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FORECASTING OF DEMAND FOR DIRECT PRODUCTION MATERIALS AS THE ELEMENT OF SUPPLY LOGISTICS OF THERMAL POWER PLANTS

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ABSTRACT. The paper highlights the problems associated with the process of forecasting realized within the supply logistics in thermal power plants. The theoretical part focuses on the importance of forecasting of inventories of raw materials in thermal power plants and the quality of logistics decisions determined by utilitarian value of data obtained, stored, processed and transmitted within the logistic system. The practical part presents the results of studies conducted in one of the thermal power plants in the south of Poland and the results of forecasting of the demand for the materials directly used in manufacturing process.

Key words: inventory management, utilitarian value of data, forecasting, forecasting methods.

INTRODUCTION

The production of the high-quality electricity in the quantities sufficient to cover energy requirements of households and business enterprises is the main goal of power plants. Due to the fact, that the energy cannot be stored, the main importance of the inventory management of power plants is put on the management of raw materials, and especially the raw materials, which are necessary to ensure the continuity of the production process. Therefore, the primary objective of the purchasing is to ensure the availability of needed raw materials for the production at a minimum cost. The forecasting of the demand for raw materials is one of the most important activities determining the effectiveness of the inventory management.

The paper presents the results of studies conducted in one of the power stations located in the south part of Poland. Its main goal is to identify the factors, which affect the demand level of production raw materials as well as to present the possibilities of the forecasting process of the demand in power plants. The attempt was made to find the best possible method of the forecasting of the demand for the coal, which is the main source of the energy.

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THE IMPORTANCE OF FORECASTING OF STOCKS LEVEL OF RAW MATERIALS IN LOGISTIC PURCHASMENT SYSTEM

The production of the high-quality electricity in the quantities sufficient to cover energy requirements of households and business enterprises is the main goal of power stations. Due to the fact, that the energy cannot be stored, the main importance of the inventory management of power plants is put on the management of raw materials, and especially the raw materials, which are necessary to ensure the continuity of the production process. The inventory is one of the main components of logistic processes and should be characterized by the efficiency and the flow profitability [Sarjusz-Wolski and Skowronek 2003]. The efficiency ensures the complete cover of requirements of participants of the logistic processes and the flow profitability ensures the optimal cost level. The primary objective of the purchasing is to ensure the availability of needed raw materials for the production at a minimum cost. The forecasting of the demand for raw materials is one of the most important activities determining the effectiveness of the inventory management. The inventory management is very important for the company due to the facts that [Twaróg 2003]:

1. The inventory costs are an important part of total logistic costs,
2. The stocks levels impact the customer service level,
3. The costs regulations of trade-off types affect the costs of inventory maintenance.

The support of the decision making process is the main goal of the forecasting, particularly at the tactical level [Syntetos et. al. 2010]. This goal determines functions of the forecasts in the company, namely [Cieślak 2005]:

1. Preparation – the forecasting is the activity, which prepares other activities,
2. Activation – the designated forecasts are the incentives to undertake actions leading to reach the goals or to oppose them, depending on the balance of benefits and losses, which could be obtained by the company,
3. Information – to indicate the changes in forecasted occurrences and to reduce the uncertainty of the future events.

The purposefulness of forecasting activities results from the conditions under which the company operates, and particularly from the conditions of the uncertainty. In case of the procurement, they are determined by [Tempelmeier 2000]:

- demand levels for raw materials, which could vary throughout the planning period,
- unknown replenishment time (the purchase of the following stock batch),
- the discrepancy between ordered and delivered quantity of goods,
- the lack of the consistency between the inventory records, conducted by the inventory staff and the actual inventory level (inventory differences).

In addition, the companies are supplied by different suppliers and therefore the risk connected with lead-time can occur. The risk and the uncertainty are inseparable elements of the way, how the company functions, and therefore they cannot be eliminated. However, due to the properly conducted forecasting process, they can be reduced to the level, which does not threaten the functioning of the company. The knowledge of the future demand levels supports the process of constructing of replenishment plans. The corrected chosen methods of forecasting of the future demand are the conditions of the correctness of replenishment plans [Syntetos and Boylan 2010]. The right information as well as data of appropriate characteristics are necessary to fulfil this goal.

