BAKHVALOV, L.A. and TEYMENSON, I.E. Forecasting algorithms of production and consumption dynamics of world countries resources on the base of Kondratyev's cycles. *Application of Computers and Operations Research in the Minerals Industries,* South African Institute of Mining and Metallurgy, 2003.

Forecasting algorithms of production and consumption dynamics of world countries resources on the base of Kondratyev's cycles

L.A. BAKHVALOV and I.E. TEYMENSON
Moscow State Mining University, Moscow, Russia

Irrational usage of mineral commodities leads to depletion of natural resources and various ecological violations in natural environment. Fulfilment of a number of measures and strategic decisions by given problems requires a correct forecast of trends of social-economic systems.

For solving the task of long-term forecasting special procedures, considering Kondratyev's big cycles of world conjuncture, have been embedded into algorithms of unknown parameters identification and recovering of factors of different countries mineral resources production and consumption models.

In the paper the classification of long cycles types, existing forecasting algorithms on the basis of Kondratyev's '*long waves*' or '*K-waves*' and the modified algorithm, developed by us, which allows to reduce time and financial expenses and to improve the forecast quality, are presented. Furthermore, the article includes several forecasts of mining branch corrected models factors, received by us, permitting complex prognosis of economic and social development of different scale and control level systems.

In the paper workability of proposed forecasting algorithms on the base of '*K-waves*' and adequacy of created models to researched processes are proved.

Introduction

In many countries irrational usage of mineral commodities or a wasteful attitude to Earth's resources is observed. It leads to exhaustion of natural resources and ecological violation owing to an enormous quantity of mining-production industry waste.

To avoid an irrational usage of resources and a possibility of ecological violations the following measures are required:

- providing full extraction of valuable components from worked-up fields, eliminating or reducing to the minimum wastage of mineral commodities production, refining and transportation
- intensifying exploration of non-renewable resources reserves, including usage of various huge world ocean resources, searching for new alternative sources of raw fuel and energy.

Correct strategic decisions on these matters are impossible without planning and forecasting social-economic processes. Furthermore, to make these strategic decisions it is necessary to complete a long-term forecasting of economic development for each country and the world as a whole 30–100 years forward with a given accuracy[1].

In papers[2-4], presented at international symposia earlier, it was proposed and proved the structure of mining branch dynamics models, developed by us, suggested identification algorithms for developed models unknown parameters which considered non-observable trajectories on the basis of Marquardt's method and least squares method (LSM). Models created allow forecasting for 1–2 years with an error of 5–15 per cent for most factors and for 5–10 years with an error, equal to 10–20 per cent. Additionally, obtained results had shown the accuracy of recovering non-observable trajectories with maximum deviations from real values within 10–15 per cent, proving, that partially or completely non-visible technological, mineral-raw indicators and social-economic processes can take place at factors forecasting.

However, analysing trends of the processes studied, we had collided with the problem, concerned with instability of forecasts for long time interval—30–50 years and more. This instability is explained by economic growth, which is a peculiarity of modern economic systems evolution in market conditions. Economic growth is not always stable; its rate fluctuates; it is interrupted and even changed during world and national crisis periods. Periodic fluctuations of growth rates, called economic cycles or waves, are observed in world economics. Long waves of about 50 years or big cycles of world conjuncture, discovered by Russian economist N.D. Kondratyev, are associated not only with growth rates. They are located in a conjuncture of prices, investments, trade and demographics.

Thus, to increase the quality of long-term forecasting, to correct and elaborate developed models, special algorithms of forecasting of mining branch factors dynamics on the basis of Kondratyev's long cycles have been introduced in them. Also it has increased the set of factors, characterizing mining industry and level of countries economic development, extended the time row of indicators and the number of countries, included in the complex model.

Kondratyev's 'long waves' and other theories of cycles

Theories which study cycles concerning parameters of time can be divided into three groups, and, accordingly, three types of cycles can be defined: '*reserves cycle*' (2–3 years), '*construction cycle*' (15–20 years), '*long waves*' (40–60 years). The eight main groups of '*long waves*' theories[5] are:

- Marxist theories (P. Bakkara, L. Fontviey, D. Gordon)
- Innovation theories (J. Schumpeter, S. Kuznets, G. Mehsh, J. van Duijn)
- Theory of over-accumulation in capital sector (J. Forrester)
- Theories concerned with manpower (K. Freeman)
- Prices theories (W. Rostow, B. Berry)
- Integration approach and monetary conceptions (J. Delbecke, P. Korpinen, R. Batra)
- Sociologic explanations and class struggle cycles (M. Olsen, S. Vibe)
- Theory of military cycles (J. Goldstain).

