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Asset Integrity Management System

Anne-Sophie DECAUX, Director,
Technical Division - GRTgaz – France

Samir AKEL, Consultant,
Technical Division - GRTgaz – France

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Background

High capitalistic industries, as for instance gas transmission or distribution operators, require high level of expenses in order to permanently maintain the reliability of the existing assets. In order to reach the goal of reliability, action plans are decided and carried out in order to mitigate all kinds of identified threats harmful to safety, quality and environment. These action plans may be ruled within the frame of Asset Management principles. Risk assessment is undoubtedly among those principles and, on this subject, standards ([1], [2], [3] and [4]) are already published. It is useful to underline the definition of Asset Management given by [2] : "*set of coordinated activities that an organization uses to realize value from assets in the delivery of its outcomes or objectives*". Action plans targeting reliability may be considered within such activities, however the term "*coordinated*" needs to be technically qualified. As defined in the Oxford English Dictionary, it means : "*bringing the different elements of a complex activity into an efficient relationship*". This "*efficient relationship*" may be a global cost effective asset management in order to minimize the organization overall risk (quite similar to *ALARP* principle). In other words and according to a proper interpretation, this simply means : "*make sure you spend the right €, on the right activity, at the right time*".

Unfortunately, the mentioned standards only give essential requirements leaving beside the detailed methodology which is often subject to an individual in-house development. It is quite disappointing that in this field, primarily dealt with by technicians and engineers before financiers, no technical as well as economical frames are given on how to handle this subject. Some attempts are made based on a risk matrix assumption where, even if relevant, expert opinion prevails. It remains as a subjective approach with no frame of reference and hardly exportable to other companies.

It is true that risk assessment is not a scientific concept, and therefore one may expect that proposed approaches in this field will remain subjective, hence with some margin of uncertainty. It is quite unlikely that, one day, a standard would exist giving a unique methodology drawing the path to follow in order to make a risk assessment dedicated to asset management.

Aim

Our goal in this paper is to give an operational tool in the field of risk assessment contributing to asset management, as much objective as possible. It is not a full solution for technicians/engineers, nevertheless it gives a modest step forward less conceptual than what already exists in this field nowadays. Future improvements are indeed unavoidable.

Although we focus hereafter on the case of gas transmission operators, it is obvious that the proposed methodology applies to any company having physical assets to manage in order to maintain an overall reliability of the industrial process allowing to meet its strategic goals.

Methods

For a gas transmission operator, the proper physical assets are mainly made up of :

- Pipelines
- Compression stations
- Regulating gates
- Interconnection stations

Maintaining a high level of reliability of the gas transmission system leans on the individual reliabilities of all above technical components. Action plans are therefore deployed component by component. As for illustration, a sample of those action plans may be :

- Inspection and rehabilitation of the whole grid (by In Line Inspection)
- Reducing Third Party Interference (one call system, GIS, survey, slabs)
- Replacement of risky old or obsolete equipments (specific valves, regulators)
- Corrosion protection (Cathodic Protection)
- Training (to avoid wrong maneuver)
- Compression stations maintenance
- Regulating gates maintenance

Most of these action plans are permanent and often cost expensive. The corresponding budgets are compartmentalized and allocated plan by plan in continuity with the recent past. This induces a risk reduction for each threat and consequently, a decrease of the operator overall risk which finally improves the system reliability. It may however still be possible to further improve reliability and reduce the overall risk without requesting additional expenses by "*coordinating*" those action plans.

