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Dynamic modelling of the reliability and availability of complex installations of natural gas transmission networks

Application to a blending station

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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).

In the context of developing the performance of the Transmission network and its approach to manage risk, GRTgaz asked the Gas and New Energies Research Centre of the GDF SUEZ Research and Innovation Division (CRIGEN-DRI) for support in an investment project for the reinforcement of an operating installation.

The approach developed by CRIGEN-DRI is based on a systemic approach, and enables to evaluate the reliability and availability of any type of industrial installation. This approach, and the tools used, were chosen to guarantee a high level of flexibility and adaptation to the wide range of GRTgaz installations. This document details the different stages of the study process (technical and organizational aspects) and illustrates them with an example-study of a blending station. Although particularly complex, this example shows the relevance of the development choices made by CRIGEN-DRI and the significant contribution of the expert knowledge of GRTgaz.

This article also highlights the richness of the results provided by the approach (indicators of reliability and availability) and proposes a stage during which these values are consolidated before being made available to decision-makers.

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1. 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 provide delivery (Public Distribution and Industrial Customers) or pre-pressure-reduction functions on the transmission network.

Within the context of its activities, GRTgaz must meet 3 key objectives:

- To ensure the safety of people and property;
- To ensure the continuity-of-supply of natural gas, particularly during cold periods (2% risk);
- To develop the performance achieved by the transmission network.

CRIGEN-DRI supports the subsidiaries of the GDF SUEZ Group in developing innovative practices, systems, tools and approaches. GRTgaz called on the asset management expertise of CRIGEN-DRI to help it with the investment decision-making for the reinforcement of a transmission network installation.

2. Context and issues

The installations and structures of natural gas transmission networks must achieve high availability and reliability objectives. Meeting these targets helps control the risks associated with safety and continuity-of-supply on the transmission network.

These influence the national doctrines implemented by GRTgaz and lead to the reinforcement of:

- The structure and layout of these installations, e.g. by integrating rescue equipments;
- Maintenance strategies, by increasing the frequency of preventive inspections and adapting the technical content of the activities carried out.

These measures contribute to significantly increasing expenditures related to the operating assets (CAPEX and OPEX).

In a context in which the European energy market is being deregulated, it becomes crucial for the managers of these networks to use methods and tools that make it possible to guide their (re)design choices and find an optimal balance between:

- Achieving availability, reliability and risk management objectives;
- Forecast expenditures in OPEX and CAPEX.

Needs for decision-support tools

Predictive reliability and availability modelling tools help shed initial light on these issues. Indeed, these tools contribute toward demonstrating and justifying technical, organizational and economic choices regarding objectives in terms of safety and industrial performance.

These tools also allow the opportunity for redesign projects to be studied:

- Predictive analysis of the trend of reliability and availability;
- Impact of operational changes, such as an increase in performance demands.

3. Presentation of the GRTgaz blending station

Since 2006, GRTgaz has been operating a unique installation in France for the production of B gas using a blend of H gas and nitrogen. This installation has 4 main parts:

- An H gas stream (in black);
- A nitrogen stream (in blue);
- A B gas stream (in green);
- A centralized management system designed to guarantee the safety of the installation, its performances and the conformity of the B gas produced.

The diagram below shows the material and functional architecture of this installation:

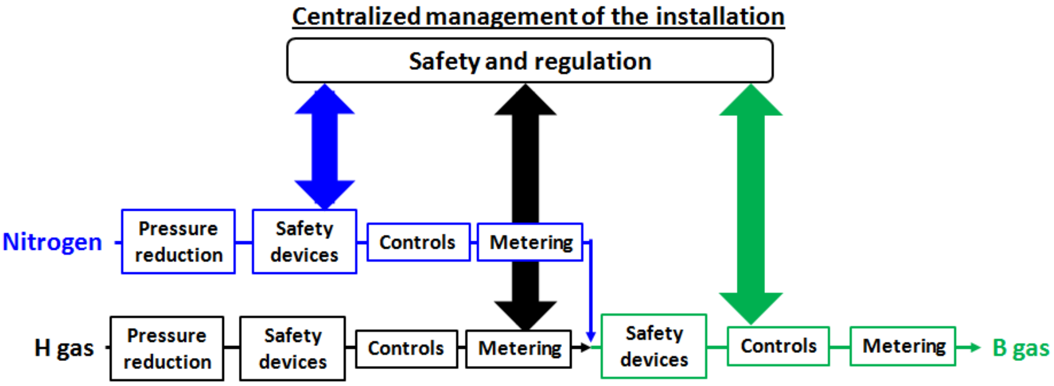

Figure 1 : Material and functional architecture of the blending station

This installation presents several specific aspects:

- Specific operational aspects:
  - A specific organization for management, maintenance and emergency interventions. This organization includes the intervention of operators with specific skills;
  - An installation functioning discontinuously, according to downstream gas consumption.
- Specific technical aspects:
  - Recent launch (2006) and successive modifications made before 2010 to increase industrial performance (design and dimensioning adapted to the needs of GRTgaz);

  - A complex installation, made up of various materials and with an advanced regulating system.

These features are particularly restrictive when analyzing reliability and availability. The developments made by CRIGEN-DRI were geared toward adapting a systemic approach, [1], and constructing an integrated risk model, [3].

4. An integrative approach to evaluate reliability and availability

CRIGEN-DRI has developed an integrative approach that allows:

- Analysis of functions and risks associated with all types of industrial installation;
- Analysis of the external and internal phenomena that influence the operational performance of these installations:
  - The organization of operation and maintenance;
  - The operating constraints associated with managing the network (pressures and flow rates);
  - External phenomena, such as the influence of the weather (which influence the level of performance demanded of the installations of the transmission network);
  - Material and functional failures (linked to regulation).
- To understand, assess and model the reliability and availability of these installations.

This approach is based on a 4-step analysis process:

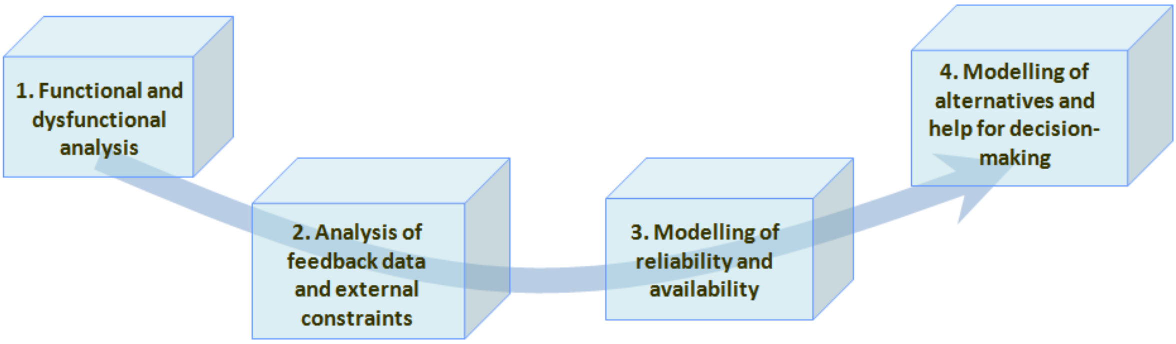

Figure 2 : The 4 steps of the analysis process

Implementing such a process requires the involvement and mobilization of different parties and technical Experts. The study of the blending station thus led to the creation of a multidisciplinary working group within GRTgaz:

- Installation operator and engineers in charge of monitoring the network;
- Network simulation and design / dimensioning study engineers;
- Reliability and equipment Experts.

