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Information Technology for Monitoring of Municipal Gas Consumption, Based on Additive Model and Correlated for Weather Factors

Oleg Nazarevych[1], Volodymyr Gotovych[1], Grigorij Shymchuk[1]
[1] *Department of Computer Science, Faculty of Computer Information Systems and Software Engineering, Ternopil Ivan Puluj National Technical University, Ternopil, Ukraine*
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Abstract. The present article deals with the practical implementation of information technology for monitoring the gas consumption of the city (regional centers) on the basis of proposals additive model and taking meteorological factors. Justified and suggested automating the monitoring system of gas consumption. The functional diagram of the formation of a database of measurements and framework developed of a database to store statistical data measurement of gas consumption and meteorological factors for interval accumulation hour, day and week.

Keywords: gas consumption, information technology for monitoring of municipal gas consumption, "Caterpillar-SSA" method, regression analysis, change-point detection method by Brodsky-Darkhovsky.

1. Introduction

This article deals with the practical implementation of information technology for monitoring the gas consumption of the city (regional centers) on the basis of proposals additive model and taking meteorological factors. Justified its main requirements and suggested automating the monitoring system of gas consumption. There was given a description of the functional diagram of the formation and accumulation of a database of measurements of gas consumption and meteorological factors. Suggested form of DB for storing of information for interval accumulation hour, day and week. The given example illustrates the results of applying automate system for monitoring of gas consumption of the city.

2. The definition of the problem

Basing on the statistical data of gas consumption measurements and municipal weather histories, it is necessary to suggest an information technology for monitoring of municipal gas consumption; to describe the functioning of information system, intended for data collection from Flowtech measuring complexes and weather histories; to develop a database structure in order to store data measurements in the following accumulative steps: an hour, a day and a week; to suggest an automated monitoring system for municipal gas consumption and an algorithms for statistical data processing, based on the proposed mathematical model and with regard to the weather factors available.

3. The objectives of the monitoring

Under the monitoring of municipal gas consumption processes, we understand the complex task, intended for a gas consumption measurement, a database formation and a statistical characteristics determination. Primarily, this is the determination of trend components and residual components within the gas consumption time units, the determination of tasks, put for a current and a long-term monitoring and prognosticating; the carrying out of a comparative analysis in order to find out the real-time and predictable values of gas consumption processes, which are mainly analyzed on the annual basis with the following data accumulative steps: a week, a day and an hour.

Under the monitoring of municipal gas consumption, we understand the following:

1) The current monitoring (operative and short-term), that is:

– The measurement of current characteristics of gas consumption in the accumulative intervals: an hour, a day, a week;

– The data visualization of the gas consumption measurements and the weather factors by means of the corresponding charts. For example, a gas consumption chart, an operating pressure chart and an average temperature chart (by hourly and daily steps);
– The visualization of hourly and daily charts in the form of an additive components summing up, as follows: a trend, quasi-harmonic components and a stochastic remainder.

2) The long-term monitoring:
– The measurement of current characteristics of gas consumption in the accumulative intervals: a week, a month, a quarter, a year;
– The data visualization of the gas consumption measurements taken and the weather factors available by means of the corresponding charts. For example, a daily gas consumption chart and an average daily air temperature chart;
– Basing on the mathematical model to carry out an analysis and a prognostication of the gas consumption, taking into consideration the temperature values, forecasted for the next day.

4. The additive model of the municipal gas consumption

As a result of a priori analysis of statistic data of measurements of municipal gas consumption in a regional center, there was determined a topology of the gas consumers and main factors, influencing the dynamics of gas consumption within an annual observation interval [1,2].

As the common mathematical model there was preferred a vector random process:

$$\Theta(\omega,t)=\left(\xi_1(\omega,t),...,\xi_n(\omega,t)\right),\quad t\in T,\quad \omega\notin\Omega \tag{1}$$

where $\xi(\omega,t)$ is the random processes vector, associated with the technological parameters of gas consumption, as follows: a volume of the consumed gas, an operating gas pressure in a pipeline, an air temperature in a city, and a change of consumer's topology.

That is, the state of a gas consumption system at the defined moment is characterized by many random values. Since the measurement data are discrete, and the change of consumers' topology takes place at two main levels (central heating availability or unavailability), therefore, such mathematical model will belong to the models class with a discrete state and a discrete time of the system.

