IRSTI 06.81.30

Borodin A.I.[1], Streltsova E.D.[2], Yakovenko I.V.[3]

[1]d.e.s., Professor, Plekhanov Russian University of Economics, Russia, Moscow, e-mail: aib-2004@yandex.ru
[2]d.e.s., Professor, e-mail: el_strel@mail.ru
[3]PhD, Associate Professor, e-mail: iranyak@mail.ru
[2,3]M.Platova South Russian State Technical University, Russia, Novocherkassk

MATHEMATICAL MODELLING OF FINANCIAL STABILITY OF PROCESSES OF THE COMPANY WORKING UNDER RISKS

The article proposes a mathematical model for estimating the probability of bankruptcy of a firm, existing under condition of uncertainty and targeted critical levels of its financial state. The subject of research is a large logistic company, working under risks of the international market. The article aims to examine the problems of a company's financial strength in the light of a breach in its work under condition of uncertainty and the issue of the irrational usage of its financial resources during a certain period of time. The data is analyzed by applying the process of a resource withdrawal from the resource container with linear trend and perturbations common for such a case. The advantage of this model is that it allows both to conduct the analytical research and to perform the modeling experiments. The data analysis over the period from 2014 to 2018 exposed the company profitability staggers caused by structure and value changes of the financial flows and, as a result, the bankruptcy risk. In this case it is necessary to develop a model, determining the probability of reaching the zero level of profitability using the business activity array data in consideration of the detected risks.

Key words: financial stability, risks, enterprise, mathematical modeling, bankruptcy, financial condition.

Бородин А.И.[1], Стрельцова Е.Д.[2], Яковенко И.В.[3]

[1]э.ғ.д., профессор, Г.В. Плеханов атындағы Ресей экономикалық университеті,
Ресей, Мәскеу қ., e-mail: aib-2004@yandex.ru
[2]э.ғ.д., профессор, e-mail: el_strel@mail.ru [3]PhD, доцент, e-mail: iranyak@mail.ru
[2,3]М.И. Платов атындағы Оңтүстік Ресей мемлекеттік политехникалық университеті, Ресей, Новочеркасск қ.

Тәуекелдік жағдайында жұмыс істейтін компания үрдістерінің қаржылық тұрақтылығын математикалық модельдеу

Мақалада белгісіздіктің және қаржылық жағдайдың мақсатты сыни деңгейлерінің жағдайында жұмыс істейтін компанияның банкротқа ұшырау ықтималдығын бағалау үшін математикалық модель ұсынылады. Зерттеу пәні халықаралық нарықтық тәуекелдер жағдайында жұмыс істейтін ірі логистикалық компания болып табылады. Мақаланың мақсаты – белгісіздік жағдайда компания жұмысына кедергі келтіретін және белгілі бір уақыт кезеңінде оның қаржы ресурстарын тиімсіз пайдаланудан туындаған компанияның қаржылық күштерінің мәселелерін зерттеу. Деректер ресурстық контейнерден ресурстарды алу үрдісін сызықтық үрдіс және осындай жағдайға тән наразылықтарды қолдану арқылы талданады. Бұл модельдің артықшылығы – оны пайдаланып аналитикалық та, модельдік те зерттеу жүргізу мүмкіншілігі бар. 2014-2018 жылдар аралығындағы деректерді талдау қаржы ағымдарының құрылымы мен құндылығының өзгеруіне, нәтижесінде банкрот болу тәуекелінің пайда болуына байланысты компанияның кірістілігінің өзгеруін көрсетті. Бұл жағдайда анықталған тәуекелдерді ескере отырып, іскерлік белсенділіктің деректерін пайдаланып, кірістіліктің нөлдік деңгейіне жету ықтималдығын анықтайтын үлгі әзірлеу қажет.

Түйін сөздер: қаржылық тұрақтылық, тәуекелдер, кәсіпорын, математикалық модельдеу, банкроттық, қаржылық жағдай.

