SIMULATION MODEL – SUPPORT TO INVESTMENT DECISION-MAKING IN THE COAL INDUSTRY

by

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The paper deals with the problem of using coal as an energy resource bearing in mind the requirements of the modern society. Necessary changes in the coal industry demand a certain level of investments. Making relevant investment decisions is of crucial importance for the future efficiency of the system mine-power plant. The proposed model incorporates the procedure of decision-making simulation under the conditions of uncertain parameters. Net present value is used as the main criterion in decision-making. Different functions of probability distribution (normal, uniform and triangular distribution) are applied for the estimation of uncertainties related to certain parameters. For others, the estimation of future conditions is based on the Monte Carlo method and the simulation of geometric Brownian motion.

Key words: *coal industry, investment, fuzzy logic, simulation model*

Introduction

Coal is still an extremely significant source of energy from global perspective, regardless of long period of use and other sources. This is especially stressed when it comes to the production of electrical energy. Bearing in mind current conditions and future trends in the field of energy generation and consumption, it can be concluded that coal will have its place in energy balances in the future as well. Having said this stated, one must not neglect the fact that the use of fossil fuels is facing more demands every day. This complicates the situation in the coal production. The demands are primarily related to the reduction of harmful components emission to the atmosphere, and to the issues of safety and environment protection. Restrictive factors of production today are as well: stricter attitude towards coal quality, price fluctuation, and changing market conditions. Previous way of functioning and survival of certain mines is therefore being questioned more often.

By looking at the system coal producer – consumer, it is easy to differentiate interests of both sides which need to be satisfied. From consumer's point of view, assurance is required when it comes to quality, contracted amounts, and coal price, while producer's aim is profitable

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operation (acceptable level of profit). Bearing in mind specificity and reality of the systems in question, it is difficult to speak in absolute terms, which brings us to the idea that the consumer requires "acceptable level of quality" when it comes to coal quality. In other words, if the request of a thermo-power plant is the content of S 1%, in the case of coal delivery with the content S = 1% it could be acceptable. Therefore, investment decisions of mining companies should result in profit maximization with total consumers' satisfaction.

Investment decisions are supported by numerous models of linear and non-linear programming, simulations, fuzzy logic, whole number programming, *etc*. Here we decided for simulation model.

When it comes to energy in Serbia and in other Western Balkan countries, one can agree that apart from general issues, here we also face problems of changing ownership structure, reorganization and redefining position and functioning of energy complexes. Special types of problems arise when it comes to coal exploitation such as: outdated technology, low efficiency, difficult working conditions, non-lucrative production, social issues, *etc*., on one side, and obvious need for coal of higher quality on the local market, on the other.

Some mines will definitely not be able to continue with operations, while others will have to go through the process of adapting to harsh conditions of market operations. Planners and project engineers of energy systems will face significant investment decisions.

Part of support to the investment decision-making is reflected in introducing flexible alternatives in the mining projects by using simulations which aim at describing decision-making ambience as realistically as possible. One of such models is suggested in this paper.

Production planning strategy is in a direct link with the amount of financing required for its implementation. In this way, decision-making on the level of production can be identified with investment decision-making. Source of risk for mining projects can encompass any number of parameters related to the items such as coal quality, reserve quantity, production costs, product price, *etc*. Development of the model represents the description of how the system operates, first qualitatively in terms of conditions, events, mechanisms and procedures which are included in the model ("conceptual model"), and then quantitatively expressed in algorithms which describe conceptual model ("computing model"). Conceptual model is developed by using our general knowledge complemented by necessary discussions with other experts. Recording the presence of risk in entry parameters is the first phase in the assessment of possible effects, and it is followed by much more important phase – quantification of identified risks. Financial feasibility determine whether the real project value will be sufficient for compensating financial obligations such as repaying debts, costs of production and maintenance, interest, and other similar costs. Present and future cash flows are a good measure for determining financial feasibility of projects. Net present value (*NPV*) is one of the oldest and the most elegant methods for ranking financial feasibility of projects. It is also known as the method of discounted cash flow (DCF). When calculating net present value, annual difference between incomes and costs is discounted back to its present value and summed up cumulatively. The ability to define all uncertainties in the decision-making process, as well as the ability to include flexible alternatives in a project is recognized as very important for long-term success of mining company's operations.