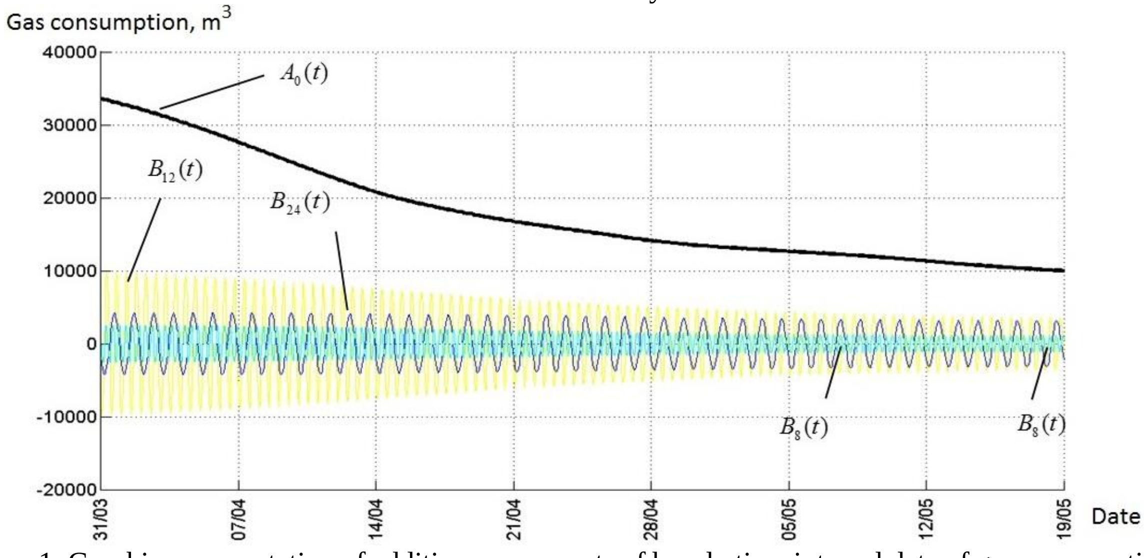


Figure 1: Graphic representation of additive components of hourly time interval data of gas consumption: $A_0(t)$ (trend) and $B_8(t)$, $B_{12}(t)$, $B_{24}(t)$ (quasi-harmonic) on the interval of 5 weeks during the spring 2009.

At the stage of a prior statistic processing, there was suggested that the singular spectrum analysis method [3] is to be used. The use of such a method, in essence, is the inverse task: basing on a time intervals analysis of a gas consumption it is necessary to create a mathematical model, because it could not be a priori given.

Depending on the actual steps in the accumulation of gas consumption statistic data, the definite mathematical model will be correspondingly changed. Thus, for the hourly time interval data of gas consumption, we will consider hereby the additive and mathematical models:

$$\nu(\omega,t) = A_0(t) + \sum_{j=1}^{k} B_j(t) + \xi(\omega,t) \quad (2)$$

where, $A_0(t)$ is the annual trend; $B_j(t)$ is the sum of cyclic (quasi-harmonic) components; $\xi(\omega,t)$ is the stochastic remainder (Fig. 1).

5. The functional diagram of database formation of measurements

A correct setting of operating pressure in the municipal gas supplying system is the principal requirement for the technological process of a gas supply at a gas distribution station. Its value directly depends on a daily municipal gas consumption, which should be predicted by the city weather factors, currently available and forecasted for the next day. As it was mentioned above, the most significant factor, affecting a gas consumption process is an atmospheric temperature, humidity and strength of wind.

