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PROGNOSTIC MODELING OF TOTAL STEEL PRODUCTION AND ACCORDING TO PRODUCTION TECHNOLOGY IN POLAND

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The publication presents the prognostic modeling of steel production in Poland by 2020. Based on the general framework predicting, an attempt was made to adjust the model to empirical data, which were related to the size of steel production in Poland. Two prognostic approaches were used. The first approach included determination of prognoses for total steel production on the basis of empirical data for the 1990-2014 period. The second approach used empirical data for the volume of steel production according to production technologies for the 2000-2015 period. Prognoses until 2020 were determined in both cases. Thus obtained prognoses were related to changes observed on the global steel market.

Key words: steel production, basic oxygen furnace (BOF), electric arc furnace (EAF), prognostic model, Polish steel industry

INTRODUCTION

Metallurgical market in Poland has undergone a radical transformation in recent decades. From subsidized state-owned enterprises to private companies operating at their own risk. Privatized state-owned enterprises as a part of their rehabilitation programs adapted each business area to the conditions of market economy. One of these areas was the volume of production. Volumes of production were adapted to the needs of the market, eliminating unused production capacity and outdated technology [1]. In this publication, an attempt was made to predict changes in the volume of steel production for the next years based on changes in the volume of steel production in Poland in recent years. The construction of predictions for previous periods (the prediction ex-ante), had a recurring nature and consisted of the use of calculations of prognosis from previous periods. The size of steel production in Poland /M mt and the share of BF/BOF steel (steel from integrated processes) and the share of EAF steel (steel produced in electrical process)/M mt were the basis for predictions made.

PREDICTING THE VOLUME OF CRUDE STEEL PRODUCTION

Empirical data: steel production in Poland in years 1990-2014 (Table 1). Prognosis method: One of the adaptive prediction models is the autocorrelation and autoregression (AR) model. This modeling is based on minimizing the value [2] of: the relative average error of expired prognosis Ψ root mean squared error of expired prognosis RMSE*.

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Table 1 **Crude steel production in Poland [3]**

Year	Crude steel/ M mt	Year	Crude steel/ M mt
1990	13,5	2002	8,4
1991	10,3	2003	9,1
1992	9,8	2004	10,5
1993	8,9	2005	8,3
1994	11,0	2006	10,0
1995	11,7	2007	10,7
1996	10,4	2008	9,7
1997	11,6	2009	7,1
1998	9,9	2010	8,0
1999	8,8	2011	8,8
2000	10,5	2012	8,2
2001	8,8	2013	8,0
		2014	8,6

In the first stage, a prognosis is built based on the linear model (Figure 1). A thorough analysis of the resulting linear regression model, however, precludes its use for accurate predictions of steel production in future periods. Firstly, the obtained coefficient of determination R2 was equal to 0,4444 - only approx. 44 % of the empirical results can be explained by the linear model (Table 2). Secondly − after analyzing a simple match, one can notice that the assumption of a random distribution of residuals (i.e. their mutual independence) adopted in this regression model is not correct. The prognosis of steel production for the years 2015-2020 obtained using a linear model is pointing downward. The yearly decline of production is about 100 thous. mt. In 2020, the predicted volume of crude steel production will amount to 7.24 M mt (Figure 1). Already in 2015 the volume of production fell to 7,9 M mt of crude steel. In reality, in 2015 Poland produced 9,2 M mt of crude steel, i.e. 1,3 M mt more than in the prognosis. The next step was to analyze the correlation modeling of time series with itself - autocorrelation (AR). Construction of models is based upon the premise that there is an autocorrelation between the predicted val-

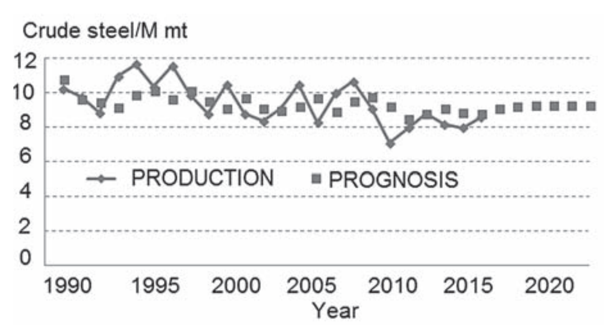

Figure 1 Prognosis of crude steel production based on the AR (1) model [4]