Outstanding Russian scientist and economist, Professor Nikolay Dmitrievich Kondratyev (1892-1938) in the middle twenty years of the 20th century discovered big cycles of conjuncture, which became known by the scientific world as Kondratyev's '*long waves*' or '*K-waves*'. Analysing the statistics by dynamics of cast iron and lead production, coal out-turn and consumption, average level of marketable prices, capital percentage, wage, external trade turn and other indicators of development in England, France, Germany and USA for 100–140 years, Kondratyev succeeded in defining two complete and one partial big conjuncture cycles with length of 48–60 years, on a par with 54–55 years.

Latest researchers have gone considerably further than Kondratyev in wave fluctuations statistic investigation by dynamics of inventions, basic innovations, economic development indicators, technics generations and directions changing, '*long waves*' influence on employment level, social processes, education, production and management organization, ecology, etc. But one thing remains indisputable: Kondratyev's contribution to the treasury of scientific knowledge consists in setting the problem of long-term cyclic fluctuations in development of economy and concomitant spheres of public life.

Existing methods of forecasting countries resources considering '*K-waves*'

At present there exist the large number of theories on the existence of big cycles or long waves and different forecasting techniques of world countries economic indicators considering methods of cycles of Kondratyev and his followers defining, as has been shown above. In this paper we shall pay attention, by our opinion, to main forecasting techniques considering Kondratyev's cycles:

- The defects method of N.D. Kondratyev includes the following steps[6]:
  - fulfilment of distinguishing some 'general trend' from analysed data rows. Exclusion is performed by division of 'general trend' into population;
  - interpolation of a curve in the form of an analytic formula not higher than 3rd order;
  - determination of a deviation of theoretic row from empiric one in the form of a curve, depicting the given row varying acceleration, for each time point;
  - definition of prognostic function of economic and social trends by residuals.
- The objective analytic forecasting method of S. Gubanov is divided by stages[7]:
  - statistic data interpolation, herewith the selection criterion of interpolation polynomial degree is the defects minimum and the procedure accuracy maximum
  - estimation of the corresponding orthogonal polynomial coefficients, and on this base—algebraic polynomial coefficients, i.e. determination of the analytically defined interpolation function
  - differentiation of the polynomial received for a transition to an acceleration function
  - integration by the interpolation formula, which allows to compare crisis phases by its absolute values and to determine a balance achievement in separate cycle bounds.
- The method of countries economic development forecasting, created by V.R. Okorokov on the base of the defects method and the objective analytic forecasting method, consists of the following steps[1]:
  - processing of input data (data are explored for reliability and homogeneity, data rows are transformed into a stationary form by distinguishing a trend component)
  - exploring of a row for a fluctuations presence, wherefore spectral analysis techniques are usually applied, which determine fluctuations, dominant by power
  - smoothing (filtration) of the processed row to remove short- and middle-term fluctuations from it
  - interpolation of the row by LSM with Chebyshev's polynomial; selection of a curve degree is calculated in dependency with row length and spectral analysis results
  - investigation of the interpolation curve by extremum for long cycles periodicity elicitation
  - extrapolation of the interpolation curve for an interval equal to '*long cycle*'
  - falling of the extrapolated row under reverse transformations for receiving initial indicators dimensionality.
- The method of analogy or parameters estimation of indicators of linear differential equations system, developed by S.M. Menshikov and L.A. Klimenko, includes[5]:
  - choosing of a model known by fluctuations physics and described by way of linear differential equations system
  - estimation of *a priori* coefficients values in the theoretical model designed
  - calculation of correlation estimates, showing reducing fluctuations with the period of 53,7 years
  - substitution of *a priori* coefficients by empiric ones in the model assigned.

Modification algorithm of resources forcasting considering '*K-waves*'

The following tasks for long-term forecasting of dynamic model factors of different countries mineral resources production and consumption have been set by us:

- insertion in the model of raw mineral and social-economic factors
- forecasting of interconnected mining branch factors and social-economic indicators

- recovering of partially or completely non-observable (non-measurable) trajectories or indicators for the purpose of its inclusion in a long-term forecasting algorithm
- decreasing of time and financial outlays at modelling and forecasting mining branch factors and social-economic indicators.