Бородин А.И.[1], Стрельцова Е.Д.[2], Яковенко И.В.[3]

[1]д.э.н., профессор, Российский экономический университет имени Г.В. Плеханова, Россия, г. Москва, e-mail: aib-2004@yandex.ru
[2]д.э.н., профессор, e-mail: el_strel@mail.ru [3]PhD, доцент, e-mail: iranyak@mail.ru
[2,3]Южно-Российский государственный политехнический университет имени М.И. Платова, Россия, г. Новочеркасск

Математическое моделирование финансовой устойчивости процессов компании, работающей в условиях риска

В статье предложена математическая модель для оценки вероятности банкротства фирмы, существующей в условиях неопределенности и целевых критических уровней ее финансового состояния. Предметом исследования является крупная логистическая компания, работающая в условиях рисков международного рынка. Целью статьи является рассмотрение проблем финансовой мощи компании в свете нарушения ее работы в условиях неопределенности и проблемы нерационального использования ее финансовых ресурсов в течение определенного периода времени. Данные анализируются путем применения процесса извлечения ресурса из контейнера ресурсов с линейным трендом и возмущениями, общими для такого случая. Преимущество этой модели заключается в том, что она позволяет проводить как аналитические, так и модельные исследования. Анализ данных за период с 2014 по 2018 год выявил колебания прибыльности компании, вызванные изменениями структуры и стоимости финансовых потоков и, как следствие, риском банкротства. В этом случае необходимо разработать модель, определяющую вероятность достижения нулевого уровня рентабельности с использованием данных массива бизнес активности с учетом обнаруженных рисков.

Ключевые слова: финансовая устойчивость, риски, предприятие, математическое моделирование, банкротство, финансовое состояние.

Introduction

The development, study and adaptation of flexible models analyzing and perfecting the market tendencies and the financial flows has always been an important aspect in the economic forecasting theory. This scientific field becomes especially important in the post-crisis period. In the terms of market balance recovering well time detection and minimization the full liquidation of the negative financial tendencies is drastically important both inside of the single company and the entire market (Kalashnikov, 1996).

European and American methodological-theoretical systems of bankruptcy probability and financial stability modeling are based on the researches of Altman (1968), Ohlson (1980) and Zorin (2003) whose works still play the foundational role in the enterprise financial stability analyzing.

Among the Russian authors it is hard not to mention the works by A.A. Novoselov (2001), Munjishvili (2014), etc. These works mainly focus on such financial risk analytical methods like Lundberg inequation, Kramer method, Sparre-Andersen risk models, Poisson process.

As a rule, the models designed to estimate the bankruptcy probability of a company are demonstrated by the example of insurance companies operating as an economic entity in which the collective risk as a financial stability indicator can be clearly shown and characterized (Micel, 2013). However, the methods used to analyze financial and statistic indicators of insurance company performance have a drawback: they do not consider the macroeconomic risks, affecting financial stability of companies operating on the international market (Telipenko, 2014).

Basic results

The article aims to examine the problems of a company's financial strength in the light of a breach in its work under condition of uncertainty and the issue of the irrational usage of its financial resources during a certain period of time. The data is analyzed by applying the process of a resource withdrawal from the resource container with linear trend and perturbations common for such a case. The advantage of this model is that it allows both to conduct the analytical research and to perform the modeling experiments.

The company under study is a large logistic provider on the international market. One of its major activities is delivering the imported goods to Eastern Europe. To carry out one such deal successfully it is necessary to consider the claims and possibilities of three or more states (state of origin, recipient state, and transit state). Using various world currencies, indirect dependence on other world states economic stability and reliability, additional risks arising due to using various transport chains and links (e.g. inconsistency of legislature, 'trust factor' towards the agents of other states, criminal aspects) make the unforeseen expenses possible. Unfortunately, these expenses, along with those arising in the course of many other deals, not always can be covered by insurance, but they essentially influence the total revenue of logistic companies. Amid the crisis these and other risks are of great importance since they cause the reduction of company's financial stability.

As a rule, standard indicators and analytical models of company's besides company's inner accountable figures also consider local market specifications (seasonal fluctuations, political and economic stability in a state, company's image and policy). In this case the subject of analysis is the results of company's activity on the international market in pre-crisis and crisis periods.

The data analysis over the period from 2014 to 2018 exposed the company profitability staggers caused by structure and value changes of the financial flows and, as a result, the bankruptcy risk. In this case it is necessary to develop a model, determining the probability of reaching the zero level of profitability using the business activity array data in consideration of the detected risks.