THE UTILITARIAN VALUE OF INFORMATION FOR FORECASTING OF THE DEMAND FOR RAW MATERIALS' STOCKS

The quality of logistic decisions depends mainly on the utilitarian value of data obtained, stored, processed and transmitted within the logistic system of the company. The date passes on the contents of a message, which presents the information. The management of the information of the appropriate utilitarian value is necessary to the correct realisation of the forecasting process. The following features determine the utilitarian value of the information: timeless, relevancy, completeness, ease of understanding and reliability [Bukowski 2004]. The definitions (stated by Bukowski [2004]) and the exemplary characteristics of each feature in accordance to the requirements for the procurement about the correct forecasting of raw materials for the production company are presented in the table 1.

Table 1. Characteristics of utilitarian value of information for the demand planning of stocks levels of raw materials
Tabela 1. Cechy wartości użytkowej informacji na potrzeby planowania popytu na zapasy surowcowe

Characteristics	Definition	Examples
timeless	monotonically not increasing function of the delay, with which the information reaches the decision maker	▪ information on stocks levels of raw materials, which are updated periodically ▪ information on the demand for a raw material in a given period of the time ▪ cost of stocks maintaining of raw materials for a given time or a period of the time
relevancy	the compliance of the information with the needs of the user	▪ the recording of each stock movement (and not only stocks level at weekly periods) in order to estimate the point of placing the orders
completeness	the difference between the source information and the information obtained by the user	▪ identification of methods to estimate the missing data
ease of understanding	the usefulness of the information for the direct use by the decision maker	▪ keeping the cost records according to logistics requirements to assess the raw materials' supply processes
reliability	the compliance of the information with the situations described by this information	▪ the information on stocks levels of raw materials recorded always by the use of the same method ▪ depreciation deduction calculated with the use of the same rates throughout the whole depreciation period (in order to eliminate the creativity in the accounting)

The access to the information of high utilitarian value increases the effectiveness of logistics systems. The access to data and the appropriate logistics information is necessary for the analysis, estimation and finally making the right decision to realize the aims of the logistics. It should be pointed out, that only one numerical value does not mean anything. The observation of any event in only one moment of the time or a period provides only one worthless value [Jetzke 2007]. It is necessary to possess the whole set of data, which creates information, which fulfill all conditions for it to be of a utilitarian value.

THE APPLICATION OF SELECTED METHODS FOR THE FORECASTING OF THE DEMAND OF RAW MATERIALS USED DIRECTLY IN THE PRODUCTION IN POWER PLANTS

The raw materials used directly in the production process belong to the tangible assets. They are characterized by the total consumption in the production process and ensuring its undisturbed course [Cebrowska 2005]. Therefore, each unit of these materials should have the stocks of raw materials of proper structure and in sufficient quantities to ensure its proper functioning. Such raw material used directly in production process of power plant is the fuel, which is processed into the electric and thermal energy. The hard coal is the traditional raw material used in power plants. The energetic coal is characterized by:

- calorific value, i.e. the combustion heat and the combustion value,
- humidity,
- content of combustible compounds,
- ash content,
- content of sulphur and other trace elements,
- milling susceptibility.

The caloric value determines the amount of the coal, needed to be burned to produce a given quantity of the electric and thermal heat. The excessive moisture content decreases the caloric value of the burned fuel. The ash content determines the ash content of exhaust fumes, the ash fall on the grounds and the dust content in the atmosphere as well as the amount of the removed slag. The sulfur content determines the sulfur content in the atmosphere, the content of trace and radioactive elements determines the additional harmfulness of the ash fall on the grounds and the dust content in the atmosphere. The trace elements stay in the fly ash and the slag after the burning of the coal.

