OPERATIONS & MAINTENANCE:
AN INTEGRATED APPROACH TO ENHANCE SAFETY AND RELIABILITY
OF DISTRIBUTION NETWORKS

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ABSTRACT

Background
Aem Gas operates five different gas distribution infrastructures, operating in eleven different cities, the main being the one in the city of Milano (Italy).
Milano gas distribution system origins in the late 1800s, delivering town gas, produced in directly owned facilities. The distribution network ad those days was mainly made of grey cast iron pipes with lead-yarn joints. Starting in the eighties of last century, Aem Gas run a complete conversion program from town gas to natural gas: this meant a significant increase in leakages form lead-yarn joints, due to dryness of natural gas compared to town gas and due as well to different operating pressure levels.

Approach
The changing in the characteristics of the network brought to a new approach to its operation and maintenance, “reliability centred” in order to ensure the adequate level of reliability connected also with the different inlet characteristics. So Aem Gas has developed sound and optimised maintenance programs, with a strong theory background and/but flexible in their application.
Criteria adopted always concern safety issues, but involve as well economical (in terms of opportunities and technologies) and overall operation coherence. Operation coherence of the distribution system means, in this context, the enhancement of independence and reliability of a system that is on a continuous path of changing and expansion anyway.
It is through these key factors that safety issues have been approached in order to reduce leakages coming from lead-yarn joints as well as fragile breaking. These two represent the main causes for leakages (almost the 80%) as well as the most significant target for the activity of emergency services. Prevention and reduction of leakages generated by these to factors will enable to increase reliability of the system and service quality, together with saving of time and resources.

Method
The first step has been to collect a wide range of data, organising them in order to obtain the maximum possible amount of key, discriminating information. Next step has been to analyse data in order to define a priority approach, targeting the most critical pipeline sections (in terms of material, connection, laying, etc.); the analysis has been developed also using a network analysis and simulation model to check size of pipes, pressure levels, interconnections between different parts of the pipeline, so obtaining as well a significant increase of the overall efficiency of the network.

After the analysis, substitution plans have been defined through the collection of the interventions as much as possible in homogeneous areas, in order to increase efficiency of the operations.
With the same approach, other safety aspects have been dealt with, increasing the capability to face large-scale emergency situations such as loss of supply at a city gate (that could produce, if not approached properly, the loss of supply for almost all the distribution network).

Results
Through an optimised combined approach (data analysis and network simulation) it has been possible to increase the overall reliability and safety of the network itself and its management as well. The approach has helped also to check procedures in use, enhancing their efficiency and fitting them on the specific real operational needs.
The paper will analyse in detail the main issues faced, the approach adopted, the drivers considered to define substitution plans, the effect of simulation modelling on them and the overall enhancement of the network reliability obtained and that can be obtained in the next future.
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1 DEVELOPMENT OF THE GAS NETWORK IN MILAN

1.1 DEVELOPMENT IN THE USE OF MATERIALS

The design method and performance characteristics of the gas distribution networks are improving all the time, but at a slow rate, following the innovations introduced in steel metallurgy as applied to the construction of pipelines.

We span from the pipelines in grey cast iron with lead-yarn joints (used since the end of the nineteenth century to the mid twentieth century) to second generation pipelines in grey cast iron (PAM) made from material of improved quality and with superior physico-mechanical characteristics compared to those of first generation. The pipelines in Pam cast iron, which come with mechanical joints, owe their name from the sole supplier of the period which was the French foundry Pont a’ Mousson. This type of pipe, used since 1960 for twenty years, represents 20 % of the present low pressure network.

The problems associated with brittleness and resistance to flexion and torsion were overcome with the arrival of spherical ductile iron, at the end of the 70s. Many properties of these pipelines, such as their resistance to ground chemical agents and electrolyte corrosion, in addition to their ease of installation, provided by the express joints, widely used in PAM cast iron pipes, make them the most widely used type.

Almost a third of our low pressure network consists of pipelines made of ductile iron. Steel is still a widely used material found in gas networks all over the world. In Milan it was used concurrently with cast iron from the beginning of the twentieth century. It was used, in particular, in special projects (such as, crossings over roads and canals) and in the building of rising service lines. Since the 1950s, steel has been subjected to careful studies and monitoring. Indeed, the high and medium pressure network has cathode protection plants to protect it from corrosion from electrolytic agents.

In the early 1980s PVC was used experimentally and then entirely replaced before the conversion of the network to natural gas.

Nowadays, high density polyethylene is the predominant material used in low pressure networks, but is destined to be widely used also in the medium pressure network.

