International Gas Union Research Conference 2011

Assessing the reliability of pressure-reducing stations as part of the GRTgaz investment prioritisation strategy

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ABSTRACT

GRTgaz, a subsidiary of the GDF SUEZ group, is responsible for natural gas transmission activities in France (excluding south-west France). As part of its industrial assets management strategy, GRTgaz asked the Gas and New Energies Research Centre of the GDF SUEZ Research and Innovation Division (CRIGEN-DRI) for support in developing tools to facilitate decision-making around investment in renewing/upgrading pressure-reducing stations.

The resulting procedure is based on a systemic approach which can be used to analyse the reliability of existing pressure-reducing stations and to generate individual forecast estimates of occurrence for four undesired events, in terms of safety, continuity-of-supply and from an economic standpoint. The analysis process comprises four steps and, based on maintenance feedback data, assesses the reliability of equipments and, in turn, of each existing pressure-reducing station.

The procedure was launched in 2009 and provides a range of indicators used in the GRTgaz national steering comity responsible for investments in renewing and upgrading pressure-reducing stations. It also generates the input data needed to analyse and monitor the operational reliability of the latter.

The aim of the next stage of development is to automate reliability assessments using a tool linked to GRTgaz Computerized Maintenance Management System (CMMS) application.

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Introduction

GRTgaz, a subsidiary of the GDF SUEZ Group, is responsible for natural gas transmission activities in France. GRTgaz markets and operates the French natural gas transmission system (excluding south-west France), which includes:

- 32,200 km of high-pressure network;
- 25 compressor plants;
- around 5,300 pressure-reducing stations, which perform delivery (public distribution and industrial customers) and preliminary pressure-reduction functions.

GRTgaz has therefore to meet three major objectives:

- ensure the safety of people and property;
- ensure the continuity of gas supply, particularly during cold periods (2% risk);
- consolidate transmission system performance.

CRIGEN-DRI helps subsidiaries of the GDF SUEZ Group to develop innovative strategies, tools, systems and practices. GRTgaz asked CRIGEN-DRI to help it develop and implement a strategy for managing its industrial assets.

1. Background and critical factors facing GRTgaz

GRTgaz wishes to acquire decision-making tools allowing it to measure and improve the effectiveness of its investment programmes and to justify its choices to third parties. GRTgaz has developed a standard procedure for prioritising investments projects to renew or upgrade its pressure-reducing stations. It allows GRTgaz to prioritise investment requests at a national level based on an analysis of each candidate station, inform a technical and an economic standpoint.

The technical criteria are used to describe the general condition of each facility and the critical factors associated with their operation:

- impact in the case of a failure: location within the network, gas flow rate, general location (urban/rural);
- general condition: e.g. whether parts of the station are obsolete;
- equipments: quantity of equipments by type and by technology;
- saturation level: used as a basis on which to identify available performance margins;
- forecast risk levels in relation to three key critical factors: security, continuity-of-supply and trends of maintenance costs.

The values recorded for each of these criteria are derived from three data sources:

- operator observations and comments related to information not contained in GRTgaz Information System (e.g. equipment obsolescence);
- results obtained through GRTgaz tools, including that used to estimate saturation levels;
- results of a statistical analysis of the forecast reliability of pressure-reducing stations based on maintenance feedback data (CMMS).

The following sections outline the procedure put in place to assess the forecast reliability of each pressure-reducing station based on GRTgaz maintenance feedback data.

2. Description of a pressure-reducing station and features of existing GRTgaz stations

GRTgaz pressure-reducing stations regulate the pressure of natural gas on the transmission system. The diagram below shows the layout of a typical pressure-reducing station and the main types of equipments used.

