

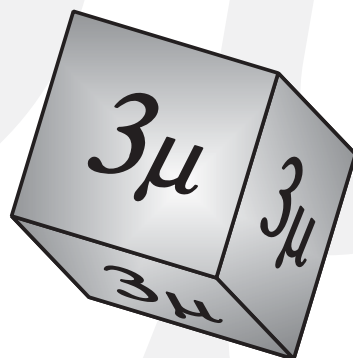
VYSOKÁ ŠKOLA BÁŇSKÁ - TECHNICKÁ UNIVERZITA OSTRAVA



JEDNOTA ČESKÝCH MATEMATIKŮ A FYZIKŮ, pobočka Ostrava
KATEDRA MATEMATIKY A DESKRIPTIVNÍ GEOMETRIE VŠB -TU Ostrava

Sborník z 22. semináře

Moderní matematické metody v inženýrství česko-polský seminář (3mi)



3.6. - 5.6. 2013

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Vážené kolegyně, vážení kolegové,

mezinárodní seminář Moderní matematické metody v inženýrství pokračoval letos dvaadvacátým ročníkem. Organizaci semináře v souladu s tradicí zajistila ostravská pobočka Jednoty českých matematiků a fyziků a Katedra matematiky a deskriptivní geometrie VŠB-TU Ostrava. Do hotelu Excelsior v Horní Lomné u Jablunkova přijelo 67 účastníků, z toho 25 zahraničních (24 z Polska a 1 ze Slovenska). Výraznou převahu mezi účastníky mělo mládí, což je určitě potěšující.

Cyklus tří plenárních přednášek z historie matematiky zaměřil v tomto roce pan doc. RNDr. Jindřich Bečvář, CSc. z Matematicko–fyzikální fakulty Univerzity Karlovy v Praze na matematiku ve starověkém Řecku. Jeho přednášky nazvané Aristarchovo měření vesmíru a Eratosthenovo měření Země, Archimédův pískový počet a Boj s nekonečnem všechny účastníky velmi zaujaly.

Bylo předneseno celkem 29 referátů a komentováno 24 posterů. Příspěvky byly zaměřeny odborně na matematické modelování, simulace, kódování, statistiku, aplikace matematiky v geologii, geodézii a ekonomii, ale i metodicky na analýzu náročnosti studia matematiky na technických vysokých školách, přijímací testy nebo na úroveň znalostí studentů. Pro velký zájem projevovaný v minulém ročníku byl i na letošní seminář zařazen workshop GeoGebra. Jeho pokračování se předpokládá i v dalších ročnících. Novinkou byl kulatý stůl na téma Výuka matematiky na technický vysokých školách, během kterého došlo k výměně názorů na obsah vysokoškolské matematiky a na zkušenosti s metodikou její výuky. Diskuse se také zabývala neustále klesající úrovní znalostí studentů, kteří na vysoké školy nastupují.

Spolufinancování semináře z prostředků EU z Fondu mikroprojektů v Euroregionu Silesia (CZ.3.22/3.3.04/13.03561) umožnilo účast širokému okruhu zájemců, včetně doktorandů a zejména výrazně vyšší účast polských kolegů z příhraničních vysokých škol.

Změna nastala také ve výstupech ze semináře. Sborník všech příspěvků je vydáván na CD, zatímco příspěvky v anglickém jazyce jsou publikovány v tradiční tištěné podobě. Příspěvky byly dodány ve formě camera ready, takže neprošly ani odbornou ani jazykovou úpravou. Připravujeme také vydání mimořádného čísla časopisu AEEE (Advances in Electrical and Electronic Engineering), v němž budou otištěny odborné články navazující na vybrané příspěvky. Výběr provádí ediční rada časopisu s ohledem na jeho zaměření. Články pak projdou standardním recenzním řízením.

Závěrem si Vás dovoluujeme pozvat na příští, již 23. ročník semináře, který proběhne v termínu 2.–4. června 2014 opět v hotelu Excelsior.

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PRIMAL-DUAL NONLINEAR RESCALING METHOD WITH DYNAMIC SCALING PARAMETER UPDATE FOR CONVEX OPTIMIZATION PROBLEMS

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Abstract: Nonlinear rescaling is a tool for solving large-scale nonlinear programming problems. However, the explanation and the appropriate setting of parameters were not discussed in previous research. Primal-dual nonlinear rescaling method with dynamic scaling parameter update (PDNRD) was tested on quadratic programming problems with quadratic constraints arising from 3D contact problems. Based on the numerical experiments, the conclusions about the setting of PDNRD method parameters were made.

1 Introduction

Nonlinear rescaling (NR) methods can solve large-scale nonlinear programming problems with thousands of variables and constraints. They were successfully used to the radiotherapy treatment planning and are applied at some hospitals in USA and Europe (see [1]). The basic idea of NR methods is a nonlinear transformation of constraint functions to improve the properties of Lagrangian.

We consider the convex optimization problem

$$\begin{cases} \text{minimize} & f(x), \quad x \in \mathbb{R}^n, \\ \text{subject to} & c_i(x) \geq 0, \quad i = 1, \dots, r. \end{cases} \quad (1)$$

Function f is convex and functions c_i are concave, $\forall i = 1, \dots, r$. For problem (1) we define Lagrangian

$$L(x; \lambda) = f(x) - \sum_{i=1}^r \lambda_i c_i(x). \quad (2)$$

We assume that:

(A) The Slater condition holds.

