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ROUTINE FORECASTING OF THE DAILY PROFILES OF HOURLY WATER DISTRIBUTION IN CITIES. AN EFFECTIVENESS ANALYSIS

Sample results have been oresented of verifying three groups of methods of forecasting the time series of short-duration water distributions in city water grids. The analysis covered: ARIMA class models, the time series exponential smoothing methods and artificial neural networks. Since chronological sequences of observations from the immediate past were analyzed, the adopted models did not take any external variables into account. The forecasting errors in the case of multilayer perceptron neural networks were found to be comparable or smaller than the errors of prediction by the ARIMA class models and by the methods of the exponential smoothing of time series.

1. INTRODUCTION

The history of waterworks dates backs to ancient times. Waterworks were first built in Assyria, Babylonia, Egypt, Persia and later in Greece, Rome and Spain, as aqueducts, i.e. above-ground systems supplying water via pipes from sources to points of destination. Waterworks have evolved over years and with technological and economic progress, the latest technical and technological innovations (in both facilities and materials) would be used in their construction.

Today waterworks resemble factories producing water for household and industrial needs. Besides water intakes and the water distribution network, waterworks incorporate several objects and facilities, forming water supply systems. The latter, often supplying vast urban and industrial areas with water, require coordinated efforts in order to optimize their operation. The operating parameters of water supply systems can be optimized if one has, besides other things, a calibrated model of the flows and a prognostic water distribution model for short- and long-term forecasting [1–3].

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Models of flows in water distribution systems have been used for years to solve various problems connected with the design of the rational modernization and expansion of water supply systems and their current operation [1, 4–7].

Prognostic models of the water distribution process can be used to manage a water supply system, to optimize the operation of a pumping station, to determine the amount of water losses, to determine the doses of the reagents (including water disinfectants) and to program repairs and upgrading work [1, 8, 9].

Considering the above, research on improving water distribution forecasting techniques and implementing them in software packages for optimizing water supply system operation was undertaken. A methodology for forecasting hourly water distributions and selected results of such forecasting are presented below.

2. METHODOLOGY FOR FORECASTING HOURLY WATER DISTRIBUTIONS

Water distribution has a composite deterministic-random character. A model of a series of its observations is a stochastic process which, because of the influence of the trend and factors having a distinctly cyclical character, is nonstationary [1, 2, 10]. Despite its actual continuity in time (e.g. Fig. 1), it is assumed that water distribution can be considered as a random sequence (a stochastic process with discrete time).

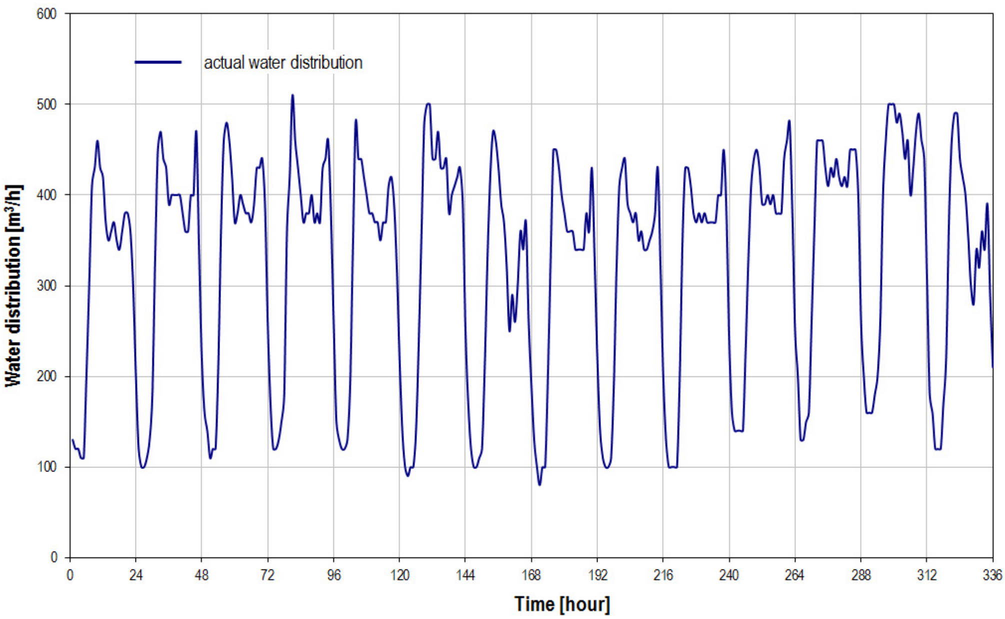

Fig. 1. Typical time series of hourly water distribution

Time series models are usually used to describe and forecast water distribution processes. The most commonly used time series are [1, 2, 8–10]:

- ARIMA, ARIMAX and SARIMA class models,
- models of the exponential smoothing of time series (e.g. multiplicative model Winters),
- artificial neural networks (ANNs),
- fuzzy models, wavelet analysis and other.

Since in such models the algebraic relations between the input parameters and the forecasted parameter are determined, it is essential to select a water supply system from which the needed input data can be acquired. Considering that prognostic models of short-duration, water intakes do not require external data, the only representative input data are the yields of all the supply sources, including those of the water pumping station and the network reservoirs.

Today, water companies increasingly often use supervisory control and acquisition systems (SCADA) to collect the above mentioned data. The data obtained from such systems form time series of values recorded at a measurement step set by the user. Properly long periods of continuous measurements are needed for the analyses. The authors' experience indicates that the minimum period of continuous measurements needed to build such prognostic models and to generate forecasts (by means of a proper prognostic model) is respectively half a year and one week [1, 2].

The next major stage in building a prognostic model is the selection of data (from the collected data) to be used and the specification of their representation. The choice of proper data for modelling has a significant effect on the quality of the generated ex post and ex ante forecasts while the calibration of input values is essential when ANN models are employed.

The choice of a model for forecasting depends on the character of the analyzed time series. ARIMA and ANN models are highly suitable for forecasting short-duration water distributions. The studies made by the authors indicate that the optimal structure for ARIMA models is $(1, 0, 0\ (1, 1, 0)_{24}$ and the architecture of artificial neural networks can be limited to one hidden layer with 15 neurons. Models of the exponential smoothing of time series are characterized by simple structure but they are not suitable for the forecasting of fast changing values [1, 2].

In the final stage, the validity of the model is tested adopting the mean-square error of the ex post forecast and the results of the analyses of model residuals (frequency distributions, periodograms) as the validity criteria.

3. SELECTED RESULTS OF ANALYSES

The selected analytical results presented in Table 1 and in Figs. 2–4 illustrate the effectiveness of forecasting hourly water distributions by means of the ARIMA models, the exponential smoothing of time series and perceptron multilayer artificial neural networks.

Table 1

Day of week	Average water distribution [m³/h]	Absolute forecast error [m³/h] (relative [%])		
		ARIMA (1,0,0)(1,1,0)$_{24}$	Exponential smoothing (multiplicative WINTERS model)	ANN MLP s120 1:120-6-1:1 (weekdays MLP s60 1:60-5-1:1 (Saturdays) MLP s120 1:120-5-1:1 (Sundays)
Monday	344.17	23.49 (6.83)	22.01 (6.40)	22.62 (6.57)
Tuesday	354.17	22.34 (6.31)	33.37 (9.42)	29.59 (8.36)
Wednesday	351.67	16.97 (4.83)	19.86 (5.65)	17.40 (4.95)
Thursday	336.25	26.31 (7.82)	28.07 (8.35)	18.90 (5.62)
Friday	343.33	18.10 (5.27)	21.91 (6.38)	17.88 (5.21)
Saturday	365.42	14.82 (4.05)	16.17 (4.42)	21.59 (5.91)
Sunday	340.00	34.34 (10.10)	34.44 (10.13)	32.63 (9.60)