Neither existing nor shown above forecasting methods on the basis of Kondratyev's '*long cycles*' have not allowed the simultaneous solving of all tasks of recovering and forecasting mining branch models factors. Thus, on the basis of existing methods the modified algorithm of long-term forecasting of countries resources, considering '*K-waves*', has been developed. This algorithm allows to function in conditions of partially or completely non-observable trajectories.

Main stages of this algorithm are represented as follows:

1 Normalization of statistics for getting the same data sizes or arrangement of indicators to common units (percentage, tons, dollars etc.).
2 Scanning and removing of possibly mistaken segregate values in statistical data.
3 Determination of a required for forecasting quantity of missed data, so-called non-observable trajectories, for the purpose of its further recovery.
4 Subjective setting of a forecasting horizon for different indicators of mineral-raw resources and countries economics according to the rule, by which a forecasting horizon should not exceed 1/3 of a data volume for receiving high accuracy.
5 Modelling of processes of different countries resources production and consumption. In papers[2-4] it has been shown that for describing mining branch dynamics the following models classes can be used:

- Linear and non-linear discrete models of world countries resources dynamics:

$$x_s^l[n+1] = \sum_{i=1}^{q} b_{si} x_i[n], \qquad [1]$$

$$x_s^l[n+1] = \sum_{i=1}^{q} b_{si} x_i[n] + \sum_{i=1}^{q}\sum_{j=i}^{q} b_{sij} x_i[n] x_j[n] + \sum_{i=1}^{q}\sum_{j=i}^{q}\sum_{k=j}^{q} b_{sijk} x_i[n] x_j[n] x_k[n], \qquad [2]$$

where $x_s[n+1]$– the future value of the time row for the certain indicator, n = 1, 2, ..., N–years
$x_i[n]$, $x_j[n]$, $x_k[n]$ $x_i[n]$– values of the time row for certain indicators in the current year
b_{si}, b_{sij}, b_{sijk}– unknown parameters of the model.

- Linear and non-linear discrete dynamic models of countries resources increment.
- Linear and non-linear discrete models of world countries factors dynamics.
- Linear and non-linear differential models of countries resources production and consumption dynamics with non-observable trajectories.

6 For filling statistical skips, found at the stage 3, original algorithms (techniques), created by authors[2,3] for recovering partially or completely non-observable trajectories, have been used:

- For transition processes, most brightly expressed in unstable economics of separate countries, unknown parameters identification algorithm of differential equations system on the basis of LSM is used. The given algorithm had been considered earlier in paper[3], where non-observable trajectories can be represented as:

$$u_\sigma(t) = k_\sigma t^{\lambda\sigma} \exp^{(\mu\sigma t)}, \qquad [3]$$

where κ_σ, λ_σ, μ_σ—unknown parameters.

- For mixed processes (transitive and intransitive) are applied:
  - an algorithm of non-measurable parameters identification on the base of LSM with Chebyshev's orthogonal polynomials for recovering non-observable trajectories.

In general form the polynomial as an approximated function of partially or completely non-observable trajectories recovery can be represented in the next form:

$$U(t) = \sum_{j=1}^{P} z_j \Phi_j(t), \qquad [4]$$

where z_j—function coefficients
Φ_j—an approximated function
$j = 1,\ldots, P$.

A minimization functional for choosing coefficients and Chebyshev's polynomial degree is expressed by the following formula:

$$\delta(z_1,\ldots,z_P) = \sum_{i=1}^{T}\left(y_i - U(t_i)\right)^2 = \sum_{i=1}^{T}\varepsilon_i^2 = \min, \qquad [5]$$

where $\tilde{y}$—an experimental value of an explored dependent indicator
$\delta(z_1,\ldots,z_p)$—a functional of a deviation minimization y from U
$z_1,\ldots,z_p$—Chebyshev's polynomial coefficients.

Coefficients z_j from the expression [4] can be found as:

$$\overset{\frown}{Z} = \left(X^T X\right)^{-1} X^T \tilde{Y} = \Phi X^T \tilde{Y}. \qquad [6]$$

- an algorithm of parameters identification and recovering of non-observable trajectories on the basis of the Marquardt's method with procedure of Runge-Kutta IV integration.