For illustration, the following table gathers a list of action plans corresponding to identified threats with their assumed risk level and the yearly amount of expenditure for their risk mitigation. Usually, action plans cover a long term period (usually a sliding 10 year program) and are reproduced as well as updated from one year to another. This simply describes the current situation.

	risk level	expenses of year n+1	…	expenses of year n+10	*action plan total cost*
action plan 1	R_1	e_1 M€	…	e_1 M€	$E_1 = 10.e_1$
…	…	…	…	…	…
action plan p	R_p	e_p M€	…	e_p M€	$E_p = 10.e_p$
		$e = \sum e_i$	…	$e = \sum e_i$	$E = 10.e$

Table 1 – Generic illustration for risk and cost data

The proposed approach has not the pretention of turning upside down the current situation. Its goal is to redistribute the total budget per year in order to reach, at the end, an improved global performance better than the observed nowadays one, with no additional cost. The redistribution is based on a cost/risk balance between the threats as well as the corresponding action plans. The methodology is to seek for another cost distribution e'_i (instead of current e_i) per action plan and per year aiming at reducing even more the overall risk under the condition that no additional cost per year is required :

$$\sum_{i=1}^{p} e'_i = \sum_{i=1}^{p} e_i = e$$

Risk concept

Whatever the type of the conducted activity, any industry copes with hazards. In gas industry, hazard is an unintentional release of gas related to a network failure followed or not by an ignition. This situation can be qualified by a potential danger. The danger is usually measured by a "risk" level. It is therefore appropriate to start by describing the process leading to this danger and how its risk level can be estimated.

I – Bird Pyramid : Hazards may be described by the well known Bird Pyramid which gives, step by step, the relative uncontrolled process leading to an undesired serious event. The case of third party interferences gives an interesting illustration :

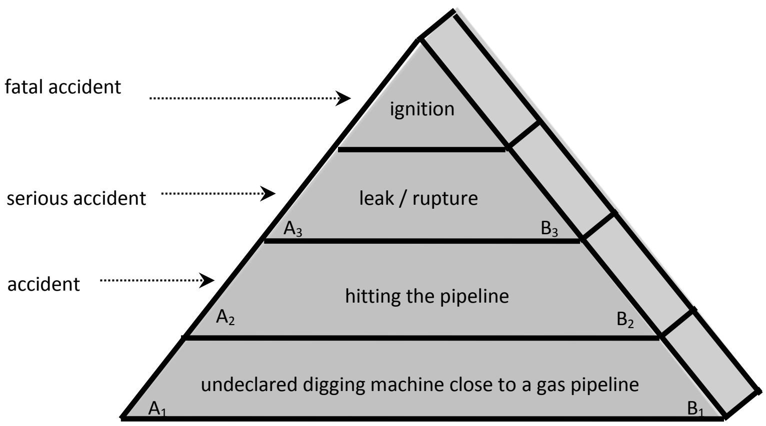


Figure 1 – Bird Pyramid : case of Third Party Interference

The Bird Pyramid shows a qualitative description of the threats an operator is facing. All threats don't have the same weight and the challenge is to target mainly important ones by choosing the right cost effective action plans. This notion hints that an adequate measure of the threat/danger is to be performed in order to assess the opportunity of launching such action plans. The risk concept is dedicated to this measure of performance.

II – Basic risk assumptions : Risk is an empirical concept, yet imprecise and subject to interpretation. Its aim is to measure, in the case of a specific industrial threat, the associated danger level. Commonly, as also mentioned in some standards/references [6] and [7], risk is defined as the combination of two components : the probability (or frequency – this notion is widely used) of a hazardous event related to threat "*j*" and its consequence. This combination can be expressed as following :

$$Risk_j = frequency_j \times consequence_j$$

As shown in the Bird Pyramid and for the sake of illustration, such a hazardous event may be in the case of Third Party Interference (*TPI*) :

- an undeclared digging machine beside a buried gas pipeline or,
- hitting the pipeline or,
- an unintentional release of gas (leakage or rupture)

<u>Assumption 1</u> : Generic definition of risk

In order to take into account all those elementary undesired events and instead of only considering a single type of event among several ones (*3 in the previous illustration of TPI*), we shall generalize the frequency notion and define a pseudo frequency as following :

$$pseudo\ frequency_j = \prod_{i=1}^{n} frequency_{ij}$$

where *n* designates the number of levels of the Bird Pyramid (i.e. the number of elementary events leading to the fatal accident) and $frequency_{ij}$ (*per year*) the one related to the elementary event "*i*" of the concerned threat "*j*".

