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MODEL-BUILDING FOR TIME SERIES OF HEAT DEMAND

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Abstract: *The paper presents model design of time series of heat demand course. The course of heat demand and heat consumption can be demonstrated by means of heat demand diagrams. These diagrams are of essential importance for technical and economic considerations. Therefore forecast of the diagrams course is significant for short-term and long-term planning of heat production. The aim of paper is to give some background about analysis of heat demand course and its utilization for building up a forecast model by means of Box-Jenkins methodology. The paper show a sample of model design for calculation of heat demand prediction in locality of the city Olomouc.*
Key words: *prediction, district heating control, box-jenkins, modeling, time series analysis*

1. INTRODUCTION

Improvement of technological process control level can be achieved by the time series analysis in order to predict their future behaviour. We can find applications of this prediction also in the control of the Centralized Heat Supply System (CHSS), especially for the control of hot water piping heat output. Knowledge of heat demand is the base for input data for the operation preparation of CHSS. The term "heat demand" means an instantaneous heat output demanded or instantaneous heat output consumed by consumers. The course of heat demand and heat consumption can be demonstrated by means of heat demand diagrams. The most important one is the Daily Diagram of Heat Demand (DDHD) which demonstrates the course of requisite heat output during the day (See Fig. 1). These heat demand diagrams are of essential importance for technical and economic considerations. Forecast of these diagrams course is significant for short-term and long-term planning of heat production.

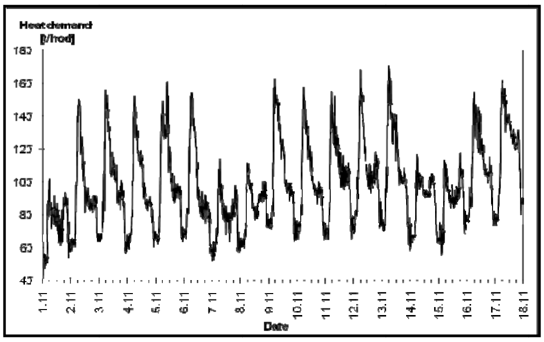

Fig. 1. DDHD from the concrete locality

2. FORECAST METHOD FOR CONCRETE TIME SERIES OF HEAT DEMAND

It is possible to use different solution methods for the calculation of time series forecast. (For example: solution by means of linear models, solution by means of non-linear models, spectral analysis method, neural networks etc.). In the past, lots of works were created which solved the prediction of DDHD and its use for controlling the District Heating System (DHS). Most of these works are based on mass data processing. Nevertheless, these methods have a big disadvantage that may result in out-of-date real data. From this point of view it is suitable to use the forecast methods according to the Box –Jenkins methodology (Box & Jenkins, 1976). As this method achieves very good results in practice, it was chosen for the calculation of DDHD forecast.

Identification of time series model parameters is the most important and the most difficult phase in the time series analysis. This paper is dealing with the identification of a model of concrete time series of the DDHD. We have particularly focused on determination of difference degree as well as on obtaining a suitable order of autoregressive process and order of moving average process.

3. DETERMINATION OF DEGREE OF DIFFERENCING

Many observed non-stationary time series exhibit certain homogeneity and can be accounted for by a simple modification of the ARMA model, the autoregressive integrated moving average (ARIMA) model. Determination of a degree of differencing d is the main problem of ARIMA model building. In practice, it seldom appears necessary to difference more than twice. That means that stationary time series are produced by means of the first or second differencing. A number of possibilities for determination of difference degree exist.

1) It is possible to use a plot of the time series, for visual inspection of its stationarity. In case of doubts, the plot of the first or second differencing of time series is drawn. Then we review stationarity of these series.

2) Investigation of estimated autocorrelation function (ACF) of time series is a more objective method. If the values of ACF have a gentle linear decline (not rapid geometric decline), an autoregressive zero is approaching 1 and it is necessary to difference.

3) Anderson (Anderson, 1976) prefers to use the behaviour of the variances of successive differenced series as a criterion for taking a decision on the difference degree required. The difference degree d is given in accordance with the minimum value of variances $\sigma_z^2, \sigma_{\nabla z}^2, \sigma_{\nabla^2 z}^2$.

An example of the determination of the difference degree for our time series of DDHD is shown in this part of paper. The course of time series of DDHD contains two periodic components (daily and weekly periods). The daily period presents increase and decrease in heat demand during the day. Heat demand drop at the weekend forms the weekly period of DDHD. The general model according to Box-Jenkins enables to describe only one periodic component. From this point of view we will further consider only time series of the DDHD without Saturday and Sunday values. This time series exhibits an evident non-stationarity. It is necessary to difference. The course of time series of the first differencing looks stationary now. This fact is possible to demonstrate by the sample ACF of DDHD and estimated ACF of the DDHD after the first differencing.

It is also possible to use the estimated variance of non-differenced and differenced series for making a comparison. In our case we have obtained the following results: $\hat{\sigma}_z^2 = 1081.2$;

$\hat{\sigma}^2_{\nabla z} = 90.5$; $\hat{\sigma}^2_{\nabla^2 z} = 164.8$. From these results and figures above, it is suitable to choose the first differencing of the DDHD (*d=1*).