- (B) Functions $f, c_i, \forall i = 1, \dots, r$, are twice continuously differentiable on the set \mathbb{R}^n .
- (C) The optimal set $X^* := \text{Argmin} \{f(x); c_i(x) \geq 0, \forall i = 1, \dots, r\}$, is bounded and not empty.

2 Basic concept of NR methods

First, special nonlinear functions are defined.

Definition 2.1. Twice continuously differentiable function $\psi : (t_0; +\infty) \rightarrow \mathbb{R}$, where $-\infty < t_0 < 0$, satisfying conditions

- (i) $\psi(0) = 0, \psi'(0) = 1,$
- (ii) $\psi'(t) > 0, \forall t \in (t_0; +\infty),$
- (iii) $\psi''(t) < 0, \forall t \in (t_0; +\infty),$
- (iv) $\exists a > 0 : \psi(t) \leq -at^2, \forall t \in (t_0; 0),$
- (v) $\exists b > 0 : \psi'(t) \leq bt^{-1}, \forall t > 0,$
- (vi) $\exists c > 0 : \psi''(t) \geq -ct^{-2}, \forall t > 0$

is called **NR function**.

Remark 2.1. Functions $\psi_1(t) = 1 - e^{-t}$, $\psi_2(t) = \ln(t+1)$ and $\psi_3(t) = \frac{t}{t+1}$ are NR functions. These functions are commonly used in NR theory (see [6]).

Remark 2.2. We consider function

$$\psi_q(t) = \begin{cases} \ln(t+1), & x \geq -0.5, \\ at^2 + bt + c, & x < -0.5, \end{cases}$$

where

$$a = -\frac{1}{2(\tau+1)^2}, \quad b = \frac{2\tau+1}{(\tau+1)^2}, \quad c = \ln(\tau+1) - \frac{3\tau^2+2\tau}{2(\tau+1)^2}, \quad \tau = -\frac{1}{2}.$$

Function $\psi_q \in \mathcal{C}^2(\mathbb{R})$ is NR function (see [6]). This function was used in numerical experiments (see section 4).

The key idea of NR methods is to transform problem (1) using a NR function ψ to the equivalent problem

$$\begin{cases} \text{minimize} & f(x), \quad x \in \mathbb{R}^n, \\ \text{subject to} & k^{-1}\psi(kc_i(x)) \geq 0, \quad i = 1, \dots, r, \end{cases} \quad (3)$$

where $k > 0$ is **scaling parameter**.

It is obvious (from definition 2.1) that problems (1) and (3) have the same admissible sets and also the same optimal sets. The Lagrangian for the equivalent problem (3) is given by the following formula

$$\mathcal{L}(x; \lambda, k) = f(x) - k^{-1} \sum_{i=1}^r \lambda_i \psi_i(kc_i(x)). \quad (4)$$

Algorithm 2.1. Initial approximations $x^0 \in \mathbb{R}^n$ and $\lambda^0 \in \mathbb{R}_{++}^r$ are given. Let $k > 0$ is a scaling parameter. We suppose that approximation $(x^s, \lambda^s) \in \mathbb{R}^n \times \mathbb{R}_{++}^r$, $s \in \mathbb{N}_0$, is known already. We find next primal-dual pair (x^{s+1}, λ^{s+1}) using the following formulas

$$\begin{aligned} x^{s+1} & : \quad \nabla_x \mathcal{L}(x^{s+1}; \lambda^s, k) = 0, \\ \lambda_i^{s+1} & = \quad \psi'(kc_i(x^{s+1})) \lambda_i^s, \quad i = 1, \dots, r. \end{aligned} \tag{5}$$

Theorem 2.1. For any given $(\lambda, k) \in \mathbb{R}_{++}^r \times \mathbb{R}_{++}$ there exists $\hat{x} \in \mathbb{R}^n$ such that

$$\mathcal{L}(\hat{x}; \lambda, k) = \min_{x \in \mathbb{R}^n} \mathcal{L}(x; \lambda, k).$$

Proof: see [5] page 206.

The main aim of NR is to improve properties of Lagrangian. The existence of the unconstrained Lagrange minimizer is unknown in general case (dealing with classical Lagrangian L). However, according to theorem 2.1, the unconstrained minimizer of the Lagrangian \mathcal{L} always exists.

3 Primal-dual NR method with dynamic scaling parameter update

To obtain higher convergence rate of the method, we dynamically change the scaling parameter (see [7]). We define a function which measures the distance between approximation (x, λ) and solution (x^*, λ^*) .

Definition 3.1. Function $\nu : \mathbb{R}^n \times \mathbb{R}^r \rightarrow \mathbb{R}_+$, defined as follows

$$\nu(x, \lambda) = \max \left\{ \|\nabla_x L(x; \lambda)\|, -\min_{1 \leq i \leq r} c_i(x), \sum_{i=1}^r |\lambda_i c_i(x)| \right\}, \tag{6}$$

is called **the merit function**.