Overview of previous researches

Planning of the production level is being analyzed, compared and optimized based on the effects as distinct from the group of parameters which are directly measurable, like production costs per ton, and parameters which can be quantified, like *NPV*. Previous analyses have been showing the tendency to treat a deposit as a homogeneous unit as distinct from real situation which implies that the deposit can be divided in zones of different magnitudes, quality, and locations.

Trigeorgis [1] suggests a model based on decision tree for a mining project in which the *NPV* of the remaining cash flows is uncertain. The project includes continuous option with early project cutting, option in which the stage of development of a part of deposit is postponed for two years, and option in which the production level is increased for 50% after the development stage and production period of six years. Samis *et al.* [2, 3] ssuggest a model also based on decision tree, in which product price is the main cause of uncertainty. In their model the decision-maker has an option to open a large part of the deposit of low quality when the exploitation of a small part of the deposit of high quality is finished in the following nine years. Woodhall [4] was one of the first people to quantify the impact of flexibility in mining production in the study which treats the life cycle of exploitation and its impact.

The theory of real options is largely based on the basic principles of financial operations theory. According to Copeland *et al*. [5, 6], real options are generally classified as growth options (ex. increasing production, starting production, or widening project scope), delaying option which allows for new information on cutting option (ex. decreasing production, stopping production, or decreasing project scope).

When quantifying real options, it is of utmost importance for the management of a mining company to have the ability to identify risks, determine their probability, explore their impacts by applying simulations, define flexible alternatives, and to determine values of all alternatives by quantifying real options. Such methods comprise confined types of equations, table form of cash flow simulation, Monte Carlo models dependant on simulation path, partial differential equations, and other numerical methods (Mun [7], Trigeorgis [8], Copeland [9], Winston [10], and Samis *et al*. [11]).

Model assumption

Strategic decisions are the ones which directly affect operations of a mining company. These key decisions are primarily related to the mining company's operations. There are three main directions of the production planning strategy: maintaining the current level, increasing the level, and decreasing the level, which can also contain a final option, that is suspending production for a while or permanently. Suspending of production is only acceptable if mining company can not organize production on economically effective way. Production planning strategy is directly related to the quantity of financial funds which is necessary for its implementation. Taking into account the mentioned fact, the biggest risk for mining company's operations lies in the strategy of increasing production level, as it requires the biggest financial investment. The easiest solution is to maintain current production level and hence eliminate operations' risks. However, by its nature every company tends to expand which enables bigger chances for business survival. On the other hand, current production level (regarding quantity and quality) often fails to satisfy consumers' needs, as the company is facing stricter demands regarding environment protection, resulting in a change of production plan as an imperative.

Unique aspect of mining is the fact that it deals with non-renewable resources. The result is that incomes in mining derive from partial "elimination" of the main commodity of the project, in this case coal layer. Second influence of this characteristic of mining is reflected in the fact that all mines have definite exploitation period, which is determined by the size of the deposit and production capacity. While resources are being depleted, investors must achieve adequate return on funds invested, and new deposits must continuously be explored and prepared for exploitation.

Previous facts point out that the company's management must have a clear production development strategy *i. e.* must have a developed decision-making procedure under the mentioned conditions.

Determining decision-making criteria

When calculating *NPV*, annual difference between incomes and costs is discounted back to its present value and summed up cumulatively. *NPV* is defined as a difference between the sum of discounted cash flows which are expected from the investment and initial amount of invested capital. This relation is represented in eq. (1):

$$NPV = \sum_{t=0}^{T} \frac{CF_t}{(1+r)^t} = -CF_0 + \frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + \cdots + \frac{CF_T}{(1+r)^T} \tag{1}$$

where CF_T is the net cash flow at time t (year, half a year, month...), r – the discount rate, and T – the total duration of the project.

Uncertainty (indeterminateness) in mining projects and need for flexibility

Uncertainty in mining projects is generally estimated with regards to internal (endogenous) and external (exogenous) conditions. Internal conditions are those that result from characteristics of the deposit and excavation method, like coal quality, physical-mechanical characteristics of working environment, management, planning, mining equipment, and infrastructure. External conditions are determined by external equivalent, like market price of the raw material, demands for environment protection, political risks, governmental policy, requests from shareholders, and social and industrial relations.