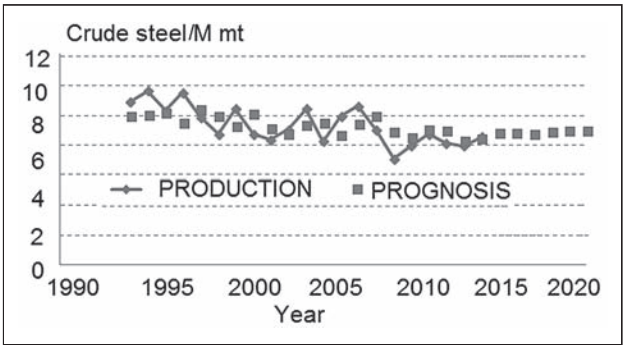

Figure 2 Prognosis of crude steel production based on the AR model (1,4) [4]

ues of the variable, and the values of the delay time. Autocorrelation coefficients r_k for shifting about k components are calculated using the following relationship:

$$r_k = \frac{\sum_{t=1}^{n-k}\left(y_t - \overline{y}\right)\left(y_{t+k} - \overline{y}\right)}{\sum_{t=1}^{n}\left(y_t - \overline{y}\right)^2} \qquad (1)$$

where:

$$\overline{y} = \frac{1}{n}\sum_{t=1}^{n} y_t \qquad (2)$$

is the average of data that makes up the original time series. Considering the results obtained as a function whose arguments are the k numbers, a graph called autocorrellogram may be plotted. The obtained calculation results are an array of autocorrelation coefficients, which facilitates selection of the most optimal AR model. My study to predict the volume of steel production used both the linear autoregressive model with one explanatory variable BACK 1 - an AR model (1) and the linear autoregressive model with two explanatory variables: BACK1 and BACK4 - that is AR model (1,4). Parameters of these models were evaluated with the smallest sum of squared residuals [2]. The obtained model AR (1):

Volumes of production of steel = 5,936 + 0,363 * BACK1.

The modeling is based on minimization of the value (obtained results) of:

o the relative average error of expired prognosis Ψ = 0,0954

o the root mean squared error of expired prognosis RMSE * = 0,934.

The obtained model AR (1,4):

Volumes of production of steel = 3,80 + 0,369 * BACK 1 + 0.,17 * BACK 4

The modeling is based on the minimization of the value (obtained results) of:

o the relative average error of expired prognosis Ψ = 1,108

o the root mean squared error of expired prognosis *RMSE**= 0,768.

Based on the performed AR (1) modeling, the size of predicted of steel production has a growing trend (Figure 1). In 2020, Polish steel industry will produce 9,32 M mt, about 729 tons more than in 2014. Based on the performed AR (1,4) modeling, the size of predicted of steel production has a growing trend (Figure 2). In 2020, Polish steel industry will produce 9,04 M mt, about 440 thousand tons more than in 2014. All results of the prognosis are presented in Table 2. Difference between prognosis of steel production volume and real data in 2015 is smaller in the AR model (1). According to the statistical data in 2015, Poland produced 9,2 M mt of crude steel [3].

PREDICTING THE STEEL PRODUCTION PATTERN BY PROCESSES

The analysis of steel production volume according to production forms was started at 2000, when steel was

Table 2 **Results of prognosis of crude steel production [4]**

Year	Linear model Crude steel/M mt	AR(1) model Crude steel/M mt	AR(1,4) model Crude steel/M mt
1990	11,17		
1991	11,04	10,84	
1992	10,91	9,68	
1993	10,78	9,50	
1994	10,65	9,17	10,01
1995	10,52	9,93	10,09
1996	10,39	10,19	10,24
1997	10,26	9,71	9,57
1998	10,12	10,15	10,46
1999	9,99	9,53	9,99
2000	9,86	9,13	9,30
2001	9,73	9,75	10,19
2002	9,60	9,13	9,19
2003	9,47	8,99	8,81
2004	9,34	9,24	9,43
2005	9,21	9,75	9,58
2006	9,08	8,95	8,68
2007	8,94	9,57	9,46
2008	8,81	9,82	10,02
2009	8,68	9,24	8,96
2010	8,55	8,51	8,59
2011	8,42	8,84	9,07
2012	8,29	9,13	9,02
2013	8,16	8,91	8,36
2014	8,03	8,84	8,49
2015	7,90	9,15	8,88
2016	7,77	9,26	8,85
2017	7,63	9,30	8,80
2018	7,50	9,31	8,91
2019	7,37	9,32	9,01
2020	7,24	9,32	9,04

practically no longer produced in open hearth furnaces (grey colour in Tables), 2003 marked the end of open hearth furnace production. The main currently used production methods include steel from integrated processes (BF/BOF) and steel produced in electrical process (EAF). The prepared prognoses of changes to the volume of steel production according to production forms until 2020 were based on empirical data for the 2000-2015 period (Table 3).