This group enabled the whole best available knowledge on the installation to be collected. CRIGEN-DRI representatives, in charge of industrial asset management activities, ran this working group and implemented all the processes presented above.

a. Step 1: functional and dysfunctional analysis of the installation

This qualitative analysis enables the identification of internal and external phenomena that affect the reliability, availability and performance achieved by the installation. The proposed approach is based on the methods of internal, external functional and dysfunctional analysis used in System engineering, [1].

Comment: in the case of operating installations, the length of this analysis may be reduced if updated studies of the type Reliability Centered Maintenance (RCM) are available.

External and internal functional analyses

This phase of analyses starts with the characterization of 3 key elements:

- The lifecycle phases of the installation, in line with the context of the study;
- The external elements that interact with the installation;
- The composition of the installation (equipments features).

This information enables the scope covered by the installation to be defined, and the primary and secondary functions the installation performs.

Initially applied macroscopically (integration of external elements), these analyses help to understand the interactions between internal elements:

- Basic components of the installation, and contributions to these functions;
- Regulation and safety constraints.

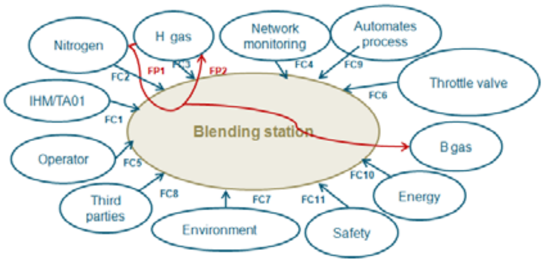

Figure 3 : Functional analysis

This phase therefore enables to understand the macroscopic and microscopic functioning of the installation. It leads to identify the required functions of the installation.

Dysfunctional analysis

The final step in this analysis aims to provide an exhaustive list of all internal events (such as hardware and software failures) and external events (such as climatic events) that will degrade or indeed block the achievement of these functions.

In particular, this analysis allows to identify equipment failures that will block the achievement of the required functions of the installation:

- Directly if these failures impact significantly the performance of the installation;
- Indirectly if these events lead to safety control systems being activated.

These two phases of analysis make it possible to identify the reliability and availability modelling parameters, which are developed in step 3 (cf. section 4.c.).

b. Step 2: analysis of feedback data and external phenomena

This step aims to assess the occurrence of failures and all the phenomena listed as critical to the functioning of the installation. It thus provides the best possible assessments for the previously identified parameters.

Analysis of Maintenance feedback data

Maintenance feedback data contains a description of all the maintenance operations carried out on an industrial installation: preventive actions and maintenance operations carried out following a failure. It also enables to identify the cause of each failure that occurred during operation and to know the technical actions provided during the related corrective maintenance operation.

The recent launch of the blending station, and the technical modifications made since, complicate this analysis (reduced volume of maintenance feedback data). To make up for these limits, it was decided to base this analysis on an expanded scope of knowledge:

- Maintenance feedback data related to the installation to be studied or to technically comparable equipment;
- Data from external bases or constructor knowledge, for equipments with a limited GRTgaz feedback;
- The judgment of the Operator of the blending station and Reliability and Maintenance Experts of GRTgaz, who allow the assessments produced to be added to, adjusted and validated.

Classic statistical tools, as presented by [2], were used to produce these assessments. Average failure rates, and probabilities of failure on demand (case of equipment stressed on an occasional basis), were thus assessed for each equipment and each of the failure modes recorded in step 1 (cf. section 4.a.).

Analysis of external phenomena

Multiple external phenomena can influence the functioning of the blending station:

- The external aggressions, related to climatic or human aspects;
- The upstream and downstream network operating conditions;
- The loss of electrical power.

Only the influence of upstream and downstream network operating conditions has not been taken into account.. The youth of the current configuration of the installation did not make it possible to collect a sufficient quantity of information to construct a relevant model.