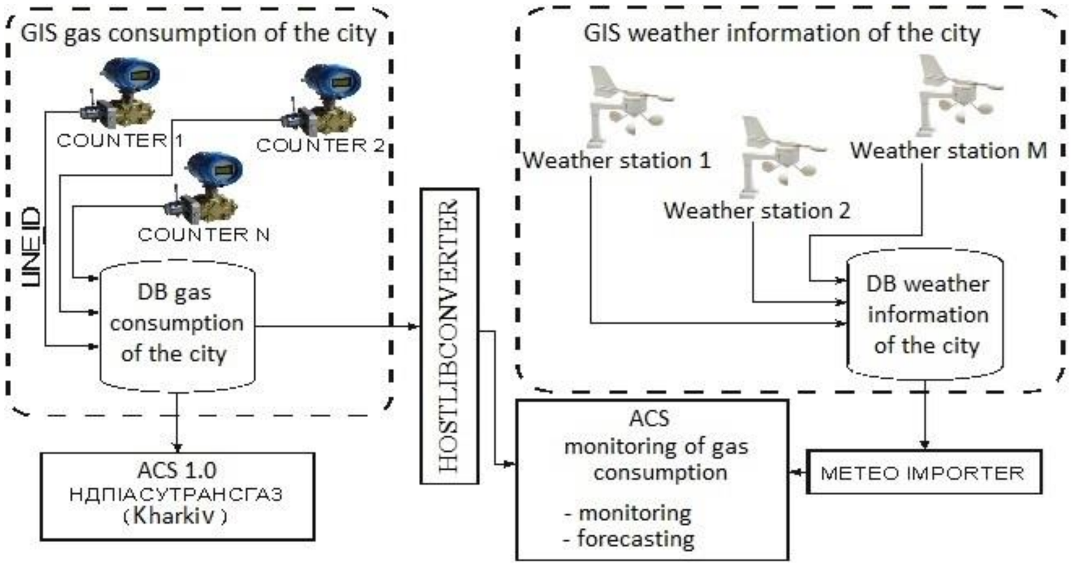


Figure 2: The functional diagram of database formation of gas consumption measurements and meteorological information.

In this article it is proposed to combine both the information, taken from the geographic information system (GIS) for gas consumption registration, and the city meteorological information. Such dataware is the basis for functioning of the already developed database for accumulation of the measurements of city gas consumption and city weather history data. The functional diagram of the database, formed of weather history data and measurements of municipal gas consumption, is shown on the Fig. 2.

Such combination of the information recourses, received from two GIS, will duly provide a city with a complex monitoring and a prognostication of gas consumption, which will be rather useful for the automation of the dispatching service in a gas supplying organization.

6. The structural diagram of database

The input reading data are binary files from the counter in industrial format Hostlib for Flowtech measuring complexes. For binary data import of HostLib format to the database there was developed software «HostLibConverter 1.0» [4]. For weather history data import there was developed software «MeteoInfoSpace Temperature Importer».

As a result of the development of information technology, there was suggested a database, the chart structure of which allows to store and to form the time intervals for monitoring, subsequent statistical analysis and prognostication of municipal gas consumption along with its duly correction for existing weather factors. The list of main database charts and links is shown on the Fig. 3.

