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FEASIBILITY STUDY OF TRANSPORTATION EQUIPMENT SELECTION ON SURFACE COAL MINE "BOGUTOVO SELO"

TEHNO-EKONOMSKA ANALIZA TRANSPORTNE OPREME NA PRIMERU POVRŠINSKOG KOPA UGLJA BOGUTOVO SELO

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Abstract: *Computer simulation modeling provides a means for studying many types of transportation systems with various types of loading operations in short time. This paper presents technical-thnological and economical conditions analisys for justfication of in pit crushing system for waste transportation on coal open pit mine „Bogutovo Selo" for period up to 2017. year. Base tool for that comparative analisys was simulation modeling in GPSS/H and PROOF software package and DCF method. Verification and validation of models have been done by mine data for past period.*

Key words: *Open-pit mine, transport, model, shovel, truck, in pit crusher, belt conveyor, computer simulation*

Apstrakt: *Računarski simulacioni modeli daju osnovu za razmatranje više različitih kombinacija opreme u veoma kratkom vremenu. Ovim radom je izložena tehničko-tehnološka i ekonomska analiza opravdanosti uvođenja kombinovanog transporta otkrivke na površinskom kopu uglja Bogutovo Selo za period eksploatacije do 2017. godine. Osnovni alat za uporednu analizu bilo je simulaciono modeliranje u GPSS/H i PROOF softverskom paketu i DCF ekonomska metoda verdnovanja. Verifikacija i validacija razvijenog modela je izvršena na osnovu statistički obrađenih podataka sa površinskog kopa u proteklom periodu.*

Ključne reči: *Površinski kop, transport, model, bager, kamion, primarna drobilica, trakasti transporter, računarska simulacija*

1. INTRODUCTION

Strategic long-term or short-term decision-making includes the analysis of numerous different factors, but as a rule, it also implies a certain degree of randomness. The success of mining companies depends on efficient mining, which is, among other things, based on quality planning and control of conveyance costs. Computer simulation models with stochastic elements offer the basis for the fast and quality analysis of different equipment layouts. Computer simulation has been used previously in mining industry for the modelling of rail haulage in coal mines, belt conveyor transport, mining operations in drift and drivages, truck conveyance,

1. UVOD

Strateške odluke u kompanijama uključuju razmatranje više različitih faktora, kratkoročno i dugoročno, i po pravilu, uvek uključuju izvestan stepen slučajnosti. Uspešnost rudarskih kompanija zavisi od efikasne eksploatacije mineralnih sirovina između ostalog zasnovane na kvalitetnom planiranju i upravljanju troškovima transporta. Računarski simulacioni modeli sa elementima stohastike daju osnovu za razmatranje više različitih kombinacija opreme brzo i kvalitetno. Simulacije su u rudarstvu korišćene za modeliranje šinskog transporta u rudnicima uglja, transporta trakastim transporterima, rudarskih operacija u prostorijama i monitoring and dispatching system in surface mines, ore and coal homogenization etc. [1].

Mining engineers presently apply some general-purpose packages to simulate certain particular systems, for example the theory of waiting queues and to write simulation programs using some of the conventional programming languages, such as *Fortran, Paskal, Visual Basic.* Besides, they also use some special-purpose languages that are designed to program discrete simulation models. The most frequently used simulation languages are *GPSS*, SLAM, SIMAN, and AutoMod [2]. The use of simulation languages to analyse the conveyance in surface mines enables easy program modelling by monitoring the sequence of activities and the occurrence of events within the system, with or without the stochastic nature of their occurrence. By introducing random occurrences into the simulation of mining conveyance it is possible to analyse the performance of the equipment more realistically, particularly with respect to the effects of failures.

In mining industry every economic decision includes the consideration of cash flow - outflow and inflow of cash that appears in the form of different currencies. Consequently, economic evaluation must comprise methods that are able to bring into line these values in a determined moment (usually, the present)

This paper presents the techno-economic and feasibility study that deals with the implementation of a compound conveyance method, applied in the open cast mine, Bogutovo Selo, which includes overburden transportation combined with the crushing plant. This study covers the period until the end of its exploitation life (till 2017.). Computer discrete simulation models of discontinuous compound loading-transporting system developed within the GPSS/H language were one of the basic tools, along with the Direct Cash Flow method - DCF for economic evaluation.

In order to achieve the required production the simulation model should provide the analysis of the following issues:

- Production forecasts applying different patterns of the conveyance system;
- The number of trucks required for the performance of the actual loading equipment;
- The transmission efficiency of the crushing plant and the required capacity of the inlet hopper;
- Required capacity of the belt conveyor system.

2. DEVELOPMENT OF THE SIMULATION MODEL

In order to apply successfully the computer simulation methods for the analysis of the system it

hodnicima rudnika, kamionskog transporta, monitoring i dispečing sistema na površinskim kopovima, homogenizacije rude i uglja itd. [1].

U rudarstvu inženjeri, pored opšte namenskih paketa za simulaciju određenih sistema, teorije redova čekanja i pisanja simulacionog programa nekim od tradicionalnih programskih jezika, kao što su *Fortran, Paskal, Visual Basic,* danas koriste specijalne jezike namenski pisane za programiranje diskretnih simulacionih modela. Najčešće korišćeni simulacioni jezici su *GPSS*, SLAM, SIMAN, i AutoMod [2]. Korišćenje simulacionih jezika pri razmatranju transporta na površinskim kopovima omogućuje lako programsko modelovanje praćenjem toka aktivnosti i pojave događaja u sistemu sa ili bez stohastičke prirode njihovog pojavljivanja. Uključivanje slučajnosti u simulaciju rada rudarskih transportnih sistema daje mogućnost realnijeg razmatranja opreme, prvenstveno, u smislu uticaja pojave kvarova.

Svaka ekonomska odluka u rudarstvu uključuje tokove gotovine (keš flou) - odliv i priliv novca, koji se pojavljuju u različitim momentima. Shodno tome, ekonomske procene moraju da sadrže način za usklađivanje ovih vrednosti za neki određeni momenat (obično, sad).

U ovom radu je izložena tehničko-tehnološka i ekonomska analiza opravdanosti uvođenja kombinovanog transporta otkrivke sa drobiličnim postrojenjem na površinskom kopu Bogutovo selo u periodu do kraja veka eksploatacije kopa (do 2017. god.). Kao osnovni alat korišćeni su računarski diskretni simulacioni modeli diskontinualnog i kombinovanog utovarno-transportnog sistema koji su razvijeni u GPSS/H jeziku i metoda direktnog keš flou-a (Direct cash flou-DCF) za ekonomsku procenu.

Simulacionim modelom, u funkciji željene proizvodnje kopa, potrebno je analizirati :

- predviđanje proizvodnje sa različitim strukturama transportnog sitema,
- potreban broj kamiona u radu za postojeću utovarnu opremu,
- propusnu moć drobiličnog postrojenja i potrebnu zapreminu prijemnog bunkera i
- potreban kapacitet sistema transportera sa trakom.

2. RAZVOJ SIMUALCIONOG MODELA

Kod tehnike proučavanja sistema računarskim simulacijama treba razlikovati modelovanje kao postupak kojim se uspostavlja veza između realnog is necessary to distinguish the two basic procedures. The modelling as a procedure used to establish the connection between the real system and the model and the simulation process, which relates to the connections between the model and the simulation mean (computer).

Mostly, the conveying systems in surface mines represent examples that illustrate discrete systems. The models of continuous systems, which are generally non-linear, are solved with differential equations. Certain values, such as the quantity of the material in reloading bins and feeders, change continuously in time during modelling of the belt conveyor network. Under determined conditions it is possible to elaborate a simulation of this process by applying discrete- event simulation. Namely, it is precise to analyse the continuous values that are observed in sufficiently short intervals. [3,4].

The number of trucks in the system and their corresponding capacity may be determined by applying the previously developed computer simulation model of the open cast mine, Bogutovo Selo. The model is developed on the basis of the current state of the mining system and the performance parameters obtained during the previous period. The simulation model is developed in the GPSS/H 3.0 simulation language and the statistical processing of data was performed with Expert Fir software.