Table 3 **Production of crude steel, BOF steel and EAF steel [4]**

Year	Crude steel/M mt	BOF steel/M mt	EAF steel/M mt
2000	10,498	6,800	3,285
2001	8,809	5,823	2,809
2002	8,367	5,799	2,561
2003	9,107	6,070	3,037
2004	10,578	6,858	3,721
2005	8,336	4,893	3,443
2006	9,992	5,766	4,225
2007	10,631	6,198	4,433
2008	9,727	5,225	4,502
2009	7,128	3,236	3,893
2010	7,993	3,995	3,998
2011	8,776	4,424	4,353
2012	8,348	4,227	4,132
2013	7,950	4,399	3,551
2014	8,558	5,067	3,491
2015	9,202	5,323	3,879

Both adaptation models and econometric models (linear, non-linear and including autocorrelation) were used in order to create a prognosis of the total volume of steel production in Poland, taking into account the production processes used. Tests of accepted methods showed that the best fit was obtained using autoregression (AR) and the crawling trend method – prognosis using the harmonic weights method. In the case of the autoregression model, Durbin-Watson statistic was estimated and an autocorrellogram was created. The obtained autocorrellogram confirmed that offsets may be included in the AR model in the case of BOF BACK 1, EAF BACK 1, 2,6. The following assumptions were applied to the crawling model: Segments with k = 4 observations were selected, weights, or factors taking into account information aging were calculated using formula 3:

$$C_{t+1}^{n} = \frac{1}{n-1} \cdot \sum_{i=1}^{t} \frac{1}{n-1} \quad (3)$$

Ex-ante prognoses were calculated using formula 4

$$y_T^* = y_n + (T-n) \cdot (\sum_{t=2}^{n} w_t \cdot c_t) \quad dla \quad T = n+1, \ldots, \tau \quad (4)$$

Tables 4 and 5 present ex post and ex ante errors calculated for individual prognostic methods. Tables 6 and 7 provide a summary of results obtained for BOF and EAF processes.

The following prognostic model was obtained using the AR model (1) with the BOF process:

$$y_T^* = 2{,}426 + 0{,}5193*BACK1$$

Table 4 **Ex post and ex ante errors for prognostic methods – BOF process [4]**

Type of model	Estimation		
	ex post		ex ante
	ψ	*RMSE	ψ
Crawling model (k=4)	0,059	0,379	0,0046
Model autoregression AR(1)	0,124	0,772	0,0499

Table 5 **Ex post and ex ante errors for prognostic methods – EAF process [4]**

Type of model	Estimation		
	ex post		ex ante
	ψ	*RMSE	ψ
Crawling model (k=4)	0,039	0,171	0,0340
Model autoregression AR(1,2,6)	0,041	0,171	0,0615

Table 6 **Prognosis of BOF steel production [4]**

Year	BOF steel/ M mt	AR (1) model Crude steel/M mt	Crawling model Crude steel/ M mt
2000	6,800		6,455
2001	5,823	5,957	5,932
2002	5,799	5,450	6,058
2003	6,070	5,438	6,107
2004	6,858	5,578	6,147
2005	4,893	5,987	5,665
2006	5,766	4,967	5,795
2007	6,198	5,421	5,711
2008	5,225	5,645	4,993
2009	3,236	5,140	3,954
2010	3,995	4,106	3,855
2011	4,424	4,501	4,134
2012	4,227	4,723	4,344
2013	4,399	4,621	4,535
2014	5,067	4,711	4,898
2015	5,323	5,057	5,348
2016	prognosis	5,190	5,433
2017	prognosis	5,122	5,542
2018	prognosis	5,086	5,652
2019	prognosis	5,067	5,761
2020	prognosis	5,057	5,871

The correlation factor of R=0,3217 indicates rather poor model fitting to empirical points of data.

Conclusion from prognosis: according to the models (Table 6) BOF steel production will be on level 5,06 or 5,87 M mt in 2020 in Poland.

The following prognostic model was obtained for the electric process:

$$y_T^* = 5{,}893 + 0{,}178*BACK1 – 0{,}334*BACK2 - 0{,}338*BACK6$$

whereby the correlation coefficient was R = 0,7340 – indicating good model fitting to empirical data points.

Conclusion from prognosis: according to the models (Table 7) EAF steel production will be on level 3,7 or 4,2 M mt in 2020 in Poland.

Adding steel production volumes in BOF and EAF processes results in the total steel production for prognosed years.