There are several advantages in the use of PE, such as, the ease of laying of the pipelines, reliable welds and a great number of accessories, in addition to its resistance to chemical agents present in the ground which makes it a better alternative to steel.

1.2 DEVELOPMENTS IN THE AREAS OF USE OF GAS

In Milan gas was first used for street lighting.

In some historical document are listed for the first time the number of lights present for the period 1787 to 1867. The use of gas for lighting began in 1845, when a third of the lamps used were supplied with gas (or manufactured gas).

1.3 THE INCREASE IN THE USE OF GAS

The first figures showing manufactured gas consumption for city lighting were of more than 140,000 cm/year for the year 1845 which became, in little more than twenty years, in 1867, 1,195,000 cm/year.

Figure 1 (below) shows the increase of annual consumption of natural gas from 1998 to 2004.
Figure 1

Annual Supply [cm/year*1,000]

Year
1998 1999 2000 2001 2002 2003 2004
888,649 931,261 947,233 1,035,849 1,015,387 1,080,338 1,120,544

Figure 1
2 RADICAL CHANGES RESULTING FROM THE CONVERSION TO NATURAL GAS

As indicated in the figure above the present natural gas network consists of three distinct functional levels as defined by their pressure and construction characteristics. These three levels are high, medium and low pressure. The high and medium pressure pipelines are built in arc welded steel with active and passive protection against corrosion.

They are also provided with line sectioning valves as well as with valves for the rapid emptying of the individual sections. When in use, the high pressure operates at 12 bar and the medium one at an average of 1.5 to 5 bar.

The lowest pressure operates at 22 mbar and varies greatly depending on the construction and the building materials used as indicated in the tables above. This network is powerfully reinforced by a mesh, it does not have line sectioning valves and its supply is provided by over 250 district governors.

2.1 NEW SITUATIONS AND NEW RISKS – THE GAS NETWORK IN A CONTINUOUSLY EVOLVING CITY

The gas distribution network has been designed and implemented to grow with the city. Therefore, it is structurally and functionally suited for manufactured gas. The conversion towards natural gas has been a revolutionary and in some cases a traumatic change. To minimize this, the process of conversion was carefully studied and frequently modified during its implementation.

The whole organizational machinery responsible for carrying out the introduction of natural gas has been under severe pressure as a result of unclear mappings, the first empirical attempts at simulating and predicting the behaviour of both the new network and the one undergoing the conversion and the transportation issues.

The process of conversion has been implemented according to the plan summarized as follows:

1. Milan and the surrounding towns connected to the network were divided into 134 areas with approximately 5,000 customers per area.
2. The LP and MP networks were divided into sections and converted by parts following the conversion programme; the manufactured gas was burnt off with mobile torches before the new gas was introduced.
3. before implementing the conversion all major customers underwent the necessary transformations and while waiting for the nozzles to be replaced domestic customers were given detailed information on how to use natural gas.
4. district governors were all initially provided with glycol atomizers to reduce the hygroscopic properties of natural gas and therefore maintain the correct level of humidity around the old yard joints of the LP network.
5. thanks to the experience gained during the initial stages of the introduction of natural gas, the conversion to this gas could be carried out also in the early and late winter months, a period which was once totally banned for this type of activity.

After the conversion the new gas introduced some mechanical stresses within the structure of the network itself and upset the delicate balance which are at the basis of its distribution system. Manufactured gas with its high water vapour content forced frequent and regular inspections of the siphons for the collection of condensation and demanded the rigorous observance of the inclines of the pipelines during their laying. Furthermore, once collected the water vapour had to be processed by special means in order to neutralize pollutants present in the condensate.

As a result of these requirements, water vapour had high running costs, but the vapour characteristic of manufactured gas ensured the air-tightness of the lead-yarn joints, present in over a third of the low pressure network (LP).

After the conversion to natural gas, the gradual removal of the siphons and the widespread use of polyethylene ensured a marked reduction of costs of implementation and maintenance of the network.
2.2 ADJUSTMENT OF THE NETWORK IN RELATION OF THE MAIN CHARACTERISTICS OF NG

Gas dispersal from lead-yarn joints and from fractures
The distribution system, which had been designed and implemented to distribute manufactured gas, offers, after the introduction of natural gas, a high capacity supply system, which, however, suffers from some structural problems.

The majority of these had already been taken into account and resolved with pre-emptive actions, such as the replacement of entire pipeline sections of the medium pressure network and the removal of the siphons and of the flanged joints as well as of other mechanical joints.

About 20 Km of the PVC network laid in the 1970s as a pilot experiment were completely replaced, because the sealing resin was unsuitable for direct contact with natural gas.