The level of the coal consumption in one of the power plant in the southern Poland was studied in this research. The analysis covers 78 periods (consecutive months from July 2002 up to December 2008). The aim of this study was to verify the suitability of selected methods for forecasting of the coal consumption in the first half of 2009. The basic models used for forecasting of the coal consumption included:

1. the model of development trend,
2. the Holt's linear model (the most commonly used model of the forecasting of the short-term demand is the simple model of the exponential smoothing (Brown's model) [Wallström and Segerstedt 2010], the trend and random fluctuations found in the analyzed data were the reasons to use Holt's model),
3. ARIMA model,
4. one equation econometric model,
5. the logit model.

Due to the fact, that all above mentioned methods are described in detail in the literature, including the literature covering the logistics and logistics management [Sarjusz-Wolski 2000, Krzyżaniak 2002], only the most important characteristic of them were presented in this paper.

The model of development trend is a model in which there is a trend and the time variable is the explanatory variable. The time variable determines the influence of unknown factors onto the formation of the level of estimated variable and enables the quantitative analysis of these changes. The linear equation of the trend function was used to describe the level of the coal consumption [Cieslak 2005]:

$$y_t = \alpha + \beta t.$$

The parameter β describes the direction of the development of studied phenomenon, as well as the stable increase of the values of estimated variable in the time unit.

The Holt's linear model is used for smoothing of time series including the trend and random fluctuations. It consists of two equations [Cieślak 2005]:

$$F_{t-1} = \alpha y_{t-1} + (1 - \alpha)(F_{t-2} + S_{t-2})$$
$$S_{t-1} = \beta(F_{t-1} - F_{t-2}) + (1 - \beta)S_{t-2}$$

where: F_{t-1} – smoothed value of forecasted variable at the given moment (period) *t-1*

S_{t-1} – smoothed value of the trend growth at the given moment (period) *t-1*

α, β – model parameters having the value within the interval [0; 1].

The forecast value at the moment (period) $t>n$ is determined by the formula:

$$y_t^* = F_n + (t-n)S_n$$

where: y_t^* – the forecast of the variable Y determined at the moment (period) *t*,

F_n – smoothed value of forecasted variable at the moment (period) *n*,

S_n – smoothed value of trend growth at the moment (period) *n*,

n – the number of points in time series of forecasted variable.

The ARIMA model is a mixed one and consists of the autoregression and the moving average. It can be applied for modeling and forecasting of stationary and non-stationary series, which could be transform to the stationary ones. In practice, most of the time series is of non-stationary nature and because the non-stationary model can be featured by the spurious regression, the stationarity of the series should be examined before the selection of the forecasting method [Gruszczyński 2004]. The process: ARIMA (p, d, q), where *d* is the level of the integration, *p* is the order of the autoregression and *q* is the moving average, could be presented as [Cieślak 2005]:

$$y_t = \varphi^*_1 y_{t-1} + \ldots + \varphi^*_{p+d} y_{t-p-d} + \varepsilon_t - \theta_1 \varepsilon_t - \ldots - \theta_d \varepsilon_{t-q}$$

where: ε_t – forecasting error.

The model of trend estimation, the Holt's linear model as well as ARIMA model are the models of times series. The estimations of the accuracy and relevance of forecasts based on time series are made by [Zeliaś at al. 2004]:

1. the estimation of expected value of empirical deviations of the value of forecasted variable from the determined forecasts (errors *ex ante*),
2. the calculation of expected value of empirical deviations of the value of forecasted variable from the determined forecasts (errors *ex post*).

The one equation econometric model assumes the relationship between the variable explained (y_t) and the explanatory variables (x_{it}) and has a form [Cieślak 2005]:

$$y_t = \sum_{i=0}^{m} \alpha_i x_{it} + \xi_t \qquad t = 1,\ldots,n$$

where: α_i – values of structured parameters

ξ_t – random component.

The estimation of parameters indicates the average change of the value of the dependent variable if the independent variable *i* changes by one unit and when other variables do not change. The verification of the one equation econometric model consists of: the signification of the estimations of parameters, the coefficient of determination, the linearity of the model, the normality of the distribution of residuals, the heteroscedasticity of a random component and the autocorrelation of a random component.