The GPSS/H language is oriented towards processes. In this simulation language the program is composed as a collection of process descriptions, constituting segments of the program that determine the sequence of activities and operations, which are through their performance executed over the attributes of the model objects [5]. The only dynamic object in GPSS is "transaction". The program in GPSS consists of a series of static objects known as blocks, through which the transactions are "moving" during simulation. The transaction is moving through the object until it comes across a block that has no conditions to accept it or a TERMINATE block, which eliminates the transaction from the model. During the passage of the transaction through one model block the corresponding block procedures are executed altering specific object attributes thus affecting the setting of the model. Within the principal segment of the model, transactions represent truck movement [6]. Static entities may represent queues, tables, storehouses, facilities etc.

To analyse the conceptual solution of the transport system in the open cast mine, Bogutovo Selo it was necessary to adopt average length values of transport routes, which were obtained by connecting specific bulk material spots in the mining districts with dumping sites, namely with locations determined for crushing plants.

sistema i modela, dok je simulacija proces koji se odnosi na veze između modela i sredstava za simulaciju (računara).

Većina transportnih sistema na površinskim kopovima su primeri diskretnih sistema. Modeli kontinualnih sistema, koji su obično nelinearni, rešavaju se sistemom diferencijalnih jednačina. Pri kreiranju modela sistema transportera sa trakom, određene veličine, kao što su količina materijala u pretovarnim bunkerima i dodavačima, menjaju se kontinualno u vremenu. Pod određenim uslovima moguće je napraviti apstrakciju ovog procesa njegovom diskretizacijom tako da se posmatrane kontinualne veličine razmatraju u dovoljno malim intervalima [3,4].

Određivanje broja kamiona u sistemu i odgovarajućeg kapaciteta sistema obavljeno je primenom prethodno razvijenog računarskog simulacionog modela površinskog kopa Bogutovo Selo. Model je razvijen na bazi sadašnjeg stanja sistema eksploatacije i pokazatelja rada u prethodnom periodu. Simulacioni model je urađen u GPSS/H 3.0 simulacionom jeziku, a statistička obrada podataka obavljena sa ExpertFit softverom.

GPSS/H je jezik orjentisan na procese. Program u ovom simulacionom jeziku komponuje se kao skup opisa procesa u obliku delova programa koji određuju redosled aktivnosti i operacija koje se njihovim izvođenjem vrše nad atributima objekata modela .[5]. Jedini dinamički objekat u GPSS-u je "transakcija". Program u GPSS-u sastoji se od niza statičkih objekata koji se nazivaju blokovi, kroz koje se u toku simulacije "kreću" transakcije. Transakcija se kreće kroz model sve dok ne naiđe na blok koji nema uslova da je primi ili na blok TERMINATE koji uklanja transakciju iz modela. Pri prolazu transakcije kroz jedan blok modela izvršavaju se odgovarajuće blok procedure koje menjaju pojedine atribute objekata i time utiču na okruženje modela. U glavnom delu modela transakcija predstavlja kretanje kamiona [6]. Statički entiteti mogu biti redovi (QUEUE), tabele (TABLE), skladišta (STORAGE), poslužitelji (FASILITY) itd.

Za analizu koncepcijskog rešenja transporta na površinskom kopu Bogutovo Selo usvojene su prosečne dužine transportnih trasa dobijene povezivanjem određenih centara masa na revirima i odlagalištima, odnosno usvojenim lokacijama drobilica.

Razvijeni simulacioni model kombinovanog transportnog sistema zahteva sledeće ulazne podatke: karakteristike mreže transportnih puteva, karakteristike kamiona, karakteristike bagera, The developed simulation model of the compound transport network requires the following input data; features of the transport roads network, truck properties, excavator properties, crushing plant features, belt conveyor features, distribution of probable characteristic values in connection with the system performance, such as periods of equipment serviceability or failure and distribution of speeds for full and empty trucks and other data such as bulk density and bulk modulus of the material transported, etc.

Input data are classified into four separate files. Excavators file contains information about the type and manufacturer, bucket capacity, specific parameters that determine the distribution of serviceability and failure periods. The files containing data on trucks and CBS system are organised in a similar manner. The file of transport road networks contains data on the number of transport routes, number of route sections, length, slopes and radii of curves for each section of the transport route. By creating a collection of input files it is possible to simulate the performance of the system with different properties simply by entering the name of the file type when the program starts.

The model determines the framework of the transportation process considered and the connections between static and dynamic elements in the model. The excavators, conveying routes, crushing plant and belt conveying system are regarded as static elements. It is possible to assess the effects of translocation of excavators and/or crushing plants in the model by entering new transport routes with respective elements for a sufficiently short period of observation. The other conceptual approach is to locate the excavator in the centre of the material that is to be excavated and to connect it with the transport routes leading towards the disposal site/crushing plant. In this way it is possible to establish an average length of the truck transport and to assess the performance of the system over a longer period of time including the static element stated. It may be noted that, at the level of a conceptual elaboration of the model, the change of transport routes transfers the static elements in the system into dynamic.

The model considers trucks and the material transported as dynamic elements. The trucks travel from the loading point towards the crushing plant transporting the excavated material. Empty trucks move from the crushing plant towards the excavator, from the crushing plant towards the parking place for shift take-over, or towards the repair and maintenance service and from the parking place/ repair and maintenance service towards the excavator. It is considered that the transport routes are able to provide simultaneous truck traffic in both directions (two-way roads). The time schedule of movement for full and empty trucks, and the transfer of the material loaded

karakteristike drobilice, karakteristike transportera sa trakom, raspodele verovatnoće karakterističnih veličina povezanih sa radom sistema, kao što su vremena ispravnosti i otkaza opreme ili raspodela brzina kretanja punih i praznih kamiona, ostali podaci kao što su gustina materijala koji se transportuje, koeficijent rastresitosti materijala itd.

Ulazni podaci su razvrstani u četiri nezavisne datoteke. Datoteka o bagerima sadrži informacije o tipu i proizvođaču bagera, o zapremini kašike bagera, o određenim parametrima raspodela vremena u kvaru i vremena ispravnosti bagera. Slično su organizovane i datoteke sa podacima o kamionima i DTO sistemu. Datoteka o mreži transportnih puteva sadrži podatke o broju transportnih pravaca, broju deonica, dužini, nagibima i radijusima krivina za svaku deonicu transportnog puta. Kreiranjem više skupova ulaznih datoteka omogućeno je simuliranje rada sistema sa različitim karakteristikama jednostavnim unosom naziva pomenutih tipova datoteka pri pokretanju programa.

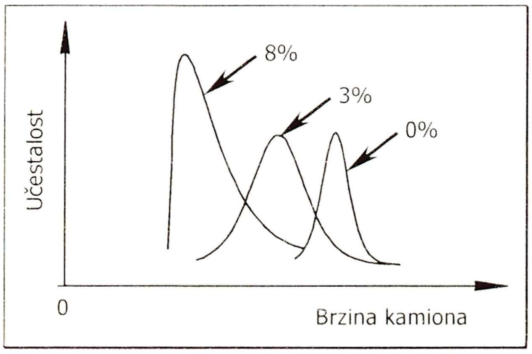
Modelom je određen okvir transportnog procesa koji se razmatra i veze između statičkih i dinamičkih elemenata u modelu. Kao statički elementi u sistemu razmatraju se bageri, transportne trase, drobilično postrojenje i sistem transportera sa trakom. Mogućnost razmatranja uticaja promene položaja bagera i/ili drobiličnog postrojenja u modelu se ostvaruje unosom novih transportnih trasa sa svojim elementima za dovoljno mali vremenski interval posmatranja. Drugi konceptni pristup je postavljanje bagera u centar masa koje treba da se otkopaju i njegovo povezivanje transportnim trasama do odlagališta/drobiličnog postrojenja, čime se uprosečuje dužina kamionskog transporta i omogućava razmatranje rada sistema u dužem vremenskom periodu sa ovim statičkim elementima. Možemo da kažemo na nivou konceptne razrade modela da promenom transportnih trasa i statičke elemente u sistemu prevodimo u dinamičke.