Mathematical model: the line functional

Finding the solution of various practical tasks demand the studying the probabilistic characteristics accounting time to reach some prescribed level by a process on the exit of a inertial accumulative detector (1,2). Let us consider an additive mix ξ(t) of a determined positive signal s(t) and noise x(t):

$$\xi(t) = s(t) + x(t) \ . \qquad (1)$$

If such an additive mix comes on the input of a line detector, then the result of the detection is random and the following value is formed on the output

$$\eta(t) = \int_0^t [s(t') + x(t')]\, dt' \qquad (2)$$

Let us consider the schemes which actuate as soon as a value η*(t)* reaches the some prescribed level *L* . As far as η *(t)* is a random process, the time to reach the *L* level is random as well. For the positively determined functions *s(t)* and large *t* values this moment of time will be defined by reaching level η *(ī)* = *L,* in other words, it will be determined by a moment of time *T* for which the random event {*A:* η (ī) = L} will be executed. For the reaching moments the following condition is observed

$$P(\tau) = \left\langle \delta\left(\tau - \eta^{-1}(L)\right) \right\rangle , \qquad (3)$$

Where δ(.) is a Diroc delta-function and $\eta^{-1}(L)$ is an inverse function to η *(ī)*. Here and further the operation of finding the absolute mathematical expectation toward the set of the realizations of a random process *x(t)* will be put in <.> brackets. In other words this operation is a functional integral in the space of {x(t)} functions. From the properties of the δ-function goes that

$$P(\tau) = \left\langle \frac{d\eta(\tau)}{d\tau} \delta\left(\eta(\tau) - L\right) \right\rangle . \qquad (4)$$

Using Fourier representation for δ -functions, we shall obtain

$$P(\tau) = \frac{1}{2\pi} \int_{-\infty}^{\infty} (-i\lambda)^{-1} \exp(i\lambda L) \frac{d}{d\tau} \left\langle \exp\left(-i\lambda\eta(\tau)\right) \right\rangle d\lambda \ . \qquad (5)$$

Next we will assume that x(t) is a Markovian normal process (MNP). Let us consider the characteristic function Q_t(χ) = <exp (-iχη(ī))>. Since x(t) is a normal process, the η (t) process is also normal. For it we have

$$\langle \eta(\tau) \rangle = \int_0^\tau s(t)\, dt ,$$

$$D_\tau = D(\tau) = \langle \eta^2(t) \rangle - \langle \eta(t) \rangle^2 = \int_0^\tau \int_0^\tau \langle x(t_1)x(t_2) \rangle \, dt_1 \, dt_2 \tag{6}$$

Due to the normality of a random value η(t) = η (ῑ) the modified moments are enough to evaluate the characteristic function value Q_t(χ), which gives us Q_t(χ) = exp (-iχ <η(t) >) - χ^2 D_t/2). Therefore

$$P(\tau) = \frac{1}{2\pi} \int_{-\infty}^{\infty} exp(i\lambda\tau) Q_\tau(\lambda) \, d\lambda \, , \tag{7}$$

thus

$$P(\tau) = \frac{1}{2\pi} \int_{-\infty}^{\infty} (-i\lambda)^{-1} exp(i\lambda L) \frac{d}{d\tau} exp\left(-i\lambda \langle \eta_\tau \rangle - \frac{1}{2}\lambda^2 D_\tau\right) d\lambda \, . \tag{8}$$

ῑ differentiation and consequent χ integration leads to the expression of general type

$$P(\tau) = \frac{1}{\sqrt{2\pi D_\tau}} \left[\dot{D}_\tau \frac{L - \langle \eta_\tau \rangle}{D_\tau} + \langle \dot{\eta}_\tau \rangle \right] exp\left\{ -\frac{(L - \langle \eta_\tau \rangle)^2}{2D_\tau} \right\}. \tag{9}$$

To obtain the expressions suitable for numerical simulation it is vital to have a concrete type of random MNP x(ῑ) together with corresponding <η(t) > and D_τ functions.

Below, the well-known Wiener process, to use which it is sufficient to set the intensity ó, is considered.

In the article the regular linear process s(t) with constant c will be used. Therefore <η(t) > = cῑ , <η(t) > = c. Next, for Wiener process we have $D_\tau = \frac{ó\tau}{2}, D_\tau = \frac{ó}{2}$.