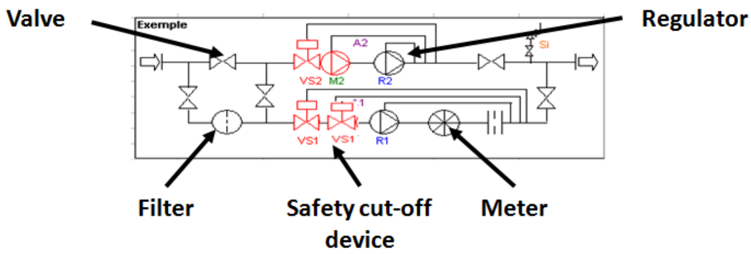

Figure 1 : Layout and equipments of a typical pressure-reducing station

The station's primary function of regulating the pressure of natural gas on the network is performed by one or more regulators depending on the conditions upstream and downstream of the station (pressure levels and flow rates). Its secondary functions (ensuring that the network operates safely, metering and filtering) are performed using specific equipments. For each type of equipments, a range of factors need to be borne in mind, namely the kind of stresses to which it is exposed, the types of failures it can potentially generate and its overall impact on the performance and safety of the station.

This variety of factors is even wider when considering the whole existing GRTgaz pressure-reducing stations:

- variety of different layouts: the required performance level of some facilities means that special enhanced layouts are needed (in particular two pressure-reducing lines);
- range of technologies: the equipments are produced by several manufacturers and thus have specific technical and technological features(based on GRTgaz historical industrial policies);
- differing operational conditions: the pressure levels and gas flow rates of the stations are determined by where they are located within the transmission network (preliminary pressure-reduction, delivery to a public distribution operator or an industrial customer).

Macroscopic analysis of GRTgaz feedback reveals that pressure-reducing stations are highly reliable:

- undesired events in connection with critical factors in terms of security and continuity of supply are extremely rare;
- isolated equipment failures are also rare, occurring at an average rate of fewer than two events per station per year.

This context significantly limits how relevant classical reliability studies are since the effectiveness of these methods used and of the assessments carried out depends on:

- the volume of feedback data available for each facility (direct link with the levels of uncertainty around the results generated);

- the capacity to factor in the specific features of individual pressure-reducing stations: layout of facilities, technical and technological features of equipments and the age of the latter;
- the time needed to conduct such analyses.

This situation therefore means that it is impossible to conduct individual analyses on each pressure-reducing station. CRIGEN-DRI has therefore focussed on developing an approach structured around a systemic analysis which can be implemented at national level.

3. Procedure for assessing the reliability of GRTgaz pressure-reducing stations based on feedback

a. Objectives

The method developed enables to estimate the levels of risk related to the operation of pressure-reducing stations over a 30-year period. These risks are:

- abnormal increase of pressure downstream;
- interruption of the gas supply;
- external leaks;
- increase in maintenance costs.

It thus provides forecast risk indicators for each undesired event and each facility during the 30-year period:

- forecast estimate of the number of undesired events;
- total annual maintenance costs.

b. A systemic analysis approach

The proposed procedure is structured around a systemic analysis approach and aims to reduce the complexity of the problem to be solved. The reliability of pressure-reducing stations is assessed by:

- analysing stations and their equipments when performing normally;
- analysing stations and equipments when not performing normally, i.e. to identify equipment failures involved in one or more of the four undesired events outlined above;
- incorporating failures into multi-risks models, which contain all possible connections between equipment failures and the four undesired events.

There are three main advantages to this approach:

- makes analysing GRTgaz feedback data more feasible;
- facilitates analysis of GRTgaz operating pressure-reducing stations since the focus is shifted away from the specific features of each individual station (layout, equipments, etc.);
- makes it easier to realise a broad-scale analysis, enabling to assess individual risk levels and to provide the objective general overview required to prioritise operating pressure-reducing stations.