From first order optimality conditions it is obvious that

$$\nu(\hat{x}, \hat{\lambda}) = 0 \Leftrightarrow (\hat{x}, \hat{\lambda}) \in X^*.$$

We set the scaling parameter according to the formula $k = \nu(x, \lambda)^{-1/2}$. If a primal-dual sequence $\{(x^s, \lambda^s)\}_0^{+\infty}$ tends to (x^*, λ^*) , then $\nu(x^s, \lambda^s) \rightarrow 0^+$. Hence also $k_s \rightarrow +\infty$ when $s \rightarrow +\infty$.

Newton's method with step length (e.g. backtracking line search algorithm) is used to solve nonlinear equations (5). Consequently, one step of PDNRD method consists of solving one or several primal-dual systems of linear equations and the update of the scaling parameter.

4 Chord problem

We consider a problem

$$\min_{u \in \mathcal{K}} \mathcal{J}(u), \tag{7}$$

where

$$\mathcal{J}(u) = \frac{1}{2} \int_0^1 \|u'(t)\|^2 dt - \int_0^1 u(t)^T f(t) dt,$$

$$\mathcal{K} = \left\{ u \in (H_0^1(0; 1))^2 : u_2(t) \geq 0, \forall t \in (0; 0.5), \|u(t)\| \leq 1.4, \forall t \in (0.5; 1) \right\},$$

$$f(t) = (36\pi^2 \sin 6\pi t, -4\pi^2 \sin 2\pi t)^T.$$

Minimization problem (7) describes loaded chord fixed at the endpoints that is partially above the plain and partially inside the cylindrical tube (see figure 1). Function $u(t)$ is the chord deflection. This problem is described and solved by means of an interior-point algorithm in [3].

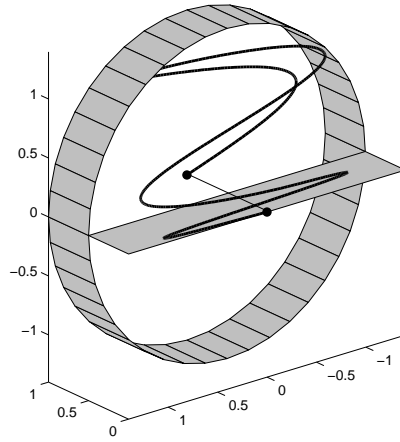


Figure 1: The chord deformation.

Solution: First, the finite element approximation is used to transform the original problem (7) to the following problem

$$\begin{cases} \text{minimize} & \frac{1}{2}x^T Ax - x^T b, \quad x \in \mathbb{R}^n \\ \text{subject to} & g_i^2 - x_{i+m}^2 - x_{i+2m}^2 \geq 0, \quad i = 1, \dots, m, \\ & x_i - l_i \geq 0, \quad i = 1, \dots, m, \end{cases} \quad (8)$$

where $n = 3m$ is the number of variables, $A \in \mathbb{R}^{n \times n}$ is symmetric and positive definite, $b \in \mathbb{R}^n$, $g \in \mathbb{R}_+^m$, $l \in \mathbb{R}^m$. This is a convex programming problem so we can use NR approach to solve it. Function ψ_q was used to rescale the conditions and subsequently we obtain the equivalent problem.

The chord problem was solved using PDNRD method. Computations were performed in MATLAB on PC Intel Pentium (1.7 GHz) with 1GB RAM. The number of iterations (*iter*), the number of solutions of the primal-dual system (*PD*) and the solution time in seconds (*time*) are reported in table 1. The main result from table 1 is non-increasing number of iterations and number of solutions of primal-dual system while increasing the number of variables.

n	r	$iter/PD/time$
64	32	6/14/0.203
128	64	6/12/0.219
256	128	4/10/0.532
512	256	4/12/3.094
1024	512	3/6/9.578
2048	1024	4/7/62.375
4096	2048	4/9/553.481

Table 1: Solution of the chord problem for different choices of n using PDNRD method with parameters $k_{init} = 2 \cdot 10^5$, $\omega = 10$, $\sigma = 10^5$, $\theta = 0.4$, $q = 0.5$, $\eta = 0.01$, $\varepsilon = 10^{-6}$.

5 Conclusion

PDNRD method was described and numerical experiments with this method were made. It was made out that increasing the number of variables in a problem has not a consequence in increasing the number of solutions of primal-dual system. This fact supports the applicability of PDNRD method on problems of arbitrary size. The performance of PDNRD method can be compared with an interior-point algorithm, which was also used to solve quadratic programming problems with quadratic constraints (see [3]).

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APPLICATION OF MODELS WITH AUTOREGRESSIVE VARIABLES FOR METHANE HAZARD FORECASTING IN HARD COAL MINES

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Abstrakt: In the article a manner of forecasting the methane-bearing capacity of a longwall in a coal mine has been presented, which allows taking appropriate methane hazard preventive measures. Forecasting models contain autoregressive variables. The parameters of these models are estimated by the classic and general methods of least squares or by the instrumental variables method. A manner of selecting an appropriate method to estimate the forecasting model parameters has been presented.

Introduction

Methane hazard in Polish hard coal mines is one of the most common natural threats. With an increasing depth of mining, the hazard increases its range, appearing also in mines which until recently were non-methane ones. Almost all workings where coal is mined are so-called longwalls.

The worked-out parts of a coal seam are most frequently removed by the so-called roof fall, which means that outside the wall support the rock lying over the seam breaks, thus filling the space left by the mined coal and formed a result of rock collapse. Rock layers lying over the roof fall bend and crack in big slabs or only bend. In the seam and its vicinity, that is, in rock layers lying over and under the worked-out seam a relaxed zone is formed, in which pressure is lower than it might be expected on the basis of the depth of the bedding of the considered rock mass point.