Kao dinamičke elemente model razmatra kamione i transportovani materijal. Kamioni se kreću od mesta utovara do drobiličnog postrojenja prevozeći otkopani materijal. Prazni kamioni se kreću od drobilice do bagera, od drobilice do parkirališta za primopredaju smene, odnosno servisne službe i od parkirališta/servisne službe do bagera. Smatra se da transportni putevi omogućavaju istovremeni saobraćaj kamiona u oba pravca (dvosmerni putevi). Vremenska slika trajanja aktivnosti kretanja punih i praznih kamiona, kao i kretanja materijala sa trakom na transporteru, dobija se u zavisnosti od brzina tih dinamičkih elemenata i dužine trasa po kojima oni treba da se kreću. Brzine kretanja on belt conveyors is obtained in dependence of the speed developed by these dynamic elements and the length of the routes travelled by them. The speed rates of the trucks are considered as random values within the framework of the given limits determined by the conditions of the transport route. In the course of one simulated transfer the rate of the material transported by the belt is constant.

Truck speeds are generated according to the distributions adopted for known inclined sections and equal-type distributions with mathematical expectations obtained according to the regression curve of such expectations as function of the slope [7]. Such approach offers an improved flexibility of the model in terms of new inclinations in transport routs that actually do not exist in the mine and therefore are not available for analysis. Figure 1 presents the intensity of distributions adopted and their mutual position against possible slopes.

kamiona se smatraju slučajnom veličinom u okviru zadatih granica definisanih uslovima transportne trase. Brzina kretanja materijala na traci je konstanta u toku jednog simulacionog prolaza.

Brzine kamiona generišemo prema usvojenim raspodelama za poznate nagibe deonica i raspodelama istog tipa sa matematičkim očekivanjima dobijenim prema regresionoj krivoj tih očekivanja u funkciji nagiba deonica[7]. Ovaj pristup daje veću fleksibilnost modela u smislu novih nagiba transportnih puteva na posmatranom kopu koji trenutno ne postoje i nije ih moguće analizirati. Na slici 1 su prikazane gustine usvojenih raspodela i njihov međusobni položaj prema mogućim nagibima deonica.



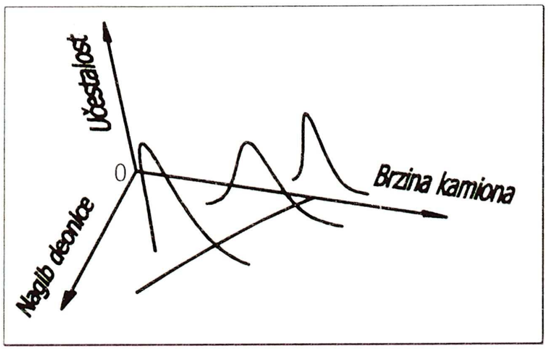


Figure 1 Distribution intensity for the generation of full truck speed rates depending on the slope of the road section

Slika 1 Gustine raspodela za generisanje brzina kretanja punih kamiona u zavisnosti od nagiba deonice puta

Apart from the previously stated, the model describes the equipment serviceability schedule. In terms of this schedule each excavator and truck, crushing plant, belt conveyor and spreader may have two conditions: serviceable and out of service. These conditions are to be generated on the basis of collected data and practical parameters. The time-span of serviceable and intervals and breakdown intervals are regarded as random values. Due to these conditions the system should be considered as a continuous entity in order to avoid the limitations imposed by the periods of performance or failure. When one excavator breaks down the trucks assigned to it are, at the unloading point reassigned to the serviceable excavator with the fewest number of trucks in the waiting queue.

The structure of the simulation model clearly identifies six characteristic sections, as follows:

1. Sub-model for the simulation of truck movement,
2. Sub-model of truck's transport cycle,
3. Sub-model of shovel excavator loading process

Pored opisanog, model razmatra vremensku sliku ispravnosti opreme. Svaki bager i kamion, drobilica, transporter sa trakom i odlagač mogu da imaju dva stanja u tom smislu: ispravan i neispravan. Ova stanja moraju da se generišu na osnovu prikupljenih podataka i iskustvenih pokazatelja. Dužine intervala ispravnosti i kvara smatraju se slučajnim veličinama. Zbog ovih stanja opreme sistem je potrebno tretirati kao neprekidan da nebi ograničavali vremena rada i otkaza opreme. Pri otkazu jednog bagera, njemu dodeljeni kamioni se na mestu istovara dodeljuju onom ispravnom bageru koji ima najmanji broj kamiona u redu čekanja.

U strukturi simulacionog modela jasno se izdvaja sedam karakterističnih delova i to:

1. podmodel za simulaciju kretanja kamiona,
2. podmodel transportnog ciklusa kamiona,
3. podmodel procesa utovara bagerom kašikarom,

4. Sub-model for the simulation of in-service and out-of- service modes,
5. Dub-model of the process denoting the unloading of the truck into the crushing plant,
6. Sub-model of material reloading from crusher to belt conveyor,
7. Sub-model for the execution of simulation experiments and the control of their number and duration,

The simulation model is used to assess the simultaneous operation of three excavators. In this way it is possible to perceive the mutual interaction between discontinuous systems, excavator-trucks, and to acquire a real notion of trucks congestion at points of unload into inlet hoppers of the semi-stationary crusher plants in combined transport systems.

The model is verified during its designing. The completed model was validated by comparing previously recorded capacities of the actual system and the capacity obtained as the result of simulated output. It should be mentioned that animation was used for model designing and verification since it is the most natural way of testing the techniques installed in the model.

Animation in computer simulation analyses is highly popular due to its simple and user-friendly presentation of numeric results obtained by simulation of considered system components. This was one of the basic reasons to develop the animation structure of the model that would be used to analyse the considered issues of conveyance in the surface mine, Bogutovo Selo - Ugljevik. The program PROOF ANIMATION has been used, along with the programming language GPSS/H, which is delivered along with it. In this way the animation is provided after the completion of simulation. It was necessary to supply the program code with additional directives for the dump of the new animation file with the extension *.atf (animation trace file), which provides the dynamic presentation of the system in time. Besides, the basis with the disposition of the transport routes in the mine and other parameters recommendable for dump are formatted in the editor of the Proof Animation program during the animation session. Figure 2 presents the structure of inputs used to design the animation.

In the GPSS/H program model the commands PUTPIC and BPUTPIC dump the queues of the animation file with characteristic words TIME, CREATE, PLACE AT etc.

4. podmodel simulacije stanja ispravnosti i otkaza opreme,
5. podmodel procesa istovara kamiona u drobilicu,
6. podmodel pretovara materijala iz drobilice na trakasti transporter i
7. podmodel za izvođenje simulacionih eksperimenata i kontrolu njihove dužine i broja

Simulacionim modelom razmatran je istovremeni rad tri bagera čime je omogućeno sagledavanje međusobne interakcije diskontinualnih sistema bager-kamioni, a isto tako i dobijanje realne slike nagomilavanja kamiona na istovaru u prijemne bunkere polustacionarnih drobiličnih postrojenja kod kombinovanog sistema transporta.

Verifikacija modela je obavljana u toku njegovog kreiranja, a validacija gotovog modela je izvršena upoređivanjem snimljenih kapaciteta realnog sistema i kapaciteta dobijenog kao izlaz simulacionog modela. U procesu kreiranja i verifikacije modela korišćena je animacija kao najprirodniji način za proveru svih mehanizama ugrađenih u model.

Popularnost animacije u računarskim simulacionim analizama je posledica jednostavnog i pristupačanog prikaza numeričkih rezultata simulacije razmatranih komponenti sistema dinamički. Ovo je bio osnovni razlog da se razvije i animaciona struktura modela za analizu razmatrane problematike transporta na površinskom kopu Bogutovo Selo - Ugljevik. Korišćen je PROOF ANIMATION računarski program koji se isporučuje zajedno sa GPSS/H jezikom. Na ovaj način se dobija animacija posle završetka simulacije. U kodu programskog modela bilo je neophodno dodavati naredbe za ispis nove, animacione datoteke sa nastavkom *.atf (animatin trace file) koja daje dinamičku sliku sistema u vremenu. Pored toga u editoru Proof animation programa formirana je osnova sa situacijom transportnih puteva na kopu i ostalim parametrima koji su bili poželjni za ispisivanje u toku animacione sesije. Na slici 2 data je struktura ulaza za kreiranje animacije.

U GPSS/H programskom modelu naredbama PUTPIC i BPUTPIC ispisivali su se redovi animacione datoteke sa karakterističnim rečima TIME, CREATE, PLACE AT itd.