In modified assumptions, taking into account the normalization of desired distribution density P(ῑ) of reaching time ῑ, we have

$$P(\tau) = \sqrt{\frac{\gamma}{\pi\tau\tau_c}} \exp\left\{ -\gamma \frac{(\tau - \tau_c)^2}{\tau\tau_c} \right\}, \qquad \gamma = \frac{c}{\sigma} L \, , \qquad \tau_c = \frac{L}{c} \, . \tag{10}$$

Numerical simulation of financial stability

For the model example the following parameters were chosen: calculation duration ῑ ≤ 365 и ῑ ≤ 400 (days), time interval Δ ῑ = 1, smashup level L1 = 365 и L2 = 400, regular component c = 1, random component intensity ó = 0,1. In this model the system 'forgets' about its state by the next time interval. Statistic simulation sample scope amounts to M. Such sample scope magnitude M offers an opportunity to draw a conclusion about the values of desired probabilities (P) up to P = 0,001 or P = 0,999 on the basis of statistic simulation results. The main results of numerical calculations are presented below in the form of amplitude histograms and cumulative curves corresponding to them.

In the figure 1 five ways of functional implementation and two critical levels of enterprise financial state L1 = 365 and L2 = 400 are represented (2). It is obvious that upon reaching the chosen levels the functional η(t) (2) has an amplitude distribution; the reaching moments are distributed as well.

In the figure 2 the empiric histograms showing how the times required for the random functional η(t) to reach critical levels of financial state L1 = 365 and L2 = 400 (days) are distributed. Judging from the shape it reminds the normal law, however, in our case the function is described by the expression (10), which is different from the normal one. It is essential to notice that due to the presence of a random component in the phenomenon under study empiric distributions, lumped around the critical levels L1 = 365 and L2 = 400 consider the smashup probability which may take place before or after these time levels.

Cumulative curves (accumulated empiric probabilities corresponding to the time histogram presented in figure 2) are presented figure 3.

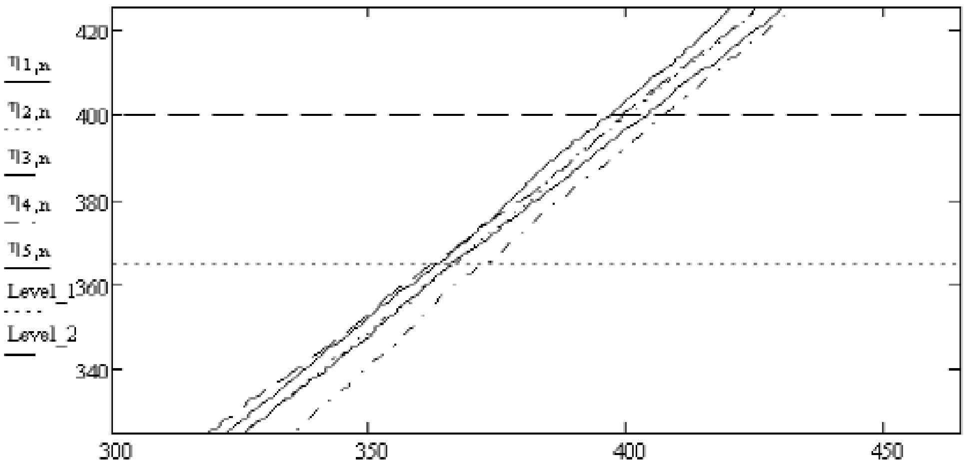

Figure 1 – The first 5 realizations of *η(t)* line functional

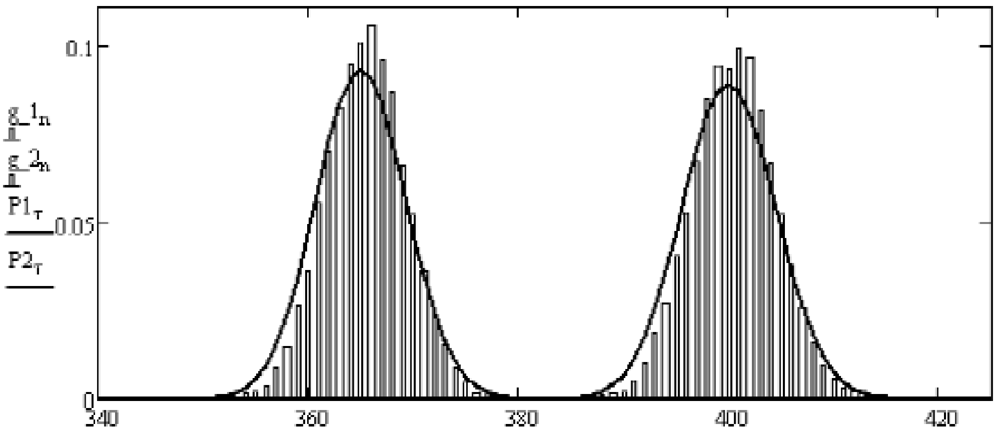

Figure 2 – Empiric histograms g_1 and g_2 of reach time allocation of a random functional ***η(t)*** and their analytical analogs P1 and P2 according to the formula (10);
critical levels of financial state, L_1 = 365 and L_2 = 400