Apart from coal seams to be mined, a rock mass contains coal seams or layers which are not suitable for mining. They are most often described as off-balance seams.

Methane is mainly contained in coal seams and layers in which it is bound by a coal skeleton by means of intermolecular forces, which is referred to as adsorption.

A change in methane physical parameters, for example a change in pressure, causes a change in the amount of the sorbed methane. Methane transition from the sorbed state to the free one is called desorption.

The mining of a seam results in methane release from the mined coal and the occurrence of the desorption phenomenon in the whole relaxed zone. Due to a difference between methane pressure in the deposit and atmospheric pressure in the workings and in the exploited part of the seam, methane flows to the workings, thus creating a risk of methane ignition, explosion

or the formation of an atmosphere which is unsuitable for breathing because the content of oxygen is too low. Mining in the conditions of methane hazard requires methane preventive measures. In order to appropriately adjust methane prophylactics to the degree of hazard, it is advisable to use a short-term methane hazard forecast, based on continuous automatic measurements of methane concentration. The further part presents the principles of creating a statistical model for forecasting the amount of methane released into the longwall area.

Forecasting model creation

The manner of creating a forecasting model has been presented on the basis of continuous measurements taken by means of a telemetric system in the vicinity of longwall 160 in coal seam 315, which is located in the Mining Enterprise „Silesia”. The measurements were used to calculate the mean daily concentration of methane as well as the mean daily methane-bearing capacity of the longwall area (the mean amount of methane released in a minute). Methane-bearing capacity values are a time series. Measurement data also included the volume of air flowing through the longwall area as well as the daily output and longwall progression. The measurements were taken for 319 days, from 19th April 2012 to 3rd March 2013. Daily fluctuations of the amount of methane released into the workings are influenced by many factors, among which only some are measurable. One of such factors, important for the mine’s activity, is daily output per face. Due to the formation of a relaxed zone, which is a time-dependent phenomenon, the computing model of the average methane-bearing capacity of the longwall area on a particular day has been presented in a form of linear equation of two variables, the output on the considered day and the preceding day

$$M(t)=a_1+a_2W(t)+a_3W(t-1)+u(t) \quad (1)$$

where a_0 , a_1 , a_2 – equation parameters, u – random component, t – subsequent day of measurements ($t=1, 2, \dots, 319$), $W(t)$ – output in subsequent days, $W(t-1)$ – output on the day preceding the analysed one.

The programme for statistical calculations GRETL [5] was used to calculate the parameters of model (1), which are presented in Table 1. The significance of the parameter was defined on the basis of Student’s Test („t-Student” column), and the probability of the parameter value zeroing has been presented in the column „Probability p ”. It was assumed that significant parameters were the ones whose level of significance reached $p \leq 0,05$.

Table 1. Model (1) parameters

Parameter	Parameter value	Standard parameter error	t-Student	Probability p
\hat{a}_1	13.0321	0.51609	25.2516	<0.00001
\hat{a}_2	0.00125898	0.000180532	6.9737	<0.00001
\hat{a}_3	0.00153	0.000180532	8.4750	<0.00001
Residual standard error	4.91	Corrected R^2		0.365
Correlation coefficient r	0.61	Residual autocorrelation coefficient γ		0.88

The conducted test revealed no co-linearity of variables. The probability value p indicates that both independent variables are significant. However, the results of calculations are unsatisfactory due to a big residual standard error, low determination coefficient and residual autocorrelation. Residual autocorrelation frequently increases errors related to the determination of model parameters’ estimators, as it increases their variances and co-variances. The use of so determined parameter estimators for the forecasting model leads to increased forecast errors.

Another consequence of residual autocorrelation is the occurrence of wide residual ranges having the same sign (Fig. 1).