This preliminary analysis forms the basis of the study process detailed below.

c. A four-stage process

The procedure for estimating the reliability of operating pressure-reducing stations is based on a four-stage process:

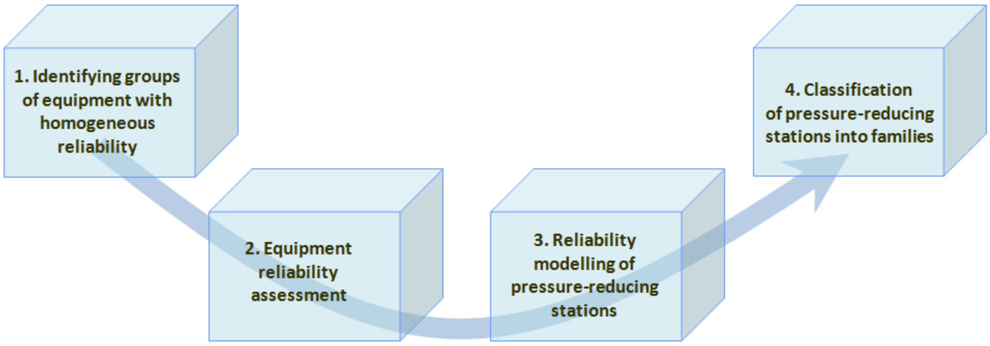

Figure 2 : A four-step analysis process

This process covers all stages of the reliability study:

- from consolidating and processing the input data (GRTgaz asset data and maintenance feedback data);
- to incorporating the results of the study into GRTgaz tools and internal processes.

d. Stage 1: Classification of existing equipments

This is the first stage of the process and entails consolidating and preparing the analysis input data. During this stage, each type of equipments is analysed and groups of homogeneous-reliability equipments are identified for each type of failure involved in one of the four undesired events.

This entails identifying the technical, technological and/or operational criteria responsible for the differences in reliability observed between equipments of the same type (regulators, valves, etc.). The purpose of such analyses is illustrated in the figure below:

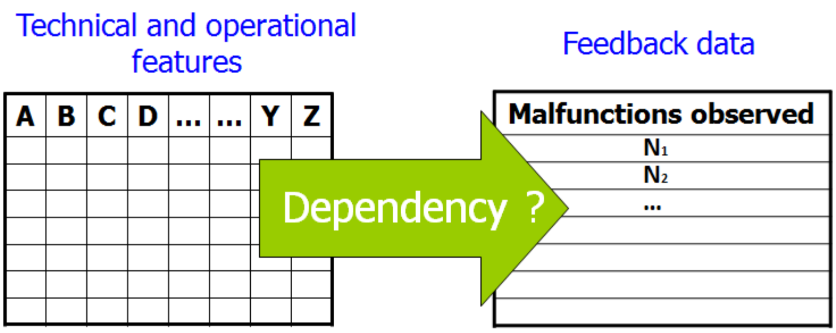

Figure 3 : Identifying criteria with impact on operational relaibility of equipments

Work carried out to date has shown that conventional statistical tools such as multiple correspondence analysis (MCA), Partial-Least-Square(PLS) and logistic regression do not yield relevant results. Such tools are unsuitable where a large proportion of equipments within each equipment-type experiences no failure within the feedback analysed.

Using Bayesian networks [2] has proved to be the only way of identifying the criteria which most appropriately explain the presence of failures within each equipment-type (see figure opposite).

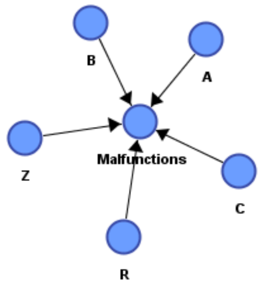

Figure 4 : Bayesian network

In particular, this tool helped to identify the "Manufacturer" and "Technology" criteria as being particularly relevant in explaining the differences in reliability observed between regulators (in the case of certain types of failure).

e. Stage 2: Estimating equipments reliability

Reliability is estimated for each type of failure and for each group of homogeneous-reliability equipments. Age is also factored into such assessments and thus enables reliability trends to be monitored throughout the equipments life time (assessment of the potential effects of ageing).