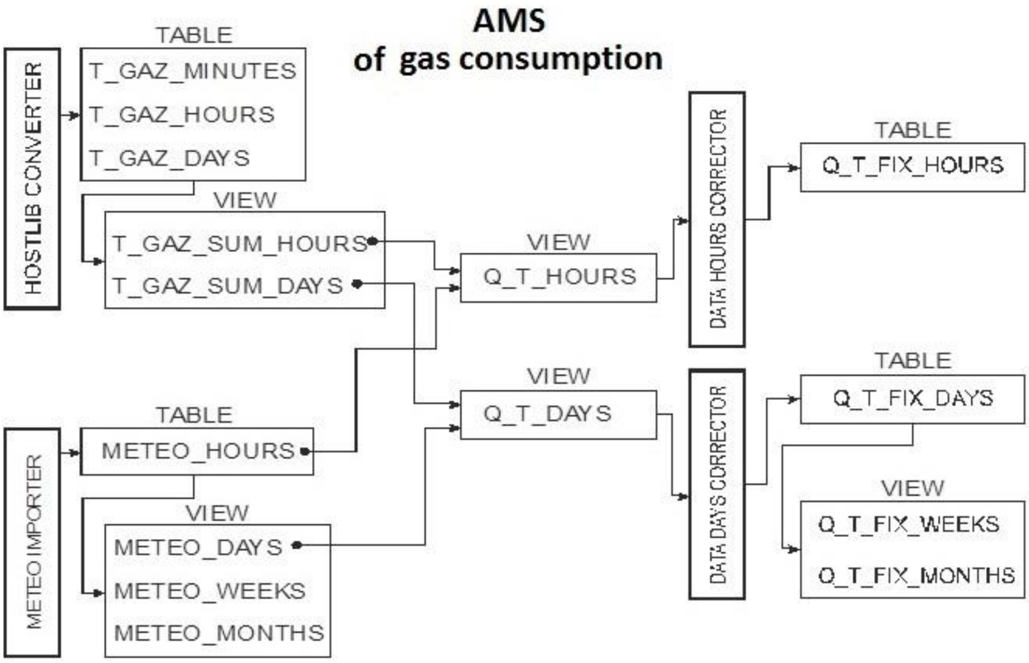


Figure 3: Structure of BD and links between the charts

The designed BD has original (entering) information about gas consumption and meteorological factors for the town that is presented in the charts: T_GAZ_MINUTES, T_GAZ_ HOURS, T_GAZ_DAYS, METEO_HOURS. The charts T_GAZ_ SUM_HOURS and T_GAZ_SUM_DAYS are virtual charts that are based on the previous ones and contain summarized information of all meters (COUNTER) for indicated informational line (LINE_ID). The result of forming VIEW T_GAZ_SUM_DAYS can be received by means of the following SQL inquiry:

```
CREATE VIEW `t_gaz_sum_days` AS select `t_gaz_days`.`TS`
AS `TS`,sum(`t_gaz_days`.`Q`) AS `Q`,`t_gaz_days`.`LINE_ID` AS `LINE_ID`
from `t_gaz_days` group by `t_gaz_days`.`TS`,`t_gaz_days`.`LINE_ID`
order by `t_gaz_days`.`TS`;
```

In that manner, the charts of average atmospheric temperature within a day, a week and a month METEO_DAYS, METEO_WEEKS, METEO_MONTHS were formed.

For carrying out of a regression analysis and a short-term prognostication of gas consumption, the combined virtual charts Q_T_HOURS and Q_T_DAYS of a gas consumption and air temperature with hourly and daily accumulative intervals, were formed.

The data on gas consumption and an average atmospheric temperature are to be stored in the tables T_GAZ_HOURS_TE and METEO_HOURS correspondingly. The synchronized formation of time units is launched with instruction LEFT OUTER JOIN. The observation sampling interval is specified by instruction BETWEEN.

The time units with discretization intervals: a week, a month and a year, are formed through the summing up of primary hourly information. For example, in order to obtain the gas consumption data for a day, we have to sum up 24 hours for each day, and in order to obtain the weekly data, we have to sum up 7 days for each week within the observation interval.

The data on gas consumption by hours to be stored in the VIEW T_GAZ_SUM_HOURS.

7. The automated system for monitoring of gas consumption

A logical completion of the information technology is the implementation of an automated system for monitoring and prognostication of municipal gas consumption. There are three constructional stages (Samarskiy’s concept «Model-Algorithm-Program»):

– Construction of mathematical models and methods;
– Algorithm creation for processing of statistic measurement data;
– Implementation of the software, based on models and algorithms.

As of now, a municipal dispatching service uses the software package «ASK 1.0», developed by Scientific and Research Institute of Automated Control Systems for Gas Transport (Kharkiv, Ukraine). The software package is intended for:

– Data reading from automatic calculators (AC) of gas consumption;
– Database formation of specified structure (so called Hostlib-format);
– Remote input of atmospheric pressure into calculators of gas parameters, and time correction;
– Review and analysis of the information received;
– Formation, review and print (or filing) daily and monthly reports, done in a specified form.

Actually, this software package implements the geographic information system (GIS), intended for the polling of automatic calculators of municipal gas consumption.

The biggest drawback of this system is the impossibility to perform a data analysis of measurements in combination with weather factors. That is why, the process of analysis and subsequent adoption of management decision on gas supply parameters is rather routine and, to a greater extent, manually operated. For this reason, there was proposed an automated system for monitoring and prognosticating of gas consumption, together with its correction for weather factors, based on an additive mathematical model.

The Fig. 4 shows the structural diagram of automated system for monitoring of a municipal gas consumption, which contains the following main sections:

1) Monitoring;
2) Prior processing and correcting of measured data;
3) Statistical processing of measured data;
4) Prognostication of gas consumption;
5) Diagnostics of accident conditions.

The monitoring means the charts drawing with operating parameters of a gas consumption process, as follows: Q as a volume of consumed gas (m3), RBS is a working gas pressure in a pipeline system (in kilogram-force per square centimeter), T is an air temperature in a city (°C). Monitoring is to be divided into current and long-term ones, which, in turn, are to be divided into operative, short-term, weekly, monthly and yearly monitoring.

Example of daily monitoring is represented on Fig. 5. Operator controls the working gas pressure and must keep a given working pressure in within 5% of the nominal value.

