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Simulation-Based Analysis of the Goldmine System Operation

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***Abstract* – The research demonstrates the efficiency of the simulation technique application for the analysis of goldmine system operation with a particular focus on truck-shovel system. The research has been carried out within the modelling competition "IIE/Rockwell Student Simulation Competition" arranged by an international organization IIE (Industrial Engineering). The information on the goldmine system structure and operation has been provided by the competition organizers, thus allowing the authors of the article to analyse the system operation based on real data and to propose recommendations and solutions for increasing goldmine efficiency through the optimization of technical resources used. A simulation model of the goldmine system is developed by means of Arena simulation environment.**

***Keywords* – simulation, design of experiments, optimization, conceptual modelling, linear regression analysis**

I. Introduction

Simulation is the method of analyzing and improving system operation, while operating with the real system is too expensive or time consuming. It is possible to control the experimental conditions during the simulation, which is very important for comparing alternatives and making direct comparisons. Using simulation it is possible to predict system performance, to compare alternative system designs and to determine the effect of alternative management strategies on system performance [5].

Fig. 1. Goldmine system structure

The goldmine system operation problem focuses on the challenges of modelling material handling operations, common in mining and construction operations.

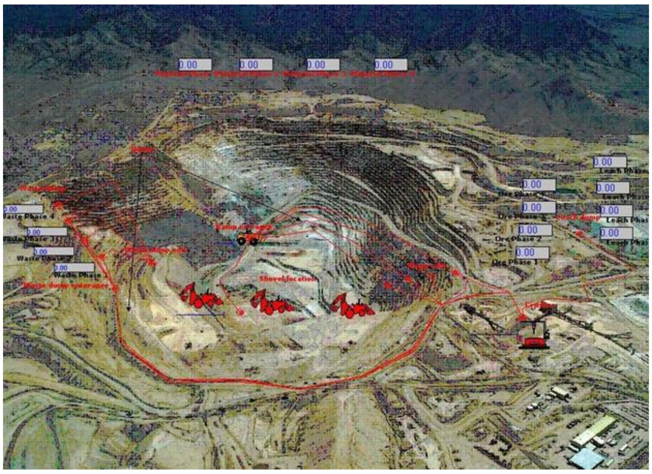

Fig. 2. The simulation model of the goldmine system

These operations are characterized by cyclical processes with highly variable activity times resulting in uncertainty and its estimation. Discrete event simulation can be a powerful tool to analyse such systems [1]. Goldmine system structure is represented in Fig. 1. The simulation model of the goldmine system is shown in Fig. 2.

II. Conceptual Model of the Goldmine System

For better understanding of the system processes, its conceptual model has been developed, which at the same time is also a template for creating the simulation model. Goldmine conceptual model consists of the following components (see Table 1):

1. modelling objectives – the analysis of the effective usage of technical resources in order to increase the volume of produced gold ore;
2. input data: empty and loaded truck speed; truck loading and unloading time; the time between excavator breakage and excavator repair times; goldmine operation time which is 2 shifts per day, each 9 hours long, 30 days per month;
3. output data or parameters as excavator utilization; initially 3 excavators are available in the system; the obtained amount of the waste and the gold ore; the average number of trucks in use according to all possible four excavation phases, initially 30 trucks are available in the system; crusher average queue length

TABLE I

MAIN COMPONENTS OF THE GOLDMINE SYSTEM

Component	Description
Excavators	Truck loading and unloading times, breakage/repair times, working time
Trucks	Empty and loaded truck driving speeds, unloading times, carrying capacity, working time
Crusher	Exploitation limit, working time
Leach dump	Distance from other system objects
Waste dump	Distance from other system objects
Materials	Type of material, amount of material
Ramps	Length
Queue to the excavator	Waiting in line

There are different ways available for representation of the conceptual model. To develop the conceptual model of the goldmine system, four different approaches have been evaluated, namely, list of components, process flow diagram, business process logic flow chart and activity cycle diagram [2].