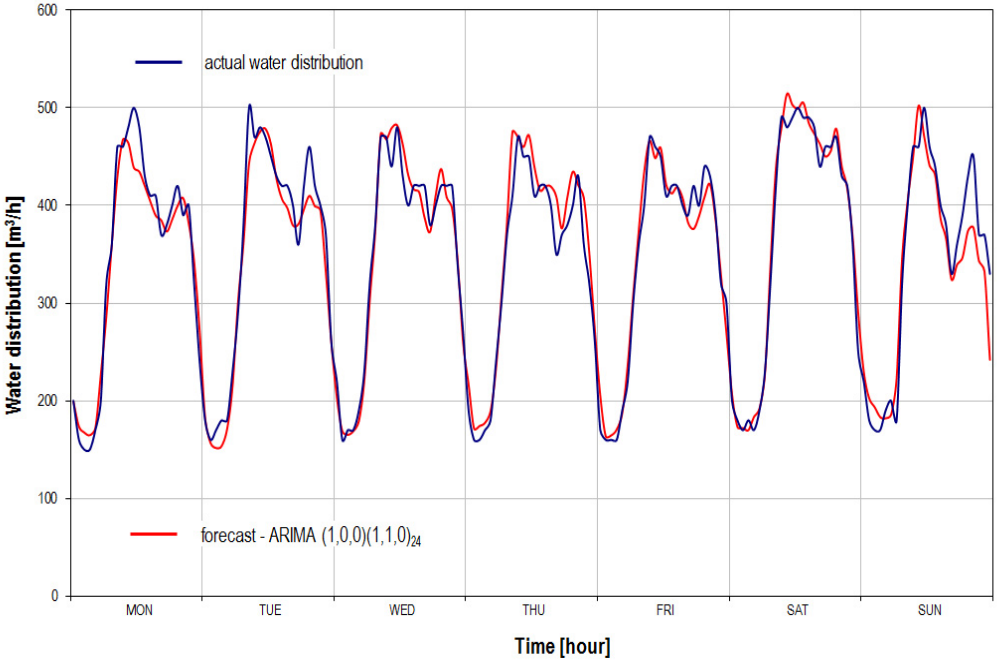

Fig. 2. Actual and forecasted hourly water distributions according to the ARIMA model

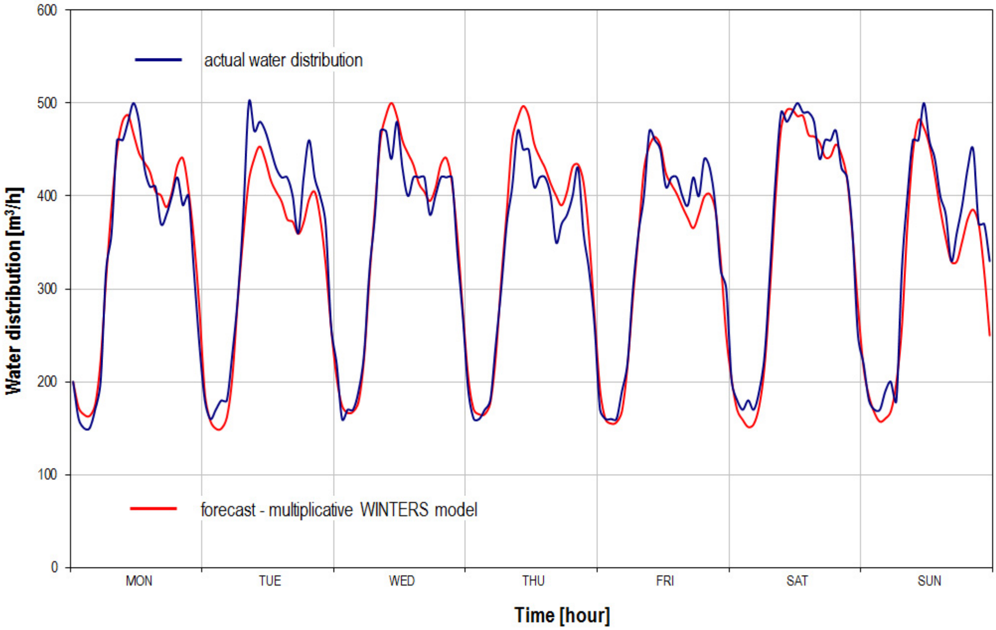

Fig. 3. Actual and forecasted hourly water distributions according to multiplicative WINTERS model