Simulation (quantification) of risk

The models which contain variables not known with adequate level of accuracy are stochastic or probabilistic models. To make a decision, it is required to assess real conditions of certain entry parameters which influence the decision to the largest extent, as well as to assess their future conditions. As the decision-maker is not able to determine with certainty accurate values of entry parameters, he/she is in the position to determine the probabilities of their occurrence. This approach largely reflects real conditions *i. e.* ambience where the decision is being taken, and it simplifies the job of the decision-maker. If one wants to describe entry parameters with continuous distribution of the probability of their occurrence, then there is no definite group of possible outcomes. In a simple way, Monte Carlo simulation creates artificial values, for given parameter, by generating thousands and sometimes hundreds thousands ways of outcomes and by analyzing their prevailing characteristics.

Triangular distribution is used for the quantification of intangibility of the parameters of capital expenses *i. e.* investments in our model. The most unfavorable situation is usually used in the quantification of the intangibility of the parameters of capital expenses – that capital expenses are always bigger than the desired ones and that the probability of smaller ones occurring is significantly reduced. Uniform distribution is used for the quantification of intangibility of the transport costs' parameters. Normal distribution is used for the quantification of intangibility of the parameter of coal price (fig. 1).

Determining uncertainty of basic commodity

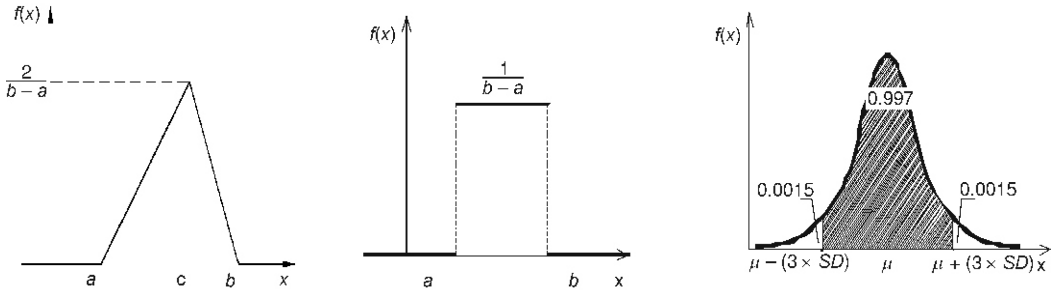

Figure 1. Functions of probability distribution which represent investment, transportation costs, and coal price

Mine's basic commodity is the coal deposit. This value is unstable quantity, and it's changing depending on current market price, quality and quantity of coal and deposit exploitation. In most cases companies own only mine and separation, therefore separated coal is their final product which is placed on the market.

Annual incomes from selling coal concentrate are represented in eq. (2):

$$P_{\mathrm{annual}} = \sum_{i=1}^{n} K_i V_i \tag{2}$$

where K_i is the coal quantity, V_i – the market value of coal, and P_{annual} – the annual income.

Market value (price) of coal is determined based on the contract (terms) of sale with the consumer.

Estimation of production costs

If there are indications that the changes of production costs in the future will have a non-linear character, that is that their future value may have random magnitudes, stochastic differential equation of geometric Brownian motion is used for the simulation of costs flow. In the context of costs it becomes:

$$\mathrm{d}C = \mu C \mathrm{d}t + \sigma C \mathrm{d}W \tag{3}$$

where $\mathrm{d}C$ is the cost increment during small time interval $\mathrm{d}t$, μ – the trend of costs deriving from regression, σ – the standard deviation of costs deriving from regression, C – the current value of costs, and $\mathrm{d}W$ – the stochastic cost increment in Brownian motion during $\mathrm{d}t$.

When solving stochastic differential eq. (3) the following expression perform simulation process:

$$C(t) \quad C(t_0)\,\mathrm{e}^{(\mu \quad \frac{\sigma^2}{2})(t \quad t_0) \quad \sigma\sqrt{t \quad t_0}\,N(0,1)} \tag{4}$$

where $C(t_0)$ is the current value of costs in the moment $t = 0$, and $N(0,1)$ – the random value of normal distribution with mean number 0 and standard deviation 1.