The table below indicates the formulae used for each type of failure, each group of equipments and each age group [3]:

Equipment functioning in continue	Safety cut-off devices – intermittent runs
$$\hat{\lambda}_j(X,T) = \frac{N_{mal\_observed}\ {}_j(X,T)}{\text{Period of operation }(X,T)}$$ where: • $\hat{\lambda}j\,(X,T)$ = the average estimated rate for type-j failures occurring in equipments within group X and age-group T; • $N_{mal\_observed}$ j(X,T) = the number of type-j failures identified in feedback and generated by equipments within group X and age-group T.	$$\hat{P}_j(X,T) = \frac{N_{mal\_observed\_scheduled\_intervention}\ {}_j(X,T)}{N_{scheduled\_intervention}}$$ where : • Pj(X,T) = estimated likelihood of a type-j failure occurring on demand to equipments within group X and age-group T; • $N_{scheduled\_intervention}$ (X,T) = number of preventive maintenance operations performed, during the feedback analysed, on equipments within group X and age-group T; • $N_{mal\_observed\_scheduled\_intervention}$ ${}_j$(X,T) = number of type-j failures observed on demand during preventive maintenance operations and generated by equipments within group X and age-group T.

Safety devices operate in an intermittent way. This leads to estimate specific indicators as to reliability. The proposed procedure compensates for the lack of information about the level of demand on the equipments and is based instead on the results of preventive maintenance operations (operational tests).

This procedure has been used to estimate over 800 reliability indicators for 10 types of equipments and 20 types of failure.

Comment 1: These assessments are based on feedback acquired on operating equipments in operation at the start of the study, until the first of the 2 following events: the end of the feedback period or the renewal of the equipment.

Comment 2: Assessment of uncertainties associated with these estimates

An uncertainty analysis has to be realised in the case of reliability estimates based on feedback data. This additional analysis helps to quantify how representative the average estimates obtained are.

To ensure that the end results of the analysis are relevant, the decision was taken to impose a threshold value on these uncertainties. Where the stated threshold is exceeded, the relevant equipment categories are grouped together (primarily by age group), which directly results in:

- a less precise analysis of equipments reliability;
- a significant and necessary reduction in uncertainties.

This approach has a fundamental influence on the results obtained at the end of the study. It thus contributes to maintain uncertainties at an acceptable level and to obtain exploitable results.

Value of these assessments

Stages one and two of the analysis help to define a set of reliability indicators to be used in other processes and activities. Analysing feedback in this way makes it possible to differentiate reliability estimates between operating equipments: by age, by technical (manufacturer, technologies) and operational (type of customer supplied) criteria.

The figure opposite illustrates an example of the results obtained for a particular equipment type. It shows the differences observed between two categories of equipments (same manufacturer but different technologies) by age:

- scale of existing facilities in operation (histogram);
- average estimates and 95% confidence intervals (dashed curves) associated with the average failure rates (expressed as failures per unit of time and per equipment).

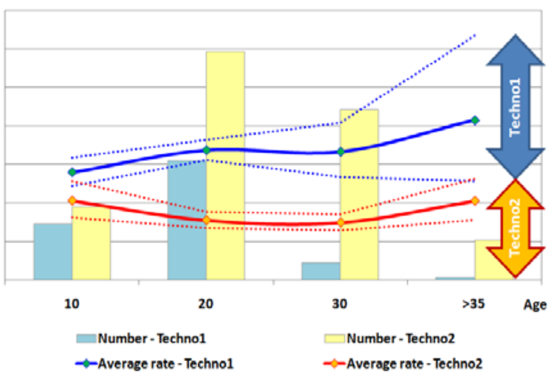

Figure 5 : Example of reliability estimates provided by the analysis

The values cited above reveal a significant difference (in statistical terms) between the reliability of equipments in these two groups, regardless of the age-group considered. Such assessments are particularly relevant when managing maintenance of various equipments.

f. Stage 3: Modelling reliability of pressure-reducing stations

How reliably a given pressure-reducing station performs depends both on its layout and on the features of its equipments. The third stage of the process entails fault-tree modelling to assess a reliability indicator, namely the failure rate of the pressure-reducing station over a period of 30 years. The failure rate will change during the 30-year period as the age of its components increases.