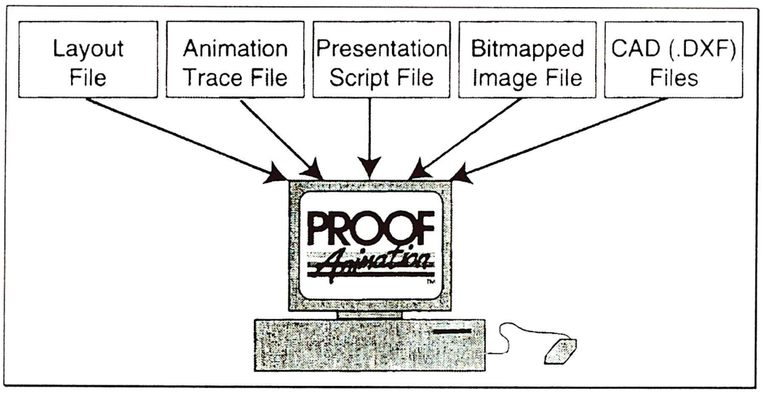


Figure 2 Structure of inputs used to design the animation in the Animation Proof program, [8]
Slika 2. Struktura ulaza za kreiranje animacije u Animation Proof programu,[8]

3. CURRENT TRANSPORT SYSTEM

In the surface coalmine, Bogutovo Selo according to former designs, the discontinuous mining system has been applied for removal, loading and transport of overburden. The removal of overburden is carried out without prior blasting, except for the portions with limestone massif. The removal and loading of overburden is performed with hydraulic shovel excavators H-341 with 14 m^3- shovel capacity and RH-120 with 12 m^3-shovel capacity.

The overburden is transported towards the disposal site by trucks Faun K.100 (90,7 t), LH M120 (108,7 t), Wabco (108,7 t) and M30 (117 t).

On the bases of exposed problems and in order to estimate as precisely as possible the mining parameters that determine the performance of the equipment it was necessary to collect the input data and classify them into shift reports and schedules of working cycles. All the data samples are statistically analysed and after that it was possible to obtain their theoretical distributions.

The average annual output of the excavators H-241 and RH120 is 1,795x10^6 m^3 of solid material and the average number of effective operating hours per annum is 4027 h. This means that the average hourly capacity of 446 m^{3}s/h has been fulfilled.

The average annual operating time of the truck LH-120M is 2980 h and of the Faun K-100 it reaches 3388 h. The average speed that has been developed with full trucks is17 km/h, while 19,8 km/h is the maximum speed recorded with full trucks. The average speed of empty trucks is estimated to 18,9 km/h.

Apart from the parameters stated above it was also precise to assess the reliability of the equipment. and developed graphs, histogram/intensity of the frequencies of serviceability and breakdown time-spans for the excavator DEMAG H-241.

3. POSTOJEĆI SISTEM TRANSPORTA

Prema dosadašnjim projektnim rešenjima na površinskom kopu uglja Bogutovo Selo za otkopavanje, utovar i transport otkrivke koristi se diskontinualni sistem eksploatacije. Otkopavanje otkrivke se obavlja bez prethodnog miniranja izuzev u delovima krečnjačkog masiva. Za otkopavanje i utovar otkrivke koriste se hidraulički bageri kašikari H-241, sa zapreminom kašike od 14 m^3 i RH-120, sa zapreminom kašike od 12 m^3.

Transport otkrivke do odlagališta obavlja se kamionima Faun K.100 (90,7 t), LH M120 (108,7 t), Wabco (108,7 t) i M30 (117 t).

Na osnovu postavljenih problema, u cilju što tačnije procene eksploatacionih pokazatelja rada opreme, izvršeno je prikupljanje ulaznih podataka grupisanih u uzorke iz smenskih izveštaja i vremenske studije ciklusa rada opreme. Svi uzorci su, zatim, statistički analizirani i dobijene su teoretske raspodele tih podataka.

Prosečno ostvarena godišnja proizvodnja bagera H-241 i RH120 iznosi 1,795 x 10^6 m^3 čvrste mase, a njihov prosečni ostareni godišnji fond rada je iznosio 4027 h, čime je ostvaren prosečni časovni kapacitet od 446 m^{3}č/h.

Prosečno godišnje vreme rada kamiona LH-120M iznosi 2980 h, a kamiona Faun K-100 3388 h. Ostvarene prosečne brzine punih kamiona iznose 17 km/h. Evidentirane maksimalne brzine kretanja punih kamiona iznose 19,8 km/h. Prosečna brzina kretanja praznih kamiona je procenjena na 18,9 km/h.

Pored navedenih pokazatelja razmotreni su i elementi pouzdanosti opreme i dobijeni su dijagrami histogrami/gustina učestalosti vremena trajanja ispravnosti i kvara bagera DEMAG H-241.

The average time-span for the breakdown of the excavator H-241 is 3,3 h and for the excavator RH-120 it amounts to 3,64 h. The serviceability time-span for the excavator H-241 is 19,4 h on the average and for the excavator RH-120 it is 20 h. The average duration of breakdown and repair for the truck LH-120 is 9,9 h and for the truck Faun K-100 it is 8,35 h.

On the basis of collected data about the actual system this paper analyses the following combinations of discontinuous systems in conjunction with or without crushers and rubber belt conveyors:

- RH120/Faun K.120 (90 t)
- RH120/LH M.120 (110 t)
- H241/CAT 785B (136 t)

Prosečno vreme trajanja otkaza bagera H-241 je 3,3 h, a bagera RH-120 3,64 h. Vreme ispravnosti bagera H-241 iznosi u proseku 19,4 h, a bagera RH-120 20 h. Prosečno vreme trajanja kvara i opravke kamiona LH-120 iznosi 9,9 h, a kamiona Faun K-100 8,35 h.

Na osnovu prikupljenih podataka o realnom sistemu u radu su razmatrane sledeće kombinacije diskontinualnih sistema u kombinaciji i bez drobilica i transportera sa gumenom trakom:

- RH120/Faun K.120 (90 t)
- RH120/LH M.120 (110 t)
- H241/CAT 785B (136 t)

4. SIMULATION OF DISCONTINUOUS TRANSPORT SYSTEMS

Input data: Distribution of overburden quantity per disposal site, given in Table 1.

4. SIMULACIJA DISKONTINUALNOG TRANASPORTNOG SISTEMA

Ulazni podaci: Distribucija količina otkrivke po odlagalištima je data u tabeli 1.

Table 1 Distribution of overburden per disposal site
Tabela 1 Distribucija otkrivke po odlagalištima

Disposal site	Mining field-district			
	(C1)	(C2)	(C3)	Total, m^3
(O1)	16.256.278	-	-	16.256.278
(O2)	25.133.496	7 000 .000	21.007.818	53.141.314
(O3)	-	13 041 908	-	13 041 908
(O4)	-	-	35.309.438	35.309.438
Total, m^3	41.389.774	20.041.908	56.317.256	117 748 938

Figure 3 presents the animation screen of the model that displays transport routs per each face.

Statistically processed data about the scheduling of specific activities within the transport cycle, statistically processed values per each year and the values that were obtained from the investor were used for the generation of random values:

- In the model truck speed rates are generated as Normal Distribution, and they were determined according to:

- Sample of speed rates recorded in the mine,
- Truck performance curves (haulage and breaking features), and
- Safe conditions for truck driving (breaking, haulage, curves).

Na slici 3 je prikazan ekran animacije modela sa prikazanim transportnim trasama po otkopima.

Za generisanje karakterističnih slučajnih vrednosti veličina u modelu korišćeni su statistički obrađeni podaci vremenske studije pojednih aktivnosti transportnog ciklusa, statistički obrađene vrednosti po godinama i vrednosti veličina dobijenih od samog investitora.

- Brzine kretanja kamiona su u modelu generisane Normalnom raspodelom, a određene su prema:

- uzorku snimljenih brzina na kopu,
- krivama performansi kamiona (vučna i kočiona karakteristika) i
- sigurnim uslovima vožnje kamiona (kočenje, vuča, krivine).