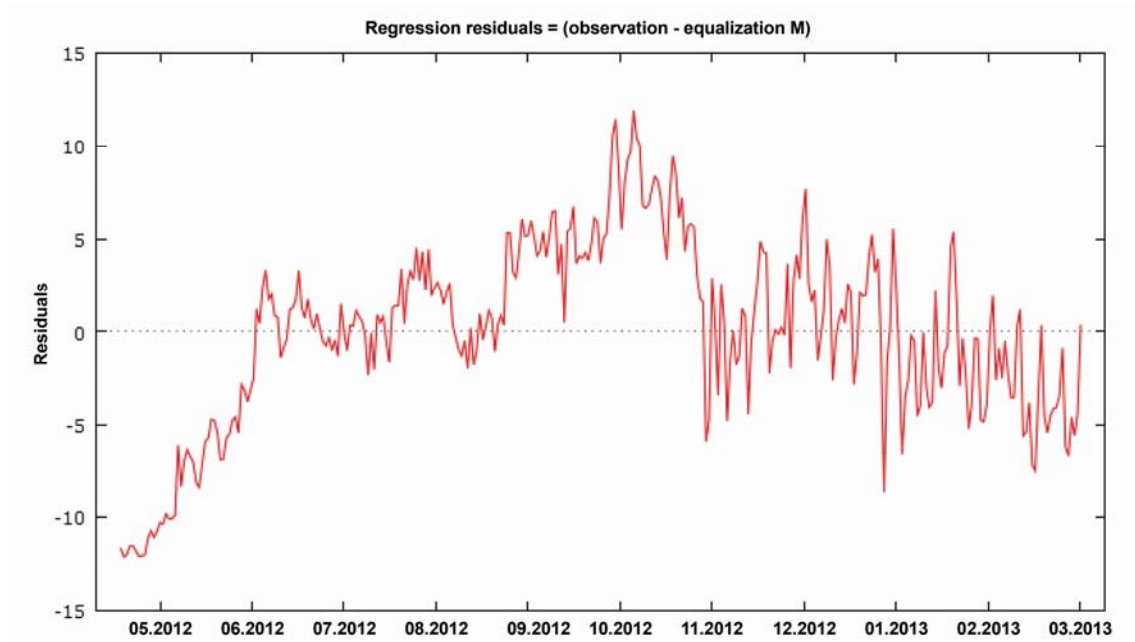


Fig. 1 A graph of model (1) residuals

Fig. 2 presents graphs of the measured and computed mean daily methane-bearing capacity.

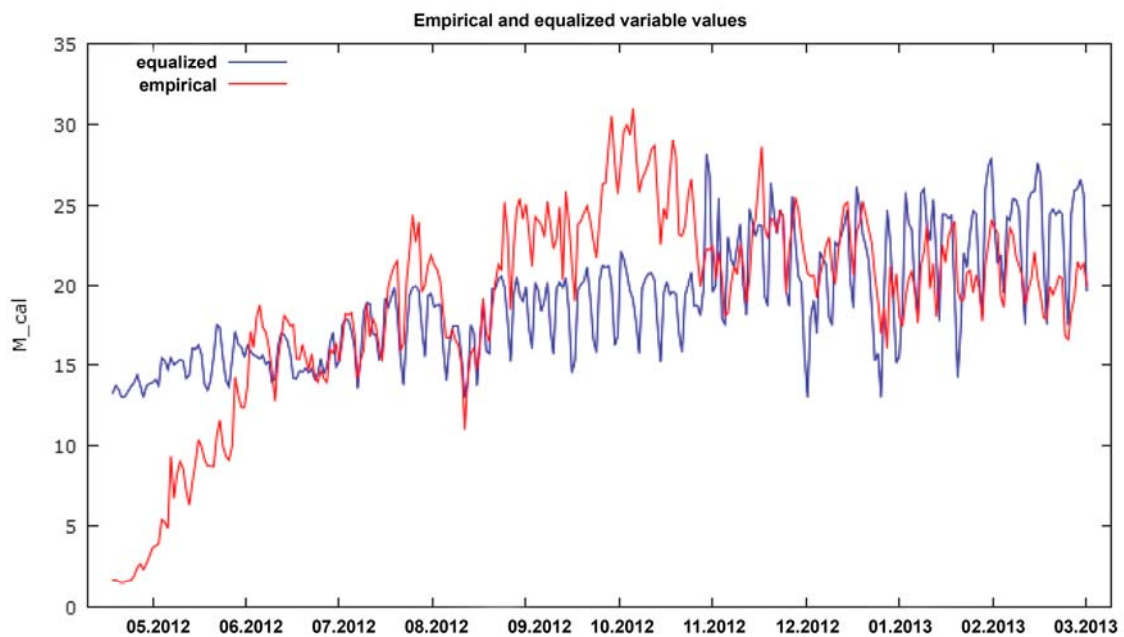


Fig. 2. Measured (empirical) and computed (equalized) values of the mean daily methane-bearing capacity of a longwall.

Residual autocorrelation can frequently be removed by introducing into the independent variables the so-called dependent variable delayed value, i.e. the value of independent variable having a lower index. In the considered model it would adopt the following form:

$$M(t)=a_1+a_2W(t)+a_3W(t-1)+ a_4M(t-1) +u(t) \quad (2)$$

where a_i – model coefficients ($i=1...4$), $M(t-1)$ – the value of methane-bearing capacity on day $t-1$. The remaining determinations as in formula (1).

The parameters of formula (2) can be estimated by the least square method. Their values have been presented in Table 2.

The results of parameter estimations indicate that the only significant variable is the delayed value of methane-bearing capacity. Output parameters are burdened with very big errors and are insignificant. Practice shows that it is not true. Big errors result from the autocorrelation of model residuals. The autocorrelation coefficient equals 0.83, therefore, the removal of autocorrelation by introducing a delayed variable ended in failure. However, it is noticeable that the correlation coefficient is very high while the residual standard error – very low.

Table 2. Model (2) parameters

Parameter	Parameter value	Parameter standard error	t-Student	Probability p
\hat{a}_1	2.71	0.191705	14.1363	<0.00001
\hat{a}_2	-4.42253e-06	4.72614e-05	-0.0936	0.92551
\hat{a}_3	6.41935e-05	4.84037e-05	1.3262	0.18573
\hat{a}_4	0.536786	0.0075499	71.0984	<0.00001
Residual standard error	1.19	Corrected R^2		0.96
Correlation coefficient r	0.98	Residual autocorrelation coefficient γ		0.83

If the classic least square method is applied when using a delayed variable, the estimation residuals are very often correlated with the delayed variable. In such a case the obtained values of the model parameter estimators are burdened and inconsistent. It is therefore necessary to check if such a situation occurs in the considered case.

