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Forecasting of failures in district heating systems

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A B S T R A C T

This work presents the method of failures forecasting in district heating systems on the basis of time series analysis.

Statistical data concerning the frequency of damage in communal heat distribution networks from a ten-year time period have been used in the article. The data were subjected to statistical analysis. The methods of exponential smoothing, ARIMA, homologous period trend estimation and seasonal indicators were applied as the most adequate for this type of data. Four forecast models of damage in district heating systems were formulated and the best optimal model for the system was selected.

After verification, the methods of failure prediction in district heating systems can be applied in the operating process of a heat supply system. These methods give us answers to many questions about planning of repairs, maintenance emergency service, planning of finances and purposefulness of operational control.

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1. Introduction

The term 'forecast' was introduced to science by Hippocrates. From Greek, 'forecast' means knowledge and anticipation. Forecasting makes conclusions about the future reliability state of an element on the basis of a proper mathematical model, based on information regarding the past and future reliability of this element. The aim of forecasting (statistical concluding) is providing information for the effective functioning of the reliability control apparatus in the area of system operation. [4,6].

On the basis of forecasting the gradual and immediate failure of an element included in a given system it is possible to prepare a forecast of reliability indices. Forecasting the failure of an element means creating a forecast of the moment at which the failure occurs and the probability of its existence. It makes it possible to assess the system regarding its specificity and the influence on its reliability [12,16–20,22,23].

A failure may be defined as a partial or full loss of properties of the technical system which may significantly decrease its efficiency or even lead to its complete disappearance. A failure is the result of a great number of factors of a random character both on the micro and macro scales [10,16]. Contemporary knowledge does not fully describe the mechanisms of cooperation of these factors in the aspect of a failure. The process of creating failures may be considered as a "black box". The concept of a "black box" relies on treating the phenomenon or process as unavailable for research and limited only to an analysis, mainly between input and output parameters [9]. This approach allows us to find a model of the creation of failures, which

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is a probability model due to its nature. This model, with engineering accuracy, allows the anticipation of failures. The methods presented are applied to the particular case of heat distribution [2,11,13].

The heat supply system includes three subsystems: the subsystem of heat production, constituting the source of heat (heat and power station, heating station), the subsystem of heat supply (SbHS) which constitutes district heating systems along with utilities, and the subsystem of heat distribution, which includes district heating substation and internal central heating installations [3]. Taking into account the structure, specificity and tasks of each subsystem is a condition for their proper assessment with regard to reliability. A district heating system is a repairable structure. However, repair is limited to the exchange of a short section of pipeline or an element of the utilities installed in the network, as a result of which the process of renewal does not significantly influence a change in the reliability properties of the entire system [2,21]. There is a probability of endless failures of a given section, regardless of its length. The duration of failures is short in comparison to the network operation, which allows the assumption that the renewal is immediate. The methods of performing forecasts are properly selected for the needs, with regard to the kind of facility or goods and the time the forecast is being prepared for. The forecasting methods for the needs of reliability are adjusted to the technique of preparing forecasts: they may be calculating or simulating methods [7]. It is proposed to prepare a forecast of SbHS failures on the basis of empirical data on the failures of district heating systems in the real system of heat supply by means of the simulating method with the use of a computer technique (Statistica 10.0).

2. Preliminary analysis of operating data

In order to create a model describing the forecast of SbHS failures, data regarding the overall number of failures in the sections of a district heating system within a selected heating centre has been used. The scope of the data regards 79 months of observations of heat network failures. Fig. 1 presents the tendencies of changes in the number of failures within the given period.

The forecast regarding the number of failures within the given SbHS included four methods: the exponential smoothing method, ARIMA, homologous period trend estimation method and index analysis.

Analysing the operating data regarding the failures in district heating systems (Fig. 1), it must be stated that they indicate a typical seasonal character where the maximum values concern autumn and winter months: September, October, November, December and January when the system is working and is maximally loaded and, moreover, the parameters of operation change while shifting from the summer season into the winter one. On average, most failures are in October (mean $\bar{x} = 290$) and November (mean $\bar{x} = 249$). In these months there is also a maximum level of this phenomenon. The differentiation is the highest in September std. dev. (σ) = 91.6) and November (std. dev. (σ) = 94.4), which was established by the standard deviation. In the summer season the number of failures decreases. The lowest average level is noted in June (40) (Table 1).

Seasonal fluctuations decrease in amplitude. The character of the entire series is dampened, which means that with time SbHS has fewer and fewer failures. By means of the ANOVA Kruskala–Wallisa test it has been determined whether the differences in the levels of failures, from the monthly perspective, are significant statistically. The test showed that the number of failures for particular months was significantly different $p < \alpha$ ($p = 0.0008$), (α – level of significance, p – probability test).

There are no outliers in the monthly failure numbers (Fig. 2). The model includes seasonal fluctuations, which is why it is purposeful to check autocorrelation, as one of the assumed models requires a stationary process of a series before performing the forecast, which is connected with elimination of autocorrelation before the forecast.

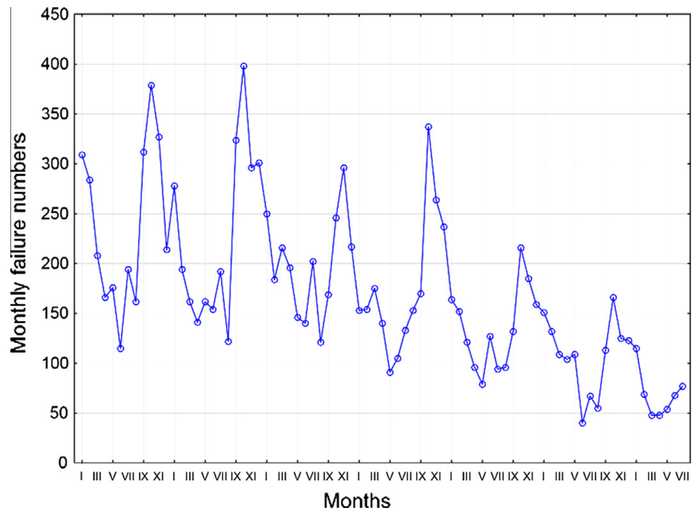

Fig. 1. Changes in the monthly number of failures in the given SbHS.

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