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Natural gas consumption forecasting for anomaly detection

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ABSTRACT

Natural gas consumption forecasting is critical for many gas supplier companies tasks - e.g. gas procurement optimization, pipe network monitoring, management and security. This paper presents the joint work we carried out with HERA S.p.A., Italian gas provider leader, which goal is to forecast gas consumption for a given gas network as well as detecting anomalous gas flows according to historic data so to facilitate the monitoring and security processes in their central control room.

Historic network conditions are sampled every 15 min, each sample is composed by a gas flow, an outside temperature, and the timestamp the sample was recorded. Descriptive analyses were carried out using historic data in a village and a small city, then two forecasting techniques were defined, one based on a nearest neighbor approach, one employing local regression analysis.

Experimental results show that the historical data collected and stored can be used to reliably forecast gas consumption. A quantitative and qualitative comparison of the two methods is discussed in details so to highlight strengths and weaknesses. Moreover, due to the peculiarity of the domain, we worked with domain subject-matter experts to understand the capability of the methods in detecting anomalous gas consumption.

Our results clearly show our forecasting techniques effectively support control room operators in identifying anomalous consumption. Providing a forecasting functionality is the first relevant step towards creating a full expert system that makes it easier for advanced operators to interpret the gas network behavior and that suggests the less-skilled ones the correct reactions to be taken upon the occurrence of anomalous events.

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1. Introduction

Natural gas is the cleanest energy source over the fossil fuels. Abundant gas resources, increasing investments, and long-term contracts contribute, year after year, to lower gas price, improve infrastructures, and increase its usage in residential, industrial environments as well as transportation. Due to this mix of reasons natural gas consumption has grown significantly over the past years, moreover having seen the European Commission efforts on lowering carbon energies this trend is forecasted even to raise.

Worldwide, natural gas, is mainly used for residential, commercial and industrial environments; also electric energy generation significantly contributes to gas consumption whilst transportation still plays a secondary role.

In Italy, gas distribution to users is managed by regional gas suppliers who are responsible for gas procurement, distribution and pipe network management. They faces many challenges in their business like forecasting gas demands for optimizing procurement, pipe network monitoring for maintenance and security reasons, gas meters reading for user profiling, customer segmentation, fraud prevention, etc. Among these challenges, those linked to security and service delivery are obviously of main concern. With this in mind, monitoring gas flow and pressure within the pipe network represent a key activity for many security and service related control workflows.

This research and experimental work is an outcome of a joint collaboration between the University of Bologna and Hera S.p.A., which is a regional company, manly operating in Emilia–Romagna, for gas, water, electricity and drainage services. Hera aims at improving its gas services because they are, among the others, those

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mainly affected by security law regulations and needs for proactive actions.

In particular Hera faces a challenge in managing their gas network: understanding anomalous gas flows. When gas flow shows anomalies, it causes leaps in pressure. There are two kinds of pressure leap: negative leaps which could cause end user meters to be locked due to security devices installed on them; and positive leaps which could cause high stress to network components and, when extreme, cause bursts.

For example a negative spike of pressure causes meters to lock and it can only be unlocked via manual intervention. This is due to a security policy regulating the unlocking process, the gas engineer is allowed to proceed only with the customer's supervision in order to avoid gas leaks inside its building. As per positive pressure spikes, Hera historically experienced a pipe burst due to high pressure in 2006. The leakage originated an explosion and a building collapsed causing casualties.

Over the past 5 years, Hera has started a journey for improving his monitoring capabilities over its gas pipe network. Along this journey, Hera, have installed an advanced sensor network where gas pressure and flow are read on any gateway (i.e., entry point linking the Italian national gas network and the local networks where end users are connected to). Sensors communicate with the central data bank providing real-time meter's readings.

The sensor network has now collected a huge quantity of readings. Hera would like to leverage such information to create gas usage model that allows to predict (1) the gas consumption with a high forecasting resolution and a short forecasting horizon, (2) the consumption window that marks normal consumption variations from anomalous peak. Such forecasting functionality can be immediately exploited by the control room users to judge the overall network status by comparing the predicted values against the values read by the sensor network. This comparison facilitates the detection of anomalous gas flows undergoing in the pipe network and can be used to raise automatic warnings.