The test conducted by means of GRETL programme revealed that in the analysed case the autocorrelation between $M(t-1)$ and $u(t)$ does not occur. Neither does the co-linearity of independent variables. For this reason, the general Cochrane-Orcutt method of least squares [3, 6] can be used to estimate the parameters of model (2). The real model adopts the following form:

$$M(t)=a_1+a_2W(t)+a_3W(t-1)+ a_4M(t-1) +\gamma u(t-1)+\varepsilon(t) \quad (3)$$

Where γ – residual autocorrelation coefficient u , $\varepsilon(t)$ - pure random component.

The parameter values of model (3) computed by means of GRETL programme, using the Cochrane-Orcutt method have been presented in Table 3.

Table 3. Model (3) parameters

Parameter	Parameter value	Parameter standard error	t-Student	Probability p
\hat{a}_1	1.61771	0.464439	3.4831	0.00057
\hat{a}_2	9.0598e-05	2.53796e-05	3.5697	0.00041
\hat{a}_3	0.000139381	2.53599e-05	5.4961	<0.00001
\hat{a}_4	0.561089	0.0132415	42.3735	<0.00001
γ	0.8707			
Residual standard error	0,63	Corrected R^2		0.99
Correlation coefficient r	0,99	Residual autocorrelation coefficient ε		-0.013

A graph of model residuals ε has been presented in Fig. 3, and a graph of measured and computed values (according to model 3) of the mean daily methane-bearing capacity is shown in Fig. 4.

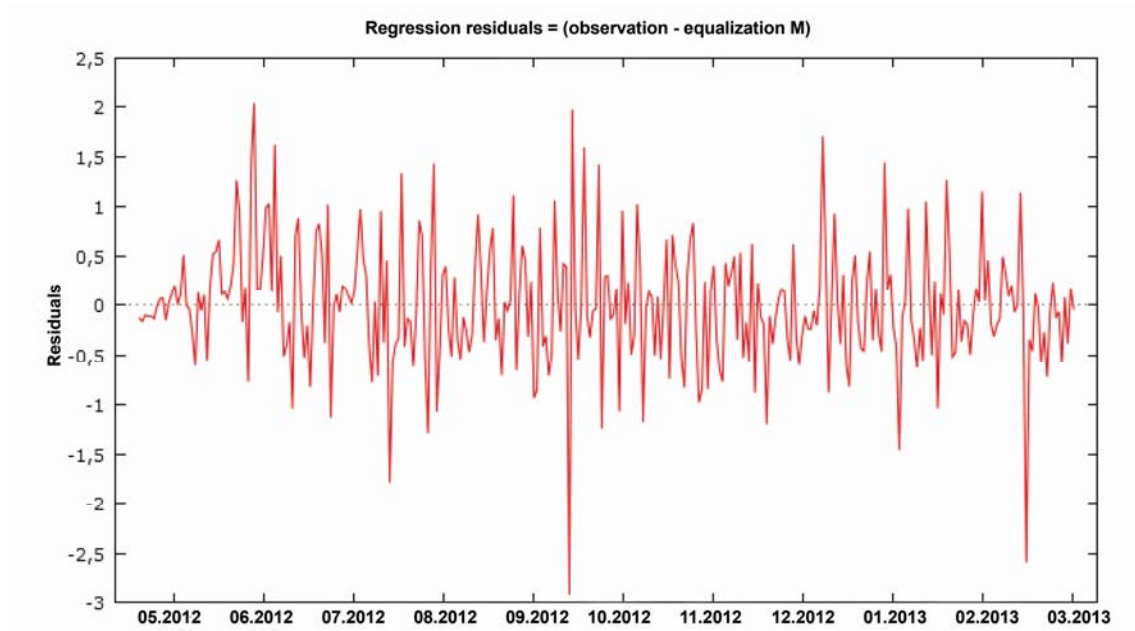


Fig. 3. A graph of model (3) residuals.

