012). An ageing pipeline renewal policy is the sequence of decisions or the choice of an alternative intervention on conduct: repair, replace or rehabilitate, for each pipe section in a given year.

2. Reliability model integrating pipeline degradation state standards:

Pipeline sections whose failure rate is λ_0 when operated in usual conditions are considered. After years of operating and due to ageing, their failure rate is changed. It is considered that this new failure rate λ is expressed using λ_0 according to Cox multiplicative model. This model establishes a parametric relationship between environment or failure risk factors, and the longevity distributions. The method is mainly based on the proportional hazards assumption that assumes that each factor affects the life expectancy in a constant manner over time (KUK 1986):

$$\lambda = \lambda_0(t).g(Z) = \lambda_0(t).exp(\sum \gamma_i.Z_i(t)) \qquad (1)$$

Where λ is the instantaneous failure risk at time *t* under stresses Z,
$\lambda_0(t)$ is the base risk,
$g(Z)$ the Co-variable,
$\gamma_i.(t)$ the constants.

The reliability of a pipeline section is evaluated by the probability that the boundary state function of a cross section of the segment under consideration is positive at time *t*. Under the term boundary state function of a cross section of a pipeline section, it is meant the difference between the functions that determine the bursting pressure and the value of the operating pressure. The main factors which affect the integrity and the probability of failure of a pipe section are considered as random variables: the size of defects (depth, length, width), the parameters of the segment under study (pipe wall thickness, diameter, elastic limit and fracture ultimate tensile strength of the pipe material), and finally the service pressure.

3. Approach to the problem

For a pipeline of p sections, with three alternatives, the possible number of policies is 3^p. The assessment of all these possibilities is laborious for a pipeline of several hundred kilometers, therefore genetic algorithms are used to explore all of the pipelines renewal polices (Abdelbaki et al. 2008). Using a set of starting policies, the genetic algorithm will explore a large number of solutions, retaining the best solutions found. The line is segmented into sections. A sequence of decisions on the line is represented by a "chromosome" and each section of pipe is represented by a code reflecting the renewal option to implement. As a code using one of the numbers: 1, 2 or 3, which correspond respectively to the repair, replacement or rehabilitation options.