For the second risk component, i.e. "*consequence*", we shall consider the worst scenario where an ignition occurs leading to losses *C* (human and properties) – *C* can be eventually expressed in terms of cost consequence.

According to the above definitions, the risk associated to any threat "*j*" can be then expressed by :

$$Risk_j = [\prod_{i=1}^{n} frequency_{ij}] . C_j$$

This is a generic risk definition where one may recover the common standardized one for *n = 1* (only one level in the Bird Pyramid).

For the Third Party Interference case (*j = TPI*), this assumption leads to the following evaluation of the risk level (*it is not a unique evaluation*) where we considered that the frequency of each elementary event "*i*" (*i = 1 to 3*) is proportional to the dimension of the corresponding level of the pyramid (see figure above) :

$$Risk_{TPI} = [(A_1B_1)_{TPI}.(A_2B_2)_{TPI}.(A_3B_3)_{TPI}].C_{TPI}$$

Assumption 2 : Risk mitigation

When a threat is identified, the operator defines an appropriate action plan to carry out in order to mitigate the risk. We shall consider that most of the action plans intervene at the early stage of the hazardous process described in the Bird Pyramid by reducing all the undesired elementary events at all levels in the same proportion (α %) as illustrated in the following figure :

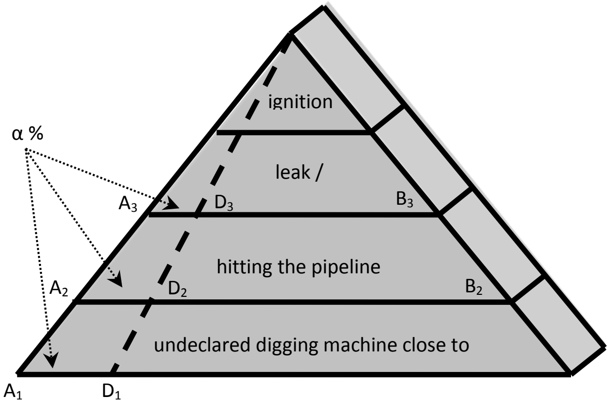


Figure 2 – Risk reduction assumption

According to this assumption and as a successful consequence of carrying out the right action plan, the residual risk level is expressed as following :

$$Residual\ Risk_j = [\prod_{i=1}^{n}(frequency_{ij}.(1-\alpha_j))].C_j = [(\prod_{i=1}^{n}frequency_{ij}).(1-\alpha_j)^n].C_j$$

The parameter α_j is fundamental since it governs the risk reduction, it depends on the level of the resource dedicated to mitigate threat "j". It should logically be proportional to the allocated annual cost e'_j, therefore we shall assume that this parameter is empirically given by the following ratio :

$$\alpha_j = \frac{e'_j}{E_j}$$

where E_j is the expected total resource required by action plan "j" on the long term (over a decade for instance – see table 1). This assumption hints that the risk will decrease to zero once the whole resource E_j is spent. This is a strong assumption but, as we'll see later in the case study, we consider the present approach valid only on the mid-term cycle (i.e. the first few years of the long term cycle : the first 3 years over the mentioned decade on which the action plans are programmed). At the end of this mid-term cycle, the procedure should be re initialized taking into account new feedback recorded on the past few years in order to measure the real residual risk as well as the effectiveness of the corresponding action plan.

Assumption 3 : Additive principle

The risk is quantified individually threat by threat. We shall assume that the overall risk of the transmission operator is the sum of all the individual risks [5] providing that, for the sake of consistency :

- the pseudo frequency level "*n*" is the same for each threat,
- all elementary frequencies are expressed in absolute values, otherwise there is no consistency in combining frequencies expressed per unit of length (/km as for pipelines) and frequencies per unit of equipment (for valves/regulators for instance).

