Evaluation of Grey Prediction Method of Energy Consumption

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Summary - Energy management in ceramic industry. Short data series prediction of energy consumption. Design of optimal grey prediction model. Qualitative data series characterization. Calculation of grey prediction parameters a and b by means of selective procedures in solving overdetermined linear systems. Evaluation of results based on prediction error and data series characterization.

I. INTRODUCTION

The basis for strategic approach to production system is an effective management as a carrier of system knowledge and ability to ensure the survival of a company. In the world of total competition it is obvious that control of production cost is the main component in company success. Ceramic industry is known as a huge energy consumer with up to 33% of product cost spent for energy [1]. Energy cost consists of human and technology component: basically human component stemming from the product market demand and from nonawareness of workers for energy saving habits and technology component depends on the process at hand. The separation of these components can yield a fruitfull result in leading the company toward minimum production cost. The time of identification of these components demans handling of short data series. Therefore we have chosen the grey system technique to assist in obtaining best system oriented solution [2].

II. DATA AND METHOD DESCRIPTION

There are two major energy supplies used in ceramic industry: natural gas and electrical energy. Although participating only 10% in energy consumption electrical energy amounts to 23% of energy costs in KIO ceramic industry in 2002, because of higher price for overload taxation. Therefore the focus of the energy management system in the KIO ceramic industry has been primarily concentrated to decreasing electrical energy cost. Data on electrical energy consumption before and after installation of new light system for production hall and factory environment are given in Table 1. Light system is the highest consumer of electrical energy in KIO d.d. Taking into account the neccessity for fast identification of costs a method has been investigated for modeling prediction of electric energy consumption. Three possible methods have been taken into account: artificial neural network (ANN) [3], grey system theory [4],[5],[6],[7], and qualitative data series modeling [8],[9]. The following prediction parameters are of interest: time horizon, accuracy and model testing. Prediction based on the grey system theory has advantage because it principally needs only four data points for their construction and testing.

Having only one variable for prediction so called single variable grey model or GM(1,1) has been applied [10].

GM(1,1) is an order differential equation model that constructs the predictor in five steps:

Forming of the vector $X^{(0)}$ from nonegative primary time series data as

$$X^{(0)} = \left[X^{(0)}(k)\right] \quad (1).$$

Value k in equations (1)..(5) is a nonegative integer: $k = 1,2,3,\ldots,m\ ,\ m \geq 4$

Vector $X^{(1)}$ of nonegative cummulative data (AGO) is formed from (1) as

$$X^{(1)} = \left[X^{(1)}(k)\right] \quad (2),$$

with the relation

$$X^{(1)}(k) = \sum_{i=1}^{k} X^{(0)}(i) \quad (3).$$

Grey difference equation is formed as

$$X^{(0)}(k) + aZ^{(1)}(k) = b \quad (4),$$

where

$$Z^{(1)}(k) = \alpha X^{(1)}(k) + (1-\alpha)X^{(1)}(k-1) \quad (5).$$

So called IAGO grey prediction model iz formed from differential equation

$$\frac{dX^{(1)}}{dt} + aX^{(1)} = b \quad (6),$$

with initial condition

$$X^{(1)}(1) = X^{(0)}(1) \quad (7),$$

as

$$X'^{(0)}(k+1) = (1-\exp(a))(X^{(0)}(1) - \frac{b}{a})\exp(-a_k)$$
(8).

Here X' represents predictive value of X in the next time interval. Coefficients a, b from equation (4) and a_k from equation (8) are obtained from the overdetermined linear system of three, four or more equations with two unknowns a and b [10],[11].

Prediction error equals to

$$e(k+1) = \frac{X'^{(0)}(k+1) - X^{(0)}(k+1)}{X'^{(0)}(k+1)},$$
$$k+1 \le m$$ (9),

where $k+1$ is the next interval of prediction and $X^{(0)}(k+1)$ is the known target value.

As an example the value $a_k = a_3$ is the last a in the calculation of a from the overdetermined linear system (10) where for $\alpha = 0.5$ and data series $X^{(0)} = (2,3,1)$. Target value is: $X^{(0)}(4) = 2$.

$X^{(1)}(k) = (2,5,6)$, $Z^{(1)} = (2,4.5,3.25)$ and a set of linear equation (4) equals to

$$\begin{aligned} 2+2a &= b \\ 3+4.5a &= b \\ 1+3.25a &= b \end{aligned}$$
(10).

The correspondent set of equations for determining average a and b for the use of in equation (8) is given as:

$$\begin{aligned} 2+2a_1 &= b_1 \qquad & 2+2a_2 &= b_2 \\ 3+4.5a_1 &= b_1 \qquad & 1+3.25a_2 &= b_2 \end{aligned}$$

$$\begin{aligned} 3+4.5a_3 &= b_3 \\ 1+3.25a_3 &= b_3 \end{aligned}$$
(11),

$$a = (-0.4, 0.8, -1.6) \quad b = (1.2, 3.6, -4.2)$$
(12),

The average values for a and b are: $a = -0.4$ $b = 0.2$ and $a_3 = a_k$. Therefore, from (8):

$$X'^{(0)}(4) = 4.082$$
(13),

$$e(4) = 51\%$$
(14).