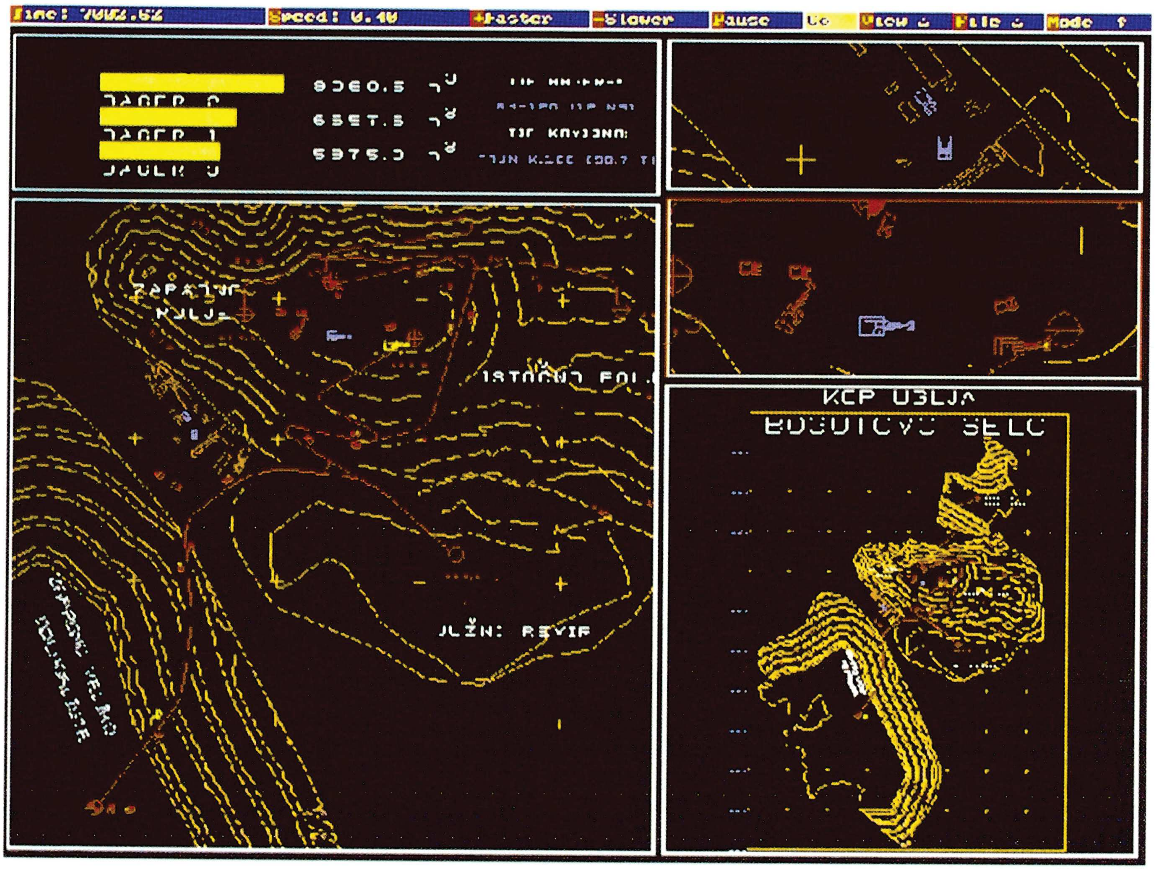


Figure 3 Animation screen displaying a discontinuous transport system in the surface mine, Bogutovo Selo - Ugljevik

Slika 3 Prikaz ekrana animacije modela diskontinualnog sistema transporta na površinskom kopu Bogutovo Selo Ugljevik

Performance and repair hours are generated as Weibullxs and Pearsonxs distributions, which were determined according to samples of data collected in the mine.

Simulation results: The results obtained from simulation experiment with the model of discontinuous transport were thoroughly analysed. It may be concluded that according to achieved excavator capacities and maximum capacity balance between excavators and trucks it was possible to determine the number of trucks that is required for the considered combinations with loading and transport equipment.

The number of trucks required for one-excavator performance is determined according to the results of simulation experiments and statistically obtained average excavator performance. Figure 4 presents the simulation results for the system RH-120/Faun K.100 for the transport route - West Field - Large Western Disposal Site (C1-O2). Table 2 presents the required number of systems with the optimal number of trucks for the designed annual capacity.

Vremena rada i popravke opreme su generisana Weibull-ovom i Pearson raspodelama, određenim prema uzorcima prikupljenih podataka na kopu

Rezultati simulacije: Analizom rezultata simulacionih eksperimenata sa modelom za diskontinualni transport, prema ostvarenim kapacitetima bagera i maksimalnom stepenu usklađenosti kapaciteta bagera i kamiona, određen je potrebni broj kamiona u sistemu za razmatrane kombinacije utovarne i transportne opreme.

Potreban broj kamiona za rad sa jednim bagerom određen je prema rezultatima simulacionih eksperimenata i statistički dobijenog prosečnog učinka bagera. Na slici 4 prikazani su rezultati simulacije za sistem RH-120/Faun K.100 za transportnu trasu Zapadno polje- Veliko zapadno odlagalište (C1-O2), a u tabeli 2 dat je potrebni broj sistema sa optimalnim brojem kamiona u sistemu za projektovani godišnji kapacitet.

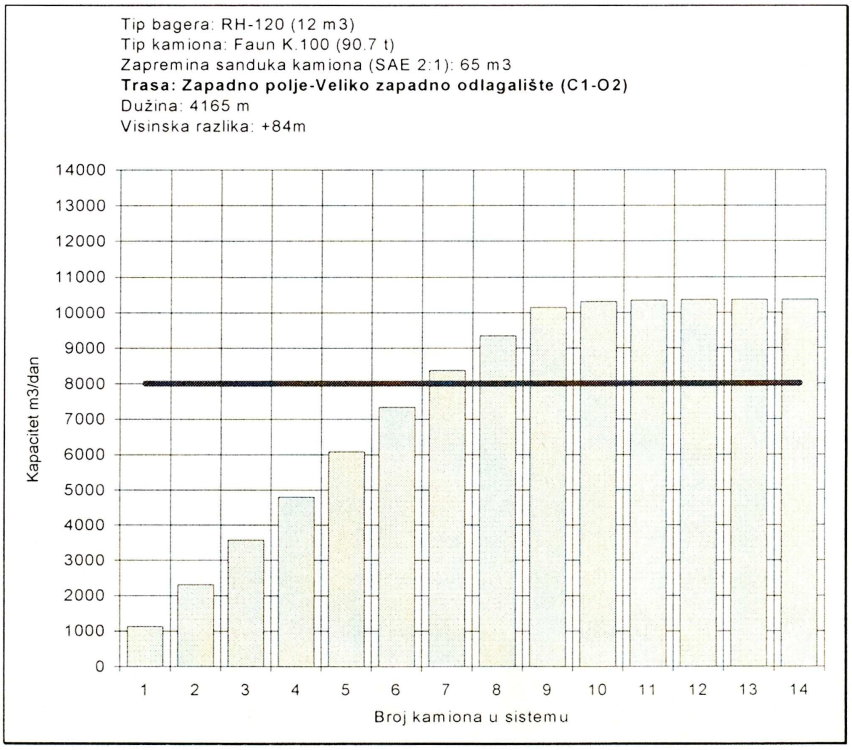


Figure 4 Diagram of capacity balance
Slika 4 Dijagram usklađenosti kapaciteta

Table 2. Required number of excavators and trucks
Tabela 2. Usvojeni broj bagera i kamiona

Route - length	Required number of systems/trucks		
	RH-120/ FAUN K.100	RH-120/ LH M120	H-241/ CAT 785B
$L_{C1\text{-}O1}$=2335m	4/20	5/20	5/15
$L_{C1\text{-}O2}$=4165m	5/35	5/35	5/25
$L_{C2\text{-}O2}$=4115 m	4/28	5/35	4/20
$L_{C2\text{-}O3}$=1625m	5/20	4/12	4/12
$L_{C3\text{-}O2}$ =2525m	5/25	5/20	5/15
$L_{C3\text{-}O4}$=1815m	4/16	4/16	4/12

5. SIMULATION OF COMBINED TRANSPORT SYSTEM

Input data: The total amount of overburden is transported towards the crushing plant and from there belts conveyors transfer it to the Large Western Disposal Site. The distribution of overburden per mining districts/fields is:

for C1-D5=41 389 774 m^3,
for C2-D5=20 041 908 m^3,
for C3-D6=56 317 256 m^3.