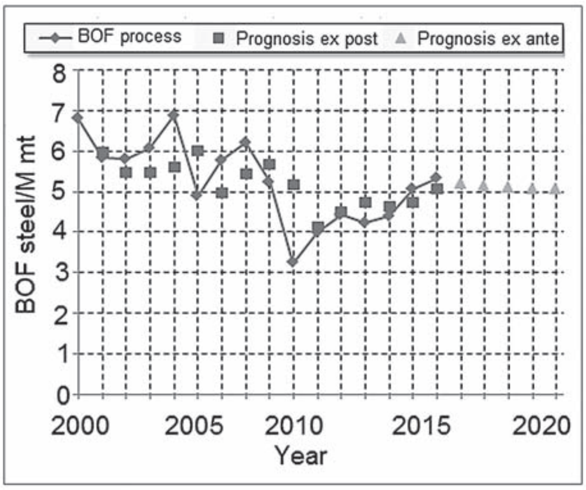

Figure 3 Prognosis of BOF steel production[4]

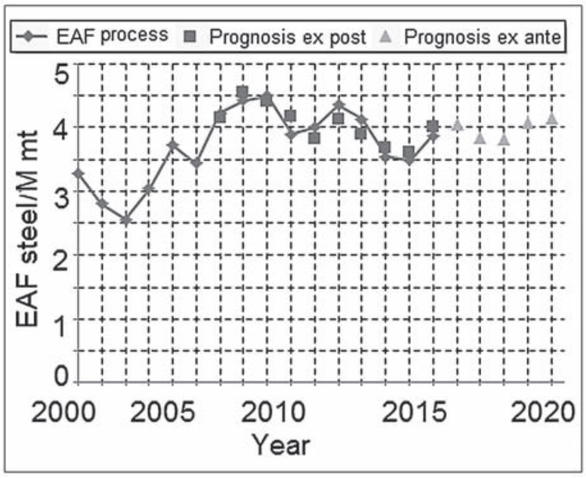

Figure 4 Prognosis of EAF steel production[4]

Table 7 **Prognosis of EAF steel production [4]**

Year	EAF steel/M mt	Crawling model Crude steel/M mt	AR (1,2,6) model Crude steel/M mt
2000	3,285	3,072	
2001	2,809	2,762	
2002	2,561	2,812	
2003	3,037	3,026	
2004	3,721	3,458	
2005	3,443	3,729	
2006	4,225	4,146	4,151
2007	4,433	4,379	4,544
2008	4,502	4,354	4,404
2009	3,893	4,093	4,186
2010	3,998	4,093	3,823
2011	4,353	4,181	4,139
2012	4,132	4,028	3,902
2013	3,551	3,767	3,674
2014	3,491	3,565	3,622
2015	3,879	3,641	4,011
2016	prognosis	3,850	4,064
2017	prognosis	3,820	3,848
2018	prognosis	3,790	3,822
2019	prognosis	3,761	4,087
2020	prognosis	3,731	4,162

CONCLUSION FROM PROGNOSIS FOR STEEL PRODUCTION IN POLAND

The prognosed volume of steel production in Poland shall slightly exceed 9 M mt per year (optimistic scenario) or oscillate around 9 M mt (pessimistic scenario), changes to steel production using the BOF method will be small, converter steel shall comprise over 50 % of the total steel production in Poland, with the remaining share held by steel produced in electric furnaces, the increase of steel production in electric furnaces during the analysed period may result from potential, temporary standstills of blast furnaces because of their upgrades or decreased demand and resulting excess of production capacity in Polish metalwork industry.

REFERENCE THE RESULTS TO THE GLOBAL PROGNOSIS

In 2050, the use of steel will increase. Consumption is projected to be 1,5 times higher than current levels. Optimistic predictions are conditioned by the necessity to meet the needs of growing population [5-7]. In Europe according to a British company MEPS this increase can be “slow but steady”. The European Commission plans (“Horizon 2020”) predict that the European Union’s economic growth will slow in the near future. Public sector spending for the next few years will be very limited, and with it, investments in infrastructure. The private sector will be in turn limited by more restrictive lending policies of banks. The recovery in the consumer goods sector also has to be modest. An opportunity for development of the steel market will create demand (total share of the construction and car production in the demand for steel is about 40 % in the EU). It is therefore necessary to realize the link between these sectors and the EU initiative, CARS2020, an initiative to stimulate demand for alternative fuel vehicles and an initiative on sustainable construction, including renovation of buildings [8].

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Note: The responsible translator for English language is translate office Niuans, Gliwice, Poland