The logit model is an econometric model of zero-one variables. It describes the formation of the random endogenic variables, having the values of zero or one and a form of [Kufel 2011]:

$$y_i^* = \ln\frac{P_i}{1-P_i} = \beta_0 + \sum_{j=1}^{k}\beta_j x_{ij} + u_i$$

where: y_i^* – logit,

P_i – the probability of the dependent variable y_t, determined on the basis of the logistic distribution by the use of the equation:

$$\frac{P_i}{1-P_i} = e^{y_i^*} = e^{\beta_0+\sum_{j=1}^{k}\beta_j x_{ij}+u_i}$$

$$\hat{P}_i = \frac{P_i}{1+e^{-y_i^*}} = \frac{1}{1+e^{-(\beta_0+\sum_{j=1}^{k}\beta_j x_{ij})}}$$

The marginal effect for the variables is significant in the logit model, which is the estimation of first derivative of the average and indicates the direction – the slope change of the probability of a given variable. The estimated marginal effects indicate that:

– the growth of the value of a given variable increases the probability that the variable has a value 1, if the marginal effect is positive,

– the decline of the value of a given variable increases the probability that the variable has a value 1, if the marginal effect is negative.

The significance of factors used as the explanatory variables in the model is tested by the use of *t*-student test. It is also possible to use in the verification process as follows (the measures of fitting for a model of quality variables are described in detail by Maddala [2006]):

– number of cases of the corrected prediction, i.e. the estimated coefficient of the determination R^2, which allows to estimate generally the degree of the model fitting to the date based on the sample used to create a model – in other words, it is a number of cases, for which the model correctly determined the forecasted value,

– McFadden's pseudo R-squared, which is the measure of R^2 type (although it has no equivalent in other R^2 defined for linear regression),

– the probability ratio test, i.e. the test of significant of the estimated equation (if *p* is less than the assumed level of the significance, than there is the significance of the whole regression),

– the coefficient of correlation, which is described as the correlation of variable y_i with theoretical values of the model $\hat{P}_i$, i.e. $R = r(y_i, \hat{P}_i)$.

The described methods were used to create the forecast of the coal consumption. The following assumptions were taken:

1. The time variable is the explanatory variable – a model of development trend,

2. Due to the existence of a small decreasing trend and radon fluctuations, the Holt's linear model was used,
3. The process of the coal consumption is a stochastic process, which could be stationary or non-stationary – ARIMA model *(p, d, q),*
4. The coal consumption depends on the production scale or its parameters – one equation econometric model,
5. The zero-one variable (which is equal to 1, if the decrease of coal consumption occurred simultaneously with the increase of the production and is equal to 0 in other cases) depends on coal parameters – the logit model.

The estimations results for models of time series are presented in the table 2 and for the econometric model in the table 3.

Table 2. The estimations results for models of time series with the dependent variable *coal comsumption*
Tabela 2. Wyniki estymacji modeli szeregów czasowych dla zmiennej *zużycie węgla*

Model	**Estimation of parameter**	**Level of significance *p***
development trend	α = 152015.614 β = -407.021	<0.00001 <0.00001
Holt's	α = 0.8 β = 0	
ARIMA (1, 0, 1)	φ_1 = 0.995519 θ_1 = -0.234807	<0.00001 0.03267

The linear function was the best-fitted function in case of the model of the development trend (the highest level of the coefficient of the determination was observed for this function). The parameters α and β for the Holt's model were chosen so, that errors *ex post* of the extinct forecast were the lowest ones. The parameters *p, q* and *d* for ARIMA model were chosen on the basis on estimated criteria of the models' selection: AIC, BIC, HQC, previously proving the stationarity of the process of the coal consumption by the appropriate test.