The prior processing and correcting of measured data stipulates two main tasks. Firstly, the removal of all wrong values from the results of measurements in semi-automatic mode, when system indicates «suspicious» values of gas consumption and an operator is to decide to save or to delete such information.

Secondly, there are cases when some meters fail and pass incorrect data of measurements for gas consumption or other wrong gas pipeline operating parameters. For this reason, it is important for an operator to correct data and to input correct values. For this purpose, there are special tables Q_T_FIX_HOURS and Q_T_FIX_DAYS with the data duly adjusted for hourly and daily values, and reflected in the structural diagram DATABASE (Fig. 3).

The statistical processing of measured data is the main section, containing implementation of mathematical models and methods in the form of information technology specific algorithms, intended for monitoring of municipal gas consumption.

This section has the following features: a) trends allocation (by EMD and singular spectrum analysis methods), quasi-harmonic components and stochastic remainder; Estimation of mathematical expectation and variance dissipation for annual and quasi-harmonic components; b) Partition of a gas consumption time unit into seasonal sections (analysis of stochastic remainder by variance change [5], and temperature analysis with use of the date of beginning and ending of municipal seasonal central heating operation); c) Correlation analysis (Check the correlation dependence Q-T at each allocated seasonal section); d) Regression analysis (creation of regression line for each seasonal section). Here we note that these calculations are carried out with two kinds of measured and accumulated data: hourly and daily gas consumption data and city temperature data (Fig. 6).

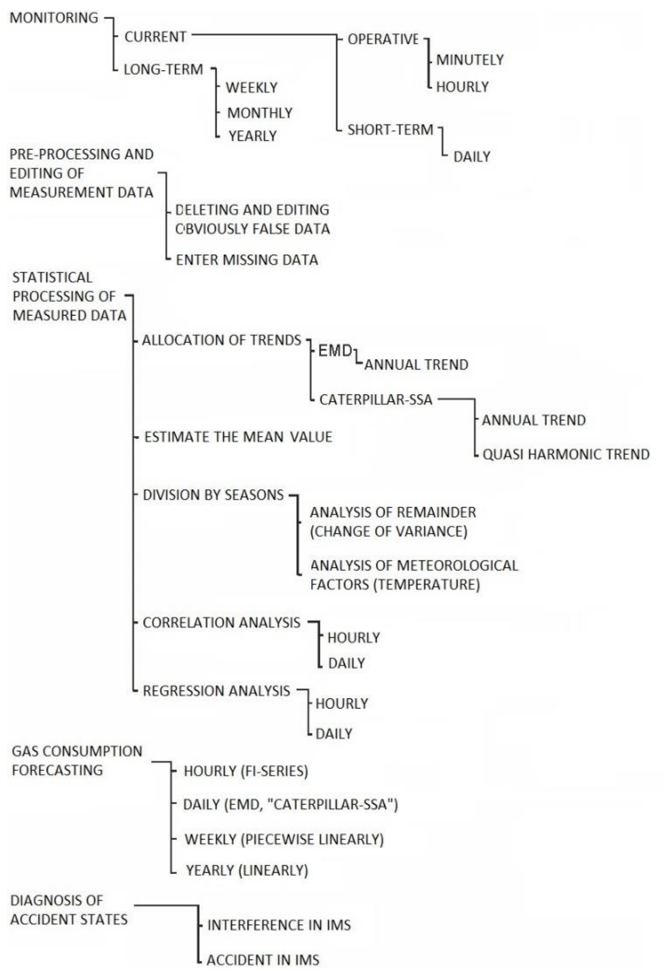
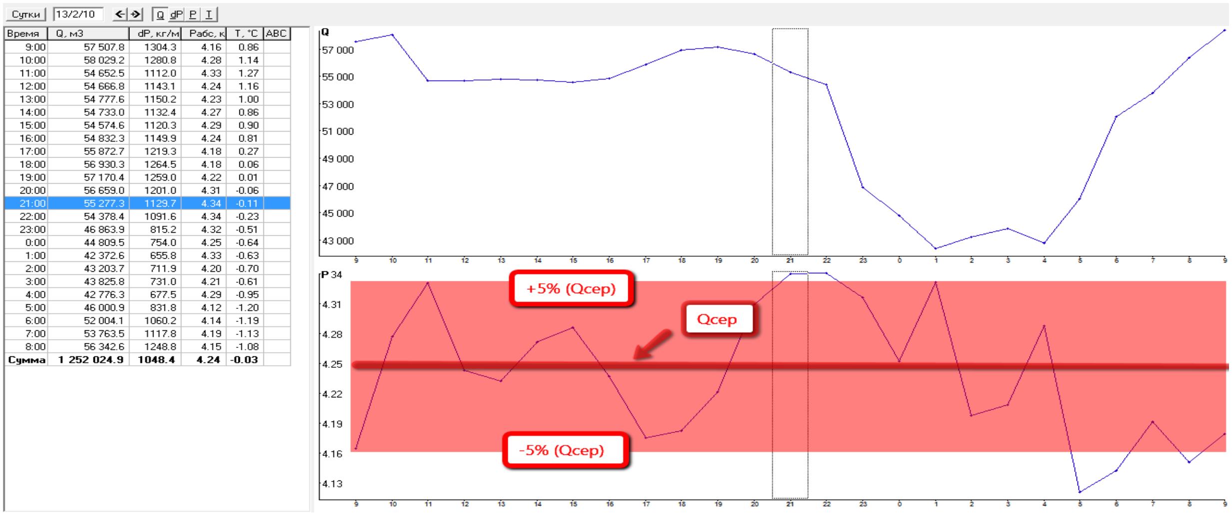