The pipelines in grey cast iron with lead-yarn joints (or old cast iron called GTV, i.e. “ghisa tipo vecchio”) had been subject to intensive annual modernization campaigns.

This was the result of direct experience as well as the experience gained by other countries (for example, in Britain) which also used first generation grey cast iron pipelines with lead-yarn joints and which therefore are brittle and subject to radial breakages and gas escapes from the joints.

Gas filling
The probability of manufactured gas (MG) to form gas clouds is less than that of natural gas (NG), particularly at running pressures, which in the low pressure (LP) network are more than three times higher (from 7 to 23mbar).

The volatility of natural gas and its lower relative density make it less likely that it will form gas clouds in areas where leaks may have accidentally dispersed in.

Toxicity
Compared to NG manufactured gas was toxic and a health hazard if inhaled. Natural gas may kill through suffocation but not through poisoning.

Priming explosive potential
Another dangerous property of the old manufactured gas was its explosive power and the lower energy required for priming the explosion.

By contrast, natural gas has ten times more explosive power.

Running pressure in the network
Both the LP and the medium pressure (MP) networks have seen a marked increase in their maximum operating pressure (MOP), going from 7.5 to 20 mbar and from 0.5 to 1.5bar, respectively.

Odorization of the gas
During the summer, to compensate for the decrease of odorizer in the areas recently converted to natural gas, it was necessary to use supplementary odorizing systems. These, however, have not been as successful as it was hoped. Fortunately, the absorption phenomenon observed in the metal pipes gradually diminished and, with the aid of specific configurations of the distribution network it has been possible to solve the problem with satisfactory results.

Conditioning
District governors (or reduction plants) have been supplied with glycol foggers to reduce the gas dispersion occurring in joints, due to the low water vapour. In the first 5 years of the natural gas-based network, these foggers have markedly reduced the number of dispersions.

It was then decided to stop using and then gradually remove this equipment, thanks to the ever-increasing number of encapsulated joints which avoided such events.
2.3 NEW LAYOUT OF THE GAS SUPPLY

ABSENCE OF GAS HOLDERS AND STOCKS
Natural gas offers more flexibility compared to manufactured gas in terms of its supply and the total absence of the need for stocks.

The complete reliance on self-produced gas and the need to optimize the manufacturing process made it essential to stock the fuel, so as to make it available at peak times of the day (morning, midday and evening). The costs were high both for running such a system and for the maintenance of the compressor groups present in the three main stocking areas. (Bovisa, Orobia and Canavese).

The volume of gas required at the three daily peaks of demand, has now doubled compared to the times when manufactured gas was used. This demand is easily provided for, through the great availability of gas at the supply points, which join the national network. Here there are no restrictions at accessing the gas supply, except during peak periods, which makes it possible to configure the whole distribution system according to the demands made on it and the supply points available.

The reliability and flexibility of the network has increased markedly since the conversion to natural gas was implemented.

The flexibility of the system is such that in the summer it is possible to supply the whole network even when 3 out of the 4 pipelines are stopped in one of the entry points. This allows ordinary maintenance to be carried out on sections of the network and of the reduction pipelines at the entry point, which would be set on stand-by.

However, every year periods of peak consumption demand become longer, exceeding the supply that can be provided in case of default of one of the entry points. For this reason, it has been necessary to develop more efficient maintenance plans and emergency operation plans, which can be supported by simulation studies of flow dynamics by modelling the network. These would help maintain the reliability of the distribution services, by a better use of technical and human resources during emergency cases thus ensuring the redistribution of the demand load on the network.
3 DEVELOPMENT OF THE MAINTENANCE CRITERIA USED DURING AND AFTER THE CONVERSION TO NATURAL GAS

3.1 RELIABILITY AND SAFETY IN AN INTEGRATED APPROACH

As indicated in the preceding chapter the introduction of natural gas in Milan was an opportunity to act on the structure of the network. The interventions were planned and executed integrating for the first time both safety and reliability issues:

- In terms of safety, in the first three years, sections of pipes in grey cast iron (which are subject to brittleness fractures) were replaced by lead-yarn joints of less than 150mm in diameter
- meshing and reinforcement of the pipes to support the new transient settings;
- removal of tulip and gibaux joints which are unsuitable for the higher pressures used
- new district governors (temporary and permanent) were built to guarantee the reliability of supply of the increasing demand determined by the greater number of customers expected in the years to come.

SCORE SYSTEM

In the programme to finalize the introduction of natural gas, the priorities for the replacement of the pipes were determined from the beginning of 1987 by a score system model (i.e. an additive model) which was based on available historical data. This included the number of gas dispersals, the cause for the dispersal (breakage or joint), the diameter of the pipe from where the gas was dispersed, the year in which the pipe was laid, the depth of pipe in the ground etc.