The simulation procedure is performed in the following way: one of the possible flows of production costs which consists of a line of values (C_0, C_1, C_2,..., C_T), starting from the moment $t = 1$, $t = 2$, ..., to the final moment $t = T$ is calculated by using the computing eq. (4). This equation is repeated adequate number of times, resulting in a representative sample ready for statistical processing which gives expected values. Since the change of costs is of dynamic nature, annual income is of dynamic nature as well.

Option value analysis

First step in calculating is to define the *NPV*. Simulation approach is suggested in this chapter, in order to include uncertainty in *NPV* calculations. Stochastic model which describes simultaneous behavior of risk factors which have the most significant influence on uncertainty of *NPV* is created. Simulation results in probability distribution of risk factors for the duration of the project. Probability distributions related to risk factors will directly affect the probability distribution of *NPV*. Since full distribution of the net present value is available, one can choose the measure (indicator) of uncertainty, like reliability interval or value under risk. The model computes values of the project V_t for each year t in the period of project duration $t = 1, 2,...,T$. Project value is a complex function of a large number of risk factors which influence incomes P_t and expenses R_t on annual level. Project value in year t is defined as:

$$V_t \quad V_t(X_{1t,...,}X_{Nt}) \quad P_t(X_{1t,...,}X_{Nt}) \quad R_t(X_{1t,...}X_{Nt}) \tag{5}$$

where is X_{1t},..., X_{Nt} is the risk factors which influence incomes and expenses.

Depending on the functional shape for R_t and P_t, some of these factors may influence incomes only or expenses only, and others both. When applying annual discounting rates r_1, r_2,..., r_T, *NPV* is defined as:

$$NPV \quad NPV(V_{1,...,}V_T) \quad {}^{T}_{t \quad 1} \frac{V_t}{\prod\limits_{j \quad 1}^{t}(1 \quad r_i)} \tag{6}$$

A constant discounting rate is often applied for the entire duration of the project, in which case r_t is replaced with r. Investment costs (capital expenses – CAPEX) are included in a way to deduct their constant value from the net present value. Assumption of the model is that the risk factors X_{1t},..., X_{Nt}, which influence incomes and expenses, are identified as critical for *NPV* calculations. The model provides the values of $C^b_{1t},\ldots,C^b_{Nt}$, $b = 1$,.., B; $t = 1$,...,T, where B represents the number of simulations. These simulations represent probability distribution of the chosen (identified) risk factors where all information on uncertainty comes from. Simulated *NPV* dimensions are derived from *NPV* calculation, using simulated values of risk factors, so that:

$$NPV^b \quad NPV(V_1^b,\ldots,V_T^b) \quad b \quad 1,\ldots,B \tag{7}$$

where

$$V_t^b \quad P_t(X_{1t}^b,\ldots,X_{Nt}^b) \quad R_t(X_{1t}^b,\ldots,X_{Nt}^b) \tag{8}$$

After the simulations NPV^b, $b = 1,\ldots, B$ are available, they can be used to estimate the distribution of the NPV. Simulations serve as a basis for determining all statistical indicators for the NPV under the conditions of uncertainty.

Decision-making

The decision to increase the production level/capacities can be treated as an investment decision. It is necessary to prepare part of the deposit for exploitation in order to increase the production level, which implies the realization of an adequate volume of mining operations. It is necessary to provide adequate mining equipment which will be engaged in the exploitation process. Realization of the aforementioned activities requires adequate financial means *i. e.* adequate investment. Based on the aforementioned facts comes a logical question: "Is the investment justifiable?" Final decision is made on the basis of the investment justifiability indicators.

The NPV is used for making the decision:

$NPV > 0.02 \div 0.05 \times$ INVESTMENT	*Positive decision on the suggested volume of production increase and technical-technological solutions which provide for that volume is taken.*
$0 < NPV = 0.02 \times$ INVESTMENT	*Decision-making is delayed and the correction of the suggested volume of production increase and technical-technological solutions is suggested.*
$NPV < 0$	*Negative decision on the volume of production increase is taken and current production level is maintained.*

Theoretically speaking, it is enough that the criterion of the net present value fulfills the condition $NPV > 0$ for the positive decision to be taken. However, taking into account all of the aforementioned specificities of mining as investment environment, this criterion is a bit more rigorous in order to increase safety for investors in making the final decision.