The parameters identification algorithm on the base of the Marquardt's method had been briefly represented earlier[3]. There it was intended for getting estimations and recovery of non-observable indicators of mining branch models to forecast at short-term and middle-term time intervals. In the algorithm of countries resources long-term forecasting, considering '*K-waves*', the Marquardt's identification algorithm plays, from our point of view, quite another and more important role, than before. It is used for recovering missed and inexact data, i.e. for primary statistics preparation for analysing and forecasting. Therefore, in this paper the modified Marquardt's identification algorithm was introduced for the first time, where the integration procedure of Runge-Kutta IV provides greater accuracy of a non-measurable factors recovery.

An economic process is described by the system of differential equations:

$$dx_s / dt = \sum_{i=1}^{q} r_i\ \varphi_{si}(Z,U,X),$$
$$du_\gamma / dt = \sum_{i=1}^{q} b_i\ \psi_{\gamma i}(Z,U,X), \qquad [7]$$

where b, r—unknown parameters of differential equations system

$Z(t) = \{z_1(t), z_2(t),\ldots, z_\xi(t)\}$—controlling reactions

$U(t) = \{u_1(t), u_2(t),\ldots, u_\gamma(t)\}$—non-observable trajectories of the system

$X(t) = \{x_1(t), x_2(t),\ldots, x_s(t)\}$—measurable indicators of the system.

In Marquardt's identification method for coefficients estimation the functional is formed:

$$F(B)=\sum_{i=1}^{N}\sum_{s=1}^{z}\sum_{h=1}^{NT} w_{ish}\left(\tilde{X}_s(t_h)/Z_i(t)-\hat{X}_s(t_h/Z_i(t),B)\right)^2 \quad [8]$$

where w_{ish}—weighted coefficients for compensation of different dimension accuracy $X_s(t_h/Z_i(t))$

$\hat{X}_s(t_h/Z_i(t))$—experimental values, $i = 1, 2,\ldots, N$, $h = 1, 2,\ldots, NT$, $s=1,\ldots, z$

$\hat{X}_s(t_h/Z_i(t, B^0))$—trajectories, which are obtained by integration of equations system [7].

Using a theorem of continuous differentiation of differential equations decisions and Taylor's theorem for a searching process organization of functional minimum $F(B)$ near initial B^0, we have for each t_h:

$$\hat{X}_s(t_h/Z_i(t),B)\approx\hat{X}_s(t_h/Z_i(t),B^o)+\sum_{r=1}^{T}\left(d\hat{X}_s(t_h/Z_i(t),B)/db_r\right)*\left(b_r-b_r^o\right). \quad [9]$$

Substituting [9] into [8], and differentiating the expression got by Δb_l, we receive the equations system, which can be written in the matrix form as:

$$(A+\theta*1)*\Delta B=P, \quad [10]$$

where I—a square unit matrix by proportions $q \times q$

θ—a regularizing parameter, $0 \leq \theta \leq \infty$.

The iteration procedure for searching B^*, which minimize $F(B)$, looks like:

$$B^n=B^{n-1}+\Delta B^{n-1}. \quad [11]$$

The procedure for Runge-Kutta IV integration is expressed in the following form:

$$y_{n+1}=y_n+\Delta y_n,\ n=n+1, \quad [12]$$

where y_{n+1}—a new function value;

Δy_n—a function increment:

$$\Delta y_n=\frac{(k_1+2*k_2+2*k_3+k_4)}{6}, \quad [13]$$

where k1, k2, k3 and k4—coefficients, which can be calculated by formulas:

$$k_1=h*f(x_n,y_n),$$
$$k_2=h*f\left(x_n+\frac{h}{2},y_n+\frac{k_1}{2}\right), \quad [14]$$
$$k_3=h*f\left(x_n+\frac{h}{2},y_n+\frac{k_2}{2}\right),$$
$$k_4=h*f(x_n+h,y_n+k_3),$$

where h—an integration step.