The other elements were modelled thanks to data collected on comparable installations of the transmission network of GRTgaz.

c. Step 3: reliability and availability dynamic modelling

Three methods are classically used to produce this type of model: reliability diagrams, Markov graphs and Petri networks, [2: 5]. Only Petri networks offer the qualities required for this study:

- Easily adaptable to multi-component systems
- Consideration of complex operating rules and organizational factors
- Ease of implementation, thanks to resolution by Monte Carlo simulations

Structure of the model developed

The structure proposed by CRIGEN-DRI, of a pyramidal type (cf. opposite), has the advantage of:

- Clearly explaining the sub-models relating to each component / factor influencing the availability of installations:
  - The components, sub-systems and systems;
  - The functional dependencies between these material entities.

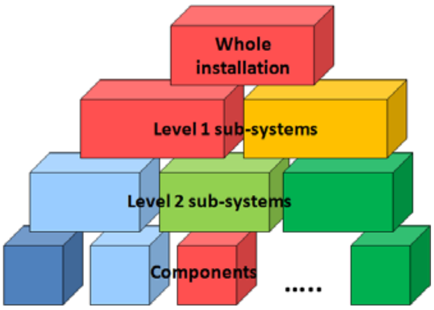

Figure 4 : Modelling architecture

- Structuring the model of installations. The functional hierarchy between each material assembly (components, sub-systems and systems) is implemented in the model, making it easier to read, use and update.

This choice also helps to ensure the flexibility and adaptive capacity of these models.

Simulation support

This dynamic modelling must have a base that allows performing simulations representative of the functioning of the installation. The identification of reference operating cycles requires the collection of:

- Results provided by design / engineering study tools;
- The opinions of technical Experts that allow these results to be adjusted.

The GRTgaz blending station operates discontinuously, mainly during the winter period. The length of these cycles depends on:

- The consumption of natural gas downstream from the installation;
- The duration and intensity of climatic phenomena, i.e. periods of cold (winter), which affect this consumption.

GRTgaz transmission network simulation tools, coupled with climatic models developed by CRIGEN-DRI, enabled several scenarios to be determined that are representative of the operating cycles of the blending station (duration and annual frequency).

Results of the modelling

This proposed modelling allows different classes of indicators to be quantified:

- 2 indicators of reliability, which characterize the occurrence of failures during operation:
  - Estimates of the mean failure rate (in terms of failure / hours of operation);
  - Probabilities of failure on demand.
- 2 indicators of availability, which characterize the performance of the installation over time and incorporate the effects produced by maintenance activities:
  - An instantaneous value, corresponding to a one-time measure of the status of the installation studied (available or unavailable);
  - An asymptotic value, which provides a long-term vision.

Each of these values enables to:

- Describe the behaviour of the installation and its performance over multiple time horizons: short, medium and long term;
- Verify the relevance of the modelling developed by CRIGEN-DRI and validate the representativeness of the results obtained.

The graph below illustrates the behaviour of the blending station, simulated on the first operating cycles. This figure highlights:

- The stability of the estimates of instantaneous availability during the operating cycles (between 99% and 99.5%);
- The one-time drop in these estimates during stop / start phases. The values are thus between 96.5% and 97.5%.

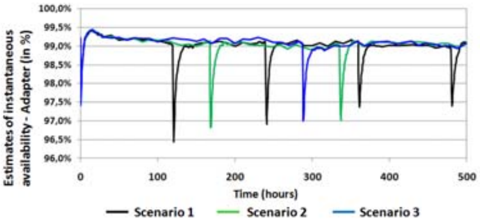

Figure 5 : Results of availability simulations

The presence of two phases is explained by the stressing of different equipments during a cycle:

- The equipments associated with ensuring safety and stopping the installation are mostly functioning during start / stop phases (taps, safety flaps and valves);
- Only regulating equipments and control system, in flow and pressure, are stressed during the B gas production phase.

Integration within an investment decision-making process

The results provided by these models allows to characterize the behaviour of the installation studied (a blending station in the context of this study). However, it is difficult to interpret these values without a reference base. Accordingly, three standard installations of a transmission network were modelled to provide reference indicators of reliability and availability.