Numerical example

Brown coal mine "Soko" is taken as an example for testing the proposed simulation model. It is assumed that the mine will supply thermal-power plant at a distance of approximately 100 km distance. Requests in relation to coal quality are the content S < 1.5%, ashes <13%, and lowest calorific value > 16.000 kJ/kg. Necessary coal quantities 200.000 t per year, and average price 33 €/t. In order to be able to meet those demands, it was estimated that it is necessary to invest max. 5,500,000 € in the period of 2 years. This investment would allow for the excavation of 10,000,000 t coal reserves. Project time frame taken into account is 15 years.

Inputs:

Production capacity

- Year I 100,000 t/year
- Year II 150,000 t/year
- Year III...XV 200,000 t/year

Investment
Triangular distribution
- Minimum 5,500,000,00 €
- Maximum 5,500,000,00 €

Investment plan
- Year I 65%
- Year II 35%

Production costs
Differential equation
- Current production costs 20 €/t
- Trend (year) 2%
- Standard deviation (year) 5%

Transportation costs
Uniform distribution
- Minimum 2 €/t
- Maximum 3 €/t

Coal price
Normal distribution
- Middle price 33 €/t
- Minimum 31 €/t
- Maximum 35 €/t

Discount rate 8%
Project plan
- Project duration 15 years
- Investment period 2 years

Simulation produced the following results:
Sample 500
- Arithmetic mean 3,579,007,00 €
- Standard deviation 3,973,529,00 €
- Maximim 14,156,825,00 €
- Minimum –8,239,679,90 €
- Range 22,396,505,00 €
- Q (75%) 6,445,053,00 €
- Q (25%) 1,207,631,00 €
- Q (75%) – Q (25%) 5,237,422,00 €
- $NPV > 0$ 81,7%
- Expected NPV 50,1%
- Kurtosis –0,150797
- Skewness –0,113188
- Standard error 177,702,00 €
- Confidence coefficient 0,95
- Confidence factor 1,96
- Up limit 3,927,302,00 €
- Low limit 3,230,712,00 €

Probability and cumulative distribution function of *NPV* are presented in figs. 2 and 3, respectively.

The result obtained by simulation model suggests that the project can be implemented.

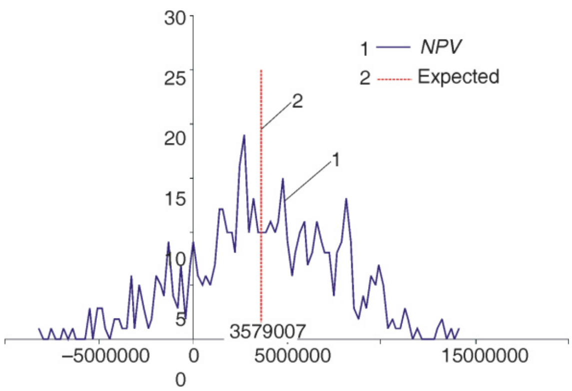

Figure 2. Probability distribution function of *NPV*

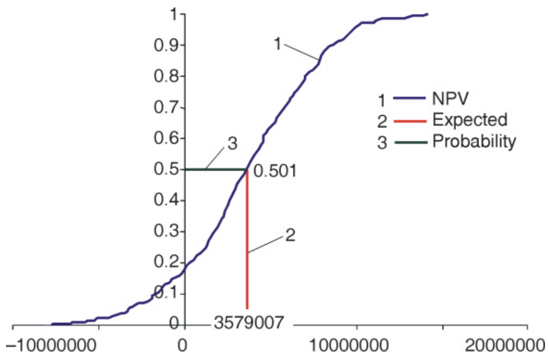

Figure 3. Cumulative distribution function of *NPV*

Conclusions

Coal as an energy source still represents a signification solution despite numerous limits and obvious shortcomings. Nevertheless, to keep using coal, it is necessary to comply with complex demands of the modern society. This is primarily directed to the environmental protection problems. Conclusion is that many mines demand additional investment in excavation system reconstruction.