Table 3. The estimations results for econometric models with the dependent variable *coal comsumption*
Tabela 3. Wyniki estymacji modeli ekonometrycznych dla zmiennej zależnej *zużycie węgla*

Model	**Estimation of parameter**	**Level of significance p**
Independent variable of the rate of production of the electricity	α_0 = 105426 α_1 = 4.89911	<0.00001 0.00002
Dependent variable: combustion value	const: α_0 = 480629 combustion value: α_1 = -16743.2	0.00002 0.00172
Model	**Estimation of parameter**	**Marginal effect for averages**
logit model	const: β_0 = -17.8830 combustion value: β_1 = 0.000722553	 3.32958E-05

In case of one equation econometric models, the variables for which the significance of parameters standing around them was proved, were taken as the independent variables. Due to the fact, that the autocorrelation of residuals of first order was observed, the Cochrane'a-Orcutt method was applied.

The model with one independent variable *combustion value* turned out to be the best one in case of the logit model.

The verification of the prognostic process in case of time series were done on the basis of the relative error of the forecast *ex ante* (η_t), calculated by the use of the formula:

$$\eta_t = \frac{v_t}{y_t^*} \quad t \in [n+1,...,T], \textit{ where: } v_T = \left[\frac{(T-\bar{t})^2}{\sum_{t=1}^{n}(t-\bar{t})^2} + \frac{1}{n} + 1 \right]^{0,5} \cdot s$$

T – number of the moment or the period, for which the forecast was estimated,

$\bar{t}$ – average value of time variable in time series with *n* observations,

s – residual standard deviation.

The error for used methods was given in the table 4.

The smallest relative errors were observed in case of forecasts calculated by the use of the Holt's linear model, which proves the highest accuracy of the forecasts. The smallest forecasts accuracy was found for ARIMA model. Unfortunately, the estimated errors are significantly higher than 10%, which indicates they cannot be accepted according to generally accepted criteria given in the literature [Zeliaś et al. 2004]. However, due to the character and the importance of the estimated variable, it can be accepted even in case the error is higher than 10%. The recipient of the forecast can take his own criteria for its acceptability. Taking into the consideration a fact, that the amount of the used coal is determined not only by the rate of the production or its parameters but also the technical and technological aspects of the production infrastructure, the criterion of the acceptability of the forecast can be increased.

Table 4. The relative *ex ante* errors of forecasts for time series models
Tabela 4. Względne błędy prognozy *ex ante* dla modeli szeregów czasowych

the period of the empirical verification of the forecast	**forecast error v_t/y_t^***		
	the development trend model	**Holt's model**	**ARIMA (1,0,1)**
t=79	0.158	0.153	0.142
t=80	0.158	0.154	0.179
t=81	0.159	0.155	0.210
t=82	0.160	0.157	0.237
t=83	0.161	0.158	0.262
t=84	0.161	0.159	0.284

The forecasts errors cannot be calculated for estimated econometric models without the previous estimation of values of variables taken as independent ones. Therefore, the verification of the model was conducted according to measures and statistical tests accepted in the literature. The results of the verification process were presented in the table 5.

Table 5. The results of the verification of econometric model for dependent variable *coal consumption*
Tabela 5. Wyniki weryfikacji modeli ekonometrycznych dla zmiennej zależnej *zużycie węgla*

Model	**results of the verification**
independent variable *rate of the production of the electricity*	residual standard error = 13963.7 coefficient of determination R^2 = 0.547058 corrected coefficient R^2 = 0.541019 statistics of Durbin-Watson test = 2.17146 autocorrelation of residuals of first order = -0.0874121 Test of normality of residual distribution: test statistics: $\chi^2(2)$ = 0.14778 when p = 0.928774
independent variable *combustion value*	residual standard error = 14947.4 coefficient of determination R^2 = 0.480226 corrected coefficient R^2 = 0.473296 statistics of Durbin-Watson test = 2.08418 autocorrelation of residuals of first order = -0.0438203 Test of normality of residual distribution: test statistics: $\chi^2(2)$ = 1.81919 when p = 0.402688
logit model	number of cases of 'correct prediction' = 74 (94.9%) McFadden's pseudo-R-squared = 0.0219796 probability ratio test: Chi-squared (1) = 0.527779 (p = 0.467542)

The verification process confirmed the goodness of one equation econometric model. Therefore, the coal consumption can be forecasted depending on the ratio of the production or its parameters. Only the logit model cannot be considered a good one, since the high value $p>0.1$ in the test of the significance of the estimated equation does not indicate the significance of the whole regression.