More generally, prediction parameters for GM(1,1) are: α from (5), data series length m from (1), and data series step Δ (when taking each second data point $\Delta = 2$, third $\Delta = 3$, etc.).

III. RESULTS

An optimum prediction for light energy demand in KIO d.d. has been developed with $\alpha = 0.4$ [10], data series length $m = 4$, and data series step $\Delta = 1$. Slightly worse prediction results are obtained with $\alpha = 0.4$, $m = 4$ and $\Delta = 12$, that is with the prediction from the same month of the previous years. Such data on GM(1,1) prediction of electrical energy consumption of the light system from Table 1 are given in Table 2. Added are data on prediction of light system maintenance for a four years period.

IV. PREDICTION EVALUATION

Evaluation of GM(1,1) method can be done considering external features i.e. compared to ANN prediction and to semiqualitative prediction. But being superior to both methods in prediction accuracy there only remains to evaluate the internal method features. There are two distinctive features of the grey method that are interesting: its volatility in choosing data series combinations and exactness of the solution of the system given with calculating parameters a and b from (4). Volatility of data series combinations in prediction of electrical energy consumption is rather limited, thus the solution of the parameters a and b were analyzed in more detail. In order to introduce some necessary short term data patterns [8] for relevant analyzis, typical graphical signatures as “A”, “V”, “M”, “W”, “J” and “L” are used, Table 3, column 1. Added to Table 3 are prediction errors to goal function equal to data mean value, column 3; prediction errors for a and b parameters with ommition of one value of the a and b parameters outside of the 2σ from their mean values [12], column 4; prediction errors for a and b parameters with ommition of both parameter values when lying outside of the 2σ from the mean value, column 5. Test of the results is given with the inclusion of 1% random noise into prediction data, columns 6,7, and 8. Data for Table 3. have been obtained from GM(1,1) model with the following prediction parameters: $\alpha = 0.5$, $m = 5$ and $\Delta = 1$. Data series $X^{(0)}(k)$ are given in column 2.

V. DISCUSSION

Grey system modeling from GM(1,1) exhibits usually optimum accuracy for $\alpha = 0.5$. As visible from Table 2, results of prediction highly depend on the nature of data: the more human induced data the lower prediction accuracy. In GM(1;1) used for demand prediction of electrical energy nevertheless the parameter $\alpha = 0.4$ was found as a better suited , Table 2 and [10]. However the accuracy of the prediction depends highly on the shape of the data series used for prediction. For short data series some of these shapes can be approximated with characteristic signatures such as given in Table 3, column 1. Standard solution of the overdetermined system given with (4) exhibits spread out of prediction accuracy between 2.00% and 23.3%. Calculating the solution for a and b from (4) in such a way that data exceeding 2σ range should not be taken into account two possible results can be expected: one with dropping out only parameter a or b that exceeds 2σ range or one with dropping out parameter pair a and b that exceeds the 2σ range either in a or in b part or in both of them. The cases where solutions exceeded 3σ have shown generally unstable solution of the GM(1,1). Parameter a_k was calculated as the last nonomitted value of a. The first solution gives better results than "full calculation" in three signatures: "M" "J" and "L" but two solutions were worst: "A" and "W". The second solution with omitting a pair of values exceeding 2σ range gives better solution than "full calculation" for "M" "W" and "L", slightly worse for "J" and equal for "A" and "V".Mean accuracy of the "full calculation" was 8.49%, omitting one value exceeding 2σ range was 7.42%, and omitting a pair of values exceeding 2σ range was 5.25%, giving thus prommising results for further investigations of the method.

Table 1. Data on electrical energy consumption of light system for production hall and factory environment in KIO ceramic industry from 2002 to 2004.

Year	2000	2001	2002	2003	2004
Month	KWh	KWh	KWh	KWh	KWh
January	85625	117321	103064	115628	114274
February	116172	111237	125188	136748	94000 *
March	80602	109773	116894	131598	88589
April	98400	119912	122398	130077	75432
May	91100	115016	120251	129935	
June	98288	108345	134989	123669	
July	86283	107640	112156	124862	
August	109841	122218	134312	145377	
September	118625	120227	126808	139932	
October	101351	114937	134676	137466	
November	110389	123788	131819	122452	
December	102646	97255	94284	121597	
Total	1199323	1367669	1456837	1559340	

* start of new light system

Table 2. Data series and GM(1,1) prediction for light costs with $\alpha = 0.4$, $m = 4$ and $\Delta = 12$.