Investments in coal industry are demanding in terms of amount, long periods until production commencement and extremely high level of uncertainty of entry parameters. All this makes investment decision-making harder. Functional dependencies among variables which are controllable and the ones that cannot be influenced, as well as the dependencies among the production level and economic indicators in mining are very complex and often of a non-linear character. These dependencies compose one economic system, which demands many skills to be maintained on a positive level. Though some of the variables can be defined precisely with deterministic approach, such simplification will not be sufficient for understanding the dynamic nature of a mine as a whole. In reality, functional dependencies change in time. Taking into account the aforementioned facts, it is necessary to create such decision-making model whose main role would be to encompass relevant variables, define their influence on the decision and find a solution in accordance with the defined criterion, that is indicate the strategic direction for decision-making.

A precise model of support to decision-making is a precondition for successful decision-making. Modeling implies a simulation approach in order to include uncertainty in *NPV* calculations. A stochastic model simultaneously analyses the behavior of risk factors which have the most significant influence on uncertainty of the net present value. Simulation results in the distribution of risk factors' probability for the duration of the project. When these distributions are included in *NPV* calculations it results in *NPV* probability distribution. These results show expected profitability and risk which moves profitability away from expected value.

Nomenclature

B – number of simulations
C – current value of costs, [€]
CF_T – the net cash flow at time t (year, half a year, month...), [€]
$C(t_0)$ – current value of costs in the moment $t = 0$, [€]
dC – cost increment during small time interval dt, [€]
dW – stochastic cost increment in Brownian – motion during dt, [€]
K_i – coal quantity, [t]
$N(0,1)$ – random value of normal distribution with mean number 0 and standard deviation 1
NPV – net present value, [€]
P_{annual} – annual incomes from selling coal, [€]
P_t – incomes, [€]
r – the discount rate, [%]
R_t – expences on annual level, [€]
T – total duration of the project, [years]
V_i – market value of coal, [€/t]
X_{1t} – risk factors which influence incomes and expenses
V_t – values of the project, [€]

Greek letters

μ – trend of costs deriving from regression
σ – standard deviation of costs deriving from regression

References

[1] Trigeorgis, L., A Real-Options Application in Natural-Resource Investments, *Advances in Futures and Options Research, 4* (1990), pp. 153-164
[2] Samis, M., Poulin, R., Valuing Management Flexibility by Derivative Asset Valuation, *Proceedings*, 98th CIM AGM, 1996, Edmonton, Canada
[3] Samis, M., Poulin, R., Valuing Management Flexibility: A Basis to Compare the Standard DcF and MAP Valuation Frame Works, *CIM Bulletin, 91* (1998), 1019, pp. 69-74
[4] Woodhall, M., Managing the Mining Life Cycle: Mineral Resource Management in the Deep Level Gold Mining, M. Sc. Project Research Report, University of the Witwatersrand, Johannesburg, South Africa, 2002
[5] Copeland, T. E., Keenan, P. T., How Much is Flexibility Worth?, *The McKinsey Quarterly,* (1998), 2, pp. 38-49
[6] Copeland, T. E., Keenan, P. T., Making Real Options real, *The McKinsey Quarterly,* (1998), 3, pp. 128-141
[7] Mun, J., Real Options Analysis: Tools and Techniques for Valuing Strategic Investments and Decisions, John Wiley and Sons, Hoboken, N. J., USA, 2002
[8] Trigeorgis, L., Real Options, Managerial Flexibility and Strategy Resource Allocation, *The MIT Press*, Cambridge, Mass., USA, 1996
[9] Copeland, T. E., Antikarov, V., Real Options a Practitioner's Guide, Thompson Texere, New York, USA, 2003
[10] Winston, W., Financial Models Using Simulation and Optimization, Palisade, Newfield, N. Y., USA, 1998
[11] Samis, M., Davis, G., An Overview of Using Real Options to Value and Manage Mining Projects: Workshop Notes, 2004 MEMS AGM Pre-Conference Workshop, Toronto, Ont., Canada, 2004

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