SUMMARY AND DISCUSSION

The supply of the power plant in the coal is an important element of logistics, because it is a basic raw material used directly in the production process. Due to the fact, that the share of costs of fuel in material cost in the analyzed plant and periods was within the range from 86.04% to 95.35% and its share in total costs was within the range from 36.61% to 54.27%, the proper management of its purchase guarantees the economics of the logistics process. Therefore, the problem of the estimation of the coal consumption in the production seems to be an important problem especially that the process of the energy production is carried out "on-line", because the energy cannot be stored. The method applied in this study indicate that the calculated forecasts could be useful in the decision making process of the supply system of power plants. The forecasting process can be performed based on the time series models as well as on cause-effect models, depending on whether the explanatory variable showing the level of the coal consumption is: the time variable, the rate of the production or the coal parameters. Unfortunately, the big random variability of the coal consumption in the production process in the power plant is the reason of the big errors of the forecasts. The reasons of the forecasts errors could be also the form of the available data, which not always allows building a good and correct model. Furthermore, the raw materials used directly in the production process are not the only materials necessary to perform the production process in the power plants. The identification of problems connected with the production process with reference to the forecasting could be an incentive to find new analytical solutions in this area. Therefore the direction of the future researches was formed, particularly including following tasks:

- the influence of the uncertainty and the variability of the demand on the raw materials directly used in the production process on the decisions in the area of the materials management,
- the application of methods for analyzing and forecasting of the discrete demand,
- stochastic approach to the materials planning,
- errors analysis of data used in the analysis.

The proposed methods of the analysis can help to find even better methods of the forecasting, particularly in case of the companies operating in uncertain conditions.

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PROGNOZOWANIE POPYTU NA MATERIAŁY BEZPOŚREDNIO PRODUKCYJNE JAKO ELEMENT LOGISTYKI ZAOPATRZENIA ELEKTROWNI CIEPLNYCH

STRESZCZENIE. W artykule zwrócono uwagę na problemy związane z procesem prognozowania realizowanym w ramach logistyki zaopatrzenia elektrowni cieplnych. W części teoretycznej skoncentrowano się na znaczeniu prognozowania zapasów surowcowych w elektrowniach oraz jakości decyzji logistycznych determinowanych wartością użytkową danych pozyskiwanych, gromadzonych, przetwarzanych i przesyłanych w ramach systemu logistycznego. W części praktycznej zaprezentowano wyniki badań przeprowadzonych w jednej z elektrowni cieplnych Południowej Polski i dotyczących prognozowania popytu na materiały bezpośrednio produkcyjne.

Słowa kluczowe: gospodarka zapasami, wartość użytkowa informacji, prognozowanie, metody prognozowania.

DIE PROGNOSE DER NACHFRAGE DER ROHSTOFFE FÜR DIE PRODUKTION ALS DAS ELEMENT DER BESCHAFFUNGSLOGISTIK VON THERMISCHEN KRAFTWERKEN

ZUSAMMENFASSUNG. Der Artikel unterstreicht die Probleme mit dem Prozess der Prognose innerhalb der Beschaffungslogistik in thermischen Kraftwerken. Der theoretische Teil konzentriert sich auf die Bedeutung der Prognose der Vorräte der Rohstoffen in Kraftwerken und der Qualität der logistischen Entscheidungen, die von den Nutzwert der gewonnenen Daten, gespeichert, verarbeitet und übermittelt innerhalb des logistischen Systems, abhängig sind. Der praktische Teil präsentiert die Ergebnisse von Studien in einem der thermischen Kraftwerke im Süden von Polen und die Ergebnisse der Prognose der Nachfrage für die Rohstoffe, die direkt im Herstellungsprozess verwendet wurden.

Codewörter: Bestandsmanagement, nützliche Wert der Daten, Prognose, Prognoseverfahren.

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