Risk assessment approach

I – Current situation : several threats are identified and for each threat "j" the operator intends to spend a total cost E_j during several years (or e_j per year) in order to mitigate the associated risk by means of an adequate action plan. All the action plans are launched independently with no coordination between each other (a "silo" organized program of action plans).

II – Modified situation according to the proposed approach : the same threats are considered with the same action plans ; however these action plans are to be launched gradually depending on their relative risk level (*coordinating principle*). The only required condition here is that the overall annual budget covering the whole action plans remains as in the above current situation. This target can be expressed mathematically by the following two equations :

$$\boldsymbol{Technical\,requirement}\ : \qquad Residual\ overall\ risk = \sum_{j=1}^{p} Risk_j\ (1 - \frac{e'_j}{E_j})^n$$

$$\boldsymbol{Financial\,requirement}\ : \qquad e = \sum_{j=1}^{p} e'_j$$

The purpose is to reduce as much as possible the "*Residual overall risk*" with respect to a new unknown cost distribution among all the action plans (e'_j *instead of* e_j). This can be performed by writing the following :

$$d(Residual\ overall\ risk) = \frac{\partial(Residual\ overall\ risk)}{\partial e'_j}\ de'_j = 0$$

By means of the Lagrangian multiplier, one may obtain the following expression for the new cost distribution allocated to threat "j" :

$$e'_j = E_j \,.\, [\, 1 - \beta . (\frac{E_j}{Risk_j})^{1/(n-1)} \,]$$

where the coordinating factor "β" is given by :

$$\beta = \frac{(\sum_{k=1}^{p} E_k\,) - e}{\sum_{k=1}^{p} (\frac{E_k}{Risk_k})^{1/(n-1)} \,.\, E_k}$$

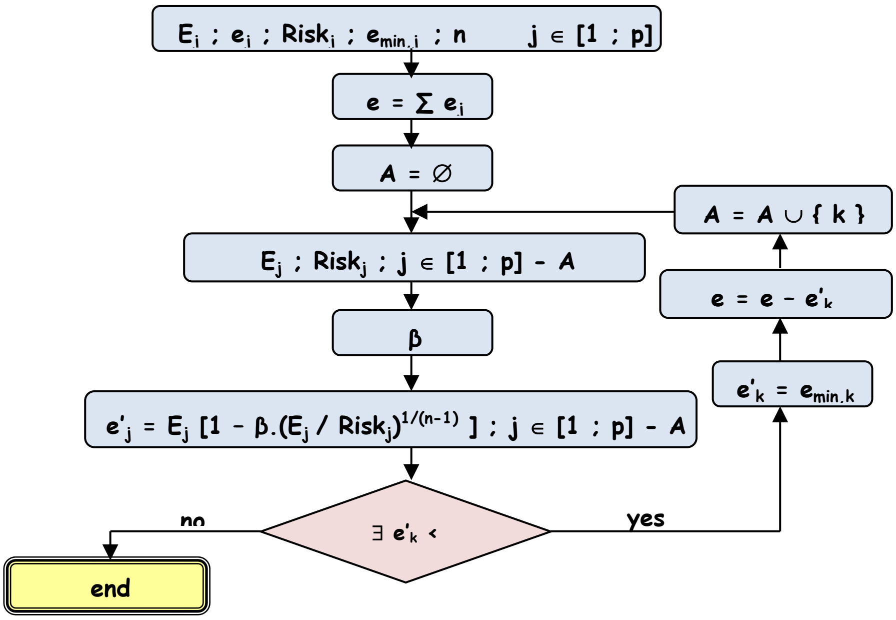
One may check that always :

$$e'_j \leq E_j$$

Unfortunately, e'_j may sometimes be negative. In this case, the optimization procedure should be performed under the additional condition :

$$e'_j \geq e_{min,j}$$

where $e_{min,j}$ (≥ 0) is an imposed minimum cost to be spent on threat "j". This could be achieved as indicated in the following iterative chart (numerical procedure) :



Discussion and relevant properties

The adopted assumptions and definitions helped us to reach a mixed technical-financial expression for an optimal cost redistribution in order to manage appropriately assets on a risk based balance. Indeed, it is founded on a pseudo scientific approach and some criticism or even objections may be admissible. In all cases, it remains an empirical approach leaning on concepts. Nevertheless, some relevant properties consistent with good sense can be underlined :

1 – For two different threats having the same total cost of their corresponding action plans, it is much appropriate to further finance the more risky one.

