Природни ресурси и технологии
Natural resources and technology

ПРИРОДНИ РЕСУРСИ И ТЕХНОЛОГИИ
NATURAL RESOURCES AND TECHNOLOGY

APPLICATION OF MONTE CARLO SIMULATION FOR RISK EVALUATION IN MINERAL INVESTMENT PROJECTS

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Abstract

Monte Carlo simulation is a useful technique for modeling and analyzing real-world systems and situations. This paper is a conceptual paper that explores the applications of Monte Carlo simulation for managing project risks and uncertainties. The benefits of Monte Carlo simulation are using quantified data, allowing project managers to better justify and communicate their arguments when senior management is pushing for unrealistic project expectations. Proper risk management education, training, and advancements in computing technology combined with Monte Carlo simulation software allow project managers to implement the method easily. In the field of project management, Monte Carlo simulation can quantify the effects of risk and uncertainty in project schedules and budgets, giving the project manager a statistical indicator of project performance such as target project completion date and budget.

This approach is essential for mining industry usually associated with high level of diversified risks.

Key words: *risk, management, investment.*

ПРИМЕНА НА МОНТЕ КАРЛО СИМУЛАЦИЈАТА ЗА УПРАВУВАЊЕ СО РИЗИЦИТЕ ПРИ ИНВЕСТИРАЊЕТО ВО ПРОЕКТИ ОД МИНЕРАЛНАТА ИНДУСТРИЈА

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Апстракт

Монте Карло симулацијата е корисна техника за моделирање и анализа на системи и ситуации од реалниот свет. Овој труд ја истражува можноста за примена на оваа метода во управувањето со ризиците во

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проектите од минералната индустрија. Монте Карло симулацијата со користење на квантифицирани податоци им овозможува на менаџерите подобро да ги аргументираат и оправдаат своите одлуки пред повисоките управни структури. Едукацијата во оваа сфера, заедно со напредокот на информатичката технологија и софтверски решенија, дозволуваат полесна и пошироока примена на оваа метода.

Во сферата на управување со проекти, Монте Карло може да ги квантифицира ефектите од ризиците во распоредот на реализација и буџетите на проектите, притоа обезбедувајќи статистички индикатори за перформансите на проектот, како што се целите за завршување или планираните буџети. Ова е од големо значење за рударската индустрија, вообичаено поврзана со високо ниво на ризик.

Клучни зборови: *управување, ризици, инвестиција.*

Introduction

The area of risk management has received significant recognition in the field of project management in recent years. Project managers and their superiors discovered that the process of identification, analysis, and assessment of possible project risks benefits them greatly in developing risk mitigation and contingency plans for complex project

This planning, in turn, helps the project manager better handle the difficult situations that invariably occur during projects, and therefore allows for more successful project completion.One method used by some project managers during the risk analysis processis Monte Carlo simulation applications. This activity has been widely used for decades to simulatevarious mathematical and scientific situations, and it is mentioned often in project management curricula and standards, such as *A Guide to the Project Management Body of Knowledge* (Project Management Institute, 2004).

Monte Carlo simulation has not yet, however, found a strong footing in the actual practice of project management in the " real world ".

This paper reviews the applications of Monte Carlo simulation and its relevance to risk management and analysis in project management. It also outlines the uses of Monte Carlo simulation in other disciplines and in the field of project management. Finally, it discusses the pros and cons of MonteCarlo simulation applications in project management environment, some examples of proposed improvements or alternatives to Monte Carlo simulation,and concludes with a recommendation that more project managers should take advantage of this simple and useful tool in managing project risks and uncertainties.

Brief history of MONTE CARLO simulation

The Monte Carlo simulation encompasses "any technique of statistical sampling employed to approximate solutions to quantitative problems. A model or a real-life system or situation is developed, and this model contains certain variables. These variables have different possible values, represented by a probability distribution function of the values for each variable. The Monte Carlo method simulates the full system many times (hundreds or even thousands of times), each time randomly choosing a value for each variable from its probability distribution. The outcome is a probability distribution of the overall value of the system calculated through the iterations of the model. The invention of this method, especially the use of computers in making the calculations, has been credited to Stanislaw Ulam, a mathematician working Risk Management, Young Hoon Kwak and Lisa Ingallson the US' Manhattan Project during World War II (Eckhardt, 1987). His work with Jon von Neuman and Nicholas Metropolis transformed statisticalsampling "from a mathematical curiosity to a formal methodology applicable to a wide variety of problems). Metropolis is actually credited with naming the methodology after the casinos of Monte Carlo, and Ulam and Metropolis published their first paper on the method in 1949.