The variety of GRTgaz operating pressure-reducing stations in both technical and technological terms is such that a specific modelling tool had to be developed. This tool is flexible enough to be able to construct fault trees automatically and to generate representative indicators for each pressure-reducing station:

- input parameters corresponding to the failure rate of the equipments used in a given pressure-reducing station are selected on the basis of the equipment's age, features and location and the types of failure considered (cf. section 3.5);
- each fault tree is structured around the layout of the pressure-reducing station and the location of each equipments (each input parameter is specifically incorporated): this structure is illustrated in the figure opposite, where the red box indicates the components included when two regulators are present on the same pressure-reducing line.

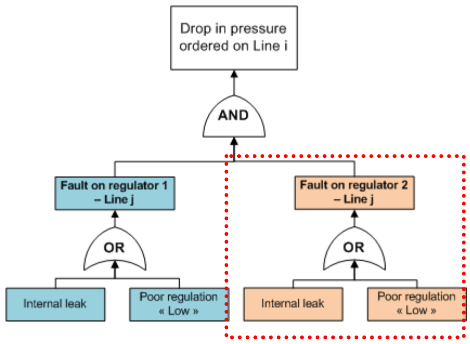

Figure 6 : Fault-tree modelling

Four fault trees – one for each undesired event – are automatically generated for each pressure-reducing station. The results of these models are used to estimate two types of indicator for a 30-year period:

- average estimate of the forecast total number of occurrences of each event;
- average estimate of total maintenance costs.

<u>Comment:</u> These forecast estimates appear to be slightly overestimated based on GRTgaz feedback, because of the static underlying hypotheses of the modelling method used. However, these values are the most appropriate for the study process applied and do not in any way undermine the way in which pressure-reducing stations are grouped together.

g. Stage 4: Categorising stations and incorporating them into the relevant tools

This is the final stage of the process and once this has been completed, the results obtained can be integrated into GRTgaz internal tools and processes.

Prioritisation by undesired event

The preliminary risk-assessments are not aggregated into a single value (e.g. in the form of economic indicator). Indeed it was decided that each forecast level of risk should remain visible.

A scoring system by category of pressure-reducing station has been put in place for each undesired event and is used to classify operating pressure-reducing stations. Facilities are thus placed in one of four risk categories ranging from 4 for the highest risk to 1 for the lowest risk.

The thresholds used to separate the categories are determined statistically and ensure that a balance is maintained between assessments of current pressure-reducing stations in each category and the 'distance' between each category (optimal balance both within and between categories of pressure-reducing stations). They are therefore highly relevant to GRTgaz prioritisation requirements.

Type of results obtained

In the absence of any overview of the relevant risks, the four undesired events being studied need to be prioritised (concept of chosen preferences). Assessments in connection with the safety and continuity-of-supply issues naturally take precedence in such an analysis. Forecast maintenance costs serve only to differentiate between two pressure-reducing stations with identical risk levels in respect of the undesired events.

The figures below show some results obtained after having prioritised each operating pressure-reducing stations:

		Categories - Safety				Total
		Category 1	Category 2	Category 3	Category 4	
Continuity-of-supply	Category 1	630	136	162	88	1016
	Category 2	1418	494	383	137	2432
	Category 3	487	206	203	80	976
	Category 4	192	11	38	30	271
Total		2727	847	786	335	4695

Figure 7 : Classification of operating stations

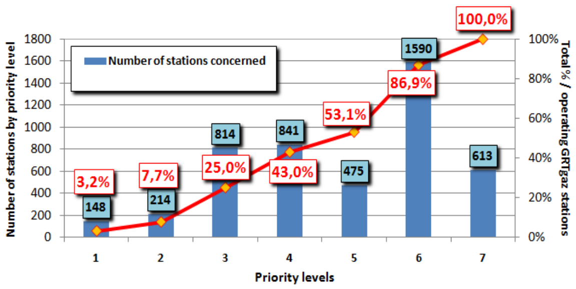

Figure 8 : Overlapping prioritisation – chosen preferences between undesired events

Preliminary prioritisation in this way gives an initial idea of the number of pressure-reducing stations with the most critical level of risks.