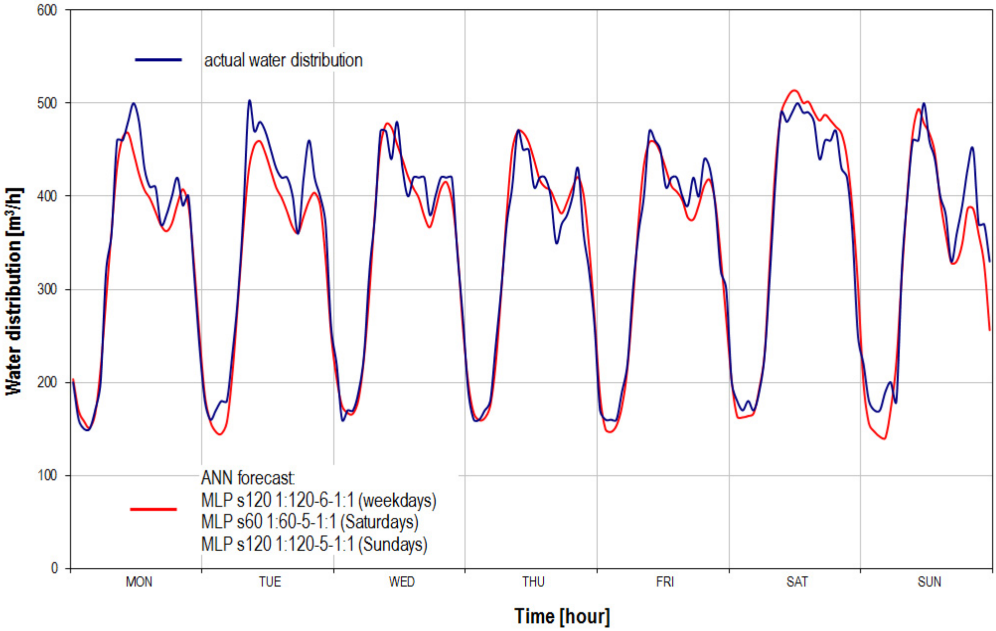

Fig. 4. Actual and forecasted hourly water distributions according to ANN models

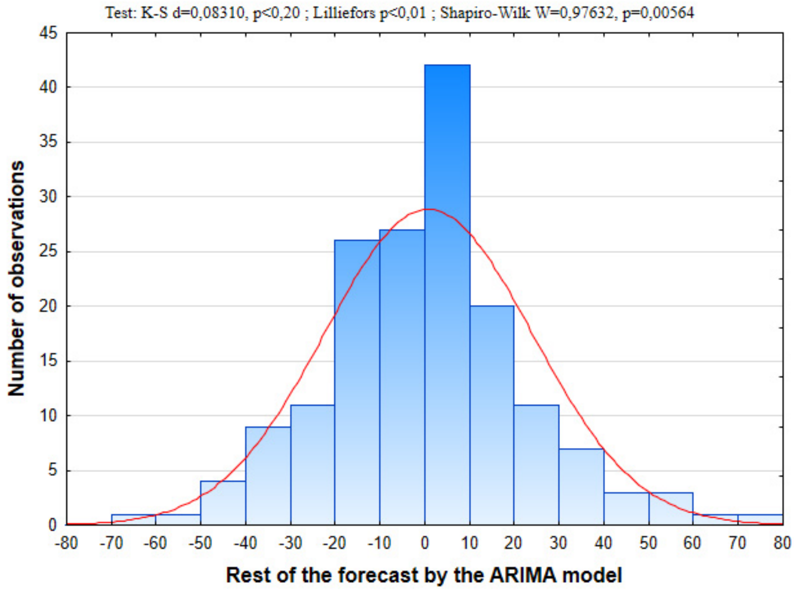

Fig. 5. Frequency distribution of hourly forecasts residues daily water intake by the ARIMA model