In this work we present two techniques to model the natural gas usage in terms of predicted consumption and normal consumption window. In particular the first technique is based on a stochastic model whilst the second is based on a local regression analysis. More in details the original contributions of the paper are:

- An in-depth analysis of the Natural Gas Consumption domain based on the data made available from Hera (see Section 2).
- The definition of two forecasting techniques the desiderata and constraints provided by the Hera domain experts (see Section 3.1 and Section 3.2).
- A large set of tests aimed at evaluating the effectiveness and efficiency of the two approaches. The comparison between the results makes it possible to better understand strength and weakness of the two methods and let the user to achieve a better understanding of gas domain (see Section 4).

The paper organization is completed by an analysis of the related literature (see Section 5) and by the conclusions that also outline our future and current researches (see Section 6).

We emphasize that the final goal of the HERA project is to develop more advanced functionalities on top of our forecasting techniques. The complete system will show both decision support system and expert system features and will be aimed at supporting the control room operator to understand the gas network behavior and to make better and faster decisions. One of the problem faced in control rooms is the limited experience of some of the operators. For this reason, HERA would (1) provide the operators with a set of tools for easily interpreting the network behavior; (2) code in an expert system the knowledge of the most skilled operators to enable the correct reactions to be taken upon the occurrence of anomalous events. In particular, interpreting the consumption patterns and the drift from the forecasted values require some intelligence. For example a smooth, progressive drift from the forecasted values could have a different interpretation with respect to a sharp peek of consumption. Peak shapes may also be related to the season, weather conditions and the network specificities (e.g. number of inhabitants, presence of industries).

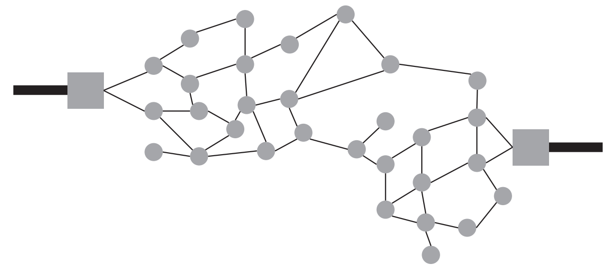

Fig. 1. A typical local gas network with several customers (circles) and two RMPs (squares).

2. Natural gas consumption: data and domain analysis

In this section we report the outcomes of the analysis we carried on the natural gas consumption domain. This rather critical step is aimed at acquiring a deep understanding of the domain specific features and it lays down the basis on which our forecasting models will be built on. Indeed, it highlights data quality issues that would potentially invalidate the prediction model on the one hand and it points out the domain's dependent and independent variables on the other.

The data are provided by HERA S.p.A., one of the italian's leaders in energy and water infrastructure management and service provider. In term of natural gas distribution, HERA mainly operates in the region of Emilia–Romagna, it manages around 14,000 Km of gas network servicing more than a million customers. The overall gas network is partitioned in several local networks typically servicing a well-defined geographical area corresponding to a town or part of a larger city. Each local network is supplied through one or more Regulation and Measurement Plant (RMP) that are the borders between the national provider network and the HERA's network. The gas flow for each local network is computed as the sum of the gas flows passing through the RMPs supplying such network. Fig. 1 shows a typical local gas network supplied thorough two RMPs (squares).

The data used in this work are related to gas consumption volumes in two different networks: *Network 1* services Voltana, a village of 2,200 inhabitants mainly including residential utilities; *Network 2* services Lugo, a small city of 33,000 inhabitants including, besides residential buildings, some commercials and offices. Both the areas shares a the same temperate climate with hot summers (with highest temperature over 30 °C degrees) and cold winters (with lowest temperatures below zero).

The dataset comprises about 35,000 observations per year per network over a period of about 3 years in total, from July 2010 to September 2013. Besides the historical values HERA provides the local temperature forecast for the next 12 h.

Definition 1 (Observations Dataset)**.** Given a natural gas network, an Observations Dataset $S = \{s_1, s_2, \ldots, s_n\}$ is a sequence of n historical samples, where each sample $s_i = (g, t, d)$ is characterized by the gas flow g expressed in Stm^3/h, the local outside temperature t in °C degrees, and a time stamp d.

Samples are collected by the HERA's SCADA system every 15 min that is the finest time precision in our project (in each day

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