Figure 4: Structural diagram of the automated system for monitoring of gas consumption



Время	Q, м3	dP, кг/м	Рабс, к	T, °C	ABC
9:00	57 507.8	1304.3	4.16	0.86	
10:00	58 029.2	1280.8	4.28	1.14	
11:00	54 652.5	1112.0	4.33	1.27	
12:00	54 666.8	1143.1	4.24	1.16	
13:00	54 777.6	1150.2	4.23	1.00	
14:00	54 733.0	1132.4	4.27	0.86	
15:00	54 574.6	1120.3	4.29	0.90	
16:00	54 832.3	1149.9	4.24	0.81	
17:00	55 872.7	1219.3	4.18	0.27	
18:00	56 930.3	1264.5	4.18	0.06	
19:00	57 170.4	1259.0	4.22	0.01	
20:00	56 659.0	1201.0	4.31	-0.06	
21:00	55 277.3	1129.7	4.34	-0.11	
22:00	54 378.4	1091.6	4.34	-0.23	
23:00	46 863.9	815.2	4.32	-0.51	
0:00	44 809.5	754.0	4.25	-0.64	
1:00	42 372.6	655.8	4.33	-0.63	
2:00	43 203.7	711.9	4.20	-0.70	
3:00	43 825.8	731.0	4.21	-0.61	
4:00	42 776.3	677.5	4.29	-0.95	
5:00	46 000.9	831.8	4.12	-1.20	
6:00	52 004.1	1060.2	4.14	-1.19	
7:00	53 763.5	1117.8	4.19	-1.13	
8:00	56 342.6	1248.8	4.15	-1.08	
Сумма	**1 252 024.9**	**1048.4**	**4.24**	**-0.03**	