7 Processing of statistics by distinguishing a trend component from statistical data.
8 Checking of factors for cyclical behaviour, i.e. exploring a row for the presence of fluctuations by means of spectral analysis techniques.
9 Division of factors, defining the world and separate countries conjuncture, with the help of the stage 8 at non-cyclical factors (scientific-technical advancement, demographic factors, natural resources consumption, reserves, etc.) and cyclical factors (production, export, import, stocks, prices, etc.).
10 Filtration of a row, processed at the stage 6, which is smoothed for removing '*reserves cycles*' (2–3 years), '*industrial cycles*' (7–11 years), '*construction cycles*' (15–20 years), and consideration of '*K-waves*' (40–60 years) without superposition and interferences from other cycles.
11 Construction of the optimum interpolation function by LSM with Chebyshev's polynomial or by Marquardt's technique with the integration procedure of Runge-Kutta IV.
12 Differentiation of the interpolation function obtained for a transition to the acceleration function, determination of all critical points and strict dating of all phases and interphasing transitions.
13 Investigation of the interpolation function, received at the stage 11, by extremum for 'long cycles' periodicity elicitation.
14 Integration by the interpolation formula for comparing crisis phases by its absolute value and determination of a balance achievement in separate cycles bounds. Critical points, found at the stage 12, also represent integration limits.
15 Extrapolation of the received analytic function for an interval, equal to the 'long cycle' period and established at stages 12, 13.
16 Reverse transformation of the extrapolated row for receiving initial indicators dimensionality.

Long-term forecasting by created algorithm considering '*K-waves*'

The modified algorithm of mining branch factors forecasting considering Kondratyev's '*long cycles*' was tested on dynamic models of different countries. Generalized criteria[4], characterizing development levels of raw mineral complexes, have been formed as the basis of statistics by more than 20 main minerals, from aluminium to zinc.

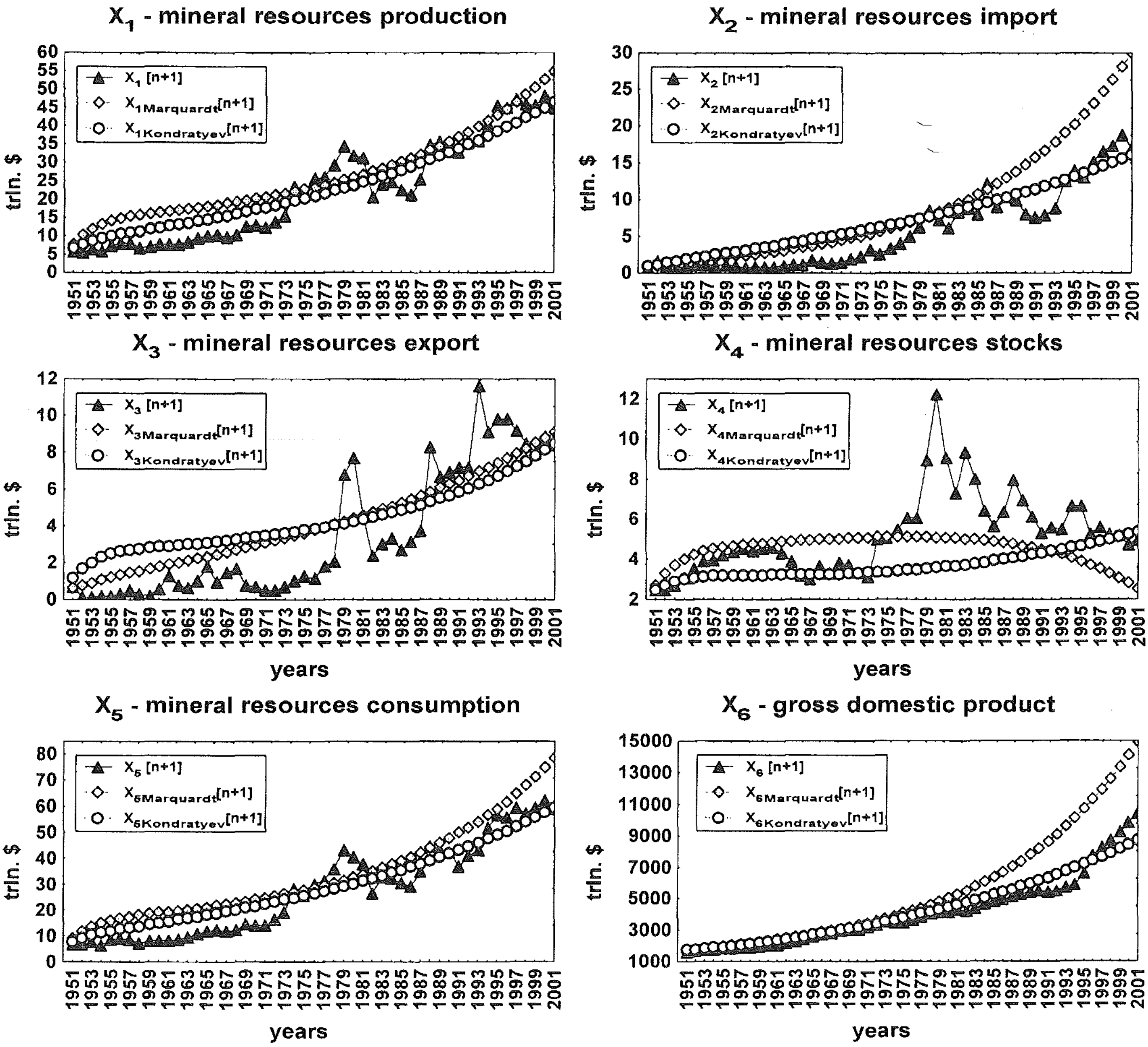
Because the statistic volume of dynamic model factors of different countries production and consumption resources is not less than 102 years (1900–2001)[8], and for social-economic and demographic factors is equal to 132 years (1870–2001)[9,10], an optimum forecasting horizon therefore totals from 34 to 44 years. Truncating the horizon, we have got the forecasting range from 30 to 50 years taking into consideration a possible widening of time intervals of indicators.