These values were obtained thanks to the application of the approach proposed above and incorporate parameters estimated on the basis of the maintenance feedback data of GRTgaz. The simulation bases used were selected according to:

- Their representativeness of the operation of these installations;
- The ability to compare the results of these models (homogeneity between indicators).

The comparative analysis carried out between these values highlighted the homogeneity of the indicators assessed for these installations and the blending station.

This study was carried out to analyze three configurations proposed by the blending station reinforcement project and defined on the basis of the opinions of GRTgaz Experts and previous results (search for reliability and/or availability enhancement).

d. Step 4: modelling envisaged configurations and help with the decision

The developments realized during the 3rd step (cf. section 4.c.) make it possible to guarantee an acceptable level of flexibility and adaptive capacity within the model. These qualities make it easier to create models relating to the alternatives studied and evaluate forecast gains related to changes in the technical architecture of the blending station and/or the organization of maintenance activities.

Example of results obtained

The figure below presents an example from the results obtained during this last step (comparison of mean availability estimated for each configuration to be studied). It enables to visualize the local / global effects of a technical and/or operational change in the installation.

This figure highlights the differences between the forecast availabilities evaluated for each configuration. Two indicators are particularly adapted to this comparison:

- The minimum availability obtained during simulations;
- The rate of growth observed in the second part of these curves.

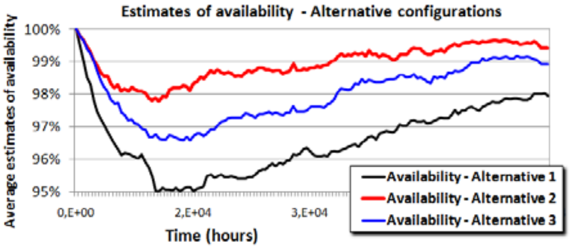

Figure 6 : Comparison between alternatives - predictive estimates of availability

Alternative no. 2 thus presents the highest levels of forecast availability over a significant simulation period. This type of analysis thus helps identify the optimal technical and/or organizational solution.

These results have been transmitted to GRTgaz decision-makers, who integrated them into their internal process (input data for carrying out cost / benefit analyses).

5. Conclusion

This study made it possible to test and measure the contributions of an integrative approach for evaluating the reliability and availability of a complex industrial installation. The process proposed, and the related modelling choices, showed a high degree of adaptive capacity in a particularly complex context:

- Presence of a reduced volume of feedback data, offset by the integration of heterogeneous data (including the GRTgaz Experts judgments);
- Complex organization in terms of operation, maintenance and emergency intervention;
- Discontinuous stressing of the installation, influenced by climatic variations.

The conduct of this study benefited from the involvement of project parties from GRTgaz and CRIGEN-DRI. These made a significant contribution to:

- The collection of available knowledge on the operational behaviour of the installation and its operating conditions;
- The construction of a model that was representative of this behaviour and adapted to the complexity of the phenomena to be taken into consideration.

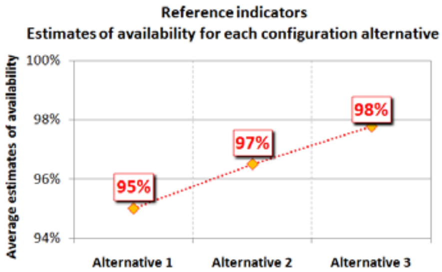

Figure 7 : Availability estimates for each alternative solution

This study made it possible to:

- Estimate current levels for the installation's availability and reliability;
- Carry out a comparative analysis with standard installations of the transmission networks;
- Help identify reinforcement solutions, technical and/or organizational, and estimate their forward performance;
- Evaluate the gains associated with each envisaged configuration.

These results offered a significant amount of additional information to GRTgaz decision-makers.

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Figure 7 : Availability estimates for each alternative solution