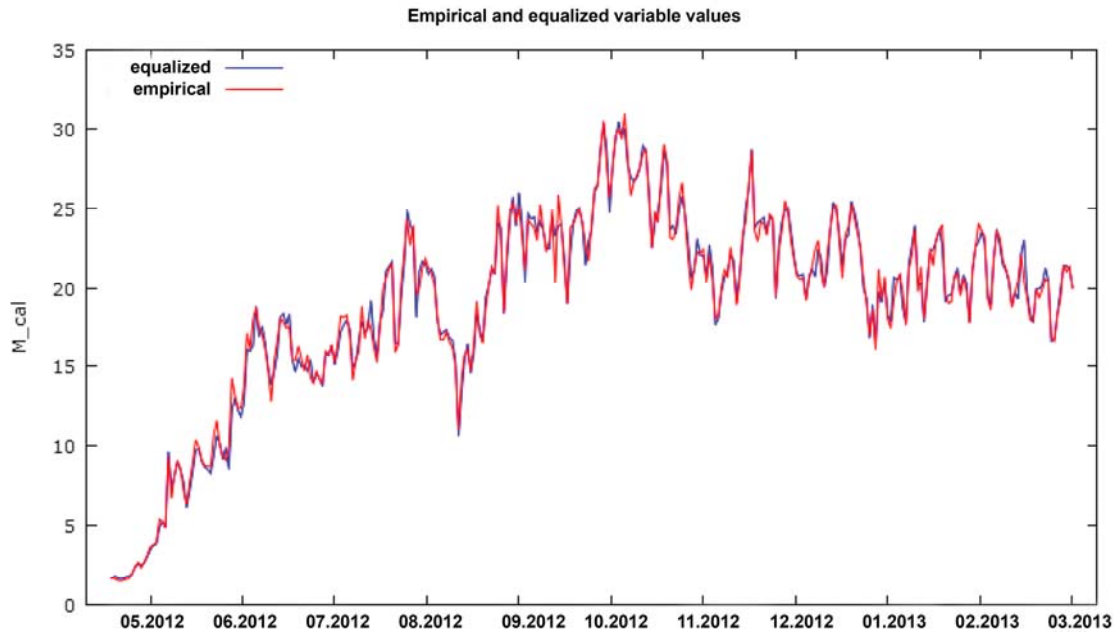


Fig. 4. Measured (empirical) and computed (equalized) values of the mean daily methane-bearing capacity of a longwall.

Model residuals do not show any correlations with $M(t-1)$ component (delayed methane-bearing capacity).

The so-developed model allows forecasting any time horizon T . A forecast for the first day of the period is an ordinary one. Assuming that the model has been developed on the basis of a sample having a numerical strength n , the prediction equation for an ordinary forecast is reflected in formula (4):

$$M(n+1)=a_1+a_2W(n+1)+a_3W(n)+ a_4M(n) +\gamma u(n) \quad (4)$$

The dynamic forecast will contain a delayed independent variable the value of which was a dependent variable in the previous step of the forecast. It is easy to check that the forecast equation will have the following form:

$$M(n+s)=a_1+a_2W(n+s)+a_3W(n+s-1)+ a_4M(n+s-1) +\gamma^s u(n) \quad (5)$$

If the Cochrane-Orcutt method does not bring the expected results, the parameters of equation (2) should be estimated by the maximum likelihood method or the instrumental variables method [4, 5, 6, 7].

The maximum likelihood method should be rejected due to a strong changeability of the process of methane release into the workings, which is the reason why methane-bearing capacity does not have a specific probability distribution.

The instrumental variables method requires additional variables, which should not be correlated with model residuals and, at the same time, should be correlated with a delayed variable in the best possible way. Simultaneous fulfilment of these conditions may be difficult to achieve. It should be remembered during the process of designing and observing. In the considered case such variables could be the longwall progression and methane concentration on the longwall area outlet.

The author of this article has rich, positive experiences in the forecasting of methane-bearing capacity (e.g. [1]) and methane concentration (e.g. [2]) by means of the above described methods.

Findings and conclusions

On the basis of the analyses conducted in this article, the following findings and conclusions can be formulated:

1. In order to increase work safety in methane mines it is advisable to take methane hazard preventive measures by introducing forecasts of longwalls' methane-bearing capacity, based on continuous measurements of methane concentration.
2. Application of the classic method of least squares may result in an estimation of the parameters of methane-bearing capacity forecasting model that is burdened with big errors, which results from the autocorrelation of model residuals.
3. One of the ways of eliminating the autocorrelation of residuals is introducing an autoregressive component in the model. Model parameters can be estimated by the classic method of least squares or one of the general methods of least squares, e.g. the Cochrane-Orcutt method.
4. In the event model residual autocorrelation occurs with an autoregressive variable, the estimated parameters are burdened and inconsistent. In such a case the instrumental variables method should be used to estimate the parameters.

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Oznaczenie gęstości hydromieszanin bez odsiarczania z dodatkiem spoiwa w postaci cementu

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Streszczenie: Artykuł prezentuje sposób wyznaczenia gęstości hydromieszanin bez odsiarczania z dodatkiem cementu w celu ustalenia możliwości ich wykorzystania do różnych gałęzi przemysłu według dokładnie określonych norm. Ze szczególnym uwzględnieniem możliwości wykorzystania w podziemnych technologiach górniczych .

Abstract: This paper presents the method of determining the density of hydromixtures without desulphurisation with the addition of cement in order to determine their eligibility for the various industries according to well-defined norm. With particular reference to the use in underground mining technologies.

1. Wprowadzenie.

W elektrowniach, w których do wytwarzania energii elektrycznej i ciepłej wykorzystuje się spalanie węgla, powstają stałe produkty spalania, czyli odpady paleniskowe (popioły i żużle) oraz odpady z odpylania gazów odlotowych. Ilość popiołów czy żużli jest zależna od jakości węgla i zawartości popiołów. Aby uzyskać 1 kWh energii elektrycznej zostaje wytworzone od 60 do 200 g odpadów. Dla rozwiązania tego problemu tworzone są różne technologie , które umożliwiają funkcjonowanie przemysłowi energetycznemu wykorzystując ten odpad jako surowiec, w procesie odzysku. Do dziedzin przemysłu w których wykorzystywanie odpadów ma największy udział należy zaliczyć: geotechnikę, budownictwo, a w niektórych przypadkach nawet rolnictwo, czy przemysł tworzyw sztucznych [1].

Istotnym odbiorcą odpadów paleniskowych jest górnictwo, które wchodzi w skład wspomnianej wyżej geotechniki.