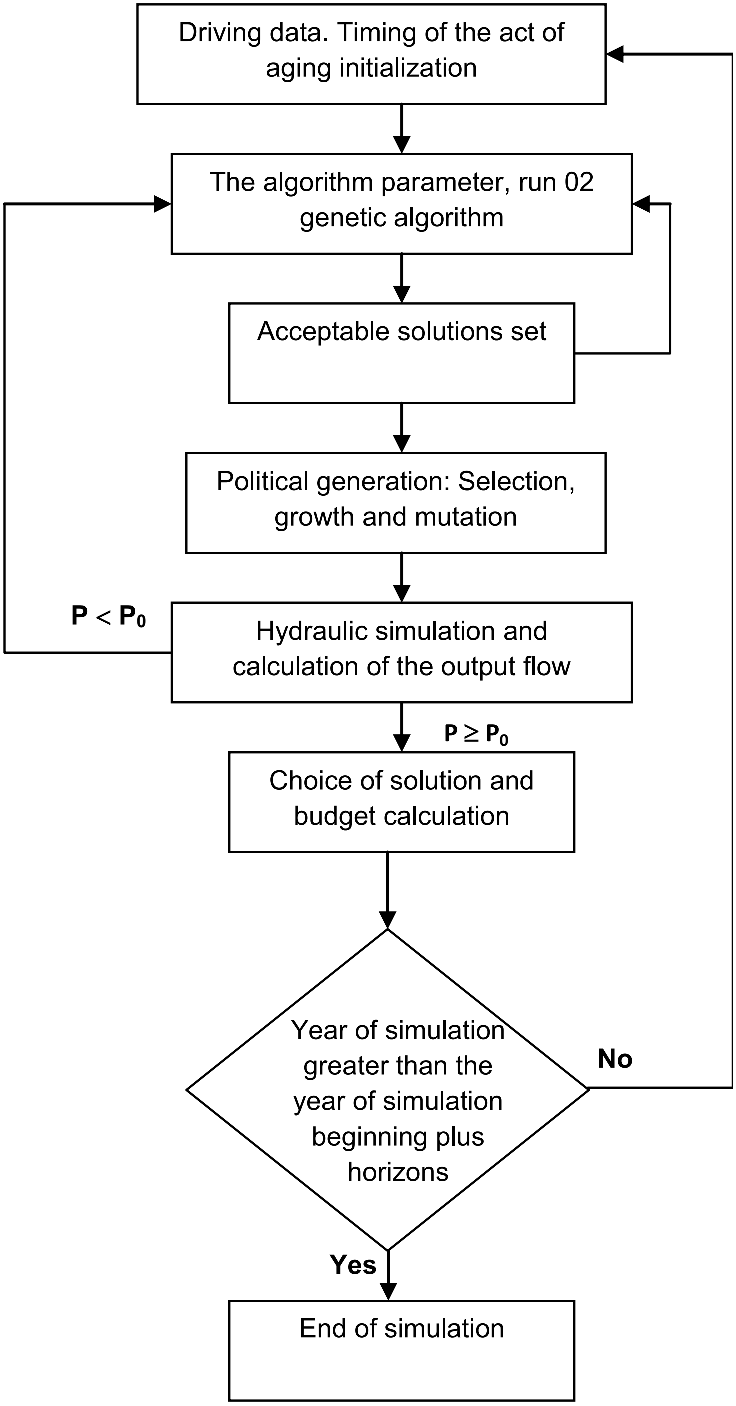

Figure 1: Flow diagram of the optimization model

In this case the chromosome is a string of characters between 1 and 3 which define alternative renewal and of length 'p' which represents the number of sections in the pipelines. The objective function, corresponding to the adjustment function which allows comparing the policies between themselves by the genetic algorithm, is the sum of the costs related to interventions on each section of pipe over a given horizon. In this context, the maintaining, rehabilitation and replacement costs of each segment are considered. For a given date, it is sought to compare the cumulative costs of the different possible alternatives over a given time horizon. The optimal decision on each section of pipe is one that minimizes the costs accumulated over the selected period. The objective function is of the form given by Goldberg (1989):

$$\begin{aligned} F_{obj} = {} & KC_m \int_{t_s}^{t=t_0+1} \lambda(t_s) e^{A(t-t_s)} dt + (1-K)\left[MC_r + MC_m \int_{t_s}^{t=t_s+1} \lambda(t_s) e^{A.T} dt \right] \\ & + (1-K)(1-M).C_{reh} + (1-M)C_m \int_{t_s}^{t=t_s+T} \lambda(t_s) e^{A.T} dt \end{aligned} \tag{2}$$

Where:

- C_m - unit repair cost
- C_{reh} - average rehabilitation cost
- C_r - average replacement cost
- t_s - failure rates in year t
- A - coefficient of failures increase
- $t = t_s + T$
- $t_s = t_0 + g$
- t_0 - the year of pipe laying
- g - the pipe age in year t_s
- T - the considered time horizon
- K, M - binary variables (1, 0), which reflect the considered alternative.

In this problem the constraints are the necessary service pressures in each section of pipe to convey the amount of requested product, P≥ Pmax. The algorithm is then calibrated by setting the size of the research population, the type of used selection, the type of growth, the likelihood of growth and mutation as shown in *Figure 1*.

4. Results and discussion

A concrete renewal program of an aging pipe is established. Data were collected directly from the services concerned. This database has been structured from the outset, with the idea to keep it updated and to analyze these data to build renewal strategies. The data collected concerns not only the pipe (diameter, material, installation date and length) but also its environment (nature of the soil) and failures experienced by the pipeline.