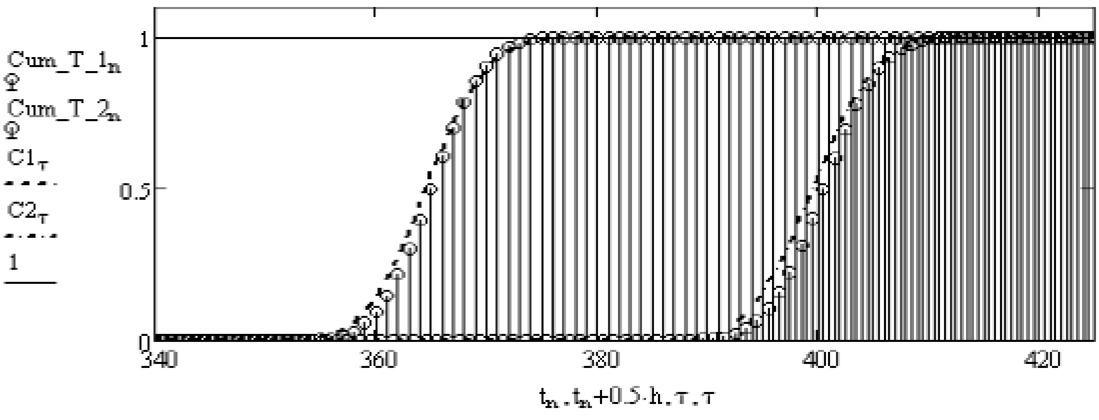

Figure 3 – Cumulative curves Cum_1_t_1 и Cum_T_2 showing how the times required
for the random functional r(t) to reach critical levels L1 = 365 and L2 = 400
are distributed and their analytical analogues C1 and C2 according to (10).

Conclusion

The analysis of the modified cumulative curves reveals that, considering the selected parameters of simulation and critical levels of financial state, there are detectable probabilities that a company will reach the set level earlier than at the set moments of time $\bar{\iota}$ = 365 и $\bar{\iota}$ = 400 (days). Therefore, to ensure the probability to avoid bankruptcy P = 0,997 (bankruptcy is probable in 3 instances out of 1000) under selected conditions $\bar{\iota}$ = 370 and $\bar{\iota}$ = 407 (days) are required respectively. In practice, this may lead to the loss of economic efficiency of a company. For instance, under otherwise equal conditions, a company will be prone to choose less risky tactics (lower productions levels, higher delivery dates, ignoring multilateral agreements, etc) in comparison to the conditions of certainty. Therefore, the issue of reducing uncertainty in the company performance and economic efficiency of the expenses necessary to enable this reduction becomes pressing.

Mathematical model, proposed in the article, can be used to solve various application tasks dealing with increasing the company operation efficiency under conditions of uncertainty and risk. The calculation results and its comparison with the analytical model reveals good match. Quite large amount of statistic selection used in this work provides the basis for using the proposed approach even for those cases, when it is impossible to obtain clear analytical expression for probability distribution P($\bar{\iota}$).

References

1 Altman E.I. Financial Ratios Discrimintal Analysis and the Prediction of Corporate Bankruptcy // Journal of Fmance. – 1968.

2 Beaver W.H. Financial ratios as predictors of failure. Empirical research in accounting selected studies // Supplement to Journal of Accounting Research. – 1966. – no. 40, pp. 71-111.

3 Богданова Т.К., Алексеева Ю.А. Прогнозирование вероятности банкротства с учетом изменения финансовых показателей в динамике // Бизнес Информатика. – 2011. - №1(15), С. 50-60.

4 Blum M. Failing company discriminant analysis // Journal of Accounting Research. – 1974. – vol. 24. – no. 1, pp. 1-25.

5 Горбатков С.А., Белолипцев И.И. Гибридный метод оценки риска банкротства на базе Байесовского ансамбля нейросетей и logit-трансформации // Науковедение. – 2013. - №6, С. 1-11.

6 Deakin E.I. A discriminant analysis of predictors of business failure // Journal of Accounting Research. – 1972. – no. 12, pp. 167-179.