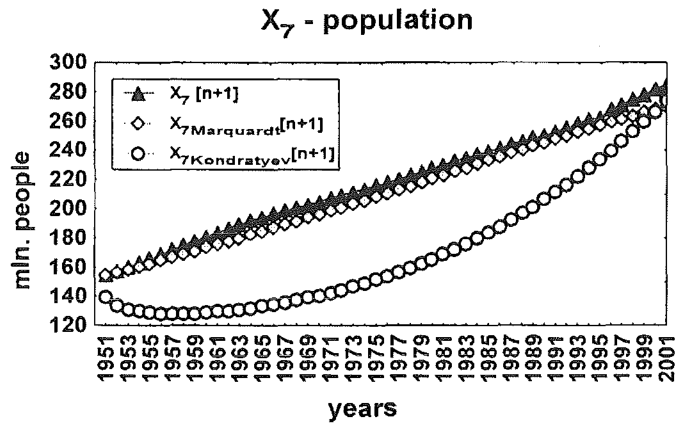
A verification of the suggested modified forecasting algorithm has been performed at following model example. The long-term forecasting of mining branch factors and social-economic indicators of USA dynamic model had been fulfilled from 1951 to 2001 applying the Marquardt's identification algorithm and the created modified forecasting algorithm on the base of Kondratyev's 'long cycles'. Comparative results of this model example are shown in Figure 1.

Long-term forecasting results from 2001 to 2050 are represented in Figure 2.

Conclusions

By applying the created modified algorithm of countries





Year	Error, percent	X1[n+1]	X2[n+1]	X3[n+1]	X4[n+1]	X5[n+1]	X6[n+1]	X7[n+1]
1951	Marquardt	*34.54*	*33.99*	*8.67*	*8.09*	*35.71*	*0.78*	*0.27*
	Kondratyev	*15.66*	*30.71*	*62.45*	*2.31*	*16.16*	*6.95*	*10.35*
1961	Marquardt	*119.81*	*304.81*	*49.75*	*8.41*	*134.14*	*15.16*	*4.38*
	Kondratyev	*66.58*	*410.78*	*130.16*	*26.89*	*89.57*	*13.23*	*29.64*
1971	Marquardt	*66.82*	*197.39*	*518.16*	*36.51*	*74.29*	*8.93*	*4.34*
	Kondratyev	*44.33*	*252.57*	*592.73*	*11.28*	*57.54*	*5.08*	*31.39*
1981	Marquardt	*14.60*	*15.42*	*0.29*	*44.17*	*10.08*	*23.25*	*3.02*
	Kondratyev	*21.31*	*10.98*	*4.28*	*60.12*	*17.11*	*7.61*	*26.60*
1991	Marquardt	*12.70*	*108.83*	*9.82*	*15.56*	*34.82*	*59.98*	*1.87*
	Kondratyev	*3.20*	*52.61*	*18.77*	*18.70*	*16.84*	*17.51*	*16.41*
2001	Marquardt	*21.77*	*76.30*	*8.31*	*49.13*	*31.62*	*43.31*	*5.25*
	Kondratyev	*3.02*	*5.38*	*0.58*	*8.19*	*0.59*	*16.50*	*3.91*

Figure 1. Comparison of mining branch factors and social-economic indicators forecasts from 1951 to 2001, received on the base of forecasting algorithms considering and not considering Kondratyev's 'long cycles'

resources production and consumption forecasting on the base of Kondratyev's 'long waves' a number of forecasts have been obtained: forecasts of natural resources factors; demographic forecasts; social and economic forecasts, etc.