MONTE CARLO simulation applications in engineering

In the field of computer engineering and design, Bhanot *et al* (2005) described the use of simulation when optimizing the problem layout of IBM's BlueGene/L supercomputer. In geophysical engineering, Monte Carlo analysishas been used to predict slope stability given a variety of factors (El-Ramly, Morgenstern and Cruden, 2002). In marine engineering, Santos and Guedes Soares (2005) described a probabilistic methodology they have developed to assess damaged ship survivability based on Monte Carlo simulation. Lei *et al*(1999) explained their use of Monte Carlo simulation in aerospace engineering to geometrically model an entire space craft and its payload, using The Integral Mass Model.

Application of MONTE CARLO simulation in project management

Monte Carlo simulation, while not yet widely used in project management, does get some exposure through certain project management practices. This exposure is primarily in the areas of cost and time management to quantify the risk level of a project's budget or planned completion date.

Project manager and subject matter experts assigns a probability distribution function of duration to each task or group of tasks in the project network to get better estimates. At hree-point estimate is often used to simplify

this practice, where the expert supplies the most-likely, worst-case, and best-case durations for each task or group of tasks. The project manager can then fit these three estimates to a duration probability distribution, such as a normal, Beta, or triangular distribution,for the task. Once the simulation is complete, the project manager is able to report the probability of completing the project on any particular date,which allows him/her to set a schedule reserve for the project.

The above can be easily completed using standard project management software, such as Microsoft Project or Primavera, along with Monte Carlo simulation add-ins, such as @Risk or Risk + , or RiskAMP. In cost management, project manager can use Monte Carlo simulation to better understand project budget and estimate final budget at completion. Instead of assigning a probability distribution to the project task durations,project manager assigns the distribution to the project costs.

These estimates are normally produced by a project cost expert, and the final product is a probability distribution of the final total project cost. Project managers often use this distribution to set a side a project budget reserve, to be used when contingency plans are necessary to respond to risk events.

Risk Management Exploring Monte Carlo Simulation Applications, Monte Carlo simulation can also be used in other areas of project management, primarily in program and portfolio management when making capital budgeting and investment decisions. Smith (1994) outlined how simulationassists managers in choosing among different potential investments and projects. He explained that by replacing estimates of net cash flow for each year with probability distributions for each factor affecting net cash flow, managers can develop a distribution of possible **Net Present Values (NPV)** of an investment instead of a single value. This is helpful when choosing between different capital investment opportunities that may have similar mean **NPV** but differing levels of variance in the **NPV** distribution.

Sample application of MONTE CARLO simulation in mineral investment project

One of most common applications of this methodology is definition of probable NPV distribution for different significant variables, including but not limited to changes in operation capacity, costs, ore grade etc.

This is most easily explained through a sample analysis of NPV sensitivity on production capacity fluctuation for hypothetic new hard rock mine operation.

NPV sensitivity on production capacity fluctuation is determined through detailed DCF analysis for each of proposed project alternatives. Sample calculation is given below.
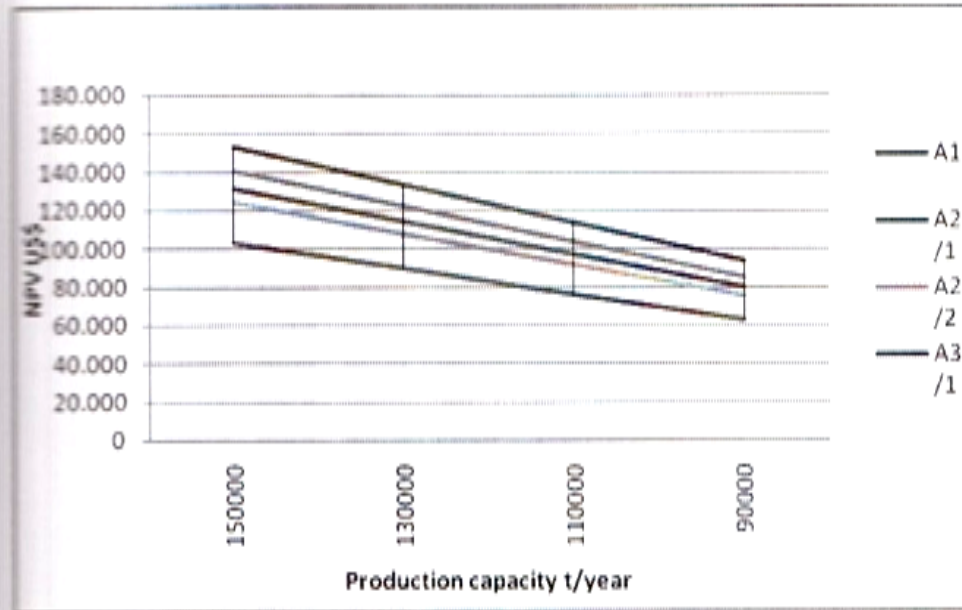
**Figure 1** - NPV calculated for different operation capacity