The collection of data and the process of updating the database has continued using a specially prepared score system form for each section of the pipeline.

Based on archive data, for instance, it has been possible to establish that the pipes in grey cast iron with lead-yarn joints of less than 250mm of diameter, were the ones most subject to breakages due to brittleness and therefore in most need for replacement. By contrast pipes of the same material but of diameter greater than 250mm were more resistant (due to their greater thickness) and gas dispersals from these units solely originated from joints. For this reason these pipes were assigned a lower priority.

Over time the score system model (i.e. the additive model) has been developed further and modified. For some years, in fact, we have used a score multiplication model which calculates risk as the product of the probability of an event occurring accidentally and the magnitude of the event itself.

To achieve this, the score system form has been updated and completed to include the site of laying (whether road or pavement), the proximity of cellars, the probability of formation of gas clouds, the expected aeration of the rooms near the pipes etc. The implementation of the database has been carried out together with a data collection campaign by the emergency technical staff.

MODEL NETWORK SIMULATOR

The model network simulator was introduced by AEM Gas in 1986. With the aid of this simulator it was possible to perform detailed analysis of the fluid-dynamics in the network itself. With this network simulator it was possible to detect, with a greater degree of accuracy, the need for meshings, reinforcement and development of new district governors, in order to optimize gas distribution and maintain acceptable levels of fluid velocity inside the pipes even during the peak supply periods.

Every year the simulator is updated and tested with the pressure values obtained in the field in certain predetermined points. An annual maintenance work plan for the following year is prepared, based on the tests carried out with the network simulator. This helps to keep the network always at an acceptable level of efficiency.

3.2 THE SIMULATIONS OF THE PLAN IN RELIABILITY TERMS

All maintenance work as well as modernization and development schemes for the network are designed, optimized and tested several times with the model simulator using hypothetical situations which may happen locally or in general. The object of simulations with multiple scenarios is mainly to ensure the
greatest economic returns for the investment made (both for the materials used and the technologies adopted) and to provide the greatest efficiency of the plants in terms of their performance, their ability to respond to new demands and their capacity to withstand emergency situations such as governors defaults or problems on main feeders.

Conditions which may arise and help to reduce road works and other inconveniences for the local population are also considered, as they arise; for example, working concomitantly with other public utilities, but also the use of trenchless or no-dig technologies (such as, re-lining, pipe-bursting, slip lining).

In this way maintenance becomes a holistic entity, which gives an added value to the distribution system as a whole.

To achieve this a number of essential parameters must be in place:
- a sufficient minimum gas supply, particularly during changes of time and season.
- gas velocity below the threshold that prevents the particulate matter from being carried through.
- a minimum drive pressure to ensure the movement of district governors
- the correct functioning of every single regulator within its expected controlling range
- the correct safety margin at the lowest pressures even in emergency situations.

The performance parameters and those which are critical for the system have to be monitored and managed, during the running of the network. There are essentially two such parameters:
- the correct balance among the entry points, obtained by the accurate measurement of the supply pressures of the MP network;
- the inevitable blockage of the filters of the district governors once the maximum known speeds are exceeded, thus activating the transport of dust.

The network, therefore, behaves like an athlete who, by continuously training, can increase his own performance limits until these are reached with ease.

Every time the maximum supply threshold is exceeded it has been found necessary to have a buffer system in place to absorb this excess, because when the values increase sharply at the peak hours the only possible actions are:
- small changes of the set point in the entry points;
- controlled release of the dust by removing the filters;
- assisted supply by using by-passes for those units which may no longer have the ability to control the system;
- peak-shaving by temporary reduction of the loads using remote activation.
4 NEW MANAGEMENT ISSUES AND THE INTENSIVE USU OF TECHNOLOGIES FOR PREDICTING THE IMPACT AND MANAGEMENT OF HIGH RISKS

4.1 INCREASE IN GAS CONSUMPTION
As indicated in figures 1 and 2 gas consumption has markedly increase in the last few years.