Details of the classification of pressure-reducing stations by category and by undesired event are forwarded to the GRTgaz national comity responsible for managing investments in renewing/upgrading pressure-reducing stations and subsequently to the regional entities in charge of drafting business plans.

4. Updating estimates of reliability of GRTgaz pressure-reducing stations

The changing features of GRTgaz operating pressure-reducing stations means that reliability assessments have to be updated regularly. The changes are caused by two factors:

- changes in feedback and in the age of the operating equipments in pressure-reducing stations
- ⇨ This could lead to a change in the age group of some equipments, which would result in their reliability assessments being modified
- Renewal of some actual pressure-reducing stations, due to GRTgaz proactive policy
- ⇨ This modifies directly the composition of GRTgaz operating pressure-reducing stations, entailing a significant decrease of the number of certain operating equipments (replaced by new one, having their own technical and technological features)

This last factor has a significant influence on the analysis process outlined in section 3.1. The changing features of the operating pressure-reducing facilities must be taken into account to ensure that the reliability assessments remain relevant. Two analysis loops have been integrated for reducing these risks:

- a short loop, conducted on an annual basis and designed to incorporate new feedback data, the changing age of materials and the specific effects linked to the renewal/upgrading of certain pressure-reducing stations
- ⇨ Only the results are updated in this loop
- a long loop conducted approximately every five years and designed to ensure that the implementation criteria remain relevant. Significant changes in the operating equipments (composition, technical and technological features) and/or their reliability must be detected as early as possible so as to limit the impact on the relevance of these results and the method. Two steps are necessary:
    - the extent to which existing analysis criteria and the operational reliability of existing equipments match up is measured (using a representativeness analysis);
    - the list and values of the criteria used to analyse the equipments reliability and classify pressure-reducing stations into categories is updated.

This update is facilitated by the modular structure of the procedure. Indeed, the study process would not be significantly affected if one of the analysis stages was revised.

5. Benefits of the strategy

Assessments generated using this method make it possible to:

- estimate the forecast reliability of each pressure-reducing station and evaluate the individual risk levels for four undesired events related to safety, continuity-of-supply and operational expenditures issues ;
- prioritise these stations with a view to implementing an efficient renovation policy.

The assessments provide a useful insight that helps with making investment decisions (results are integrated into GRTgaz national process and its associated tools).

The estimates and indicators evaluated as part of this procedure can also be used for other activities:

- purchasing policy: monitoring the reliability of new equipments to measure any divergence from the stipulated technical specifications
- industrial policy: monitoring the operational reliability of all equipments currently in use
    - detecting ageing
    - problems with implementation and control during operation
- maintenance policy: monitoring the activities performed and analysing the effects of preventive maintenance strategy (e.g. volume of activities, the ability to detect deterioration of materials ahead of time).

Future prospects

This work demonstrates the quality and usability of available feedback data (provided by a CMMS application – Computerised Maintenance Management System). New activities will be launched to support the next update of pressure-reducing stations maintenance strategy.

The approach adopted will be modified slightly to take into account the dynamic processes related to maintenance activities. Dynamic stochastic modelling in the form of Petri networks [4] will be implemented as a tool for optimising maintenance of pressure-reducing stations, based on technical and organisational aspects.

One advantage of using Petri networks is that doing so makes it possible to overcome certain limitations associated with the fault-tree method.

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FIGURES