Figure 5: Chart of hourly monitoring Q and P during the day

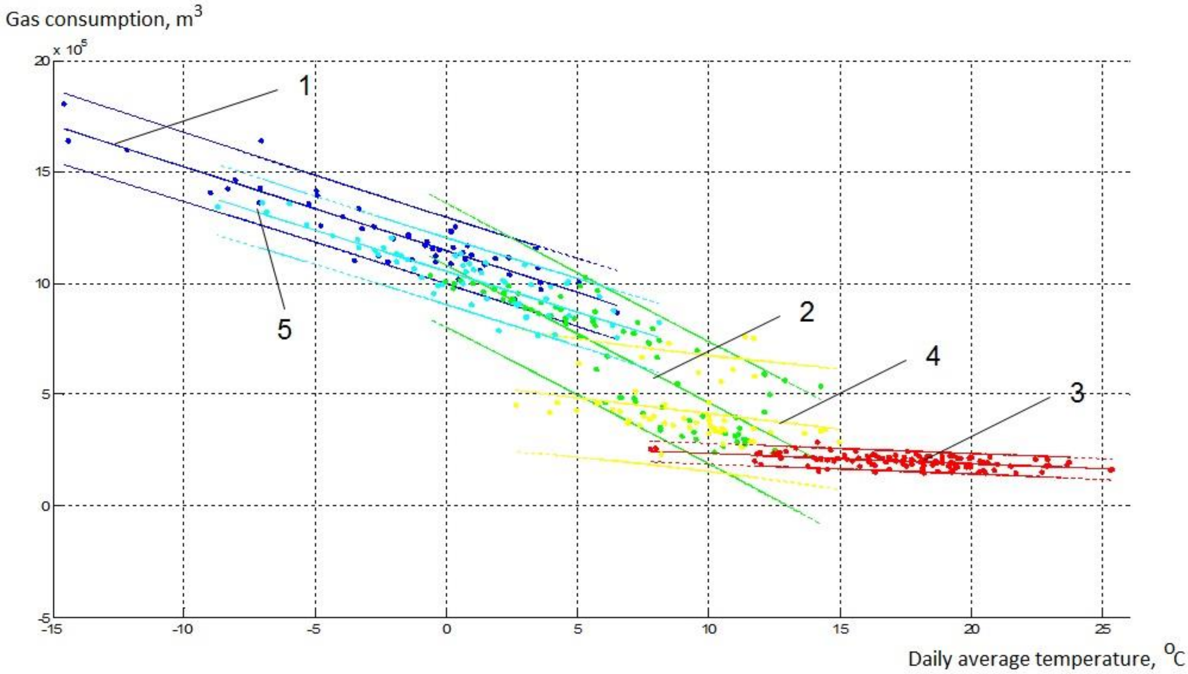


Figure 6: Chart of regression line for five seasons time series gas consumption in 2009: 1 - heating; 2 - winter and spring; 3 - unheated; 4 - autumn and winter; 5 - heating

The prognostication of gas consumption is a key stage in the monitoring of gas consumption. Both the total municipal gas consumption for preceding day and the predicted value, calculated on expected city average daily temperature for the next day, determine the volume of gas consumption for that next day. According to these values, the operating gas pressure in the pipeline is to be duly adjusted, affecting directly the natural gas feed rate. Wrong adjusting of technological parameters for gas supply (especially, an operating pressure in a gas pipeline) leads to accident conditions, and as well as to a possibility of unplanned shutdowns of gas supply to certain categories of consumers. The gas consumption prognostication section contains implementation of the following algorithms: prognostication of hourly gas consumption for the next day, daily prognostication for the period of 3-5 days, weekly prognostication (piecewise-linear) and yearly (linear). These types of prognosis give analytical material for a dispatching service and a managing staff of a gas supplying subject, enabling them to carry out operatively a short-term and a long-term management policy and strategic planning in the forthcoming years.

The diagnostics of accident conditions makes possible to review the values as of a certain day and hour, obtained with some problems, such as: operator intervention in operation of automated measuring devices, malfunction of automated measuring devices, and manual input of values (work with constants).

The format of the data, transmitted from automated counters, provides three types of accidents: A, B, and C. The symbol A indicates that an emergency situation occurred (for example, analog sensor malfunction, dP indicates that the results is below the minimum value, voltage is less than it is acceptable, power failure and failure in data transmission occurred). B indicates an unauthorized interference in calculator memory. The symbol C indicates the work with constants (manual input of gas consumption, pressure and other characteristics, affecting gas consumption values).

8. Conclusion

This article presents a solution for the practical implementation of information technology for monitoring the gas consumption of the city on the basis of additive model and taking meteorological factors. The structure of BD was suggested and a database to store statistical data measurement of gas consumption and meteorological factors for interval accumulation hour, day and week, month, and year was developed. The informational technology was designed to monitor gas consumption on the basis of mathematical model. Suggested system of monitoring automatizes functions and tasks of production and organizational management of technological processing of gas consumption of the city (regional centers).

9. References

[1] Nazarevych O.B. Separation of annual trend as additive components of time series gas consumption. Bulletin TNTU (Mathematical modeling. Mathematics. Physics). 16(4)(2011) 201-209.

[2] Nazarevych O.B. Statistical analysis of the dynamics of gas consumption. Modeling and information technology collected works (Institute of problems modelling in energy NAS of Ukraine named GE Puchov). 61(2011) 37-45.

[3] Golyandina N.E. Analysis of Time Series Structure: SSA and Related Techniques. Boca Raton: Chapman&Hall/CRC. (2000)305.

[4] Nazarevych O.B. Computer program - HostLibConverter 1.0. AS the registration of copyright №40120 " Computer program HostLibConverter 1.0" [Text]. (2011).

[5] Brodsky B.E. A nonparametric method for the segmentation of the EEG. Computer Method and Programs in Biomedicine 60(1999)93-106.