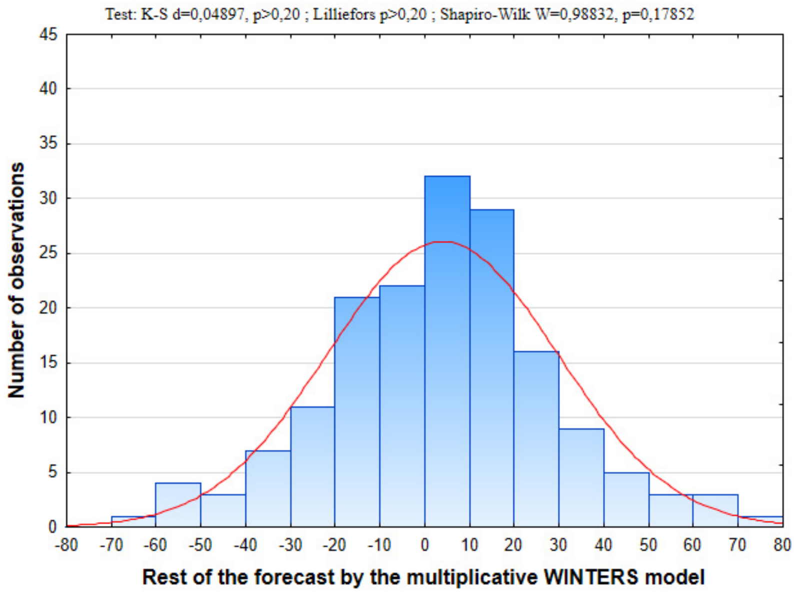

Fig. 6. Frequency distribution of hourly forecasts residues daily water intake by the multiplicative WINTERS model

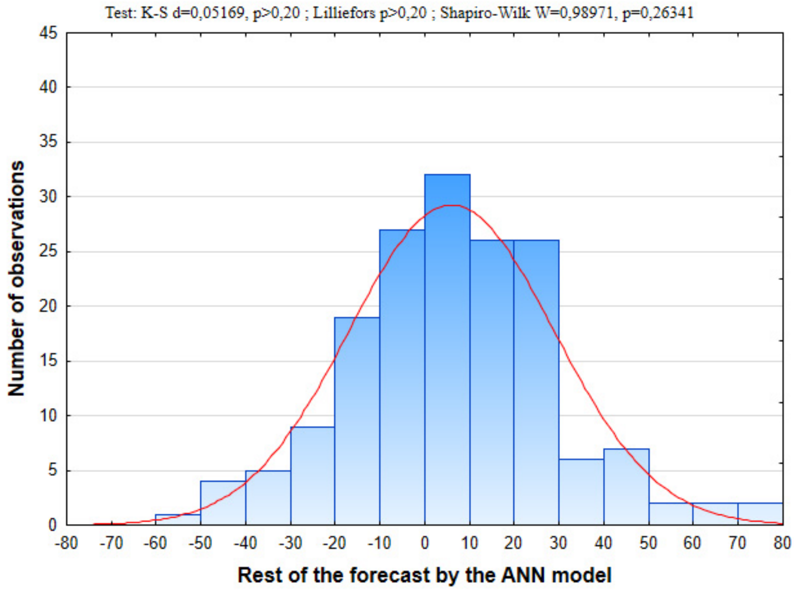

Fig. 7. Frequency distribution of hourly forecasts residues
daily water intake by the ANN model

An analysis of the relative errors of the selected 24-hour profiles of hourly water distribution shows that they are at a satisfactory level (in the range 4.83–10.13%). The smallest maximal errors (revealed when the forecast residuals in the particular hours of the daily profile are examined) are generated by the ARIMA model and the ANN model and the largest errors arise when the WINTERS model is used. This is due to the fact that the models of the exponential smoothing of time series do not keep up with the fast changes in time series values.

Figures 5–7 show the analysis of residues of forecasts. These analyses indicate the compliance of distribution of residuals with the normal distribution.

4. CONCLUSIONS

The results of the routine forecasting of the daily profiles of hourly water distribution and an analysis of its effectiveness indicate relatively good quality of prediction by means of the ARIMA models, the exponential smoothing of time series and perceptron multilayer artificial neural networks.

Besides their economical parameterization, the ARIMA class models offer the advantage that water distribution forecasting can be initiated at a relatively small number of past observations of the process. The ARIMA model structure $(1,0,0)(1,1,0)_{24}$ can be regarded universal – suitable for forecasting water distributions in the water supply systems of cities widely differing in the number of inhabitants and the water needs structure. The exponential smoothing of time series and artificial neural networks are a viable alternative.

The models of the exponential smoothing of time series are characterized by structural simplicity and are easily implementable into expert systems but their main drawback is that they do not keep up with the fast changes in time series values.

The multilayer perceptron has a simple architecture with a single hidden layer whereby its additional training or fresh training does not require long-lasting computations. In the procedures for selecting perceptron network structures, one can limit the delay to 5 days of the same type (weekdays, Saturdays and Sundays together with holidays), the number of hidden layers to 1 and the number hidden layer neurons to 15.

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