2 – For two different threats having the same risk level, it is much appropriate to further finance the less expensive action plan.

Moreover, one expects that the effort should logically target threats having the lowest cost per risk unit. The present approach is completely consistent with this trend since, in the above expression of the cost split, the governing ratio is the global cost over the risk level of the corresponding action plan ($E_j/Risk_j$). Action plans may be prioritized according to this ratio, beginning by the lowest ones.

Last but not least, one may observe that financing the action plans depends on relative values of the individualized risk levels (i.e. risk ratios $Risk_i$ /$Risk_j$). This property hints that it is rather useless to seek for high precision values of the absolute individualized risk per threat $Risk_j$ since only risk ratios are relevant. Therefore, if absolute risk values are not available, it is still possible to give absolute risk levels based on expert's opinion (i.e. *empirical risk classification for each threat based on a standardized risk matrix – see below*), hoping that risk ratios will mitigate expert's subjectivity and uncertainty.

Additional remarks

In the above expression of the cost redistribution, the approach is valid for $n > 1$. However, numerically it is still possible to get close to the case $n \sim 1^+$. The latter refers to a simple linear risk reduction along with the annual expenses induced by the action plan. It is important to underline that the linear case is very simplistic and does not fit with reality often complex. In this case and as shown hereafter in the full case study, threats are to be dealt with in series, i.e. one by one : all the effort is to be focused on the threat having the lowest ratio " global cost/risk" (E_j/$Risk_j$) until it is considered completely mitigated ; afterwards, the effort is redirected on the next threat having the new lowest ratio "global cost/risk", and so on…

If now we consider high values of n, the above expression becomes :

$$e'_j = e_j$$

which means that the cost distribution is no more function of the risk. All the threats are treated simultaneously with no coordination, i.e. for n = ∞, we recover the current uncoordinated program.

The real situation is somewhere between those 2 extremes : n = 1 and n = ∞. We recommend in practice the specific case of n = 2 which is the most simple non linear approach, hence the previous expression becomes :

$$e'_j = E_j \,.\, [\, 1 - \frac{(\sum_{i=1}^{p} E_i\,) - e}{\sum_{i=1}^{p} \frac{E_i^2}{Risk_i}} \; x \; \frac{E_j}{Risk_j}\,] \qquad\qquad e'_j \geq \; e_{min,j} \; \geq 0$$

Risk evaluation

Even if based on empirical assumptions, the above described how it is possible to reach an asset integrity management model. Risk constitutes the heart of the approach and yet needs to be evaluated. In the chapter "Risk concept", we gave a procedure based on Bird Pyramid which may be followed. However, in many cases it could be quite impossible to compare Bird Pyramids and the corresponding risks. In this case, it is recommended to follow a standard approach based on a risk matrix as shown in the following figure :

consequence	5	10	15	20	25
	4	8	12	16	20
	3	6	9	12	15
	2	4	6	8	10
	1	2	3	4	5
	frequency / probability				

- illustration : subjective risk matrix -

You need here a panel of relevant experts having the aim to place the different risks in the aforementioned matrix based on their own experience. As mentioned above, even if expert's opinion is subjective, the induced uncertainties are mitigated by the fact that only risk ratios prevail.