Na wzrost wykorzystywania odpadów pochodzących z elektrowni istotny wpływ ma opanowywanie coraz to prostszych i tańszych technologii odzysku odpadów paleniskowych w górniczych wyrobiskach jak również użytkowe właściwości wytwarzanych mieszanek tych

odpadów. W górnictwie, dzięki specjalnym technologiom, wykorzystujemy odpady energetyczne najczęściej do profilaktyki pożarowej, wzmocnienie górotworu, podsadzanie zbędnych wyrobisk, czy uszczelniania górotworu. Odpady oraz ich mieszaniny przeznaczone do wykorzystania w górnictwie powinny być zgodne z zalecanymi wymaganiami normowymi oraz przepisami bezpieczeństwa pracy [2].

Sposób oznaczenia gęstości wykonuje się za pomocą metody pikometrycznej, dokonuje się ważenia masy próbki mieszaniny popiołowo - wodnej o danej objętości. Próbkę mieszaniny popiołowo - wodnej waży się w specjalnym naczyniu zwanym pikometrem, wykonanym z materiału nieporowatego. Znana jest masa naczynia[4,5].

Ważenia dokonuje się na wadze laboratoryjnej. Do wyznaczenia gęstości stosuje się wzór:

$$\rho = \frac{m - m_1}{V} \left[\frac{\text{kg}}{\text{m}^3} \right]$$

gdzie:

m - masa próbki wraz z naczyniem miarowym wyrażaną w [kg],

m₁ - masa suchego naczynia miarowego wyrażaną w [kg],

V - objętość zajmowana przez próbkę w naczyniu miarowym wyrażaną w [kg]

2. Oznaczenie gęstości mieszaniny.

Dla zadanych rozlewności 160, 200 i 240 mm wyniki badań oznaczenia gęstości mieszanin wodno-popiołowych sporządzonych na bazie popiołu bez procesu odsiarczania, i dodatku cementu w ilości 2,5; 5; 10 oraz 15% przedstawione są w tabeli 2.1 .

Tabela 2.1					
Wyniki badań oznaczenia gęstości mieszanin popielowo-wodnych sporządzonych na bazie popiołu bez procesu odsiarczania oraz cementu w ilości 2,5; 5; 10 oraz 15%					
Oznaczenie mieszaniny	Popiół	Cement	Rozlewność		Gęstość
			(+/- 5mm)		
	%	%	mm		[Mg/m ³]
1	97,5	2,5	160	159	1,55
2			200	197	1,53
3			240	240	1,499
4	95	5	160	162	1,56
5			200	197	1,536
6			240	237	1,5
7	90	10	160	165	1,575
8			200	196	1,54
9			240	244	1,51
10	85	15	160	165	1,58
11			200	196	1,55
12			240	240	1,53

Na podstawie uzyskanych wyników badań w zakresie stosowanych rozlewności można zauważyć, iż:

- wzrost udziału cementu w badanych mieszaninach o danej rozlewności nie wpływa znacząco na zmianę ich gęstości,
- wzrost rozlewności badanych mieszanin o danym udziale cementu powoduje obniżenie ich gęstości.

3. Wnioski.

Uwzględniając wymagania zalecanej w omawianej tematyce normy PN-G-11011:1998 [3] oraz biorąc pod uwagę otrzymane wyniki badań laboratoryjnych można określić minimalny udział cementu oraz zakres rozlewności hydromieszanin do zastosowania w podziemnych technologiach górniczych. Wielkości te przedstawione są w tabeli 3.1.

Tabela 3.1		
Wymagany udział cementu oraz rozlewność hydromieszanin przeznaczonych do zastosowania w podziemnych technologiach górniczych.		
Technologia górnicza	Udział cementu	Rozlewność
Doszczelnianie zrobów zawałowych	min. 2,5%	160-240mm
Podsadzka zestalana w górnictwie węglowym	-	-
Wypełnianie pustek i wyrobisk	min. 10%	160-200mm
Wykonywanie korków oraz pasów podsadzkowych	-	-
Izolacja pól pożarowych	min. 2,5%	160mm
	min. 10%	200mm
Iniekcja skał porowatych i luźnych	min. 2,5%	160mm
	min. 10%	200mm

Jak wynika z przedstawionych w tabeli 3.1 wielkości, przebadane w pracy hydromieszaniny w zakresie rozlewności 160-240mm przy udziale cementu do 15% nie spełniają określonych kryteriów i nie mogą być zastosowane do podsadzki zestalającej oraz korków i pasów podsadzkowych.

Aby hydromieszanina sporządzona na bazie popiołów mogła być wykorzystana w technologii doszczelniania zrobów powinna w swoim składzie posiadać minimalny udział cementu 2,5% oraz charakteryzować się rozlewnością w zakresie 210-240mm.

By możliwe było wykorzystanie hydromieszanki do wypełniania pustek i wyrobisk minimalny udział cementu powinno wynosić co najmniej 10% przy rozległości 160-200mm.

W technologii izolacji pól pożarowych przy rozległości 160mm minimalny udział cementu wynosi co najmniej co najmniej 2,5% natomiast przy rozległości 200mm wartość cementu musi osiągnąć poziom minimum 10%.

Ostatnia rozpatrywana technologia iniekcji skał porowatych i luźnych charakteryzuje się odpowiednio minimalnym udziałem cementu 2,5% przy rozległości 160mm oraz 10% przy rozległości 200mm.

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