A stretch of 90 km pipeline is considered, linking two intermediate compression stations. The X 60 steel 40" diameter pipeline was built 41 y ago. This section is segmented into 34 elementary sections. The evolution of the failures occurrence is obtained by an exponential smoothing, which allows assessing the failure rate and subsequently the number of failures in a given year. For the 34 Sections the increase in the number of failures was estimated depending on the age of the pipe. The parameters of the model and the initialization of the genetic algorithm were then defined by the growth and mutation probability integration (attachment) and the size of the population of the policies to be considered at the beginning of the simulation. The determination of the initial settings of the genetic algorithm is performed by simulations with different values of the initial population and growth and mutation probability. For each simulation, two parameters are set while the third is varied, to describe the evolution of the objective function. Three sensitivity analyses were performed. The size of the population varies between 40 and 320 in increments of 40, the growth probability ranged from 0.6 to 1.00 in increments of 0.05. For the mutation probability, the values have been taken between 0.05 and 0.25 with increments of 0.05.

By the analysis of simulations, a triplet of initial values is determined for the genetic algorithm. For the size of the population, the 150 value is retained; 1 for the growth probability and 0.25 for the mutation probability. The simulation horizon considered is T = 10 years. The starting year of simulation is 2012; the simulation therefore ends in 2022. The solutions given by the genetic algorithm have been reduced only to those who satisfy the operating hydraulic constraints of the pipeline under consideration. In Figure 2, is presented a fragment of obtained results relating to the replacement of the pipes for 2013.

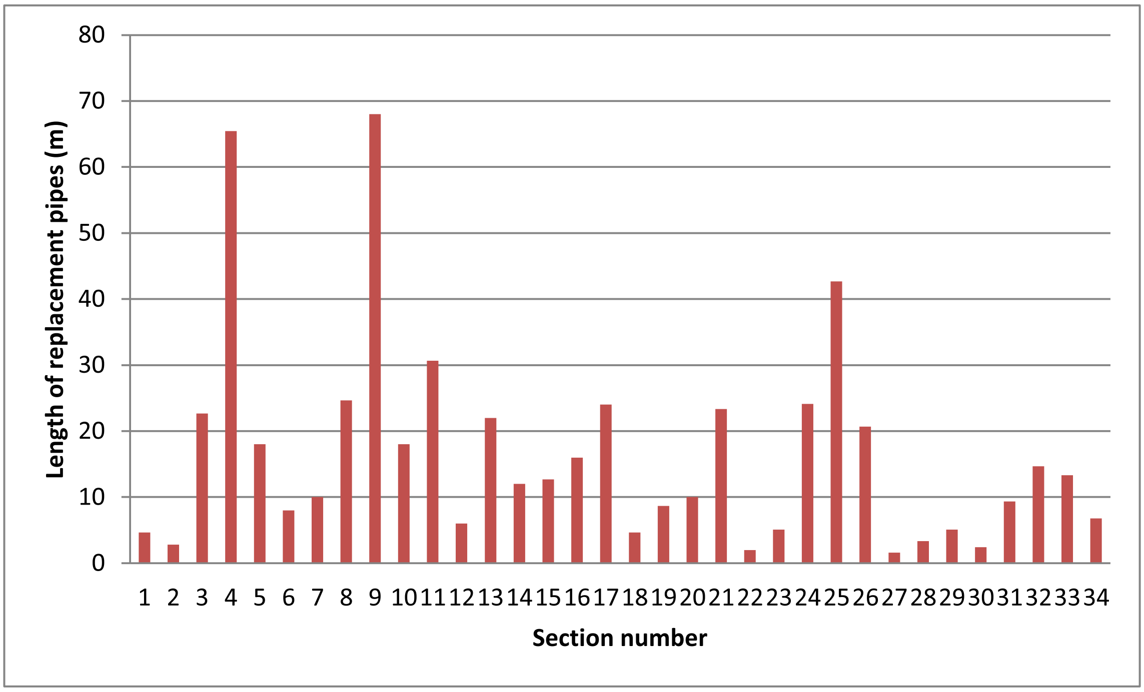

Figure 2 : Replacement diagram

5. Conclusion

The decision on renewal of the ageing hydrocarbons transport pipelines is a multi objective problem requiring the availability of specific data for the hierarchy, the determination of optimal date and renewal programming. The criteria used should be linked to the operation of the pipeline under consideration, to its hydraulic and structural deterioration and the generation of scenarios. These actions will enable transporting large quantities of hydrocarbons under better security conditions and to deal efficiently with the aging of hydrocarbons transport pipelines.

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