It is essential to avoid the negative consequences which such changes may cause like, for example:
- Increase in gas velocity in the pipes
- Increase in the number of districts governors subject to filter blockage
- An ever increasing significant drop in pressure
- Increase in the number of areas which need further development in order to face the predicted increase in demand
- The demand at the peak time gets progressively closer to the limit which can be delivered by the supply points of the transport network

4.2 DIFFERENT ACTIONS ON THE AREA
After the introduction of natural gas, Milan was subject to numerous building projects by other operators, some of which are still being carried out. Some of these operations are listed as follows in chronological order:
- the Urban Lighting Plan (1998-2001), which involved about 600 km of excavation to replace/install around 50,000 lighting points;
- the cabling with fiber optics (1999-2001), carried out with 400 km of excavation;
- the construction of 100 new underground car parks (since 2003) to increase the number of available parking spaces;
- the new railway link to connect the stations in the city with those of the nearby towns;
- the metro tramway to connect directly by railway areas which were previously only linked by the public bus system;
- the implementation of Urban Requalification Plans (reutilization of former industrial areas);
- the development of the underground train network system;
- the construction of new district heating networks to connect in the next 5 years 250,000 customers;
- the creation of new bus lanes for public transport.

The extent of such public works in such a short time frequently involves interruptions, damage, displacement of the ground etc, which can compromise the state of gas pipes and cause breakages.

4.3 FROM AN APPROACH BASED ON SAFETY (A CRITICAL SITUATION IS IMPROVING) TO THE CHALLENGE OF MAINTAINING A RELIABLE NETWORK

More and more the interventions on the distribution plant are based on reliability rather than safety issues.

On the other hand the importance on safety issues have changed.

Initially the problem was the gas dispersal from the lead-yarn joints due to a change in the type of gas distributed, as described in chapter 2.1. The impact of this effect on the running of the network is continuously decreasing thanks to the regular replacement and repairing of the pipes.

Nowadays, instead, safety issues mainly focus on “external agents” which affect the network, like the ones mentioned earlier in paragraph 4.2 and upon which there is no direct control. A solution to this can, therefore, only depend upon the promptness of response to the breakdowns and on the monitoring of the area.

For this reason, during the construction works AEM Gas provides support to the operators in all the main sectors which are active on the territory (cableers, railway transport, aqueducts, the sewage system etc). This is to ensure that the building regulations for these additional services are abided to without interfering with the gas network.

The constant rise in consumption, makes the reliability of the system an increasingly important and dominant issue in the management of the distribution system, particularly if safety is more and more just a question of managing the breakdowns or the damage.

For this reason AEM Gas has developed and is further refining an emergency plan in case there is a complete interruption in an entry point. This is because the breakdown of such a supply point in winter or at certain times of the day, may result in an insufficient supply of the network and, if not solved at an early stage, an interruption of supply for the customers.

It may be seen from figures 3 & 4 that the network may have problems if there are breakages at one of the three supply points for the Milan plant; that of 300,000 Scm/h, 250,000 Scm/h and 100,000 Scm/h.

Moreover, in case of problems at any of these three sites, the decrease in capacity may be compounded by problems of fluid velocity which, if too high, may lift the dust in the pipes and therefore block the filters in the district governors.

For all these reasons, in addition to the studies carried out with the model simulator, the application of the emergency plan is tested together with the staff. This allows the data to be verified further and the personnel to be trained on how to manage such events. This provides a feedback on issues which may go beyond the mere determinations made by the simulator.
4.4 EVALUATION OF THE ARRANGEMENTS FOR THE SUMMER AND DEFINITION OF SUPPLY CONFIGURATIONS FOR THE EFFECTIVE DISTRIBUTION OF ODORIZER

A new study currently underway at AEM Gas S.p.A. involves the use of the fluid-dynamic model to analyse the network during the summer season.

Infact, the model was designed and developed to analyse the setup of the network in winter, that is, in a season in which the high consumption may negatively affect the performance of the network.

The summer season, on the other hand, has completely different prerogatives: a lower consumption with a more linear supply curve (figure 5).

A comparison of the data for 2004 may help to understand better the performance of the network in different periods of the year:

Typical winter day (19/02/04):
- daily supply = 6,900,000 Scm
- Maximum peak = 459,000 Scm/h
- Minimum peak = 92,000 Scm/h

Typical summer day (17/07/04):
- daily supply = 530,000 Scm
- Maximum peak = 35,000 Scm/h
- Minimum peak = 7,700 Scm/h

Figure 5

The above study looks at two aspects of distribution during the summer period: A more efficient and effective management of the supply points, which exploits the summer season to carry out maintenance work on the points themselves. Determination of the best arrangement for a uniform distribution of odorizer in the network.

The second point is of particular relevance: it is common to increase the amount of odorizer in the network over the summer, in order to compensate for its degradation due to its longer presence in the pipes; this adds to the specific costs, often without obtaining the desired effects.
This study wants to determine the network arrangement that can give the set-point values on some district governors, which would help to keep constant the amount of odorizer (in mg/cm) in the network in the different seasons. In the case of low-flow, this would be done using the correct calibration of the fluid-dynamic model.