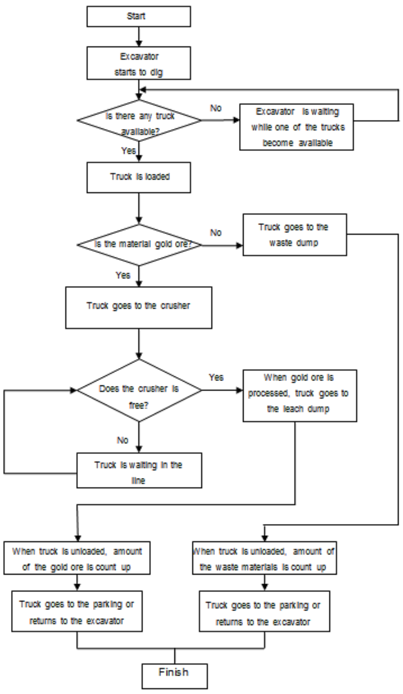

Fig. 3. Process logic flow chart

In order to compare different approaches, 3 dimensions and 10 criteria have been selected as shown below:

1. specification dimension: validity, visualization, complexity of the design, accuracy, simplicity;
2. dimension of use: transparency, credibility, usefulness, completeness;
3. implementation dimension: feasibility.

Based on the comparative analysis results, the most valuable is business process logic flow chart (see Fig. 3). Due to its complex structure, this conceptual model provides the accurate representation of system and its processes, which is important for the simulation model development process, and it is easy readable and clearly understandable. The simulation model is created according to the developed conceptual model.

III. DESIGN AND ANALYSIS OF EXPERIMENTS

The simulation model of the goldmine system has been developed by means of a standard edition of Arena professional simulation software. A dynamic, discrete-event and stochastic simulation model has been created. Design and analysis of experiments have been performed in order to achieve better understanding of the real world system that is being modelled and to find ways of improving the system [5]. If the input data is not satisfactory and the experimentation is not carried out correctly then the understanding gained may be incorrect and the improvements cannot be identified properly. That is why it is essential to obtain accurate results on the model performance.

In order to obtain accurate results on the Goldmine simulation model performance, the number of replications and the run length have been determined. The aim is to ensure that enough output data have been obtained from the simulation in order to estimate the model performance with sufficient accuracy [5]. The goldmine simulation model is a terminating system, because it starts in an empty condition and it has a natural end point – the end of 30 days or a month.

To determine the number of replications, the confidence interval method has been applied. The significance level of 5% has been selected, which gives 95% probability that the value of the true mean lies within the confidence interval. 20 replications, each 30 days long, have been performed using the goldmine simulation model. Fig. 4 shows cumulative mean and confidence intervals graphically for the crusher average queue length. The number of replications is selected as the point where the interval reaches and remains below the desired level of deviation. Within current research deviation less than 10% is satisfactory. It is concluded that 3 replications are enough to obtain accurate results.

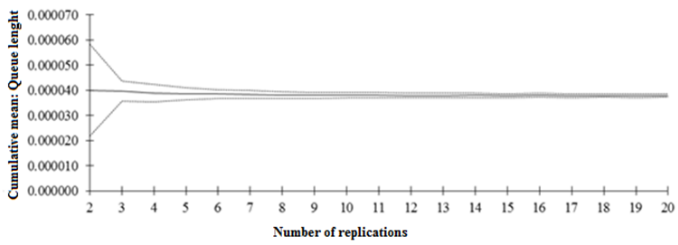

Fig. 4. Number of replications

To determine the appropriate run length, the graphical method has been applied. Three replications have been performed by means of the goldmine simulation model. The run length has been selected as the point where the convergence is seen as acceptable, which is at the level of less than 5%. As Fig. 5 shows, the run length of 720 hours or 30 days is necessary.

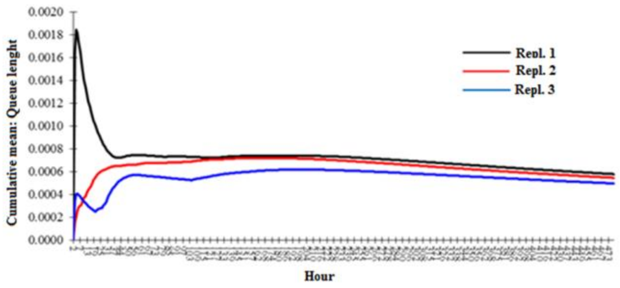

Fig. 5. Run length selection

To find interdependency between performance measures and experimental factors, the design and performance of simulation experiments have been completed. For this purpose, the 2^k full factorial design and linear regression analysis have been performed. The performance parameter is the amount of the produced gold ore in tons in a month. Four experimental factors have been considered: number of shovels, number of trucks, system phase and time between shovel failures. The input data is shown in Table II.

The 2^k full factorial design defines the alternative scenarios of the organization of the goldmine technical resources. 16 different scenarios have been executed in accordance with the 2^k full factorial design.

TABLE II

INPUT DATA

The values of factors	x_1	x_2	x_3	x_4
x_j^0	2	15	2	30
Δx_j	1	5	1	10
$x_{j_{min}}$	1	10	1	7
$x_{j_{max}}$	3	20	3	40

Each factor value has been increased or decreased respectively and then all 16 scenarios have been simulated, as well as results have been recorded. The development of experiments is shown in Table III.