Results – Full case study

In order to illustrate the proposed approach, we shall study a "virtual" case of a gas transmission operator who is dealing with 5 threats (p = 5) :

- Threat 1 : third party interference
- Threat 2 : obsolete regulators
- Threat 3 : metal corrosion
- Threat 4 : wrong maneuver
- Threat 5 : landslide areas

For each threat, the operator launched one or several action plans where annual costs are programmed based on historical considerations without any coordination ("silo" approach) :

threat	action plan	current annual cost
1	Slabs & Survey	8 M€
2	Regulator replacement	3.5 M€
3	Inspection/rehabilitation	10 M€
4	Training campaign	1.2 M€
5	Technical reinforcement	0.8 M€

Table 2 – Full case study : cost data

The program cost is therefore : e = 23.5 M€/year. Besides, the "virtual" feedback led to the following risk data (n = 2 for the 5 threats) :

threat	frequency – per year (level 1)	frequency – per year (level 2)	pseudo frequency	risk R_j
1	3 000 undeclared digging engines beside the grid	5 near misses (pipeline damages)	15 000	15 000 C
2	500 malfunctions	8 critical malfunctions	4 000	4 000 C
3	2 000 metal defects	10 critical metal defects	20 000	20 000 C
4	200 wrong maneuvers	10 near misses	2 000	2 000 C
5	50 landslides	20 near misses	1 000	1 000 C

Table 3 – Full case study : risk data

As one may notice, we assumed that the consequence C of the threat is the same presuming that, in the gas industry, the fatal accident commonly adopted corresponds to the worst scenario, i.e. an unintentional release of gas followed by an ignition with impact on persons (human losses/injuries). Under this assumption, the numerical value of C is not required since only risk ratios are relevant. Of course, different values for C per threat remain possible in the approach, providing that a realistic estimation is performed.

A software (AIMS©) was developed in order to simulate asset integrity management based on risk assessment. It was used for this "virtual" illustration.

a – Simulation under the condition $e_{min,j} = 0$

	average cost (M€/year) for a period of 3 years			
	n ~ 1⁺	n = 2	*n = 3*	*n = 4*
Slabs & Survey	*0*	9.3	*8.7*	*8.4*
Regulator replacement	*0*	0.0	*1.6*	*2.3*
Inspection/rehabilitation	*23.5*	13.0	*11.6*	*11.0*
Training campaign	*0*	1.1	*1.1*	*1.2*
Technical reinforcement	*0*	0.1	*0.5*	*0.6*
total	*23.5*	23.5	*23.5*	*23.5*

Table 4 – Full case study : numerical simulation for $e_{min,j} = 0$

Since we considered two levels in the Bird Pyramid and to be consistent with the approach assumptions, only case n = 2 applies (in bold). Nevertheless, for evident illustrative reasons, we supposed that the same risk level is valid for n = 1, 3 and 4. The table shows that for n = 1, threats are to be treated in series since it focuses on threat 3 only. Parallel or simultaneous treatment of the threats is more and more effective with increasing values of n.

b – Simulation under the condition $e_{min,j}$ = 50% e_j

	average cost (M€/year) for a period of 3 years			
	n ~ 1⁺	n = 2	*n = 3*	*n = 4*
Slabs & Survey	*4.0*	8.4	*8.6*	*8.4*
Regulator replacement	*1.8*	1.8	*1.8*	*2.3*
Inspection/rehabilitation	*16.8*	12.0	*11.5*	*11.0*
Training campaign	*0.6*	0.9	*1.1*	*1.2*
Technical reinforcement	*0.4*	0.4	*0.5*	*0.6*
total	*23.5*	23.5	*23.5*	*23.5*

Table 5 – Full case study : numerical simulation for $e_{min,j}$ = 50% e_j

Except for the case n ~ 1^+, the above illustrations show that threats 1 and 3 (respectively TPI and corrosion) deserve more resources than what is currently allocated while the resources dedicated to threats 2 and 5 (respectively obsolete regulators and landslide areas) may be reduced.