In practice, many time series have seasonal components. These series exhibit periodic behaviour with a period *s*. Therefore it is necessary to determine a degree of seasonal differencing - *D*. The seasonal differencing is marked by ∇_s^D . In seasonal models, necessity of differencing more than once occurs very seldom. That means *D=0* or *D=1*. It is possible to decide on the degree of seasonal differencing on the basis of investigation of sample ACF. If the values of ACF at lags *k*s* achieve the local maximum, it is necessary to make the first seasonal differencing (*D=1*) in the form $\nabla_s z_t$.

As our time series of the DDHD exhibits an obvious seasonal pattern, it is necessary to make an analysis of the seasonal differencing of our time series, as well. The course of the ACF sample evidences the seasonal pattern. These functions have their local maxima at lags 48, 96, etc. That represents a seasonal period of 24 hours by a sampling period of 30 minutes. On the basis of the executed analysis, it is necessary to make the first differencing and also the first seasonal differencing of the DDHD in the form (1).

$$\nabla\nabla_{48} z_t = z_t - z_{t-1} - z_{t-48} + z_{t-49} \tag{1}$$

For the comparison, it is possible to calculate the variances of time series and differenced series according to (Anderson, 1976). The results are $\hat{\sigma}^2_{\nabla_{48} z} = 137.9$; $\hat{\sigma}^2_{\nabla\nabla_{48} z} = 99.8$.

4. DETERMINATION OF AR PROCESS ORDER AND MA PROCESS ORDER

After differencing the time series, we have to identify the order of autoregressive process AR(p) and order of moving average process MA(q). The traditional method consists in comparing the observed patterns of the sample autocorrelation and partial autocorrelation functions with the theoretical ACF and PACF patterns. (Brockwell & Davis, 1996).

Order of autoregressive operator *p* and order of moving average operator *q* are not usually high; therefore only 20 values of ACF and PACF will be enough to compute.

The order of model is usually difficult to determine on the basis of the ACF and PACF. This method of identification requires a lot of experience in building up models. From this point of view it is more suitable to use the objective methods for the tests of the model order.

4.1 Criteria for model order

A number of procedures and methods exist for testing the model order (Cromwell et al., 1994). These methods are based on the comparison of the residuals of various models by means of special statistics. In this paper, the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC) and Schwarz test are used for testing. The sample of test result of the model order of the DDHD is included in the Tab. 1. The table represent the values of the AIC in dependence on model order (*p*, *q*).

The minimum value of AIC, BIC and SC is for *p=0* and *q=3*. According to these results and on the basis of the general theorem (small values of model order), it is obvious that we would tentatively identify our time series as the MA(3) process. This fact is also possible to confirm by the analysis of ACF and PACF samples described above. Adequacy of this tentative model may be examined by means of Portmanteau test.

p \ q	0	1	2	3	4	5	6
0	3499.5	3343.2	3318.8	3295.4	3312.7	3298.8	3311.5
1	3396.6	3315.5	3918.3	3323.3	4499.6	N/A	3319.4
2	3364.9	N/A	N/A	3298.5	3499.8	N/A	N/A
3	3333.5	3300.2	3364.6	3315.2	3304.6	N/A	N/A
4	3312.6	3300.7	3315.8	N/A	N/A	3966.3	4109.2
5	3305.2	3304.5	3306.7	N/A	N/A	4129.6	6152.9
6	3305.5	3306.8	7479.6	3650.6	3352.1	5117.7	5684

Tab. 1. Values of Akaike Information Criterion

4.2 Diagnostic checking – Portmanteau test

If the fitted model is adequate, it should transform the observations to a white noise process. Thus, a logical method of diagnostic checking is to compute the residuals and then estimate and examine their autocorrelation function. If the model is appropriate, then the residual sample autocorrelation function should not differ significantly from zero for all lags greater than one. Adequate model can be tested by means of Portmanteau test. We may obtain an indication of whether the first *K* residual autocorrelation considered together indicate adequacy of the model. This indication may be obtained through an approximate chi-square test of model adequacy. We consider the test statistic in the form (2), which is approximately distributed as chi-square with *K-p-q* degrees of freedom if the model is appropriate.

$$Q = (N - d - s) \cdot \sum_{k=1}^{K} r_k^2(\hat{a}) \tag{2}$$

Where *N* is a number of values, *d* is the difference degree, *s* is the season period, $r_k^2(\hat{a})$ is value of ACF sample of residuals.

If the model is inadequate, the calculated value of *Q* will be too large. Thus we should reject the hypothesis of model adequacy if *Q* exceeds an appropriately small upper tail point of the chi-square distribution with *K-p-q* degrees of freedom. The chi-square statistic applied to the first 28 autocorrelations is Q=35.99. Comparing this value with a 5 percent value chi-square variable with 25 degrees of freedom, we find out that $\chi^2_{0.05,25} = 37.7$ and so we would conclude that there is no strong evidence to reject the model.

5. CONCLUSION

This paper presents the method for building up the model of time series of DDHD. The model is used for prediction of heat demand. This prediction of DDHD is necessary for the control in the Centralized Heat Supply System (CHSS), especially for the qualitative-quantitative control method of hot-water piping heat output – the Balátě System (Balátě, 1982). The modelling is based on the Box-Jenkins methodology. The time series analysis was made for the DDHD from the concrete locality.

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