Samp le	Electrical energy consumption, kWh	Prediction of electrical energy consumption, kWh	Maintenance material costs	Prediction of maintenance material costs	Maintenance material per item	Prediction of maintenance material
1	115628	88381	713,89	482,26	5	3,49
2	136748	124541	2669,59	1555,64	10	6,86
3	131598	94655	445,00	166,63	15	5,99
4	130077	107012	421,42	266,67	12	5,72
5	129935	102675	1952,60	513,06	45	13,02
6	123669	119603	1407,00	4649,83	21	15,19
7	124862	96580	3408,56	5243,90	18	42,63
8	145377	122312				
9	139932	123899				
10	137466	119124				
11	122452	120588				
12	121597	98320				

Table 3. Prediction errors of signatures for different solutions of parameters a and b from the equation (4); prediction of series mean value with $\alpha = 0.5$, $m = 5$ and $\Delta = 1$. All errors are given in percentages.

Signature	Data series values $X^{(0)}(k)$	Error of full calculation	Error with mean included and one exceeding 2σ excluded	Error with mean included and both exceeding 2σ excluded	Error of full calculation with 1% noise added	Error with mean included and one exceeding 2σ excluded, 1% noise added	Error with mean included and both exceeding 2σ excluded, 1% noise added
A	0.9	-4.42	-7.16	-4.42	-4.95	-6.86	-2.66
	0.94				-4.09	-5.93	-4.56
	0.99				-4.34	-7.78	-4.87
	0.97				-5.78	-7.96	-3.79
	0.91				-4.81	7.08	-3.09
V	1.05	3.67	3.67	3.67	4.01	3.84	3.50
	0.99				2.29	4.54	2.49
	9.94				4.29	3.36	3.99
	0.97				3.18	3.24	3.99
	1.03				3.95	3.72	4.65
M	0.99	-23.9	-10.32	-10.32	23.21	9.66	11.37
	1.1				23.95	10.34	10.03
	1.02				21.73	9.99	9.64
	1.2				25.00	9.71	10.17
	0.93				23.51	11.14	9.96
W	1.2	10.56	15.79	4.74	10.35	15.80	4.87
	1.06				11.37	15.05	5.13
	1.12				11.12	16.39	5.73
	1.02				11.72	15.65	5.71
	1.17				10.71	16.39	5.77
J	1.05	-2.00	-1.64	-2.42	-1.07	-0.72	-2.90
	1.01				-3.28	-2.37	-3.20
	1.07				-0.68	-1.79	-2.98
	1.09				-0.79	-1-29	-2.10
	1.13				-3.68	-3.08	-1.22
L	1.15	7.00	5.91	5.91	7.93	6.79	6.87
	1.09				6.59	5.02	5.33
	1.03				6.65	6.10	5.33
	1				8.08	7.50	5.27
	1.04				8.26	5.70	5.98

REFERENCES

[1] Arif Hepbasli, Nesrin Ozalp: “Development of energy efficiency and management implementation in the Turkish industrial sector“, *Energy Conservation and Management*, pp 231-249, Vol. 44, Issue 2, January 2003.

[2] Cheng Biao: "The Grey Control of Industrial Processes“, *Journal of Huangshi College*, 1, pp 11-23, 1986.

[3] Doerffner K.: “Konnektionismus“, *B.G. Teubner Verlag*, Stuttgart 1991.

[4] Zhongmo Li: “Primary Application of the Grey System Theory in the Study of Earthquake Forecast“, *Journal of Seismology*, 4, pp 27- 31, 1986.

[5] Jianer Huang: “Application of Grey Statistics to Investment Decision Making of Forestry“, *Economic Problems of Forestry,* 2, pp 44-51, 1987.

[6] Chen Mianyun: “Grey Dynamic of the System of a Boring Machine“, *Journal of Huazhong University of Science anf Technology*, 6, pp 7-11, 1982.

[7] Deng Julong: “Control Problems of Grey Systems“, *Systems and Control Letters*, 5, pp 288-294, 1982.

[8] Jagnjić Ž. Bogunović N., and Jović F.: “Time series classification based on discrete-space feature extraction“, *Modelling and Simulation 2003. ESM ‘2003 / Di Martino, B, Y. L. Tianruo i Bobeanu C. (ur.)* Ghent: Eurosis- ETI, pp 221-225, 2003.

[9] Jović F.: “Qualitative Reasonning and a Circular Information Processing Algebra“. *Informatica*, pp 31-47, 21 (1997.)

[10] Xianmin Wang, Zaikang Chen, Changzhi Yang, Youming Chen: “Grey predicting theory and application of energy consumption of building heat – moisture system“, *Building and Environment* pp 417-420, 34 (1999.)

[11] Yao A.W. i Chi S.C.: “Analysis and Design of a Taguchi-Grey based Electricity Demand Predictor for Energy Management Systems“, *Energy Conservation and Management* Vol 45, 7-8, pp 1205-1217, 2004.

[12] Jović F., Vorko A. i Fischer D.: “Solving a linear model of nonfatal risk behavior and injuries in school children“, *Computer Methods and Programs in Biomedicine*, pp 65, 123-132, 2001.