Herewith it was brought out, that though a rising trend of development of explored social-economic processes is maintained till 2050 on a par with 150 per cent or $2^1/_2$ times by comparison with known data in 2001, but relational

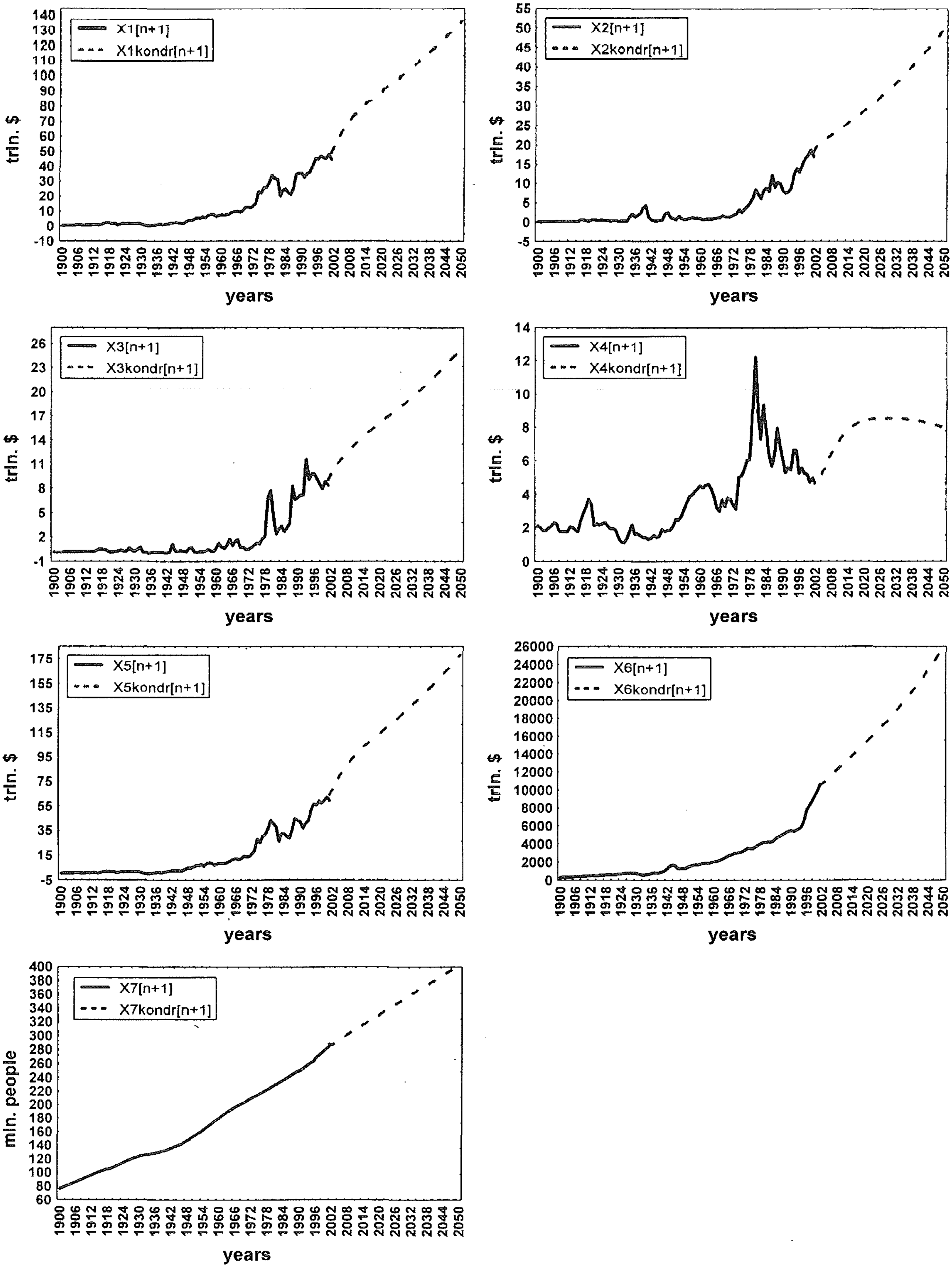


Figure 2. Forecast of USA dynamic model factors from 2001 to 2050

growth rates of explored factors in 21st century beside the second half of 20th century has been reduced approximately 5 times. This shows apparent understanding of mineral resources depletion by mankind and the transition of most countries all over the world from an extensive to an intensive production method.