In order to determine the influence of experimental factors on the amount of produced gold ore, linear regression analysis has been performed. Obtained multifactorial linear regression model has been formed using the data obtained in the 2^k factorial design.

TABLE III

2^K FACTORIAL DESIGN

No.	x_1	x_2	x_3	x_4	y
1.	-1	-1	-1	-1	269209.7
2.	-1	-1	-1	+1	287956.3
3.	-1	-1	+1	-1	268963.3
4.	-1	-1	+1	+1	288156.7
5.	-1	+1	+1	+1	294113.3
6.	-1	+1	-1	-1	273326
7.	-1	+1	-1	+1	294038.3
8.	-1	+1	+1	-1	270626.7
9.	+1	-1	-1	-1	332666.3
10.	+1	-1	-1	+1	371762.3
11.	+1	-1	+1	-1	331643.3
12.	+1	-1	+1	+1	370690
13.	+1	+1	+1	+1	649503.3
14.	+1	+1	-1	-1	630085
15.	+1	+1	-1	+1	646059.7
16.	+1	+1	+1	-1	624193.3

Obtained multifactorial linear regression model explains 77.24 % of the changes in the amount of produced gold ore. The four factor linear regression model is presented below:

$$\hat{y} = 387687.1042 + 106888.3125 \cdot x_1 + 72556.10417 \cdot x_2 - 450.8541667 \cdot x_3 + 12597.89583 \cdot x_4 \quad (1)$$

For the factors x_1, x_2 and x_4, the main effect is positive. This means that if the number of shovels or trucks or the amount of time between failures is increased, the amount of produced ore increases. Similarly, a negative main effect identifies a decrease in the response. This means that if the system phase is increased, the amount of produced ore decreases. The size of the main effect also indicates which factors have the greatest effect on the response, as well as helps identify the most important factors [5].

Sensitivity analysis has been performed within the research to assess the consequences of changes in model inputs. The values and 95% confidence intervals of the factor coefficients β_0, β_1, β_2, β_3, β_4 have been defined. The confidence intervals of the factors are the following:

$$\begin{aligned} 60132.1781 \le \beta_1 \le 153644.4469 \\ 25799.96976 \le \beta_2 \le 119312.2386 \\ -47206.98857 \le \beta_3 \le 46305.28024 \quad (2) \\ -34158.23857 \le \beta_4 \le 59354.03024 \end{aligned}$$

To estimate the significance of each factor, the hypothesis of each factor should be verified:

$$H_0{:}\beta_1=0,\ H_0{:}\beta_2=0,\ H_0{:}\beta_3=0,\ H_0{:}\beta_4=0,$$

$$H_0{:}\beta_1\neq0,\ H_0{:}\beta_2\neq0,\ H_0{:}\beta_3\neq0,\ H_0{:}\beta_4\neq0.$$

The hypothesis tests show that there are two statistically relevant experimental factors – the number of shovels and the number of trucks. The results of sensitivity analysis show that the number of shovels and number of trucks are statistically relevant experimental factors with confidence of 95%, while the system phase and time between shovel failures are not.

IV. Optimization Task

Optimization is a method, which helps increase the efficiency of system activity [4]. The optimization goal of the simulated system is to increase the total produced material quantity and to diminish costs for material transportation. The number of used resources in the goldmine directly affects the amount of total produced material. Resources that are used in the simulated system are shovels, crushers and trucks, which are used for material transportation. The number of trucks affects production costs, so that it is necessary to determine the optimal number of trucks according to their costs and quantity of produced material. Before optimization, 3 shovels, 2 crushers and 30 trucks have been used in the simulation model. The analysis of simulation replications shows that approximately 560 000 t of gold ore are produced during a period of 30 days. During optimization, it is possible to change a number of used resources by decreasing the number of used trucks and increasing the number of shovels and crushers to 5 each, instead of 3 and 2, respectively.

Optimization has been done using Arena built-in optimization tool OptQuest, which applies three meta-heuristic search strategies, i.e., scatter search, tabu search and neural networks. Scatter search is the main search strategy in OptQuest package. It is one of evolutionary algorithms, which operates with a set of solutions and uses special procedures for making combinations of solution [3].

The tool OptQuest provides the search process during optimization, when the objective optimal value is searching by changing control values on the defined constraints [4].

For optimization performance, the optimization model has been created defining controls, constraints and objectives.