5. SIMULACIJA KOMBINOVANOG TRANSPORTNOG SISTEMA

Ulazni podaci: Ukupna količina otkrivke se transportuje do drobiličnog postrojenja, a odatle trakastim transporterima na Veliko zapadno odlagalište. Distribucija količina otkrivke po revirima/poljima iznosi:

za C1-D5=41 389 774 m^3,
za C2-D5=20 041 908 m^3,
za C3-D6=56 317 256 m^3.

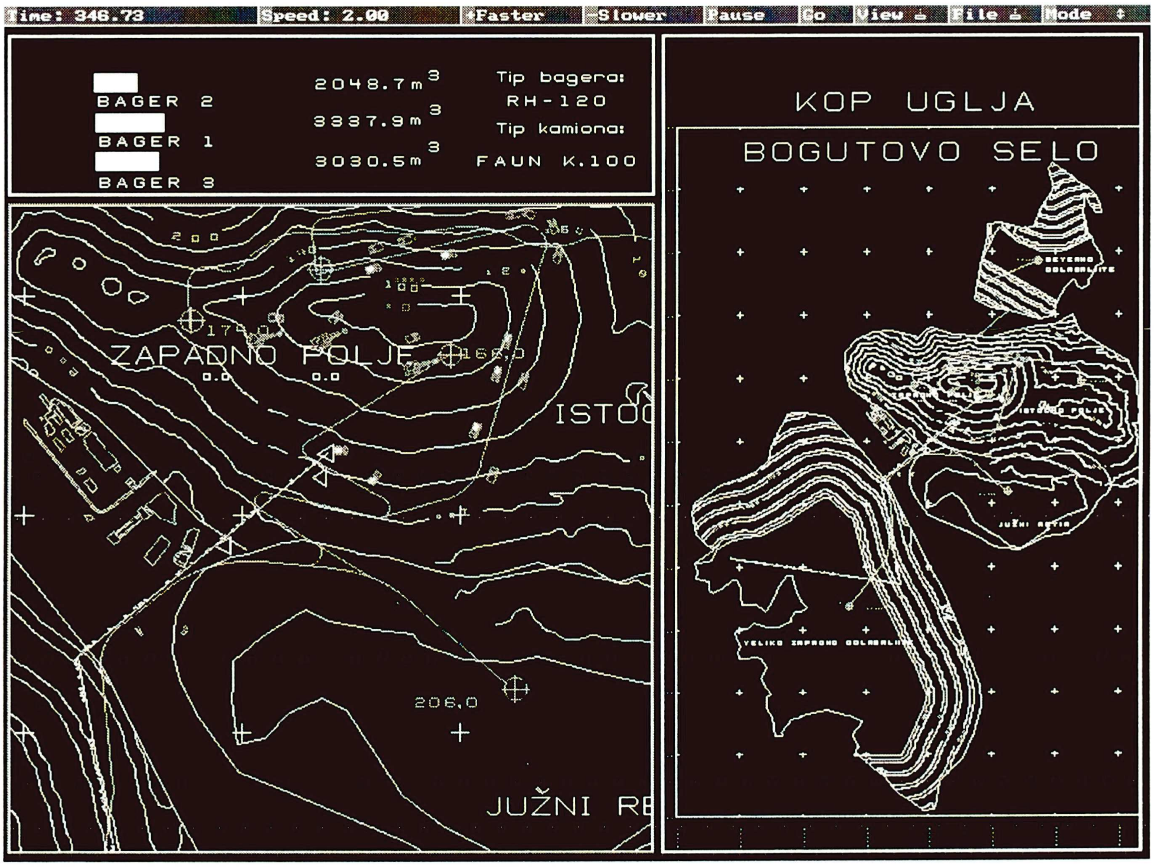


Figure 5 Animation scope display of the combined transport system model in the surface mine, Bogutovo Selo - Ugljevik

Slika 5 Prikaz ekrana animacije modela kombinovanog sistema transporta na površinskom kopu Bogutovo Selo Ugljevik

Apart from the values that were processed and used for the discontinuous system model (excavators-trucks) the model of combined transport also considers the performance of the crushing plant and a group of belt conveyors.

- Parameters of discontinuous transport are considered in the same way as in the excavator-truck model.
- Crushing plants achieve the capacity of 3000 t/h of bulk material and are supplied with 200 m^3-inlet hoppers. Inlet hoppers and crushers are feed from two sides. In order to acquire a real and accurate image of crushers' performance over a longer period of time the model considers the breakdowns, which are generated through total efficiency according to Triangular Distribution with parameters (0,80/0,85/0,95).

Within the model it is considered that belt conveyors are in every moment able to receive the entire quantity of overburden that goes through the crusher with uniform loading on the conveyor. The reloading of the material from the crusher to the belt conveyor system

Pored veličina koje su obrađene i korišćene u modelu diskontinualnog sistema (bager-kamioni), model kombinovanog transporta razmatra rad drobiličnog postrojenja i grupe trakastih transportera.

- Parametri diskontinualnog transporta se razmatraju isto kao i u modelu sistema bager-kamioni.
- Drobilice ostvaruju kapacitet od 3000 t/h rastresite mase i imaju prijemne bunkere zapremine 200 m^3. Prijemni bunker drobilice se puni sa dve strane. Radi dobijanja realne slike rada drobilica za duži vremenski period u modelu se razmatraju kvarovi koji se generišu preko ukupne spremnosti po Trougaonoj raspodeli sa parametrima (0,80/0,85/0,95).

Transporteri sa trakom se u modelu razmatraju tako da uvek mogu da prihvate svu količinu otkrivke koja prolazi kroz drobilicu sa ravnomernim utovarom na transporter. Pretovar materijala iz drobilice na sistem transportera sa trakom u modelu je kreiran primenom postupka diskretizacije kontinualnih is designed within the model by applying the discrete-event simulation of continuous processes. Discrete time interval lasts 1 minute.

Simulation results: According to the results of simulation it was possible to determine the number of trucks in the system, Table 3,

Table 4 presents the number of excavators required for the optimum number of trucks in the system for the planned production rate.

procesa. Vremenski diskretizacioni interval iznosi 1 minut.

Rezultati simulacije: Prema ostvarenim rezultatima simulacije određen je potreban broj kamiona u sistemu, tabela 3.

U tabeli 4 dat je potreban broj bagera sa optimalnim brojem kamiona u sistemu za planirani obim proizvodnje.

Table 3 The number of trucks required for one-excavator performance within a combined system
Tabela 3 Potrebni broj kamiona za rad jednog bagera u kombinovanom sistemu

Transport route	Number of trucks required in the system		
	RH-120 / Faun K.100	RH-120 / LH M.120	H-241 / CAT 785B
C1-D5	4	4	3
C2- D5	5	4	3
C3- D6	3	3	2
C1-D5 Western Field - crusher(D5)-Large northern disposal site C2-D5 Eastern field - crusher(D5)- Large northern disposal site C3-D6 Southern Mining District - crusher (D5)- Large northern disposal site			

Table 4 Required number of excavators/trucks
Tabela 4 Potrebni broj bagera/kamiona

Transport route	Required number of excavators/trucks		
	RH-120/ FAUN K.100	RH-120/ LH M120	H-241/ CAT 785B
L_{C1-D5}=1725m	5/20	5/20	5/15
L_{C2-D5}=1725m	4/20	5/20	5/15
L_{C3-D6}=975 m	5/15	4/12	4/8

6. ECONOMIC ANALYSIS

Significant calculations of investments that are to be made in mining industry must inevitably include a detailed demonstration of cash flow that occur each year in the course of the mining process. The first stage comprises the calculation of the total cash flow (the sum of anticipated positive and negative flows) that occurs every year. In the next stage this value is by means of discount rates translated into present value. The discount rate is generally higher than long-term interest rates to take into account the fluctuations and other factors.

In simple estimates, future values (FVs) are calculated by multiplying the current values with the respective rate of interest. Or, equivalently, future values (anticipated cash flow) are translated into present value (PV).