c – Simulation in case of a global cost reduction

This case is met in shortage periods where any company is obliged to proceed to cost reductions. If we take for instance the case of a global cost reduction of 10%, the present approach leads to an individual new cost redistribution, as shown in the following table :

	average cost (M€/year) for a period of 3 years					
	uncoordinated		coordinated		coordinated $e_{min,j}$ = 50% e_j	
Slabs & Survey	7.2	*(-10%)*	8.4	*(+5%)*	7.7	*(-4%)*
Regulator replacement	3.2	*(-10%)*	0.0	*(-100%)*	1.5	*(-57%)*
Inspection/rehabilitation	9.0	*(-10%)*	11.7	*(+17%)*	10.8	*(+8%)*
Training campaign	1.1	*(-10%)*	1.0	*(-20%)*	0.8	*(-30%)*
Technical reinforcement	0.7	*(-10%)*	0.1	*(-87%)*	0.3	*(-63%)*
total	21.2	*(-10%)*	21.2	*(-10%)*	21.2	*(-10%)*

Table 6 – Full case study : in case of imposed cost reduction of 10% (n=2)

To complete the approach, the procedure should be re initialized after a defined period of application (typically as in the illustration after a cycle of 3 years). The following diagram shows schematically how to proceed iteratively :

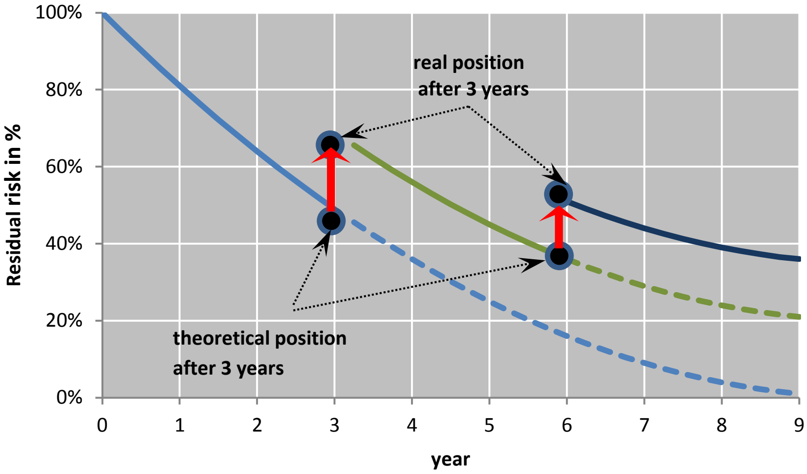


Figure 4 – Iterative procedure principle

1. After a period of 3 years, a comparison is made between risk reduction issued from the approach and real measured residual risk by means of the recorded feedback or expert’s opinions.
2. All the risk levels are re initialized according to the real measured one and the whole procedure is restarted over a new cycle of 10 years.

This iterative procedure compensates the strong empirical assumption related to risk reduction and expressed by the ratio :

$$\alpha_j = \frac{e'_j}{E_j}$$

where E_j is considered as the long term cost which allows to overcome the corresponding risk. E_j should be readjusted at the end of each 3 year cycle.

Conclusions

Based on risk assessment, the present approach contributes to asset management. Only technical risks were presently considered which, in the gas industry, are the most serious ones. However a generalization of this approach may deal with quality and environmental risks. The basic problem is how to compare those 3 types of risk. A pure financial assumption may be adopted in order to appreciate the consequence of the threat. In this case, the proposed approach remains applicable.

As shown in the “virtual” illustration, despite the cost distribution change, the overall trend does not turn upside down the current situation. In real cases, the same trend should be often observed, i.e. the adjustments related to the redistribution of the expenses can be handled without any great impact on the company organization as for instance the manpower redeployment. The approach offers a smooth transition based on a three year cycle.

As a final remark, the methodology developed in the present paper tackles how to risk/cost coordinate different action plans in order to optimize the overall risk. The same methodology may also be applied inside an action plan. For illustration, the reader can refer to paper [8] dealing with pipeline survey optimization.

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