Forecasting values, received in the model example, have attested that Marquardt's algorithm gives good results for most factors on the forecasting period of 30 years, but for 30–50 years the best results are obtained with the help of the created modified algorithm, which decreases the error of forecasting at 50 years approximately 15 times. The modified algorithm forecasting error at 50 years (up to 2001) in comparison with Marquardt's algorithm equals from 0.58 to 16.5 per cent for selected factors, indicative of the workability of the modified algorithm on the base of '*K-waves*', correspondence of econometric models to social-economic processes studied and opportunity of forecasting for long-term period.

On the basis of enhanced forecasting algorithms with using of '*K-waves*', the software for deriving short-, middle- and long-term forecasts of development strategy of mining branch factors dynamics for different world countries has been developed. This software uses Microsoft programming environment and databases, providing compatibility with most office applications, simplicity and convenience of using created programs by end user.

The performed formalization of main features of a social-economic systems functioning on the basis of Kondratyev's '*long waves*' has permitted to estimate the quality and effectiveness of accepted decisions by level of resources consumption and optimization, to forecast its possible positive and negative consequences and to use obtained appraisals for making appropriate strategic control decisions.

References

1. OKOROKOV, V.R. and NIKISHIN, E.S. Tsykly N.D. Kondratyeva y dinamika ekonomicheskogo razvitiya Rossii (N.D. Kondratyev's cycles and dynamics of Russia's economic development). *Uchenye zapisky sektzii ekonomiki MANVSH.* Sankt-Petersburg, SPbGUEF, 2000.
2. BAHVALOV, L. and TEIMENSON, Y. Decision making risk at identification's algorithms of dynamic parameters of economic systems with non-visible trajectories. *Risk Analysis II. Proceedings of 2nd International Conference on Computer Simulation in Risk Analysis and Hazard Mitigation*, Bologna, Italy. Prof. Brebbia, C.A. (ed.). Ashurst Lodge, WIT Press, 2000. vol. 1, pp. 235–244.
3. BAHVALOV, L.A. and TEIMENSON, Y.A. Identification algorithms of world countries mineral resources production and consumption dynamics models. *APCOM* 2001. *Proceedings of the 29th International Symposium on Computer Applications in the Mineral Industries*, Beijing, China. Profs. Xie, H, Wang, Y, and Jiang, Y (Eds). Lisse, A.A.Balkema Publishers, 2001. vol. 1, pp. 735–740.
4. PUCHKOV, L., BAHVALOV, L., and TEIMENSON, Y. Mathematical models of mining industry influence on countries' macroeconomics. *APCOM*'99. *Proceedings of the 28th International Symposium on Computer Applications in the Mineral Industries*, Golden, USA. Prof. Dagdelen, K (ed.). Colorado School of Mines. vol. 1, 1999. pp. 711–718.
5. MENSHIKOV, S.M. and KLIMENKO, L.A. Dlinnye volny v ekonomike. Kogda obschestvo menyaet koju (Long waves in economics. When society changes skin). Moscow, Mejdunarodnye otnosheniya, 1989.
6. KONDRATYEV, N.D. Problemy ekonomicheskoy dinamiki (Problems of economic dynamics). Moscow, 1989. *Ekonomika.*
7. GUBANOV, S. Tsiklichnost—forma krizisnosti (Cycles– the form of crisis). *Ekonomist*, no. 1, 2000.
8. World Mineral Statistics/Production: Exports: Imports. London, British Geological Survey (BGS). Natural Environment Research Council: Her Majesty's Stationery Office, 1897–2001 years.
9. MADDISON, A. Monitoring the World economy 1820–1992. Paris, Development Centre of the Organization for Economic Co-operation and Development (OECD), 1995.
10. MADDISON, A. The world economy: a millennial perspective. Paris, Development Centre of the Organization for Economic Co-operation and Development (OECD), 2001.