The first series of estimates use simple formulae for the scaling of anticipated cash flow to the equivalent calculating time reference. Simple estimates are classified into two categories:

6. EKONOMSKA ANALIZA

U značajnim kalkulacijama koje su vezane za investicije u rudarstvu, neizostavno je kompletno prikazivanje za sve tokove gotovine koji nastaju svake godine tokom trajanja eksploatacije. Prvo se proračunava keš flou u celosti (suma očekivanih pozitivnih i negativnih tokova), koji nastaje svake godine, a onda se ova vrednost prevodi u sadašnju vrednost preko diskontne stope. Diskontna stopa je obično veća od dugoročne kamatne stope, kako bi bila uzeta u obzir kolebanja i drugi faktori.

U jednostavnim proračunima, buduće vrednosti (FVs – future values) se izračunavaju tako što se tekuće vrednosti množe odgovarajućom kamatnom stopom. Ili, ekvivalentno, buduće vrednosti (pretpostavljeni keš flou) se prevode u sadašnju vrednost (PV – present value) odbijanjem tj. deljenjem sa kamatnom stopom.

Prva serija kalkulacija primenjuje jednostavne formule za preračunavanje pretpostavljenih tokova gotovine (keš floua) na ekvivalentnu vremensku referencu za izračunavanje. Jednostavne kalkulacije su grupisane u dve kategorije i to:

- how to scale the future value against the equivalent present value, and
- How to scale the regular series of equal values that occur during over the period of several years to the equivalent unique present amount and vice versa.

In order to establish the relation between present and future values it is advisable to use two functions: the function denoting the calculation of the amount with interests (future values) and the function denoting the calculation of present values. [10]. The future value (amount with interest) is determined according to the formula:

$$FV = PV \times (1 + i)^n \quad (1)$$

Where:
FV - future value
V - present value
i - interest rate for a determined period of time
n - number denoting the period of time - year
$(1 + i)^n$ - correlation factor

In order to establish the relation between regular series of values that occur in the course of several years and the equivalent unique factor it is advisable to use the function of repatriation (return) of capital and the function of depreciation reserve.

The function of repatriation of capital is used to distribute the amount of present value over the period of n years. The results constitute a series of equal values that occur at the end of each year for a determined period of time. In general:

$$\text{Factor of capital growth} = i/[1-(1/(1+i)^n)] = i \times (1+i)^n/[(1+i)^n-1]$$

This factor is multiplied with the initial overall cost in order to obtain the equivalent of the annual cost.

The elements obtained by simulation experiments were reduced to the present value by applying the discount rate of 8% per annum, taking into account that it must be properly evaluated to what extent and in which direction the choice of the discount rate affects the accomplished results.

The sizing of the transport system is critical during the III, IV and V year, according to the anticipated schedule of overburden removal and distribution. The overburden is transported from the Western Field of the Northern Mining District to the Large Western Disposal Site (C1-O2). Figure 6 shows the comparative layout of the required number of trucks with 136 t of load bearing capacity within a discontinuous and combined system.

- kako preračunati buduću vrednost na ekvivalentnu sadašnju i
- kako preračunati regularne serije jednakih vrednosti koje nastaju u periodu od nekoliko godina na ekvivalentan jedinstven iznos u sadašnjosti i obratno.

Da bi se uspostavila relacija između sadašnjih i budućih vrednosti koriste se dve funkcije: funkcija proračuna iznosa s kamatom (buduće vrednosti) i funkcija proračuna sadašnje vrednosti [10]. Buduća vrednost (iznos s kamatom) određuje se obrascem:

$$FV = PV \times (1 + i)^n, \quad (1)$$

gde je:
FV - buduća vrjednost (future value),
PV - sadašnja vrjednost (present value),
i - kamatna stopa za određeni vremenski period (interest rate),
n - broj vremenskih perioda - godina (number),
$(1 + i)^n$ - vezni faktor (faktor korelacije).

Da bi se uspostavila relacija između regularnih serija jednakih vrednosti koje nastaju tokom perioda od nekoliko godina i ekvivalentnog jedinstvenog iznosa, koriste se funkcija povraćaja kapitala i funkcija amortizacijskog fonda.

Funkcija povraćaja kapitala se koristi za raspoređivanje iznosa sadašnje vrednosti na period od n godina. Rezultat su serije jednakih vrednosti koje nastaju na kraju svake godine za određeni vremenski period. U opštem slučaju:

$$\text{faktor povraćaja kapitala} = i/[1-(1/(1+i)^n)] = i \times (1+i)^n/[(1+i)^n-1].$$

Ovaj se faktor množi početnim ukupnim troškom kako bi se dobio ekvivalent godišnjeg troška.

Svođenje elemenata dobijenih simulacionim eksperimentima na sadašnju vrednost izvršeno je primenom diskontne stope od 8% godišnje, s tim da je dodatno ocenjeno u kojoj meri i u kom pravcu izbor diskontne stope utiče na dobijene rezultate.

Prema predviđenoj dinamici otkopavanja i distribucije otkrivke kritičan period sa aspekta dimenzionisanja transportnih sistema javlja se u III, IV i V godini eksploatacije sa Zapadnog polja Severnog revira pri transportu otkrivke na Veliko zapadno odlagalište (C1-O2). Na slici 6 dat je uporedni prikaz potrebnog broja kamiona nosivosti 136 t u diskontinualnom i kombinovanom sistemu.

The Figures 7 and 8 show the structure of aggregate investment. The material and energy costs are dominant and their share in aggregate investment ranges from 38% to 43% in dependence of the transport alternative.

Slike 7 i 8 pokazuju strukturu ukupnih ulaganja. Dominantno mesto imaju troškovi materijala i energije koji učestvuju sa 38% do 43% u ukupnim ulaganjima po varijantama transporta.

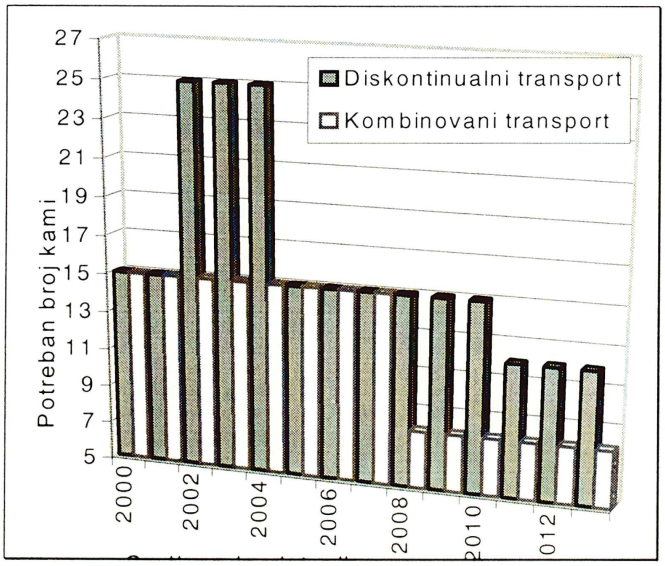


Figure 6 The required number of 136-t load-bearing capacity trucks in operation
Slika 6 Potreban broj kamiona nosivosti 136 t u radu

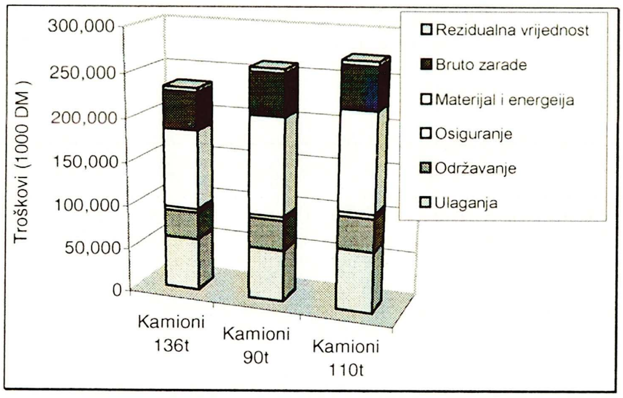


Figure 7 Structure of costs accounted for discontinuous systems of overburden conveyance

Slika 7 Struktura troškova diskontinuiranih transportnih sistema na otkrivci

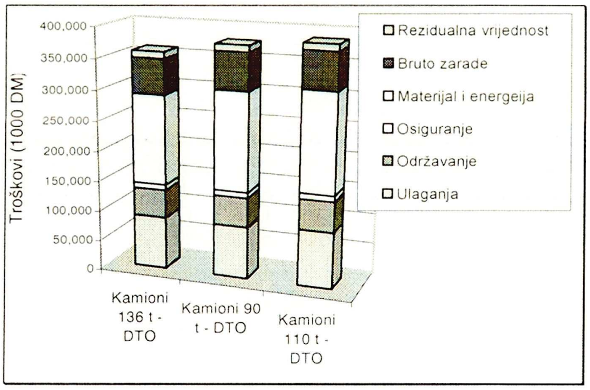


Figure 8 Structure of costs accounted for combined systems of overburden conveyance

Slika 8 Struktura troškova kombinovanih transportnih sistema na otkrivci

In order to make a correct comparison of different alternatives for overburden conveyance it is necessary to assess the number of necessary substitutions within the truck-motor pool over the considered mining period. According to the accepted depreciation rate of 14,3%, the annual substitution of trucks should take place after seven years of performance, namely in 2007. On the other hand, the service life of the CBS system is much longer and it comes to about 20 years. However, the initial investment for the installation of such a transportation system is notably higher, i.e.