Direct dependence of NPV and production capacity changes is obvious. Also it could be noted that in expected range of production capacities (90.000 to 150.000 t/year) NPV is positive for all alternatives.

Probable NPV distribution for different production capacities is analyzed with Monet Carlo simulation. Table with NPV values for different production capacities as a basis for simulation is given in the table below.

Tab. 1 - Simulation input

	Minimum	Probable	Maximum
A1	62.510	89.275	102.658
A2/1	79.858	114.025	131.108
A2/2	75.301	107.677	107.677
A3/1	93.521	133.251	153.115
A3/2	85.378	122.251	140.687

Histograms of probable NPV distribution and probability for each NPV value for E=500 (E- number of iterations) are given below.

Alternative A1

Alternative A2/1

Alternative A2/2

Alternative A3/1

Alternative A3/2
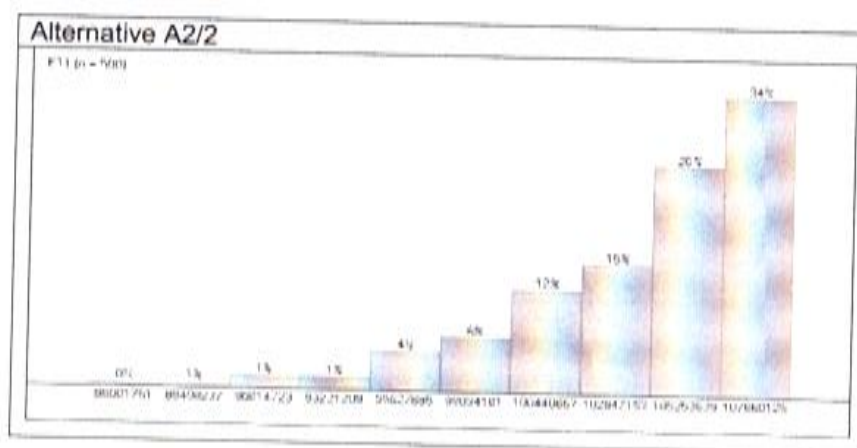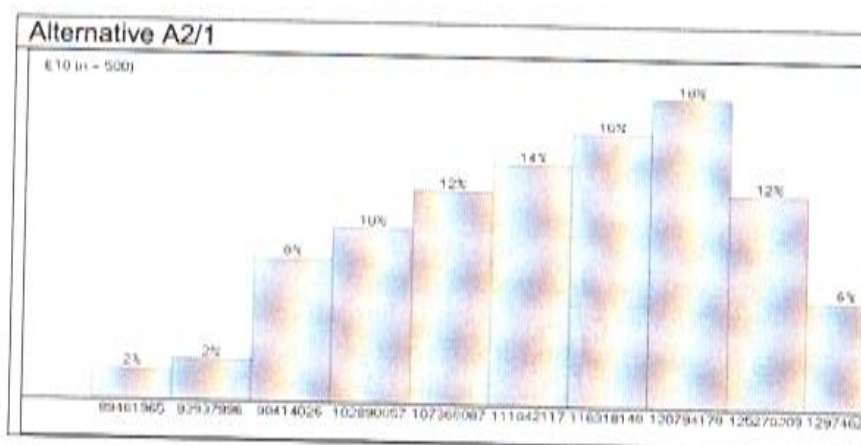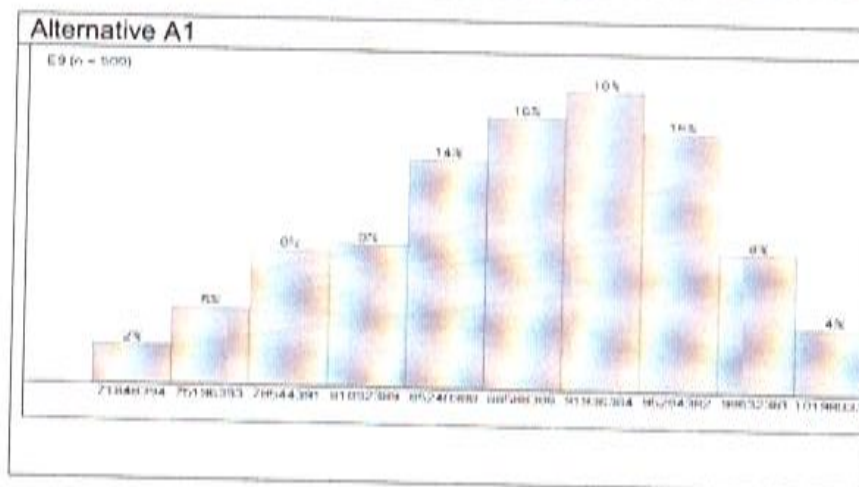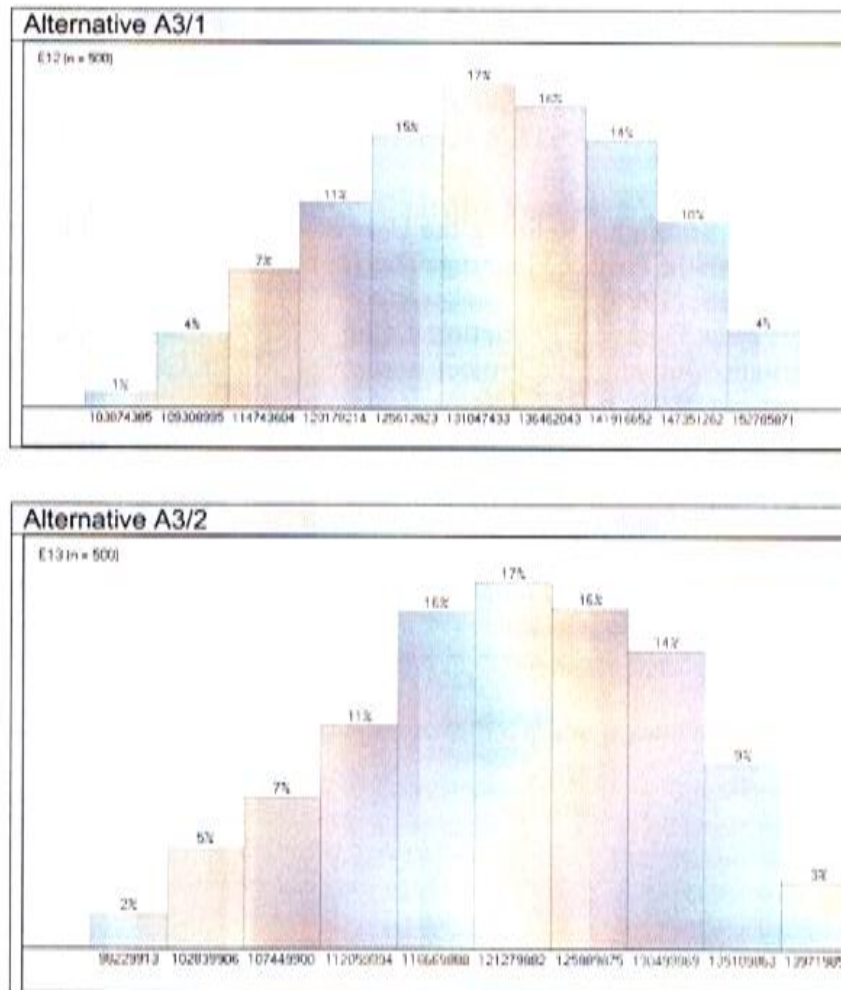
SUMMARY, RECOMMENDATION, AND FUTURE DIRECTIONS

This research examines the Monte Carlo simulation method and its uses in various fields, focusing primarily on its use in the field of project management.

Examples of practical use of the simulation method have been listed and discussed, as well as its advantages and limitations. Many researchers have proposed improvements to the standard methods of Monte Carlo simulation currently used in project management, and most of these improvements deserve strong consideration and possible future implementation, depending on individual project needs and the practicality of the improvement. One would expect that as Monte Carlo simulation becomes more popular in

project management, more creative studies will propose practical, applicable improvements to current practices and continue to contribute positively to the field.

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