7 Chesser D. Predicting loan noncompliance // Journal of Commercial Bank Lending. – 1974. – no. 13, pp. 2-15.

8 Edmister R.O. An empirical test of financial ratio analysis for small business failure prediction // The Journal of Financial and Quantitative Analysis. – 1972. – no. 16, pp. 1477-1493.

9 Kalashnikov V. Probability of ruin // Fundamental and Applied Mathematics. – 1996. - № 4, pp. 1050-1100.

10 Zmijewski M.E. Methodology Issues Related to the Estimation of Financial Distress Prediction models // Journal of Accounting Research. - 1984.

11 Мицель А.А., Кабалин А.А. Модели Писка и прогнозирования банкротства преприятия // Управление риском. – 2013. - № 1, С. 44-52.

12 Novoselov A. Mathematical modeling of financial risks. Measurement theory. – Russian Academy of Sciences, Siberian Branch, Institute of computational modeling. – Novosibirsk. – 2001.

13 Ohlson J.A. Fmantial Ratios and the Probabilistic Prediction of Bankruptcy // Journal of Accounting Research. – 1980.

14 Munjishvili T., Munjishvili Z. Knowledge demonstration and assessment system “Cyber1” // International Journal “Information Technologies & Knowledge”. – 2014. – vol. 8. – no. 3, pp. 271-279.

15 Telipenko E.V., Zakharova A.A. Bankruptcy risk management of a machine builder // Applied Mechanics and Materials. – 2014. – vol. 682, pp. 617-622.

16 Zorin V. Elements of the theory of risk processes. – Nizhniy Novgorod: UNN. – 2003, 25 p.

References

1 Altman E.I. (1968) Financial Ratios Discrimintal Analysis and the Prediction of Corporate Bankruptcy. Journal of Fmance.

2 Beaver W.H. (1966) Financial ratios as predictors of failure. Empirical research in accounting selected studies. Supplement to Journal of Accounting Research, no. 40, pp. 71-111.

3 Blum M. (1974) Failing company discriminant analysis. Journal of Accounting Research, vol. 24, no. 1, pp. 1-25.

4 Bogdanova T.K., Alekseeva Yu.A. (2011) Prognozirovanie veroyantosti bankrotstva s uchetom izmeneniya finansovyh pokazateley v dinamike [Forecasting the probability of bankruptcy to reflect changes in financial indicators in dynamics]. Business Informatics, no. 1(15), pp. 50-60.

5 Chesser D. (1974) Predicting loan noncompliance. Journal of Commercial Bank Lending, no. 13, pp. 2-15.

6 Deakin E.I. (1972) A discriminant analysis of predictors of business failure. Journal of Accounting Research, no. 12, pp. 167-179.

7 Edmister R.O. (1972) An empirical test of financial ratio analysis for small business failure prediction. The Journal of Financial and Quantitative Analysis, no. 16, pp. 1477-1493.

8 Gorbatkov S.A., Beloliptsev I.I. (2013) Gibridniy metod otsenki riska bankrotstva na base bayesovskogo ansamblya neyrosetei i logit-transformatsii [Hybrid method for estimating the risk of bankruptcy based on the Bayesian ensemble of neural networks and logit models]. Naukovedenie, no. 6, pp. 1-11.

9 Kalashnikov V. (1996) Probability of ruin. Fundamental and Applied Mathematics, vol. 4, pp. 1050-1100.

10 Micel A.A., Kabalin A.A. (2013) Modeli riska i prognozirovanija bankrotstva predprijatija [Risk models and enterprise bankruptcy prediction]. Upravlenie riskom, no. 1. pp. 44–52.

11 Munjishvili T., Munjishvili Z. (2014) Knowledge demonstration and assessment system “Cyber1”. International Journal “Information Technologies & Knowledge”, vol. 8, no. 3, pp. 271-279.

12 Novoselov A. (2001) Mathematical modeling of financial risks. Measurement theory. Russian Academy of Sciences, Siberian Branch, Institute of computational modeling, Novosibirsk.

13 Ohlson J.A. (1980) Fmantial Ratios and the Probabilistic Prediction of Bankruptcy. Journal of Accounting Research.

14 Telipenko E.V., Zakharova A.A. (2014) Bankruptcy risk management of a machine builder. Applied Mechanics and Materials, vol. 682, pp. 617-622.

15 Zmijewski M.E. (1984) Methodology Issues Related to the Estimation of Financial Distress Prediction models. Journal of Accounting Research.

16 Zorin V. (2003) Elements of the theory of risk processes. Nizhniy Novgorod: UNN, 25 p.