According to the previously defined optimization task, two resources – the number of shovels and the number of crushers – have been chosen as variables for optimization as controls. The next stage of optimization model creation is to determine system responses, which are output parameters of the system. According to the defined optimization task, the objective corresponds to the system responses. The goal function of the optimization model is presented below:

$$F = \sum_{i=1}^{n} k \cdot a_{ij} \cdot (b_{ij} \cdot c_i)^{-1} \to max ,$$

where

a_{ij} – the produced material of i^{th} quantity in j^{th} phase,

b_{ij} – i^{th} number of the used trucks in j^{th} phase,

c_i – i_{th} truck cost.

The objective is to reach the maximum value of the goal function with defined constraints to the number of trucks, number of shovels and number of crushers.

Two variables have been chosen as constraints, which correspond to the number of available resources. Both constraints have been defined using the defined variables in the simulation model: number of crushers and number of shovels. During optimization, the number of simulations and replications is equal to 10, but tolerance is 0.0001. There has been an attempt to increase the number of replications during the optimization, but the result of this has been useless – the search time for an optimal solution has increased significantly, but the precision of solutions has remained the same. The search process fro an optimal solution is shown in Fig. 6. OptQuest package shows the best solution search trajectory.

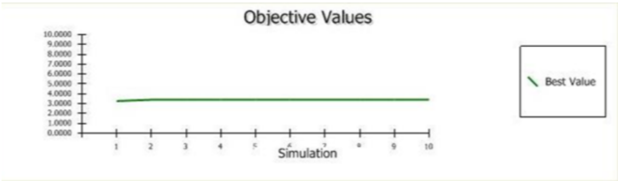

Fig. 6. The search process for an optimal solution

The results of the optimization are summarized in Fig. 7. The best result corresponds to the number of trucks equal to 18. The best value of objective has been found during the second simulation experiment. Decreasing the number of used trucks, costs for ore transportation reduce by 40% in comparison with the simulation results before and after optimization.

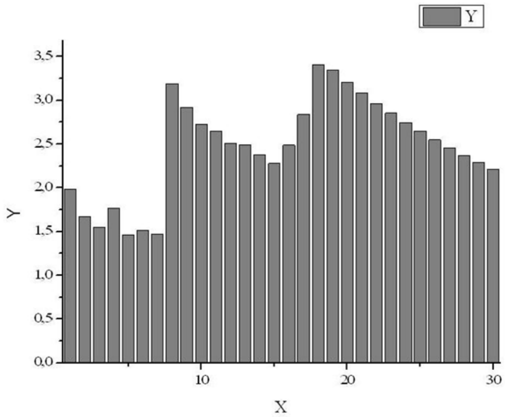

Fig. 7. Optimization results

Based on optimization results, the following recommendations for efficiency improvement of material handling system are developed:

- to reduce the number of transporting trucks from 30 to 18, thereby reducing costs for operation of shovel-truck system;
- to consider the possibility of renting additional trucks for the third and fourth excavation phases;
- to increase the number of crushers from 2 to 3, thereby reducing the total time of produced material transportation (consider, if both crushers are busy, trucks wait in a queue, and as a result the total time for transportation increases).

Conclusions

Within the research, functional processes and operation rules of the goldmine system have been investigated. Business process model of the goldmine system has been described in the form of logic flow chart taking into consideration real data. The design of experiments has been elaborated and various simulation experiments have been performed in order to find interdependency between the performance measure and experimental factors by applying the sensitivity analysis. An optimization model has been developed according to the defined optimization task, and optimal values of system parameters have been determined, using OptQuest software. As a result, the research goal has been achieved, and optimal structure of the goldmine system has been provided.

References

[1] Arena Rockwell Automation 18th Annual Arena Student Simulation Competition: Problem Statement, 2011. - 6 pp.

[2] Brooks R., Tobias A. Choosing the Best Model: Level of Detail, Complexity and Model Performance//Mathematical and Computer Modelling. – No. 24(1996), pp. 1-14.

[3] Fundamentals of Scatter Search and Path Relinking /F. Glover, M. Laguna and R. Martí Control and Cybernetics, vol. 39, 2000, pp. 653-684.

[4] OptQuest for Arena. Arena OptQuest User's Guide, PUBLICATION ARENAOUM001E-EN-P–April 2010, - 48 p.

[5] Robinson S. Simulation: The Practice of Model Development and Use. – Warwick Business School, John Wiley & Sons, Ltd, 2004. – 339 p.