Pri upoređivanju varijanti transportnog sistema za otkrivku potrebno je imati u vidu broj zamena voznog parka kamiona u posmatranom periodu eksploatacije. Za usvojenu amortizacionu stopu od 14,3% godišnje zamena kamiona treba da se obavi posle sedam godina eksploatacije, odnosno 2007. godine. Sa druge strane, vek DTO sistema je duži i iznosi oko 20 godina, ali su inicijalna ulaganja za uvođenje ovakvog vida transporta velika, 30-46,1% veća u odnosu na ulaganja za diskontinuirani transportni sistem.

from 30 to 46,1% higher if compared with the investment made for discontinuous transport systems.

The total costs accounted for transport systems are not proportional to the increase of truck load-bearing capacity. Actually, analysis shows that lower transportation costs are accounted for the 90-t load-bearing capacity trucks than for 110-t trucks, which does not seem to be logical. However, this is the consequence of lower mechanical efficiency, which characterised these trucks during the period of their performance in conditions typical for surface mines.

Combined transport systems, taking into account every layout, have higher dynamic cost for approximately 57,5 to 69%, i.e. 1.0 to1, 24 DM/m^3.

Table 5 presents the review of dynamic cost accounted for the transportation of overburden considering each alternative solution. Figure 9 shows the change in discounted costs for discontinuous and combined transport systems until the end of the mining period.

Ukupni troškovi transportnih sistema nisu proporcionalni povećanju nosivosti kamiona. Naime, analizom su dobijeni manji troškovi transporta sa kamionima nosivosti 90 tona od troškova transporta sa kamiona nosivosti 110 tona, što predstavlja izvesnu nelogičnost. Međutim, ovo je posledica manje mehaničke spremnosti ovih kamiona, koju su pokazali u proteklom periodu rada u uslovima koji su vladali na površinskom kopu.

Kombinovani transportni sistem u svim kombinacijama opreme ima veći dinamički trošak za oko 57,5-69%, odnosno 1.0–1,24 DM/m^3.

U tabeli 5 dat je pregled dinamičkog troška transporta otkrivke po varijantama, a na slici 9 data je promena diskontovanih troškova za diskontinuirani i kombinovani transportni sistem do kraja eksploatacionog perioda.

Table 5 Ranking of transport alternatives
Tabela 5 Rang varijanti transporta

TRANSPORT SYSTEM	Dynamic cost, DM/m^3
DISCONTINUOUS	
RH120/90t	2.40
RH120/110t	2.55
H241/136t	2.16
COOMBINED	
RH120/90t / DTO	3.55
RH120/110t/DTO	3.65
H241/136t / DTO	3.40

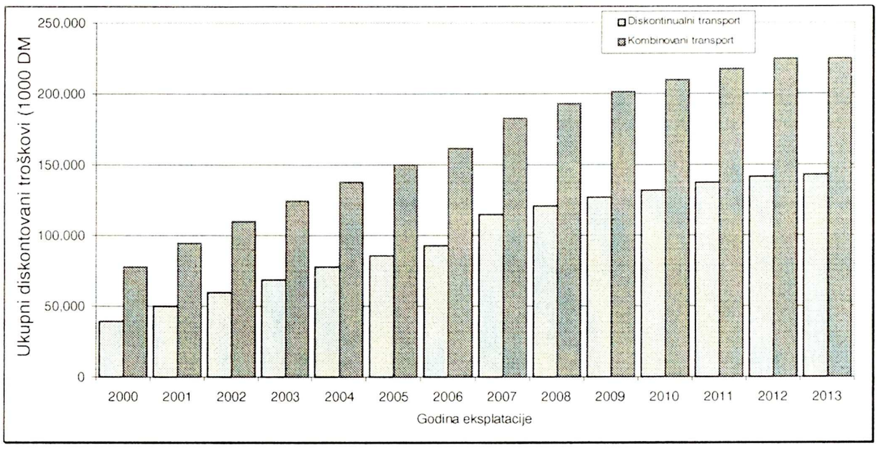


Figure 9 Relationship between total discounted costs for discontinuous and combined transportation of overburden
Slika 9 Odnos ukupnih diskontovanih troškova za diskontinuirani i kombinovani transport otkrivke

Economic analysis, as a crucial segment of strategic decision-making should be additionally incorporated in the simulation modelling of mining

Ekonomska analiza kao ključni segment pri donošenju strateških odluka treba da se dalje inkorporira sa simulacionim modelom procesa processes. This involves the assessment of the economic risk of specific investment, which again implies a certain level of randomness.

7. CONCLUSION

The computer simulation model provides essential data on considered systems and their alternatives, which in conjunction with economic parameters enable accurate evaluation and correct decision-making. Simulation models may be regarded as laboratories or trial plants that may be used to analyse processes when it is not possible, or it would be too expensive to experiment with the real physical system

Optimal machine structure within discontinuous transport systems in terms of surface mining in the open cast mine, Bogutovo Selo - RS is the following; excavator with shovel capacity of 14 m^3 and truck of 136 tons of load-bearing capacity.

Dynamic performance costs for this system, over the considered mining period amount to 2.16 DEM/m^3, which is for about 11-18% lower than the costs accounted for the current, presently available machine structure. The conveyance of overburden material should be carried out, as before, by means of discontinuous transport. However, the technical and technological structure of the current system should be modified in future, when new trucks are acquired.

In terms of combined transport systems, over the considered mining period, a cost increase may be expected for about 1,24 DM/m^3 of overburden if compared with discontinuous transport systems.

Initial investment accounted for the combined transport system is higher for approximately 45% in relation to discontinuous systems, which is significant.

eksploatacije, uvođenjem pristupa ocene ekonomskog rizika određenih investicija, koja se opet, zasniva na izvesnom stepenu slučajnosti.

7. ZAKLJUČAK

Računarski simulacioni modeli obezbeđuju esencijalne podatke o razmatranim sistemimima i njihovim alternativama, koji zajedno sa ekonomskim parametrima omogućavaju njihovo vrednovanje i donošenje pravilnih odluka. Simulacione modele možemo da posmatramo kao laboratorije ili probna postrojenja u kojima se izučavaju procesi u onim slučajevima kada je nemoguće eksperimentisati sa realnim fizičkim sistemom, ili bi to bilo i suviše skupo.

Optimalna struktura mašina u diskontinuiranom transportnom sistemu za uslove eksploatacije na površinskom kopu Bogutovo Selo, RS je bager zapremine kašike 14 m^3 i kamion nosivosti 136 tona.

Dinamičiki troškovi rada ovog sistema, za posmatrani period eksploatacije iznose 2.16 DEM/m^3, i manji su za, oko, 11-18% od troškova koji nastaju sa postojećom strukturom mašina kojom rudnik trenutno raspolaže. Transport otkrivke treba i dalje realizovati sa diskontinualnim transportnim sistemom, s tim da postojećem sistemu treba promeniti tehničko-tehnološku strukturu prilikom kupovine sledećeg kompleta kamiona.

U slučaju primene kombinovanog transportnog sistema, za posmatrani period eksploatacije, mogu se očekivati veći troškovi za, oko, 1,24 DM/m^3 otkrivke u odnosu na diskontinualni transportni sistem.

Početna investiciona ulaganja u kombinovani transportni sitem veća su za, oko, 45% u odnosu na diskontinuirani sistem, što predstavlja veoma značajnu stavku.

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