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Liene Andersone, Anna Boguševiča, Aleksandra Petrakova, Jūlija Petuhova. Zelta atradnes sistēmas darbība, pielietojot imitācijas modelēšanu
Pētījumā apskatīta imitācijas modelēšanas tehnikas pielietošanas efektivitāte zelta atradnes sistēmas darbības izpētē. Izmantojot Arena Professional modelēšanas vidi, izveidots zelta atradnes imitācijas modelis. Pētījuma ietvaros tika izstrādāts zelta atradnes sistēmas konceptuālais modelis, kas tika attēlots četros dažādos veidos – komponenšu saraksta, procesa plūsmu diagrammas, biznesa procesa loģikas plūsmu diagrammas un aktivitātes cikla diagrammas veidā. Modeļu salīdzinošā analīze tika veikta, balstoties uz katram modelim piešķirto baļļu skaitu, šiem nolūkiem tika izstrādāta konceptuālo modeļu novērtēšanas sistēma. Pētījuma rezultātā tika noteikts, ka vispiemērotākais un efektīvākais zelta atradnes sistēmas konceptuāla modeļa attēlojums ir biznesa procesu loģikas plūsmu diagramma. Pētījumā tiek veikta zelta atradnes imitācijas modeļa eksperimentu plānošana un analīze. Pētījuma mērķis ir izpētīt metodes imitācijas modelēšanas eksperimentu taktiskai un stratēģiskai plānošanai, realizējot zelta atradnes sistēmas imitācijas modelēšanas projektu. Pētījuma gaitā, lai iegūtu ticamu rezultātu, apskatīts nepieciešamais imitācijas mēģinājumu skaits un modelēšanas laiks. Lai analizētu alternatīvus sistēmas darbības scenārijus un noteiktu rezultāta jutīgumu uz ieejas parametriem, aprakstītas tādas metodes kā pilnais un daļējais faktoriālais eksperiments, regresijas analīze, korelācijas analīze, hipotēžu pārbaude. Pētījuma ietvaros tika veikta iekraušanas-izkraušanas darbu optimizācija, pamatojoties uz definēto optimizācijas uzdevumu. Optimizācijas modelis tika realizēts OptQuest rīkā, kas meklē optimālo mērķa funkcijas vērtību, mainot vadības mainīgo vērtības un ievērojot definētos ierobežojumus. Risināmajā uzdevumā mērķa funkciju bija nepieciešams maksimizēt. Pēc optimizācijas tika veikta iegūto optimizācijas laika rezultātu analīze, nosakot optimālo kravas mašīnu, ekskavatoru un drupinātāju skaitu. Izstrādāto optimizācijas modeli var izmantot, lai paaugstinātu pētāmas sistēmas darbības efektivitāti.

Лиене Андерсоне, Анна Богушевича, Александра Петракова, Юлия Петухова. Анализ работы системы золотого рудника с использованием имитационного моделирования
В ходе исследования, на примере изучения работы системы золотого рудника, была рассмотрена эффективность применения имитационного моделирования. Используя среду моделирования Arena Professional, создана имитационная модель золотого рудника. В рамках исследования была разработана концептуальная модель для системы золотого рудника, отображенная четырьмя различными подходами – в виде списка компонентов, диаграммы потоков процесса, диаграммы логических потоков бизнес-процесса и диаграммы активности цикла. Сравнительный анализ моделей был произведен на основе количества баллов, присужденных каждой модели, для этих целей была разработана система оценивания концептуальных моделей. В результате исследования было установлено, что наиболее подходящим и эффективным способом отображения концептуальной модели системы золотого рудника является диаграмма логических потоков бизнес-процессов. В рамках исследования производится планирование и анализ экспериментов имитационной модели золотого рудника. Цель исследования – изучить методы для тактического и стратегического планирования экспериментов имитационного моделирования, реализуя проект имитационного моделирования системы. Для получения достоверных результатов в работе рассмотрены методы определения необходимого количества экспериментов и времени моделирования. Для анализа альтернативных сценариев работы системы, а также для определения зависимости результатов и входных параметров, рассмотрены такие методы, как полный и частичный факторный эксперимент, регрессионный анализ, корреляционный анализ и проверка гипотез. В ходе исследования была произведена оптимизация погрузочно-разгрузочных работ золотого рудника. Оптимизационная модель была реализована, используя средство оптимизации OptQuest, которое ищет оптимальную величину целевой функции, изменяя значения оптимизируемых переменных и соблюдая установленные ограничения. Решая данную задачу, целевую функцию было необходимо максимизировать. Анализируя результаты оптимизации, было определено оптимальное количество грузовых машин, экскаваторов и дробилок в системе. Разработанную оптимизационную модель можно использовать для повышения эффективности деятельности исследуемой системы.